Extended abstract No. 399

CONSTRAINTS ON THE ABILITY OF PEATLAND ECOSYSTEMS TO BUFFER INCREASING NITROGEN DEPOSITION

Chris Field
Manchester Metropolitan University; E-mail: c.field@mmu.ac.uk

Simon Caporn, Nancy Dise, both Manchester Metropolitan University
Lucy Shepperd, Centre for Ecology and Hydrology Edinburgh

SUMMARY

Over recent years much attention has been given to the carbon balance of peatland and heathland ecosystems and their role as important global carbon stores, yet they are also important for other ecosystem services including as sinks for atmospheric nitrogen pollution . This study contrasted soil exchangeable N and nitrogen losses in leachate at three ericaceous-dominated ecosystems. Leachate N increased below threshold soil C:N values which were highest in the raised bog and lowest in the upland heath, whilst extractable N was greatest in the upland heath compared to the lowland heath and the raised bog. We therefore conclude that, in addition to soil C:N and the size of C pool, the type of organic matter was an important determinant of N leaching through carbon limitation of the microbial community. Sites with a deeper, microbially active *Calluna* litter layer, such as upland heaths, leach less nitrogen than *Sphagnum* rich ombrotrophic bogs.

KEYWORDS: Nitrogen, Deposition, Sequestration, Leaching, Mineralisation

INTRODUCTION

Ericaceous ecosystems are populated to differing degrees by a mosaic of dwarf shrubs from the *Ericaceae* family including heather (*Calluna vulgaris*), grasses and sedges and different moss species such as *Hypnum jutlandicum*, or, in the case of raised bogs, *Sphagnum* species. They cover large altitudinal ranges over different soil types, encompassing dry and sandy lowland heaths, from well-drained upland moors to ombrotrophic bogs (mires) holding deep reserves of saturated peat. In addition to acting as an important global carbon store, the peatland landscape also plays a significant role in the provision of other key ecosystem services including biodiversity, drinking water provision, and as a sink for atmospheric pollution including nitrogen deposition.

Pollution from reactive nitrogen is acknowledged as a significant contributor to ecosystem change throughout the world that affects ecosystems in different ways. N deposition has been shown to increase the growth of ericaceous plants such as *Calluna vulgaris* across a number of ecosystem types including upland heath (Caporn *et al.*, 1995), lowland heath (Power et al., 1995) and ombrotrophic bogs (Bubier et al., 2007). This increase in growth of higher plants can cause competitive exclusion of slower-growing species and lower plants including lichens and mosses with subsequent reductions in biodiversity (Carroll et al., 1999).

Aside from change in above-ground vegetation, enhanced N supply alters the biogeochemical functioning of an ecosystem. When N exceeds plant and microbial requirements, excess nitrate and ammonium may leach from a system, especially nitrate which is a mobile anion and is poorly bound in most soils. Studies have found that nitrate leaching is responsive to N deposition in forest soils (Wilson and Emmett, 1999) whereas some ericaceous ecosystems show a strong ability to buffer N additions which has been linked to the prevalence of recalcitrant humic compounds in the soil capable of immobilising N (Pilkington *et al.*, 2005a). Increased N deposition can also increase mineralisation as decomposer organisms are often limited by N and must absorb mineral N to grow; in this case added N will stimulate mineralisation through reduction of C/N (Kristensen and Henriksen, 1998; Emmett *et al.*, 1998). However, as N deposition continues to increase and C:N ratio reduces further the system may become C limited and N availability may exceed both plant and microbial requirements. When this happens, any nutrients not immobilised (or held on exchange sites within the soil) will be leached from the system (Emmett *et al.*, 1998). Leached N compounds subsequently enter freshwater systems and cause acidification and eutrophication of these habitats.

