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RESEARCH ARTICLE

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Throughfall nutrients in a degraded indigenous *Fagus orientalis* forest and a *Picea abies* plantation in the North of Iran

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Abstract

Aim of study: The objective of this study was to compare the quantity and quality of *TF* (throughfall) in an indigenous, but degraded, stand of *Fagus orientalis* and *Picea abies* plantation.

Area of study: Forests of Kelar-Dasht region located in Mazandaran province, northern Iran.

Material and Methods: TF measured by twenty collectors that were distributed randomly underneath each stand. For 21 storms sampled in 2012 (August-December) and 2013 (April-June), we analyzed pH, EC, Ca^{2+}, Mg^{2+}, K^+, NO_3^-, and P of gross rainfall (*GR*) and *TF*.

Main results: Cumulative interception (*I*) for *F. orientalis* and *P. abies* were 114.2 mm and 194.8 mm of the total *GR*, respectively. The amount of K^+ (13.4 mg L^{-1}) and Ca^{2+} (0.9 mg L^{-1}) were higher (for both elements, $p = 0.001$) in the *TF* of *P. abies* compared to those of *F. orientalis* (6.8 and 0.5, mg L^{-1}, respectively) and *GR* (3.2 and 0.37 mg L^{-1}, respectively). Conversely, mean P concentration was doubled ($p = 0.022$) in the *TF* of *F. orientalis* (11.1 mg L^{-1}) compared to *GR* (5.8 mg L^{-1}).

Research highlights: P. abies plantations may provide a solution for reforestation of degraded *F. orientalis* forests of northern Iran, yet how *P. abies* plantations differentially affect the quality and quantity of rainfall reaching subcanopy soils (*TF*) compared to *F. orientalis* is unknown. Understanding the connection between hydrological processes and nutrient cycling in forest ecosystems is crucial for choosing the appropriate species to rehabilitate the degraded indigenous forests with nonindigenous species.

Keywords: concentration; hydrological process; interception; reforestation.

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Introduction

The Caspian forest ecosystem of Iran is considered one of the last remnants of indigenous deciduous forests in the world. In comparison to European broad-leaved forests, the Caspian forests seem to have remained from the Tertiary and, therefore, can be called a “relic” ecosystem (Haghdoost *et al*., 2011). In Iran, the Caspian forests are located on the “green strip” extending over the Northern slopes of the Alborz mountains range and Southern coasts of the Caspian Sea. This zone has a total area of 1.84 million ha, comprising 15% of the total Iranian forests and 1.1% of the country’s area. These forests range elevationally from sea level to 2800 m, encompassing a variety of forest types (Haghdoost *et al*., 2011). One forest type, oriental beech (*Fagus orientalis* Lipsky), has been degraded dramatically due to the industrial over exploitation of wood and livestock overgrazing. To restore the Caspian deciduous forest of northern Iran and, as a result, conserve water and soil, reforestation projects were extensively performed by the Forest, Rangeland and Watershed (FRW) organization of Iran since 1960. Norway spruce (*Picea abies* (L.) Karst.) originated from Yugoslavia as one of the most popular, fast-growing, nonindigenous species for reforesting degraded beech forests, owing to *P. abies*’ wider ecological adaptation in comparison to other native hardwoods (Yousefi *et al*., 2013).

Characteristics of indigenous forest ecosystems are highly affected by nonindigenous species after reforestation. Although plantations of nonindigenous species have been considered a viable management strategy for rehabilitation of indigenous tree communities (Chapman & Chapman, 1996), these plantations, mostly coniferous, have considerable effects on ecosystems and, more specifically, on soil fertility and nutrient cycling (Haghdoost *et al.*, 2011). Ecological and environmental effects of nonindigenous species increase with increasing the area of forest plantations.

Forest hydrology is focused on the physico-chemical characteristics of water in forested areas and its circulation and distribution (Chang, 2006). When it rains, a proportion of rainfall never reaches to the forest floor, as the it is intercepted by leaves, branches, and stems and subsequently evaporated by a process called interception loss (*I*). Throughfall (*TF*) is the part of the incident rainfall which passes through the forests canopy, either directly in gaps or interacting with the vegetation (Sadeghi *et al.*, 2014, 2015a, b). The amount of water reaching the forest floor by flowing down the stems via converging branch flow is called stemflow (*SF*). *I* can be estimated as the difference between the gross rainfall (*GR*) measured above the canopy or in a neighboring open area and the sum of *TF* and *SF* sampled beneath the canopy (Lloyd *et al.*, 1988; Mahendrappa, 1990; Tobon *et al.*, 2000; Sadeghi *et al.*, 2014, 2015a, b). The *I* of nondigenous forest is strongly influenced by its structure: *e.g.*, species composition, dimensions, basal area, and understory (Keim *et al.*, 2005; Pypker *et al.*, 2011; Sadeghi *et al.*, 2014, 2015a). The size and shape of the canopy (*e.g.*, foliation period, leaf and stem surface areas, gap fractions, and canopy storage capacity) and climatic parameters (*e.g.*, rain intensity, rain duration, wind speed) influence on the amount, intensity, and spatial distribution of throughfall (Link *et al.*, 2004; Mużyło *et al.*, 2012; Sadeghi *et al.*, 2014, 2015a, b). Hence, variations in these characteristics create variations in *TF* value.

