Atmospheric Environment 97 (2014) 296–309

Contents lists available at ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

Determination of atmospheric nitrogen deposition to a semi-natural peat bog site in an intensively managed agricultural landscape

Miriam Hurkuck [a,*], Christian Brümmer [a], Karsten Mohr [b], Ludger Grünhage [c], Heinz Flessa [a], Werner L. Kutsch [a]

[a] Thünen Institute of Climate-Smart Agriculture, Federal Research Institute for Rural Areas, Forestry and Fisheries, Bundesallee 50, 38116 Braunschweig, Germany
[b] Landwirtschaftskammer Niedersachsen, Mars-la-Tour Str. 1-13, 26121 Oldenburg, Germany
[c] Justus-Liebig-University of Gießen, Department of Plant Ecology, Heinrich-Buff-Ring 26, 35392 Giessen, Germany

HIGHLIGHTS

- Denuder systems and micromet equipment were used to determine airborne N input.
- More than 80% of total N was deposited as ammonia.
- Concentration and deposition peaks coincided with main fertiliser application.
- A fivefold exceedance of the ecosystem-specific critical load was found.

ARTICLE INFO

Article history:
Received 20 December 2013
Received in revised form
12 August 2014
Accepted 14 August 2014
Available online 15 August 2014

Keywords:
Nitrogen deposition
Ammonia
Ombrotrophic bog
Denuder filter samplers
Critical load
Intensive agriculture

ABSTRACT

Rising levels of atmospheric nitrogen (N) deposition have been found to affect the primary productivity and species composition of most terrestrial ecosystems. Highly vulnerable ecosystems such as nutrient-poor bogs are expected to respond to increasing N input rates with a decrease in plant species diversity. Our study site – a moderately drained raised bog and one of only very few remaining protected peatland areas in Northwestern Germany – is surrounded by highly fertilised agricultural land and intensive livestock production. We quantified the annual deposition of atmospheric N over a period of two years. Dry deposition rates of different N species and their reactants were calculated from day and night-time concentrations measured by a KAPS denuder filter system. Dry N deposition amounted to 10.9 ± 1.0 kg N ha^{-1} yr^{-1} (year 1) and 10.5 ± 1.0 kg N ha^{-1} yr^{-1} (year 2). More than 80% of total deposited N was attributed to ammonia (NH_3). A strong seasonality in NH_3 concentrations and depositions could be observed. Day and night-time concentrations and depositions, however, did not differ significantly. Total N deposition including bulk N deposition resulted in about 25 kg N ha^{-1} yr^{-1}. Our results suggest that the intensive agricultural land management of surrounding areas and strongly emitting animal husbandry lead to N inputs into the protected peatland area that exceed the ecosystem's specific critical load up to fivefold. This gives rise to the assumption that a further shift in plant species composition with a subsequent alteration of the local hydrological regime can be expected.

1. Introduction

Atmospheric nitrogen (N) deposition can be a major driver of change in most natural and semi-natural terrestrial ecosystems and particularly threats species composition, diversity, and functioning of ecosystems adapted to nutrient poor conditions. Galloway et al. (2004) reported an increase in anthropogenic reactive N generation rate by a factor of >10 in comparison to the late 19th century due to increased agricultural production and energy consumption. Anthropogenic N deposition mainly originates from ammonia (NH_3) volatilisation caused by agricultural activities and from NO_x emissions from combustion processes (Erisman et al., 2011). NH_3 deposition can have significant effects on the nutrient imbalance of terrestrial plants and increasing N fertilisation potentially limits plant growth (e.g. Van der Eerden, 1982). NH_3 accumulation within plant cells may lead to growth reduction, an increased sensitivity to

* Corresponding author.
E-mail address: miriam.hurkuck@ti.bund.de (M. Hurkuck).

http://dx.doi.org/10.1016/j.atmosenv.2014.08.034

e.g. frost and can even cause toxic effects such as alkali burning of plant tissue and subsequent necrosis (Krupa, 2003; Van der Eerden, 1982). Furthermore, N saturation of ecosystems results in N dispersion to atmosphere, streams, and groundwater, and nitrate (NO_3) enrichment. Consequently, increasing nitrous oxide (N_2O) emissions from soils may occur due to denitrification and nitrification processes (Vitousek et al., 1997).

Experiments in various ecosystems demonstrated that both long-term low (~10 kg ha^{-1} yr^{-1}) and short-term high (>25 kg ha^{-1} yr^{-1}) levels of N addition resulted in a reduction in plant species numbers as well as shifts in plant species composition (Bobbink et al., 1998; Clark and Tilman, 2008; Mountford et al., 1993). In nutrient-poor ecosystems like peatlands, high levels of N deposition can affect the primary production resulting in shifts in plant species compositions and decreases in plant diversity (Verhoeven et al., 2011).

Ombrotrophic bogs belong to those ecosystems which are most sensitive to increased N inputs (e.g. Berendse et al., 2001; Bobbink et al., 2010; Gunnarson and Rydin, 2000). Critical N loads have been estimated to range from 5–10 kg N ha^{-1} yr^{-1} (Bobbink et al., 2010; Bobbink and Roelofs, 1995; UNECE, 2004). Tomassen et al. (2003) showed in an ombrotrophic bog in the Netherlands that the exceedance of this deposition level results in an invasion by more nitrophilous grasses and trees (e.g. *Molinia caerulea*, *Betula pubescens*) and a decline in the native ecosystem-specific species.

