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Comparison of forest edge effects on throughfall deposition in different forest types

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Conversion of pine plantations into oak or birch forests would reduce by 85–90% the nitrogen and potentially acidifying throughfall deposition induced by forest edge effects.

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ABSTRACT

This study examined the influence of distance to the forest edge, forest type, and time on Cl^-, SO_4^{2-}, NO_3^-, and NH_4^+ throughfall deposition in forest edges. The forests were dominated by pedunculate oak, silver birch, or Corsican/Austrian pine, and were situated in two regions of Flanders (Belgium). Along transects, throughfall deposition was monitored at distances of 0–128 m from the forest edge. A repeated-measures analysis demonstrated that time, forest type, and distance to the forest edge significantly influenced throughfall deposition of the ions studied. The effect of distance to the forest edge depended significantly on forest type in the deposition of Cl^-, SO_4^{2-}, and NO_3^-: the edge effect was significantly greater in pine stands than in deciduous birch and oak stands. This finding supports the possibility of converting pine plantations into oak or birch forests in order to mitigate the input of nitrogen and potentially acidifying deposition.

1. Introduction

In general, forest edges are steep transitions of vegetation height, which disturb the vertical wind profile. When approaching a forest edge, wind flow partially penetrates it and partially lifts over it. As a result, wind speed and air turbulence are enhanced at the forest edge compared to the forest interior, increasing dry deposition velocities via inflow and advection processes (Draaijers et al., 1994). Through inflow, pollutants are blown onto the collecting surface in the forest edge and advection enhances exchange of pollutants between the atmosphere and the forest (Draaijers et al., 1994). The resulting dry deposition enhancement in the forest edge has been amply demonstrated by deposition models (e.g., Wiman and Ågren, 1985), wind tunnel studies (e.g., Ould-Dada et al., 2002), air concentration measurements (e.g., Wiman and Lannefors, 1985), and throughfall deposition measurements (e.g., Hasselrot and Grennfelt, 1987; Weathers et al., 2001; Wuyts et al., 2008; for an overview see De Schrijver et al., 2007a). In forest edges, throughfall deposition is increased up to four times compared to the forest interior. This so-called forest edge effect decreases exponentially with increasing distance from the edge, until it reaches a more or less interior forest level starting at 8–108 m from the edge (De Schrijver et al., 2007a; Devlaeminck et al., 2005; Draaijers, 1993; Wuyts et al., 2008). The level of throughfall deposition enhancement and the penetration depth of the edge effect depend on several factors, including the ion under consideration (Beier and Gundersen, 1989; Draaijers et al., 1994; Spangenberg and Kölling, 2004; Wuyts et al., 2008), meteorological conditions such as wind speed and direction (Draaijers et al., 1988; Wuyts et al., 2008), edge orientation (De Schrijver et al., 1998; Draaijers et al., 1994), and edge structural features such as leaf area index (LAI) and stand density (Draaijers, 1993; Weathers et al., 2001; Wuyts et al., 2008). Research on how forest type influences edge effects is lacking, except for a comparison of *Picea abies* L. Karst. and *Fagus sylvatica* L. by Spangenberg and Kölling (2004) and a study by Wuyts et al. (2008) on *Pinus nigra* ssp. *laricio* Maire and *Betula pendula* Roth.

Recent studies have shown that forest type significantly influences throughfall deposition in forest ecosystems (Augusto et al., 2002; De Schrijver et al., 2004, 2007b, 2008; Herrmann et al.,

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2006; Lovett et al., 1996; Oulehle and Hruska, 2005; Robertson et al., 2000; Rothe et al., 2002; Van Ek and Draaijers, 1994). A review by De Schrijver et al. (2007b) revealed that, when the site and climate are similar, coniferous forests annually receive significantly higher throughfall deposition quantities of nitrogen (N) and sulphur (S) than do deciduous forests. The review revealed that in regions with high open-field N deposition (>10 kg N ha^{-1} $year^{-1}$) throughfall deposition was higher in coniferous stands than in deciduous stands, and that this difference increased with increasing NH_4^+ deposition in open-field. In regions with relatively low open-field N deposition (<10 kg N ha^{-1} $year^{-1}$), NH_4^+ throughfall deposition fluxes were lower under coniferous canopies than under deciduous ones. Furthermore, Van Ek and Draaijers (1994) found similar throughfall deposition fluxes of SO_4^{2-} for stands of pedunculate oak (*Quercus robur* L.) and Scots pine (*Pinus sylvestris* L.), which they attributed to enhanced canopy leaching, induced by leaf sprouting, in the oak stands. Consequently, both time and region are expected to influence the forest type effect on throughfall deposition of potentially acidifying ions (N + S), as well as of inorganic N ($NH_4^+ + NO_3^-$).

Conversion of secondary spruce and pine forests into deciduous forests, on sites where deciduous tree species would thrive under natural conditions, has been suggested for several reasons. These include a decrease in the deposition of N and potentially acidifying ions and a consequent decrease in soil acidity (Brandtberg et al., 2000; Brandtberg and Simonsson, 2003), a decrease in seepage of NO_3^- and SO_4^{2-} and accompanying cations into groundwater (De Schrijver et al., 2004; Herrmann et al., 2005; von Wilpert et al., 2000), and less biodiversity loss (Gärtner and Reif, 2004). In Flanders, most of the Scots and Corsican pine plantations are located on sandy soils (Bos en Groen, 2001), which are particularly sensitive to acidification (De Schrijver et al., 2006; Van Ranst et al., 2002). In the first successional stages, pedunculate oak and silver birch are the intended tree species in the closer-to-natural forest ecosystems. In order to gain more insight into how edge effects are influenced by forest type, we compared throughfall deposition of N + S and N in six forest stands that differed in tree species composition along transects starting at the forest edge and ending in the forest interior. In addition, we examined the influence of region and time, and their interaction with the forest type in influencing edge effects. To accomplish this, we chose three forest types (*Q. robur*, *B. pendula*, and *P. nigra*) and selected two regions, one in the west and one in the north of Flanders.