Chemistry of *TF* changes as incident rainfall passes through the forest canopy. Tree foliage absorbs some solutes from rainfall, thus reducing concentrations in the *TF*–NO_3^- is a common example (Van Stan *et al.*, 2012). Conversely, concentrations of other solutes in the *TF* increases as they are washed off from leaves—Na^+ is typically observed as behaving this way (Li *et al.*, 1994; Prakasa Rao *et al.*, 1995; Chiwa *et al.*, 2004; Zeng *et al.*, 2005). Ecological factors, like this canopy exchange with *TF*, should be taken into account for choosing an appropriate species in reforestation projects. Canopy exchange will regulate the chemical composition of meteoric water fluxes reaching forest soils. Hence, in considering species for reforestation, managers must compare how the chosen specie's canopy exchange will be altered as this will, in turn, alter the quality and quantity of rainfall in an ecosystem. Thus, the objectives of this research were to (i) compare *I* and *TF* quantity by an indigenous *F. orientalis* forest and a *P. abies* plantation and (ii) compare the nutrients inputs of Ca^{2+}, Mg^{2+}, NO_3^-, P, and K^+ of *TF* under a *F. orientalis* forest and *P. abies* plantation. Since large areas of the *F. orientalis* forests have been replaced with *P. abies* plantations, this paper reports how the amount and chemical compositions of *TF* may have been changed. This indigenous *F. orientalis* is a typical degraded beech forest in terms of structure, tree morphology, etc. So, the results of this research may be extended to other degraded beech forests in the Caspian Forests of northern Iran.

Materials and Methods

Site description

The study was performed at two forest locations. The first site was an indigenous, but degraded, monospecific forest of *F. orientalis* of uneven age (ranging from 70-80 years old). The second site was a 43-year old neighboring *P. abies* plantation. Both forests are situated in the Kelar-Dasht region located in Mazandaran province, the Caspian region, northern Iran (36° 30' N, 51° 9' E; 1320 m above the Caspian sea level) (Fig. 1). Measurements at each site were per-

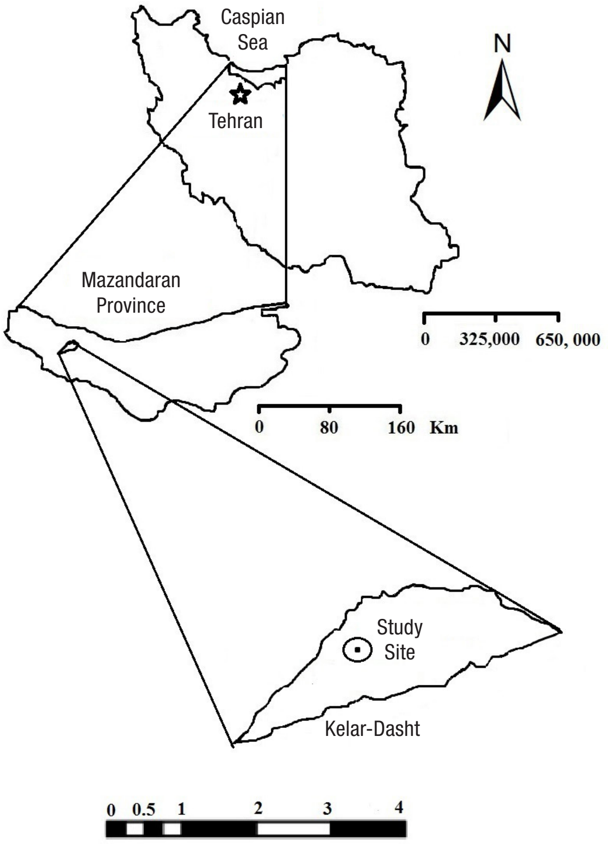

Figure 1. The study site located at the Kelar-Dasht area, Mazandaran Province, the Caspian region, North of Iran.

formed in 0.5 ha plots (Fig. 2). Tree densities for *F. orientalis* and *P. abies* were 196 and 701 tree ha^{-1}, respectively. Mean tree height and diameter at breast height (DBH) were 9.5 m (SD: ±2.9 m) and 93 cm (SD: ±15 cm) for *F. orientalis* and 20.2 m (SD: ±3 m) and 28 cm (SD: ±6 cm) for *P. abies*, respectively. It is noteworthy that, in contrast with the sampled degraded *F. orientalis* forest, the height and DBH of *F. orientalis* trees in non-degraded Caspian forests can reach up to 40 m and 100 cm, respectively (Tabari *et al.*, 2007).

