Differences in Rainfall Interception during the Growing and Non-growing Seasons in a *Fraxinus rotundifolia* Mill. Plantation Located in a Semiarid Climate

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ABSTRACT

We estimated the rainfall interception loss (I), canopy storage capacity (S), the ratio of mean evaporation rate from the wet canopy (E) over the mean rainfall intensity (R) (mm h⁻¹) (E/R), and free throughfall coefficient (p) in a *Fraxinus rotundifolia* Mill. stand located in an afforested Park land in a semiarid region of Iran. For each storm event, I was calculated as the gross rainfall (GR) minus throughfall (TF). S was estimated by indirect methods: the minimum, the mean, and the Gash and Morton. Fifty-five rainfall events were recorded (cumulative GR 197.2 mm), with 31 events occurring during the growing season (total GR 88.0 mm) and 24 events measured during the non-growing season (total GR 109.2 mm). The mean ratio of I to GR equalled 39.2% during the growing season vs. 23.9% during the non-growing season. For the growing season, S was estimated to be 0.27, 0.21, and 0.23 mm using the minimum, mean, and Gash and Morton methods, respectively. For the non-growing season, these values were estimated to be 0.17, 0.13, and 0.15 mm, respectively. During the growing and non-growing seasons, E/R were estimated to be 0.13 and 0.11, respectively, with the corresponding p values of 0.39 and 0.52. The loss of the leaves resulted in decline in I, S, and E/R, and increase in p. For semiarid regions, these values are useful for solving some water management problems.

Keywords: Canopy storage capacity, Free throughfall coefficient, Seasonal variability.

INTRODUCTION

Trees strongly influence with the hydrology of forest ecosystems (Gash et al., 1995; Chang, 2006). Gross rainfall (GR) that enters the forest canopy can be temporarily stored, with substantial portion evaporating back to the atmosphere. Upon entering the forest canopy, GR reaches the forest floor as throughfall (TF), runs down the stems as stemflow (SF) or evaporates back to the atmosphere as interception loss (I). Throughfall (TF) will reach the forest floor directly as direct throughfall (p), or drip from the canopy after hitting a branch or leaf (Návar, 2011; Sadeghi et al., 2014, 2015). Stemflow (SF) is the amount of water flowing to the ground via trunks/stems (Návar and Bryan, 1990), and I is the portion retained by canopy cover and evaporated into the atmosphere (Aboal et al., 1999; Crockford and Richardson, 2000; Návar, 2013). I can represent 10 to 25% of GR in deciduous forests (Crockford and Richardson, 1990; Bruijnzel, 2000; Carlyle-Moses, 2004; Šraj et al., 2008; Návar, 2013) and up to 40% in evergreen forests (Gash et al., 1980; Asadian, 2007; Návar, 2013). Hence, changes in the forest

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canopy structure will impact I and may alter soil moisture content and surface runoff (Herwitz, 1985; Chang, 2006).

The magnitude of I is greatly affected by the canopy storage capacity (S) and the ratio of mean evaporation rate from the wet canopy, $\bar{E}$ (in mm h$^{-1}$) to the mean rainfall intensity during rainfall, $\bar{R}$ (in mm h$^{-1}$) ($\bar{E}/\bar{R}$) (Gash and Morton, 1978; Návar and Bryan, 1994; Návar et al., 1999a, 1999b; Návar, 2013). S is defined as the amount of water stored on a fully saturated canopy when evaporation is negligible and rainfall has ceased (Gash and Morton, 1978; Návar and Bryan, 1990; Sadeghi et al., 2014, 2015). Many factors can affect the size of S including canopy cover, leaf area index, and seasonal variation in leaf area index (Gash et al., 1980, 1995; Návar and Bryan, 1990; Pypker et al., 2005; Muzylo et al., 2009, 2012; Fathizadeh et al., 2013).

I processes are highly variable with season, therefore, measuring the magnitude of I is crucial, in particular during the dry season, in semiarid and arid regions where soil moisture availability, survival of understory vegetation, as well as local subsurfaces flow rates are limiting factors for plant growth and vitality (Carlyle-Moses, 2004; Sadeghi et al., 2015). The lack of affordable instruments that directly quantify canopy variables results in the use of indirect methods that include the minimum method (Jackson, 1975), Gash and Morton (1978) method (as described in material and methods), the intercept method (Návar, 1993), and the IS method (Link et al., 2004).

