IN-CANOPY THROUGHFALL MEASUREMENTS IN NORWAY SPRUCE: WATER FLOW AND CONSEQUENCES FOR ION FLUXES

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Abstract. Canopy throughfall was collected in funnels equipped with tipping buckets. The funnels were installed at 4 distances from the tree trunk and at 6 depths in the canopy of a Norway spruce forest at Klosterhede, Denmark. The throughfall water flux was registered during individual rain events. The smallest quantity of throughfall was sampled closest to the tree trunk, and the largest quantity of throughfall was sampled in the periphery of the canopy at all levels in the canopy. The quantity of throughfall was highest at the top of the tree and decreased down through the canopy. The intensity of the water flow decreased through the canopy which brought the throughfall water in contact with the foliage for longer periods in the lower canopy than in the upper canopy.The higher wettability caused a larger leaching of especially potassium in the lower canopy. Differences in rain intensity did not influence the distribution and the pattern of water flow in the canopy.

1. Introduction

Water flowing through a forest canopy plays a fundamental role in the transport of dissolved and suspended solids, and the water within the canopy influences the chemical, physical, and biological processes that occur on the vegetation surfaces (McCune & Boyce, 1992).

Knowledge of the hydrological characteristics of the canopy is required to understand the movement of water, nutrients, and atmospheric pollutants as well as the canopy interaction processes (leaching and uptake of nutrients and pollutants) that operate within the forest canopy.

In this study, the flow of throughfall water during individual rain events was examined on its way through different parts of the canopy. The effect of quantity and intensity of precipitation on the water flow and the consequences for leaching and uptake of mineral nutrients and pollutants in coniferous tree canopies were evaluated.

2. Materials and methods

The study was conducted in a 74 years old Norway spruce stand at Klosterhede Plantation in the western part of Jutland, Denmark. The forest site was located 15 km from the North Sea and dominated by strong westerly winds. The characteristics of the forest stand (Table I) are described in detail by Beier & Rasmussen (1993).

An 18 m high tower was raised in the forest. Horizontal girders were mounted at six levels in the tower (7, 9.5, 11, 13, 15, and 16 m above the ground) (Figure 1). The girders pointed towards the trunks of two trees (A and B).

On the horizontal girders, 31 funnels were installed in 4 distances from the trunks (0.1, 0.5, 0.9, and 1.3 m) (Figure 1). Filters were placed in the funnels to minimize contamination of the samples. Two additional funnels collected bulk precipitation.

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TABLE I

Stand characteristics and climate (Beier & Rasmussen, 1993).

Tree species	Norway spruce (*Picea abies* (L.) Karst.)
Age (1993)	74 years
Trees per ha	860
Tree height	18 m
Basal area	29 m^2/ha
Leaf Area Index	4.8 m^2/m^2
Yearly precipitation	860 mm
Main wind direction	W, SW

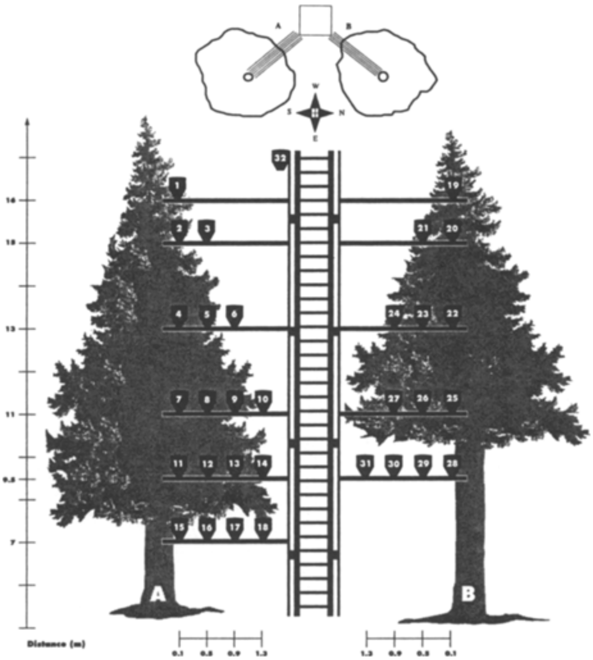

Fig. 1. The set-up of funnels at four distances from the trunks (0.1, 0.5, 0.9, and 1.3 m) and at six levels in the canopy (7, 9.5, 11, 13, 15, and 16 m above the ground) of tree A and B.

