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RESEARCH ARTICLE

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Replacing an oriental beech forest with a spruce plantation impacts nutrient concentrations in throughfall, stemflow, and *O* layer

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Abstract

Aim of study: To measure the nutrient leaching from the canopy and the *O* layer in a natural oriental beech (*Fagus orientalis* Lipsky) forest and a Norway spruce (*Picea abies*) plantation.

Materials and methods: From mid-July to early November, 2013, we measured throughfall (*TF*) (n=45), stemflow (*SF*) (n=12) and leaching from the *O* layer (n = 30) in a 0.5 ha sample plot in the Caspian region, Mazandaran province in northern Iran.

Main results: Concentrations of PO_4^{3-}, Na^+, Mg^{2+}, Ca^{2+} and K^+ in the throughfall and the *O* layer in both beech and spruce forests significantly increased relative to gross rainfall (GR). Concentrations of Ca^{2+} and Na^+ in *TF* and *SF* were significantly higher in the spruce forest compared with the beech forest. Furthermore, in both forests, cumulative fluxes of all studied elements (with the exception of NH_4^+ and NO_3^-) during the study period were statistically different from those of *GR* ($P<0.05$).

Research highlights: This study demonstrates that changing from a natural beech forest to a spruce plantation significantly alters nutrient fluxes exiting the canopy and the *O* layer. This information provides essential information on how planting exotic species will affect nutrient cycles in this region.

Additional keywords: Beech forest; Norway spruce plantation; Throughfall; Nutrient leaching; *O* layer.

Authors´ contributions: Pedram Attarod: Design and conception; Parisa Abbasian: Writing and data analysis; Thomas Grant Pypker: Language editor and scientific comments; Mohammad Taghi Ahmadi: Field measurements, Ghavamoddin Zahedi-Amiri: Technical comments; Hamid Soofi- Mariv: Map preparation; and Vilma Bayramzadeh: Scientific comments.

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Introduction

The nutrients entering the forest floor via rainfall is altered by the canopy and the litter layer. When rainfall enters a forest canopy, a portion of gross rainfall (*GR*) reaches the forest floor by dripping from vegetation or by passing directly through tree canopies as throughfall (*TF*). The remaining *GR* either reaches the forest floor by flowing along stems as stemflow (*SF*) or evaporates back to the atmosphere (Hanchi & Rapp, 1997; Sadeghi *et al.*, 2016). The chemical compositions of *TF* and *SF* changes after contacting canopy elements. In addition to the nutrients from wet deposition, *TF* and *SF* can absorb nutrients present in the canopy. The nutrients may transfer to the available nutrient pool in the soil thereby affecting forest soil fertility (Levia & Frost, 2003) and nutrient dynamics (Parker, 1983). Upon entering the *O* layer, the chemical composition of the rainwater is further altered (Levia & Frost, 2003).

Forest canopies alter the chemical composition of precipitation due to an interaction between precipitation and the crown of the trees. By restoring degraded forests with a nonnative species, the concentration of elements, pH, and electrical conductivity (EC) in *TF* are altered (Eaton *et al.*, 1973). In addition, the nutrient concentration can be affected by other factors such as stand density, canopy structure, rainfall intensity, rainfall continuity, rain angle, crown size, branch shape, branch angle, bark, and the nutrient content of atmospheric rainfall (Cattan *et al.*, 2009). For example, coniferous forests at the same site and under the same climatic conditions intercept more atmospheric pollutants than deciduous forests annually (De Schrijver *et al.*, 2007).

Forest nutrient cycles are linked to the hydrological cycle because water acts as the main transporting agent and solvent for nutrients. Rainfall is a considerable source of nutrients for forest ecosystems and plays an important role in the transfer of material from the canopy to the litter and mineral soil. Three processes are generally linked to the change in elemental concentrations of precipitation (Parker, 1983): (1) accumulation of atmospheric suspended solids on the surface leaves and branches, (2) secretion of plant tissues to the outer surface of leaves and branches, and (3) absorption of chemical nutrients by the foliage (plant tissues). Plant leaves have retention and adsorption capacities for atmospheric particulate pollutants because of their unique surface characteristics and leaf distribution (Schaubroeck *et al.*, 2014; Fan *et al.*, 2015). The leaf surfaces collect nutrients because of evaporation from the leaf surface, the absorption of particulate matter by leaves and by the accumulation the plant secretions on the leaf surface. The quantities of these elements differ depending on the type and characteristics of plant species, topographic and climatic conditions (Carlyle-Moses *et al.*, 2004). Some substances enter the leaf via passive processes driven by concentration gradients (Fernández & Eichert, 2009). The remainder remains on the leaf surface and can alter the chemical composition of *TF* (Adriaenssens *et al.*, 2012). Hence, canopies are both a sink and a source of nutrients (Lovett & Lindberg, 1984). The changes of elements concentration depend on the type of forest (conifers or hardwoods), forest structure and ecological and climatic factors (Iida *et al.*, 2005; Herbst *et al.*, 2007).

