Foliar Absorption of Atmospheric Ammonia by Ryegrass in the Field

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ABSTRACT

The dry deposition of ammonia (NH_3) in the field was measured simultaneously at increasing distances from a point source (a dairy farm) using a biomonitor. The biomonitor was Italian ryegrass (*Lolium multiflorum* Lam.) grown in pots and supplied with ^{15}N-labeled N. The use of ^{15}N improved the precision and lowered the detection limit of the method compared with calculating the NH_3 deposition using the difference method (N-balance method). Atmospheric NH_3-concentrations were measured by drawing air through traps containing sulfuric acid. At the end of a 6-wk period in the growing season, the deposition of N was 3.0 g N/m² and 0.7 g N/m² at average atmospheric concentrations of 89 and 6 μg NH_3-N/m³, respectively. Estimated deposition velocities ranged from 0.7 to 3.4 cm/s with an average of 1.6 cm/s (s.d. 1.2 cm/s).

IT HAS BEEN SHOWN that atmospheric ammonia (NH_3) can be absorbed as well as released from plants (Dabney and Bouldin, 1985; Harper et al., 1987; Schjørring et al., 1987; Whitehead and Lockyer, 1987). The flux of NH_3 is controlled partly by atmospheric NH_3 concentrations, as plants can absorb NH_3 at high concentrations of atmospheric NH_3 and lose NH_3 at low concentrations. In most natural ecosystems the supply of N is low and plants are in general N-deficient. It is therefore unlikely that plants in these ecosystems will lose N in the form of NH_3 during growth. However, during senescence ammonia volatilization can occur from ryegrass (*Lolium multiflorum* Lam.) (Whitehead et al., 1988). Micrometeorological measurements have shown that heather [*Calluna vulgaris* (L.) Hull] and pine (*Pinus* sp.) woods absorb atmospheric NH_3 (Duyzer et al., 1987). It has been demonstrated that Douglas fir [*Pseudotsuga menziesii* (Mirbel) Franco] absorbs ^{15}N-enriched NH_3 in the field (Nason et al., 1988) and laboratory (Pang, 1984). Plants exposed to atmospheric NH_3 in chambers increase their absorption of NH_3 almost linearly with concentrations of NH_3 in the air in the range 14 to 700 μg NH_3/m^3 (Whitehead and Lockyer, 1987).

The aim of the present investigation was to simultaneously measure atmospheric NH_3 concentrations and foliar absorption of NH_3 by plants in the field. The plants were grass grown in pots (biomonitors) with a low supply of N. The biomonitors were placed in the field at increasing distances from a point source of atmospheric NH_3. It was evaluated whether or not plant absorption of NH_3 was correlated with the average concentration of atmospheric NH_3. Deposition velocities of NH_3 were estimated.

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MATERIAL AND METHODS

Plant Growth and Analysis

Absorption of atmospheric NH_3 was estimated by measuring dilution of ^{15}N in Italian ryegrass grown in pots. The pots (area 491 cm², volume 8.8 L) contained 7.4 kg N-free sand. On the sand surface 0.75 g seed (0.018 g N) was spread evenly and covered with a 1-cm layer of sand. Initially, the pots were watered with a N-free nutrient solution (Sommer, 1988). Ten and 25 d after sowing, 0.224 g N as KNO_3 with 2.786 atom % ^{15}N excess was supplied to each pot with the nutrient solution. Nutrient solution without N was supplied when needed.

The pots were placed in a greenhouse for 28 d after sowing. Groups of four to five pots were placed in the field 20, 40, and 60 m east and 20, 40, 60, 80, and 130 m west of a dairy farm dung yard in the prevailing wind direction. One group was placed 10 m south of the source. When the pots were placed in the field, plants from other five pots were harvested and analyzed (control). Pots were positioned such that the plants were at the same height as the crop in the field.

After 47 d exposure, plants from all pots were harvested. The roots were recovered by gently washing the sand from the roots. The plant material was oven-dried at 80 °C for 24 h, weighed, and ground.

Analyses for total N and ^{15}N enrichment in the dried and finely ground plant material were carried out using an elemental analyser (Carlo Erba NA 1500) interfaced to an isotope ratio mass spectrometer (Delta, Finnigan MAT).

Measurements of Atmospheric Ammonia and Inorganic Nitrogen in Rain Water

The atmospheric NH_3 concentration was measured by drawing air at 0.5 L/min through traps containing 60 mL 0.1 *M* H_2SO_4. The trap consists of a 100-mL test tube with a gas dispersion tube. The flow was provided by a diaphragm pump (Neuberger NMP 8.0 L, 12 V DC). The traps situated 1.2 m above the crops were changed weekly and the concentration of NH_4^+ measured colorimetrically (Dansk Standardiseringsråd, 1975). The measurements were carried out in two 7-d periods 1 and 2 wk after the start of exposure.

