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Concentration-dependent NH_3 deposition processes for moorland plant species with and without stomata

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Abstract

Currently, in operational modelling of NH_3 deposition a fixed value of canopy resistance (R_c) is generally applied, irrespective of the plant species and NH_3 concentration. This study determined the effect of NH_3 concentration on deposition processes to individual moorland species. An innovative flux chamber system was used to provide accurate continuous measurements of NH_3 deposition to *Deschampsia cespitosa* (L.) Beauv., *Calluna vulgaris* (L.) Hull, *Eriophorum vaginatum* L., *Cladonia* spp., *Sphagnum* spp., and *Pleurozium schreberi* (Brid.) Mitt. Measurements were conducted across a wide range of NH_3 concentrations (1–140 $\mu g\,m^{-3}$).

NH_3 concentration directly affects the deposition processes to the vegetation canopy, with R_c, and cuticular resistance (R_w) increasing with increasing NH_3 concentration, for all the species and vegetation communities tested. For example, the R_c for *C. vulgaris* increased from 14 $s\,m^{-1}$ at 2 $\mu g\,m^{-3}$ to 112 $s\,m^{-1}$ at 80 $\mu g\,m^{-3}$. Diurnal variations in NH_3 uptake were observed for higher plants, due to stomatal uptake; however, no diurnal variations were shown for non-stomatal plants. R_c for *C. vulgaris* at 80 $\mu g\,m^{-3}$ was 66 and 112 $s\,m^{-1}$ during day and night, respectively. Differences were found in NH_3 deposition between plant species and vegetation communities: *Sphagnum* had the lowest R_c (3 $s\,m^{-1}$ at 2 $\mu g\,m^{-3}$ to 23 at 80 $\mu g\,m^{-3}$), and *D. cespitosa* had the highest nighttime value (18 $s\,m^{-1}$ at 2 $\mu g\,m^{-3}$ to 197 $s\,m^{-1}$ at 80 $\mu g\,m^{-3}$).

Keywords: Canopy resistance; Compensation point; Cuticular resistance; Stomatal uptake; Flux chamber; Ammonia

1. Introduction

Dry deposition of NH_3 to vegetation can occur directly through stomatal uptake or onto the cuticle (Sutton and Fowler, 1993; Jones et al., 2007). Uptake from the stomatal cavities occurs when gaseous NH_3 dissolves into the apoplastic solution. Deposition to the cuticle occurs either to cuticular surface water, which is present even when humidity is as low as 50% due to the presence of deliquescent salts (Burkhardt and Eiden, 1994), or directly onto dry plant surfaces, adsorbed to surfaces waxes. Factors known to affect deposition of NH_3 to vegetation including temperature and humidity (van Hove et al., 1990; Sutton et al., 1995), surface wetness (Duyzer et al., 1987), diurnal variations (Hutchinson et al., 1972), co-deposition with acidic

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gases like SO_2 (van Breemen et al., 1982; Wyers and Erisman, 1998), and NH_3 concentrations (Sutton et al., 1993a, b; Flechard et al., 1999; Jones et al. 2007). NH_3 has already been demonstrated to deposit differently to different species and vegetation communities. For example, Schjoerring et al. (1998) demonstrated that NH_3 deposits in greater quantities to *Deschampsia flexuosa* than *Calluna vulgaris*. However, the quantitative response of the canopy resistance (R_c) in different species to increasing NH_3 concentrations remains unknown. Therefore modelling of deposition processes assumes that there is a fixed value for R_c despite the vegetation or species present (e.g., Singles et al., 1998; Smith et al., 2000).

Moorland ecosystems are a mosaic of stomatal and non-stomatal plants including bryophytes and lichens. These two groups are likely to respond differently to NH_3 deposition due to structural and physiological differences. Of particular importance in many moorlands are *Sphagnum* spp., *Cladonia* spp., and *Pleurozium schreberi*, none of which have been previously studied in relation to NH_3 uptake. *C. vulgaris*, *Eriophorum vaginatum* and *Deschampsia cespitosa* are also keystone species in many types of moorlands, again little research has been conducted upon them in relation to NH_3 deposition.

Sphagnum papillosum and *Sphagnum capillifolium* are dense mat-forming mosses that can retain large volumes of water in their spongy mass and they grow in low-nutrient habitats (Watson, 1964). *Sphagnum* has been shown to be highly sensitive to increased levels of nitrogen deposition, responding with clear physical effects such as necrosis and the collapse of *Sphagnum* hummocks, reduced growth (productivity) and increased parasitism (Bragazza et al., 2005; Gunnarsson and Rydin, 2000; Jauniainen et al., 1998).

Cladonia portentosa and *Cladonia arbuscular* are mat-forming lichens found predominantly on ombrotrophic bogs and moorlands. *Cladonia* can make a significant contribution to ecosystem functioning for primary production and for nutrient and water cycling (Ellis et al., 2005). *Cladonia* was shown by Vagts and Kinder (1999) to be highly susceptible to NH_3 deposition. Similarly, Sheppard et al. (2005) showed visible damage in *C. portentosa*, including bleaching and new algal growth with increased NH_3 concentrations and deposition.

P. schreberi is a common mat-forming pleurocarpous moss of moorlands (Watson, 1964). *P. schreberi* responds negatively to NH_4^+ fertilization (Dirkse and Martakis, 1992; Pitcairn et al., 1995), and Solga et al. (2005) found decreasing biomass production and increasing tissue nitrogen content under high bulk nitrogen deposition.

E. vaginatum is a highly successful, tussock-forming sedge (Cyperaceae) which inhabits infertile and wet semi-natural areas (Cholewa and Griffith, 2004). Its occurrence in ombrotrophic habitats suggests intolerance of high nitrogen, but Defoliart et al. (1988) and Shaver and Laundre (1997) showed that *E. vaginatum* has increased growth with added NH_4^+. These results suggest that increases in nitrogen deposition will allow the *E. vaginatum* to compete more effectively in the wet bogs and out-compete co-occurring organisms such as *Sphagnum* spp.

D. cespitosa is a densely tufted perennial grass, which occupies a wide range of habitats and climates (Chiapella and Probatova, 2003). Previous studies have shown that *D. cespitosa* reacts positively to an increase in N supply and shows strong growth responses, e.g., Bowman and Bilbrough (2001) demonstrated an increase in *D. cespitosa* biomass, with increased NH_4^+ supply.

C. vulgaris is an ericaceous shrub, and the dominant species in many heathlands (Averis et al., 2004; Gimingham, 1972). It has been shown to respond strongly to nitrogen, which indicates that it is nitrogen limited in these semi-natural ecosystems (Gimingham, 1972). With increased N deposition *C. vulgaris* becomes more susceptible to secondary effects such as frost, drought, and beetle attacks (e.g., Pitcairn et al., 1995).

In a previous paper (Jones et al., 2007), it was demonstrated that the R_c increased with increasing concentration for a mixed moorland vegetation canopy due to saturation of the cuticle. This work did not identify the relative importance of individual species in an ecosystem, and the effects that they will have on deposition rates. This paper extends the findings in Jones et al. (2007) by examining differences in NH_3 deposition rates between non-stomatal and stomatal species. The aims of the paper are to

- identify differences in NH_3 deposition between non-stomatal and stomatal species;
- identify differences in nighttime and daytime NH_3 deposition among species;
- allow a better understanding of NH_3 deposition for improved modelling and for the better understanding of NH_3 effects in ecosystems.