Chiwa *et al.* (2004) studied the chemical elements of the *TF* in a *Picea sitchensis* plantation in six different forest habitats with intense air pollution in China. They concluded that EC, Ca^{2+}, K^+, Mg^{2+}, and Zn in the *TF* increased after passing through the canopy. Shen *et al.* (2013) also investigated the concentration of chemical elements and pH of *TF* under the canopy of planted stands of *Acacia mangium* and *Dimocarpus longan* in China and noted that the amount of pH in both stands were more than in *GR*. Abbasian *et al.* (2015) also showed that the concentrations of some elements increased after passing through the canopy in a *Picea abies* plantation and a *Fagus orientalis* natural stand.

In addition, the *O* layer interacts with rainwater and can provide cations to deeper soil layers horizons (Eaton *et al.*, 1973, Bernhard-Reversat, 1975). The amount of nutrients exiting the *O* layer strongly depends on the quantity of *TF* (Ashagrie & Zech, 2010). The quantity of elements in the *O* layer in *Fagus orientalis* and *Picea abies* stands differs from elements exiting the *O* layer because of differences in the quality and quantity of net rainfall reaching the forest floor (Hojjati *et al.*, 2009).

Change in the type of tree species in a geographic area creates significant changes in the composition of water entering the forest soil via precipitation (Llorens & Domingo, 2007). Anatomy, morphology, and physiology in different species may also play a role in *TF* chemistry. Increased concentrations of plant nutrients in *TF* depends on canopy structure because the accumulation of particles, dusts, and gaseous compounds are generally higher in evergreen, coniferous canopies, than in deciduous species (Draaijers *et al.*, 1992; De Schrijver *et al.*, 2004). 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 in different species and to differences in the efficiency of different canopy structures for filtration dry deposition. Bhat *et al.* (2011) stated that *TF* quality and thus the amount of plant nutrients that reach the forest floor by *TF* depend on composition of tree species.

The Caspian forests of northern Iran were historically comprised of broadleaved deciduous forests that covered an area of 1.8 million ha, contained 15% of the total forests of Iran and represented 1.1% of the country's area (Abbasian *et al.*, 2015). It is a green belt stretching over the northern slope of the Alborz mountain ranges and covers the southern coast of the Caspian Sea (Sagheb Talebi *et al.*, 2014). The forests began to degrade due to overexploitation of wood and livestock overgrazing in the past few decades. Since the 1960s, the Forest, Range, and Watershed Management Organization (FRWO) of Iran established restoration projects in an effort to restore the deciduous forests of northern Iran and to conserve water and soil (Abbasian *et al.*, 2015). Degraded forests have been restored using native and indigenous species in northern Iran. Plantations of indigenous species are regarded as a viable management strategy for rehabilitation of native tree communities (Chapman & Chapman, 1996). However, many of the Caspian forests in northern Iran have been replaced with *P. abies* plantations. The increase in nonindigenous species may alter ecological process in these regions (Abbasian *et al.*, 2015). When native deciduous forests are replaced with non-native coniferous species, the soil fertility and nutrient cycling can be significantly impacted. Planting nonnative tree species can alter water and nutrient cycling (Chiwa *et al.*, 2004; Shen *et al.*, 2013; Abbasian *et al.*, 2015). The objectives of this research were to compare and contrast how replacing a natural oriental beech forest (*Fagus orientalis* Lipsky) in the Caspian region with a coniferous forest, i.e., Norway spruce (*Picea abies*), impacts nutrient concentrations (NO_3^-, NH_4^+, PO_4^{3-}, Ca^{2+}, K^+, Mg^{2+}, and Na^+ in mg L^{-1}), pH, and EC of *TF*, *SF*, and the *O* layer.

Materials and Methods

The geographic location and characteristics of the study stands

The study sites were located in the Caspian region of northern Iran (Lajim region, Mazandaran province; 36° 15' N, 53° 10' E; 1000 m above the Caspian sea level) (Fig. 1). The first site was a beech forest (Fig. 2; Table 1). About 15 percent of the forest floor was covered by *Ilex spicigera, Rubus fruticsos*, and *Crataegus sp.* shrubs. The second site was a 45 ha nonnative Norway spruce plantation planted in 1964 (Fig. 2; Table 1). The two sites were immediately adjacent to one another on the same soils. The slope and aspect of the sites were identical.

