Turk J Agric For
33 (2009) 557-568
© TÜBİTAK
doi:10.3906/tar-0902-3

Research Article

Partitioning rainfall into throughfall, stemflow, and interception loss in an oriental beech (*Fagus orientalis* Lipsky) forest during the growing season

Mohammad Taghi AHMADI[1], Pedram ATTAROD[1,*], Mohammad Reza MARVI MOHADJER[1], Ramin RAHMANI[2], Jafar FATHI[3]

[1]Forestry and Forest Economics Department, Faculty of Natural Resources, University of Tehran, Karaj - IRAN

[2]Faculty of Forestry and Wood Industries, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan - IRAN

[3]Kheyrud Forest Research Station, Faculty of Natural Resources, University of Tehran, Karaj - IRAN

Received: 10.02.2009

Abstract: Partitioning gross rainfall (GR) into throughfall (TF), stemflow (SF), and interception loss (I), which has a very significant effect on water balance and the nutrient cycle in forest ecosystems, was studied in a natural oriental beech (*Fagus orientalis* Lipsky) forest situated in the Caspian Forest of northern Iran. Measurements were made inside a plot with an area of 0.5625 ha located in the Kheyrud Forest Research Station of Tehran University during the 2008 growing season. GR was measured based on an average of the records of 3 rain gauges located in an open area approximately 160 m from the study plot. Thirty-six TF manual gauges were randomly placed beneath the beech canopies and SF was collected from 6 selected beech trees using spiral-type SF collection collars. Measurements were made on a rainfall event basis. The cumulative GR depth of 23 events was 309.9 mm; TF: 209.9 mm; SF: 7.8 mm; I: 92.2 mm. On the event scale average ratios of TF:GR, SF:GR, and I:GR were 65.9%, 2.0%, and 32.1%, respectively. A strong positive correlation was observed between SF:GR and GR ($r^2 = 0.963$), while very weak correlations were observed between I:GR and GR ($r^2 = 0.230$), and between TF:GR and GR ($r^2 = 0.173$). As the size of rainfall events increased, intercepted GR by the oriental beech forest canopies, and loss through evaporation decreased. Interception loss contributes a notable amount of rainfall and its measurement is an essential element in assessing water balance on the catchment scale.

Key words: Beech, growing season, interception loss, throughfall

Introduction

In forest ecosystems rainfall is partitioned by forest canopies into throughfall (TF), stemflow (SF), and interception loss (I), and this separation is a very important part of forest hydrology (Marin et al. 2000; Iida et al. 2005). Net rainfall (NR) reaches the forest floor via TF and SF (Manfroi et al. 2004; Levia and Herwitz 2005; André et al. 2008a). TF is the portion of rainfall that reaches the forest floor by passing directly through or dripping from tree canopies.

* E-mail: attarod@ut.ac.ir

SF is the fraction of the rainfall that reaches the forest floor by running down the stems of trees after the incident rainfall is intercepted by leaves and branches, and is subsequently diverted to the boles of trees (Staelens et al. 2008).

The I is the fraction of the incident rainfall intercepted by the canopy and subsequently evaporated; it does not reach the forest floor (Samba et al. 2001). The I is commonly calculated indirectly as the difference between gross rainfall (GR) measured above the canopy or in a neighboring open area and the sum of TF and SF sampled simultaneously on the forest floor (Staelens et al. 2008).

The interactions between vegetation and rainfall are of considerable significance from the physiological, ecological, and hydrological points of view (Aboal et al. 1999). In particular, rainfall partitioning by forest canopies plays an important role in water balance on the local and catchment scale due to the control that forest canopies exert by modifying both evaporation and the redistribution of incident rainfall (Llorens and Domingo 2007).

Obviously, TF and SF, considered hydrologic processes, have a remarkable contribution to the hydrologic budgets of forest ecosystems. Moreover, solute inputs through SF and TF are of geo-ecological importance to forests, as they affect soil chemical properties, soil moisture gradients, and soil erosion processes, as well as the location of epiphytes and areal zonation of understory herbs (Andersson 1991; Chang and Matzner 2000; André et al. 2008b; Berger et al. 2008).

The I is a major component of water balance in forested areas, as demonstrated by numerous studies (Herbst et al. 2006; Herbst et al. 2007; Sraj et al. 2008).

Rainfall partitioning in forests is a function of rainfall characteristics, meteorological conditions, vegetation structure, and the interactions between these factors (Hall 2003; Toba and Ohta 2005; Deguchi et al. 2006; Staelens et al. 2008).

The temperate deciduous forests of northern Iran, known as the Caspian forests, cover an area of around 2 million hectares of a narrow strip over 800 km long and 20-70 km wide, ranging from the level of the Caspian Sea up to 2200 m.

Oriental beech (*Fagus orientalis* Lipsky), the most important tree species in the Caspian forests, occupies almost 18% of the total forest area in the region and is the dominant tree species between 700 and 1800 m above the level of the Caspian Sea.

The climate in the beech forests of Iran is very humid and cold in the lowlands and midlands up to 1700 m, and very humid and ultra cold in the highlands up to 2200 m (Sagheb-Talebi et al., 2004).

The main objective of the present study was to quantify the partitioning of GR into TF, SF, and I in a natural oriental beech forest during the growing season.

Table 1 shows the results of several rainfall partitioning studies in beech forests. Although oriental beech forests are distributed widely in several countries, comprehensive and integrated research has not been performed in Iran or in other countries covered with oriental beech forests. The present study is, therefore, the first to investigate rainfall partitioning above the canopy of an oriental beech forest.

'Growing season' in this study refers to the time of year when the deciduous leaf cover is at an approximately stable maximum, approximately from May to November (Carlyle-Moses and Price 2006).

Materials and methods

Study site description

The study was carried out in the Kheyrud Forest Research Station of Tehran University, located approximately 7 km east of Nowshahr, Mazandaran province, northern Iran (Figure 1).

