THE FATE OF NITROGEN IN ANIMAL EXCRETA APPLIED TO GRASSLAND

H.G. van der Meer[1] and D.C. Whitehead[2]

[1]Centre for Agrobiological Research (CABO),
P.O. Box 14, 6700 AA Wageningen, The Netherlands
[2]Institute of Grassland and Environmental Research (IGER),
Hurley, Maidenhead, Berkshire, SL6 5LR United Kingdom

ABSTRACT

Results are reported from experiments conducted at Wageningen, The Netherlands, and Hurley, United Kingdom, to assess the fate of nitrogen (N) in animal excreta after application to grassland. The proportion of urine N lost by volatilization of ammonia was, on average, 13 % in the experiments at Wageningen and 14 % in the experiments at Hurley. Ammonia losses from cattle dung were also 13 % of the N content at Wageningen, but only about 2 % at Hurley.

Other rapid losses of urine N were observed. At Hurley, they were attributed to drainage through macro-pores and cracks in the soil, whereas in the Dutch experiments at least part of these losses appeared to be associated with nitrification.

Recovery of urine N in the harvested herbage was at a maximum of 60 % after urine applications made in April, May or early June and decreased to less than 20 % after applications in August. A simultaneous similar increase of residual inorganic N in the soil was observed, which was subject to leaching and denitrification during the winter.

Only a small proportion of the N content in cattle dung was recovered in the harvested herbage.

INTRODUCTION

The return of nitrogen (N) in excreta is an important part of the N cycle in grazed pastures. Grazing ruminants generally excrete 75-95 % of the ingested N in faeces and urine (Whitehead, 1970). For dairy cows, grazing intensively managed pastures in Western Europe, this amounts to 400-500 g N per cow day (Van Vuuren and Meijs, 1987) and, assuming a grazing season with 700 cow days ha^{-1}, to approximately 300 kg N $ha^{-1}yr^{-1}$ Recently, there has been growing concern about the contribution of excretal N to N losses from grassland, in particular through the volatilization of ammonia and leaching of nitrate.

This paper reports results from research undertaken in The Netherlands and the United Kingdom to assess the fate of urinary and faecal N applied to grass swards. For details we refer to the original papers (Vertregt and

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Rutgers, 1988a and b; Whitehead and Bristow, 1990; Lockyer and Whitehead, 1990; Van der Meer and Vertregt, in preparation).

MATERIALS AND METHODS

Research in The Netherlands was carried out in 1986-1988 with artificial urine and fresh cattle dung on good permanent grassland on a sandy soil (pH-KCl = 5.0; organic matter = 5.7 %) near Wageningen. Artificial urine was prepared according to Doak (1952), and contained generally 12 g N l^{-1}, 89.1 % of the N being urea N. Dung was collected from dairy cows grazing grass that received a high rate of fertilizer N; it contained 13.8 % dry matter, 0.392 % total N, 0.029 % ammonium N, 0.0018 % nitrate N, 0.137 % K, and 0.101 % P. The results reported here, originate mainly from 7 experiments with artificial urine in 1986, and 1 with dung in 1987. The experiments were designed to study the effects of various factors on ammonia volatilization and each consisted of 2 treatments, each with 3 subplots of 2 m x 0.54 m (see Fig. 2). Artificial urine was applied to 2 subplots per treatment (dung only to 1), the third subplot served as a control plot and received to urine.

Before the start of the experiments, the experimental area had been fertilized (since early April 1986) at either a high or a low rate of N (calcium ammonium nitrate), viz. about 80 or 25 kg $ha^{-1}month^{-1}$, and the grass had been cut weekly with a lawn mower to keep a dense sward. In all experiments, the urine was applied to swards with 4 days regrowth. After the urine application, no further fertilizer N was applied, and the grass was harvested when the yield of the best growing subplots of the experiment was equivalent to approximately 2.5 ton dry matter per ha.

Artificial urine was applied at a rate of 5 l m^{-2} (generally 60 g N m^{-2}), and dung at a rate of 32 kg m^{-2} (125 g N m^{-2}). Both urine and dung were spread evenly over the plots. The dung was applied on 1 July 1987 and covered and killed the sward completely. This was simulated on the control plots by spraying with paraquat and covering the sward with black plastic. Almost 2 months after dung application, topped perennial ryegrass tillers were planted on the subplots at a distance of 10 cm x 5 cm.

During the first 10 days after urine application, ammonia volatilization was measured continuously with a ventilated tunnel on 1 subplot per experimental treatment. Details of the equipment have been published by Vertregt and Rutgers (1988b). In the experiment with dung and in some experiments with urine, volatilization measurements were continued for 30 days after application.