Climate

In the region, the mean (± standard deviation, SD) precipitation (2003-2017) was 512 mm yr^{-1} ± 150, with February being the wettest month (72 mm $month^{-1}$) and July the driest (18 mm $month^{-1}$) (Kiasar Meteorological Station, 35 km away from the site; 36° 14′ N, 53° 32′ E; 1294 m above the Caspian sea level) and 564 mm yr^{-1} ± 113, with November being the wettest month (72 mm $month^{-1}$) and June the driest (32 mm $month^{-1}$)

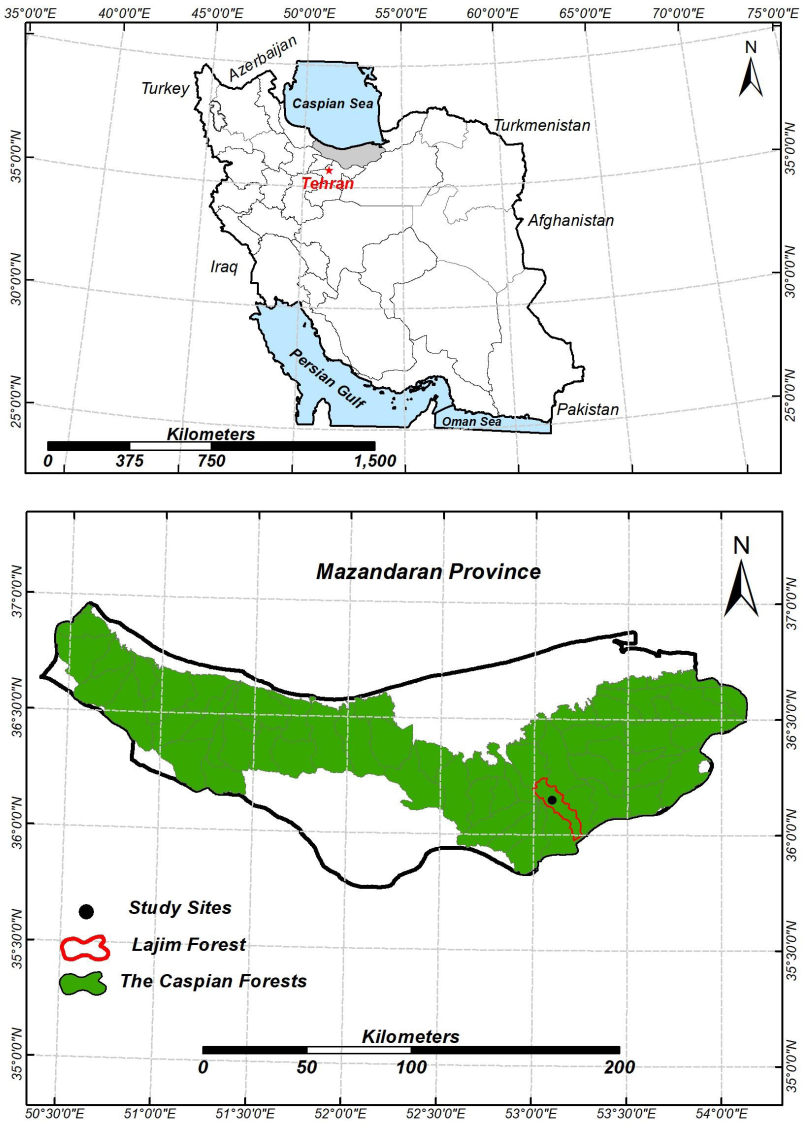

Figure 1. The study sites located at the Lajim area, Mazandaran Province, the Caspian region of northern Iran.


Figure 2. The oriental beech forest (*Fagus orientalis*) (right) and a nonnative Norway spruce (*Picea abies*) plantation (left) in Lajim located in Mazandaran province, the Caspian region of northern Iran.

(Pole-Sefid Meteorological Station; 17 km away from the site; 36° 08′ N, 53° 5′ E; 610 m above the Caspian sea level)). Mean annual air temperature (T) recorded by Kiasar Meteorological Station was 12.5 °C ± 0.6, with August (21.6 °C) being the warmest month and January (3.0 °C) the coldest. Mean annual T recorded by Pole-Sefid Meteorological Station was 16.1 °C ± 0.7, with August (25.6 °C) being the warmest month and January (7.1 °C) the coldest.

