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The Role of Rainfall Size in Canopy Interception Loss: An Observational Study in a Typical Beech Forest

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Abstract: Canopy interception loss (*I*) is the fraction of the gross rainfall (*GR*) that intercepted by forest canopy and subsequently evaporated; it does not reach the forest floor. *I* is commonly calculated indirectly as the difference between *GR* and net rainfall (NR i.e. sum of the throughfall (*TF*) and stemflow (*SF*)). The goal of the present study was to understand the role of *GR* size in controlling the *I* in an oriental beech (*Fagus orientalis* Lipsky) forest located at the midland of the central Caspian forests. Measurements were carried out on a rainfall event basis in a 0.5625 ha sample plot of a pure oriental beech forest in the Kheyrud Forest Research Station of Tehran University. *GR* was measured based on an average of three rain collector records placed in an open area close to the study plot. Thirty six *TF* manual collectors were randomly placed beneath the beech canopies and *SF* was collected from six selected beech trees using the spiral type *SF* collection collars. During the measurement period, from June 2008 to November 2009, a total of 53 rainfall events were recorded. The mean rainfall events was 18.9 mm (SD: ±11.8 mm) ranging from 2.8 to 48.6 mm. The amount of cumulative *GR* depth transformed into *NR* was 760.3 mm (75.9% of *GR*) and the remaining, 241.2 mm or 24.1% of *GR*, was intercepted by the canopies and subsequently returned to the atmosphere. At the event scale average ratio of *I*/*GR* was 28.1% (SD: ±8.8%). Regression analysis suggested a strong positive power correlation between *I* and *GR* (r^2= 0.817; p ≤ 0.01), while a fairly strong negative exponential correlation was observed between *I*/*GR* and *GR* (r^2= 0.581; p ≤ 0.01). As the size of the rainfall events increased, intercepted *GR* or *I/GR* by the oriental beech forest canopy and loss through evaporation decreased. We concluded that *I* in an oriental beech forest contributes a remarkable percentage of incident *GR* and it was strongly affected by the amount of *GR*.

Key words*:* Interception loss · *Fagus orientalis* Lipsky · Net rainfall · Stemflow · Throughfall

INTRODUCTION

In forest ecosystems gross rainfall (*GR*) is partitioned into throughfall (*TF*), stemflow (*SF*) and interception loss (*I*). Net rainfall (*NR*) reaches the forest floor through the canopy via *SF* and *TF*. The *TF* is the portion of rainfall that reaches the forest floor by passing directly through or dripping from tree canopies. The *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. The *I* is the fraction of the incident rainfall intercepted by the canopy and subsequently evaporated; it does not reach the forest floor [1]. *I* is commonly measured indirectly as the difference between *GR* measured above the canopy or in a neighboring open area and the sum of the *TF* and *SF* sampled simultaneously on the forest floor [2].

The interactions between vegetation and rainfall are of considerable significance from the physiological, ecological and hydrological points of view. In particular, rainfall partitioning by forest canopies plays an important role in water balance on the local and catchment scales due to the control that forest canopies exert by modifying both evaporation and the redistribution of incident rainfall [3].

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The *I* from forests usually represents a significant proportion of *GR* and is an important component of the overall forest evaporation. Therefore, it always plays an important role in the water balance of forested watersheds [4].

As demonstrated by numerous studies rainfall partitioning in forests is a function of rainfall characteristics, meteorological conditions, vegetation structure and the interactions between these factors [2].

The main objectives of the present study were to quantify the contribution of *I* to the *GR* as well as to understand the role of *GR* size in controlling the *I* (i.e. the linkage between *I* and *GR* size) in an oriental beech (*Fagus orientalis* Lipsky) forest located at the midland of the central Caspian forests during the growing season.

MATERIALS AND METHODS

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

Measurements were made in a 0.5625-ha plot of a pure and natural oriental beech forest at the midland of the central Caspian forests (36°35'N, 51°37'E and 1410 m above the level of the Caspian Sea). Measurements were made during the 2008 and 2009 growing seasons; 2008 from 24 June to 5 December and 2009, from 5 May to 30 November.

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, respectively. In the study plot, mean tree crown depth was 18.5 m.

