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Ammonia volatilization from grassland receiving nitrogen fertilizer and rotationally grazed by dairy cattle

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Abstract

The micrometeorological mass balance method was used to measure ammonia (NH_3) volatilization from rotationally grazed swards throughout the 1987 and 1988 growing seasons. In both years the swards were dressed with calcium ammonium nitrate (CAN) split over 7 dressings. In 1987 the sward received a total of 550 kg N ha^{-1}, in 1988 a total of 550 or 250 kg N ha^{-1}. For the 550 kg N ha^{-1} treatments there were 8 and 9 grazing cycles, respectively, in 1987 and 1988 and 7 for the 250 kg N ha^{-1} treatment. Losses from the 550 N sward were 42.2 and 39.2 kg N ha^{-1} in 1987 and 1988, respectively; this was equivalent to 8.5 and 7.7% of the N returned to the sward in the excreta of the grazing cattle. The NH_3 loss from the 250 N sward was 8.1 kg N ha^{-1} in 1988, which was equivalent to 3.1% of the N returned to the sward in excreta during the growing season. There was a wide variation in NH_3 volatilization between the individual grazing periods. This indicates the necessity of continued measurements throughout the growing season to obtain reliable data on NH_3 volatilization. Soil humidity is suggested to be a key factor, because emissions were high from wet soil, and low from drier soil. Results of a Monte Carlo simulation study showed that the measured NH_3 loss from the 250 and 550 N swards had a standard deviation of 13 and 5% of the mean, respectively.

Introduction

On grazed swards with a fertilizer N input of 200 kg N ha^{-1} yr^{-1} and more – as is common in the Netherlands – only a minor portion of the N from ingested herbage is retained in milk or live weight gain. The remainder, about 75–95%, is excreted in dung and urine [10, 17]. Generally, the recovery of excreted N in herbage yield is low on well fertilized swards [10]. The fraction not recovered in herbage yield may be immobilized by the soil microbial biomass or may be lost from the soil-grassland system through a combination of NH_3 volatilization, nitrate leaching and denitrification.

NH_3 losses to the atmosphere are of great concern, because of the impact they may have on aerosol chemistry [21] and acid deposition [1]. The major input of NH_3 into the atmosphere is thought to be the NH_3 volatilized from urine and faeces excreted by farm livestock [1]. Only limited data exist on NH_3 losses from grazed swards. Losses were found to depend on fertilizer input [9]; total dressings of 210 and 420 kg N ha^{-1} yr^{-1} resulted in NH_3 losses of 10 and 25 kg N ha^{-1}, respectively [9]. A grass-clover sward gave a loss of 7 kg N ha^{-1} [9]. On tropical pastures dressed with 374 kg N ha^{-1} yr^{-1}, NH_3 losses amounted to 17–34 kg N ha^{-1} [7].

NH_3 losses from grazed pastures are thought to result mainly from urine deposited by cattle [9, 10]. The main N component in urine is urea, which has a high potential for NH_3 volatilization [5]. The extent of the NH_3 loss is also affected by soil and environmental factors [5] and possibly grassland management. In the present study NH_3 losses from rotationally grazed swards were measured continuously throughout the grazing season. The swards were grazed with dairy cows and supplied with a total of 250 or 550 kg N ha^{-1} yr^{-1} as calcium ammonium nitrate (CAN). It was hypothesized that higher N dressings would increase herbage yield and herbage N concentration, and thus N intake and N excretion by the cows. More N excretion increases the potential for NH_3 loss. Measured losses were therefore related to the estimated N returns via dung and urine to the sward.

Materials and methods

Method

A micrometeorological mass balance method, similar to the method described by Denmead [3], was used to measure NH_3 losses from grazed plots throughout the 1987 and 1988 growing seasons. This method assumes that the vertically integrated product of wind speed and the difference between the centre and boundary of the plot in NH_3 concentration of the air, divided by the fetch is equal to the NH_3 flux from the soil surface. The fetch, which is the distance between upwind boundary and the centre of the plot should be known exactly.