Climate

Long-term (1991-2012) meteorological parameters recorded by the nearest station to the study site, Kelar-Dasht Nursery Meteorological Station (36° 29' N, 51° 8' E; 1150 m above the Caspian sea level), shows that the mean yearly rainfall is 430 mm (SD: ±76 mm). November is the rainiest month (60 mm; SD: ±35 mm) while August is the driest (21 mm; SD: ±16 mm). The dry period begins in May and ends in August. The meteorological records also indicate that the mean annual air temperature is 15.5 °C (SD: ±0.9°C) ranging from 2.8 °C (SD: ±0.9) in February to 21.8 °C (SD: ±1.3) in August.

Measurements of *GR* and *TF*

Four manual funnel-type collectors consisting of 9 cm diameter were installed in an adjacent open area to the study sites for *GR* measurement. Mean *GR* was determined based on an average of the four collectors. *GR* was measured manually either immediately after an event or at sunrise following a night time rainfall (more details can be found in Sadeghi *et al.*, 2014). For *TF* measurement, twenty collectors (9 cm diameter funnel-type), of similar shape and size as the *GR* collectors, were distributed randomly (Carlyle-Mosses *et al.*, 2004) underneath the *F. orientalis* canopy. Another twenty collectors were put beneath the *P. abies* canopy. Mean *TF* was calculated using the twenty *TF* measurements per rainfall event. The amount of *I* and *I:GR*(%) per event rainfall (for 21 storms) were calculated as the difference between *GR* and *TF*.

A fabric covered the neck of the collectors to prevent litter, needles, and debris from entering the collectors. All collectors were washed and rinsed with distilled water before being reinstalled. *GR* and *TF* were measured in 2012 from August to December and 2013 from April to June. Measurement of snowfall was ignored from January to April.

SF was not measured assuming that only a small fraction of the *GR* is normally allocated to *SF* under the present circumstances. Rough-barked species like *P. abies* typically have low *SF* values (Helvey & Patric, 1965; Geiger, 1965) and although *F. orientalis* is smooth-barked, previous work on this species has shown its stemflow to be ~2% (Ahmadi *et al.*, 2011). Therefore, *I* was calculated as the difference between the amounts of *GR* and *TF* (*e.g.*, Sadeghi *et al.*, 2014, 2015a, b).

Chemical analysis

For chemical analysis, the 20 *TF* samples collected per event were combined into 4 composite samples per site (making 4 *TF* samples from each site) per month. All 4 *GR* samples from the open were selected for analysis per month. Accordingly, within three months of sampling period, 36 total samples were analyzed (3 months * 4 samples/month * 3 research sites -*GR*, *F. orientalis*,

Figure 2. The degraded indigenous forest of *Fagus orientalis* (A) replaced with a *Picea abies* plantation (B) in Kelar-Dasht, Mazandaran province, the Caspian forests of northern Iran

and *P. abies*). Samples were immediately filtered after collection and stored at 4°C. The samples were analyzed in a specialized laboratory of soil, plant, and water analysis located in Mazandaran province, northern Iran. The pH was measured with a microprocessor pH/Ion meter (Jenway, UK) and the electrical conductivity (EC) was measured with a microprocessor EC meter (Jenway, UK). Calcium (Ca^{2+}), magnesium (Mg^{2+}), and potassium (K^{+}) were determined using the Flame Photommeter (Jenway pf7, UK). Chemical analysis of *GR* and *TF* for nitrate (NO_3^-), and total phosphorus (P) was determined by UV/V Spectrophotometer (SQ-2800, US).

Sampling design and study variables

Solute fluxes per event (mg m^{-2} $event^{-1}$) were estimated by the concentration of each solute in *TF* (mg L^{-1}) multiplied by the amount of *TF* per event (L $event^{-1}$). The enrichment ratio was defined as the ratio of solute concentrations of *TF* over the solute concentrations of *GR*. The average concentration of each *TF* solute per month per stand was compared to the average concentration of same solute in *GR* samples of the same month.

Statistical Analysis

Regression curves were adjusted between relative interception (*I:GR*)% *vs.* gross rainfall (*GR*) (mm $event^{-1}$) for the indigenous *F. orientalis* stand and nonindigenous *P. abies* plantation. One-way ANOVA and Duncan test were performed for statistical comparison the values of pH, EC, and concentrations of nutrients (Ca^{2+}, Mg^{2+}, K^{+}, NO_3^-, P, and K^{+}) between the *GR* and *TF* of stands. For significant differences in amount of enrichment between stands, student t-test was used.

