Atmospheric Environment 161 (2017) 71–81

Contents lists available at ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

Deposition pattern and throughfall fluxes in secondary cool temperate forest, South Korea

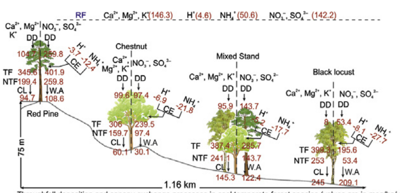
Mukesh Kumar Gautam[*,1], Kwang-Sik Lee[*], Byeong -Yeol Song

Division of Earth and Environmental Science, Korea Basic Science Institute (KBSI), Chungbuk 363-883, Republic of Korea

HIGHLIGHTS

- Throughfall, dry deposition, and canopy exchange fluxes were assessed in 4 stands.
- Stand types was the dominant factor controlling the variation in fluxes.
- Coniferous stands had the highest nitrogen and sulphur net throughfall deposition.
- Canopy leaching and dry deposition are important components of throughfall.
- Despite nearness to sea, pedogenic constituents dominate throughfall fluxes.

GRAPHICAL ABSTRACT



Throughfall deposition and canopy exchange processes in cool temperate forest species (values are in meq/ha/yr).

ARTICLE INFO

Article history:
Received 11 February 2017
Received in revised form
19 April 2017
Accepted 21 April 2017
Available online 27 April 2017

Keywords:
Throughfall fluxes
Canopy exchange
Dry deposition
Base cations
Cool temperate forests
South Korea

ABSTRACT

Chemistry and deposition fluxes in the rainfall and throughfall of red pine (*Pinus densiflora*), black locust (*Robinia pseudoacacia*), and chestnut (*Castanea crenata*) monocultures, and mixed red pine–black locust –chestnut stands were examined in a nutrient-limited cool temperate forest of central South Korea. Throughfall was enriched in both basic and acidic constituents relative to rainfall, suggesting that both dry deposition and canopy leaching are important sources of throughfall constituents. Net throughfall fluxes (NTFs) of cations and anions significantly differed among four different stands as well as seasonally. Red pine exhibited highest fluxes (TF and NTF) for Ca^{2+}, black locust for K^+, mixed stands for Mg^{2+}, and chestnut for Na^+. In contrast, NTF of SO_4^{2-}, NO_3^-, and $NH_4^+$was highest in the red pine, intermediate in the chestnut and mixed stands, and lowest in the black locust. In general, canopy uptake of H^+ and NH_4^+ for all stands was higher in summer than in winter. Dry deposition appears to play a major role in atmospheric deposition to this cool temperate forest, especially in summer. Dry deposition for both cations and anions displayed high spatial variability, even though stands were adjacent to one another and experienced identical atmospheric deposition loads. Canopy leaching of K^+ (95–78% of NTF), Mg^{2+} (92–23% of NTF), and Ca^{2+} (91–12% of NTF) was highest for the black locust, lowest for chestnut, and intermediate for the red pine and mixed stands. The present study documented significant changes in throughfall chemistry and NTF among different forest stands, which presumably be related with the differences in the canopy characteristics and differences in their scavenging capacity for dry deposition and canopy exchange. Difference in the canopy retention of H^+ and base cation leaching suggests that canopy exchange was mainly driven by weak acid excretion and lesser by H^+ exchange reaction. Our results indicate that despite a high base cation deposition, a combination of higher input of acidifying constituents, low soil pH, and total acidic deposition approaching South Korean critical loads make regional forest vulnerable to acidification.

* Corresponding authors.
E-mail addresses: mukeshcric@gmail.com (M. Kumar Gautam), kslee@kbsi.re.kr (K.-S. Lee).
[1] Present address: Department of Natural Science, Baruch College, City University of New York, 55 Lexington Avenue, 24th St, New York, NY 10010, United states.

http://dx.doi.org/10.1016/j.atmosenv.2017.04.030
1352-2310/

1. Introduction

In (semi-)natural forest ecosystems, ionic load transfer via atmospheric deposition has a critical effect on the biogeochemistry (Adriaenssens et al., 2012; Fenn et al., 2013; Liu et al., 2016) and bioavailability of nutrients, particularly base cations (Ca, Mg, K, and Na) and nitrogen (Draaijers and Erisman, 1995; Finér et al., 2004; Kopacek et al., 2011; Fenn et al., 2013). Forest canopies receive chemical inputs from atmosphere as wet deposition (Staelens et al., 2008), dry deposition (Sun et al., 2014), and cloud droplet (occult deposition) (Lindberg et al., 1986). Depositional studies showed the importance of dry deposition in the forests (Sun et al., 2014; Liu et al., 2016) as a primary source of inorganic ion in TF (Schaefer and Reiners, 1990). As the incident rainfall reacts with canopy while traversing it, both quantitative and qualitative changes occur in its chemistry primarily due to (i) dry deposition wash off, and (ii) canopy exchange processes through foliar leaching and uptake (Lindberg et al., 1986; Liu et al., 2016). As a result, significant amounts of nutrients are transferred from the vegetation and added to the forest floor (Parker, 1983; Schaefer and Reiners, 1990). This helps in replenishing the labile soil nutrient pool, which is bioavailability zone for plants from where they derive their nutrient supply. The rate and intensity of transfer are therefore critical for ecosystem processes at the patch, stand, and/or landscape level (Johnson and Lindberg, 1992; Gonzalez-Arias et al., 2000; Polkowska et al., 2005).