Gross rainfall, Throughfall, Stemflow, and *O* layer

At both sites, *GR, TF, SF*, and *O* layer were sampled in flat, 0.5 ha plots from mid-July to early November 2013 (n = 38 at both sites) (Table 1; Fig. 2). The two 0.5 ha plots were 100 m from each other. *GR* was measured using five plastic funnel-type collectors with a 9 cm diameter and 30 cm height. The collectors were located in a clearing that was approximately 200 and 300 m away from the beech forest and the spruce plantation, respectively. *GR* collectors were fixed and mounted separately on a wooden pole one meter from the ground (Attarod *et al.*, 2015). The clearing was of sufficient size to allow for a minimum of a 45-degree angle between the gauge opening and adjacent trees (Sadeghi *et al.*, 2016). We measured the water collected in the collectors immediately after rainfall or the day following each storm. After sampling, the collectors were washed with distilled water.

TF was sampled in a 0.5 ha area using 45 randomly placed collectors that were of the same shape and size used for *GR* collectors. The collectors were distributed beneath the forest canopy in a way that covered almost the entire surface uniformly in each stand. *SF* was collected randomly from 12 trees using spiral-type *SF* collection collars installed at breast height (Toba & Ohta, 2005). Collars were constructed from 3 cm thick plastic, were sealed to the stems in an upward spiral pattern and the water diverted into bottle gauges on the forest floor. After each rainfall event, the *TF* collectors were washed by distilled water and were dried.

Water exiting the *O* layer was collected using 30 plastic collectors installed just below the entire *O* layer of forest soil so that the collector openings were placed towards the soil surface and were below of the target layer. To prevent litter entering the collector, the opening of each collector was covered with a nylon mesh (Santa Regina & Tarazona, 2001; Shachnovich *et al.*, 2008; Bulcock & Jewitt, 2012). After a rainfall event, the collectors were washed with distilled water and placed back in the same location. Although there is no general guideline for sampling of leachate from soil organic horizons, we followed the recommended procedure of several researchers for installing the collectors (Santa Regina & Tarazona, 2001; Shachnovich *et al.*, 2008; Bulcock & Jewitt, 2012).

Chemical analysis

All of the *TF* samples of the 45 collectors were combined together for each rainfall event. This procedure was repeated for *SF*, the *O* layer, and *GR*

Table 1. Characteristics of the oriental beech forest (*Fagus orientalis*) and the Norway spruce (*Picea abies*) plantation.

Characteristic	Beech forest	Spruce plantation
Tree density (tree.ha^{-1})	136	592
Diameter at breast height (DBH) (cm)	44.5 ± 12.3	36.5 ± 5.9
Total height (m)	29.5 ± 7.1	27.5 ± 4.6
Canopy height (m)	17.2 ± 4.4	19.4 ± 5.3
Canopy percentage (%)	90	85
Tree Age (yr)	60	50

samples for each rainfall event. The same volume of rainwater collected in the collectors were mixed for each sample. Samples of three sequential rainfalls were combined to get 150 mL samples for *TF, SF*, the *O* layer, and *GR* in each stand and the open area. The samples were immediately filtered after collection and kept at 4 °C in opaque glass containers. The samples were analyzed in a specialized laboratory of soil, plant, and water analysis. No special pretreatment was done before chemical analysis.

In total, 38 samples for each of *TF, SF, O* layer, and *GR* were analyzed for pH, EC, and nutrient concentrations for each stand (266 samples in total). The concentrations of NO_3^-, NH_4^+, PO_4^{3-}, Ca^{2+}, K^+, Mg^{2+}, and Na^+ (mg L^{-1}) were determined using the Flame Photometer and Spectrophotometer methods according to standardized guidelines (Michopoulos *et al.*, 2001; Levia & Herwitz, 2002; Chuyong *et al.*, 2004; Adriaenssens *et al.*, 2012; Bulcock & Jewitt, 2012). pH and EC were measured with microprocessors of pH/Ion and EC meters (Jenway, UK), respectively.

Data analysis section

A one–way analysis of variance was used using SPSS Ver.19 to evaluate significant differences in element concentration (mg L^{-1}), pH, and EC (dS m^{-1}) in *GR, TF, SF*, and *O* layer in forest stands and the open area.

Results

Acidity and electrical conductivity

There was no significant difference between the pH of *GR, TF*, and *SF* in the beech forest. Within the spruce plantation, pH was significantly lower in the *TF, SF* and *O* layer relative to *GR*. In addition, pH of *O* layer measured at both forests were significantly lower than pH of *TF*. The EC of *GR* (0.08 dS m^{-1} ± 0.01) was significantly lower than those measured in *TF* (0.11 dS m^{-1} ± 0.02 for beech and 0.14 dS m^{-1} ± 0.02 for spruce) and SF (0.12 dS m^{-1} ± 0.02 for beech and 0.14 dS m^{-1} ± 0.03 for spruce) (Table 2). However, EC of the *O* layer in the spruce plantation (0.13 dS m^{-1} ± 0.02) was significantly higher than *GR* (0.08 dS m^{-1} ± 0.01).