Curtis *et al.* (2004) found a C/N threshold for N leaching in their experiment studying leachate from moorland systems subject to different ambient N inputs. They suggested that C:N ratio tended to be responsive to N deposition and indicate potential N saturation, and that leachate appeared to respond to C/N. Pilkington *et al.* (2005) also suggested that C:N ratio could be a predictor of N leaching and added that large stocks of C in SOM provided an effective sink for N inputs. There is further supporting evidence that soil carbon pool can determine nitrate leaching in both heathland (Evans et al., 2006) and forests (Dise et al., 1998), and more recently, Dise et al. (2009) examined a database of plot and landscape scale N studies from 248 forest sites and found that soil C/N was one of the most consistent indicators of N leaching.

The aim of this study was to explore the relationship between soil CN and leachate N and to contrast the results between the ecosystems studied and explore the possible mechanisms for these responses.

MATERIALS AND METHODS

Fieldwork in this study was carried out at three different sites all of which were ericaceous dominated ecosystems. The sites differed in climate, soil type, hydrology, and, to a certain extent, vegetation. Two were heathlands, one a dry lowland heath, the other a wet upland heath, and one site was an ombrotrophic bog. The bog site, Whim Moss, is located in south-east Scotland; Ruabon upland heath is situated in North Wales; Budworth Common lowland heath is located in north-west England. At Ruabon and Budworth N is added as $NH_4^+NO_3^-$ at loads up to 120 kg N ha^{-1} yr^{-1}. At Whim, N additions are split between wet reduced ($NH_4^+Cl^-$) and wet oxidised ($Na^+NO_3^-$) forms, with a ‘dry’ NH_3^- deposition emitted from a gaseous source. N addition loads at Whim are up to 56 kg N ha^{-1} yr^{-1}. N additions commenced in 1996 and 2002 at Budworth and Whim respectively, and 1989 at Ruabon, although the current research was carried out on newer plots established in 1998.

Soil solution samples were collected for a period of at least 18 months at each site: at Whim between May 2006 and October 2007; Budworth between June 2006 and April 2008;Ruabon between November 2006 and May 2008. The method of collection differed slightly between the sites. Micro-rhizon samplers (Van Walt Ltd., Surrey, UK) were used at Whim and Ruabon, whereas zero-tension lysimeters were used at Budworth. At all sites the soil solution was collected at 10 cm depth and filtered to 0.2μm. KCl extractable (6%) N was measured in soil cores removed seasonally between May 2006 and May 2007 for Ruabon and Whim, and between November 2007 and November 2008 for Budworth. Mineralisation rates were estimated by taking a second core, adjacent to and at the same time as the 1st core. This was placed in a polythene bag, returned to the soil and incubated for approximately three months. Both soil solution and soil extractants were analysed for NO_3^- and NH_4^+ using a Dionex ICS 2000 ion chromatograph (Dionex UK Ltd., Surrey, UK).

RESULTS

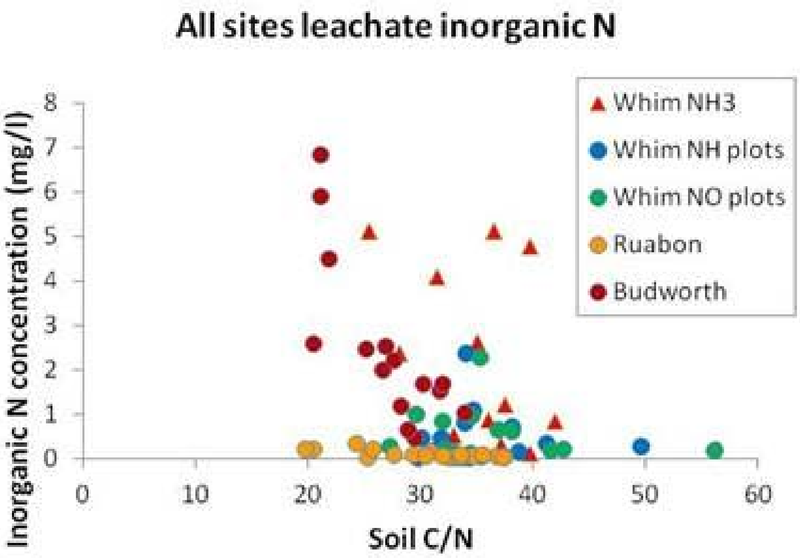
The highest concentrations of NH_4^+ & NO_3^- in soil solution, relative to soil C/N, were measured in samples from along the NH_3^- transect at Whim (see figure 1). The lowest concentrations were measured in samples from the Ruabon field site where only plots receiving the highest level of N deposition had significant amounts of N in the soil solution. Responses in the wet-N plots at Whim were of similar magnitude to Budworth, albeit N deposition was much greater in the highest treatment at Budworth. Soil C/N was strongly related to leachate N at Ruabon, Budworth and the NH_3^- transect at Whim, but not in the wet plots at Whim (see Figure 1).