Seasonal changes in the canopy characteristics will alter S, p, and $\bar{E}/\bar{R}$, thereby influencing I (Pypker et al., 2011). During the dormant period, senescence of leaves occurs in deciduous trees and hence S is reduced (Pypker et al., 2011). S, I, and p in deciduous forest alter significantly in leaf and leafless periods (e.g., Návar, 1993; Pypker et al., 2011; Muzylo et al., 2012; Fathizadeh et al., 2013) (Table 1).

In semiarid to arid regions, it is becoming common to afforest to control air pollution and provide green space. The establishment of plantations may alter the hydrology in these regions (Sadeghi et al., 2014, 2015). However, relative to temperate and tropical forests, there has been little research on the impact of canopy structure on I, S and p in semiarid regions (e.g., Herwitz, 1985; Jetten, 1996; Holder, 2004; André et al., 2008; Ahmadi et al., 2009, 2011; Friesen et al., 2013).

*Fraxinus rotundifolia* Mill. is a native tree that is widely used in plantations in arid and semiarid regions of Iran (Jazirei and Ebrahimi-Rostaghi, 2005). The tree tolerates low and high temperatures (Jazirei and Ebrahimi-Rostaghi, 2005) and is broadly used as an ornamental tree along streets, in gardens, and in forest parks. No research has been reported concerning the stand-based measurement of I for *F. rotundifolia* plantations. The objectives of this research were (1) to break stand level partitioning of GR into TF and I and (2) to estimate seasonal I, S, $\bar{E}/\bar{R}$, and p values for a *F. rotundifolia* afforestation in a semiarid climate zone.

**Table 1.** Review of canopy storage capacity (S) from various research for the deciduous forest.

<table>
<thead>
<tr>
<th>Species</th>
<th>S (mm)</th>
<th>Study area</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Carpinus betulus</em></td>
<td>1.0 (*), 0.65 (×)</td>
<td>United Kingdom</td>
<td>Rutter et al. (1975)</td>
</tr>
<tr>
<td><em>Quercus robur</em></td>
<td>0.88 (*), 0.28 (×)</td>
<td>New Zealand</td>
<td>Rowe (1983)</td>
</tr>
<tr>
<td><em>Nothofagus</em></td>
<td>1.5 (*), 1.2 (×)</td>
<td>Germany</td>
<td>Hörmann et al. (1996)</td>
</tr>
<tr>
<td><em>Asperulo-fagetum</em></td>
<td>1.28 (*), 0.84 (×)</td>
<td>Belgium</td>
<td>Staelens et al. (2008)</td>
</tr>
<tr>
<td><em>Fagus sylvatica</em></td>
<td>1.1 (*), 0.4 (×)</td>
<td>Iran</td>
<td>Fathizadeh et al. (2013)</td>
</tr>
<tr>
<td><em>Quercus brantii</em></td>
<td>1.56 (*), 0.56 (×)</td>
<td>Mexico</td>
<td>Návar (2013)</td>
</tr>
<tr>
<td><em>Quercus spp.</em></td>
<td>0.90 (all seasons)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Star (*) and cross (×) signs denote growing and non-growing seasons, respectively.
MATERIALS AND METHODS

Site Description

The study was conducted in a 350 m\(^2\) plot located on the Chitgar Forest Park, west of Tehran city, Iran (lat. 35°10´ N, long. 51°10´ E, 1,250 m asl) (Figure. 1). The park was established in 1968 to purify air, provide green space and sustain groundwater. The Park covers an area of 1,450 ha and the slope range is mostly between 2 to 30%. Approximately 12% of the total Park area contains pure stands of *F. rotundifolia*. Mean tree height and diameter at breast height (DBH) were 6 m and 17 cm, respectively. Stand density and basal area are 1,100 stems ha\(^{-1}\) and 0.23 m\(^2\) ha\(^{-1}\), respectively. After planting, the stands have not been managed.

There was no meteorological record at the Park. However, a nearby meteorological station, Chitgar Meteorological Station (ca. 4 km distance, 35°44´ N, 51°10´ E, and 1,215 m asl), reported that from 1996-2012, mean annual precipitation (± standard error) was 272.0 mm (SE±21.4 mm). The wettest and driest months are March (46.1 mm; SE±10.2 mm) and August (0.8 mm; SE±0.3 mm), respectively. The dry period begins in May and ends in October. The wet period, extends from November to April, and historically contributes 88% of the total annual precipitation. The area has a mean annual temperature of 17.0°C (SE±0.2°C). August is the warmest month with average temperature of 29.3°C (SE±0.3°C) and January is the coldest month (3.8°C; SE±0.8°C). The forest has a semiarid climate by using the De Martonne Aridity Index classification (I\(_{DM}\)= 10.1). The prevailing wind direction in the area is from W to NW.

