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**Ammonia deposition  
and N trace gas  
emissions**

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# The relationship between ammonia emissions from a poultry farm and soil NO and N<sub>2</sub>O fluxes from a downwind source

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## Abstract

Intensive livestock farms emit large concentrations of  $\text{NH}_3$ , most of which is deposited very close to the source. The presence of trees enhances the deposition. Rates to down wind forests can exceed  $40 \text{ kg N ha}^{-1}$ . The steep gradient in large  $\text{NH}_3$  concentration and deposition at the edge of a downwind forest to background concentrations within a few hundred meters provides an ideal site to study the effect of different rates of N deposition on biological and chemical processes under similar environmental conditions. We have investigated the effect of different rates of  $\text{NH}_3$  deposition (62, 45, 24 and  $5 \text{ kg NH}_3\text{-N ha}^{-1} \text{ y}^{-1}$ ) on the flux of NO and  $\text{N}_2\text{O}$  from soil in a mixed woodland downwind of a large poultry farm (160 000 birds) in Scotland, which has been operating for about 40 years. Measurements were carried out for a 6 month period, with hourly NO flux measurements, daily  $\text{N}_2\text{O}$  fluxes close to the farm and monthly at all sites and monthly cumulative wet and dry N deposition. The increased  $\text{NH}_3$  and  $\text{NH}_4^+$  deposition to the woodland increased emissions of NO and  $\text{N}_2\text{O}$  and soil available  $\text{NH}_4^+$  and  $\text{NO}_3^-$  concentrations. Average NO and  $\text{N}_2\text{O}$  fluxes measured 15, 25 and 45 m downwind of the farm were  $111.2 \pm 41.1$ ,  $123.3 \pm 40.7$ ,  $38.3 \pm 28.8 \mu\text{g NO-N m}^{-2} \text{ h}^{-1}$  and  $9.9 \pm 7.5$ ,  $34.3 \pm 33.3$  and  $21.2 \pm 6.1 \mu\text{g N}_2\text{O-N m}^{-2} \text{ h}^{-1}$ , respectively. At the background site 270 m downwind the  $\text{N}_2\text{O}$  flux was reduced to  $1.75 \pm 2.1 \mu\text{g N}_2\text{O-N m}^{-2} \text{ h}^{-1}$ . NO emissions were significantly influenced by seasonal and daily changes in soil temperature and followed a diurnal pattern with maximum emissions approximately 3 h after noon. For  $\text{N}_2\text{O}$  no consistent diurnal pattern was observed. Changes in soil moisture content had a less clear effect on the NO and  $\text{N}_2\text{O}$  flux. On average the NO emissions expressed as a fraction of the elevated N deposited were 7.1% (at 15 m), 6% (at 25 m) and 2.3% (at 45 m) downwind of the farm, whereas for  $\text{N}_2\text{O}$  the emissions were only 2.8% (at 15 m), 3% (at 25 m) and 3% (at 45 m) downwind. These emission fractions exceed the emission factor of 1% advised by the IPCC for  $\text{N}_2\text{O}$  emissions resulting from atmospheric N deposition.

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## 1. Introduction

The deposition of nitrogen (N) to the soil has increased since the industrial revolution and now ranges from less than  $5 \text{ kg N ha}^{-1} \text{ y}^{-1}$  in pristine environments to over  $80 \text{ kg N ha}^{-1} \text{ y}^{-1}$  in the most polluted locations of Europe (Fowler et al., 2004). In many areas N deposition is dominated by reduced N,  $\text{NH}_3$  (ammonia) and  $\text{NH}_4^+$  (ammonium), which together contribute to 60% of the total annual emission rate in the UK (Fowler et al., 2004). Most of the reduced N is deposited over a much shorter distance than oxidised N, and for islands like the UK the export of  $\text{NH}_3$  to other countries is negligible. The livestock industry is the single largest source of  $\text{NH}_3$  and intensive livestock farms create significant local hotspots of elevated atmospheric  $\text{NH}_3$  concentrations (Theobald et al., 2004). The rate of deposition is dependent on the downwind land use and the surface roughness. Deposition rates to a forest can be 2 to 3 fold larger than to shorter vegetation (Fowler et al., 2004). Fowler et al. (1998) have shown that over 60% of the elevated  $\text{NH}_3$  emitted was deposited to a downwind forest within 50 m, but declined to background concentrations within a few hundred meters. The high rates of N deposited to the forest floor increased the N content of the plant tissues and the soil and also soil emissions of  $\text{N}_2\text{O}$  (nitrous oxide) and  $\text{NO}$  (nitric oxide) (Pitcairn et al., 1998; Skiba et al., 2004). Such high emissions will eventually result in changes in the forest floor plant communities to nitrogen tolerant species (Pitcairn et al., 1998). The steep gradient of  $\text{NH}_3$  deposition rates does provide an ideal opportunity to study the effect of different rates of N deposition on biological and chemical processes under similar climatic conditions. In this paper we have concentrated on the significance of an intensive poultry farm for increased downwind emissions of the atmospheric pollutants  $\text{NO}$  and  $\text{N}_2\text{O}$ .

