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Validation of model calculation of ammonia deposition in the neighbourhood of a poultry farm using measured NH_3 concentrations and N deposition

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ABSTRACT

Substantial emission of ammonia (NH_3) from animal houses and the related high local deposition of NH_3-N are a threat to semi-natural nitrogen-deficient ecosystems situated near the NH_3 source. In Denmark, there are regulations limiting the level of NH_3 emission from livestock houses near N-deficient ecosystems that are likely to change due to nitrogen (N) enrichment caused by NH_3 deposition. The models used for assessing NH_3 emission from livestock production, therefore, need to be precise, as the regulation will affect both the nature of the ecosystem and the economy of the farmer. Therefore a study was carried out with the objective of validating the Danish model used to monitor NH_3 transport, dispersion and deposition from and in the neighbourhood of a chicken farm. In the study we measured NH_3 emission with standard flux measuring methods, NH_3 concentrations at increasing distances from the chicken houses using passive diffusion samplers and deposition using ^{15}N-enriched biomonitors and field plot studies. The dispersion and deposition of NH_3 were modelled using the Danish OML-DEP model. It was also shown that model calculations clearly reflect the measured NH_3 concentration and N deposition. Deposition of N measured by biomonitors clearly reflected the variation in NH_3 concentrations and showed that deposition was not significantly different from zero ($P < 0.05$) at distances greater than 150–200 m from these chicken houses. Calculations confirmed this, as calculated N deposition 320 m away from the chicken farm was only marginally affected by the NH_3 emission from the farm. There was agreement between calculated and measured deposition showing that the model gives true estimates of the deposition in the neighbourhood of a livestock house emitting NH_3.

1. Introduction

Livestock production is the most important source of ammonia (NH_3) in the atmosphere (Bouwman et al., 1997; Hutchings et al., 2001) and, in Europe, manure in animal houses may account for more than one-third of the NH_3 emitted from livestock manure (ECETOC, 1994; Hutchings et al., 2001). Close to the source, NH_3 is deposited on vegetation, soil and water (Asman and van Jaarsveld, 1991). This deposition may cause acidification and eutrophication of natural ecosystems (Fangmeier et al., 1994).

In addition, the NH_3 may be transported over long distances as ammonium (NH_4^+), mainly in the form of particles. The long-distance transport of ammonium (NH_4^+) has been regulated by the EU and the UN by the inclusion of this emission type in the Gothenburg Protocol on long-range transboundary air pollution (United Nations, 2004) and the EU National Emissions Ceilings Directive—NECD (EEA, 1999) regulations.

The risk of high local deposition of NH_3 from livestock operations is regulated by national legislation. In Denmark the regulation is based on a zoning principle. Natural or semi-natural ecosystems designated as being worthy of protection are classified according to their critical load capacity (Fisher et al., 2007), i.e. their capacity to assimilate nitrogen (N) without concurrent changes in the flora and fauna. Up to 300 m from N-vulnerable ecosystems, livestock producers are not permitted to increase their NH_3 emissions when changing their production system. It is expected that, with time, few—if any—livestock producers will be situated in this zone (Anonymous, 2006). At distances between 300 and 1000 m from these ecosystems, farmers who wish to change or increase their livestock production have to comply with strict rules and emission thresholds. Obviously there is a need for precise and accurate models for assessing how much the livestock production will affect N deposition in nearby natural ecosystems.

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Models for assessing the dispersion of NH_3 from animal housing have been tested on data from measurements of dispersion of NH_3 from a synthetic source (Asman et al., 1989), but few studies have examined and tested the models by calculating the deposition of NH_3 near the animal houses of actual livestock production farms or cattle feedlots (Hao et al., 2006). In the 1980s and 1990s, the deposition of NH_3 near a dairy farm was examined using biomonitors (Sommer, 1988; Sommer and Jensen, 1991), showing that this method can be used to provide information on local NH_3 deposition. However, no measurements of emissions from animal houses and no dispersion studies were carried out, and therefore these measurements can not be used to verify recently developed models for assessing local deposition of NH_3.

The objective of the current study was to provide data needed to validate the Danish OML-DEP model that is used to assess transport, dispersion and deposition of N in the neighbourhood of livestock farms. Further, the study provided measurement of total N deposition and NH_3 gradients near a chicken farm as affected by the emission of NH_3 from the chicken houses, which was also measured.

2. Materials and methods

The NH_3 deposition in the neighbourhood of the chicken house was measured using plant biomonitors enriched with ^{15}N placed at different distances and directions from the farm (Fig. 1). The deposition measurements were carried out from 1 September to 25 October 2005 (i.e. for 54 days). Passive diffusion samplers were used to provide long-term mean values (weeks) of the NH_3 concentration in different directions and distances from the farm in the period (Fig. 1). The NH_3 concentration was measured at three periods in intervals of 2–3 weeks in the period from 5 September until 17 October 2005. Meteorological data were combined with the estimates of emission from the animal houses to assess the local NH_3 concentration and deposition of N. It was decided to carry out the deposition measurements within a 300 m zone for the purpose of getting a significant response when measuring NH_3 concentration and deposition gradients. To determine the crop response to NH_3 deposition, a winter wheat fertilizer response trial was established at distances 60–200 m from the chicken house (Fig. 1). The winter wheat was drilled in the soil in September 2004 and harvested in July 2005.