Field Measurements

Gross rainfall, throughfall, and stemflow

Measurements were made from 1 September 2012 to 25 July 2013. The forest has an average growing season of 195 days (1 April to 15 November). GR was measured with 10 manual rain-gauges that were 9 cm in diameter and 22 cm in height. The GR gauges were placed on the ground in forest openings that were 30 m away from the *F. rotundifolia* stand. TF was measured using 50 manual rain-gauges of the same type as

![Figure 1. Research site inside the Chitgar Forest Park near Tehran city, Tehran Province, Iran.](image-url)
the rain-gauges used to quantify GR. TF rain-gauges were randomly distributed beneath the forest canopy within the study plot. Past research suggests that indirect methods can result in biased estimates of I and S in areas with high spatial heterogeneity of TF (Sadeghi et al., 2014). To reduce the potential for bias, we used a large number of rain-gauges (50) that were randomly relocated during the measurement period (Lloyd and De Marques, 1998). Half of the TF rain-gauges were relocated every five rainfall events, the other half remained fixed in their positions (Sadeghi et al., 2015).

Only rain storms over 0.3 mm were measured and included in the analysis. It was assumed that a wet canopy requires at least 4 hours to completely dry. Field observation showed that the stemflow, SF, is not a critical component of GR partitioning in our stand, hence, the SF measurement was neglected. Consequently, I was calculated by subtracting TF from GR, both of which were measured for each rainfall event. If the rainfall occurred during the day, the water was collected within 2 hours after an event, but if the rainfall occurred late in the afternoon or evening hours, rainfall was measured the next morning. The average from the rain-gauges installed in the open area and underneath the stand was used to calculate GR and TF, respectively.

**Canopy Storage Capacity, the \( \frac{GR}{TF} \) Ratio, and \( p \)**

We used indirect regression methods that relate TF and GR to determine the canopy saturation point \((P_s)\). The amount of GR that is necessary to saturate the canopy before the drip of TF occurs is defined as \(P_s\), which is equal to \(S\) if \(p\) is zero, and can be estimated subjectively by finding the inflection point on a graph relating TF to GR for multiple storms (Leyton et al., 1967; Pyper et al., 2005; Motahari et al., 2013; Sadeghi et al., 2014, 2015). Stand level S can be estimated by three generally accepted graphical indirect methods that relate GR to TF (e.g., Leyton et al., 1967; Klaassen et al., 1998; Link et al., 2004; Pyper et al., 2005, 2011; Sadeghi et al., 2014). The common methods for S calculations are described below:

1. Minimum method (Leyton et al., 1967): \(S\) was estimated by fitting a regression line to a graph relating \(GR\) (x-axis) to \(TF\) (y-axis) for \(GR\) events that were greater than \(P_s\) \((R_1)\) and \(\frac{GR}{TF}\) being negligible. \(S\) was assumed to equal the x intercept. This procedure has been successfully applied by Návar and Bryan (1990) for semiarid shrubs of NE Mexico.

2. Mean method (Jackson, 1975): This requires two regression lines relating \(GR\) (x-axis) and \(TF\) (y-axis). The first regression line \((R_1)\) is fit to storms where \(GR\) is \(\geq P_s\) \((R_1)\) and a second regression line is fit to storms where \(GR\) is less than \(P_s\) \((R_2)\). The differences between \(GR\) and \(TF\) at the intersection point of \(R_1\) and \(R_2\) provides the estimates of \(S\).

3. The Gash and Morton (1978) method: Similar to the minimum method, it assumes that evaporation is negligible and estimates \(S\) by relating \(GR\) (x-axis) vs. \(TF\) (y-axis) for storms where \(GR\) is greater than \(P_s\) \((R_1)\). In contrast with the minimum method, Gash and Morton (1978) estimated \(S\) to be equal to the absolute value of the y-intercept i.e., when \(GR=0\).