## 2. Site description and methods

Measurements were made in mixed woodland downwind of a large poultry farm in Scotland, which has been operating for about 40 years, from January to mid July 2004.

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The poultry farm grows broilers in 8 sheds (63 m long), each containing 20 000 birds on a 40-day cycle. The sheds are arranged in parallel pointing from NNW to SSE. The prevailing wind direction is from the SW. The edge of this farm borders onto the woodland located on freely drained brown earth (pH 3.2 in CaCl<sub>2</sub>, 9.5% C and 0.44% N), containing a mixture of pine and birch with undergrowth of grasses in the sunnier parts and brambles, ferns and mosses dominant in the shadier parts.

Four sites were established at increasing distance downwind from the centre of the closest of the poultry sheds. The closest site (A) was established at the edge of the woodland at 15 m directly opposite the centre of the shed. The second site (B) was installed 17 m away from A and 15 m opposite the downwind edge of the poultry shed, and therefore was 25 m downwind of the centre of the farm building. Site C was located 18 m east of site A and 45 m downwind from the centre of the poultry shed. A “background” site (D) was installed 270 m downwind of the farm (NW).

Monthly concentrations of atmospheric NH<sub>3</sub> and NO<sub>2</sub> were monitored using continuous time-integrated sampling with passive diffusion samplers. Triplicate ALPHA samplers for NH<sub>3</sub> and triplicate diffusion tubes for NO<sub>2</sub> were installed at a height of 1.5 m at all sites and were prepared and analysed according to standard protocols developed at CEH (Tang et al., 2001). Throughfall containers (2 per site) containing the biocide thymol collected rainwater falling through the tree canopy over a 0.2 m<sup>2</sup> area at sites A-C. At the background site D 3 rainfall collectors (0.035 m<sup>2</sup>) were installed at a height of 1.5 m. Throughfall and rainfall samples were bulked to provide a monthly sample analysed for NH<sub>4</sub><sup>+</sup> and NO<sub>3</sub><sup>-</sup> concentrations by standard colorimetric methods.

For manual N<sub>2</sub>O measurements by the static chamber approach, two small round polypropylene chambers (31 l) (MacDonald et al., 1997) were installed. Fluxes were measured at roughly monthly intervals, by closing the chambers for 1 h periods. Samples were collected by syringe and stored in Tedlar bags until analysis within 3 days of sample collection, by gas chromatography using an electron capture detector (ECD). A daily sample of the N<sub>2</sub>O flux was obtained from an automatically closing chamber (1 m<sup>2</sup>, 130 l) positioned between site A and B, 20 m downwind of the centre point of the

shed, and is described in detail by Kitzler et al. (2005). Chambers were closed for one-hour periods every midday and samples were stored in glass vials for up to 14 days prior analysis for N<sub>2</sub>O by gas chromatography using an ECD detector. Routine tests showed that over the two-week period concentrations of 1 ppm N<sub>2</sub>O did not deteriorate inside the vials.

NO fluxes were measured by the dynamic chamber approach. At the three closest sites (A-C) 2 square automatically closing dynamic PTFE chambers (18 l) were installed for hourly NO, NO<sub>2</sub> and O<sub>3</sub> flux measurements. The chamber system is described in detail by Pilegaard et al. (1999). Two small fans stirred the air in each chamber. Upon closure ambient air from a single location, and 1 m above the soil surface, was pushed through the chamber at a rate of 11 l min<sup>-1</sup>. At the opposite chamber outlet the combined pump pressure of the NO<sub>x</sub> and O<sub>3</sub> analysers drew air into the analysers at a rate of 2 l min<sup>-1</sup>. One minute average NO, NO<sub>2</sub> and O<sub>3</sub> concentrations were recorded on a 23x Campbell data logger. These data could be viewed and downloaded online via a modem. The analysers, logger and pumps were housed in a waterproof powered shed.

The chambers closed in sequence for 8 min in the order Site A, Site B, a blank chamber fitted with PTFE bottom adjacent to the two chambers at site B and then site C. In the remaining 4 min of every hour ambient air was analysed for NO<sub>x</sub> and O<sub>3</sub>. In order to avoid long residence times of unstable gases in the supply lines (6 mm bore), these were kept to a maximum, but same length of 20 m. This maximum distance between chambers and analysers also determined the distances between the 3 transect sites. Unfortunately the fourth site was too far to be connected to the automated NO<sub>x</sub> flux measurement system and the power supply. Fluxes were calculated from the concentration difference between the chamber and blank chamber, the flow rate of air through the chamber and the surface area of the chamber. The chemical reactions of NO with O<sub>3</sub> inside the chambers were taken into account, as described by Butterbach-Bahl et al. (1998).

