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 PO43−, Na+, Mg2+, Ca2+ and K+ in the throughfall and the O layer in both beech and spruce forests significantly increased relative to gross rainfall (GR). Concentrations of Ca2+ 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 NH4+ and NO3−) 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.


Received: 26 Feb 2019. Accepted: 05 Aug 2019.

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Funding: This research was financially supported by Iran National Science Foundation (INSF), Research Grant: 92024036.

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

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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 of 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\textsuperscript{2+}, K\textsuperscript{+}, Mg\textsuperscript{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. Abbasi 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 ($\text{NO}_3^-$, $\text{NH}_4^+$, $\text{PO}_4^{3-}$, $\text{Ca}^{2+}$, $\text{K}^+$, $\text{Mg}^{2+}$, and $\text{Na}^+$ 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 fruticosos*, 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 ($\pm$ standard deviation, SD) precipitation (2003-2017) was 512 mm yr$^{-1} \pm 150$, 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$^{-1} \pm 113$, with November being the wettest month (72 mm month$^{-1}$) and June the driest (32 mm month$^{-1}$)
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* patterns.

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

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Beech forest</th>
<th>Spruce plantation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tree density (tree ha⁻¹)</td>
<td>136</td>
<td>592</td>
</tr>
<tr>
<td>Diameter at breast height (DBH) (cm)</td>
<td>44.5 ± 12.3</td>
<td>36.5 ± 5.9</td>
</tr>
<tr>
<td>Total height (m)</td>
<td>29.5 ± 7.1</td>
<td>27.5 ± 4.6</td>
</tr>
<tr>
<td>Canopy height (m)</td>
<td>17.2 ± 4.4</td>
<td>19.4 ± 5.3</td>
</tr>
<tr>
<td>Canopy percentage (%)</td>
<td>90</td>
<td>85</td>
</tr>
<tr>
<td>Tree Age (yr)</td>
<td>60</td>
<td>50</td>
</tr>
</tbody>
</table>
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 NO₃⁻, NH₄⁺, PO₄³⁻, Ca²⁺, K⁺, Mg²⁺, 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 Ca²⁺ in GR (Ca²⁺GR = 5.51 mg L⁻¹ ± 0.71) was significantly lower than that of TF and SF in the beech forest (Ca²⁺TF = 9.36 ± 1.40 and Ca²⁺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 Mg²⁺ and Na⁺ concentrations in GR (Mg²⁺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 (Mg²⁺TF = 0.97 ± 0.22, Mg²⁺SF = 1.35 ± 0.35, and Mg²⁺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 (NO₃⁻ and NH₄⁺) 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. NO₃⁻ concentration in GR (NO₃⁻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 Ca²⁺ concentration of GR (Ca²⁺GR = 5.51 mg L⁻¹ ± 0.71) was lower than the TF and SF in the spruce (Ca²⁺TF = 14.24 ± 1.71 and Ca²⁺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 Mg²⁺ and Na⁺ concentrations of GR were statistically different versus concentrations in TF, SF, and the O layer in spruce plantation (Mg²⁺TF = 1.13 ± 0.35, Mg²⁺SF = 1.31 ± 0.40, Mg²⁺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).

<table>
<thead>
<tr>
<th></th>
<th>GR Open area</th>
<th>TF Beech</th>
<th>TF Spruce</th>
<th>SF Beech</th>
<th>SF Spruce</th>
<th>O layer Beech</th>
<th>O layer Spruce</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>7.3[0.36]</td>
<td>7.1[0.61]b</td>
<td>6.7[0.52]b</td>
<td>7.0[0.73]ab</td>
<td>6.5[0.85]bc</td>
<td>6.7[1.21]bc</td>
<td>5.7[1.18]bc</td>
</tr>
<tr>
<td>EC</td>
<td>0.08[0.01]c</td>
<td>0.11[0.02]bc</td>
<td>0.14[0.02]bc</td>
<td>0.12[0.02]bc</td>
<td>0.14[0.00]bc</td>
<td>0.09[0.02]bc</td>
<td>0.13[0.02]bc</td>
</tr>
</tbody>
</table>

Forest Systems
August 2019 • Volume 28 • Issue 2 • e010
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
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 Ca²⁺, K⁺, Mg²⁺ and Na⁺ in TF were significantly greater than GR (Fig. 3). The increased concentrations, e.g. Ca²⁺ 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 Ca²⁺ 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, Ca²⁺ ions were likely washed from the crown of the trees. Past researchers report that the concentration of Ca²⁺ in TF can increase by 5-8 times relative to GR (Dezzeo & Chacón, 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 Ca²⁺ 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 Ca²⁺ (50%), Mg²⁺ (60%), and K⁺ (90%) in TF of beech and P. abies stands.

Similar to our study, Abbasian et al. (2015) reported that PO₄³⁻ 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 PO₄³⁻ concentrations relative to GR. For example, Rodrigo et al. (2003) showed that PO₄³⁻ 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 PO₄³⁻ during the non-growing season in a Castanopsis eyrei stand.

The increase in Mg²⁺ concentration in our study was in consistent with Balestrini et al. (2007). They reported that the concentration of Mg²⁺ increased because of interactions with the canopy in P. abies and F. sylvestrica stands due to the wash off of dry deposited Mg²⁺ from the crown surface. Dezzeo and Chacón (2006) also showed that the concentration of Mg²⁺ 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., 2012; Adriaenssens et al., 2007) who measured the concentrations of cations input through TF in oak, European beech, and P. abies forests in Italy, reported that Ca²⁺, K⁺, Na⁺, Mg²⁺ and NH₄⁺ concentrations were higher in both broadleaf and conifers than GR.

Similar to Muoghalu and Oakhumen (2000), we showed that concentrations of PO₄³⁻, Ca²⁺, K⁺, Mg²⁺, and Na⁺ in the SF generated by both stands were more than what was found in of GR (Fig. 3). Moreover, the amounts of Ca²⁺ 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 Ca²⁺ and Na⁺ in coniferous forest were higher than deciduous. The PO₄³⁻ 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⁺, Ca²⁺, and Mg²⁺. 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 NO₃⁻ between the GR and SF and TF in both stands (Fig. 3). In addition, no significant difference was observed in NH₄⁺ 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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