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A simple biomonitor for measuring ammonia deposition in rural areas

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Summary. Knowledge of the contribution of NH_3 to the total deposition of N in rural areas is sparse, because the determination of NH_3 deposition is costly and labour-intensive. A simple biomonitor consisting of barley plants grown in pots with an inert growth medium is therefore proposed for estimating total N deposition, including NH_3. The rise in total N of the plant-soil system reflects the deposition. The biomonitor was tested near a dairy farm. Different N contents in the green biomass reflected differences in deposition, and the deposition correlated very well with NH_3 levels in the area and in two background stations. The biomonitors were placed above the crop, the measurements thus representing total N at the edge of a plant community. In 1 month the deposition in the NH_3 plume was 8 kg N ha^{-1}.

Key words: Ammonia emission – Ammonia absorption – Nitrogen cycle

Danish, Dutch, and Belgian calculations reveal that for all three countries the NH_3 evaporation is high and unevenly spread over the country in yearly quantities between 10 and 100 kg NH_3-N/ha (Buijsman 1983; Sommer 1985; Meeus-Verdinne et al. 1985). Deposition of NH_3 may therefore represent a large N input to the soil-plant system in areas with high livestock production, since animal manure is recognised as a major source of atmospheric NH_3 (Söderlund and Svensson 1976).

In fields, the deposition contributes to the crop's need for nutrients, whereas in natural ecosystems NH_3 deposition can cause acidification and destabilization by changing the nutrient status of the soil-plant system (Nihlgård 1985; Roelofs et al. 1985). Direct measurement of the yearly deposition of NH_3 is sparse, but in The Netherlands a yearly deposition of 60 kg NH_3-N ha^{-1} has been measured in throughfall, as reported by Breemen et al. (1982).

Technical difficulties and high costs in investigating the dry deposition of NH_3 and NH_4^+ (Ferm 1986) are presumably the reasons for the small number of measurements reported so far. The use of micrometeorological mass-balance methods demands frequent analyses and has therefore never been used for a whole year (Denmead et al. 1978; Dabney and Bouldin 1985). These measurements have revealed diurnal and seasonal fluctuations in the flux into and out of a plant system, which means that integrated investigation for a whole year is needed to quantify the yearly deposition.

Farquhar et al. (1980) have shown that there is a flux out of a non-manured and non-fertilized plant community into the atmosphere when the concentration of NH_3 is lower than the compensation point, which is 4 ± 2 µg NH_3 m^{-3}, and a flux into the community when the NH_3 concentration is higher than the compensation point. This finding has been explained by the continuous fixation and release of NH_4^+ via the glutamate-glutamine system. Therefore, the NH_4^+ and NH_3 in the cellular transport system is constant, and the flux of NH_3 is a result of the partial pressure of the NH_3 gas. This hypothesis is in agreement with investigations showing that NH_3 is taken up by plants via stomata (Hutchinson et al. 1972) and metabilized into amino acids and proteins (Porter et al. 1972). Further measurements show that NH_3 concentrations in unpolluted areas are at the level of the compensation point (Denmead et al. 1982; Ryden and McNeill 1984; Cadle 1985; Erisman et al. 1986).

As plants are the main recipients of NH_3 a biomonitor was developed to measure the effect of NH_3 concentration on the actual deposition of nitrogenous compounds. Experiments in growth

chambers have shown that it is possible to measure plant uptake of NH_3 in the range 5–14000 µg NH_3 m^{-3} (Faller and Linser 1972; Hutchinson et al. 1972; Porter et al. 1972; Farquhar et al. 1980; Cowling and Lockyer 1981). Barley (*Hordeum vulgare*) grown in pots with an inert growth medium was therefore chosen to estimate the deposition of NH_3-N in the surroundings of a farm.

