Ammonia

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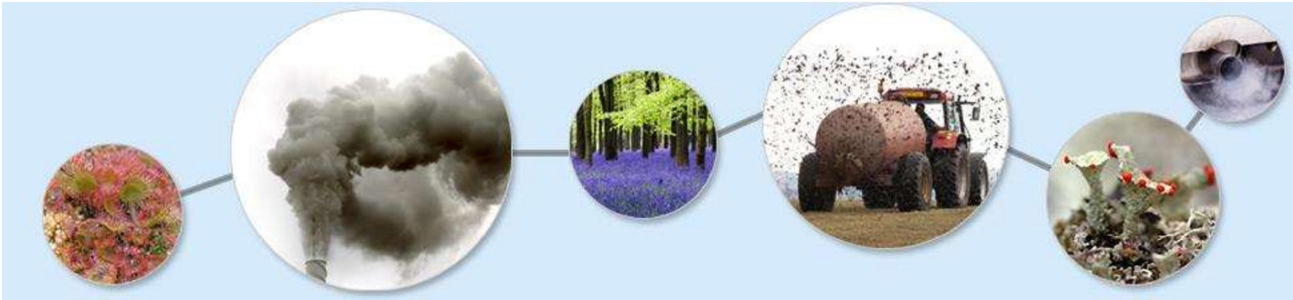

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Ammonia

What is it?

Ammonia (NH_3) is a highly reactive and soluble alkaline gas. It originates from both natural and anthropogenic sources, with the main source being agriculture, e.g. manures, slurries and fertiliser application.

Excess nitrogen can cause eutrophication and acidification effects on semi-natural ecosystems, which in turn can lead to species composition changes and other deleterious effects (Bobbink et al., 2010; Krupa, 2003; Pitcairn et al., 1998; Sheppard et al., 2008; Van den Berg et al., 2008; Wiedermann et al., 2009)

Ammonia comes from the breakdown and volatilisation of urea. Emissions and deposition vary spatially, with "emission hot-spots" associated with high-density intensive farming practices. Other agriculture-related emissions of ammonia include biomass burning or fertiliser manufacture. Ammonia is also emitted from a range of non-agricultural sources, such as catalytic converters in petrol cars, landfill sites, sewage works, composting of organic materials, combustion, industry and wild mammals and birds (Sutton et al. 2000, Wilson et al. 2004).

Emissions

At the turn of the 21st century, total ammonia emissions in the UK were estimated to be 283 kt N yr^{-1} (Sutton et al. 2000) with 228 kt coming from agricultural sources (Pain et al. 1998). In 2010 the agricultural sector was responsible for 89% of UK NH3 emissions (CEIP, 2010; Defra, 2011). National NH_3 emissions in the UK are mapped at a 5 km grid resolution, using the AENEID model

(Dragosits et al. 1998) for agricultural sources, and at a 1 km or 5 km grid resolution for non-agricultural sources and are freely available from the National Atmospheric Emission Inventory (http://naei.defra.gov.uk/).

Emissions trends have mostly been downward since peak in late 1980s and early 1990s but have now flattened. As the climate warms, volatilisation of ammonia emissions will lead to a further rise in ammonia concentrations.

High emission areas with intensive dairy farming can be distinguished from low emission areas with extensive sheep and beef farming or “hot-spot” patterns associated with intensive pig and poultry farming. Emissions from agricultural sources vary temporally with agricultural practice. Seasonal variation is also associated with climate; volatilisation being highest when it is warmer. Some non-agricultural emission sources (e.g. seabird colonies) contribute only small amounts to the overall NH_3 emissions in the UK but, due to their location, are often the dominant emission source in remote and otherwise “clean” areas. Larger seabird colonies have been shown to emit similar amounts of NH_3 to large intensive poultry farms (Sutton et al. 2000, Wilson et al. 2004).