Mean soil extractable N increased with N deposition at both Ruabon and Budworth, although levels were much lower at Budworth (see Figure 2). At Whim, allowing for the smaller high N treatment, extractable N sat between values at Ruabon and Budworth. Notably, extractable NO_3^--N was very low at Whim in comparison with the other sites (not shown).

Annual net mineralisation was lowest at Budworth and greatest at Ruabon, with Whim between the two and remaining unchanged as N increases. Annual net nitrification was similar at all sites apart.

DISCUSSION

Despite several years of N addition, breakthrough of N in leachate was well buffered at all sites, signifying high levels of immobilisation within the systems either through plant or microbial uptake or bonding onto soil exchange sites. All the soils buffered increases in N remarkably well, particularly Ruabon . Significant leachate breakthrough did not occur at Ruabon until a C/N of around 25 was reached. Whilst observations at both Ruabon and Budworth are consistent with theories which describe increasing inorganic N leachate as C/N falls, the site with the most organic matter, Whim - a peat bog, responds differently. A high C:N ratio and large amounts of organic matter should theoretically protect Whim from reaching an N leaching threshold, however, it is suggested that the C/N that triggers the onset of leaching is higher than the other sites due to the quality of organic matter at the site and



that this threshold has already been reached. Indeed, leachate N is greater at Whim than Ruabon and similar in magnitude to Budworth with its sandy-podzol soil.

Fig. 1. Correlation of leachate inorganic N concentration to soil C/N ratio.

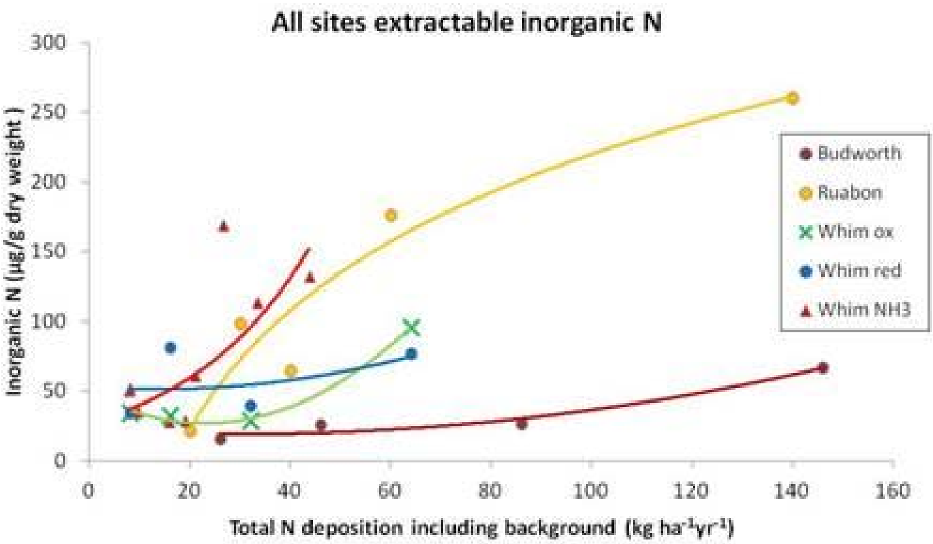


Fig. 2. Extractable inorganic N concentration in relation to total experimental N deposition.