Materials and methods

The level of NH_3 concentration in the atmosphere was determined with a simple absorber consisting of a cup (10 cm high) containing 100 ml 0.1 *M* sulphuric acid. The cup was sheltered against rain with a petri dish held 2 cm above the aperture by four sticks and protected against insects with a net. The absorbers were exposed for 14 days and closed with a lid when removed to avoid contamination. The content of NH_4^+ was measured colorimetrically (Dansk Standardiseringsråd 1975) after neutralizing the sample with 2 *M* NaOH.

The deposition of N was estimated by exposing barley grown in pots (570 cm^2) containing N-free rockwool (Grodan) and measuring the N increase in the plant and in the rockwool. Nutrients were supplied in a solution (Table 1) used for watering the plants when needed. After 800 mg N was supplied to the pots the N was excluded from the nutrient solution. Twenty-five barley (*Hordeum vulgare* var. Harry) seeds containing 15 mg N were sown per pot. The seeds were germinated indoors and then placed outside under a roof. At growth stage 3–4 on the Feeke's scale the pots were exposed under field conditions.

Table 1. Content of the nutrient solution

Element	mg/l	Element	mg/l
K	78.20	Fe	2.00
Ca	60.12	Mn	1.50
Mg	12.15	B	0.20
S	16.00	Cu	0.20
P	31.00	Zn	0.20
N	110	Mo	0.02

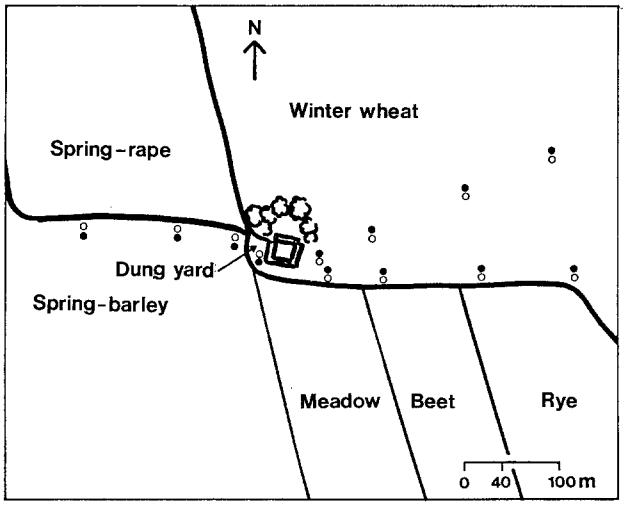

Fig. 1. Map showing locations of experimental pots and absorbers; ●, absorber; ○, three pots

After 1 month's exposure the plants were harvested at the rockwool surface. The plants were oven-dried at 80 °C and the weight of the dry biomass was determined. The rise in N content of the rockwool was estimated by measuring total N in the rockwool before the experiment and in the rockwool including roots after the experiment.

The dry plant material and rockwool was ground in a mill to a size of 1 mm. In two samples of 1 g per pot the total N content was determined in a Kjeldahl destructor and with a colorimetric NH_4^+-determination method (Dansk Standardiseringsråd 1975).

Field description. The N deposition was determined near a dairy farm with a herd of 60 cows. The dung yard was empty when the pots were placed in the area. There were no hedges or trees within 300 m east and 200 m west of the stables. The land use in the area and the placement of the pots and absorbers are shown on the map (Fig. 1). The pots and absorbers were placed in groups of three pots and one absorber. The groups were placed east, east-north-east, and west of the farm, in a garden, and in a meadow in a forest. The absorbers were placed 1 m above the ground, and the pots were first placed on the ground and later on small benches to secure a constant distance from the pots to the vegetation.

The wind direction was mainly westerly, and the mean wind speed was 4.1–6.0 m s^{-1}. For 20% of the period there was no wind, and for 4% of the time the wind was variable.

Calculations. The N deposition was calculated as follows, $\Delta N = (N_{harvested} + \Delta N_{rockwool}) - (N_{fertilizer} + N_{seed})$, where ΔN is gain of N to the pot system (= deposition), $N_{harvested}$ is the total N in the plants, $\Delta N_{rockwool}$ is the gain in N content of the rockwool, $N_{fertilizer}$ is the N supplied in the nutrient solution, and N_{seed} is the N content in the seeds.