Measurements of soil temperatures at 2, 5, 7, 10 cm depth using thermocouples

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and soil moisture by theta probe (Delta T) were made continuously. Fifteen-minute averages were stored on a Campbell 21x data logger. The theta probe voltage measurements were converted to volumetric moisture contents, using conversion factors established for the study soil, rather than using the company's standard calibration factors. Soils were analysed for KCl extractable (1 M)  $\text{NH}_4^+$  and  $\text{NO}_3^-$  concentrations in the surface 10 cm twice during the measurement period.

### 3. Results

The monthly  $\text{NH}_3$  concentrations measured at the three sites close to the farm were on average 20 to 40 times larger than at the background site, 270 m away (Fig. 1a). Largest  $\text{NH}_3$  concentrations were measured at site B, which is further away from the centre of the farm building (25 m downwind of the farm) than site A; but due to its position in relation to the farm building and the prevailing SW wind direction receives the plume from all farm vents, whereas site A only receives the plume from 50% of the farm vents. This difference was reflected in the  $\text{NH}_3$  concentration measurements (Fig. 1a). Average concentrations for the three sites 15, 25 and 45 m downwind were  $34.3 \pm 20.4$ ,  $47.6 \pm 24.9$  and  $21.7 \pm 16.8 \mu\text{g NH}_3 \text{ m}^{-3}$ . Background concentrations at the site 270 m downwind were  $1.15 \pm 0.7 \mu\text{g NH}_3 \text{ m}^{-3}$ .

The  $\text{NO}_2$  concentrations did not differ between the three sites closest to the farm, but they were all slightly larger compared to the background site (Fig. 1b). This could simply reflect the frequent traffic of vehicles to the farm, which did not occur at the more remote background site. The average annual concentrations at sites A–C were  $3.9 \pm 1.4$ ,  $4.3 \pm 1.3$ ,  $4.1 \pm 1.3 \mu\text{g NO}_2 \text{ m}^{-3}$  and at the background site  $3.1 \pm 1.4 \mu\text{g NO}_2 \text{ m}^{-3}$ .

Rates of  $\text{NH}_3$  deposition to the forest floor were calculated using concentration dependent deposition velocities for  $\text{NH}_3$  as described by Fowler et al. (1998), and a deposition velocity of  $1.5 \text{ mm s}^{-1}$  was applied for  $\text{NO}_2$  (Duyzer, pers. comm.). Average  $\text{NH}_3$  deposition rates close to the farm were calculated at 62, 42, 23  $\text{kg NH}_3\text{-N ha}^{-1} \text{ y}^{-1}$  compared to the background deposition rates of 5  $\text{kg NH}_3\text{-N ha}^{-1} \text{ y}^{-1}$  (Table 1).

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Cumulative  $\text{NH}_4^+$  concentrations in throughfall were at least 6 times larger than those in rainwater and followed the same pattern observed for  $\text{NH}_3$ , with largest concentrations measured at site B, 25 m downwind, and smallest at site C, 45 m downwind (Table 1). The ranking order of  $\text{NH}_4^+$  concentrations, site B > site A > site C, was observed in most months. Nitrate concentrations in throughfall were at least 2 times larger than in rainfall, however differences between sites were negligible.

In this forest the dry deposition of  $\text{NH}_3$  was more important than the wet deposition of  $\text{NH}_4^+$ . A two fold difference between  $\text{NH}_3$  deposition and the rate of  $\text{NH}_4^+$  deposition was observed at the sites closest to the farm (A & B). This difference was reduced to a 1.5 fold difference at the site C further away from the farm. The relationship between the  $\text{NH}_4^+$  concentration in the throughfall and dry deposition of  $\text{NH}_3$  was linear and highly correlated, with  $r^2 > 90\%$  for the two sites closest to the farm (A & B).

The increased rate of N deposition to the woodland was reflected in the soil available  $\text{NH}_4^+$  and  $\text{NO}_3^-$  concentrations, measured on one occasion (31 March 2004). The same pattern as observed for the deposition rates, with largest concentrations at site B (25 m), followed by site A (15 m) and then C (45 m) was followed. The soil extractable  $\text{NH}_4^+$  and  $\text{NO}_3^-$  concentrations were  $6.8 \pm 6.0$ ,  $10.3 \pm 4.1$ ,  $3.2 \pm 1.9 \mu\text{g NH}_4^+ \text{-N g}_{\text{dry soil}}^{-1}$  and  $3.0 \pm 1.5$ ,  $9.9 \pm 5.3$ ,  $0.5 \pm 0.4 \mu\text{g NO}_3^- \text{-N g}_{\text{dry soil}}^{-1}$  at site A, B and C with  $n=6, 9, 6$ , respectively.