Meteorological parameters measured at Nowshahr Meteorological Station, the station nearest the study site between 1985 and 2008 indicated that the mean annual rainfall was 1303 mm, with high variation (SE: ±42.1). October was the wettest month (average 235 mm) and August was the driest month (average 42 mm) (Fig. 2).

The meteorological records also indicates that the long-term mean annual air temperature is 16.2°C (SE: ±0.3) and that February and August were the coldest and warmest months, with average temperature of 7.1°C and 25.1°C, respectively (Fig. 2).

Field Measurements: The *GR* was collected during the 2008 and 2009 growing seasons using 3 self-produced cylindrical plastic rain gauges, which located in an adjacent open area at a distance of 160 m from the study plot. *GR* volume collected by each of the gauges was measured manually using a graduated cylinder with an accuracy of 1 mL. The mean *GR* depth of each event was determined based on an average of 3 measurements with 3 cylindrical rain gauges.

TF was collected using the same type of manual gauges used for measuring *GR* during the study period. In total, 36 manual *TF* collectors were randomly placed vertically in the forest understory in the study plot to completely cover the study area [5].

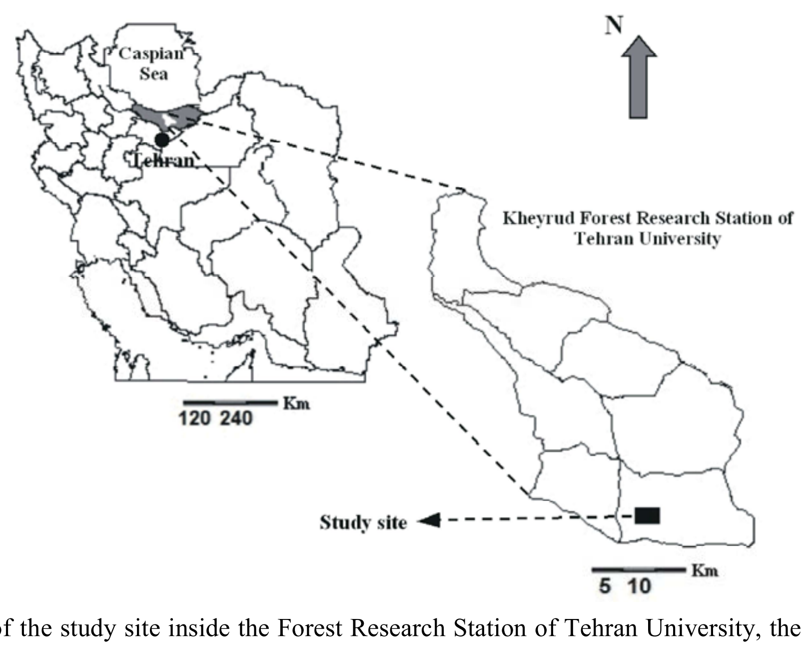

Fig. 1: Locations of the study site inside the Forest Research Station of Tehran University, the central Caspian region of northern Iran.

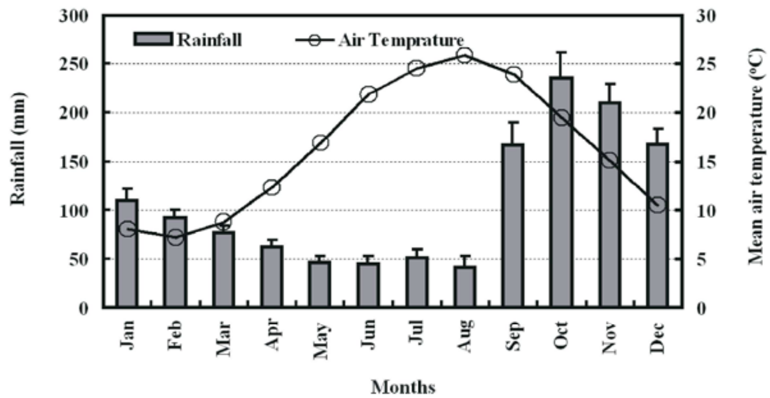

Fig. 2: Monthly mean rainfall and air temperature recorded during 23 years (1985-2008) by Nowshahr Meteorological Station, the nearest synoptic weather station to the study site. Error bars show the standard error (SE) of monthly rainfall during the recorded periods.