Atmospheric Interactions

Atmospheric ammonia has impacts on both local and international (transboundary) scales. In the atmosphere ammonia reacts with acid pollutants such as the products of SO_2 and NO_X emissions to produce fine ammonium (NH_4^+) containing aerosol. While the lifetime of NH_3 is relatively short (<10-100 km), NH_4^+ may be transferred much longer distances (100->1000 km) (Asman et al. 1998, Fowler et al. 1998). Hence NH_3 emissions contribute to international transboundary air pollutant issues addressed by the UNECE Convention on Long Range Transboundary Pollution.

In addition to the transboundary effects, NH_3 has substantial impacts at a local level: emissions occur at ground level in the rural environment and NH_3 is rapidly deposited (see Nitrogen deposition (http://www.apis.ac.uk/overview/pollutants/overview_N_deposition.htm)). As a result some of the most acute problems of NH_3 deposition are for small relict nature reserves located in intensive agricultural landscapes (Sutton et al. 1998).

Ammonia can be volatilised, emitted into the atmosphere when the surface concentration exceeds that of the surrounding air. Losses of NH_3 by volatilisation from the application of nitrogen (N) fertilisers range from negligible amounts to >50% of the applied fertiliser N, depending on fertiliser/manure type (e.g. urea higher volatilization rates than ammonium nitrate), application practice (e.g. injection, surface application) and environmental conditions (Peoples et al. 1995, Freney 2005). Solubility and dissolution processes primarily drive the magnitude of NH_3 emissions, higher in warm drying conditions and smaller in cool wet conditions.

Concentrations and deposition

Ammonia concentrations are monitored across the UK (UK pollutant deposition (http://pollutantdeposition.defra.gov.uk/)), and show large spatial variability, reflecting a combination of the large number of ground level sources, primarily related to livestock farming, and the very reactive nature of gaseous NH3. Concentrations of NH3 range from 10 µg m-3 in areas of intensive livestock production, especially dairy and beef production, to 0.1 µg m-3 in the Scottish Highlands, especially in the north-west of Scotland and in the Hebrides (RoTAP, 2012).

These concentrations can be used to estimate deposition although deposition varies with ecosystem type and meteorology. Due to the varying affinity and compensation points of ammonia for different habitats, expressed in differences in mean deposition velocities, the rates of ammonia deposition vary greatly between habitat types.

Maps of concentrations and depositions across the UK are mapped using the FRAME model and calibrated using the measured NH_3 values at monitoring stations. This means that maps of NH_3 dry deposition need to be interpreted with care, noting whether they refer to inputs to specific habitat types (e.g. woodland, shrublands and croplands) or net dry deposition averaged over entire grid squares. For the purpose of assessing critical loads exceedance, deposition values for the relevant habitats need to be used, rather than grid averages.

Areas at risk from ammonia/nitrogen impacts include those close to point sources and areas within intensive agricultural regions which see elevated ammonia concentrations.

Effects

Effects of ammonia have been established from transect studies downwind of significant NH_3 sources (van Herk 1999; Pitcairn et al. 1995, 1998; Wolseley et al. 2006) and a field release (Sheppard et al 2011). Ammonia can be taken up through the leaves via stomata, increasing the potential for nutrient N uptake. The consequences of foliar uptake and processing of an alkaline gas for cellular functions, appear to drive the deleterious effects of NH_3 on terrestrial plants. Alkalinity is also thought to be a key driver for NH_3 effects on epiphytic lichens (van Herk 2001). Atmospheric NH_3 also impacts as NH_4^+, when the NH_3 deposits to plant surfaces, dissolves and is washed into the soil where it can increase soil acidity and interfere with base cation uptake (Pearson and Stewart 1993, Fangmeier et al. 1994, Krupa 2003). Effects represent the combined effects of uptake through shoots as NH_3/NH_4^+ and roots as NH_4^+.