Results

During the study period, 21 rainfall events with cumulative amount of 380 mm were recorded. Cumulative *TF* for *F. orientalis* and *P. abies* forest were 265.9 mm (70 %) and 185.3 mm (48.8 %), respectively. The cumulative *I* for *F. orientalis* and *P. abies* were 114.2 mm corresponding to 30 % and 194.8 mm corresponding to 51.2 % of the total *GR*, respectively. Mean *GR* per event was 18.1 mm, and mean *I* per event for *F. orientalis* and *P. abies* were 5.4 and 9.3 mm, respectively. The mean values of *I:GR* showed a decreasing trend with increase in *GR* amounts per event in both forests [*F. orientalis* ($I:GR$) = $90.209GR^{-0.354}$, $r^2 = 0.67$; *P. abies* ($I:GR$) = $104.93GR^{-0.237}$, $r^2 = 0.42$] (Fig. 3).

No statistical difference was observed between pH of the *GR* and *TF* of forests. ($pH_{F.\ orientalis} = 7.2$, $pH_{P.\ abies} = 7.0$, and $pH_{GR} = 7.1$; $p = 0.6$). In contrast, EC was significantly different between *F. orientalis* (98.3 μs), *P. abies* (157.4 μs), and *GR* (71.3 μs) (Fig. 4, $p = 0.003$).

The concentrations of K^{+} (13.4 mg L^{-1}) and Ca^{2+} (0.9 mg L^{-1}) were higher (for both elements, $p = 0.001$) in the *TF* of *P. abies* plantation compared to those of *F. orientalis* (6.8 and 0.5, mg L^{-1}, respectively) and *GR* (3.2 and 0.37 mg L^{-1}, respectively). We observed no significant difference ($p = 0.409$) among Mg^{2+} concentrations of rainfall and *TF* of *F. orientalis* and *P. abies*. There was a significant difference ($p = 0.017$) between NO_3^- concentration of *GR* (6.5 mg L^{-1}) and *TF* of *F. orientalis* (3.1 mg L^{-1}). The amount of total P was significantly higher ($p = 0.022$) in the *TF* of the *F. orientalis* (11.1 mg L^{-1}) in comparison with *GR* (5.8 mg L^{-1}) (Fig. 5).

Forest canopy covers had no significant effect ($p = 0.098$) on the Ca^{2+} fluxes per event both in *F. orientalis* indigenous forest and *P. abies* plantation (Table 1). The Mg^{2+} flux of *P. abies* showed a significant decrease ($p = 0.043$) compared to *GR*. Our results suggested that NO_3^- flux per event in the *F. orientalis* forest and *P. abies* plantation were lower ($p = 0.005$) than that of *GR*. The value of P flux in *F. orientalis* was greater ($p = 0.020$) than that of *P. abies*, yet the flux of K^{+} in *P. abies* was much higher compared to *F. orientalis* ($p = 0.016$). The enrichments (concentrations of nutrients in *TF* / those in *GR*) of NO_3^-, P, K^{+},

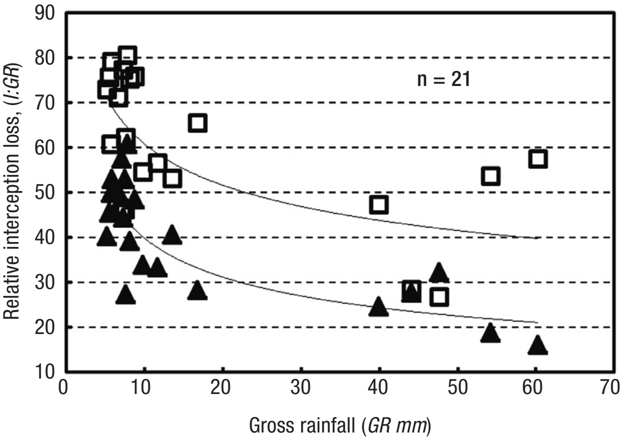

Figure 3. Regression curves between relative interception (*I:GR*)% *vs*. gross rainfall (*GR*) (mm per event) for the indigenous *F. orientalis* (close triangles) and *P. abies* (open squares) stands during the measurement period, 2012, from August to December, and 2013, April to June, in Kelar-Dasht Forest for 21 rain storms. Regression equation are ($I:GR$) = $90.209GR^{-0.354}$, $r^2 = 0.67$, and ($I:GR$) = $104.93GR^{-0.237}$, $r^2 = 0.42$, respectively. Relative interception (*I:GR*) and *GR* showed negative power relationships in two stands. Each diamond and square refers to a rainfall event and *n* shows the number of rainfall events.

