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# Effect of canopy interception on spatial variability and isotopic composition of throughfall in Japanese cypress plantations

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SUMMARY

We conducted a field monitoring experiment examining throughfall in Japanese cypress plantations located in Tochigi Prefecture, eastern Japan. A set of 20 tipping-bucket rain gauges and throughfall collectors were placed in a lattice-like distribution throughout a 10 × 10-m experimental plot to investigate the effect of the forest canopy on the spatial variability of throughfall. The isotopic composition of throughfall and open rainfall were analyzed and compared for each rainfall event. A clear relationship between throughfall rate and the radial distance to the nearest tree trunk was observed when the influence of wind was negligible; however, such a systematic pattern of throughfall was not observed during rainfall events that occurred during windy conditions. The $\delta^{18}O$ and $\delta D$ values in throughfall varied considerably, reflecting different rainwater flow paths in the saturated canopy. The analysis of stable isotope ratios in the throughfall and its comparison with isotopic composition of rainwater hitting the canopy can help elucidate the interception processes in the forest canopy.

## 1. Introduction

Rainfall in a forested area is intercepted by the vegetation canopy and partitioned into throughfall, stemflow, and water lost into the atmosphere by evaporation. Temporal and spatial patterns of throughfall vary widely (Keim et al., 2005; Levia and Frost, 2006; Staelens et al., 2006), and throughfall determines hydrological, biogeochemical, and ecological differences in forest ecosystems. The heterogeneity of throughfall input induces spatial variability in soil moisture (Eschner, 1967), the distribution of fine roots (Ford and Deans, 1978), litter decomposition (Cortez, 1998), and nitrification (Killham, 1990) in forest soils. Furthermore, a detailed understanding of rainfall interception by the forest canopy is important for studies on atmospheric deposition of contaminants, trace gas fluxes, and solute leaching (Hansen, 1995; Whelan and Anderson, 1996). The spatiotemporal variability of throughfall also affects the generation of overland flow (Nanko et al., 2008) and surface erosion (Nanko et al., 2010; Mizugaki et al., 2010) in forest ecosystems. Finally, understanding rainfall redistribution processes has important implications for the precise quantitative prediction of canopy interception loss, water yield, and storage in the forest catchment.

Field monitoring of throughfall has indicated that the spatiotemporal variability of throughfall is affected by many complex factors (Levia and Frost, 2006) including those relating to meteorology (e.g., rainfall intensity and wind speed) and the canopy (e.g., tree species and canopy structure). Throughfall variability decreases with increasing rainfall (Bouten et al., 1992). Low-magnitude events induce high variability in throughfall distribution because of the difference in initial interception loss in the canopy and openness beyond the canopy layers (Staelens et al., 2006); the spatial variability of throughfall is also affected by wind speed because wind-induced vibration of leaves changes the behavior of rainwater in a canopy (Herwitz and Slye, 1995).

The radial distance of the canopy from the tree trunk has often been used to estimate the spatial variability of throughfall. Nanko et al. (2011) evaluated the spatial variability of throughfall amount under a single Japanese cypress canopy under controlled meteorological conditions in a large-scale indoor rainfall simulator. They concluded that rainwater running on the saturated canopy surface toward the conical canopy edge resulted in an increase in throughfall with increased radial distance from the trunk. Conversely, the spatial patterns of throughfall under natural rainfall conditions

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are likely to be more complicated. The greatest amount of throughfall has been measured around the edge of the canopy (Aussenac, 1970), near the trunk (Rutter, 1963), and midway between the trunk and the canopy edge (Carleton and Kavanagh, 1990). Some studies have shown an increase in throughfall with increasing radial distance from the trunk in a spruce forest (Johnson, 1990; Pedersen, 1992; Beier et al., 1993; Hansen, 1995; Whelan and Anderson, 1996); however, this is not a uniform effect, and other studies have shown no such relationship in hardwood and pine forests (Helvey and Patric, 1965; Loustau et al., 1992). Keim et al. (2005) investigated spatial variability of throughfall beneath stands of deciduous and coniferous forest and reported that throughfall rate increased with the radial distance to the nearest tree trunk in old conifer stands. Finally, they concluded that the relationship between throughfall and the radial distance from the tree trunk depends on the species and age of the tree. Nevertheless, the manner in which the spatial pattern of throughfall under a forest canopy depends on variable conditions within a forest environment, including vegetation composition and meteorological conditions, is not well quantified.