The strong immobilisation and retention of nutrients suggested by the leachate data is supported by the extractable N and nitrification and mineralisation data. At Ruabon and Budworth exchangeable N increased positively with N addition, particularly in response to the highest level. At Whim, extractable N was generally lower in the range 42 to 109 mg NH_4^+-N g dry soil^{-1} compared to 11 to 460 NH_4^+-N g dry soil^{-1} at Ruabon, representing percentage increases above control of 166% and 3900% respectively. Extractable NO_3^--N was generally very low at Whim compared to Ruabon and slightly lower than Budworth. At Ruabon only, mineralisation was positively linked with a falling C/N in response to N.

The different responses between the sites can be attributed to vegetation type, vegetative growth response to N addition, and litter fall. At Whim, few responses were seen across the vegetation suggesting that the site was limited by other factors, such as hydrology and shrub growth that restricted litter quality and microbial acitivity. Ruabon alone possesses a uniform *Calluna* canopy which has produced a thick litter layer (up to 15 cm) which is almost entirely absent at Budworth and Whim. Given the remarkable ability for *Calluna* litter to buffer N addition (Pilkington *et al.*, 2005), the lack of this in itself would reduce the immobilisation potential of Budworth and Whim due to the absence of a labile carbon source. Furthermore, Whim alone has a large proportion of *Sphagnum* moss. Lamers *et al.* (2000) compared the %N of *Sphagnum* across a number of European bogs and found that above 18 kg N ha^{-1} yr^{-1} *Sphagnum* became saturated with N, was unable to take up additional N and would start to leak further N addition.

Lamers *et al.* (2000) suggested that this saturation would occur at a tissue C/N of between 40 and 50. Consequently, it may be that it is not just the amount of organic matter, C pool and current soil N that determines N saturation (Emmett *et al.*, 2007; Evans *et al.*, 2006), but the availability of a labile C pool suitable for mineralisation. Rowe *et al.* (2006) studied the responses of different ecosystems to N addition and the C/N at the onset of leaching in each. They attributed differences to the recalcitrant organic matter in some ecosystems and the difficulty that microbes had in breaking this down. Microbes consequently became carbon limited and this made it difficult for N to be immobilised. At sites dominated by recalcitrant vegetation such as Whim the onset of N leaching therefore appears to be at a higher C/N, with the *Sphagnum* bryophyte layer acting as a less effective sink for N deposition compared to *Calluna* litter, saturating at lower N and higher C/N levels. The absence of a definable litter layer and labile carbon available for mineralisation and immobilisation at both Budworth and Whim could therefore explain the absence of a mineralisation response to falling C/N and the earlier onset of leaching. This suggests that a *Calluna* litter layer is more effective at retaining N, despite its own recalcitrance, than *Sphagnum* moss. The third main difference between the sites is the dominant effect of the water table on all soil processes on the bog site. It is well documented that a high water table is capable of slowing soil turnover processes such as decomposition (Freeman *et al.* 2004), mineralisation and nitrification (Blodau *et al.*, 2004), and this may further prevent microbial immobilisation of N due to a lack of oxygen in the upper layers of peat.

Vegetation type at a site and its response to N appears to determine not only the propensity for an ecosystem to sequester C but its ability to buffer against N leaching. Sites rich in *Calluna* litter, such as Ruabon, were better able to retain N than those with less, such as Whim and Budworth. In the heathland sites, increased N predominantly led to increased growth which led to greater litter fall and C sequestration. The greater amount of litter in turn produced greater N buffering on both ion exchange sites and through microbial immobilisation. The balance point of this mechanism appeared to be C:N ratio which responded positively to increased growth due to greater amounts of organic matter but fell as N increased and plant and microbial requirements were exceeded. C:N ratio leaching thresholds were 25:1 at Ruabon, 32-34:1 at Budworth and 40:1 on the dry NH_3^- transect at Whim. No threshold was found for the wet plots at Whim. Carbon and nitrogen cycles were closely coupled in the heathlands but were decoupled at Whim due to the strong controlling force of hydrology. This has ultimately led to the greater reserves of C that exist at Whim but may prevent the sequestration of further C driven by N deposition.