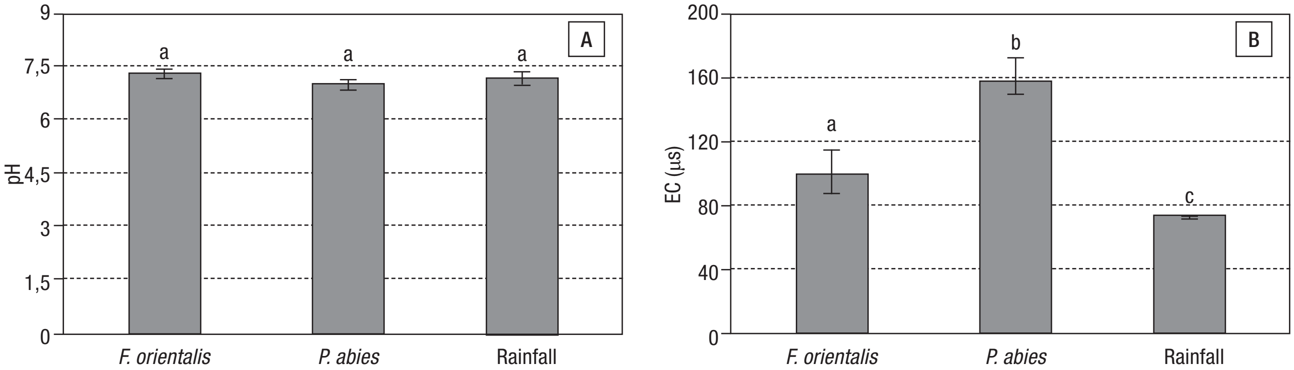

Figure 4. Mean pH (A) and EC (µs, B) during the study period (August to October, 2012) in the *Fagus orientalis* indigenous forest and the *Picea abies* plantation in Kelar-Dasht Forest (North of Iran). Error bars show the standard error of mean (SE). Dissimilar letters indicate the significant differences (Duncan, $p < 0.05$).