Soil samples for analysis of inorganic N were taken just before urine application, at day 11 after urine application, and at the end of the growing season (late October). In general, the treated and control plots were sampled in quadruplicate (6 cores per sample) and the soil cores divided into 0-10, 10-20, and 20-40 cm layers (in October also 40-60 cm).

At Hurley, United Kingdom, a series of experiments involving application of cattle urine to grass swards was carried out during 1985-1989 to assess ammonia volatilization under different environmental conditions (Lockyer and Whitehead, 1990). Nitrogen concentration in the urine ranged from 6.0 to 12.3 g l^{-1}, and the rate of urine N applied from 19.2 to 73.8 g m^{-2}. The soil was a sandy clay loam, and the experimental plots were 2 m x 0.5 m. The volatilization of ammonia was measured with the system of windtunnels described by Lockyer (1984).

In another experiment at Hurley, cattle urine, labelled with ^{15}N urea, was applied to a series of confined microplots in an old perennial ryegrass sward, to study transformations and losses of N (Whitehead and Bristow, 1990). The soil in this experiment was an imperfectly drained clay loam with a pH (in 0.001 M $CaCl_2$) of 6.2, and organic carbon and total N contents in the top 15 cm of 3.3 and 0.34 %, respectively. Microplots were installed in early June 1987 by pressing polypropylene cylinders (179 cm^2) into the sward to a depth of 30 cm. The microplots received a conditioning application of urine (70 g N m^{-2}) on 7 July. Labelled urine, containing 8.6 g N l^{-1}, was applied on 18 August to 30 microplots at a rate equivalent to 74 g N m^{-2}. Microplots were removed in triplicate at different intervals (2, 6, 10, 16, 28, 51, 111, 181, 251, and 321 days after urine application) for analysis of total N and ^{15}N in plant and soil components of the sward. In addition, assessments were made of ammonia volatilization and denitrification.

RESULTS AND DISCUSSION

Recovery of urine nitrogen in the first 10 days after application

Table 1 presents the N balances of the urine treated plots for the first 10 days after urine application. In the experiments at Wageningen, volatilization of ammonia varied between 4 and 17 % of urine N. Total volatilization in this period was not correlated with (1) mean global radiation, (2) mean soil temperature at 0-3 cm depth, or (3) initial soil moisture content of the layer 0-10 cm (Vertregt and Rutgers, 1988b). Dilution of the urine, and simulated rain immediately after urine application, decreased the percentage ammonia loss (see Fig. 2). Some measurements of volatilization between 10 and 30 days after urine application indicated that, on average, approximately 2.5 % of urine N volatilized in that period, but that the process had virtually stopped at day 30 (Vertregt and Rutgers, 1988b). Total volatilization of ammonia in these experiments averaged 13 % of urine N (range: 5-22 %).

In a similar series of experiments with cattle urine at Hurley, ammonia losses ranged from 3.7 to 26.9 % (average: 14 %) of urine N (Lockyer and Whitehead, 1990). For 7 experiments in this study, which were carried out at the same site, there was a good positive correlation ($r = 0.93$) between soil temperature at 3 cm depth over the first 3 days after application and the extent of volatilization, assessed over 15 days.

Table 1. Recovery of N from urine in the first 10 days after application to grassland. The values obtained at Wageningen are average results of 12 experimental plots on a sandy soil, established between April and August 1986, with application of artificial urine at a rate of 60 g N m^{-2} (see also Fig. 2). The values from Hurley were obtained in a study with cattle urine, labelled with ^{15}N urea, applied in August 1987 at a rate equivalent to 74 g N m^{-2} to confined microplots on an imperfectly drained clay loam soil (Whitehead and Bristow, 1990). Standard deviations in brackets.

Process of pool	% recovery of applied urine N at	
	Wageningen	Hurley
Volatilization of ammonia	10.5 (3.6)	11.0
Denitrification	n.d.	0.1
N uptake by the grass	3.2 (3.3)	4.6
Soil organic N	n.d.	9.8
Soil inorganic N	61.1 (11.4)	33.3
Not accounted for	25.3 (12.7)	41.2

n.d. = not determined.

In the experiments both at Wageningen and Hurley, in which assessments were made of the recovery of applied N, total N recovery after 10 days was less than 100 % (Table 1). In the ^{15}N experiment at Hurley, unrecovered N amounted to 37 % after only 2 days and increased slightly afterwards (Whitehead and Bristow, 1990). This large and rapid loss of N was attributed to drainage through macro-pores and/or cracks resulting from the insertion of the cylinders.

