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Risk of damage to crops in the direct neighbourhood of ammonia sources

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Abstract

In the Netherlands ammonia is emitted from several thousand sources (animal buildings, manured pastures, slurry storage facilities, etc.). Obviously, the ammonia concentrations are higher close to the source, but at this short distance vegetation has no special value in terms of nature conservation, as it mostly consists of ammonia-resistant agricultural crops. However, three crop categories include relatively sensitive species (fruity culture, glasshouse crops and arboriculture). This paper presents an estimation of the risk of ammonia damage to sensitive crops as related to the distance to the source, based on the mean and variation in emission, dispersion, regional background concentration, landscape characteristics and plant sensitivity. Some attention is paid to damage of natural vegetation and to risk-reducing measures (elevation of emission point, wind fence around the source). The goal is to provide information for regional and local officials and farmers who are dealing with risk evaluation, claims for damages, and environmental policy matters like stable reallocations etc.

Keywords: Ammonia; plant damage; atmospheric dispersion; risk evaluation

Introduction

Ammonia (NH_3) is emitted from several types of source. In 1995 the annual emission of the Netherlands was 181 10^6 kg NH_3 of which 87% was from animal husbandry, divided over animal building (54%), slurry spreading (37%) and pasturing (8%). The remaining part was from the use of artificial fertiliser, industry and household (Heij and Erisman, 1997). With a nation-wide average of 37 kg N ha^{-1} $year^{-1}$ (and a regional variation of 20–60 kg N ha^{-1} $year^{-1}$), the Netherlands currently has the highest nitrogen deposition in Europe. Approximately two-thirds of the nitrogen deposition is from NH_y (Heij and Erisman, 1997). This N deposition is a major threat to natural vegetation and forests (van der Eerden et al., 1998).

Because of its high deposition velocity, most of the NH_3 is deposited in the region of emission. Obviously, the NH_3 concentrations are higher close to the source. In many countries situations of natural vegetation and forest adjacent to animal housing is common (e.g. Rudolph, 1981; Hofmann et al., 1990; Kaupenjohann et al., 1989; Pitcairn et al., 1998), but in the Netherlands generally in the first few hundred meters from the source vegetation has no special value in terms of nature conservation as it mostly consists of NH_3-resistant agricultural crops. However, three crop categories include relatively sensitive species: fruity culture, glasshouse crops and arboriculture. From the evaluation of damage claims and literature information (Fangmeier et al., 1994), evidence exists that within arboriculture conifers are especially sensitive (van der Eerden, 1982; Hofmann et al., 1990) and that effects are often caused by reduced frost tolerance as a result of a too high foliar N content relative to other nutrients. NH_3 damage to glasshouse crops (especially cucumbers and tomatoes) is probably due to short-term peaks in exposure to NH_3 (insufficient

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assimilation capacity, acute NH_y toxicity and severe disturbance of cellular pH regulation). In fruity culture the effects are generally related to over-fertilisation causing reduced flowering and retarded fruit ripening.

Severe crop damage near a NH_3 source does not occur frequently, but expectations and claims of damage prove that it cannot be ignored. Therefore, when considering land-use planning, local authorities request an estimate of risk of crop damage in order to use this in their allowance policy.

Materials and methods

We used emission values as related to livestock and stable properties (Anon., 1991, 1994) and evaluated the variation in emission and the No Observable Effect Levels (NOEL) of NH_3. We derived the P95 from frequency distributions of available emission data (the P95 is a value which indicates that 95% of the stables have a lower emission than this value). Frequency distributions of emission concentrations were converted into occurrence of concentration–duration combinations and compared with the NOEL. A risk of damage was defined as an exceedance of the NOEL. The NOEL was derived from van der Eerden et al. (1991) and partly validated with a modelling approach: for short-term exposures we estimated the accumulation of NH_y in foliar tissue as a result of atmospheric concentration, uptake rate and detoxification capacity. For long-term exposures (one month, one growing season) we used a forest growth model to estimate the risk of nutrients imbalance. Emission concentrations of the Dutch National Air Quality network (NML) were used: one-hour averages are measured over the year in eight locations in rural regions outside the direct neighbourhood of local sources. With regression analysis the relation between concentration frequency distribution and duration of certain concentration levels was assessed. A Gaussian plume model (OPS) was used to assess the contribution of individual point sources to the local background (Van Jaarsveld, 1990). The contribution of the regional background (roughly 50×50 km) was derived from the NML and that of the local background (1×1 km) was calculated with OPS. The annual means of local and regional background concentrations were added to the exposure levels of the source to be evaluated. This addition is a simplification with some risk of underestimating peak concentrations (see Discussion section).