The increased mineral N concentrations along this  $\text{NH}_3$  deposition gradient provide the substrate for the nitrifying and denitrifying microbes, and consequently have increased the emissions of NO and to a lesser extent  $\text{N}_2\text{O}$  (Figs. 2 and 3). Average NO concentrations for the entire study period for site A, B and C were  $111.2 \pm 41.1$ ,  $123.3 \pm 40.7$ ,  $38.3 \pm 28.8 \mu\text{g NO-N m}^{-2} \text{h}^{-1}$ . The differences between the three sites were statistically significant at  $p < 0.001$ . Daily NO emissions at site A and B were larger than those measured at site C on 93% and 95% of the 190 days for which flux measurements could be calculated, respectively. Fluxes measured at site B were larger than those measured at site A on 69% of the 190 days. The relationship between the monthly average NO flux and monthly cumulative  $\text{NH}_3$  concentration was log linear and



significant ( $p < 0.001$ ) (Fig. 4).

For  $N_2O$  average fluxes for the 8 measurements were  $9.9 \pm 7.5$ ,  $34.3 \pm 33.3$ ,  $21.2 \pm 6.1$  and  $1.8 \pm 3.5 \mu g N_2O-N m^{-2} h^{-1}$  for site A, B, C and the background site D respectively. Standard deviations of the mean were large due to temporal and spatial variability. At site B largest flux rates were measured and at site C occasional negative fluxes of  $N_2O$ , indicating  $N_2O$  uptake, were measured (Fig. 3). None of these differences were statistically significantly. Fluxes at site C were larger than those at site A, possibly caused by the slightly wetter soil conditions at site C. Average soil moisture contents for site C were  $35.1 \pm 6.2 g g_{dry wt}^{-1}$  and at sites A and B  $31.3 \pm 2.3 g g_{dry wt}^{-1}$  and  $31.9 \pm 5.2 g g_{dry wt}^{-1}$  respectively.

Nitric oxide concentrations were significantly influenced by daily and seasonal temperature changes.  $NO$  emissions followed a diurnal pattern with maximum emissions approximately 3 h after noon (Fig. 5). The oscillation frequency was much larger for locations where large  $NO$  fluxes were measured compared to locations where the  $NO$  flux was small. Daily average  $NO$  fluxes, correlated significantly with daily average soil temperatures measured at the soil surface and 2, 5 and 10 cm below the soil surface. The daily average soil temperature ranged between  $-1$  and  $13$  °C at the soil surface and between  $4.3$  and  $11.7$  °C at a soil depth of 10 cm. For  $NO$  the correlations were significant at  $p > 0.001$  at all soil depths. Best linear correlations were observed between  $NO$  flux and the soil surface temperature and a depth of 2 cm depth for plots at site A and B. At site C however best correlations were obtained with soil temperatures at 5 and 10 cm depth. The linear relationships between the inverse absolute soil temperature and the natural logarithm of the  $NO$  flux at site A and B provided  $r^2$  values of 46% and 24% ( $n = 186$ ) and activation energies, calculated from the slope of the relationship, of 59 and 33  $kJ mol^{-1}$ . For site C the  $r^2$  was 39.4% ( $n = 234$ ) and the activation energy was 140  $kJ mol^{-1}$ . For  $N_2O$  the relationship with soil temperature at all depth was not significant and no diurnal pattern was observed.

The soil moisture content for the entire study period varied between 16 and 63% (v/v). A linear relationships between  $NO$  flux and soil moisture content was only ob-

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served at site C where NO emissions decreased with increasing soil moisture content ( $r^2=0.001$ ). For  $N_2O$  fluxes measured by static and auto chambers no linear relationship with soil moisture was observed. However, fluxes  $>27 \mu\text{g } N_2O\text{-N m}^{-2} \text{ h}^{-1}$  were only observed at soil moisture contents above 30% (v/v).

#### 4. Discussion

We have shown that point source emissions of  $NH_3$  significantly increased the rate of  $NH_3$  deposition to the close by woodland. Ammonia concentrations measured inside the woodland downwind of the farm were between 20 and 40 times larger than the background concentrations of  $1.15 \mu\text{g m}^{-3}$  at 270 m downwind. The background concentrations are within the range of concentrations measured and modelled for UK agricultural fields (Dragosits et al., 2002); and the FRAME (Fine Resolution Atmospheric Multi-species Exchange, Singles et al., 1998) model output for the 5 km grid square in which the study farm is situated, estimated a grid average  $NH_3$  concentration of  $1.32 \mu\text{g m}^{-3}$ . Similar elevated  $NH_3$  concentrations and relatively fast decay rates over a short distance ( $<300$  m) have been observed at several woodlands downwind of intensive poultry and pig farms (e.g. Theobald et al., 2004; Spangenberg and Kölling, 2004) and also downwind of an artificial  $NH_3$  release source over an ombrotrophic bog (Leith et al., 2004). Thus a shelterbelt can be ideal in not only screening an unsightly animal farm from the public, but also by creating a biological filter, which contains the pollution to a small local area. The side effect, however, is that the enhanced N deposition increases the emission of the atmospheric pollutants  $N_2O$  and NO and increases the risk of loss or change in biodiversity. Pitcairn et al. (1998) have reported a prevalence of N loving species and lack of N sensitive species close to the poultry farm discussed in this paper. Due to the close distance to this very large  $NH_3$  point source, the total N deposition is dominated by dry deposition of  $NH_3$  rather than wet deposition of  $NH_4$  and  $NO_3$ , which was the case for the transect of European forests investigated