Measurements were made in a 0.5625-ha plot of a pure and natural oriental beech forest (36°35′N, 51°37′E, and 1410 m above the level of the Caspian Sea), representative of the main characteristics of the oriental beech forests in the Kheyrud Forest Research Station, in terms of topography and forest structure. Measurements were made during the 2008 growing season, from 24 June to 25 October.

Tree density was 112 trees ha^{-1} and the total basal area was 86.2 m^2 ha^{-1}. Mean tree height and diameter at breast height (DBH) were 31.5 m and 49.5 cm,

Table 1. A review of measured values of relative throughfall (TF/GR), stemflow (SF/GR), and interception loss (I/GR) obtained from various studies on different species of beech (stand). GR is referred to gross rainfall

Location	Tree species	Study period	TF/GR (%)	SF/GR (%)	I/GR (%)	References
Nelson, New Zealand	Evergreen beech (*Nothofagus*)	Annual	69	2	29	Rowe 1983
Toscana, Italy	European beech (*Fagus sylvatica*)	Annual (winter excluded)	61.6	13.6	24.8	Giacomin and Trucchi 1992
Southern England	European beech (*Fagus sylvatica*)	Leafed period Leafless period	82-83 68-80	1-2 6-16	16 14	Neal et al. 1993
Burgos-Logrono, Spain	European beech (*Fagus sylvatica*)	Annual	64.4	6.6	29	Tarazona et al. 1996
Lozere, France	European beech (*Fagus sylvatica*)	Annual	64.8	20.4	14.8	Didon-Lescot 1998
Hesse forest, France	European beech (*Fagus sylvatica*)	Growing season	69	5	26	Granier et al. 2000
Pindous MTS, Greece	Beech (*Fagus moesiaca*)	Annual	80.5	8	11.5	Michopoulos et al. 2001
Calabria, Italy	European beech (*Fagus sylvatica*)	Annual (winter excluded)	76.3	1.1	22.6	Mosello et al. 2002
Ontario, Canada	Red oak (*Quercus rubra*) Beech (*Fagus grandifolia*) Sugar maple (*Acer saccharum*)	Growing season	-	4.5	-	Carlyle-Moses and Price 2006
Ghent, Belgium	European beech (*Fagus sylvatica*)	Leafed period Leafless period	59.8 79.4	9.2 10.6	31 10	Staelens et al. 2008

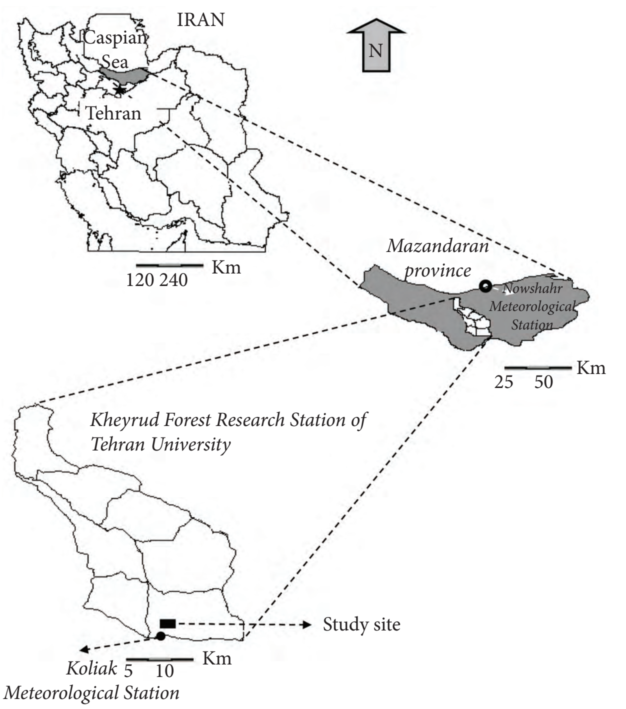

Figure 1. Study site location within the Forest Research Station of Tehran University

respectively. In the study plot, mean tree crown depth was 18.5 m. Mean angle of the north facing slope of the site was 20°.

Our experimental plot was an unmanaged and unevenly aged forest in which tree diameter ranged from 7.5 to 100 cm, and the distribution of tree diameter showed that 30%, 45%, and 25% of the trees surrounded by the experimental plot were DBH < 30 cm, DBH = 30-60 cm, and DBH > 60 cm, respectively. No tree harvesting or silvicultural practices have been carried out in the studied natural oriental beech forest.

The understory vegetation was *Ilex spinigera* Leosn. and *Crataegus* sp., and the main understory herbal covers were *Asperula odorata* (L) Scop., *Primula heterochroma* Stapf., and *Viola sylvestris* Lam.

Meteorological parameters measured at Nowshahr Meteorological Station (36°39′N, 51°30′E, 7.5 m above the level of the Caspian Sea) (Figure 1), the station nearest the study site between 1985 and 2008 indicated that mean annual rainfall was 1303 mm, with high variation (1303 ± 42.2 mm). October was the wettest month (average 235 mm) and August was the driest month (average 42 mm). An average of 38% of the total annual rain falls during the growing season, between July and October (Figure 2).

The meteorological records also indicated that the long-term mean annual air temperature was 16.2 ± 0.5 °C, and that February and August were the coldest and warmest months, with average temperatures of 7.1 °C and 25.1 °C, respectively (Figure 2). During the study period mean air temperature of 23.4 °C with low variation (23.4 ± 0.1 °C) was obtained from the meteorological records.