To estimate the contribution of NH_3 to nutrient imbalance and so to enhanced stress sensitivity we used a simulation model for growth of Douglas fir (Mohren, 1989) and adapted it for Scots pine (De Visser and van der Eerden, 1996).

Results

The species, number and age of the livestock are major determinants of the emission. Emission varies with the size of the animals and increases from 0.35 at birth up to twice the life-span average (Groot Koerkamp and Blijenberg, 1994). Other major causes of variation in emission proved to be the N content of the fodder, use of water, fodder conversion, construction properties of stable and slurry storage facility, temperature and ventilation rate. A seasonal trend (in summer 30% higher than in winter) and a daily fluctuation (daytime twice as high as during the night) exist as well (De Boer et al., 1994; Groot Koerkamp and Blijenberg, 1994; Hoeksma et al., 1992; Oldenburg, 1989). Nevertheless, the causes of a substantial part of the variation in emission are still not fully understood. For the risk estimation we derived the P95 of emission from sources with an expected similar emission based on information on livestock and type of stable.

The emission concentration has a high temporal variation as well. The P95/P50 as measured in the NML is approximately 5/1, both in emission areas (with annual means of 10–20 $\mu g\ m^{-3}$) and in immission areas (1–5 $\mu g\ m^{-3}$). The ratio of day/night concentration is about 1/3 (Aben and Dekkers, 1996).

Air quality is generally expressed in Concentration Frequency Distributions (CFDs) and percentiles (e.g. P95). For risk estimates of plant damage however, the duration of elevated concentrations is essential. Therefore, the relation between CFDs and exposure duration was assessed with the use of time series from the NML. A long persistence of high concentrations proved to be rare. For instance, in 1994 and 1995 the uninterrupted exceedance of the P95 of hourly means was 3.5 hours in average and 26 hours as a maximum (Fig. 1) and with an annual mean of 10 $\mu g\ m^{-3}$ the exceedance of 50 $\mu g\ m^{-3}$ lasted generally only 1 hour, while a duration of 10 hours was the maximum.

Input information for the OPS model is among others the source height and the surface roughness (e.g. the presence of landscape elements). These variables strongly determine the emission concentration in the first 100 m from the source (Asman, 1998). At this short distance the immission concentration can decrease up to 60% with a higher point of emission and by higher roughness. The effect is that the emitted NH_3 is dispersed over a larger area. Figure 2 gives an example of an existing situation. It clearly shows the high spatial variation in NH_3 concentration, even when expressed in annual means.

Exposure lengths were calculated based on the P95 of annual means. The annual means of local and regional background concentrations were added to the exposure levels of the source to be evaluated. These additions proved to be marginal except in cases where neigh-

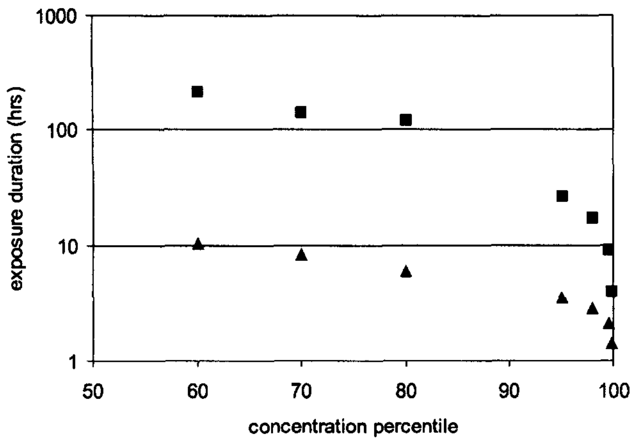

Fig. 1. Mean (▲) and maximum (■) duration of exposure as related to the concentration percentile. Data are derived from measurements in 1994–1995 on 8 locations of the NML ranging in annual means from 1.7 to 19.9 $\mu g\ m^{-3}$.