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under NOFRETETE (Pilegaard et al., 2005<sup>1</sup>). Both studies have shown strong relationships between N deposition and NO emission. A linear relationship between NO flux and wet deposition of N was observed for the coniferous forests of the European transect studied in the NOFRETETE project (Pilegaard et al., 2005<sup>1</sup>). For this forest downwind of the poultry farm, where environmental variations are minimal in comparison to the European transect, a log linear relationship was demonstrated (Fig. 4). In addition to nitrogen the most important variables that influenced NO emission rates were soil moisture and soil temperature. The literature supports the observations, that NO increased linearly with increased soil temperature, but decreased with increasing soil moisture content (Kitzler et al., 2005; van Dijk and Duyzer, 1999; Skiba et al., 1997).

For both studies, the European transect studied in the NOFRETETE project (Pilegaard et al., 2005<sup>1</sup>) and the forest downwind of the poultry farm, relationships between N deposition rate and N<sub>2</sub>O emission were very weak. For the poultry farm also relationships between N<sub>2</sub>O flux and soil moisture and soil temperature changes were much weaker than for NO. Possible reasons are the data set for N<sub>2</sub>O in this study is much smaller than for NO (monthly rather than hourly data), but perhaps more importantly, the environmental variables, particularly the redox potential of the soil, most commonly measured by the surrogates soil moisture or water filled pore space, exert a stronger control on N<sub>2</sub>O than NO.

Overall the NO and N<sub>2</sub>O emissions downwind of this poultry farm were larger than the maximum annual emissions calculated for the European transect (Pilegaard et al., 2005<sup>1</sup>). Downwind of the poultry farm maximum emissions for the study period were 123  $\mu\text{g NO-N m}^{-2} \text{h}^{-1}$  and 34.3  $\mu\text{g N}_2\text{O-N m}^{-2} \text{h}^{-1}$  compared to 75 and 81  $\mu\text{g NO-}$

<sup>1</sup>Pilegaard, K., Skiba, U., Ambus, P., Beier, C., Bruggemann, N., Butterbach-Bahl, K., Dick, J., Dorsey, J., Duyzer, J., Gallagher, M., Gasche, R., Horvath, L., Kitzler, B., Leip, A., Pihlatie, M. K., Rosenkranz, P., Seufert, G., Vesala, T., Westrate, H., and Zechmeister-Boltenstern, S.: Nitrogen load and forest type determine the soil emission of nitrogen oxides (NO and N<sub>2</sub>O), Biogeosciences Discuss., in preparation, 2005.

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$\text{N m}^{-2} \text{h}^{-1}$  in the Dutch and south German coniferous forests and  $20 \mu\text{g N}_2\text{O-N m}^{-2} \text{h}^{-1}$  in the Hungarian and Italian forests.

On average the NO emissions expressed as a fraction of the elevated N deposited were 7.1% (at 15 m), 6% (at 25 m) and 2.3% (at 45 m) downwind of the farm, whereas for  $\text{N}_2\text{O}$  the emissions were only 2.8% (at 15 m), 3% (at 25 m) and 3% (at 45 m) downwind. These emission fractions greatly exceed the emission factor of 1% advised by the IPCC for  $\text{N}_2\text{O}$  emissions resulting from atmospheric N deposition (Houghton et al., 2001). Even at the background site, 270 m downwind of the farm the  $\text{N}_2\text{O}$  emissions accounted for 1.6% of the N deposition.

## 5. Conclusions

This study has shown that increased atmospheric nitrogen deposition rates increased the emissions of NO and  $\text{N}_2\text{O}$ . For  $\text{N}_2\text{O}$  the rate of increase was larger than predicted by the IPCC (Houghton et al., 2001).

Although the emission rates of atmospheric pollutants downwind of intensive  $\text{NH}_3$  emitting livestock farms were large, the contribution to the total national NO and  $\text{N}_2\text{O}$  emissions are negligible. If we assume the conditions and emission factors observed in this study are true for the entire British poultry flock (360 million), which emits  $28 \text{ kt NH}_3 \text{ y}^{-1}$  (calculated from standard  $\text{NH}_3$  emission factors for poultry manure); then intensive poultry farming will contribute an additional  $36 \text{ t NO-N y}^{-1}$  and  $10 \text{ t N}_2\text{O-N y}^{-1}$ . This is only a small percentage of the total NO ( $7 \text{ kt NO-N y}^{-1}$ ) and  $\text{N}_2\text{O}$  ( $56 \text{ kt N}_2\text{O-N y}^{-1}$ ) emitted from British soils (Skiba et al., 2001).