A tipping bucket (Rain-O-Matic, Pronamic A/S, Denmark) was installed below each funnel. The tipping buckets (polyethylene) had a resolution of 0.25 mm of rain per tip. The date and time for each tip of all funnels were recorded from January 1993 to January 1994. 60 individual rain events were sampled.

3. Results and discussion

3.1. POSITION IN THE CANOPY

The smallest quantity of throughfall was sampled closest to the tree trunk (0.1 m) and the largest quantity of throughfall was sampled in the periphery of the canopy (1.3 m) at all levels in the canopy (Figure 2). Such systematic, spatial variability in throughfall quantity was also observed by Beier *et al.* (1993) and Pedersen (1992), where throughfall was collected at the forest floor in a Nörway spruce and a sitka spruce forest, respectively, corresponding to the lowest canopy levels in this study.

The quantity of throughfall was highest at the top of the tree and decreased down through the canopy (Figure 2), as water was intercepted in the canopy. In contrast, Fritsche *et al.* (1989) found that the quantity of water increased from the top to the bottom of a Norway spruce canopy with a maximum amount in the middle of the canopy. However, these results were based on only one sampling of throughfall (13 days).

The strong spatial variability of the throughfall quantity demonstrated an uneven distribution of the precipitation in the canopy. Reasons could be i) non-homogeneous distribution of rain drops to the canopy due to turbulent air flow just above and within the canopy, ii) horizontal translocation of water in the canopy where water is running from branch to branch, and/or iii) differences in interception related to the density of the canopy.

3.2. INTERCEPTION IN THE CANOPY

The quantity of throughfall beneath the canopy of each of the trees was approximately 50 % of the precipitation (Figure 2). The interception was therefore high compared to a study by Leyton et al. (1966), where interception was estimated in Norway spruce also by the use of throughfall measurements. The interception was probably overestimated since all funnels were placed directly beneath foliage. The forest was rather open (LAI = 4.8), and a correct estimate should include measurements beneath the open areas of the forest as well.

The results showed a large variability in the throughfall quantity according to the position of sampling in the forest. It is, therefore, important to account for the spatial variability of throughfall when interception is estimated using point measurements of throughfall. A large number of randomly placed throughfall collectors (Kostelnik *et al.*, 1989) or specially designed integrating collectors or troughs (Beier & Rasmussen, 1989; Draaijers, 1993) are necessary for a correct representation of the throughfall.

3.3. FLOW OF WATER IN THE CANOPY

Sixty rain events, larger than four mm, were recorded in 1993. The events were analyzed to test whether the distribution and the flow of water through the canopy changed with different quantities and intensities of precipitation. Four random rain events with different quantities and intensities of precipitation were evaluated in detail: January 24th, 1993 (16 mm, 3 hr), October 9th, 1993 (17 mm, 10 hr), October 12th, 1993 (34 mm, 12 hr), and September 25-26th, 1993 (38 mm, 28 hr).