Element concentrations

In general, nutrient concentrations in *GR* were significantly lower than *TF, SF* and *O* layer in the beech forest (Fig.3). The concentration of Ca^{2+} in *GR* (Ca^{2+}_{GR}= 5.51 mg L^{-1} ± 0.71) was significantly lower than that of *TF* and *SF* in the beech forest (Ca^{2+}_{TF}= 9.36 ± 1.40 and Ca^{2+}_{SF} = 10.13 mg L^{-1} ± 1.82). There was a significant difference between the average concentration of K^+ in *GR* (K^+_{GR} = 4.14 mg L^{-1} ± 0.42) compared with those of *TF, SF,* and *O* layer in the beech forest (K^+_{TF} = 10.11 ± 1.65, K^+_{SF} = 12.08 ± 2.31, and $K^+_{O\ layer}$ = 8.81 mg L^{-1} ± 1.76). The Mg^{2+} and Na^+ concentrations in *GR* (Mg^{2+}_{GR} = 0.53 ± 0.15 and Na^+_{GR} = 7.38 mg L^{-1} ± 1.24) significantly lower than the concentrations in *TF, SF*, and *O* layer in beech forest (Mg^{2+}_{TF} = 0.97 ± 0.22, Mg^{2+}_{SF} = 1.35 ± 0.35, and $Mg^{2+}_{O\ layer}$ = 0.74 ± 0.23; Na^+_{TF} = 13.23 ± 2.34, Na^+_{SF} = 13.57 ± 1.78, and $Na^+_{O\ layer}$ = 11.64 mg L^{-1} ± 2.34) (Fig.3). In contrast, the nitrogen species (NO_3^- and NH_4^+) were either statistically the same or significantly higher in *GR* relative to *TF, SF* and the *O* layer.

Similar to the beech forest, the concentration of non-nitrogen nutrients was statistically lower in the *GR* relative to the *TF, SF* and *O* layer. NO_3^- concentration in *GR* ($NO^-_{3\ GR}$ = 5.12 mg L^{-1} ± 0.41) was significantly lower ($P < 0.05$) in the *O* layer of the spruce stand (*O* layer $_{spruce}$ = 6.14 mg L^{-1} ± 1.21) (Fig.3). The Ca^{2+} concentration of *GR* (Ca^{2+}_{GR} = 5.51 mg L^{-1} ± 0.71) was lower than the *TF* and *SF* in the spruce (Ca^{2+}_{TF} =14.24 ± 1.71 and Ca^{2+}_{SF} = 14.89 mg L^{-1} ± 2.37). A significant difference was observed between average concentration of K^+ in *GR* (K^+_{GR}= 4.14 mg L^{-1} ± 0.42) compared with those of *TF, SF*, and the *O* layer of spruce (K^+_{TF} = 14.21 ± 2.06, K^+_{SF}= 14.41 ± 2.54, and $K^+_{O\ layer}$ = 12.06 mg L^{-1} ± 2.14). The Mg^{2+} and Na^+ concentrations of *GR* were statistically different versus concentrations in *TF, SF*, and the *O* layer in spruce plantation (Mg^{2+}_{TF} = 1.13 ± 0.35, Mg^{2+}_{SF} = 1.31 ± 0.40, $Mg^{2+}_{O\ layer}$ = 1.19 ± 0.46; Na^+_{TF} = 17.19 ± 2.51, Na^+_{SF} = 17.48 ± 2.03, and $Na^+_{O\ layer}$ = 13.48 mg L^{-1} ± 2.11).

Table 2. Acidity (pH) and electrical conductivity (EC, dS m^{-1}) averages of gross rainfall (*GR*), throughfall (*TF*), stemflow (*SF*), and *O* layer in the beech forest (*Fagus orientalis*) and the Norway spruce (*Picea abies*) plantation during the study period (2013, growing season). The numbers in brackets show the standard deviation (SD). Dissimilar letters indicate the significant difference (Duncan p<0.05).