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- Butterbach-Bahl, K., Gasche, R., Huber, C., Kreutzer, K., and Papen, H.: Impact of N-input by wet deposition on N-trace gas fluxes and CH<sub>4</sub>-oxidation in spruce forest ecosystems of the temperate zone in Europe, *Atmos. Environ.*, 32, 3, 559–564, 1998.
- 5 Dragosits, U., Theobald, M. R., Place, C. J., Lord, E., Webb, J., Hill, J., ApSimon, H. M., and Sutton, M. A.: Ammonia emission, deposition and impact assessment at the field scale: a case study of sub-grid spatial variability, *Environ. Pollution*, 117, 1147–158, 2002.
- Fowler, D., O'Donoghue, M., Muller, J. B. A., Smith, R. I., Dragosits, U., Skiba, U., Sutton, M., and Brimblecombe, P.: A chronology of nitrogen deposition in the UK between 1900 and  
10 2000, *Water air and soil pollution: Focus*, 4, 9–23, 2004.
- Fowler, D., Skiba, U., Nemitz, E., Choubedar, F., Branford, D., Donovan, R., and Rowland, P.: Measuring aerosols and heavy metal deposition on urban woodland and grass using inventories of <sup>210</sup>Pb and metal concentrations in soil, *Water, Air and Soil Pollution: Focus*, 4, 483–499, 2004.
- 15 Fowler, D., Pitcairn, C. E. R., Sutton, M. A., Flechard, C., Loubet, B., Coyle, M., and Munro, R. C.: The mass budget of atmospheric ammonia in woodland within 1 km of livestock buildings, *Environ. Pollution* 102, 343–348, 1998.
- Houghton, J. T., Meira Filho, L. G., Lim, B., Treanton, K., Mamaty, I., and Bonduki, Y.: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, Reference Manual Vol3, edited by: Griggs, D. J. and Callender, B. A., IPCC/OECD/IEAUK Meteorological Office, Bracknell, 2001.
- 20 Kitzler, B., Zechmeister-Boltenstern, S., Holtermann, C., Skiba, U., and Butterbach-Bahl, K.: Nitrogen oxides emission from two beech forests subjected to different nitrogen loads, *Biogeosciences Discuss.*, in press, 2005.
- 25 Leith, I. D., Sheppard, L. J., Fowler, D., Cape, J. N., Jones, M., Crossley, A., Hargreaves, K. J., Tang, S. Y., Theobald, M., and Sutton, M. A.: Quantifying dry NH<sub>3</sub> deposition to an ombrotrophic bog from an automated NH<sub>3</sub> field release system, *Water Air and Soil Pollution: Focus*, 4, 207–218, 2004.
- 30 MacDonald, J. A., Skiba, U. M., Sheppard, L. J., Ball, B., Roberts, J. D., Smith, K. A., and Fowler, D.: The effect of nitrogen deposition and seasonal variability on methane oxidation and nitrous oxide emission rates in an upland spruce plantation and moorland, *Atmos. Environ.*, 31, 3693–3706, 1997.

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- Pilegaard, K., Hummelshøj, P., and Jensen, N. O.: Nitric oxide emission from a Norway spruce forest floor, *J. Geophys. Res.*, 104, 3433–3445, 1999.
- Pitcairn, C. E. R., Leith, I. D., Sheppard, L. J., Sutton, M. A., Fowler, D., Munro, R. C., Tang, S., and Wilson, D.: The relationship between nitrogen deposition, species composition and foliar nitrogen concentrations in woodland flora, *Environ. Pollution*, 102, 41–48, 1998.
- Singles, R., Sutton, M. A., and Weston, K. J.: A multi-layer model to describe the atmospheric transport and deposition of ammonia in Great Britain, *Atmos. Environ.*, 32, 393–399, 1998.
- Skiba, U., Fowler, D., and Smith, K. A.: Nitric oxide emissions from agricultural soils in temperate and tropical climates: sources, control and mitigation options, *Nutrient Cycling in Agroecosys.*, 48, 75–90, 1997.
- Skiba, U., Sheppard, L., Pitcairn, C. E. R., Leith, I., Crossley, A., van Dijk, S., Kennedy, V. H., and Fowler, D.: Soil nitrous oxide and nitric oxide emissions as indicators of elevated atmospheric N deposition rates in seminatural ecosystems, *Environ. Pollution*, 102, 457–461, 1998.
- Skiba, U., Sozanska, M., Metcalfe, S., and Fowler, D.: Spatially disaggregated inventories of soil NO and N<sub>2</sub>O emissions for Great Britain. *Water Air and Soil Pollution*, 1, 109–118, 2001.
- Spangenberg, A. and Kölling, C.: Nitrogen deposition and nitrate leaching at forest edges exposed to high ammonia emissions in southern Bavaria, *Water, air and soil pollution*, 152, 233–255, 2004.
- Stohl, A., Williams, E., Wotawa, G., and Kromp-Kolb, H.: A European inventory of soil nitric oxide emissions and the effect of these emissions on the photochemical formation of ozone, *Atmos. Environ.* 30, 3741–3755, 1996.
- Tang, Y. S., Cape, J. N., and Sutton, M. A.: Development and types of passive samplers for monitoring atmospheric NO<sub>2</sub> and NH<sub>3</sub> concentrations, *The Scientific World*, 1, 513–529, 2001.
- Theobald, M., Dragosits, U., Place, C. J., Smith, J. U., Sozanska, M., Brown, L., Scholefield, D., Del Prado, A., Webb, J., Whitehead, P., Angus, A., Hodge, I. D., Fowler, D., and Sutton, M. A.: Modelling nitrogen fluxes at the landscape scale, *Water, Air and Soil Pollution: Focus*, 4, 135–142, 2004.
- van Dijk, S. M. and Duyzer, J. H.: Nitric oxide emissions from forest soils, *J. Geophys. Res.*, 104, 15 955–15 961, 1999.