The quantity of accumulated throughfall water was generally higher in the upper than in the lower parts of the canopy at all distances from the tree trunk (Figure 3). The accumulated throughfall closely followed the pattern of accumulated rainfall despite a delay of water during the passage of the canopy (Figure 3). After the rain

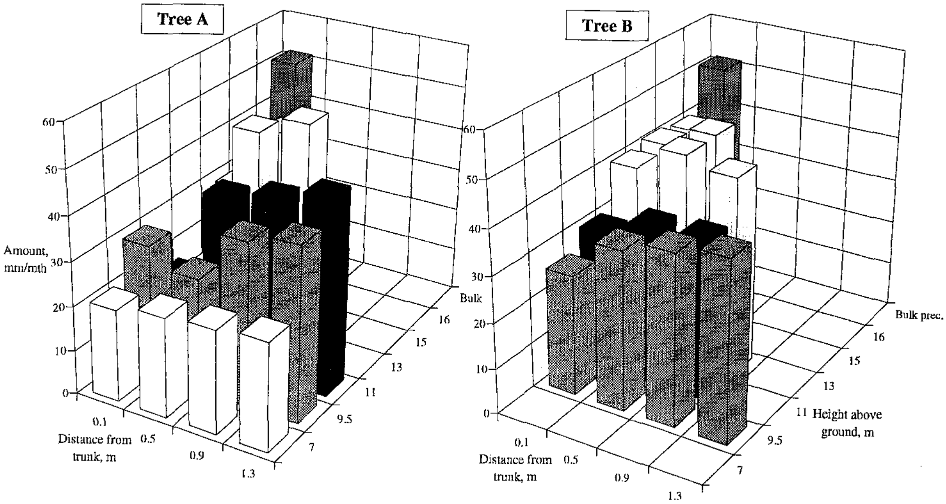

Fig. 2. Quantity of bulk precipitation and throughfall water (mm month^{-1}) as a function of the depth in the canopy (m) and the distance from the tree trunk (m) of the two trees A and B.

stopped, the last drips from the foliage were normally registered in the lower canopy.

The bulk precipitation funnel above the forest normally collected the highest quantity of water. Eventually, higher accumulated amounts of water were collected in other parts of the canopy (Figure 3). This was evident in the events of September 25-26th and October 12th where the quantity of precipitation was large. The amount of bulk precipitation was equal to or higher than the amount of throughfall until 15-20 mm of rain. Hereafter, the amount of accumulated throughfall rose and became higher than the accumulated quantity of bulk precipitation. Explanations for such unexpected high quantities of accumulated water in funnels situated lower in the canopy could be that: i) the funnels were placed in an open part of the canopy where they received both precipitation and throughfall, ii) after saturation of the canopy additional water was funnelled from other plant parts and into the collector (translocation), and/or iii) the tipping buckets tipped before actually being full which could happen in stormy weather. It is possible to view the passage of water through the canopy in three stages: an initial wetting stage, a continuing dripping stage, and a final stage when rain stops, dripping ends, and the canopy is drying. It seems possible that the canopy was totally saturated at 15-20 mm of precipitation. Hereafter, the storage of water within the canopy and the translocation of water in the canopy became as large as possible. Furthermore, throughfall to these specific funnels indicated a higher leaching of potassium, and suggested an extra dense canopy above the funnels and that throughfall water had longer contact with foliage because of translocation (Hansen, 1995). Therefore, explanation ii) seems most plausible.

In events with the same amount of precipitation, approximately the same amount of water reached the different layers in the canopy regardless of the intensity of the rain event (Figure 3). These results suggest that the distribution of water and the water flow in the canopy was independent on the rain intensity. The intensity of the water