	GR	***TF***		***SF***		***O* layer**	
	Open area	**Beech**	**Spruce**	**Beech**	**Spruce**	**Beech**	**Spruce**
pH[SD]	7.3[0.36][a]	7.1[0.61][ab]	6.7[0.52][b]	7.0[0.73][ab]	6.5[0.85][bc]	6.7[1.21][bc]	5.7[1.18][c]
EC[SD]	0.08[0.01][a]	0.11[0.02][bc]	0.14[0.02][bc]	0.12[0.02][bc]	0.14[0.00][bc]	0.09[0.02][ab]	0.13[0.02][bc]

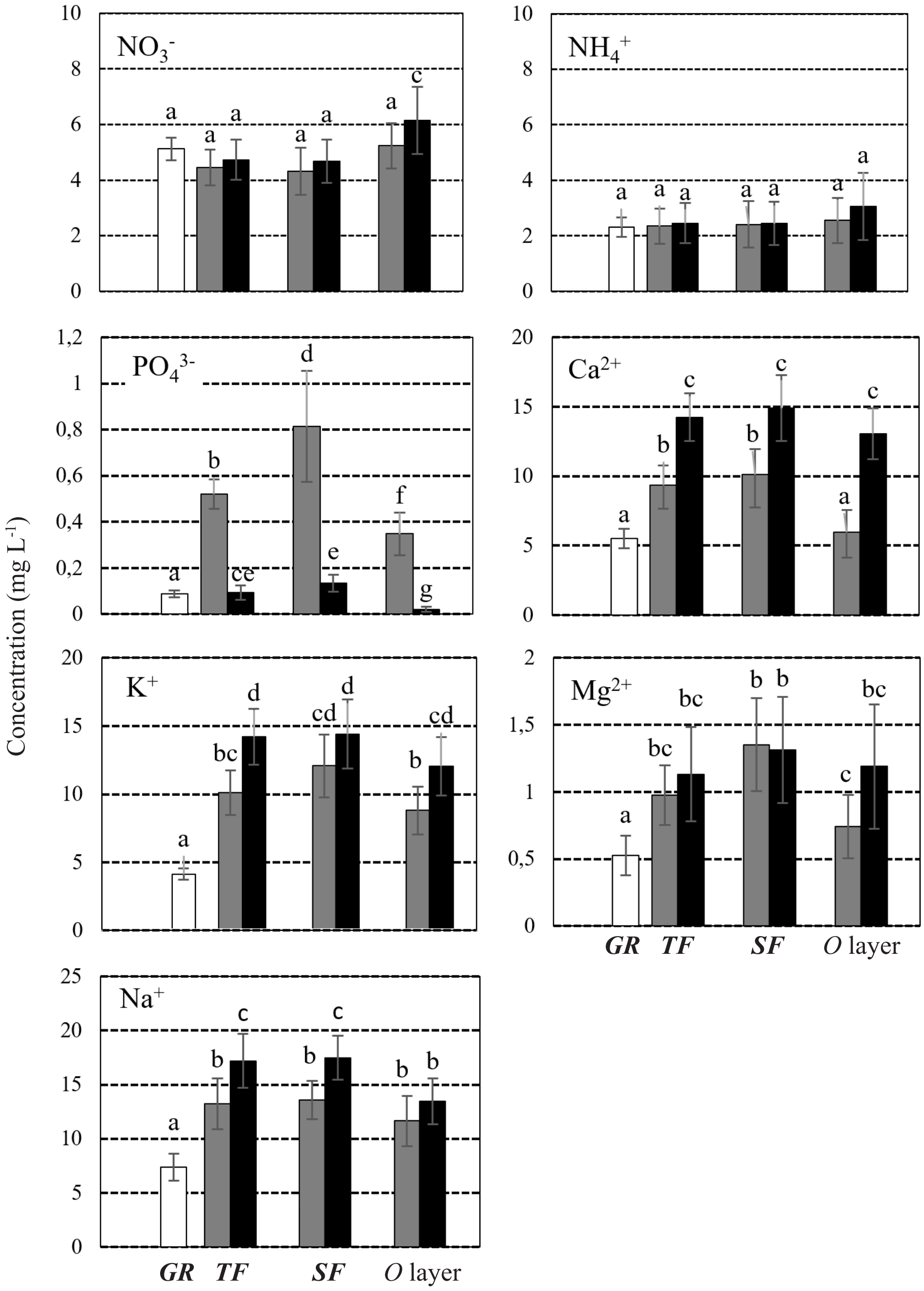

Figure 3. Mean concentrations of nutrients (NO_3^-, NH_4^+, PO_4^{3-}, Ca^{2+}, K^+, Mg^{2+}, and Na^+ (mg L^{-1})) in throughfall (*TF*), stemflow (*SF*), and *O* layer in the oriental beech forest and the Norway spruce plantation during the study period (2013, growing season). Error bars show the standard deviation (SD). Dissimilar lower-case letters indicate the significant differences (Duncan, $p < 0.05$). Grey, black and white bars show the concentrations values for beech, Norway spruce and open field rainfall, respectively.