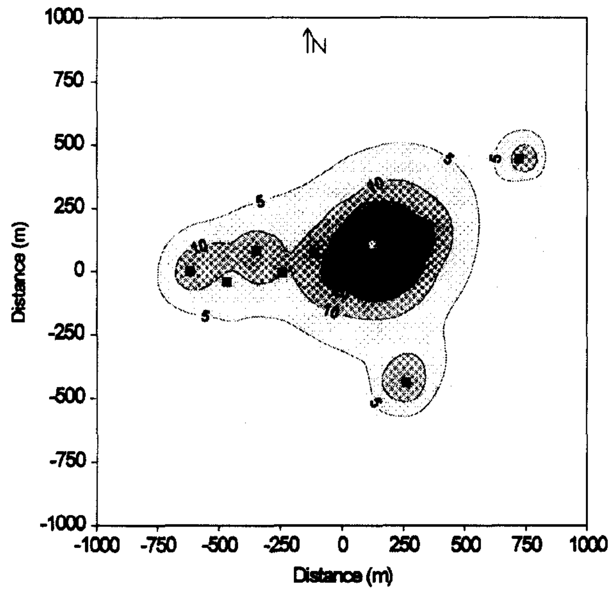

Fig. 2. Contribution of a cluster of eleven farmhouses (■) to the regional background concentration of NH_3 (annual mean in $\mu g\ m^{-3}$).

bouring sources are within 100 m from the source to be evaluated.

The NOEL as described by van der Eerden et al. (1991) is based on the evaluation of the lowest effective exposure levels observed in fumigation experiments (8, 23, 270 and 3300 $\mu g\ m^{-3}$ for a year, month, day and hour, respectively). A brief test was carried out on the reliability of this NOEL using a modelling approach. For short-term exposures (1 hour to 10 days) the NOEL may largely be determined by the accumulation of NH_y in leaf tissue up to toxic levels. For longer-term exposures an increase in stress sensitivity due to nutrients imbalance (excess of N relative to other nutrients) might be more relevant (Pérez-Soba and van der Eerden, 1996).

Literature data suggest that the uptake rate per m^2 leaf surface and per $\mu g\ m^{-3}$ NH_3 is in the range of 7–9 ng $NH_3\ s^{-1}$ during the day and 1/3 of it at night (Van Hove, 1989; Van Hove and Bossen, 1994; Pérez-Soba and van der Eerden, 1993). The maximum NH_4 concentration in leaf tissue with no toxicity is assumed to be in the range of 625 $\mu g\ g^{-1}$ dry weight (Holtan-Hartwig and Bockman, 1994). In the case of very low glutamine synthetase activity (e.g. just sufficient for assimilation of internally produced and circulated NH_4, but not for the NH_3 taken up from the atmosphere) the calculated NOEL proved to be 276 and 28 $\mu g\ m^{-3}$ for 1 and 10 day's exposure, respectively. This is similar to the experimentally derived NOEL.

With the simulation model for tree growth, the actual NH_3 uptake was calculated via simulation of photosynthesis and water limitation at meteorological conditions characteristic for the Netherlands (Van Laar et al., 1992). Dilution of N by growth was taken into account (per 0.5% increase in foliar N concentration an additional growth of 25%) and a concentration of 2.5% foliar N was assumed to be a threshold for increase stress sensitivity (Hofmann et al., 1990). The atmospheric NH_3 concentration needed to increase the needle N content within one growing season from 2 to 2.5% N was estimated to be 20–50 $\mu g\ m^{-3}$ NH_3 as a monthly mean. This again is in the range of experimentally derived NOEL, although in the higher part of it.

The calculated uptake rates were also used to evaluate the filtering capacity of a wind fence of trees around the source. This proved to be in the range 1–5% of the emission. The exposure duration as derived from emission (P95) and converted CFDs was related to the NOEL. Figure 3 gives an example and Fig. 4 shows the results for several situations.

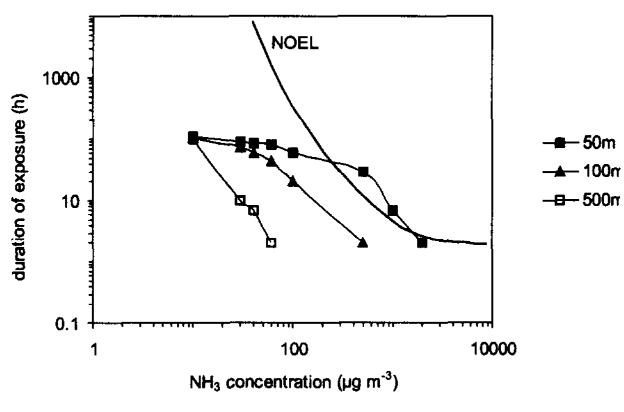

Fig. 3. NOEL and exposure levels to be expected at several distances from a stable with 750 fattening pigs with no contributions of other sources on the local or regional scale. In the area left of the NOEL-line there is no risk of NH_3 damage.