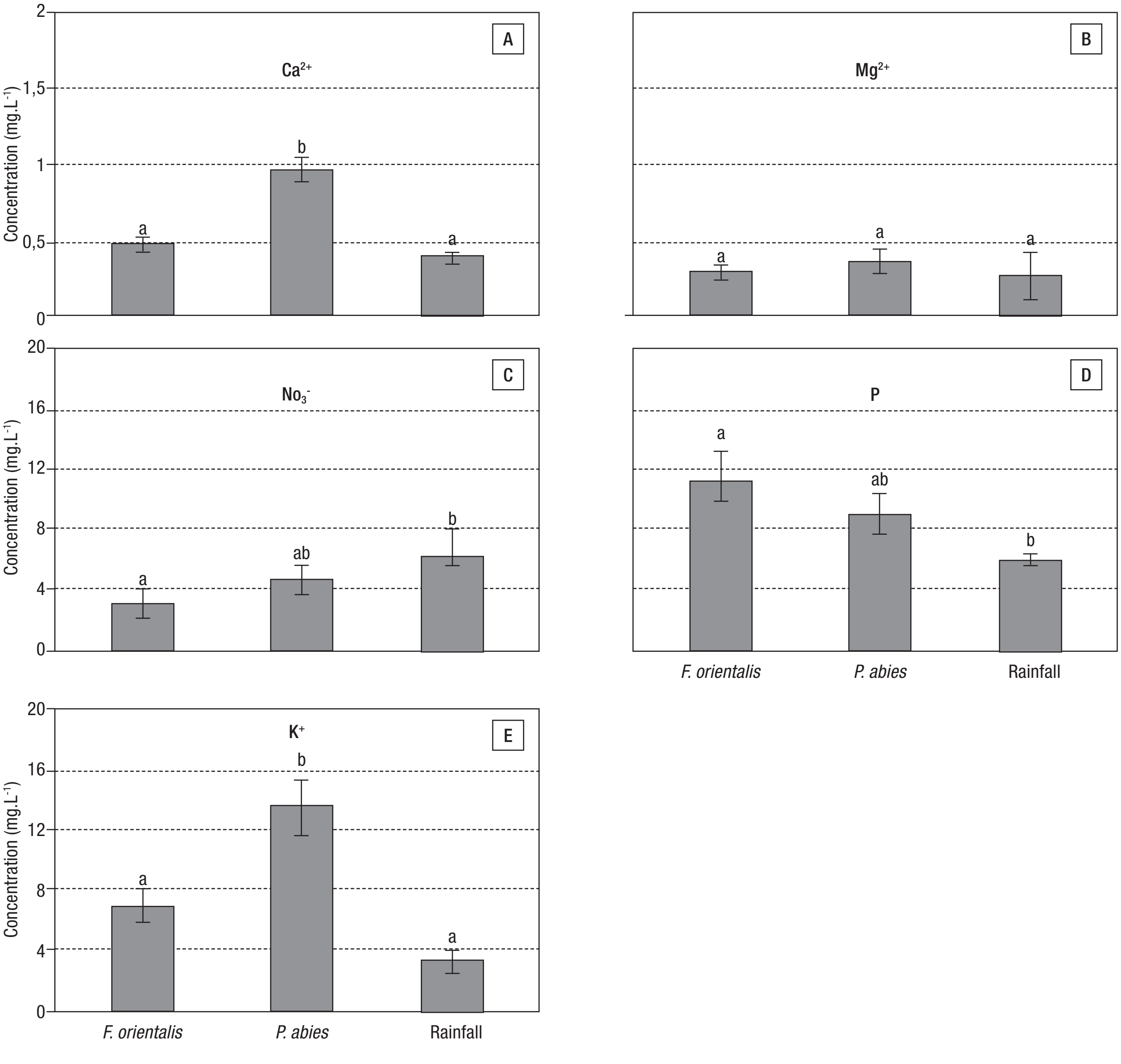

Figure 5. Mean concentrations of nutrient [Ca^{2+} (A), Mg^{2+} (B), NO_3^- (C), P(D), and K^+ (E)] during the study period, from August to October, 2012, in the *Fagus orientalis* indigenous forest and the *Picea abies* plantation in Kelar-Dasht Forest (North of Iran). Error bars show the standard error of mean (SE). Dissimilar lowercase letters indicate the significant differences (Duncan, $p < 0.05$).

and Mg^{2+} were not significantly different in the *TF* of *F. orientalis* and *P. abies*. However, the enrichment of Ca^{2+} was significantly higher in the *P. abies* plantation in comparison with the *F. orientalis* forest (t = 3.08) (Fig. 6).

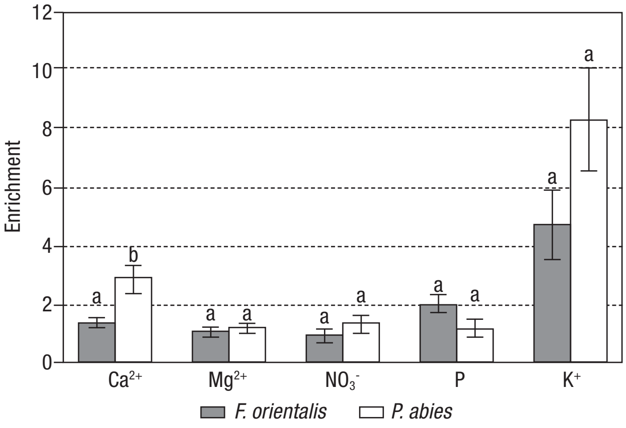

Figure 6. Mean enrichments of nutrient (Ca^{2+}, Mg^{2+}, NO_3^-, P, and K^+) in the throughfall respect to the rainfall during the study period, from August to October 2012 in the *Fagus orientalis* indigenous forest and the *Picea abies* plantation in Kelar-Dasht Forest (North of Iran). Error bars show the standard error (SE) (t-test).

Table 1. Nutrient input (mg m^{-2}) to the forest floor (Ca^{2+}, Mg^{2+}, NO_3^-, P, and K^+) per rainfall event during the study period, from July to October 2012, in the *Fagus orientalis* indigenous forest and the *Picea abies* plantation in Kelar-Dasht Forest, Northern Iran. The numbers in brackets show the standard error of mean (SE). Dissimilar lowercase letters indicate the significant differences (Duncan, $p < 0.05$).

Nutrients	**Amounts of nutrient fluxes per event (mg m^{-2})**		
	***F. orientalis* Forest**	***P. abies* Plantation**	**Rainfall (*GR*)**
Calcium (Ca^{2+}) (mg m^{-2})	12.7 [1.3]$_a$	17.0 [1.9]$_a$	13.4 [1.2]$_a$
Magnesium (Mg^{2+}) (mg m^{-2})	7.4 [1.1]$_{ab}$	6.2 [0.8]$_a$	9.8 [1]$_b$
Nitrate (NO^{3-}) (mg m^{-2})	81.3 [19.9]$_a$	85.3 [16.1]$_a$	233.5 [54.8]$_b$
Phosphorus (P) (mg m^{-2})	288.2 [45]$_b$	160.5 [23.6]$_a$	209 [14.6]$_{ab}$
Potassium (K^+) (mg m^{-2})	176.5 [27.6]$_{ab}$	241.7 [30.9]$_b$	114.8 [29]$_a$

Discussion

In our study, the average values of (*I*:*GR*)% in *F. orientalis* (30%) and *P. abies* (51. 3%) agreed to the values reported by other researchers. Literature reviews suggested that conifers tend to have greater interception capacity than broadleaved species (*e.g.,* Carlyle-Moses & Gash, 2011). In a beech forest, (*I:GR*)% values ranged from 11.5% by *F. moesiaca* (Michopoulos *et al.,* 2001) to 31% by *F. sylvatica* (Staelens *et al.,* 2008). Moreover, Link *et al.* (2004) reported that (*I:GR*)% value in temperate area was 48% of *GR* in coniferous stands. The tree density increase (*I:GR*)% (Eltahir & Bras, 1993). In our study tree density was higher in *P. abies* stand than *F. orientalis*, so the increase in *I*:*GR* can be explained too by the higher tree density.