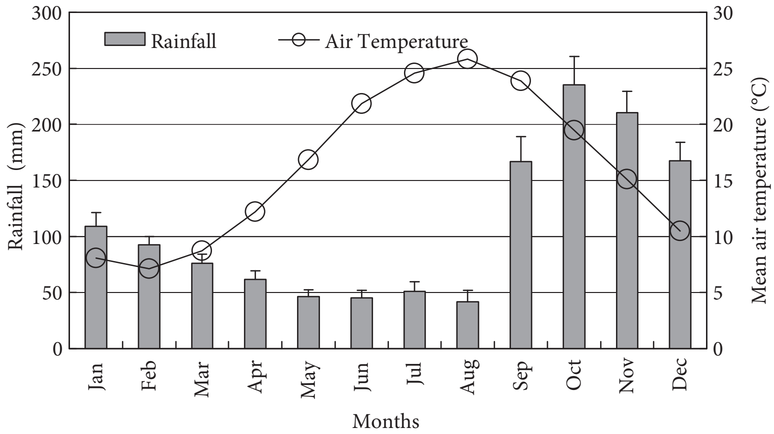

Figure 2. Monthly mean rainfall and air temperature recorded during 23 years (1985-2008) by the Nowshahr Meteorological Station, the synoptic weather station nearest to the study site. Error bars show the standard error (SE) of monthly rainfall during the recorded period

Air temperature records of a newly installed meteorological station at Koliak, 1510 m above the level of the Caspian Sea and 700 m from the study plot, showed that during the study period mean daily air temperature ranged between 14.7 °C and 28.6 °C, with a mean of 23.4 °C (Figure 3).

The Hargreaves temperature-based equation (HG) was used for estimating daily reference evapotranspiration (ET_0 HG), using only maximum and minimum temperatures, and extraterrestrial radiation (Watanabe et al. 2004):

$$ET_0 HG = 0.0135 (T_{mean} + 17.8) K_r \sqrt{T_{max} - T_{min}} R_a \quad (1)$$

where ET_0 HG is Hargreaves daily reference evapotranspiration (mm d^{-1}), T_{mean} is mean temperature (°C), K_r is an empirical coefficient (unitless), T_{max} and T_{min} are maximum and minimum daily temperatures (°C), respectively, and R_a is extraterrestrial radiation (MJ m^{-2} d^{-1}) calculated using the procedure recommended by FAO (Allen et al. 1998) and converted to depth of water (mm d^{-1}).

Different values of K_r have been suggested: 0.17 for interior lowlands (Watanabe et al. 2004), 0.16 for interior regions, and 0.19 for coastal regions (Bandyopadhyay et al. 2008).

Although the Caspian forests are located in the coastal region, to adapt K_r to the study site with different elevations the following equation was used:

$$K'_r = (1 + 2.7 \times 10^{-5} Z) K_r \quad \text{Annandale et al. 2002} \quad (2)$$

where K'_r is the corrected K_r and Z is the elevation (m).

Figure 3 shows the trends of ET_0 during the growing season calculated by Eq. (1) and K_r corrected by Eq. (2). During the growing season, mean daily ET_0 was 4.7 mm. Cumulative ET_0 value during the growing season was 578 mm, with the highest average value occurring in August (5.7 mm) and the lowest in October (3.3 mm).

According to USDA soil surveys, soil at the study site is Alfisol, without any diagnostic horizon, such as Nitric or Calcic (soil profile description). Soil humidity and temperature regimes are udic and mesic, respectively, and the organic matter accumulation, LFH layers, is higher than 5 cm.

Field measurements

Gross rainfall (GR)

GR was collected during the 2008 growing season with 3 self-produced cylindrical plastic rain gauges 9

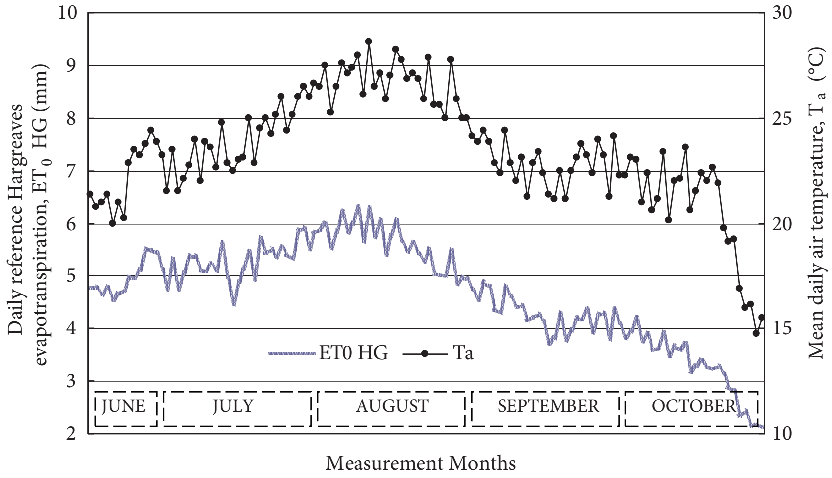

Figure 3. Daily mean air temperature (°C) obtained from the Koliak Meteorological Station (1510 m above the level of the Caspian Sea) during the study period (24 June to 25 October 2008) and Hargreaves reference evapotranspiration (ET_0 HG)

cm in diameter, which were located in a neighboring open area approximately 160 m from the center of the study plot, and was measured manually using a graduated cylinder with an accuracy of 1 mL.

GR collected by each of the gauges was measured either directly after an event or at sunrise if the event occurred during or extended into the night (Carlyle-Moses et al. 2004).

Individual rain events were defined as rainfall events delimited from the previous and following rain events by a dry period of at least 10 h; this was long enough to allow the canopy to dry out completely.

Mean GR was determined based on an average of 3 measurements with 3 cylindrical rain gauges. The GR gauges were placed without obstructions, extending into the conical space defined by a 45° angle centered on each gauge opening (Carlyle-Moses et al. 2004).

Throughfall (TF)

TF was collected using the same type of manual gauges used for measuring GR during the growing season. In total, 36 manual TF collectors were randomly placed (Carlyle-Moses et al. 2004) vertically in the forest understory in the study plot to completely cover the study area (Figure 4).