TF volume was measured at the same time *GR* was measured, using the same method. Mean *TF* depth of each event was calculated via the collected *TF* from all 36 manual gauges.

In the study plot *SF* was collected from 6 selected beech trees with different diameters by means of the spiral type *SF* collection collars installed at diameter at breast height. *SF* collection collars 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 [6]. *SF* volume was measured on a rainfall event basis manually using the same method utilized for *GR*.

The equivalent *SF* depth of each selected tree was measured by dividing the collected *SF* volume by the Crown projection area (*CPA*) ([7]. Noteworthy that the *CPA* was measured with a clinometer and a tape measure only for the 6 *SF* sampling trees. Finally, the *SF* depths of the 6 selected trees were averaged to determine the mean *SF* depth for each *GR* event.

RESULTS

During the measurement years, 2008 and 2009, 53 rainfall events were recorded. The cumulative *GR* depth was 1001.5 mm and mean *GR* depth per event was 18.9 mm, with high variation (SD: ±11.8) ranging from 2.8 mm to 48.6 mm.

Based on the rainfall frequency and extremes, for help to better understanding of the linkage between *GR* size and *I*, the rainfall events were grouped into 5 classes, 7.5 mm intervals: $GR \leq 7.5$, $7.5 \leq GR \leq 15$, $15 \leq GR \leq 22.5$, $22.5 \leq GR \leq 30$ and $GR \geq 30$ mm. During the study period, 13, 10, 11, 9 and 10 rainfall events were allocated to the mentioned classes, respectively.

On the whole of the 53 rainfall events recorded during the measurement period the sum of 760.3 mm or 75.9% of the cumulative *GR* was transformed into *NR* and reached on the forest floor, i.e. 728 mm arrived as *TF*, 32.3 mm as *SF* and the remaining 241.2 mm or 24.1% of total *GR*, was intercepted by the oriental beech canopies and subsequently returned to the atmosphere through evaporation.

On the event scale the average amount of *GR* allocated to *NR* was 14.3 mm or 71.9% of *GR* (mean *TF* depth: 13.7 mm or 69.4% (SD: ±8%); mean *SF* depth: 0.6 mm or 2.5% (SD: ±1.3%) of *GR*).

Over the measurement period, the cumulative *I* depth was 241.2 mm or 24.1% of total *GR*. The *I* expressed as percentage of *GR*, *I*/*GR*, was on average 28.1% (4.6 mm) and depending on rainfall amounts, varied in a wide range from 12.4% of *GR* (0.8 mm) to 46.1% of *GR* (8.8 mm) in the studied oriental beech forest.

The *I* was found to be closely related to the *GR* amount. A strong positive power correlation ($r^2 = 0.817$; $p \leq 0.01$) was observed between the means of *I* and *GR* depths at the event scale, i.e. during the study period *I* (mm) increased with increasing amount of *GR* (Fig. 3a).

Fig. 3(b) shows that during the measurement period, the contribution of *I* to *GR* (relative *I*; i.e. the ratio of *I* to *GR* (*I*/*GR*)) was considerably correlated with *GR* size and the mean values of *I*/*GR* showed an decreasing trend with increase in *GR* amounts, so that a negative exponential significant relationship ($r^2 = 0.581$; $p \leq 0.01$) was observed between *I*/*GR* and *GR*.

For rainfall event classes of $GR \leq 7.5$, $7.5 \leq GR \leq 15$, $15 \leq GR \leq 22.5$, $22.5 \leq GR \leq 30$ and $GR \geq 30$ mm, the average *I*/*GR* values were 34.9% (SD: ±7.1%), 33% (SD: ±5.4%), 28.6% (SD: ±8.5%), 23.7% (SD: ±5.2%) and 17.5% (SD: ±3.8%), respectively (Fig. 4).

