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A Comparison of Impacts of N Deposition Applied as NH_3 or as NH_4Cl on Ombrotrophic Mire Vegetation

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Summary

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The impacts of increased N deposition (wet; NH_4^+ and dry; NH_3) on ombrotrophic mire vegetation were compared in a two-year dose-response study. Vegetation from an ombrotrophic mire in SE Scotland was exposed in open-top chambers to a range of wet N deposition at 0 (deionised water), 8, 16, 32, 64 & 128 kg N ha^{-1} y^{-1} applied as NH_4Cl and dry N deposition as gaseous NH_3 at concentrations of 2, 6, 20, 50 & 90 $\mu g\ m^{-3}$. N concentrations in the foliage of all species showed a significant linear increase in response to dose when N was applied as wet deposited NH_4^+ in both 1999 and 2000. Comparison of the linear regression for foliar N versus $NH_4^+$and NH_3 in the dose-response relationships showed significant differences ($p<0.05$) between the form of N applied and %N concentration for two species in 1999 (*C. vulgaris* and *P. commune*) but not in 2000. There was a significant increase in *C. vulgaris* shoot growth in the NH_3 treatments compared to NH_4^+ treatments when expressed per unit deposited N. Effects of nitrogen deposited as gaseous NH_3 are generally greater than those of wet deposited NH_4^+ on moorland species, when expressed per unit deposited N.

Introduction

Increases in both wet and dry N deposition have been reported throughout Europe in the past 30 years ('UNITED KINGDOM REVIEW' 1994). Enhanced N input

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to semi-natural lowland heaths has caused changes in species composition, stimulation of secondary environmental stresses such as drought, frost and insect infestations (AERTS 1989, CARROLL & al. 1999, POWER & al. 1998). Studies of enhanced N deposition on semi-natural communities such as ombrotrophic mires and moorland have generally reported effects of wet deposition as NH_4^+ and NO_3^- (GORDON & al. 1999, CARROLL & al. 1999). Although critical loads for N, set to protect these sensitive communities are 5-10 and 10-20 kg N ha^{-1} y^{-1} respectively, the effects of increased dry N deposition as NH_3 or a comparison of NH_4^+ and NH_3 have not been widely reported (LEITH & al. 2001a).

In order to compare directly the effects of increased wet NH_4^+ deposition (expressed as kg N ha^{-1} y^{-1}) and dry NH_3 concentrations (μg m^{-3}) the deposition rates (kg N ha^{-1} y^{-1}) of NH_3 must be determined. To estimate NH_3 deposition, deposition velocities, canopy resistances and their dependence on ambient NH_3 concentrations must be known. Effects research to date has generally assumed that the dry deposition rate of NH_3 increases linearly with ambient NH_3 concentration, i.e. that deposition velocity is constant with increasing concentration. FLECHARD & FOWLER 1998 have shown that deposition velocity decreases as NH_3 concentration increases in the range 0.1-2.0 μg m^{-3}, due to chemical processes at the vegetation surface. However, this concentration range is not sufficiently wide to cover the range of NH_3 conditions in the UK where ambient concentrations close to point sources often exceed 10 μg m^{-3}.

In a 2-year open-top chamber (OTC) study, the effects of N form (NH_3 versus NH_4^+) on nutrient-limited, upland ombrotrophic mire vegetation (7 species) were compared in N dose-response experiments. The vegetation was exposed to a range of wet N deposition treatments (0-128 kg N ha^{-1} y^{-1}) applied as NH_4Cl and dry deposition as gaseous NH_3 at a range of concentrations (2-90 μg m^{-3}) for 2 field seasons (1999 and 2000). These concentrations are typical of gaseous NH_3 concentrations found in close proximity to intensive livestock units (FOWLER & al. 1998). Rates of NH_3 dry deposition were measured over a range of concentrations in a flux chamber to quantify inputs to the vegetation and the dependence of deposition rate on the NH_3 concentration.

Material and Methods

Measurements of NH_3 deposition velocities were made over ombrotrophic mire vegetation (identical to that used in the dose response experiment), using an additional OTC with a purpose built flux chamber. A full description of methods and results is given in LEITH & al. 2001b. This enabled deposition rates (kg N ha^{-1} y^{-1}) at a range of ambient NH_3 concentrations to be calculated. By applying the calculated deposition velocity to the measured NH_3 treatment concentrations the NH_3 deposition could be determined.

In the summer of 1998, a central square (1.75m x 1.75m; area = 3.06 m^2) in each of eleven OTC's was excavated to a depth of 50 cm. The excavated areas were then back-filled with peat and individual plants of seven species, *Calluna vulgaris* (L.) Hull, *Narthecium ossifragum* (L.) Hudson, *Potentilla erecta* (L.) Rauschel, *Deschampsia flexuosa* (L.) Beauv., *Eriophorum vaginatum* (L.), *Polytrichum commune* Hedw. and *Molinia caerulea* (L.) Moench from an ombrotrophic mire (30 km SW of Edinburgh). All chambers were watered with de-ionised water using either an underground drip system or by overhead misting.