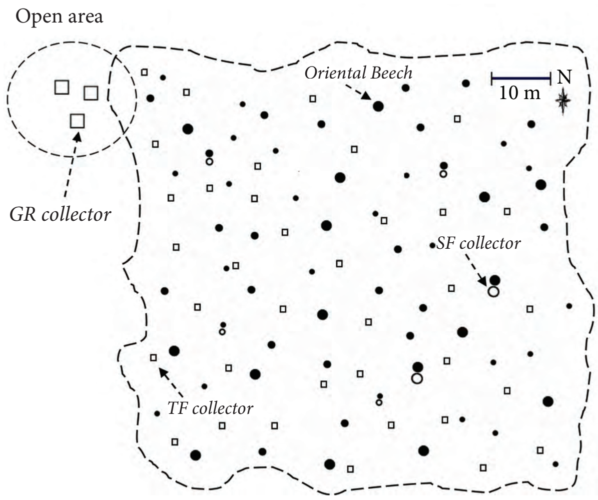

Figure 4. Positions of the oriental beech trees (filled circles), throughfall (TF) gauges (open squares), and stemflow (SF) collectors (open circles) in the study plot. Gross rainfall (GR) gauges (larger open squares) are shown in an open adjacent area. The actual positions of trees, gauges, and collectors in the study plot were surveyed using a compass and a tape measure

TF volume was measured at the same time GR was measured, using the same method. All the TF gauges were emptied and dried after each measurement. Mean TF depth of each event was calculated via the collected TF from all 36 manual gauges.

Stemflow (SF)

To attain more accuracy, a stratified random sampling design representative of the beech forest was used for the selection of sampling trees for SF measurement (Hanchi and Rapp 1997; Lewis 2003). All trees inside the study plot with DBH > 7.5 cm were divided into 3 groups: DBH < 30 cm, DBH = 30-60 cm, and DBH > 60 cm. DBH was measured to the nearest centimeter using a caliper. For each of the above-mentioned DBH group, 2 individual trees were chosen randomly. Figure 4 shows the position of each of the 6 SF sampling trees.

SF was collected from 6 selected beech trees using spiral-type SF collection collars installed at the level of the breast height during the measurement period (Toba and Ohta 2005).

The collectors encircled the trunk at least 1.5 times with an inclined angle. SF was diverted from the spiral-type collar to a 20-L collection bin via plastic tubing. SF volume was measured on a rainfall event basis with the same method used for GR measurement. All 6 SF collectors were checked after every measurement for leakage or any other problems during the study period.

Crown projection area (CPA)

The standard method of measuring the CPA is to project the edges of the crown to a horizontal surface (Delphis and Levia 2004). To calculate SF depth, the CPA was measured with a clinometer and a tape measure only for the 6 SF sampling trees.

The crown radius was measured as the distance from the center of the tree bole to the edge of the crown. To obtain the best estimate of mean crown diameter, the average of 4 main directional crown radii was used.

The equivalent SF depth of each selected tree was measured by dividing the collected SF volume by the CPA (Shachnovich et al. 2008). Finally, the SF depths of the 6 selected trees were averaged to determine the mean SF depth for each event.

Results

Gross rainfall (GR)

Twenty-three rainfall events occurred during the study period. Mean GR per event was 13.5 mm, with high variation (CV%: 58.9) ranging from 3.3 to 29.1 mm. Cumulative GR depth was 309.9 mm (Table 2), distributed over 27 rainy days. In addition, monthly GR ranged between 32.6 mm in August and 129.9 mm in September.

Based on the rainfall frequency and extremes, the GR was grouped into 3 classes: GR < 8, GR = 8-16, and GR > 16 mm. During the study period, 8, 7, and 8 rainfall events were allocated to the mentioned classes, respectively (Table 3).

Table 2. Cumulative and average gross rainfall (GR) depths and the partitioning into throughfall (TF), stemflow (SF), and interception loss (I) within the growing season in the study site. NR refers to the net rainfall, sum of TF and SF

	GR		TF		SF		I		NR	
	mm	%	mm	%	mm	%	mm	%	mm	%
Cumulative	309.9	100	209.9	67.7	7.8	2.5	92.2	29.8	217.7	70.2
Average	13.5	100	9.2	65.9	0.3	2	4	32.1	9.5	67.9

Table 3. Cumulative gross rainfall depth (GR), the percent of average relative throughfall (TF/GR), stemflow (SF/GR), interception loss (I/GR), and net rainfall (NR/GR), divided into 3 GR classes for rainfall events within the growing season

GR class (mm)	Frequency	GR (mm)	TF/GR	SF/GR	I/GR	NR/GR
< 8	8	44.7	62.6	1.0	36.4	63.6
8-16	7	82.5	67.5	1.6	30.9	69.1
> 16	8	182.7	67.9	3.2	28.9	71.1

Rainfall partitioning

Cumulative TF depth was 209.9 mm during the growing season. Mean TF depth, as a proportion of GR, was 9.2 mm (CV%: 64) or 65.9% of GR (Table 2), and ranged from 1.7 mm (53% of GR) to 21.7 mm (74.4% of GR).

A strong positive linear relationship was observed between mean TF and GR depths at the event scale ($r^2 = 0.926$), in other words, high TF production was measured during high rainfall events and low TF production was measured during low rainfall events (Figure 5a).

For the GR < 8, GR = 8-16, and GR > 16 mm rainfall event classes mean TF:GR values were roughly the same—about 62.6%, 67.5%, and 67.9%, respectively (Table 3). A weak relationship ($r^2 = 0.173$) was observed between TF:GR and GR (Figure 5b).

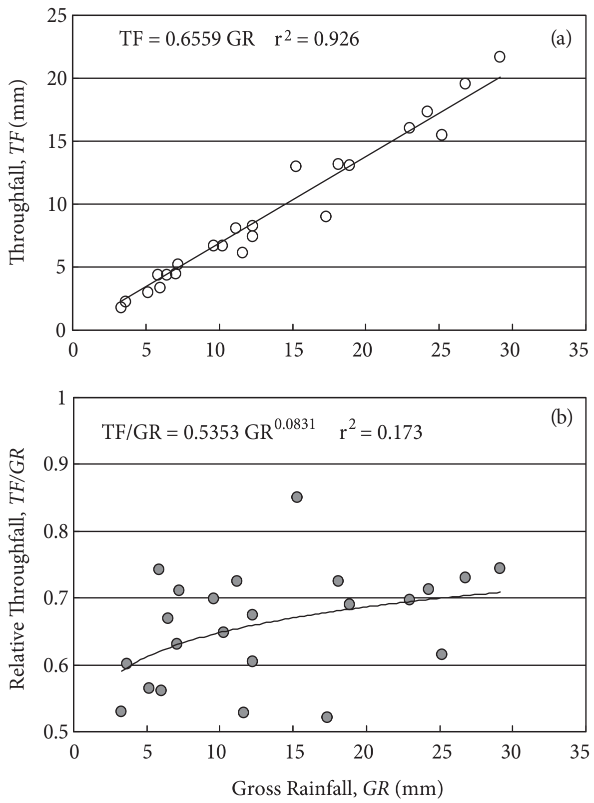

Figure 5. (a) Mean values of throughfall (TF) (mm per event) from 24 June to 25 October 2008, as a function of gross rainfall (GR) (mm per event). (b) The relationship between relative throughfall (TF:GR) and gross rainfall (GR) in the natural oriental beech forest