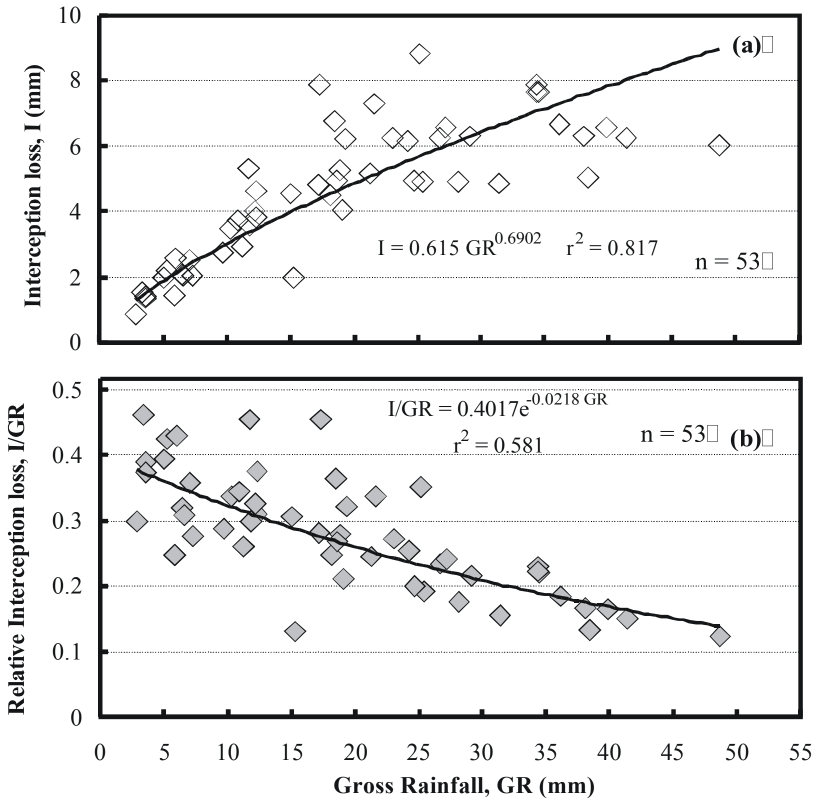

Fig. 3: (**a**) Mean values of interception loss (*I*) (mm per event) during the measurement period, 2008, from 24 June to 5 December and 2009, from 5 May to 30 November as a function of gross rainfall (*GR*) (mm per event). (**b**) The relationship between relative throughfall (*I*/*GR*) and gross rainfall (*GR*) for the natural oriental beech forest.

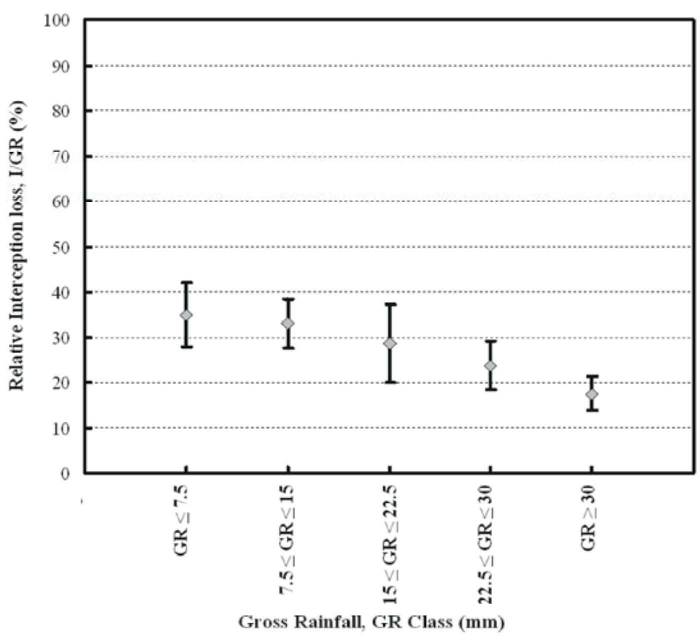

Fig. 4: The percent of average relatives interception loss (*I*/*GR*) on the *GR* event basis for 5 *GR* classes 7.5-mm intervals during the measurement period, 2008, from 24 June to 5 December and 2009, from 5 May to 30 November. Error bars show the standard deviation (SD).

DISCUSSION

To quantify the contribution of *I* to the *GR* as well as to understand the role of *GR* size in controlling the *I* in the pure and natural oriental beech forest, this study was performed at the midland of the central Caspian forests in northern Iran during the 2008 and 2009 growing seasons.