2.1. Ammonia emission

The dispersion and deposition of NH_3 was examined around two chicken houses; 14, 400 chickens were transferred to the house 1 on 30 June 2005, and 12, 700 chickens were transferred to the house 2 on 4 July. The chicken houses were emptied on 3–5 November 2005. The initial weight of the chickens was approx. 45 g and their final weight was approx. 1500 g.

Ammonia emission from the chicken houses was estimated by measuring the air exchange rate through the animal house and the NH_3 concentrations to and from the animal house. The air exchange rate was measured by use of a calibrated measuring wing (Fancom AT(M) unit 80) and the NH_3 concentration in air to and from the farm was measured using an electrochemical sensor (Dräger Polytron 1). The concentrations were measured at every second outlet and the intermediate concentrations were interpolated. The amount of emission (E_x mg NH_3-N s^{-1}) was calculated using the following equation:

$$E_x = V(C_{x,\mathrm{out}} - C_{x,\mathrm{in}}) \qquad (1)$$

where $C_{x,\mathrm{out}}$ and $C_{x,\mathrm{in}}$ are the concentrations of NH_3 (mg N m^{-3}) in air collected in the ventilation outlet and in incoming air, respectively, and V is the air exchange rate ($m^3\ s^{-1}$).

2.2. Biomonitors

Exchange of atmospheric NH_3 was estimated by measuring the dilution of ^{15}N in ryegrass (*Lolium multiflorum* Lam.) grown in pots standing on the soil. The pots had a surface area of 0.0577 m^2 (volume 10 l) and contained 13.5 kg of N-free sand. On the sand surface of each pot 0.6 g seed was spread evenly and covered with a 1 cm layer of sand. Initially the pots were watered with N-free nutrient solution (Sommer, 1988); 10 and 25 days after sowing, 0.26 g N as KNO_3 with 2.786% ^{15}N excess was supplied to each pot with the nutrient solution. Until placement in the field, N-free nutrient solution was supplied as required. Surplus rain water draining through the sand was collected and recycled automatically.

The pots were placed in a glasshouse at sowing on 1 August 2005, and on 1 September the pots with plants were placed in groups of three replicates in the field at 15–320 m distance from the farm buildings in south-west, north-west, north-east and south-east directions (Fig. 1). The biomonitors were irrigated according to demand; i.e. they were supplied with demineralized water on 6 and 16 September. The plants were harvested on 25 October after having been exposed in the field for 54 days. The roots were recovered by gently washing the sand from the roots. The harvested plant material—tops (above-ground leaves and stems) and roots

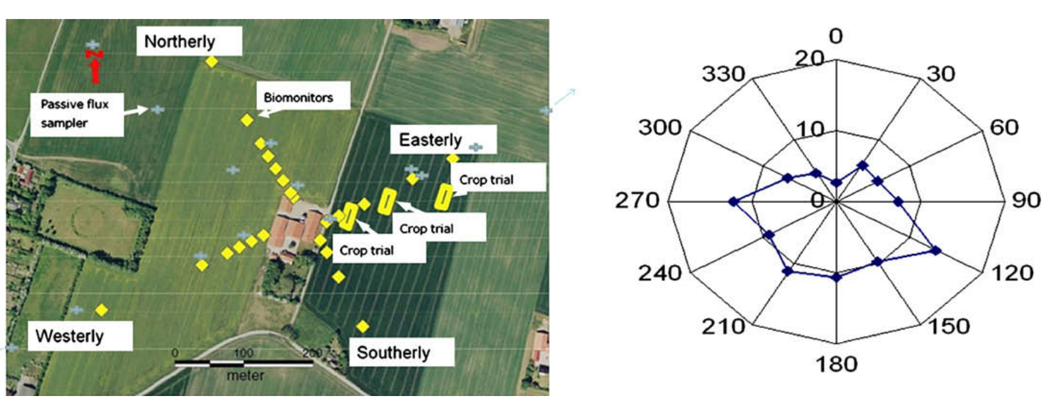

Fig. 1. (Left) Aerial photograph of the poultry farm showing the position of the ryegrass biomonitors (diamonds) located at increasing distances north-west (Northerly), north-east (Easterly), south-east (Southerly) and south-west (Westerly) of the chicken farm, the positions of the three nitrogen fertilizer trials (rectangles) and of the passive flux samplers for measuring NH_3 concentrations (blue cross). The two outermost positions of the passive denuders, which are marked with an arrow, were positioned at the following distances from the farm: (515 m west and 214 m south) and (539 m north and 215 m east). (Right) Wind rosette showing the prevailing wind directions during the experimental period.