During the field season 1998, a dose-response experiment, exposing ombrotrophic mire vegetation to either a range of NH_3 concentrations or to NH_4^+ (applied as NH_4Cl solutions) was established using eleven OTCs at the Centre for Ecology and Hydrology- Edinburgh. Six wet and five dry N deposition treatments were applied throughout the 1999 and 2000 field seasons. Six wet deposition mist treatments (de-ionised water, 8, 16, 32, 64, 128 kg N ha^{-1} y^{-1} as NH_4Cl) were applied over a 25-week period during both the 1999 and 2000 growing seasons at a rate of 12 mm per week (3 applications per week) from individual pressurized vessels via a spray droplet generator. The concentrations of the 6 wet deposition treatments were 0, 0.19, 0.38, 0.76, 1.52 and 2.85 mM NH_4Cl respectively. A full description of the application system is given in FOWLER & al. 1989. Four gaseous NH_3 treatments (6, 20, 50, 90 μg m^{-3}) were generated by volatilization of a pumped 1 % aqueous NH_3 solution into the air stream of the OTC manifold. NH_3 treatments were applied continuously throughout the growing seasons of 1999 and 2000. NH_3 treatment chambers received background ambient NH_3 concentrations of approximately 1-2 μg m^{-3} throughout the winter non-treatment period. NH_3 concentrations in each treatment chamber were continuously monitored using passive ammonia diffusion samplers (3 replicate samplers per chamber) changed every 4 weeks (SUTTON & al. 1998). The calculated depositions for 1999 and 2000 were 4, 9, 14, 34 and 48 kg N ha^{-1} y^{-1} and 4, 9, 30, 65, 80 kg N ha^{-1} y^{-1} respectively for mean measured treatment concentrations of 1.6, 4.0, 13, 30 and 73 in 1999 and 2, 8, 28, 55 and 93 μg NH_3 m^{-3} in 2000.

Above ground biomass of *N. ossifragum, P. erecta, D. flexuosa, E. vaginatum* and *M. caerulea* was determined by destructive harvest in both October 1999 and 2000. All above ground foliage was harvested and split into tillers/leaves and flowers. The tillers/leaves were then thoroughly washed with de-ionized water, to remove surface N deposition, dried at 80 ^{0}C then weighed. Sub-samples were ground, digested and analyzed for NH_4-N by the indophenol-blue method and for phosphate-P by the molybdenum-blue reaction (GRIMSHAW & al. 1989).

Ten individual shoots of *Calluna vulgaris* per treatment were randomly selected prior to shoot extension in March 1999 and 2000. Each shoot was marked with a waterproof solution, approximately 1 cm below the growing shoot tip. At regular intervals throughout the season the extension (mm) of each shoot was measured.

Results and Discussion

Although the higher N depositions in both the NH_3 and NH_4^+ treatments exceeded the critical load for moorland vegetation of 10-20 kg N ha^{-1} y^{-1} (BOBBINK & al. 1996) there was no loss of species or visible foliar injury in the two years of the experiment. This could be due to the absence in this study of the additional secondary stress factors such as heather beetle and drought reported to be required to initiate species composition change (POWER & al. 1998).

For a given amount of N deposited the effects on moorland vegetation of NH_3 appear to be greater than for NH_4^+. This is consistent with VAN DER EERDEN & al. 1990, who suggest that foliar NH_3 uptake is quicker than foliar and root assimilation of NH_4^+ or NO_3^-. It is suspected that the uptake pathway for NH_3 is through the stomata and not through the leaf surface, as DUECK & al. 1991 found little or no NH_3 absorbed to the leaf surface of either graminoid or ericaceous species.

There was a significant linear dose response relationship ($p<0.05$) between foliar N content in all plant species and NH_4-N applied in both 1999 and 2000. The N concentrations in *C. vulgaris* ranged from 1.70 % to 2.25 % and 1.4 % to 1.93 %, going from the lowest and highest NH_4^+ treatments in 1999 and 2000 respectively. The decrease in % N concentration in the second year of treatment could be due to

Table 1. Linear regression analysis of foliar N with applied N as NH_4^+ or NH_3 in 1999 and 2000. The difference in response to NH_3 and NH_4^+ (*Prob.) was tested using a generalized linear regression model, where the slope and r^2 refer to mean values of 5(6) points. Data marked with an asterisk (*) are statistically significant at $p < 0.05$.