Measurements

Differences in NH_3 concentration between the centre and the boundary of the plot were measured via NH_3 sampling traps in the centre of the plot and at the windward boundary. Eight such traps were fixed to a mast in the centre of the plot, at heights of 0.25, 0.40, 0.55, 0.75, 1.00, 1.30, 2.30 and 3.30 m. At the windward boundary of the plot, a mast was placed with five NH_3 traps, at heights of 0.40, 0.55, 0.75, 1.30 and 2.30 m. Fewer traps were placed at the boundary because the background concentration was low and essentially uniform with height. Each trap contained 20 ml 0.02 *M* H_3PO_4 held in 100 ml collection tubes. With Charles Austin pumps (85 SE) air was sucked through the acid via a gas dispersion tube (porosity 2) at a rate of 2.4 l min^{-1}, controlled by a Platon flow meter. A correction of 0.1 to 0.25 l min^{-1} was made for the measured pressure drop between the flow meter and the air inlet of the trap. Sampling and analysis of the 0.02 *M* H_3PO_4 solution was usually carried out on a 24 h basis. The tubes were transferred to the laboratory and the NH_3 concentration was determined by means of the phenolhypochlorite method [18].

Wind speed was measured on a mast outside the plot, at eight different heights, varying from 0.40 to 4.30 m. Casella cup anemometers (T16108/2) were used at the lower four positions, while Lambrecht cup anemometers (14691) were used at the four top positions. Wind direction was measured with a Porton windvane. The wind data were recorded on mechanical counters. Other weather data (rainfall, air temperature, radiation and potential evaporation) were provided by the meteorological station at the experimental site.

Sampling was continuous throughout the period May–October. In a number of cases, the sampling traps were analyzed four times a day to determine the diurnal pattern of the NH_3 emission. In 1988, extra NH_3 traps were fixed at the mast and analyzed in order to determine the accuracy of the NH_3 measurements.

Experimental treatments

The experimental site, with a size of five ha, was situated on a young marine, calcareous clay soil in the Flevopolder in the Netherlands. The sward was more than 7 years old, with ryegrass (*Lolium perenne* L.) as the dominant grass species. The top 5 cm of the soil had a clay content 19.5%, an organic matter content of 8.3%, a CEC of 0.12 mol_c kg^{-1} and a pH (KCl) of 6.8. The background NH_3 concentration in the atmosphere is relatively low in the Flevopolder, mainly because the polder is predominantly used for arable farming. In 1987, the experiment was carried out on one square test plot of 0.18 ha, heavily fertilized with a total of 550 kg N ha^{-1} yr^{-1} as CAN, split into 7 dressings. In 1988 there were two treatments, receiving totals of 550 and 250 kg N ha^{-1} yr^{-1}, split into 7 and 6 dressings, respectively. These plots were circular, with a radius of 23 m, to obtain a constant fetch, and were 80 m apart. After the last fertilizer N dressing in September of 1987 there were another two grazing periods on the 550 N plot, because herbage continued to grow until late in autumn. In 1988, the 250 N plot was grazed twice and the 550 N plot three times after the last fertilization in September.

The plots were rotationally grazed – as is common in the Netherlands – with lactating Holstein Friesian dairy cows (age 2–7 yrs). The cows first grazed on a field with the same N treatment as the test plot to become accustomed to the N concentration of the grass. Grazing on the test plot started at a target herbage yield of 1700 kg DM ha^{-1}. Stocking rates were high, 60 to 120 cows ha^{-1}, in order to have the sward grazed in one or one and a half days and to ensure that the distribution of dung and urine patches over the plot was as uniform as possible. Within two days after grazing the sward was dressed with fertilizer N and then allowed to regrow prior to the next grazing period.

The total N intake by the dairy cows via herbage and concentrates (1 kg per cow per day) and the N retention in milk and live weight gain (PJAG Deenen, pers comm) were used to calculate the N content of the excreta. The distribution of N between faeces and urine per grazing period was calculated as follows [10]:

$$\text{N retention} = 0.0087 \times (\text{number of cow grazing days}) + (\text{milk protein yield})/6.38 \quad (\text{kg N ha}^{-1}) \tag{1}$$

$$\text{N in faeces} = \text{N intake} \times 0.0078 \quad (\text{kg N ha}^{-1}) \tag{2}$$

$$\text{N in urine} = \text{N intake} - \text{N in faeces} - \text{N retention} \quad (\text{kg N ha}^{-1}) \tag{3}$$

where N intake is total N intake via herbage and concentrates in kg ha^{-1}. It is assumed that about 2/24 of the excreta were not returned to the sward immediately, because the cows were in the milking shed twice a day for about 1 h during milking time. So as to verify the N in excreta calculated from equation (3), urine produced during grazing was sampled and analyzed a number of times during the 1988 grazing season. Between 10 to 18 cows were sampled in the morning, in the afternoon and in the evening by collecting urine in 0.5 l pots attached to a bean-pole. Sampling was done on the day before grazing started on the test plot. Because of this, cow behaviour was not disturbed on the test plot. The urine was analyzed for total N by a Kjeldahl method [15].