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**Table 1.** Dry and wet N deposition to a mixed forest downwind of an NH<sub>3</sub> emitting poultry farm. Average of monthly cumulative samples (January–June 2004).

Distance from farm m	NH <sub>3</sub> -N kg N ha <sup>-1</sup> y <sup>-1</sup>		NO <sub>2</sub> -N kg N ha <sup>-1</sup> y <sup>-1</sup>		NH <sub>4</sub> -N kg N ha <sup>-1</sup> y <sup>-1</sup>		NO <sub>3</sub> -N kg N ha <sup>-1</sup> y <sup>-1</sup>	
	mean	<i>stdev</i>	mean	<i>stdev</i>	mean	<i>stdev</i>	mean	<i>stdev</i>
15	42.62	24.59	0.46	0.06	22.10	11.82	2.96	1.57
25	62.13	32.29	0.54	0.06	27.29	19.65	3.23	2.12
45	23.43	12.53	0.48	0.05	15.05	7.63	4.41	2.36
270	5.26	4.51	0.35	0.08	2.40*	1.36	1.43*	1.01

\* concentrations in rainwater

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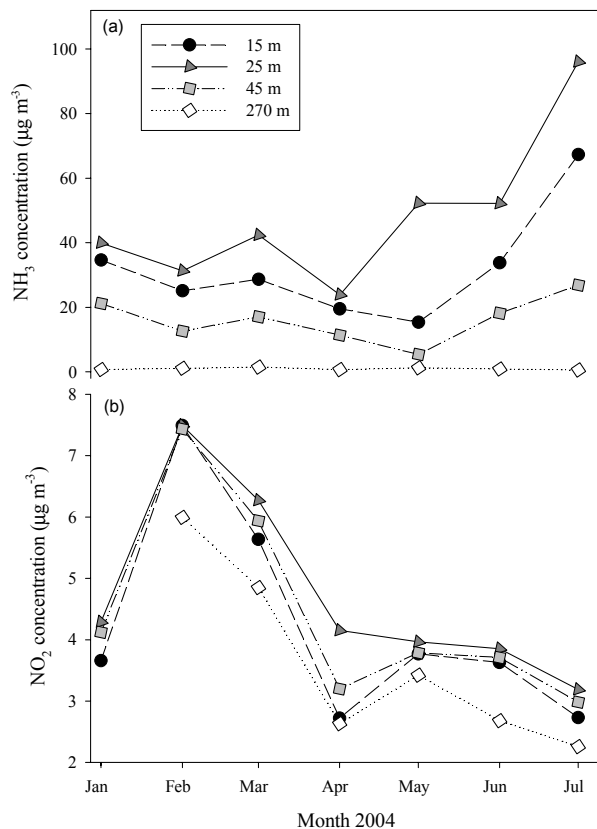
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**Fig. 1.** Concentrations of dry deposited NH<sub>3</sub> (a) and NO<sub>2</sub> (b) downwind of the poultry farm.

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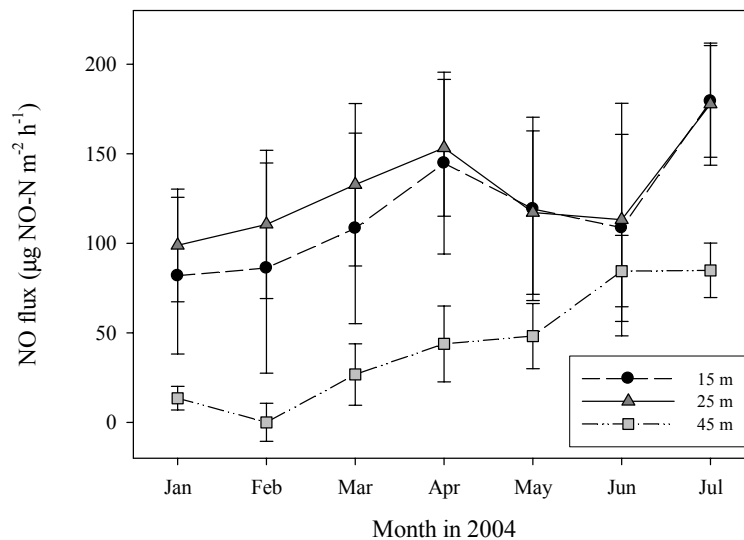
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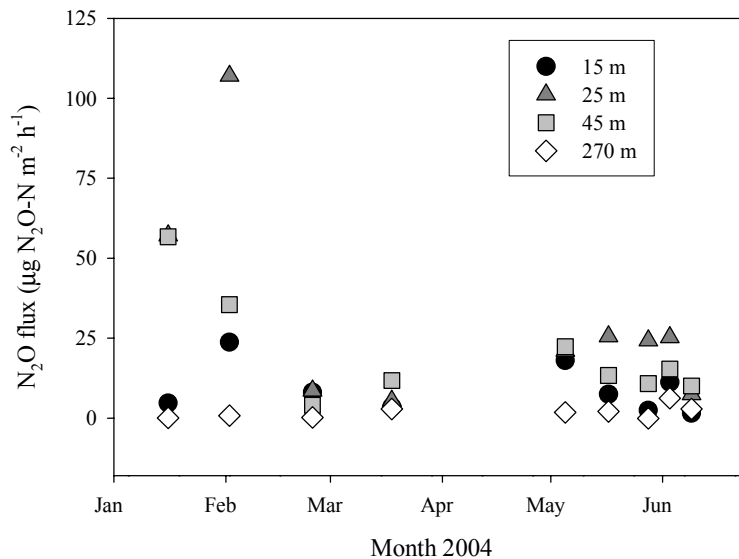
**Fig. 2.** Average monthly NO fluxes from hourly data of two automatically closing flow through chambers per site. The bars show standard errors of the temporal and spatial variability.