Rain was collected in funnels (area 452 cm²) giving an estimate of the bulk deposition. Ammonium concentrations were analyzed colorimetrically and NO_3^- was analyzed with a HPLC (Perkin Elmer, series 10).

Calculations

The content of labeled N (N_{lab}) in the plant material, and N-deposition (N_{dep}) was calculated, using the following equations.

$$N_{lab} = N_{total} \times \frac{\text{atom \% } ^{15}\text{N excess (plant)}}{\text{atom \% } ^{15}\text{N excess (N added)}}$$

$$N_{dep} = N_{total} \times 1 - \left[\frac{\text{atom \% } ^{15}\text{N excess (exposed plant)}}{\text{atom \% } ^{15}\text{N excess (control plant)}}\right]$$

In the plume of NH_3 from the dairy farm, the background concentration of NH_4^+ is constant (Allen et al., 1988; Asman and Janssen, 1986), and in rural areas background NO_x concentrations in the air are also constant. In this study, differences in the amount of N deposited are therefore related

to differences in atmospheric NH_3 concentrations. One is able to calculate the deposition velocity for NH_3, dividing differences in uptake of N with differences in atmospheric NH_3 concentration at two distances from the farm. The uptake of atmospheric NH_3 is then expressed as the deposition velocity (V_d):

$$V_d = \frac{R\,(x) - R\,(130)}{[NH_3\,(x) - NH_3\,(130)]\,E_T}$$

where

V_d = deposition velocity, cm/s
$NH_3\,(x)$ = atmospheric NH_3 concentrations in the air x m from the farm, μg NH_3-N/m^3
$NH_3\,(130)$ = atmospheric NH_3 concentrations in the air at 130 m from the farm, μg NH_3-N/m^3
$R(x)$ = rate of N deposition to biomonitor x m from the farm, g/m^2
$R\,(130)$ = rate of N deposition to the bio-monitor at 130 m from the farm, g/m^2
E_T = period of exposure, s

An analysis of variance was carried out using the procedure ANOVA in SAS, and LSD values were used to compare treatment means when the treatment effect was significant.

RESULTS AND DISCUSSION

Atmospheric Ammonia Concentration and Wet Deposition of Nitrogen

The mean concentration of atmospheric NH_3 increased from 6 μg NH_3-N/m^3 130 m east of the farm up to 89 μg NH_3-N/m^3 10 m south of its dung yard (Table 3). East and west of the farm the concentrations of NH_3 were at identical levels. The east and west NH_3 concentrations measured were much higher than those found in natural ecosystems unaffected by animal production (Ferm et al., 1988). The highest concentrations were equivalent to reported concentrations from areas with high livestock production (Pinksterboer et al., 1987).

With funnels continuously open, deposition of ions and particles with rain and dry deposition on the funnel sides is measured as bulk deposition. In rain water, the respective concentrations of NO_3^- and NH_4^+ were 0.723 mg NO_3^--N/L and 0.866 mg NH_4^+-N/L. Precipitation during the measuring period was 94 mm and the bulk deposition of N was therefore 0.007 g N/pot.

Table 1. Dry matter production, N concentrations in dry matter, and ^{15}N enrichment of Italian ryegrass tops and roots as influenced by biomonitor placement.

Distance†	Dry matter	N	Atom % ^{15}N excess
m	g/pot	%	
	Plant top		
−60	17.9	1.52	2.22
−40	21.9	1.31	2.07
−20	18.7	1.61	2.09
0	26.1	1.27	1.99
+20	24.2	1.21	2.08
+40	25.3	1.15	2.16
+60	23.5	1.19	2.25
+80	22.8	1.15	2.33
+130	25.5	1.02	2.43
LSD_{95}	2.2	0.10	0.24
Control	8.21 (SD 1.10)	3.64 (SD 0.20)	2.62 (SD 0.10)
	Plant root		
−60	60.9	0.35	2.21
−40	73.2	0.29	2.03
−20	65.6	0.34	2.06
0	82.8	0.30	1.99
+20	78.4	0.31	2.02
+40	79.1	0.29	2.09
+60	80.1	0.27	2.13
+80	83.9	0.23	2.23
+130	70.5	0.31	2.32
LSD_{95}	22.0	0.08	0.09
Control	4.63 (SD 0.20)	1.90 (SD 0.10)	2.47 (SD 0.05)

† − East, + west of dung yard.

Nitrogen Accumulation in Control Plants

The top dry matter production of the control plants harvested at the initiation of the exposure period, was higher than that of the roots (Table 1). The concentration of N in the top material was twice the concentration in the roots and 77% of total N of the plants were found in the top. There was found 79% of the labeled N in control plants (Table 2). It was found that 0.04 g N/pot was derived from sources other than the labeled N. Approximately half of this N was derived from the seeds, the rest was probably added in the deionized water or derived from assimilation of NH_3 from the air.