Results

Ammonia emissions

During the 1987 growing season, cumulative NH_3 volatilization was 42.2 kg N ha^{-1} from the sward supplied with 550 kg N ha^{-1} yr^{-1} (Table 1). The amount volatilized varied considerably between grazing periods. The NH_3 volatilization per grazing period was related partly to the amount of N excreted via dung and urine per grazing period (Table 1). Hence, the NH_3 losses were expressed as percentages of the total amount of N excreted on the pasture in each period. The relative losses varied from 4.8 to 14.8% with a mean of 8.5%. Or, expressed in a different way, the average loss was 47 g N (range 22.6 to 73.2) per cow per grazing day.

In 1988, cumulative NH_3 volatilization was 39.2 kg N ha^{-1} for the 550 N plot and 8.1 kg N ha^{-1} for the 250 N plot. The difference between the two plots was striking throughout the season. On average, 7.7% of the excreted N volatilized from the 550 N plot and 3.1% from the 250 N plot (Table 1).

Figure 1 shows typical patterns of NH_3 loss, for four consecutive grazing periods. Generally, NH_3 losses were high during the first few days after grazing and decreased to negligible amounts about 10 days after the grazing period. In most cases, a peak emission was measured on the second day. Rainfall appeared to influence this general pattern. The relatively low NH_3 emissions following grazing in the second half of August were associated with high rainfall (Fig. 1). The NH_3 emission rate varied also between day and night. During day-time the emission rate was much higher than during night-time. Maximum emission rates were recorded between 12.00 and 16.30 h (Fig. 2).

Table 1. Cow grazing days, N retention, N excretion and NH_3 emissions during the 1987 (550 N) and 1988 (550 N and 250 N) grazing seasons

Period	Cow grazing days	N retention by cows kg ha^{-1}	N excretion		NH_3–N emission		
			faeces kg ha^{-1}	urine kg ha^{-1}	kg ha^{-1}	% of N excreted on plot	g per cow grazing day
1987; 550N							
1. 7/5–2/6	149	21.7	16.9	52.2	3.36	5.3	22.6
2. 2/6–22/6'	128	18.0	17.7	63.5	9.34	12.5	73.2
3. 22/6–6/7'	109	12.8	12.8	56.2	7.05	11.1	64.7
4. 6/7–28/7	76	9.7	10.0	39.2	2.78	6.1	36.6
5. 28/7–23/8'	136	16.0	12.8	49.7	8.48	14.8	62.3
6. 23/8–16/9	124	11.2	17.2	66.8	4.01	5.2	32.3
7. 16/9–20/10	97	10.6	13.8	48.0	4.33	7.6	44.4
8. 20/10–29/10**	90	0.9	12.4	50.0	2.77	4.8	30.9
total	908	101	114	425	42.2		
mean						8.5	46.5
1988; 550N							
1. 4/5–20/5	167	22.8	22.5	58.7	2.94	3.9	17.6
2. 20/5–9/6	140	19.0	20.1	60.9	5.71	7.7	40.9
3. 9/6–7/7'	108	14.8	15.2	54.0	8.24	12.9	76.0
4. 7/7–27/7'	100	13.8	17.6	53.6	8.24	12.6	82.2
5. 27/7–17/8	101	13.8	14.6	56.5	5.44	8.3	53.8
6. 17/8–5/9	143	19.5	14.3	41.2	0.63	1.2	4.4
7. 5/9–4/10'	84	11.4	8.6	32.0	3.80	10.2	45.5
8. 4/10–31/10**	95	0.7	10.8	51.5	2.15	3.5	26.6
9. 31/10–10/11**	36	0.3	3.8	17.9	2.01	9.3	56.0
total	974	116	127	428	39.2		
mean						7.7	40.2
1988; 250N							
1. 4/5–20/5	111	16.2	13.8	27.0	0.69	1.8	6.2
2. 20/5–9/6	106	15.5	16.6	34.9	1.38	2.9	13.0
3. 9/6–13/7'	77	11.2	10.5	22.3	1.73	5.7	22.6
4. 13/7–4/8'	72	10.5	12.4	28.1	1.13	3.0	15.6
5. 4/8–5/9	63	9.3	10.1	24.6	1.77	5.5	27.9
6. 5/9–4/10'	74	10.8	11.8	31.4	0.63	1.6	8.5
7. 4/10–14/10**	76	0.5	9.0	33.5	0.77	1.8	10.1
total	580	74	84	203	8.1		
mean						3.1	14.0