In addition, \(\frac{GR}{TF}\) and \(p\) is usually estimated using the mean method (Jackson, 1975; Klaassen et al., 1998; Návar et al., 1999a; 1999b; Link et al., 2004; Pyper et al., 2005; Šraj et al., 2008; Sadeghi et al., 2014, 2015). One minus slope of \(R_1\) provided an estimate of \(\frac{GR}{TF}\) and the slope of \(R_2\) provided an estimate of \(p\).

**Data Analysis**

Throughout the study period, the rainfall events were divided into two canopy development stages: the growing season (1 September to 20 November 2012; and 15 March to 25 May 2013), and the non-growing season (21 November 2012 to 14 March 2013). The non-growing season was defined as the approximate date when all
leaves on the stand had fallen. The distinction was regularly made (at least weekly) by checking the tree phenology at the site.

**RESULTS**

**Gross Rainfall**

From 1 September 2012 to 25 May 2013, 55 rainfall events were recorded (cumulative $GR$ 197.2 mm). Thirty one events occurred during the growing (total $GR$ 88.0 mm) and 24 events were recorded during the non-growing seasons (total $GR$ 109.2 mm). $GR$ ranged from 0.3 to 10.1 mm during the growing season and from 0.3 to 14.6 mm during the non-growing season. $GR$ averaged 2.8 mm ($\pm$0.5 mm) during the growing and 4.6 mm ($\pm$0.9 mm) during the non-growing season. Three snowfall events were recorded; however, they were not included in our analysis.

**Rainfall Interception**

Over the study period, $I$ was 35.2 mm, or 17.8% of the cumulative $GR$. Values of $I$ for the growing and non-growing seasons were 22.5% (cumulative 19.8 mm), and 14.1% (cumulative 15.4 mm), respectively (Figure 2).

To examine the relationship between $GR$ and $I$, $GR$ events were categorized into two classes: $GR <$ 3.5 mm and $GR \geq$ 3.5 mm (Table 2). Mean $I$:GR values during the growing season were 48.1% for storms less than 3.5 mm and 20.6% for storms larger than 3.5 mm. In contrast, during the non-growing season, $I$:GR was smaller, averaging 35.3 and 12.6% for smaller ($GR <$ 3.5 mm) and larger ($GR \geq$ 3.5 mm) rainfall events, respectively (Table 2).

The mean $I$:GR was equal to 39.2$\pm$5.1% during the growing season and 23.9$\pm$3.6% during the non-growing season. The $I$:GR ranged from 4.3 to 100% of $GR$ during the growing season, and from 5.9% of $GR$ to 60% of $GR$ during the non-growing season.

**Figure 2.** Accumulated gross rainfall ($GR$) and interception ($I$) by *Fraxinus rotundifolia* plantation during the measurement period from September, 2012, to May, 2013, within the growing and non-growing seasons.
Table 2. Cumulative gross rainfall (GR) depth and the percent of the relative interception (I:GR) for Fraxinus rotundifolia plantation.

<table>
<thead>
<tr>
<th>GR class (mm)</th>
<th>Frequency</th>
<th>GR (mm)</th>
<th>I:GR (%)</th>
<th>Frequency</th>
<th>GR (mm)</th>
<th>I:GR (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GR &lt; 3.5</td>
<td>20</td>
<td>24.1</td>
<td>48.1</td>
<td>13</td>
<td>12.6</td>
<td>35.3</td>
</tr>
<tr>
<td>GR ≥ 3.5</td>
<td>11</td>
<td>63.9</td>
<td>20.6</td>
<td>11</td>
<td>96.6</td>
<td>12.6</td>
</tr>
<tr>
<td>Cumulative</td>
<td>31</td>
<td>88.0</td>
<td></td>
<td>24</td>
<td>109.2</td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>(± SE)</td>
<td>(± 0.5)</td>
<td>(± 5.1)</td>
<td></td>
<td>(± 0.9)</td>
<td>(± 3.6)</td>
</tr>
</tbody>
</table>

*Event based average of each class.

Figure 3. Regression analysis between the percentage of relative interception loss (I:GR)\% and gross rainfall (GR) by the Fraxinus rotundifolia plantation in the growing season and non-growing season. The regression equations are I:GR = −19.65 Ln(GR) + 49.5 with correlation coefficient = 0.54, and I:GR = −10.43 Ln(GR) + 33.46 with correlation coefficient = 0.61, respectively. Filled circles and open triangles denote rainfalls in the growing season and non-growing season, respectively.