The level of NH_3 concentration in the air was statistically tested with a two-way analysis of variance. The rise in N content in the rockwool and differences in NH_3 deposition were statistically tested in a one-way analysis of variance (Hald 1952).

Results

The level of atmospheric NH_3 concentration (Fig. 2) declined hyperbolically with distance from the stables ($P = 0.01$). The level of concentration was different for different directions, being highest to the east, intermediate east-north-east, and lowest west of the stables ($P = 0.01$). A test of Least Significant Difference ($LSD_{0.95}$) showed that the mean NH_3 concentration was different for all distances.

The N content in the rockwool rose by 0.01% ($P = 0.01$). There was no systematic trend in the increase of N with differences in NH_3 concentration. Therefore, a mean value for $\Delta N_{rockwool}$ was calculated and inserted in the equation.

The N deposition was 0.506 g N pot^{-1} at the stables, which was 10 times the magnitude of the deposition in the other groups (Fig. 3). As this difference is significant this group was not used in the statistical calculation. The level of NH_3 concentration in the group 300 m east of the farm was close to the

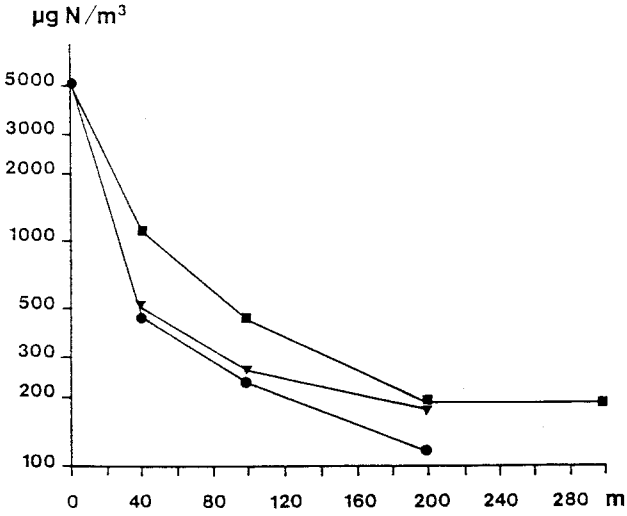

Fig. 2. Levels of atmospheric NH_3 concentrations in different directions and distances from the farm; ■, east; ●, west; ▼, east-north-east

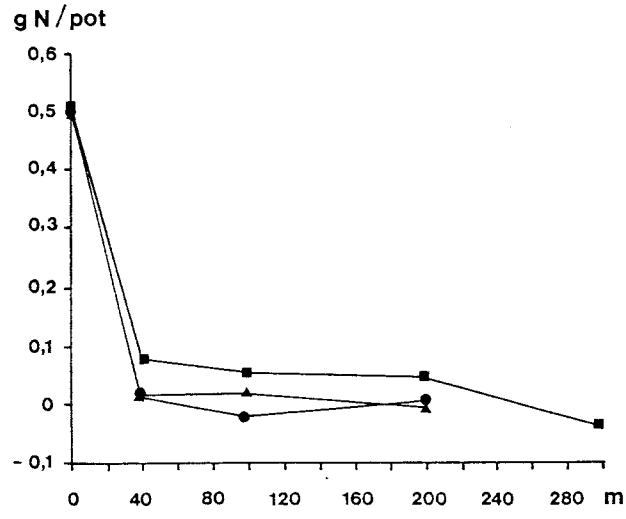

Fig. 3. Deposition of N estimated with barley (*Hordeum vulgare*) grown in pots (area 570 cm^2) exposed for 1 month. Symbol directions as for Fig. 2

background concentration and the measured deposition was therefore used to estimate background deposition in conjunction with the measured deposition in the garden and the meadow. The mean deposition in background areas was 0.00 g N pot^{-1} ($s = 0.03$).