** During this period the sward was grazed by dry cows;
' The sward was topped after grazing.

N excretion

Mean results of the urine analyses for urine collected during 1988 are shown in Table 2. The mean N concentration of the urine varied during the day, and also between days. Typically, the N concentration was higher in the early morning and lower in the evening. This diurnal variation is probably related to the drinking pattern of the dairy cows during the day. The urine from the 250 N plot generally had a lower N content, however the differences were small and inconsistent. This difference is very small in relation to the large difference in NH_3 emission per cow grazing day recorded between the 550 N and 250 N plot in 1988 (Table 2).

In 1987 there were 908 cow grazing days, and an estimated 101 kg N ha^{-1} were retained in milk and live weight gain (Table 1). An estimated 539 kg N ha^{-1} was excreted, 425 kg N in urine and 114 kg N in dung. The estimated N

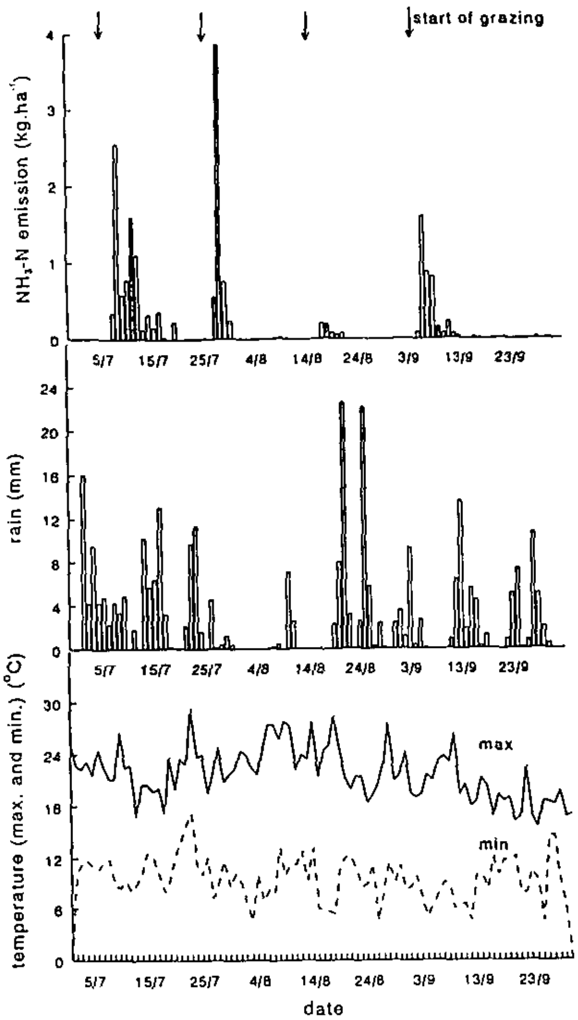

Fig. 1. Daily values for NH_3 emission, global radiation, rainfall and minimum (- - -) and maximum (—) temperatures at 1.50 m during the 4th, 5th, 6th and 7th grazing period on the 550 N plot in 1988.