Regardless of the season, I:GR decreased as GR increased (Figure 3).

The I:GR was significantly different between the growing season and non-growing season for the F. rotundifolia plantation (t= 3.54, P< 0.01). There was a negative logarithmic relationship between I:GR and GR in both the growing (I:GR = −19.65 Ln(GR) + 49.50, R²= 0.54), and non-growing seasons (I:GR = −10.43 Ln(GR) + 33.46, R²= 0.61).

Canopy storage capacity, the slope, and the free throughfall coefficients

The canopy saturation points (P_s) were estimated to be 1.0 mm and 0.8 mm in the growing and non-growing seasons,
respectively. During the growing season, $S$ was estimated to be 0.27, 0.23, and 0.21 mm using the minimum, Gash and Morton (1978), and the mean methods, respectively (Figure 4). During the non-growing season, these values were found to be 0.17, 0.15, and 0.13 mm for minimum, Gash and Morton (1978), as well as the mean methods, respectively (Figure 5). During the growing and non-growing seasons, $E/R$ values were estimated to be 0.13 and 0.11, respectively. The coefficient $p$ was calculated to be 0.39 during the growing season and 0.52 during the non-growing season.

**DISCUSSION**

The choice of tree species for a plantation could alter the amount of $I$, thereby altering water inputs at the stand-level, landscape and watershed scales (Návar, 1993; Muzylo et al., 2012). It is important to measure $I$ for different
species because it controls the amount of water input to ecosystems. $S$ is a fundamental parameter of $I$ process. It plays a critical role during small rainfall events in semiarid and arid regions where rainfall is limited (Sadeghi et al., 2013). Hence, water management must be aimed at fully enhancing the efficiency of the limited water resources. To date, there are few measurements available regarding the $I$, $S$, $E/R$ and $p$ values in plantations ecosystems in semiarid climate regions. Carlyle-Moses (2004) emphasized the importance of measuring $I$ in semiarid climate, as $I$ in these environments can be considerable.

Deciduous trees intercept more rainfall during full leaf season than leafless season (Feller, 1981; Neal et al., 1993; Hörmann et al., 1996; Staelens et al., 2008; Muzylo et al., 2012) with $I$ increasing as leaf area increases (Muzylo et al., 2012; Fathizadeh et al., 2013). In our study, the average values of $I:GR$ in growing season (39.2%) and non-growing season (23.9%), and over the periods (17.8%) were similar to the values reported by other researchers. Feller (1981) showed that the annual $I:GR$ values ranged from 10 to 20% of cumulative GR for several Eucalyptus (E. regnans, and E. obliqua) plantations in an arid climate in Australia. Dunin et al. (1985) found that the annual $I:GR$ by Eucalyptus maculata was 13% of GR in an arid climate zone. In semiarid climate zone in Mexico, Gonzalez-Sosa et al. (2009) determined that $I:GR$ in Acacia fareniana and Prosopis laevigata trees averaged 21.7, and 20.7%, respectively. Mateos and Schnabel (2001), in a study on a Quercus rotundifolia trees in a semiarid region of Spain, reported an annual $I:GR$ of 26.8%. Motahari et al. (2013) reported that the average annual $I:GR$ value in a Pinus eldarica plantation in the Chitgar Forest Park, Iran, was 37%. $I$ was estimated by Návar (2013) for oak forests and by Návar et al. (1999b) for semiarid, subtropical Tamaulipan thornscrub to be 13.0 and 18.9%, respectively.

Higher GR resulted in a shift in the partitioning of rainfall between $TF$ and $I$. At higher GR, the I:GR ratio declined probably because the importance of $S$ diminishes as storms size increase (Sadeghi et al., 2014, 2015). This research supports the work of other authors that have demonstrated a decline in $I:GR$ as GR increased (Crockford and Richardson, 1990, 2000; Staelens et al., 2008; Ahmadi et al., 2009, 2011; Fathizadeh et al., 2013; Motahari et al., 2013; Sadeghi et al., 2014, 2015). During the study period, $I$ increased as the amount of GR events increased; however, as expected, higher $I:GR$ values were obtained for the smaller GR events (Rowe, 1983; Staelens et al., 2008; Ahmadi et al., 2009, 2011; Fathizadeh et al., 2013; Sadeghi et al., 2013, 2014, 2015). The amount of $I$ for small rainfall events are frequently 100% (Horton, 1919). The higher $I:GR$ values for the small GR events is a result of a large portion of incident rainfall retained on the canopy, which evaporates during/after the rain fall.