Negative effects on vegetation occur via direct toxicity, when uptake exceeds detoxification capacity and, via N accumulation, which increases the likelihood of detrimental interactions with other abiotic and biotic stressors. Ammonia can also enrich a system with nitrogen putting under-storey species at risk as they become shaded by the expansion of nitrophiles (N loving plants) that use the additional N to increase productivity and expand the over-storey. Nitrogen enrichment affects competition for resources, favouring fast growing, tall species with rapid N assimilation rates. Mosses and lichens are most at risk, they have limited detoxification capacity relative to their uptake potential and a large surface area relative to mass (Pearson and Stewart 1993).

Many lichen species are sensitive to even small increases in NH_3 concentrations above c. 1µg m^{-3} (Wolseley et al. 2006). Current evidence suggests that the absence of acidophytic lichens (lichens loving acid conditions) from twigs and trunks of acid-barked trees, growing in NH_3 rich environments, is due to NH_3 neutralizing the bark pH (van Herk 2001). Sheppard et al. (2004)

found that monthly NH_3 concentrations > 20 µg m^{-3} decimated *Cladonia portentosa* populations in less than one year and that after three years the concentration had fallen to < 3 µg m^{-3}. Wet deposited NH_4^+ caused only restricted damage.

In mosses, NH_3 exposure can increase both the N and amino acid content of ectohydric pleurocarpous mosses. Elevations in N and amino acid content have been proposed as a well coupled indicator of NH_3-N deposition (Pitcairn et al. 2006). Moss species differ with respect to their N uptake, and presumably their tolerance (Pitcairn et al. 2006). Some *Sphagnum* (bog mosses) appear to be very sensitive, especially those that lack the red-orange pigments, carotenoids, that protect against oxidative stress (Sheppard et al 2011). Overall dry deposited ammonia-N drives species composition change and reduces species cover and diversity, much faster than the same unit of N in wet deposition (Sheppard et al 2011).

Attributing both specific effects in the field and indicators can be challenging because ammonia is a form of nitrogen which is an essential plant growth nutrient. In addition, some of the effects are difficult to separate from those caused by management, or lack of shading of the under-storey.

A summary of effects on vegetation are:

- Eutrophication leading to changes in species assemblages; increase in N loving species (e.g. grasses) and species that can up regulate their carbon assimilation at the expense of species that are conservative in their N use.
- Shift in dominance from mosses, lichens and ericoids (heath species) towards grasses like *Deschampsia flexuosa, Molinia caerulea* and ruderal species, e.g. *Chamerion angustifolium, Rumex acetosella, Rubus idaeus.*
- Increased risk of frost damage in spring (van der Eerden et al 1991)
- Increased winter desiccation levels in *Calluna* and summer drought stress
- Increase in N loving epiphytes, e.g. *Xanthoria parietina,* at the expense of epiphytes that prefer acid bark.
- Increased incidence of pest and pathogen attack, e.g. heather beetle outbreaks.
- Direct damage and death of sensitive species, e.g. lichens and mosses, *Sphagnum, Pleurozium schreberi.*
- Reduced root growth and mycorrhizal infection leading to reduced nutrient uptake, sensitivity to drought and nutrient imbalance with respect to N that is taken up via the foliage (Perez Soba 1995 for Scots pine).
- Increase in soil pH follows acidification
- Ammonia excess will lead to increases in nitrification and denitrification, contributing to greenhouse gas emissions.

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Environment Agency (http://www.environment-agency.gov.uk/)

NIEA Northern Ireland Environment Agency www.ni-environment.gov.uk (http://www.doeni.gov.uk/niea/index.htm)

Scottish Natural Heritage All of nature for all of Scotland (http://www.snh.gov.uk/)

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NATURAL ENGLAND (http://www.naturalengland.org.uk/)

Cyfoeth Naturiol Cymru Natural Resources Wales (http://www.ccw.gov.uk)

SEPA Scottish Environment Protection Agency (http://www.sepa.org.uk/)

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