Cumulative SF depth was 7.8 mm, or 2.5% of GR during the growing season. Mean SF depth of all rainfall events was 0.3 mm (CV%: 101), or 2% of GR (Table 2).

In agreement with previous studies (Xiao et al. 2000; Carlyle-Moses and Price 2006), our data also indicate that more rainfall produced more SF, ranging from 0.03 mm (0.9% of GR) to 1.1 mm (4% of GR). A very strong positive correlation ($r^2 = 0.986$) was observed between SF production and incident GR (Figure 6a).

For the GR < 8, GR = 8-16, and GR > 16 mm rainfall events SF:GR averaged 1%, 1.6%, and 3.2%, respectively (Table 3). Our results showing that SF:GR increased considerably as GR increased ($r^2 = 0.963$) confirm previous results (Figure 6b).

The results of the present study show that the cumulative I depth was 92.2 mm, or 29.8% of GR. In the oriental beech forest average GR allocated to I was 4 mm (CV%: 54.3), or 32.1% (Table 2), and ranged from 13% to 46.1% of GR during the growing season.

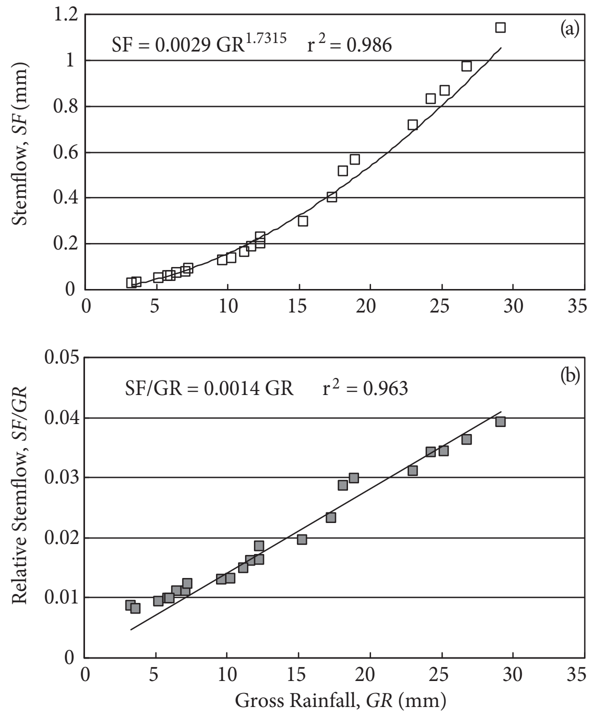

Figure 6. (a) Mean values of stemflow (SF) (mm per event) from 24 June to 25 October 2008, as a function of gross rainfall (GR) (mm per event). (b) The relationship between relative stemflow (SF:GR) and gross rainfall (GR) in the natural oriental beech forest

A positive linear regression (r^2 = 0.728) was observed between I and GR (Figure 7a).

The results indicate that the proportion of GR intercepted by the oriental beech canopies, I:GR, and loss through evaporation decreased as the size of the rainfall events increased. A fairly weak negative regression (r^2 = 0.230) was observed between I:GR and GR (Figure 7b). For the GR < 8, GR = 8-16, and GR > 16 mm rainfall events I:GR values were 36.4%, 30.9%, and 28.9%, respectively (Table 3).

Net Rainfall (NR)

In total, during the 23 rainfall events 217.7 mm, or 70.2% of GR, reached the forest floor via TF and SF, and the remaining 92.2 mm, or 29.8% of GR, was intercepted by the oriental beech canopies and subsequently returned to the atmosphere through evaporation (Table 2). A strong positive linear relationship was observed between NR and GR, and the following equation was derived:

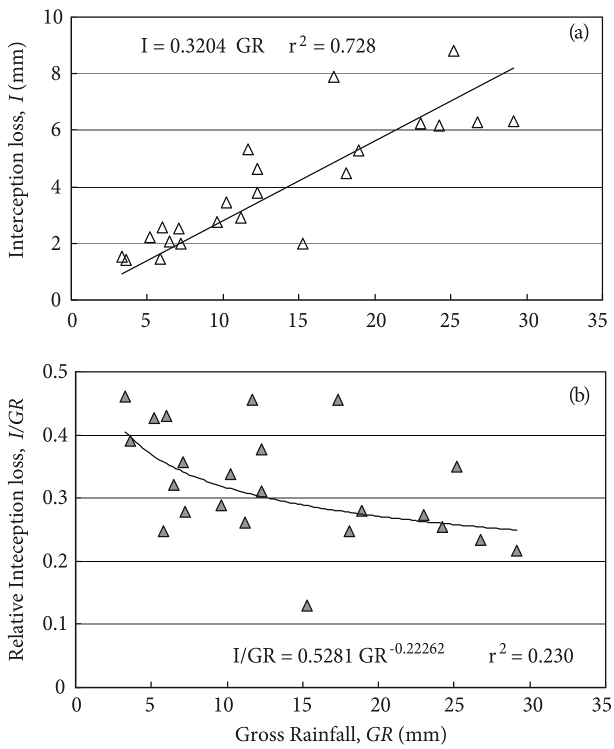

Figure 7. (a) Mean values of interception loss (I) (mm per event) from 24 June to 25 October 2008, as a function of gross rainfall (GR) (mm per event). (b) The relationship between relative interception loss (I:GR) and gross rainfall (GR) in the natural oriental beech forest

$$NR = 0.6796\ GR \qquad r^2 = 0.933 \qquad (3)$$

Mean percentages of NR:GR for GR < 8, GR = 8-16, and GR > 16 mm rainfall events were 63.6%, 69.1%, and 71.1%, respectively (Table 3). A weak positive correlation (r^2 = 0.253) was observed between NR:GR and GR.