$I$ partially depends on the size of $S$ (canopy storage capacity) (Klaassen et al., 1998; Aboal et al., 1999; Llorens and Gallart, 2000; André et al., 2008; Muzylo et al., 2009, 2012; Carlyle-Moses et al., 2010; Fathizadeh et al., 2013; Motahari et al., 2013; Sadeghi et al., 2014, 2015). Quantifying $I$ requires the calculation of gross precipitation (GR), water output ($TF$ and $SF$), and controlling factors (such as $S$ value, meteorological parameters, as well as vegetation characteristics) (Rutter et al., 1975; Herwitz, 1985; Gash et al., 1995; Jetten, 1996; Návar et al., 1999b; Holder, 2004; Link et al., 2004; Muzylo et al., 2009; Friesen et al., 2013; Sadeghi et al., 2015). In this study, three graphical indirect methods for estimating $S$ provided values that varied from 0.21 to 0.27 mm for the growing season and ranged from 0.13 to 0.17 mm for the non-growing season. Estimation of $S$ is often difficult to obtain from on-site measurement at the study site. Graphical calculations, though perhaps less accurate than direct estimates of $S$, are simple to calculate and to use. $S$ under F. rotundifolia stand was similar to those found for other deciduous stands (Table 1).

The free throughfall coefficient, $p$, was 0.39 and 0.52 in the growing and non-growing seasons, respectively. As the percentage of canopy cover decreased, $p$ increased, and as expected, higher $p$ values were observed for
non-growing season when the trees were without leaves. Therefore, when modeling I, one must account for the differences in these coefficients (Muzzylo et al., 2009). The differences in abovementioned parameters are not significant compared to the uncertainty of precipitation measurement and its spatial variability. The differences likely result from seasonal variations in leaf area, because I, S, as well as $\bar{E}/\bar{R}$ typically increase in the growing season. As expected, $p$ values decreased when the growing season started. The $\bar{E}/\bar{R}$ values were estimated to be 0.13 in growing season vs. 0.11 in non-growing season, and are consistent with the $\bar{E}/\bar{R}$ values reported for oak spp. of NE Mexico (Návar, 2013). It is likely that, during the growing season, the mean air temperature was higher than in the non-growing season - the mean daily air temperature during rainy days in the growing season were 21.7 °C vs. 18.6 °C in the non-growing season. Moreover, during the growing season, canopy cover is fully leafed; hence, the $\bar{E}/\bar{R}$ rate is higher because canopies have a higher surface area for evaporation. Past research has demonstrated that evaporation from canopy during periods of rainfall depends on meteorological parameters including air temperature, and humidity (Dunkerley, 2000; Asadian, 2007).

CONCLUSIONS

The successful long-term management of plantations in arid and semiarid regions requires consideration of $I$, $TF$, $S$, $\bar{E}/\bar{R}$, as well as $p$ values. $I$, $S$, $\bar{E}/\bar{R}$, and $p$ differed between the seasons. During the growing season, $IGR$, $S$, $\bar{E}/\bar{R}$ and $p$ were found to be 22.5%, 0.24 mm, 0.13 and 0.39, respectively. In contrast, in the non-growing season, these values were 14.1%, 0.15 mm, 0.11 and 0.52, respectively. The leaf loss resulted in decline of $I$, $S$ and $\bar{E}/\bar{R}$, and increase in $p$. These values should be considered when managing water resources. Selection of the species used in plantations has important implications in water balance in terms of their influence on $I$ and transpiration (loss of water from within the leaves). Hence, forest managers must balance their interest in wood production with the need for water resources management. Important considerations include the influence of the water balance on tree growth/survival and both local and distant irrigation needs that rely on precipitation recharging the aquifer. Moreover, information about $I$, $TF$, $S$, $\bar{E}/\bar{R}$, and $p$ would be useful to predict the effects of the silvicultural treatments (e.g., thinning) on water relations and tree growth, as well as the soil water balance.

ACKNOWLEDGEMENTS

We would like to express our gratitude to Mr. Maysam Jabbari and Mr. Shojaat Babapour for their assistance in data collection. Sincere appreciation is extended to Dr. Anoushirvan Shirvany, academic member of University of Tehran, for his encouragement and useful comments during the completion of this research.

REFERENCES


(1) 


(2) 


(3) 