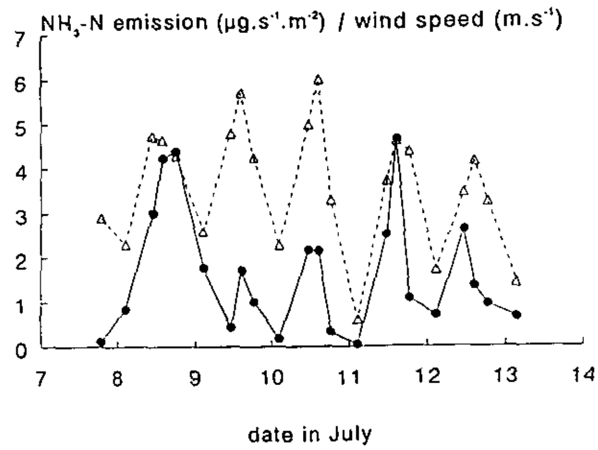

Fig. 2. NH_3 emission pattern (-●-) and wind speed (-Δ-) during the first five days of the 4th grazing period in 1988 on the 550 N plot.

Table 2. N content of urine collected from grazing dairy cows on 9 June, 27 July and 5 September 1988

Period	Total-N (g l^{-1})	
	550 N	250 N
9 June		
morning	11.1	10.0
afternoon	8.4	9.5
evening	8.0	7.1
daily mean	9.1	8.9
27 July		
morning	9.1	
afternoon	6.9	
evening	5.8	
daily mean	7.2	
5 September		
morning	9.5	9.6
afternoon	8.2	6.2
evening	7.7	7.1
daily mean	8.6	7.5

Between 10 and 18 cows were sampled per period.

excreted in urine was 3.7 times of that in dung. In 1988 there were 974 cow grazing days per ha on the 550 N plot and 580 on the 250 N plot. This difference was mainly due to the higher grass production on the 550 N plot. Calculated N excretion was 555 and 287 kg ha^{-1} on the 550 N and 250 N plots, respectively. The ratio between N excreted via urine and faeces was 3.4 and 2.4 on the 550 N and 250 N plot, respectively. Expressed per cow grazing day, the ratio of estimated N excretion via urine was 1.26 times higher on the 550 N plot than on the 250 N plot. The results of the urine analysis (Table 2) did not show a 26% difference in N excretion via urine. Thus far we are unable to interpret this difference. Possibly more urine was excreted on the 550 N plot (H. Valk, pers comm).

Discussion

Error analysis

The overall error in the cumulative NH_3 emission depends on the distribution of urine and dung patches over the plot and on the accuracy of the wind speed and NH_3 concentration measurements. During the season dung patches were counted per quarter section of the plot. The numbers per section were found to be very similar and the patches were evenly distributed. The distribution of urine patches is much more difficult to quantify. However, since dung patches were randomly distributed, the urine patches were assumed to also be evenly distributed. An almost uniform distribution of urine and dung patches provides a relatively regular pattern of NH_3 sources over the plot. A high degree of uniformity of NH_3 source is a prerequisite for the mass balance method [3]. The error of the measured wind profile was small as the log-linear wind profiles generally had a correlation coefficient of 0.95 or more and the anemometers had an error of $\pm 1\%$.

The largest error in the NH_3 emission was found in the accuracy of the NH_3 concentration measurements. The duplicate measurements of NH_3 concentration indicated that the mean coefficient of variation (cv) was 5 to 6% (Table 3). The cv was essentially independent of measuring height and NH_3 concentration.

To estimate the effect of the variations in the concentration measurements on variations in NH_3 emission from the 250 N and 550 N plots a 'Monte Carlo' simulation [13] was carried out, using a normal distribution of the logarithmically transformed NH_3 concentrations, with the cv's (Table 3) as standard deviation. For each measuring day in 1988 on the 550 N and 250 N plot 50 NH_3 emission simulations were run. Statistical analysis of the 50 cumulative seasonal NH_3 emissions for the 550 N and 250 N plots gave cv's of 5% and 13%, respectively. These results indicated that the concentration measurements were an appreciable source of error in the determination of NH_3 emission, particularly at low emission rates.