%N concentration	NH_4^+ (kg N ha^{-1} y^{-1}) Slope	r^2	NH_3 (kg N ha^{-1} y^{-1}) Slope	r^2	Prob. NH_4^+ Versus NH_3
1999					
C. vulgaris	0.004*	0.98	0.013*	0.96	0.003*
M. caerulea	0.006*	0.79	0.090	0.70	0.572
E. vaginatum	0.006*	0.91	0.001	0.01	0.314
P. erecta	0.011*	0.76	0.017	0.61	0.505
D. flexuosa	0.011*	0.90	0.022	0.61	0.116
P. commune	0.010*	0.93	0.033	0.86	0.007*
N. ossifragum	0.005*	0.78	0.008	0.43	0.536
2000					
C. vulgaris	0.004*	0.98	0.006*	0.89	0.106
M. caerulea	0.017*	0.88	0.004*	0.87	0.562
E. vaginatum	0.006*	0.96	0.005*	0.95	0.167
P. erecta	0.006*	0.71	0.008	0.91	0.530
D. flexuosa	0.011*	0.88	0.012*	0.96	0.716
N. ossifragum	0.007*	0.92	0.008*	0.93	0.542
S. capillifolium	0.010*	0.94	0.027*	0.91	0.068

growth dilution. PRINS & al. 1991 also found an increase in % N in *C. vulgaris* in response to increased NH_4^+ deposition. In the NH_3 treatment, only *C. vulgaris*, and *P. commune* showed a significant response to increasing N additions and also to the form of N applied (Table 1) in 1999. Both species exhibited greater N uptake when N was supplied as NH_3 rather than as NH_4^+ on a per unit N basis. A linear dose response relationship was also found by PITCAIRN & al. 1995, 1998 for a number of species including *C. vulgaris*. This dose response relationship found for both N forms is further support for the use of foliar N concentration as a bio-indicator of N deposition.

A significant relationship between % N and deposition was found for all species except *P. erecta* in the NH_3 treatments in 2000. This increase in foliar N concentration with increased NH_3 concentrations has been found in a number of species (FANGMEIER & al. 1994). It is not clear why this significant linear relationship was not found in 1999, but was present in the second year of treatment (2000) for *M. caerulea, E. vaginatum, D. flexuosa* and *N. ossifragum*. In contrast to 1999, none of the species in 2000 showed significant differences between the form of N applied and % N in the foliage.

Enhanced N deposition increased shoot extension in *C. vulgaris* in each year of N treatment. This is consistent with the results of CARROLL & al. 1999. Analysis of individual N treatment growth data found that Gompertz curves could be fitted to all individual treatment shoot elongation curves. There was a significant difference ($p<0.001$) between the two N forms with NH_3 treatments increasing

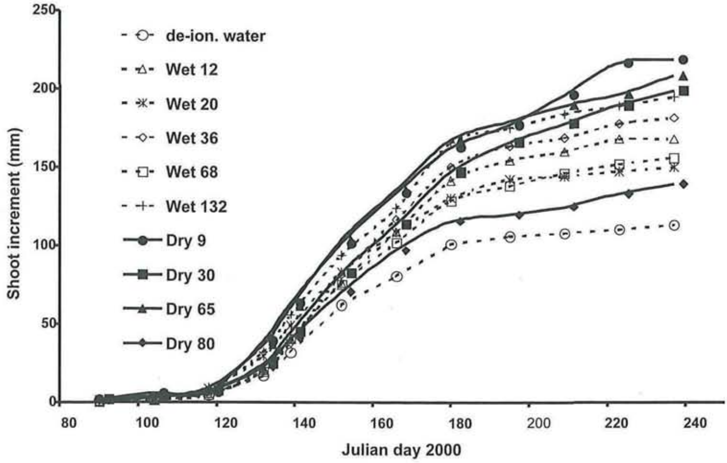

Fig. 1. Shoot extension of *C. vulgaris* shoot extension from April to September 2000. Numbers in legend refer to N deposition rate (kg N ha^{-1} y^{-1}).

shoot elongation compared to NH_4^+ treatments. This difference could be increased by excluding the high NH_3 treatment (61 kg N ha^{-1} y^{-1}) and was not included as a separate component in the analysis, because shoot elongation was significantly decreased in this high NH_3 treatment. This could be attributed to changes in shoot morphology with increased lateral branching of the terminal shoot in the highest NH_3 treatments compared to other N treatments. Comparison of the dry weights of 3 cm length of *C. vulgaris* shoots showed a 35 % increase in weight in the highest NH_3 treatment compared to lowest. Generally, on an N input basis, N applied as dry NH_3 increased shoot extension more than wet NH_4^+. The de-ionized water treatment had the smallest shoot extension compared to all the other N treatments irrespective of N form. This could be attributed to N deficiency as the foliar % N concentration decreased from 1.75 % in 1999 to 1.4 % in 2000.

This study has shown that NH_3 uptake is greater on a per unit of N deposited than NH_4^+ uptake and that the form of N applied influencec the assimilation of N and growth rates in *C. vulgaris*.

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