The labeled N that was unaccounted for (21%) was probably still present in the sand or lost when the roots were washed free of sand (Janzen and Bruinsma, 1989). It is unlikely that denitrification occurred in the sandy soil containing no organic material. Due to the high N status of the plants and low atmospheric NH_3

Table 2. Total and labeled N uptake and recovery of labeled N in the plant biomass as influenced by biomonitor placement.

Distance†	N-total	N_{lab}‡	Recovery§
m	g N/pot	g N/pot	%
−60	0.48	0.37	82
−40	0.50	0.35	78
−20	0.52	0.47	82
0	0.57	0.48	86
+20	0.53	0.47	83
+40	0.52	0.38	85
+60	0.48	0.47	81
+80	0.45	0.46	81
+130	0.47	0.49	86
LSD_{95}	0.05	0.04	NS
Control	0.39 (SD 0.03)	0.35 (SD 0.05)	79 (SD 11)

† − East, + west from the dung yard.
‡ Based on atom % N in labeled N.
§ Recovery of added labeled N.

Table 3. Concentration of NH_3 and deposition velocities (Vd) as influenced by the distance to the dung yard of a dairy farm.

Distance†	NH_3-N	Vd
m	μg/m^3	cm/s
−60	25	2.4
−20	46	1.2
0	89	0.8
+20	41	1.5
+40	17	3.4
+60	16	1.5
+80	16	0.7
+130	6	N.D.

† − West from the dung yard, + east from the dung yard.

concentrations, some of the N taken up may have been lost as NH_3 from the plant tops (Harper et al., 1987).

Nitrogen Accumulation in Exposed Plants

After 6 wk exposure in the field, the mean recovery of labeled N was 83%; this is not significantly different from the uptake in the control plants (Table 2), indicating no fertilizer N was lost during this period.

The N concentration in plants exposed in the field was low (Table 1), and plants were N-deficient during field exposure, labeled N was translocated from the top to the roots. Atmospheric NH_3 was assimilated by the plant tops and some of it was apparently translocated to the roots, because the amount of the N deposited in the roots exceeded the amount added to the plants in rain. Although N was translocated from the tops to the roots, the concentration of N in the roots was very low.

Foliar Absorption of Ammonia

The ^{15}N-enrichment of the control plants was used for calculating the deposition of N to plants exposed in the field. As the plants were growing in sand only containing labeled N, it is not necessary to assume the same amount of soil N was taken up by plants exposed to elevated concentrations of atmospheric NH_3 as plants grown in an NH_3-free atmosphere (Lockyer and Whitehead, 1986). The uptake of soil N may be depressed when the plants are absorbing large amounts of gaseous N (Okano and Totsuka, 1986). Nitrogen lost or gained while the plants were grown in the greenhouse will not affect the estimated deposition, because the ^{15}N-enrichment in the control plants is used for calculating the deposition of N to the plants in the field.

Absorption of atmospheric N can also be estimated by the difference method (Okano and Totsuka, 1986; Sommer, 1988). Using this method, the absorption is estimated as the difference between the total N of the plants harvested and the amount of N added in seeds and fertilizer. In this study, a positive correlation between the methods was observed (Fig. 1), but the N difference method underestimated the deposition. This difference could have been caused by ammonia volatilization from the plants 1 to 2 wk after fertilizer application (Harper et al., 1987) and release of root exudates into the rhizophere (Janzen and Bruinsma, 1989).

The source of NH_3 was a dairy farm [80 cows (*Bos* sp.)], which produced ca. 5.7×10^3 kg NH_4^+-N/yr (Hansen and Sibbesen, 1989). From the stable and dung yard it is assumed that 20% (Kruse et al., 1989) of the NH_4^+ evaporated giving an estimated ammonia loss of 1.1×10^3 kg NH_3-N/yr. This emission caused a deposition of N to the biomonitors, which declined rapidly to the west and east of the farm due to falling concentration of atmospheric NH_3 (Fig. 2). Ten meters south of the farm, the measured deposition is equivalent to 3.0 g N/m^2 and 130 m east of the farm the deposition is equivalent to 0.7 g N/m^2 for the 47 d the biomonitors were exposed in the field. At the end of this period, the bulk deposition was 0.14 g N/m^2, indicating dry deposition of NH_3 contributes large amounts of N to the vegetation and crops near a farm with livestock.