The concentrations of NO_3^- and Ca^{2+} in *TF, SF*, and *O* layer was significantly higher for spruce compared with the beech forest (Fig. 3). However, the concentration of PO_4^{3-} in *TF, SF*, and *O* layer of the spruce plantation was significantly lower than that of beech stand (Fig. 3).

Discussion

In general, the pH of *TF* declines relative to *GR*. As with our research (Table 2), Adriaenssens *et al.* (2012) and Douglas *et al.* (1988) reported significantly lower pH in *TF* relative to *GR* in a *P. abies* and an *Abies* *balsamifera* stand, respectively. Unlike past research, there was no significant difference between pH in *TF* of beech and spruce stands in our study. In contrast, Hongve *et al.* (2000) reported that acidity of *TF* in conifer forests located in Norway was higher than that of a broadleaf forest.

Similar to past research, EC in *GR* was lower than that of *TF, SF* and *O* layer in both forests. Previous studies broadly report that the EC increases because of interactions with the canopy (Chiwa *et al.*, 2004; Polkowska *et al.*, 2005; Wang *et al.*, 2006; Hermann *et al.*, 2006). For example, Polkowska *et al.* (2005) indicated that the EC of *TF* was higher than that of *GR* by about 0.03 to 0.05 dS m^{-1}. The increase in EC can be attributed to accumulation of charged dust particles and ions, such as Na^+ (Chiwa *et al.*, 2004). The elements may be present on the foliage/stems of the trees as a result of dry deposition from tissues tree secretions (Chiwa *et al.*, 2004).

After passing through the canopy, the concentration of Ca^{2+}, K^+, Mg^{2+} and Na^+ in *TF* were significantly greater than *GR* (Fig. 3). The increased concentrations, e.g. Ca^{2+} and K^+, were generally higher in the spruce stand relative to the beech forest. Hojjati *et al.* (2009) stated that throughfall fluxes of most of the elements were considerably higher under the canopy of spruce compared with beech. The greater concentrations of Ca^{2+} and K^+ might be attributed to the greater leaf area index (*LAI*) of the spruce forest (De Schrijver *et al.*, 2007). The increase in surface area can result in a higher rate of leaching of these cations from the needles (De Schrijver *et al.*, 2007; Tukey, 1970). In addition to the higher *LAI*, higher filtration capacity of spruce canopy and higher foliage longevity compared with beech are the main reasons for higher element fluxes in *TF* under spruce (Hojjati *et al.*, 2009). In both species, Ca^{2+} ions were likely washed from the crown of the trees. Past researchers report that the concentration of Ca^{2+} in *TF* can increase by 5-8 times relative to *GR* (Dezzeo & Chàcon, 2006). Researchers also reported that the K^+ cation is easily removed by precipitation, thereby increasing concentrations in *TF* and *SF* relative to *GR* (Parker, 1983; Edmonds *et al.*, 1991). Adriaenssens *et al.* (2012) reported that the concentrations of Ca^{2+} and K^+ in European beech and spruce forests were higher than that those of *GR*. Hojjati *et al.* (2009) stated that canopy leaching is the main reason for increasing Ca^{2+} (50%), Mg^{2+} (60%), and K^+ (90%) in *TF* of beech and *P. abies* stands.

Similar to our study, Abbasian *et al.* (2015) reported that PO_4^{3-} concentration was statistically higher in the *TF* beneath a beech forest located in the Caspian forests of northern Iran than in rainfall. Others have reported that *TF* under deciduous trees had higher PO_4^{3-} concentrations relative to *GR*. For example, Rodrigo *et al.* (2003) showed that PO_4^{3-} in *TF* under an oak stand increased after passing through the canopy mainly due to the leaching process. However, Ling-Hao & Peng (1998) showed that the canopy absorbed PO_4^{3-} during the non-growing season in a *Castanopsis eyrei* stand.

The increase in Mg^{2+} concentration in our study was in consistent with Balestrini *et al.* (2007). They reported that the concentration of Mg^{2+} increased because of interactions with the canopy in *P. abies* and *F. sylvatica* stands due to the wash off of dry deposited Mg^{2+} from the crown surface. Dezzeo and Chàcon (2006) also showed that the concentration of Mg^{2+} increased 3-4 fold.