Discussion

Partitioning gross rainfall (GR) into throughfall (TF), stemflow (SF), and canopy interception loss (I) in a natural oriental beech forest was accomplished during the growing season from 24 June to 25 October 2008. For the 23 rainfall events cumulative GR depth (309.9 mm) was attributed to TF, SF, and I as follows: 209.9 mm, 7.8 mm, and 92.2 mm, respectively. At the event scale, average values for TF:GR, SF:GR, and I:GR accounted for 65.9%, 2.0%, and 32.1%, respectively. Additionally, mean NR depth on the forest floor beneath the beech trees (sum of TF and SF) was 217.7 mm, or 70.2% of GR (Table 2).

A review of the literature on rainfall partitioning in various beech forests, in terms of age, structure, and genus (Table 1), indicates that the values for TF:GR, SF:GR, and I:GR obtained in the present study are comparable with those from other similar beech forests.

Neal et al. (1993) reported that TF, SF, and I were 82%-83%, 1.0%-2.0%, and 16% of GR, respectively, during the leafed period in a European beech (*Fagus sylvatica* Lipsky) forest located in southern England. Granier et al. (2000) reported that the average values of TF:GR, SF:GR, and I:GR in a European beech forest in France were 69%, 5.0%, and 26%, respectively, during the growing season. According to Michopoulos et al. (2001), the portions of TF, SF, and I were 80.5%, 8.0%, and 11.5% of annual GR, respectively, in a beech (*Fagus moesiaca*) forest in the Pindous Mountains of Greece.

Average values of TF:GR measured in the present study are similar to the values reported by other researchers (Table 1), although higher values of TF were represented. As an example, in southern England the measured value of TF in a European beech forest was 82%-83% of GR during the leafed period (Neal et al. 1993).

It was observed in the present study that SF constituted a small percentage of GR—2% on average—in the oriental beech forest and it was strongly correlated with GR, as reported by other researchers (Deguchi et al. 2006; Keith Owens et al. 2006; Staelens et al. 2008). The average SF value in our oriental beech forest was significantly lower than that derived from other beech forests. In a European beech forest in Belgium, SF during the leafed period was approximately 5-fold greater than that obtained in the present study (Staelens et al. 2008) (Table 1). As shown in Table 1, the measured values of SF varied widely—from 1.1% of GR in a European beech forest in Calabria, Italy (Mosello et al. 2002) to 20.4% of GR in Lozere, France (Didon-Lescot 1998).

Previous studies on rainfall partitioning reported different values for I:GR in beech forests during the leafed period, ranging from 14% to 31% (Table 1). The measured value of I:GR in the oriental beech forest, 32.1% of GR, was more than the maximum reported values. It is noteworthy that the average value of I:GR obtained in our study was higher than that reported from other board-leaved deciduous forests, typically between 15% and 25% of GR (Bruijnzeel 2000). I:GR was estimated as 23% for oak forests in the Netherlands (Dolman 1987) and 13.6% for Northeastern Mexico (Cantu-Silva and Gonzalez Rodriguez 2001).

The present study shows that interception loss contributes a remarkable amount of incident rainfall; therefore, its measurement is a significant element in the assessment of water balance in the natural oriental beech forests of Iran. As mentioned earlier, interception loss, which was not included in any previous water balance and hydrological studies of forest ecosystems in Iran, needs to be considered in future water balance studies.

Partitioning rainfall into TF, SF, and I in forest ecosystems was approved by previous researchers to be a function of incident rainfall characteristics (amount, intensity, duration, and temporal distribution of rainfall events), meteorological conditions (air temperature, relative humidity, wind speed, and wind direction) and forest structure (species composition, stand age, stand density, and canopy morphology and architecture) (Marin et al. 2000; Xiao et al. 2000; Hall 2003; Fleischbein et al. 2005; Toba and Ohta 2005; Deguchi et al. 2006; Staelens et al. 2008). It is most likely that the differences in rainfall partitioning reported by other researchers were due to differences in the above-mentioned factors.

The dissimilarities in SF:GR values of the oriental beech forest and different species of beech studied in other forests were probably due to differences in morphological traits of the different species of beech, such as canopy structure and morphology (Price and Watters 1989; Levia and Herwitz 2002; André et al. 2008c), CPA (Lawson 1967; Aboal et al. 1999; Carlyle-Moses and Price 2006), bark roughness, and bark structure (Helvey and Patric 1965; Johnson 1990; Levia and Frost 2003; Odair et al. 2004; Levia and Herwitz 2005), branch inclination angle (Van Elewijck 1989; Návar 1993; Martinez-Meza and Whitford 1996; Levia and Herwitz 2002), and canopy lichens and mosses (Levia 2004).

Moreover, literature reviews agree on the ability of high SF production in tree species with a funneling canopy shape, large CPA, smooth bark, and low canopy lichens and mosses (Johnson 1990; Návar 1993; Aboal et al. 1999; Levia and Herwitz 2002; Levia 2004; Carlyle-Moses and Price 2006; André et al. 2008b).

The results of the present study confirm that GR had a major impact on rainfall partitioning into TF, SF, and I in the natural oriental beech forest during the growing season. TF:GR and SF:GR values increased as the size of GR events increased; however, higher I:GR values were observed during small GR events.

I:GR and TF:GR, as well as NR:GR varied widely when GR values were low, while no obvious variation was observed in SF:GR, which has been previously reported (Rowe 1983; Deguchi et al. 2006; Staenles et al. 2008; Sraj et al. 2008). For small GR events, the large proportion of incident GR wetted the crown surface and subsequently contributed to the evaporation process, i.e. limited amounts of GR were allocated to TF and SF production.