At the event scale, average value of *I*/*GR* accounted for 28.1% of *GR*. A review of the literature on rainfall partitioning measured in a variety of beech forests, in terms of age, structure and genus, indicates that the value of *I*/*GR* obtained from the present study is comparable with those measured in other beech forests (Fig. 5) [2, 8-14].

Previous researches on rainfall partitioning in beech forests reported different values for *I*/*GR* during the leafed period varied widely from 11.5% of *GR* in a beech (*Fagus moesiaca*) forest in Pindous MTS, Greece to 31% of *GR* in a European beech (*Fagus sylvatica*) forest in Ghent, Belgium (Fig. 5) [2, 8-14]. The measured value of *I*/*GR* in the oriental beech forest, 28.1% of *GR*, was at the upper *I* values reported for beech forests by researchers. It is noteworthy that the mean value of *I*/*GR* obtained from our study was higher than that of reported from other board-leaved deciduous forests, typically between 15% and 25% of *GR* [15], e.g. 23% for oak forests in the Netherlands [16].

Redistribution of rainfall into *NR* 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) [2, 6, 17]. It is most likely that the differences among the magnitudes of *I*/*GR* measured in this study and those reported from other species of beech is the result of differences in the above mentioned factors.

The results confirmed that *GR* size had a major impact on rainfall partitioning into *NR* (sum of the *TF* and *SF*) and *I* in the natural oriental beech forest. During the study period, as a general trend, *I* (mm) increased as the size of *GR* events increased; however, higher *I*/*GR* values were observed during small *GR* events. This finding is in agreement with those of other studies suggesting that *I* as well as *I*/*GR* of different forest types response similarly to the *GR* size, regardless the *GR* ranges [18, 19, 20].

The magnitude of *I*/*GR* during small events is a result of a large proportion of incident *GR* being held in canopy storage and evaporated during and after rainfall. For small *GR* events, in other words, 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* productions.

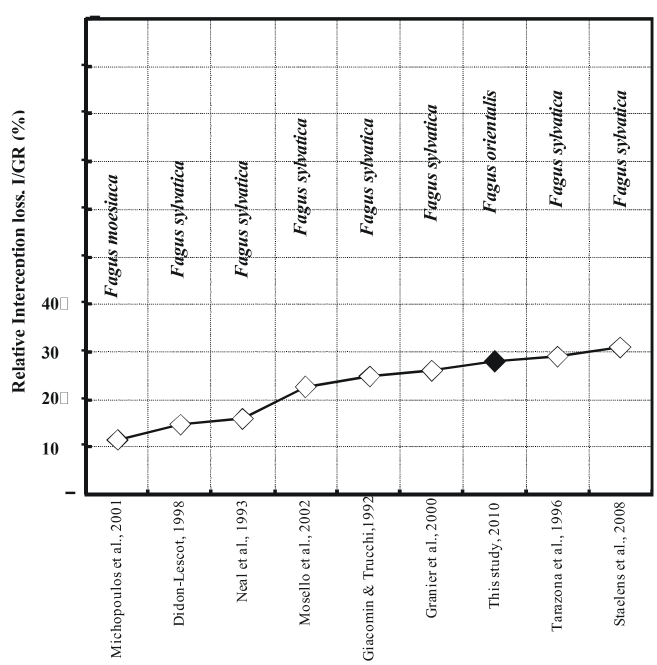

Fig. 5: A comparison of the relative interception loss (*I*/*GR*) obtained from this study (filled lozenge) with reported values for different species of beech forests (open lozenges).

Figure 4 (a) shows that the *I* increases along with the *GR* size. For *GR* event larger than 35 mm, the *I* enlargement will stop and may even decrease. This means that *I* reaches a culmination point called maximum canopy interception loss. The ability of oriental beech forest canopy to intercept the incident rainfall, always more than the force of *TF*, represents a maximum level of *I* and remained around 6 mm regardless the other meteorological conditions.

The present study shows that interception loss contributes a remarkable amount of incident rainfall and its measurement, therefore, is a significant element in the assessment of water balance in the natural oriental beech forests of Iran. Furthermore the research indicated that the proportionate amount of *GR* intercepted by the oriental beech canopies, *I*/*GR* and loss through evaporation process decreased with increasing size of rainfall event.

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