Na^+ concentration increased after canopy leaching especially in *P. abies* so that the concentration of this element in *SF* and *TF* of spruce under the canopy was statistically higher compared with beech forest (Fig. 3). Lu *et al.* (2017) showed that the concentration of Na^+ in *TF* beneath *a Pinus densata* stand was more than that of *GR*. In addition, Parker (1983) noted that the annual Na^+ return to the forest soil predominantly via *TF* and *SF* and to a lesser extent through litterfall. In general, leaching process from canopy trees is the main reason for increasing the concentration of cations in *TF* compared with *GR* (Balestrini *et al.*, 2007; Staelens *et al.*, 2007; Adriaenssens *et al.*, 2012). Balestrini *et al.* (2007) who measured the concentrations of cations input through *TF* in oak, European beech, and *P. abies* forests in Italy, reported that Ca^{2+}, K^+, Na^+, Mg^{2+} and NH_4^+ concentrations were higher in both broadleaf and conifers than *GR*.

Similar to Muoghalu and Oakhumen (2000), we showed that concentrations of PO_4^{3-}, Ca^{2+}, K^+, Mg^{2+}, and Na^+ in the *SF* generated by both stands were more than what was found in of *GR* (Fig. 3). Moreover, the amounts of Ca^{2+} and Na^+ elements in the spruce forest were higher than that of beech forest. This observation was consistent with the results of Houle *et al.* (1999) who showed that concentrations of Ca^{2+} and Na^+ in coniferous forest were higher than deciduous. The PO_4^{3-} concentration in *SF* of beech forest was higher than that of the spruce stand (Fig. 3). Liu *et al.* (2003) compared the nutrients of *GR* and *SF* in a natural mixed forest and concluded that *SF* had higher concentration of Na^+, K^+, Ca^{2+}, and Mg^{2+}. Dezzeo and Chacón (2006) by examining the changes in *SF* in a Savannah forest showed that the average concentration of nutrients in the *SF* were higher than those in *GR*.

We detected no significant difference in the concentration of NO_3^- between the *GR* and *SF* and *TF* in both stands (Fig. 3). In addition, no significant difference was observed in NH_4^+ concentrations between *SF* and *GR* for both stands. Houle *et al.* (1999)

state that NO_3^- and NH_4^+ is absorbed by branches and trunks of deciduous and coniferous stands. Houle *et al.* (1999) report that a coniferous stand had higher uptake relative to a deciduous stand, in part, because of epiphytic lichens (and associated microorganisms) that grow on trunks in the coniferous stand.

Water passing through the *O* layer during a rain event increases the cations entering the mineral soil (Eaton *et al.*, 1973; Bernhard-Reversat, 1975). For both stands, nutrients leaching from the *O* layer were either similar to (NO_3^-, NH_4^+) or significantly greater than (K^+, Na^+, Mg^{2+}) the concentrations in *GR*. The greatest difference in nutrient fluxes between the two stands was the significantly greater fluxes of PO_4^{3-} to the mineral soil in the beech stand. Moreover, the difference in the chemical composition of *O* layer in both stands and the interaction of the different elements with the *O* layer are considered important factors controlling nutrient fluxes from the *O* layer (Hojjati *et al.*, 2009; Adriaenssens *et al.*, 2012). For example, Hojjati *et al.* (2009) stated that the importance of *TF* and litterfall fluxes in total nutrient inputs to the soil surface varies depending on the nature of the elements. Stachurski and Zimka (2002) demonstrated that nearly 80% of K^+ in foliage was in ionic form, higher than those for Mg^{2+} (40%) and Ca^{2+} (20%). In general, *TF* concentrations in unlike stands explains the difference in cation concentrations exciting *O* layer in different stands (Ashagrie & Zech, 2010). In our stands, PO_4^{3-} was significantly higher in both *TF* and the *O* layer in the beech stand.

The magnitude of the change in a particular element depends on the type of forest (coniferous or broadleaf), tree species, forest structure and other ecological and climatic factors. In addition, after the *TF* and *SF* reach the forest floor, their chemical composition changes yet again when leaching through soil organic horizons. Information on the quantity and quality of the nutrient cycle in forest ecosystems and the impact of planting exotic species on these cycles provides essential and practical knowledge for better management of these forests.

Conclusion

We observed a significant decrease in the pH of *GR* when water passes through soil litter layer in both forests. The higher LAI in the spruce stand likely contributes to the increased leaching of Ca^{2+}, Mg^{2+}, K^+, and Na^+. In contrast, the trunk and branches of the beech forest significantly increased the concentrations of PO_4^{3-}. The differences in cation concentrations exciting the *O* layer appears tightly linked to changes in *TF*.

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