Rainfall that reaches the forest floor influences natural regeneration during the growing season and, in particular, in the Caspian forests in which dry spells occur during this period. Silvicultural practices may also be recommended for increasing net rainfall and consequent well-established regeneration. Moreover, measurements of rainfall partitioning at the catchment scale will certainly help forest managers to achieve higher water production in forests.

Conclusions

Primarily, the study of rainfall portioning in a natural oriental beech forest in the central part of the Caspian region in northern Iran indicates that both TF and I were major components—65.9% and 32.1% of GR, respectively, while the proportion of SF, 2% of GR, was minor during the growing season. It was observed that rainfall partitioning into TF, SF, and I was strongly affected by the level of GR.

Although this study is the first to document rainfall partitioning in an oriental beech forest, other climatic factors representing rainfall characteristics, rainfall intensity, rainfall duration, wind blowing, and relative humidity, as well as vegetative factors, leaf area index (LAI), percentage of canopy cover, and tree architecture should be considered during the growing season in particular, and when rainfall partitioning in forests is studied.

Acknowledgements

The authors wish to thank Marzban and Abbasi, forest guards at the Kheyrud Forest Research Station of Tehran University, for their help with data collection and field installations. We would like to express our thanks to engineer Jannat Babai for his help in selecting the study site.

References

Aboal JR, Morales D, Hernández M, Jiménez MS (1999) The measurement and modeling of the variation of stemflow in a laurel forest in Tenerife, Canary Islands. J Hydrol 221: 161-175.

Allen RG, Pereira LS, Raes D, Smith M (1998) Crop evapotranspiration–guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper 56, Rome, Italy.

Andersson T (1991) Influence of stemflow and throughfall from common oak (*Quercus rubra*) on soil chemistry and vegetation patterns. Can J For Res 21: 917–924.

André F, Mathieu J, Ponette Q (2008a) Effects of biological and meteorological factors on stemflow chemistry within a temperate mixed oak-beech stand. Sci Total Environ 393: 72-83.

André F, Mathieu J, Ponette Q (2008b) Spatial and temporal pattern of throughfall chemistry within a temperate mixed oak-beech stand. Sci Total Environ 397: 215-228.

André F, Mathieu J, Ponette Q (2008c) Influence of species and rain event characteristics on stemflow volume in a temperate mixed oak–beech stand. Hydrol Process 20: 3651-3663.

Annandale JG, Jovanovic NZ, Benadé N, Allen RG (2002) Software for missing data error analysis of Penman-Monteith reference evapotranspiration. Irrig Sci 21: 57-67.

Bandyopadhyay A, Bhadra A, Raghuwanshi NS, Singh R (2008) Estimation of monthly solar radiation from measured air temperature extremes. Agric For Meteorol 148: 1707-1718.

Berger TW, Untersteiner H, Schume H, Jost G (2008) Throughfall fluxes in a secondary spruce (*Picea abies*), a beech (*Fagus sylvatica*) and a mixed spruce–beech stand. For Ecol Manag 225: 605-618.

Bruijnzeel LA (2000) Forest Hydrology. In: The Forests Handbook, Vol 1. (Ed. JC Evans). Blackwell Scientific, Oxford, pp. 301-343.

Cantu-Silva I, Gonzalez Rodriguez H (2001) Interception loss, throughfall and stemflow chemistry in pine and oak forests in northeastern Mexico. Tree Physiol 21: 1009-1013.

Carlyle-Moses DE, Flores-Laureano JS, Price AG (2004) Throughfall and throughfall spatial variability in Mediterranean oak forest communities of northeastern Mexico. J Hydrol 297: 124-135.

Carlyle-Moses DE, Price AG (2006) Growing season stemflow production within a deciduous forest of southern Ontario. Hydrol Process 20: 3651-3663.

Chang SC, Matzner E (2000) The effect of beech stemflow on spatial patterns of soil solution chemistry and seepage fluxes in a mixed oak–beech stand. Hydrol Process 14: 135-144.

Deguchi A, Hattori S, Park H (2006) The influence of seasonal changes in canopy structure on interception loss: application of the revised Gash model. J Hydrol 319: 80-102.

Delphis F, Levia J (2004) Differential winter stemflow generation under contrasting storm conditions in a southern New England broad-leaved deciduous forest. Hydrol Process 18: 1105-1112.

Didon-Lescot JF (1998) The importance of throughfall in evaluating hydrological and biogeochemical fluxes: example of a catchment (Mont-Loze`re, France). In: Proceedings of the International Conference on Catchment Hydrological and Biochemical Processes in Changing Environment, Liblice, pp. 17-20.

Dolman AJ (1987) Summer and winter rainfall interception in an oak forest: Predictions with an analytical and a numerical simulation model. J Hydrol 90: 1-9.

Fleischbein K, Wilcke W, Boy J, Valarezo C, Zech W, Knoblich K (2005) Rainfall interception in a lower mountain forest in Ecuador: effects of canopy properties. Hydrol Process 19: 1355-1371.

Giacomin A, Trucchi P (1992) Rainfall interception in a beech coppice (Acquerino, Italy). J Hydrol 137: 141-147.

Granier A, Biron P, Lemoine D (2000) Water balance, transpiration and canopy conductance in two beech stands. Agric For Meteorol 100: 291-308.

Hall RL (2003) Interception loss as a function of rainfall and forest types: stochastic modeling for tropical canopies revisited. J Hydrol 280: 1-12.

Hanchi A, Rapp M (1997) Stemflow determination in forest stands. For Ecol Manag 97: 231-235.

Helvey JD, Patric JH (1965) Canopy litter and interception of rainfall by hardwoods of Eastern United States. Water Resour Res 1: 193-206.

Herbst M, Roberts JM, Rosier TW, Gowing DJ (2006) Measuring and modeling the rainfall interception loss by hedgerows in southern England. Agric For Meteorol 141: 244-256.