The isotopic composition, including the $\delta^{18}O$ value, of throughfall is different from that of rainfall. A few studies have reported how the isotopic composition of rainwater changes during its passage through the vegetation canopy (e.g., Brodersen et al., 2000; Liu et al., 2008). Brodersen et al. (2000) measured the $\delta^{18}O$ composition of throughfall in various forest stands based on weekly water sampling and demonstrated that the $\delta^{18}O$ composition of throughfall differed considerably from that of open rainfall. They concluded that selection processes seemed to be the main factor influencing the $\delta^{18}O$ value of open rainfall as it passes through the canopy because there was no positive correlation between $^{18}O$ enrichment and interception at any of the measurement sites. Alternatively, Liu et al. (2008) emphasized the importance of rainfall partitioning by the forest canopy, showing that the isotopic composition of throughfall is strongly influenced by the forest canopy structure and evaporation processes, especially during light rain events (<10 mm). Thus, recent investigations have presented evidence that the isotopic composition of throughfall reflects rainwater interception processes in the forest canopy. However, no study has simultaneously addressed the relationship of canopy interception with rainfall redistribution and examined how these processes affect the isotopic composition of throughfall. The dominant water input into forested ecosystems is via throughfall; therefore, understanding the effect of forest canopy interception on the isotopic composition of rainwater and throughfall is essential for isotope hydrology studies.

This study investigated throughfall using field experiments in a Japanese cypress forest plantation. A 10 × 10-m interception plot with a set of 20 tipping-bucket rain gauges and throughfall collectors was used to investigate the spatial variability of throughfall within the Japanese cypress plantation, as well as the influence of rainfall redistribution processes on the isotopic composition of throughfall.

## 2. Materials and methods

### 2.1. Study site description

The study site is located in the university forest of Tokyo University of Agriculture and Technology in Sano-city, Tochigi Prefecture, eastern Japan (Fig. 1). The annual precipitation in this area is 1270 mm, and the mean annual temperature is 14.2 °C (mean of the data obtained from 2001 to 2010 at the nearest national weather post). The summer monsoon rainy season is typically from mid-June to late July in the study area, and the autumn rainy season is from mid-September to late October. Half the annual precipitation occurs from July to October (Fig. 2).

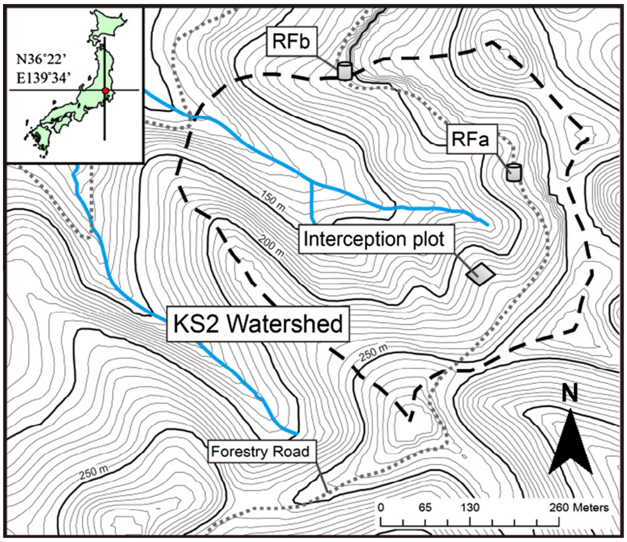

**Fig. 1.** Study site location.

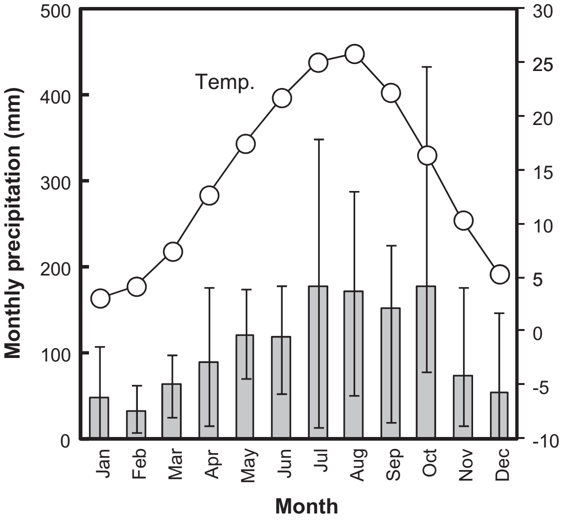

**Fig. 2.** Monthly precipitation and temperature in the study area (mean, maximum, and minimum value of monthly data for the 10-year period from 2001 to 2010).

A 10 × 10-m experimental plot was selected in Japanese cypress (*Chamaecyparis obtusa*) stands located in a small watershed (KS2); the location of the experimental plot is shown in Fig. 1. The elevation of the study site is 230 m (a.s.l.), and the slope gradient of the plot is 30 degrees. The cypress forest was planted in 1971, and the stand density is currently 2500/ha. The experimental plot encompassed 17 trees, whose diameter at breast height (DBH) ranged from 14.0 to 31.5 cm (mean DBH = 22.7 cm).

### 2.2. Observation of gross rainfall and throughfall

The field experiment was carried out over 13 months from April 2010 to April 2011. Gross rainfall was measured at a clearing site along a forestry road (RFa; 230 m a.s.l.). We selected the interception plot and the open rainfall site (RFa) at sites of equal elevation within the same experimental watershed (Fig. 1). The distance between the interception plot and the RFa site was 150 m. It is ideal to place rain gauges above canopies to monitor open rainfall; how-