N deposition from the atmosphere into ecosystems takes place by sedimenting and non-sedimenting particles and gases (see VDI 4320, Part 1). While wet only samplers exclusively collect wet sedimenting particles (rain, hail, snow, etc.), bulk samplers additionally assess dry sedimenting particles. Highly frequent fluxes of non-sedimenting gases and particles can be determined by means of micrometeorological approaches such as gradient techniques or the newly established TRANC methodology within an eddy covariance setup (Ammann et al., 2012; Brümmer et al., 2013; Marx et al., 2012). If only mean atmospheric concentrations over longer periods are available, dry N deposition can be determined by model calculations based on gradients either measured or calculated by means of atmospheric resistances and micrometeorological parameters. Standard devices to determine concentrations of a variety of reactive N compounds include filter packs (NH_4NO_3 particles), denuders or other wet-chemical samplers (NH_3, HNO_2, HNO_3) and recently developed absorption spectroscopy systems (NH_3) (Fowler et al., 2009; Sutton et al., 2007). Denuder filter systems have long been used to collect or remove gaseous and particulate species from an air sample. In 1985, among others, Peake developed a denuder system primarily for the collection of SO_2 and its atmospheric reactants and products (Peake, 1985). Known as KAPS denuder filter systems (Kananaskis Atmospheric Pollutant Sampler), this method has been further developed and modified particularly to determine concentrations of NH_3 and its reaction partners and products in the polluted atmosphere of Central Europe (Dämmgen, 2007; Zimmerling, 1994). KAPS systems were also used to determine atmospheric N fluxes into forest ecosystems. Dämmgen and Zimmerling (2002) measured fluxes of gases and aerosols above a pine forest in Northeast Germany and estimated deposition velocities. Mohr et al. (2005) applied KAPS systems to quantify N inputs into a pine forest in a region with intensive agriculture in Northwest Germany.

We used KAPS systems to determine dry N deposition to a semi-natural raised bog in Northwest Germany. The bog, which is surrounded by intensive agriculture, is one of the last protected wetland areas in this region (Mohr et al., 2013). Thus, we expected local N depositions with rates that are likely to exceed the ecosystem's specific critical load of about 5 kg N ha^{-1} yr^{-1}, the regional threshold value established by the German Federal Environment Agency (see Nagel et al., 2004), defined as deposition rate below which no significant negative effect has been observed. Nagel et al. (2004) followed the UNECE (2004) guidelines, and the lower value of the global range of 5–10 kg N ha^{-1} yr^{-1} was chosen according to precipitation and phosphorous limitation. Due to numerous farms in the vicinity of the survey area, we assumed that NH_3 is the most important contributor to local N depositions.

The objectives of this study were (i) to quantify dry N deposition and its controlling factors at a semi-natural bog ecosystem which is located in a region with intensive livestock production, (ii) to determine the contribution of different N species to total atmospheric deposition, and (iii) to identify and compare different sources of uncertainties in the approaches used.

2. Materials and methods

The study at hand was part of the integrated project ERNST (Mohr et al., 2013), whose aim was the experimental determination and modelling of N loads in bog ecosystems as well as the derivation of recommendations for reducing N emissions from agricultural practices in Germany and The Netherlands.

2.1. Site description

Measurements were carried out in the ombrotrophic bog 'Bourtanger Moor' located in Northwest Germany and Northeast Netherlands which was – prior to its cultivation in the 17th century – one of the largest raised bogs in mid Europe (Casparie, 1993). The experimental site (52°39′21.25″ N, 7°11′0.17″ E, Fig. 1) is located within a natural park and has been moderately drained. It is one of a few remaining protected bog areas in this region. The recent vegetation of the peat in the surroundings comprises mainly bog heather (*Erica tetralix*), purple moor-grass (*M. caerulea*), cotton grass (*Eriophorum vaginatum*, *Eriophorum angustifolium*) and coppices with birches and Scots pines (*B. pubescens*, *Pinus sylvestris*).

As seen from the position of the tower, the study site has a homogeneous fetch of up to 130 m to the north and east, 150 m to the south and 160 m to the west. In the mean wind direction (south–southwest) the inner homogenous fetch is about 230 m. Outside this area, surface characteristics and plant species composition were similar, but included smaller paths, hedgerows and lines of trees resulting in an outer fetch of up to 650 m facing south–southwest. Results of a footprint analysis are given in Section 2.2.4.

The land use in the vicinity is characterised by intensive crop and livestock production. In total, about 10 million animals, mainly broilers and laying hens are kept on a 30 km × 35 km area around the study site. The arable land is predominantly used for cultivation of maize, potatoes and grain and highly fertilised with organic fertilisers. Grassland is limited to small edges of the moorland.

The altitude of the site is 19 m a.s.l., the annual average air temperature is about 9.5 °C, annual precipitation about 751 mm (1980–2010; German Meteorological Service, Station Emden, distance to study site ca. 80 km). During the experimental period, annual average air temperature was 10.5 °C and annual precipitation was 781 mm (own observations). Mean annual water level was around 0.1 m below surface with considerable seasonal variation (constantly saturated soil in December and January and 0.4 m below surface in September). Peat depth is approximately 4 m.

2.2. Determination of dry N deposition

A KAPS (Kananaskis Atmospheric Pollutant Sampler; Peake, 1985; Peake and Legge, 1987) denuder filter system (Fig. 2) was used to collect gaseous NH_3, HNO_3, HNO_2, and aerosol NH_4 and NO_3