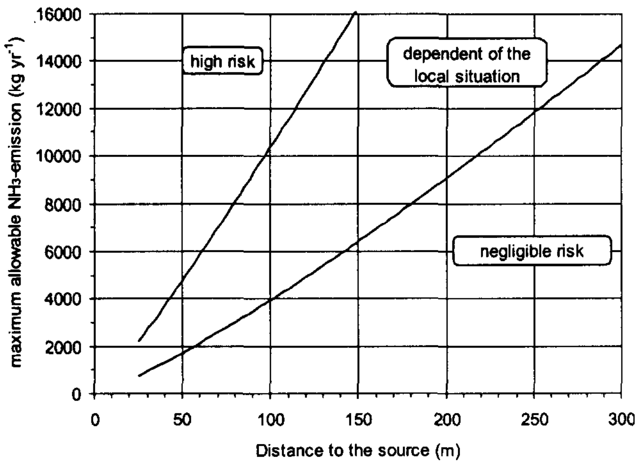

Fig. 4. Relations between the maximum NH_3-emission with no exceedance of the NOEL and the distance between source and sensitive object. A NH_3 source above the curve has too high emission or is in too short distance of the sensitive object. The lower curve indicates situations in which the prevailing wind direction (SW) is from the source to the sensitive object, the background concentration is high etc., and the upper curve shows the opposite situation (object SW of the source, low background concentration, many vertical landscape elements around the source etc.).

Evaluation

The method to assess the risk of NH_3 damage to crops as related to the distance to the source is basically very simple: it brings information on emission via a dispersion model in contact with a NOEL. However, several actions had to be taken to arrive at useful results: a P95 was derived from available emission data and the output of dispersion model calculations was converted into exposure durations. The resulting chain of information can be used as a decision support system (DSS): a safe distance for sensitive crops can be calculated taking local and regional background levels of NH_3 into account. The DSS can certainly be extended by adding more details, e.g. plant specific NOELs (in its current form the DSS only distinguishes between sensitive and non-sensitive crops). In practice, most extensions proved not to extend the applicability in legislation.

One could question whether such a DSS is also applicable for natural vegetation. To some extent, sensitive crops are probably representative for sensitive plant species in natural vegetation. The NOEL used in this DSS is defined by the lowest effective exposure levels found in fumigation experiments in which a variety of plant species was used (van der Eerden et al., 1991). For short-term exposures (< 10 d) rose, cucumber and tomato proved to be the most sensitive. For intermediate term exposures these were species from heathland vegetation and bryophytes and for long term exposures (3–12 months) some coniferous species. So, on one hand the NOEL applies at least partly to natural vegetation. On the other hand the NOEL largely neglects a number of factors with high ecological significance (e.g. the effect of exposures longer than one year, species competition and nitrogen saturation of the system).

The reliability of the method is determined by the quality of the information used. Several possibilities of over- and under-estimation exist. Recent information suggest that the emission data might be too low (Erisman and Monteny, 1998) and more validation is useful. Our definition of a "worst case" emission (P95) may be an overestimation for large sources (>10,000 kg NH_3 year^{-1}) because these are an area source rather than a point source and the ratio of maximum/mean emission may be lower. The use of OPS model is adequate, although less reliable at distances shorter than 100 m from the source. To add regional and local backgrounds as annual means may result in an underestimation of the emission concentration, because meteorological conditions that reduce dispersion may result in an increase in both the emission concentration caused by the individual source which has to be evaluated and local and regional contributions.

The conversion of CFDs into exposure lengths is essential: it improves the physiological relevance. A further improvement could be to include the rate and temperature dependency of the NH_y assimilation capacity. Another substantial improvement could be to convert atmospheric concentrations into uptake fluxes.

In this study a risk is defined as an excess of the NOEL. The NOEL is based on the lowest effective exposure level observed in artificial NH_3 fumigations. The risk is not quantified: an exceedance of the NOEL implies that an adverse effect is possible, but it does not say how severe the effect is. This could be interpreted as an overestimation of the risk of damage. On the other hand, other compounds that could act synergistically with NH_3 like SO_2 or O_3 (Fangmeier et al., 1994) were not taken into account.

If the precautions listed above are taken into account the method can be used to estimate the risk of crop damage by NH_3 on a local scale and to estimate the effect of adapting emission, increasing distance to the sensitive object or changing landscape elements.

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