ACKNOWLEDGEMENTS

This study was performed as part of a PhD thesis which was jointly funded by the Dalton Research Institute at Manchester Metropolitan University, and the Centre for Ecology and Hydrology, Edinburgh as part of the NitroEurope project.

REFERENCES

Bubier, J. L., Moore, T. R. and Bledzki, L. A. (2007). Effects of nutrient addition on vegetation and carbon cycling in an ombrotrophic bog. *Global Change Biology* **13**(6): 1168-1186.

Blodau, C., Basiliko, N. and Moore, T. R. (2004). Carbon turnover in peatland mesocosms exposed to different water table levels. Biogeochemistry **67**(3): 331-351.

Caporn, S. J. M., Song, W., Read, D. J. and Lee, J. A. (1995). The effects of repeated N fertilisation on mycorrhizal infection in heather. *New Phytologist* **129**: 605-609.

Carroll, J. A., Caporn, S. J. M., Cawley, L., Read, D. J. and Lee, J. A. (1999). The effect of increased deposition of atmospheric nitrogen on *Calluna vulgaris* in upland Britain. *New Phytologist* **141**: 423-431.

Dise, N. B., Rothwell, J. J., Gauci, V., van der Salm, C. and de Vries, W. (2009). Predicting dissolved inorganic nitrogen leaching in European forests using two independent databases. *Science of the Total Environment* **407**(5): 1798-1808.

Emmett, B. A., Boxman, D., Bredemeier, M., Gundersen, P., Kjønaas, O. J., Moldan, F., Schleppi, P., Tietema, A. and Wright, R. F. (1998). Predicting the Effects of Atmospheric Nitrogen Deposition in Conifer Stands: Evidence from the NITREX Ecosystem-Scale Experiments. *Ecosystems* **1**(4): 352-360.

Emmett, B. A. (2007). Nitrogen saturation of terrestrial ecosystems: Some recent findings and their implications for our conceptual framework. *Water Air and Soil Pollution: Focus* **7**:99-109.

Evans, C. D., Reynolds, B., Jenkins, A., Helliwell, R. C., Curtis, C. J., Goodale, C. L., Ferrier, R. C., Emmett, B. A., Pilkington, M. G., Caporn, S. J. M., Carroll, J. A., Norris, D., Davies, J. and Coull, M. C. (2006). Evidence that soil carbon pool determines susceptibility of semi-natural ecosystems to elevated nitrogen leaching. *Ecosystems* **9**(3): 453-462.

Freeman, C., Ostle, N. J., Fenner, N. and Kang, H. (2004). A regulatory role for phenol oxidase during decomposition in peatlands. *Soil Biology and Biochemistry* 36(10): 1663.

Kristensen, H. L. and Henriksen, K. (1998). Soil nitrogen transformations along a successional gradient from Calluna heathland to Quercus forest at intermediate atmospheric nitrogen deposition. *Applied Soil Ecology* **8** (1-3): 95-109.

Lamers, L., P. M. , Bobbink, R. and Roelofs, J., G. M. (2000). Natural nitrogen filter fails in polluted raised bogs. *Global Change Biology* **6** (5): 583-586.

Pilkington, M., Caporn, S. J. M., Carroll, J. A., Cresswell, N., Lee, J., Ashenden, T. W., Brittain, S. A., Reynolds, B. and Emmett, B. A. (2005). Effects of increased deposition of atmospheric nitrogen on an upland moor: leaching of N species an soil solution chemistry. *Environmental Pollution* (**135**): 29-40.

Power, S. A., Ashmore, M. R., Cousins, D. A. and Ainsworth, N. (1995). Long term effects of enhanced nitrogen deposition on a lowland dry heath in southern Britain. *Water, Air, & Soil Pollution* **85**(3): 1701-1706.

Rowe, E. C., Evans, C. D., Emmett, B. A., Reynolds, B., Helliwell, R. C., Coull, M. C. and Curtis, C. J. (2006). Vegetation type affects the relationship between soil carbon to nitrogen ratio and nitrogen leaching. *Water Air and Soil Pollution* **177**(1-4): 335-347.
Sheppard et al 2004