Rainfall-throughfall chemistry received a renewed attention in mid-nineties (Nordén, 1991; Van Ek and Draaijers, 1994; Draaijers and Erisman, 1995). During that period focus shifted from demonstrating the nutrient content of deposition and its role in the forest nutrient cycle (Parker, 1983) to understanding the behavior of individual element's ionic forms in the wake of acidification of terrestrial ecosystems (Lovett, 1994; Draaijers et al., 1996; Devlaeminck et al., 2005; Zeng et al., 2005). These studies have highlighted that incident precipitation, if acidic, loads incoming acidity (from anthropogenic precursors) into an ecosystem (Park and Shim, 2002; Bobbink et al., 2010; Fenn et al., 2013). This process creates conditions for a decrease in base cations (both foliar and edaphic), which eventually affects the long-term productivity and the health of forest ecosystems (Draaijers and Erisman, 1995; Thimonier et al., 2005; Bobbink et al., 2010).

Throughfall plays a critical role in forests growing on weathered rock systems with nutrient-poor soil and/or slow weathering rock systems with constrained nutrients supply (Vitousek et al., 1999; Johnson and Lindberg, 1992). Knowledge of the distribution and circulation of precipitation-bound nutrients (base cations, nitrogen, and sulfur) in regenerating forest ecosystems is imperative for ecological sustainability, the development of forests under various depositional regimes, and soil buffering capacities (Lovett, 1994; Johnson and Lindberg, 1992; Gautam et al., 2011). One of the priorities to obtain such information is to scale up understanding of rainfall throughfall variation at a regional scale as a prerequisite for the maintenance of forest structure and functions at the stand level.

A major conservation concern for the critical ecosystems of East Asian is to protect their structure and function. Excessive amounts of nitrogen and sulfur have been documented in East Asian ecosystems (Park and Shim, 2002). However, these loads are based on concentrations of base cations, nitrogen, and sulfur in wet and dry depositions. Little is known about the rainfall-throughfall deposition interface and the role of different forest canopies in the filtering of cations and anions for the region, especially South Korea (Lee et al., 1997; Jung et al., 2007). And these studies are limited in scope, generally focused only on describing the ionic composition of throughfall or difference between throughfall and rainfall ionic composition. However, Yoo et al. (2002) studied the ionic difference between throughfall of coniferous and deciduous species from three different regions but did not focus on canopy exchange processes. Because deposition patterns and cycling differ between rainfall and throughfall, results from rainfall cannot be extrapolated to forests to assess the effects of acidic deposition on base cation cycling. In East Asia, gneisses and granite parent rocks and soil derived from them dominate Korean peninsula (Shin, 2002). These systems are considered vulnerable to acidification (Kuylenstierna et al., 1995). For this reason, Bobbink et al. (2010) performed depositional studies in East Asia. Furthermore, the low cation exchange capacity and buffering capacities of Korean soil, which contains a relatively high proportion of coarse fragments (Park and Shim, 2002), renders these ecosystems particularly vulnerable to excessive nitrogen and sulfate oxides and associated base cation losses.

The study presents the results of analysis of rainfall and throughfall collected from four different forest stands (red pine, chestnut, black locust, and mixed composition). The objectives of the study are (1) to evaluate the chemical composition and ionic fluxes in rainfall and throughfall, and identify seasonal variations, and (2) to determine the stand level differences as well as seasonal differences in dry deposition, canopy leaching and net throughfall fluxes among forest canopies.

2. Material and methods

2.1. Study site description

Present study was conducted in the Mokryeong Mountain, South Korea (36° 43′N and 127° 24′E) (Fig. S1). Average altitude of the study area is 135 m above asl, and it is located about 100 km from the sea in both east and west directions. Mokreyong mountain is characterized by low elevation, and ranges in elevation from 173 to 248 m. The topography is rugged with gentle slope of low relief, which slopes towards south. Ridges and slope generally have shallow exposed bedrock compared to foothills. Climate of the region is cool-temperate and is both continental and oceanic in character. Region has two main seasons, hot–humid summers and cold–dry winters. The annual mean temperature during study period was 12 °C; minimum in January (−20.2 °C) and maximum in August (37.9 °C) (Korea Meteorological Administration). Annual rainfall was 1462 mm, most of which fell in summer (1079 mm) and only a fraction fell in winter (280.5 mm) (Fig. S1). During spring and early summer, region receives dust deposition from Mongolia and Northern China deserts (Ma et al., 2008). The region is characterized by highly metamorphosed and weathered high grade gneiss or granitic-gneiss complex. Soils that overlie parent material are coarse textured and grade from silty loam to sandy loam, with acidic pH (5.6 ± 0.53). The average cation exchange capacity is 15.6 cmol(+)/kg (±2.3). Exchangeable Ca^{2+}, Mg^{2+} and K^{+} are 4.3 cmol(+)/kg, 1.5 cmol(+)/kg, and 0.14 cmol(+)/kg (Fig. S4).

The cool temperate forests growing in this region are secondary in origin; about 40 years old. *Pinus densiflora* Siebold and Zucc. (red pine), *Castanea crenata* Siebold and Zucc. (chestnut) and *Robinia pseudoacacia* L. (black locust) were planted during reforestation program of 1980's. The total stem density of red pine was 654 ha^{-1} and the average tree height was 15.5 m. The total stem density and average height of chestnut were 354 ha^{-1} and 12.5 m, and that of black locust were 310 ha^{-1} and 18.5 m. The average tree density in mixed stands was 530 ha^{-1}.