Table 3. The coefficient of variation (cv) and standard error (se) of the NH_3 concentrations based on duplicate measurements from grazed plots receiving two rates of N fertilizer

N rate kg ha^{-1} yr^{-1}	Number of duplicates	Mean level μgN m^{-3}	Se μgN m^{-3}	Cv %
250 N	90	10.1	0.535	5.3
550 N	175	14.2	0.909	6.4

Another possible source of error is associated with diurnal variations in wind speed and NH_3 concentration profile (Fig. 2). These possible errors were examined by comparing the calculated NH_3 emission based on means per day and means per quarter day. This comparison was made for 19 days in 1988 (Table 4). The mean total emission calculated on a quarter-day basis was slightly higher than that based on one mean per day. The statistically significant ($p < 0.01$, Student t-test) mean difference was equivalent to about 10% of the mean per 24 hrs. This suggests, that the means given in Table 1 are underestimates of the actual emission. However the summed experimental error increases by doing quarter day measurements, because of a fourfold increase in the number of samplings and concentration measurements. Furthermore, the relative error of the NH_3 measurements tend to increase as the NH_3 concentration decreases by a factor 4. Given these arguments and that the estimated cumulative NH_3 emission based on a mean per day was only 10% lower than the summed daily total of means per quarter day and the additional costs associated with extra measurements, we consider that daily measurements are acceptable.

Effects of N fertilization

NH_3 losses from grazed plots are the sum of the NH_3 losses from applied fertilizer, dung and urine and from decaying grass after topping [20]. NH_3 losses from the applied CAN fertilizer are likely to be negligible [16]. Little herbage remained after grazing and topping, therefore only a small proportion of total herbage production decayed in the field. Furthermore, the environmental conditions during the growing season of relatively dry air and intermittent rainfall, were not conducive to NH_3 loss from decaying herbage [20, N Vertregt, pers comm]. Therefore, it is likely that the measured NH_3 losses in our experiments resulted mainly from excreta.

Generally, the volatilization potential of urine is considerably greater than that of faeces due to the very labile nature of urea which in well fertilized temperate grassland constitutes 75% or more [4, 6, 8] of the total N content of urine. The much higher potential for NH_3 loss from urine compared to dung has been confirmed in

Table 4. NH_3-N emission (kg ha^{-1}) based on four measurement periods per 24 h and on one period, for 19 days in 1988 on the 550 N plot

Date	per measuring period[1]				A + B + C + D	24 h period	(A + B + C + D) −24 h
	A	B	C	D			
20–05	0	0.61	0.13	0.10	0.84	0.63	0.21
21–05	0.13	0.21	0.21	0.02	0.65	0.68	−0.03
22–05	0.11	0.22	0.12	0.02	0.47	0.55	−0.08
23–05	0.04	0.16	0.06	0.02	0.28	0.18	0.10
24–05	0.09	0.51	0.11	0.14	0.75	0.67	0.08
8–07	0.49	0.67	0.71	0.69	2.56	2.47	0.09
9–07	0.07	0.28	0.16	0.07	0.58	0.46	0.12
10–07	0.36	0.34	0.06	0.02	0.72	0.53	0.19
11–07	0.40	0.77	0.17	0.27	1.61	1.52	0.09
12–07	0.42	0.23	0.15	0.31	1.11	1.04	0.07
27–07	0	0	0.15	0.41	0.56	0.81	−0.25
28–07	0.69	0.80	0.63	1.78	3.90	3.86	−0.04
29–07	0.30	0.26	0.04	0.06	0.76	0.49	0.27
30–07	0.07	0.04	0.02	0.11	0.24	0.12	0.12
6–09	0	0.77	0.41	0.34	1.52	1.32	0.20
7–09	0.22	0.03	0.10	0.33	0.68	0.56	0.12
8–09	0.49	0.21	0.06	0.06	0.82	0.33	0.49
9–09	0.02	0.03	0.04	0.07	0.16	0.14	0.02
10–09	0	0.05	0	0.03	0.08	0.10	−0.02
total					18.29	16.46	1.83
mean							0.097*
se							0.03458

[1] A ≈ 7.30–12.00 h B ≈ 12.00–16.30 h C ≈ 16.30–21.00 h D ≈ 21.00–7.30 h

* Differs significantly from 0 ($p < 0.01$, Student t-test).

enclosure experiments [11, 12, 14]. In our experiments it was calculated that, on the 550 N sward, about 78% of the excreted N was contained in urine and 22% in faeces. This estimated partitioning is in agreement with experimental data from well-fertilized pasture [17], where approximately 70% of the excreted N was present in urine.