There was a significant difference between the mean N deposition for the three directions and the background N ($P = 0.01$). The $LSD_{0.95}$ test shows (Fig. 3) that the deposition in the western direction was zero (the background level) and that the deposition to the east and east-north-east was significantly higher.

Discussion

The absorption of NH_3 in the absorber depends mainly on diffusion, but also on turbulence. However, as the turbulence will be approximately equal for all the absorbers, the measured concentrations will be equally overestimated. The measured NH_3 concentrations can only be used to show relative differences in support of the interpretation of the pot experiment.

In the rural area where the experiment took place, only NH_3 emitted from the farm could have caused differences in N deposition because there are no other farms with livestock in the area and no fertilizing or manuring took place. The measurements therefore give a good description of the NH_3 deposition caused by emissions from the farm.

From 0–40 m from the stables the NH_3 level (Fig. 2) in all directions declined sharply to the background concentration. Dispersion, transformation to NH_4^+ and, to a minor degree, uptake by plants caused the fall in NH_3 concentration, which is in agreement with general modelling of the NH_3 flux from a farm of this size (Asman and Janssen 1986). The NH_3 level was highest towards the east, intermediate to the east-north-east, and lowest to the west. The level of NH_3 was influenced by the NH_3 evaporation from the farm up to a distance of 40–100 m west, 200 m east-north-east, and 200–300 m east of the farm. The observed pattern was caused by the westerly wind in the observed period.

The increase in N content in the rockwool of different pots was not affected by differences in NH_3 deposition, and a mean was therefore used to estimate the rise of total N in all pots. This result agrees with earlier investigations of plant uptake of NH_3 (Cowling and Lockyer 1981; Faller and Linser 1972; Porter et al. 1972) which showed that only a minor part of deposited NH_3-N is translocated to the roots. The rise in N therefore reflects the N supply from the nutrient solution and not differences due to NH_3 deposition.

As mentioned previously, systematic differences in N deposition in this area are most likely to be caused by NH_3 deposition. The correlation is clearly seen in Fig. 3, where the deposition in the most exposed area east of the farm shows a pattern similar to that of the NH_3 concentrations. In the area affected (0–200 m) by the NH_3 emission there is a correlation between the NH_3 levels and the N deposition for all three directions. At the background station 300 m east of the farm, the deposition was lower than expected, possibly because this group was heavily infected by mildew (*Erysiphe graminis*) which can cause NH_3 loss (Jenkyn and Finney 1984). The results of the investigation therefore prove the reliability of the

biomonitor in giving a quantitative measure of N deposition in an area heavily polluted with NH_3.

West of the source the deposition declined to zero 40–100 m away from the dungyard. towards the east the deposition was 0.05–0.07 g N pot^{-1} to a distance of 200 m from the dungyard, and east-north-east, 0.02 g N pot^{-1} up to 100 m from the dungyard. The deposition to the east-north-east seems low although the area showed a relatively high NH_3 level. The low value could have been a result of the shelter from the trees in the garden lying west of the groups of pots, which diminished the flux of NH_3 through the vegetation. This finding shows that a simple biomonitor like the one used gives a good estimate of the actual deposition, and that N deposition is a function of many factors, of which NH_3 concentration is only one.

In this investigation the plants were placed above the crop level. The deposition measured was therefore comparable to the high deposition at the edge of a field, a fence, or the edge of a wood. The deposition in the pots in the plume 100–200 m east of the farm was 8 kg N ha^{-1} for 1 month. Annually, this would be about 50 kg N ha^{-1}, taking into account the shifting wind direction. This is similar to Swedish (Nihlgård 1985) and Dutch (Breemen et al. 1982) investigations in which the N deposition in woods lying near stables was 60 and more than 60 kg ha^{-1} $year^{-1}$, respectively.

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