2015

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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, Ca2+, Mg2+, K+, NO3, 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 Ca2+ (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.


Received: 28 Aug 2014. Accepted: 20 Jul 2015

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Funding: The author(s) received no specific funding for this work.

Competing interests: The authors have declared that no competing interests exist.

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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 (Haghdoot 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; Pyper 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; Mužýlo 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 performed.

**Figure 1.** The study site located at the Kelar-Dasht area, Mazandaran Province, the Caspian region, North of Iran.
Throughfall nutrients inputted to forest soils

Throughfall nutrients inputted to forest soils

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.

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, P. abies).
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 (Ca2+), magnesium (Mg2+), and potassium (K+) were determined using the Flame Photometer (Jenway pF7, UK). Chemical analysis of GR and TF for nitrate (NO3-), 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 (Ca2+, Mg2+, K+, NO3-, 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 Ca2+ (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 Mg2+ concentrations of rainfall and TF of F. orientalis and P. abies. There was a significant difference (p = 0.017) between NO3- 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 Ca2+ fluxes per event both in F. orientalis indigenous forest and P. abies plantation (Table 1). The Mg2+ flux of P. abies showed a significant decrease (p = 0.043) compared to GR. Our results suggested that NO3- 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 NO3-, P, K+,
**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 [Ca²⁺ (A), Mg²⁺ (B), NO₃⁻ (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, $p < 0.05$).

<table>
<thead>
<tr>
<th>Nutrients</th>
<th>F. orientalis Forest</th>
<th>P. abies Plantation</th>
<th>Rainfall (GR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium (Ca$^{2+}$) (mg m$^{-2}$)</td>
<td>12.7 [1.3]$_a$</td>
<td>17.0 [1.9]$_a$</td>
<td>13.4 [1.2]$_a$</td>
</tr>
<tr>
<td>Magnesium (Mg$^{2+}$) (mg m$^{-2}$)</td>
<td>7.4 [1.1]$_a$</td>
<td>6.2 [0.8]$_a$</td>
<td>9.8 [1]$_b$</td>
</tr>
<tr>
<td>Nitrate (NO$_3^-$) (mg m$^{-2}$)</td>
<td>81.3 [19.9]$_a$</td>
<td>85.3 [16.1]$_a$</td>
<td>233.5 [54.8]$_b$</td>
</tr>
<tr>
<td>Phosphorus (P) (mg m$^{-2}$)</td>
<td>288.2 [45]$_b$</td>
<td>160.5 [23.6]$_a$</td>
<td>209 [14.6]$_{ab}$</td>
</tr>
<tr>
<td>Potassium (K$^+$) (mg m$^{-2}$)</td>
<td>176.5 [27.6]$_{ab}$</td>
<td>241.7 [30.9]$_b$</td>
<td>114.8 [29]</td>
</tr>
</tbody>
</table>

**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 pseudeostrobus had higher acidity value compared with the canopy TF in *Quercus sp*. Hongve et al. (2000) concluded that TF pH was lower in coniferous com-
pared to hardwoods of Norway. Pérez-Suárez et al. (2008) also showed acidity to increase in TF compared to GR in *Pinus hartschlegelii*.

After intercepting the rainfall by the canopies, the EC values of TF increased (Wang et al., 2004; Le Mellec 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., Ca²⁺, K⁺, and P concentrations in rainfall increased as rainfall passed through the forest canopies (Fig. 5). The concentration of Ca²⁺ 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 Ca²⁺ in *F. sylvatica* was higher than that of *P. abies* and the amount of Ca²⁺ was tripled than GR when passes through the canopy. Dezzo & Chácón (2006) stated that dissolved Ca²⁺ increased 5-8 fold as GR passed through the canopy, becoming TF. In fact, Ca²⁺ is leached from leaf and bark surfaces easily (Tukey, 1970). Our study showed no significant difference in Mg²⁺ concentration of TF and GR, results that are not consistent with other research. For example, Balestrini et al. (2007) indicated that the concentration of Mg²⁺ increased as GR passed through the canopy in stands of *P. abies* and *F. sylvatica*, due to the wash off of dry deposited Mg²⁺ from the crown surface. Also, Dezzo & Chácón (2006) found the concentration of Mg²⁺ increased 3-4 fold after GR percolated through the canopy. NO₃ 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 canopies 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⁺, NH₄⁺, Ca²⁺, Mg²⁺, Na⁺, K⁺, SO₄²⁻, NO₃⁻ 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 Mg²⁺ in *P. abies* TF stand and GR had not significant difference, the higher amount of water in GR was resulted in higher amount of Mg²⁺ flux in GR in comparison with *P. abies*. As the concentration of NO₃ 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. abies* K⁺ flux was large owing to the leachability of K⁺ from the leaf tissue (Parker, 1983).

The enrichment of Ca²⁺, Mg²⁺, NO₃⁻, 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 variabil-
ity 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 *P. abies* and *F. orientalis*. No statistical differences were observed among pH of the canopy. The Ca$^{2+}$, K$^+$, and P concentrations in rainfall increased as rainfall passed through the forest canopies. NO$^-$ 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$^-$ 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.

## References


Throughfall nutrients inputted to forest soils