The amount taken up from NH_3 increased with increasing concentrations in the air (Fig. 3). It has been

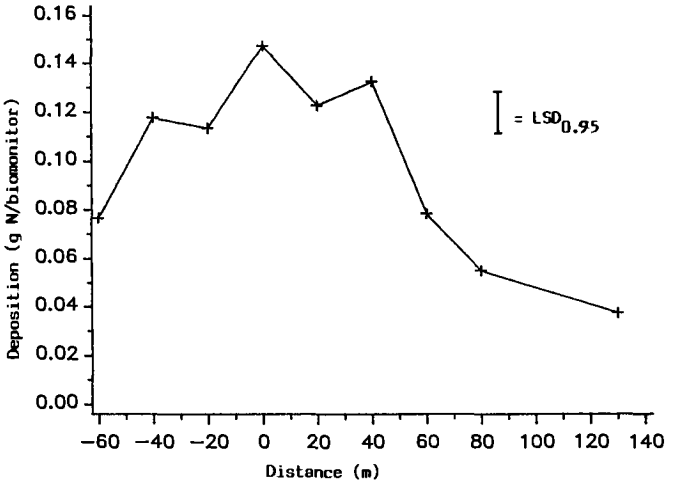

Fig. 2. Deposition of NH_3 east (+) and west (−) from the dung yard. Measured with biomonitors, area 492 cm^2.

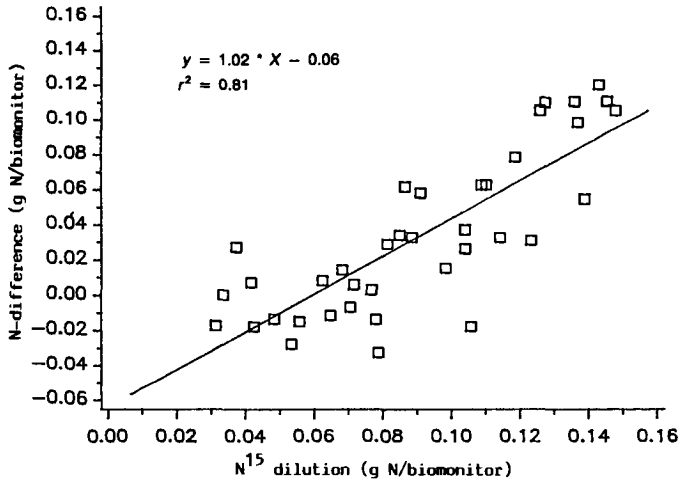

Fig. 1. Correlation between estimates of NH_3 deposition using N-difference or ^{15}N-dilution method.

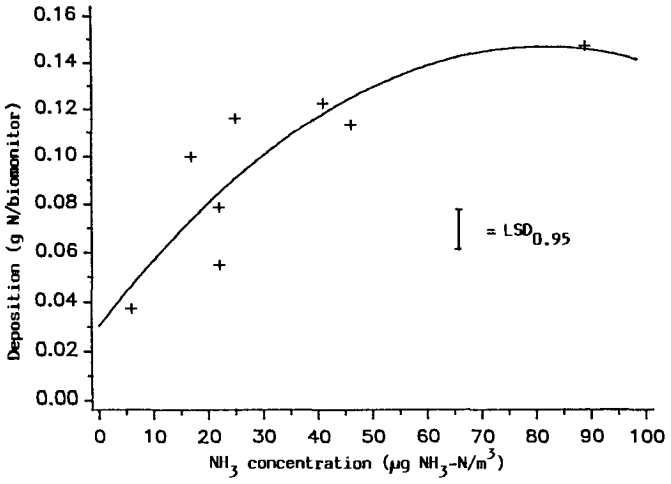

Fig. 3. Deposition of NH_3 measured with Italian ryegrass grown in post, area 492 cm^2.

shown that at atmospheric NH_3 concentrations from 14 to 709 μg NH_3/m^3 the assimilation of NH_3 was linearly correlated to the concentration (Whitehead and Lockyer, 1987). In the present experiment, the deposition of NH_3 deviates from linearity at the high NH_3 concentration near the farm. This could be an artifact caused by the wind conditions near the farm buildings, which affect the NH_3 concentration gradients above the plants. Alternatively, the plants near the farm may have been saturated with NH_4^+ during the fairly long exposure period with high concentrations of atmospheric NH_3.

Deposition velocity is an unknown function of experimental conditions (Sehmel, 1980) and shows a wide numerical range for even the same type of deposition surface. The reference heights have normally been 1.0 to 1.5 m for land surface. In this study NH_3 concentrations were measured 1 to 1.2 m above the biomonitor. The estimated average deposition velocity of NH_3 was 1.6 cm/s (SD 1.2 cm/s) (Table 3). Using a micrometeorological gradient method, a total yearly average of Vd = 1.92 cm/s (SD 1.09 cm/s) was estimated over heather (Duyzer et al., 1987).

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