The results confirmed that the amount of *GR* had a significant impact on rainfall partitioning into *TF* and *I*. As *GR* increases, the ratio of *I* to *GR* (*I*:*GR*) decrease; hence frequent small storms (short storm with high rainfall intensity) typically result in the greatest proportion of *GR* that is lost to *I* (Fig. 3), similar to the other research (*e.g.*, Sadeghi *et al*., 2014, 2015a, b).

Interception can be changed by forest management practices which affects the amount, type, and distribution of vegetation in a watershed (Sadeghi *et al*., 2014, 2015a, b), thus, estimating *I* is necessary when selecting the species for reforestation in the Caspian forests. Differences in transpiration between the species, however, should also be quantified, because transpiration rate would affect the water cycle (Sadeghi *et al*., 2014).

By modifying the species composition (*e.g.*, restoring forest cover with a nonindigenous plantation) *TF* solutes, pH, and EC are altered (Eaton *et al*., 1973). We observed *TF* solute flux and composition changed due to rainfall passing through the canopy. Inconsistent with past studies, *TF* mean pH for both stands was not significantly different than *GR*. Previous reports showed that coniferous canopies tend to have lower pH of *TF* relative to both *GR* and *TF* from hardwood canopies (Edmonds *et al*., 1991; Matsuura *et al*., 2001; Kulhavy *et al*., 2010). Variations in pH have been related to the ability of trees crowns to capture dry deposition, the chemical characteristics of dry deposition, and the frequency, intensity, duration and quantity of rainfall (Leininger & Winner, 1988). Hence, the aforementioned factors causes higher acidity in needle-leaved compared to broadleaves. Kulhavy *et al*. (2010) reported the mean pH values of the *TF* in a *F. sylvatica* stand was 5.9 against 5.4 in a *P. abies* stand. Cantu Sliva & Gonzalez Rodriguez (2001) showed that *TF* in *Pinus pseudostrobus* had higher acidity value compared with the canopy *TF* in *Quercus sp.* Hongve *et al*. (2000) concluded that *TF* pH was lower in coniferous compared to hardwoods of Norway. Pérez-Suàrez *et al.* (2008) also showed acidity to increase in *TF* compared to *GR* in *Pinus hartgewii*.

After intercepting the rainfall by the canopies, the EC values of *TF* increased (Wang *et al.*, 2004; Le Mellece *et al.*, 2010). EC value was found to be higher in *P. abies* than that of *F. orientalis*, similar to Le Mellec *et al.* (2010). This indicates that inorganic ions were leached from the two canopies (Wang *et al.*, 2004). Polkowska *et al.* (2005) found that *TF* EC can be 30-50 µSiemens higher than *GR*. Literature indicates an inverse relationship between the amount of pH and EC (Polkowska *et al.*, 2005), as we observed in our results. The relationships between pH and EC depended on canopy density, stand age and wind direction (Polkowska *et al.*, 2005).

The cations, *i.e.*, Ca^{2+}, K^+, and P concentrations in rainfall increased as rainfall passed through the forest canopies (Fig. 5).The concentration of Ca^{2+} was significantly higher in *P. abies* than *F. orientalis* stand and *GR* relating possible to the exchange of cations between the crown and the rain (Tukey, 1970). The area of canopy in coniferous species is more than deciduous trees (De Schrijver *et al.*, 2007), thus leaching water from needles of *P. abies* is higher. This result was in consistent with the results of Adriaenssens *et al.* (2012) stating the concentration of Ca^{2+} in *F. sylvatica* was higher than that of *P. abies* and the amount of Ca^{2+} was tripled than *GR* when passes through the canopy. Dezzo & Chàcon (2006) stated that dissolved Ca^{2+} increased 5-8 fold as *GR* passed through the canopy, becoming *TF*. In fact, Ca^{2+} is leached from leaf and bark surfaces easily (Tukey, 1970). Our study showed no significant difference in Mg^{2+} concentration of *TF* and *GR*, results that are not consistent with other research. For example, Balestrini *et al.* (2007) indicated that the concentration of Mg^{2+} increased as *GR* passed through the canopy in stands of *P. abies* and *F. sylvatica*, due to the wash off of dry deposited Mg^{2+} from the crown surface. Also, Dezzo & Chàcon (2006) found the concentration of Mg^{2+} increased 3-4 fold after *GR* percolated through the canopy. NO_3^- concentration decreased while passing through the canopy, as found by others (Fan & Hong, 2001; Mustajarvi *et al.,* 2008). In fact, the canopy absorbs nitrate (Harrison *et al.*, 2000). Our study suggested that the concentration of P was significantly higher in the *TF* of the *F. orientalis* in comparison with *GR*, because this element was leached from canopy as reported by Rodrigu *et al.* (2003). However, Ling-Hao & Peng (1998) in a study conducted in a *Castanopsis eyrei* stand within the growing and non-growing seasons expressed that the canopy absorbed P during the non-growing season. The increase in K^+ concentrations after the interaction of rain water with the forest canopy has frequently been observed and attributed to the high leachability of K^+ from the leaf tissue (Parker, 1983). Edmonds *et al.* (1991) showed that throughfall were generally enriched with cations (especially K^+). Balestrini *et al.* (2007) found all monitored ions (H^+, NH_4^+, Ca^{2+}, Mg^{2+}, Na^+, K^+, SO_4^{2-}, NO_3^- and Cl) increased by passing through crown. K^+ leached more than any other ionic solute in our study. Adriaenssens *et al.* (2012) also reported that K^+ concentration in *Picea TF* was the most enriched by canopy exchange. They suggested that concentrations of K^+ in the *TF* of *F. sylvatica* and *Picea* stands were more than *GR* by 37 and 17 times, respectively.

