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Heathland vegetation as a bio-monitor for nitrogen deposition and source attribution using δ ^{15}N values

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Abstract

The %N and δ ^{15}N signals in foliar nitrogen (N) from four heathland species have been monitored in a blanket bog plant community subjected to different experimental inputs of wet and dry N deposition. Interactions with combined additional treatments of phosphorus (P) and potassium (K) were also investigated. *Calluna vulgaris*, *Cladonia portentosa*, *Sphagnum capillifolium* and *Hypnum cupressiforme* were harvested for ^{15}N analysis prior to wet and dry treatment applications and again after 16 months field exposure. A significant increase was observed in both %N and δ ^{15}N values for all plant species in response to both wet and dry treatments whilst PK additions also produced significant decreases in foliar %N and associated δ ^{15}N values for several of the species sampled. These enrichments in the δ ^{15}N signals for post-treatment shoot tissue were attributable to the δ ^{15}N signal in the source application, a finding of potential value in using bio-monitors for assessment of N deposition.

Keywords: *Calluna*; *Cladonia*; *Hypnum*; *Sphagnum*; Delta 15N; Ammonia release; Whim Moss

1. Introduction

Over the past half century there has been a substantial increase in atmospheric deposition of fixed N as ammonium (NH_4^+) in rain and as dry deposition of ammonia (NH_3) (Zheng et al., 2002). Additionally, the impacts of wet and dry N deposition on a range of communities such as lowland heaths, upland moorland, calcareous grassland and coastal dunes (Bobbink et al., 1996; Carroll et al., 1999; Sutton et al., 2001) have now been reported.

Enhanced wet N deposition can increase foliar N content in a variety of vegetation types resulting in greater sensitivity to biotic and abiotic stress (Leith et al., 1999; Pitcairn et al., 1995). In particular, many plant species in semi-natural communities, such as lowland heaths, have evolved to live in low nutrient conditions, competing successfully only in soils deficient in N (Grime, 1979). Elevated N deposition to such ecosystems frequently represents a proportionately large increase in the supply of this major nutrient, and changes in species composition have consequently been observed (Power et al.,

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1998; Pitcairn et al., 1995; Carroll et al., 1999; Stevens et al., 2004). Evidence for plant species change, resulting from enhanced N deposition, has been found in the Netherlands where heathland communities, dominated by species such as *Calluna vulgaris* and *Erica tetralix*, are replaced by grassland species such as *Molinia caerulea* and *Deschampsia flexuosa* (Heil and Diemont, 1983). Additionally, many bryophytes and lichens rely largely on rainfall for their nutrient supply (Brown and Bates, 1990) and their tissue nutrient contents may closely reflect atmospheric inputs.

The %N content in shoot tissue of certain plants such as *Calluna* and various moss species was shown to be approximately proportional to atmospheric N inputs (Hicks et al., 2000; Pitcairn et al., 2003) and previous studies by Skinner et al. (2004) indicated a possible link between N deposition and %N/$\delta\ ^{15}N$ values in *C. vulgaris* shoot tissue. This effect has been further examined to determine if these two parameters can be used to quantify N deposition to areas of semi-natural vegetation.

If multiple point sources of NH_3 are located near a specific sensitive ecosystem, simply measuring foliar N concentration may indicate a deposition problem but does not permit source attribution. Studies by Karr et al. (2003) have indicated that stable isotope techniques can be applied to nitrate in watersheds to distinguish N in animal waste from that of soil, organic or fertiliser origin. The use of $\delta\ ^{15}N$ values may also have potential for atmospheric NH_3 monitoring. Agricultural point sources of N pollution may contain an isotopically distinct signal, which may be distinguished from the background values derived primarily from soil (Moore, 1974).

The experiment was established to investigate the fate and impacts of wet deposition and dry deposited N on a Scottish heathland (see Leith et al., 2004). Additionally, when considering the consequences of enhanced N deposition to a particular ecosystem, it may be necessary to characterise the interactions with other potentially limiting nutrients. For this reason we investigated treatments which also included P and K additions, chosen because of their potential interactions with N assimilation (Crawley, 1997). Nitrogen interactions with P and/or K may improve root system development, increase dry matter production and other aspects of plant development (Usherwood and Segars, 2001), and could therefore affect the N content and $\delta\ ^{15}N$ tissue signal.

The specific aims were to compare $\delta\ ^{15}N$ ratios in four common moorland species known to be sensitive to elevated N levels and assess the potential for using stable isotope signatures as bio-monitors for N deposition.

2. Materials and methods

2.1. Whim Moss field experiment

The field site at Whim Moss in the Scottish borders (Grid Ref. NT 210 530) was designed to complement previous N deposition studies on ombrotrophic bog communities, which had been carried out under the relatively controlled conditions of Open-top Chambers (OTCs; see Fowler et al., 1989; Leith et al., 2001). N applications were made at Whim Moss on an intact blanket bog, with the site being separated into two areas receiving either wet or dry deposition treatments. A detailed plan of this field site, together with further information about the experimental structure, is given in Leith et al. (2004) and Sheppard et al. (2004).

The site received relatively low background N inputs, estimated to be ca. $8\,kg\,N\,ha^{-1}\,yr^{-1}$. Dry deposition treatments were applied as an NH_3 release, supplied from $2 \times 5\,m$ fixed pipes, and controlled via a Campbell 23× logger acting on a mass flow controller (Leith et al., 2004). The release system operated in conditional response to wind direction, releasing NH_3 only over a wind sector of 180–215° and when wind speeds exceeded $5\,m\,s^{-1}$. A 'reference' plot, where background NH_3 concentrations and vegetation isotope signals were obtained, was established at a site 20 m east upwind of the experimental area, clear of the release manifold.

Annual rainfall at the site was approximately 1000 mm, with mean monthly temperatures ranging from 5° to 17 °C. Ammonia concentration gradients within the release zone were monitored using passive ALPHA samplers (Tang et al., 2001) and diffusion tubes (Hargreaves and Atkins, 1987). These were located at 1, 2, 4, 6, 8, 12, 16, 32 and 60 m from the source and mounted 0.5 m above the vegetation canopy.

Wet deposition treatments were applied in parallel to normal, on-site, rainfall patterns, with rainwater collected on a $180\,m^2$ collecting surface close to the treatment area, mixed with 4 mM concentrates of NH_4Cl or $NaNO_3$, and then sprayed onto the plots (Sheppard et al., 2004). In