2. Materials and methods

2.1. Experimental sites

We selected two regions in the northern part of Belgium (Flanders), located approximately 135 km apart (Fig. 1). These regions were characterized by high deposition of NH_3 as a result of intensive livestock breeding. Region 1 is near the North Sea coast and may be subject to higher wind speeds and a higher load of sea spray (e.g., NaCl and $MgCl_2$) than region 2, which lies further inland. Average pollutant concentration in the two areas was calculated from air concentration data obtained from three measuring stations of the Vlaamse Milieumaatschappij measuring program: AC1 at Wingene and AC2 at Zwevegem for the western region, and AC3 at Retie for the northern region. During the study period, average SO_2 concentrations were 3.27, 3.46, and 3.33 μg m^{-3}, and average NO_2 concentrations were 14.9, 16.9, and 17.0 μg m^{-3}, at AC1, AC2, and AC3, respectively.

Climatological data were obtained from two weather stations of the Royal Meteorological Institute of Belgium, WS1 at Beitem (Fig. 1(A) was selected for the western region and WS2 at Retie for the northern region. During the study period, average temperature was 10.4 °C (WS1) and 10.6 °C (WS2). Average temperature of the coldest month (January) was 1.4 °C and 0.9 °C, and average temperature of the warmest month (July) was 21.7 °C and 22.0 °C. Relative humidity was, on average, 80% (WS1) and 85% (WS2). Average wind speed during the study period was 3.7 ± 1.6 m s^{-1} and 2.6 ± 1.2 m s^{-1} at WS1 and WS2, respectively. The wind rose diagrams of WS1 (Fig. 1B) and WS2 (Fig. 1C) illustrate that the daily wind direction was south to west during 37% (WS1) and 43% (WS2) of the study period. From our open-field data, we calculated that rainfall during the study period amounted to an average of 786 mm in the western region and 783 mm in the northern region. Of this rainfall, an average of 53% and 60% fell during the spring–summer period.

In each region, three forest stands were selected on poor sandy soils (Haplic podzols; Fao-Isric-Isss, 1998) with low buffering capacity for acidifying deposition (De Schrijver et al., 2006; Van Ranst et al., 2002). All stands in the study were

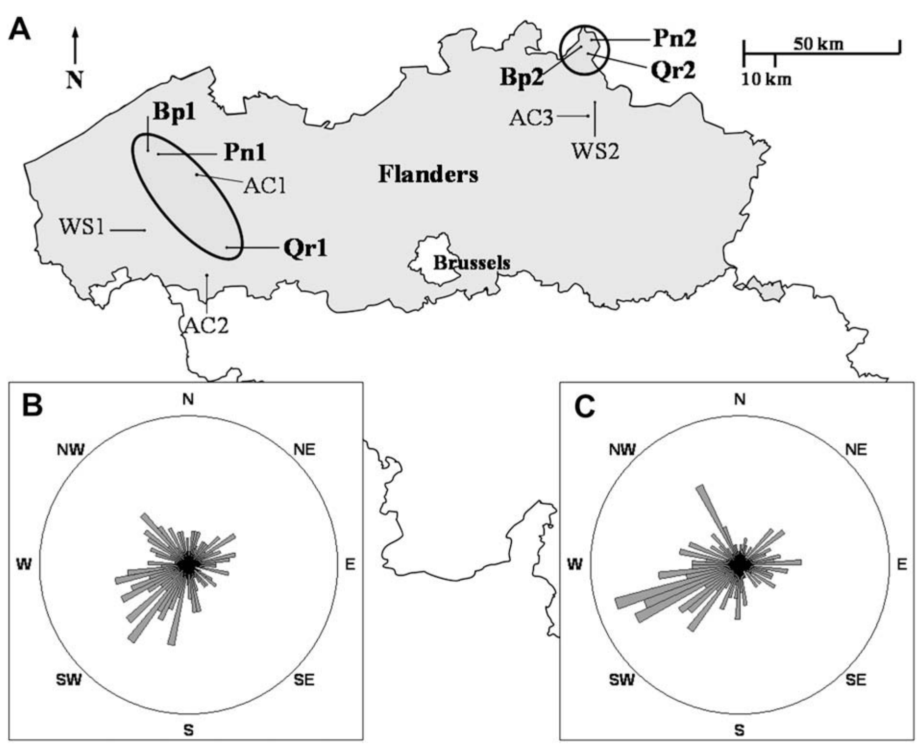

Fig. 1. (A) Map of Flanders, the northern part of Belgium, indicating the location of the two regions containing the six forest stands in this study. Qr, pedunculate oak; Bp, silver birch; Pn, Corsican/Austrian pine; WS, weather station; AC, air concentration measurement station; 1, western region; 2, northern region. (B) Wind rose at Beitem weather station (WS1). (C) Wind rose at Retie weather station (WS2).