The concentration of nutrients in *TF* (mg L^{-1}) and the value of *TF* are factors affecting the amount of fluxes in the nutrient cycle (Drápelová, 2013). Ashagrie & Zech (2010) stated difference in the *TF* nutrient flux value between different stands was mostly due to the difference in *TF* water flux. However, nutrients absorption by canopy, area of canopy, nutrients leachability from canopy also has influence on flux value (Schrumpf, 2004). Although the concentrations of Mg^{2+} in *P. abies TF* stand and *GR* had not significant difference, the higher amount of water in *GR* was resulted in higher amount of Mg^{2+} flux in *GR* in comparison with *P. abies*. As the concentration of NO_3^- and amount of precipitation in *GR* was greater than *TF*, the value of nitrate flux was significantly higher in *GR* than *F. orientalis* and *P. abies* stands. Our results suggested that P flux in *F. orientalis* was greater than that of *P. abies*, mostly as a result of *TF* volume being higher beneath *F. orientalis*. Yet, it is important to note that *P. abeis* K^+ flux was large owing to the leachability of K^+ from the leaf tissue (Parker, 1983).

The enrichment of Ca^{2+}, Mg^{2+}, NO^{3-}, P, and K^+ in *TF* relative to *GR* for *F. orientalis* canopy was 1.3, 1.1, 0.9, 1.9, and 4.7, respectively. The corresponding values were 2.8, 1.3, 1.3, 1.2, and 8 by *P. abies*. The maximum enriching nutrient in both stands was K^{+} showing that K^+ is the most enriched among the nutrients investigated in this study as reported by Cantu Sliva & Gonzalez Rodriguez (2001). Nutrient enrichment is mostly due to both dry deposition and leaching of intercellular solutes from leaves (Rodrigo *et al.*, 2003). The enrichment of nutrients in *TF* has been ascribed to the dissolution and washout of atmospheric material deposited on canopy (Eaton *et al.*, 1973; Parker, 1983; Levia & Frost, 2003) or due to exchange between rainfall and nutrients in internal plant parts (Marques & Ranger, 1997; McDowell, 1998; Liu *et al.*, 2002).

The chemical composition of *TF* has been related to forest type (Forti & Neal, 1992), type of species (Edmons *et al.*, 1991), and temporal and spatial variability of rainfall (Robson *et al*., 1994). Leaf anatomy, morphology and physiology may also play a role in *TF* chemistry. Robson *et al*. (1994) suggested that temporal and spatial variability in *TF* chemistry between forest canopies is generally attributed to non-uniformity of canopy density and to differences in the efficiency of different canopy structures for filtration dry deposition.

Planting a new species in a region, no matter native or indigenous, cause changes in the quantity of water reaching the forest floor (Sadeghi *et al*., 2014, 2015a, b). Knowledge the relationship between hydrologic and nutrient cycling and the impact of afforestation projects on these parameters can be useful for forest management and selection of appropriate species for reforestation.

Conclusion

During the study period, 21 rainfall events with cumulative amount of 380 mm were recorded. As *GR* increases, the ratio of *I* to *GR* (*I*:*GR*)% decrease and the average values of (*I*:*GR*)% in *F. orientalis* (30%) was lower than that of *P. abies* (51. 3%), thus, the amount of water that reaches the forest floor in *F. orientalis* was higher than *P. abies*. No statistical differences were observed among pH of the *GR* and those of *TF*. However, EC was different among *F. orientalis*, *P. abies*, and *GR* indicating that inorganic ions were leached from the canopies. The Ca^{2+}, K^+, and P concentrations in rainfall increased as rainfall passed through the forest canopies. NO^{3-} concentration in *GR* was significantly higher than *F. orientalis* confirming the absorption of nitrate by canopy. K^+ had the highest value of enrichment. The amounts of Mg^{2+} and NO_3^- fluxes in *GR* were higher than *TF*. Planting a new species for reforestation changes the amount of water reaching the forest floor and modifies the chemical composition of *TF*, *i.e.* the amount of nutrients input to the forest floor.

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