It has sometimes been assumed that approximately 40% of the N in urine and 5% of the N in faeces from grazing cattle volatilizes as NH_3 [2]. These percentages suggest that approximately 30% of the excreted N volatilized as NH_3–N on well fertilized grassland. Our data indicate much lower NH_3 losses of approximately 8% of the total amount of excreted N. Other recent field experiments in NW Europe indicated similar small losses, in the UK, NH_3 losses of 25 kg N ha^{-1}, corresponding to 9.0% of the excreted N, were determined on a 420 N sward [9]. Under subtropical conditions NH_3 losses may be much larger due to higher temperatures. On a 374N grazed pasture in Queensland, Australia, 14.4 to 28.4% of the urinary N volatilized as NH_3 [7].

There was an effect of fertilizer application rate on the total NH_3 volatilization loss. The loss from the 550 N plot was almost five times higher that from the 250 N plot. Part of this difference can be attributed to the difference in the total amount of excreta returned to the sward due to a lower intensity of grazing. Expressed as a percentage of the estimated excreted N, the total NH_3 volatilization loss from the 550 N plot was 2.5 times larger. The difference in emission rates from heavily and moderately fertilized swards was less pronounced in a UK study [9]. In that study NH_3 losses from rotationally grazed 420 N and 210 N plots were 9.0% and 6.7% of the excreted N. This corresponded to 12.1% and 11.2% of the total urinary N [9]. The difference between the UK study and our study regarding the effect of N fertilizer application rate may possibly be attributed to differences in soil type, like the higher clay content of the soil used in this study. Differences in climatic conditions between the UK and the Netherlands are likely to be small.

An increase in N concentration in urine will increase the potential for NH_3 volatilization. This was confirmed in an experiment with yearling steers [8]. Higher N application rates gave higher N concentrations in urine and a proportional increase in NH_3 losses. In our experiment, higher N concentrations were expected in the urine on the 550 N plot than on the 250 N plot, but the limited results in Table 2 show only minor differences, despite the large differences in NH_3 emission for the grazing periods beginning at the 9th of June and the 5th of September in 1988 (Table 1).

Effects of soil and environmental conditions

Numerous soil and environmental conditions affect NH_3 emission [5]. For instance, temperature generally has a positive effect on volatilization [5]. However in our experiment, temperature did not have a straightforward effect; warm periods did not coincide with peak emissions (Fig. 1).

There was a tendency for NH_3 volatilization to be higher from wet soil than from dry soil. For example, rain just before and during grazing in the 4th and 5th grazing period (Fig. 1) coincided with high emission rates. In contrast, during and for the first three days after grazing in the 6th grazing period it was relatively dry, and very low NH_3 losses occurred during the 6th grazing period. It is suggested that urine infiltrates more rapidly and deeply into dry soil. This would result in lower NH_4^+ concentrations in the upper layers of dry soil compared to wet soil, and reduce the potential for NH_3 volatilization.

Effects of grassland management

Some of the large differences in NH_3 losses between grazing periods (Table 1) may be due to differences in grassland management. NH_3 losses from the 550 N plot were relatively large in the 2nd, 3rd and 5th grazing period of 1987 and in the 3rd, 4th and 7th period of 1988. In all these periods the sward was topped after grazing. The resultant increase in the surface area of dung patches (combined with decaying herbage toppings [19]) may contribute to the higher NH_3 losses measured from topped swards.

Another important management decision factor is herbage yield. It was difficult to achieve the target yield of about 1700 kg DM ha^{-1} at the start of grazing, in this experiment it ranged from 1500 to 3000 kg ha^{-1}. The inverse relationship between herbage yield and herbage N content influences the N intake of cattle and consequently the N content of excreta and its potential for volatilization. Jarvis *et al.* [9] observed a positive relationship between herbage N concentration and emission percentage. However no clear relationships could be established between herbage yield, N concentration of herbage, N intake of herbage and NH_3 emission for the various grazing periods in our experiment, probably because of the confounding influence of weather conditions.

In conclusion in this experiment, the level of N fertilization had an effect on NH_3 losses. A number of environmental soil and management factors may also have an effect, consequently the nature of the relationship between N application rate and NH_3 emission from grazed swards is difficult to quantify. The data from this study suggest that reducing N application rate may be an effective tool in minimizing NH_3 losses from grazed swards. Further studies over time, on different soil types and with different management regimes are required to develop a clear understanding of the relationship between N fertilizer rates and NH_3 volatilization from grazed swards.

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