Herbst M, Roberts JM, Rosier TW, Taylor M, Gowing DJ (2007) Edge effects and forest water use: A field study in a mixed deciduous woodland. For Ecol Manag 250: 176-186.

Iida S, Tanaka T, Sugita M (2005) Change of interception process due to the succession from Japanese red pine to evergreen oak. J Hydrol 315: 154–166.

Johnson RC (1990) The interception, throughfall and stemflow in a forest in highland Scotland and the comparison with other upland forests in the U.K. J Hydrol 118: 281-287.

Keith Owens M, Lyons RK, Alejandro CL (2006) Rainfall partitioning within semiarid juniper communities: effects of event size and canopy cover. Hydrol Process 20: 3179-3189.

Lawson E (1967) Throughfall and stemflow in a pine-hardwood stand in the Ouachita Mountains of Arkansas. Water Resour Res 3: 731-735.

Levia DF (2004) Differential winter stemflow generation under contrasting storm conditions in a southern New England broad-leaved deciduous forest. Hydrol Process 18: 1105-1112.

Levia DF, Frost EE (2003) A review and evaluation of stemflow literature in the hydrologic and biogeochemical cycles of forested and agricultural ecosystems. J Hydrol 274: 1-29.

Levia DF, Herwitz SR (2002) Winter chemical leaching from deciduous tree branches as a function of branch inclination angle in central Massachusetts. Hydrol Process 16: 2867-2879.

Levia DF, Herwitz SR (2005) Interspecific variation of bark water storage capacity of three deciduous tree species in relation to stemflow yield and solute flux to forest soils. Catena 64: 117-137.

Lewis J (2003) Stemflow estimation in a redwood forest using model-based stratified random sampling. Environmetrics 14: 559-571.

Llorens P, Domingo F (2007) Rainfall partitioning by vegetation under Mediterranean conditions. A review of studies in Europe. J Hydrol 335: 37-54.

Manfroi O, Koichiro K, Nobuaki T, Masakazu S, Nakagawa M, Nakashizuka T, Chong L (2004) The stemflow of trees in a Bornean lowland tropical forest. Hydrol Process 18: 2455-2474.

Marin TC, Bouten W, Sevink J (2000) Gross rainfall and its partitioning into throughfall, stemflow and evaporation of intercepted water in four forest ecosystems in western Amazonia. J Hydrol 237: 40-57.

Martinez-Meza E, Whitford WG (1996) Stemflow, throughfall and channelization of stemflow by roots in three Chihuahuan desert shrubs. J Arid Environ 32: 271-287.

Michopoulos PP, Baloutsos GG, Nakos GG, Economou AA (2001) Effects of bulk precipitation pH and growth period on cation enrichment in precipitation beneath the canopy of a beech (*Fagus moesiaca*) forest stand. Scil Total Environ 281: 79-85.

Mosello R, Brizzio MC, Kotzias D, Marchetto A, Rembges D, Tartari G (2002) The chemistry of atmospheric deposition in Italy in the framework of the National Programme for Forest Ecosystems Control (CONECOFOR). J Limnol 61: 77-92.

Návar J (1993) The causes of stemflow variation in three semi-arid growing species of northeastern Mexico. J Hydrol 145: 175-190.

Neal C, Robson AJ, Bhardwaj CL, Conway T, Jefery HA, Meal M, Ryland GP, Smith CJ, Walls J (1993) Relationships between precipitation, stemflow and throughfall for a lowland beech plantation, Black wood, Hampshire, southern England: interception at a forest edge and the effects of storm damage. J Hydrol 146: 221-233.

Odair J, Koichiro K, Nobuaki T, Masakazu S, Nakagawa M, Nakashizuka T, Chong L (2004) The stemflow of trees in a Bornean lowland tropical forest. Hydrol Process 18: 2455-2474.

Price AG, Watters RJ (1989) The influence of the overstory, understory and upper soil horizons on the fluxes of some ions in a mixed deciduous forest. J Hydrol 109: 185-197.

Rowe LK (1983) Rainfall interception by an evergreen beech forest, Nelson, New Zealand. J Hydrol 66: 143-258.

Sagheb-Talebi KH, Sajedi T, Yazdian F (2004) Forests of Iran. Iran Research Institute of Forests and Rangelands (RIFR) Press, No: 1380-339, Tehran.

Samba SAN, Camire C, Margolis HA (2001) Allometry and rainfall interception of Cordyla pinnate in semi-arid agroforestry parkland, Senegal. For Ecol Manag 154: 277-288.

Shachnovich Y, Berniler P, Bar P (2008) Rainfall interception and spatial distribution of throughfall in a pine forest planted in an arid zone. J Hydrol 349: 168-177.

Sraj M, Brilly M, Mikos M (2008) Rainfall interception by two deciduous Mediterranean forests of contrasting stature in Slovenia. Agric For Meteorol 148: 121-134

Staelens J, Schrijver AD, Verheyen1 K, Verhoest N (2008) Rainfall partitioning into throughfall, stemflow, and interception within a single beech (*Fagus sylvatica* L.) canopy: influence of foliation, rain event characteristics, and meteorology. Hydrol Process 22: 33-45.

Tarazona T, Santa Regina I, Calvo R (1996) Interception, throughfall and stemflow in two forest of the "Sierra de la Demanda" in the province of Burgos. Pirineos 147: 27-40.

Toba T, Ohta T (2005) An observational study of the factors that influence interception loss in boreal and temperate forests. J Hydrol 313: 208-220.

Van Elewijck L (1989) Influence of leaf and branch slope on stemflow amount. Catena 16: 525-533.

Watanabe K, Yomamoto T, Yamada T, Sakuratani T, Nawata E, Noichana CH, Sributta A, Higuchi H (2004) Changes in seasonal evapotranspiration, soil water content, and crop coefficients in sugarcane, cassava, and maize fields in Northeast Thailand. Agric Water Manage 67: 133-143.

Xiao Q, McPherson EG, Ustin SL, Grismer ME, Simpson JR (2000) Winter rainfall interception by two mature open-grown trees in Davis, California. Hydrol Process 14: 763-784.