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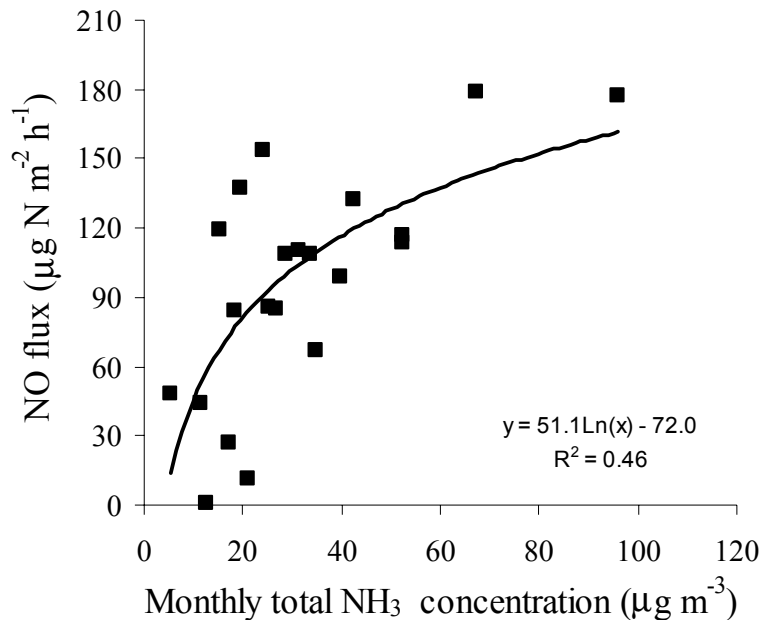
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**Fig. 3.** Nitrous oxide emission downwind of the poultry farm; average fluxes from 2 manual static chambers per site.

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**Fig. 4.** The relationship between monthly average NO flux and NH<sub>3</sub> concentrations at the three transect sites downwind of the poultry farm.

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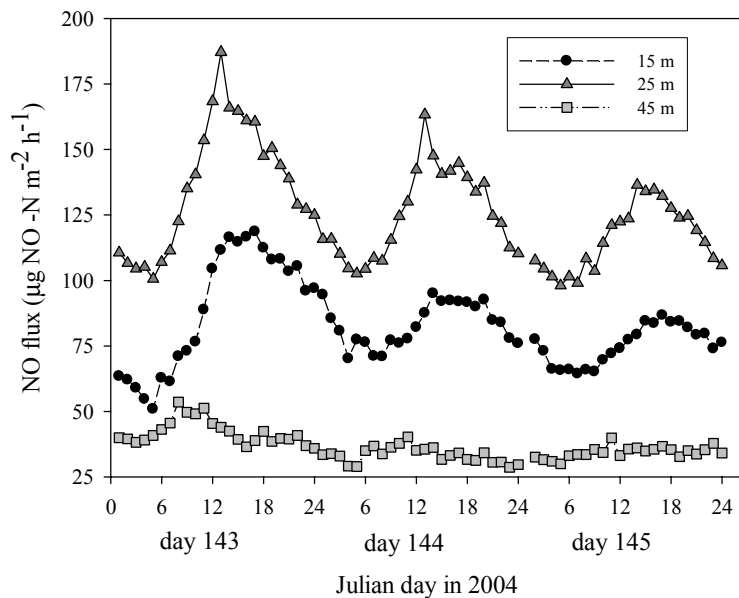
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**Fig. 5.** The diurnal variations in NO flux from 2 chamber each at 15, 25 and 45 m downwind of the poultry farm in May 2004. Data are averages from two chambers.

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