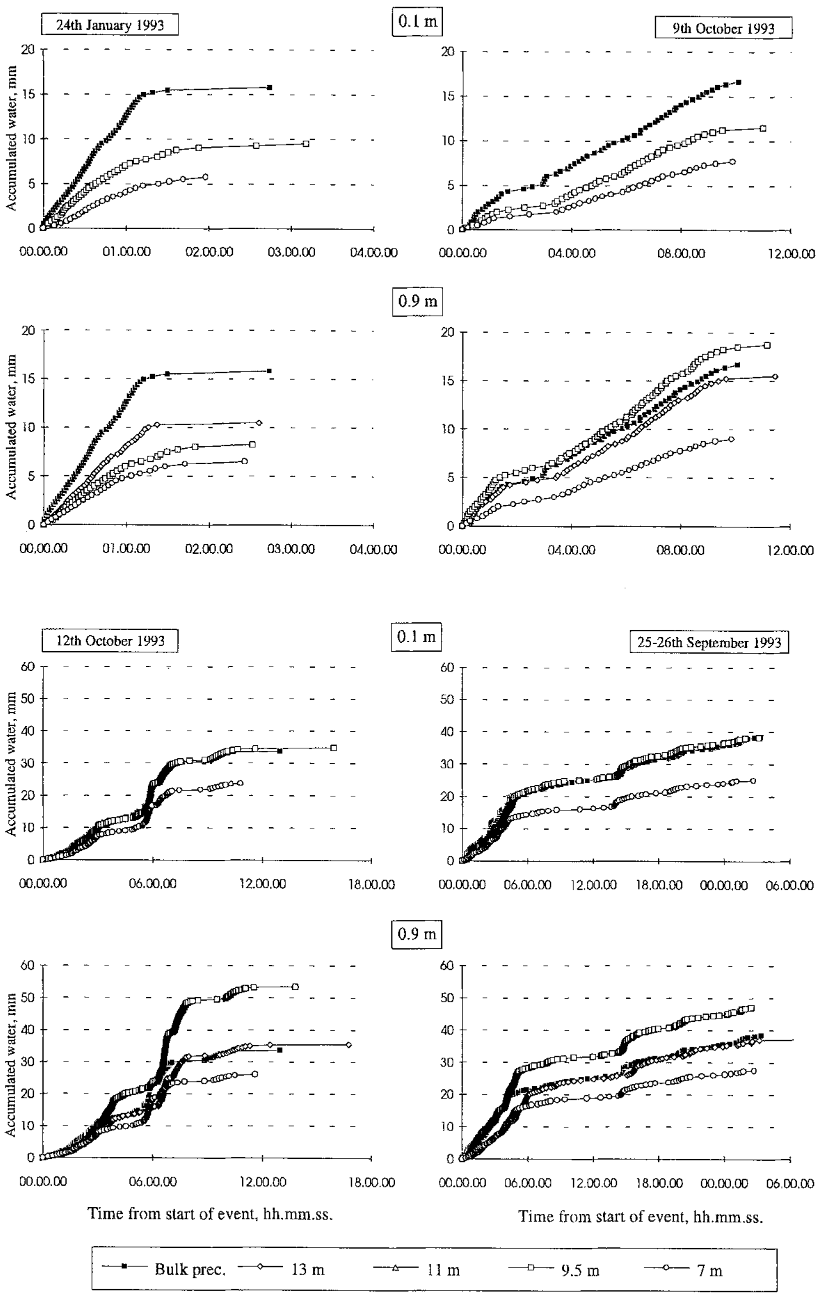

Fig. 3. Accumulated amount of water (mm) of four rain events sampled January 24th, 1993 (16 mm, 3 hr), October 9th, 1993 (17 mm, 10 hr), October 12th, 1993 (34 mm, 12 hr), and September 25-26th, 1993 (38 mm, 28 hr). The water is shown through the events for the distances 0.1 m and 0.9 m from the tree trunk and for each depth in the canopy (m).

flow generally decreased through the canopy, so that the duration of contact between water and foliage was longer in the lower parts of the canopy than in the upper parts.

3.4. CONSEQUENCES FOR CANOPY EXCHANGE PROCESSES

The smaller amount of water, the lower intensity of the water flow, and the translocation from the upper layers to the lower layers and outwards in the canopy generated a longer contact between water and foliage in the lower canopy which probably influenced the canopy exchange processes. Further, it was observed that the foliage in the bottom of a coniferous canopy was more wet (less hydrophobic) (Boyce *et al.*, 1991). Since leaching is partially controlled by the wettability of the foliar surfaces (Tukey, 1970), a larger exchange in the lower canopy seems possible. In accordance to this, Hansen (1995) observed a higher leaching of K^+ in the lower canopy and Lovett *et al.* (1989) modelled a higher leaching in the lower canopy.

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