In the Dutch experiments, the proportion of urine N not accounted for after 10 days, ranged from 5.7 to 48.3 %. Analysis of this variation revealed a negative correlation between the amount of ammonium N in the soil profile after 10 days and the amount of N not accounted for. This may point to N losses associated with nitrification. Such losses have been reported in literature (e.g. Bremner and Blackmer, 1978). In Fig. 1, unrecovered N after 10 days is plotted against an estimate of nitrification in the first 10 days after urine application. This estimate is calculated as the difference between the expected (maximum) amount of ammonium N (applied urine N minus N removed by ammonia volatilization and plant uptake) and the measured amount of ammonium N in the soil at 10 days after urine application. Fig. 1 shows that unaccounted urine N amounted to approximately 50 % of this estimate of nitrification.

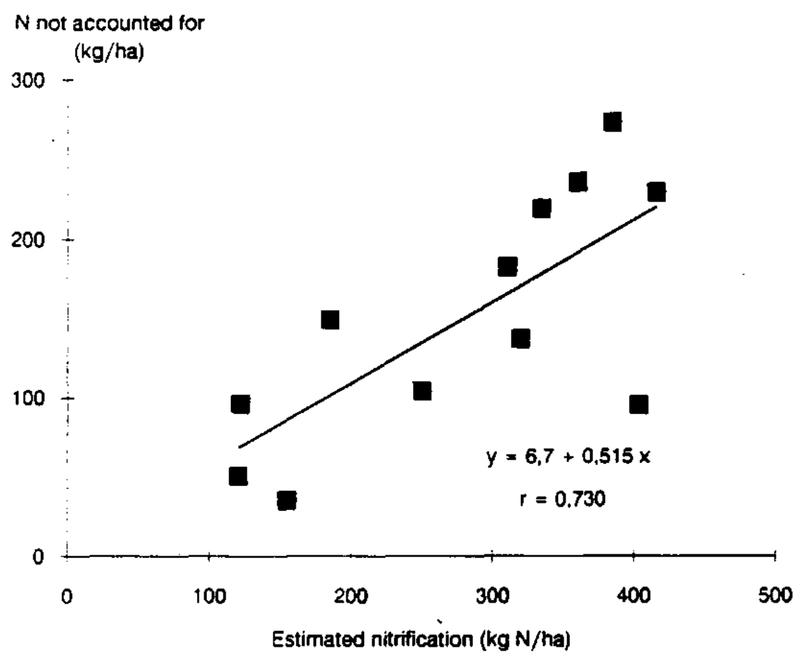

Figure 1. Relationship between estimated nitrification during the first 10 days after urine application and the amount of N not accounted for at day 11 in the 12 experimental plots of Table 1.

The hypothesis that losses of urine N occur during nitrification was tested by adding the nitrification inhibitor DCD to the artificial urine. In 3 experimental treatments with addition of DCD, unrecovered urine N was on average 7 %, a proportion similar to that recovered in soil organic matter in the study with labelled urine at Hurley (Table 1). This result supports the view that at least part of the unaccounted for loss of N in the Dutch experiments was associated with nitrification.

Recovery of urine nitrogen at the end of the season of application

Figure 2 shows the proportions of urine N (1) lost by volatilization of ammonia, (2) recovered in the harvested herbage, and (3) present as inorganic N in the soil at the end of the growing season, in 7 experiments with artificial urine on the sandy soil near Wageningen. From early applications of urine, up to 60 % of the urine N was recovered in the harvested herbage, and no residual inorganic N was found in the soil in autumn. With urine applied later in the growing season, N recovery in the harvested herbage decreased and inorganic N in autumn increased. This trend was slightly more pronounced on plots with a high N pretreatment than on plots with a low N pretreatment. In most cases, however, the sum of the proportions of urine N recovered as herbage N and soil inorganic N was about 60 % (Fig. 2). Soil inorganic N in autumn was mainly nitrate N (except on the DCD treated plots), and was completely lost during the following winter, probably by denitrification and leaching.

In the experiment with ^{15}N labelled urine at Hurley, total recovery of urine N in October in plant and soil components and in gaseous N losses was 57.2 % (Whitehead and Bristow, 1990). However, only 6.6 % of urine N was recovered in the harvested herbage and 20.5 % as inorganic N in the soil to 30 cm depth. In addition, 6.3 % was recovered in stubble, leaf litter and roots, 0.9 % in soil macro-organic matter, 8.1 % in soil microbial biomass, 3.5 % in humified soil organic matter, whereas 11.3 % was lost by ammonia volatilization and denitrification. Evidence was obtained that about 16 % of the N was lost by nitrate leaching during the following winter. In this experiment, the proportion of urine N, recovered in harvested herbage and soil inorganic N was much lower than in the Dutch experiments. As mentioned above, it is likely that the installation of the microplots resulted in a substantial and rapid movement of urine to below 30 cm.

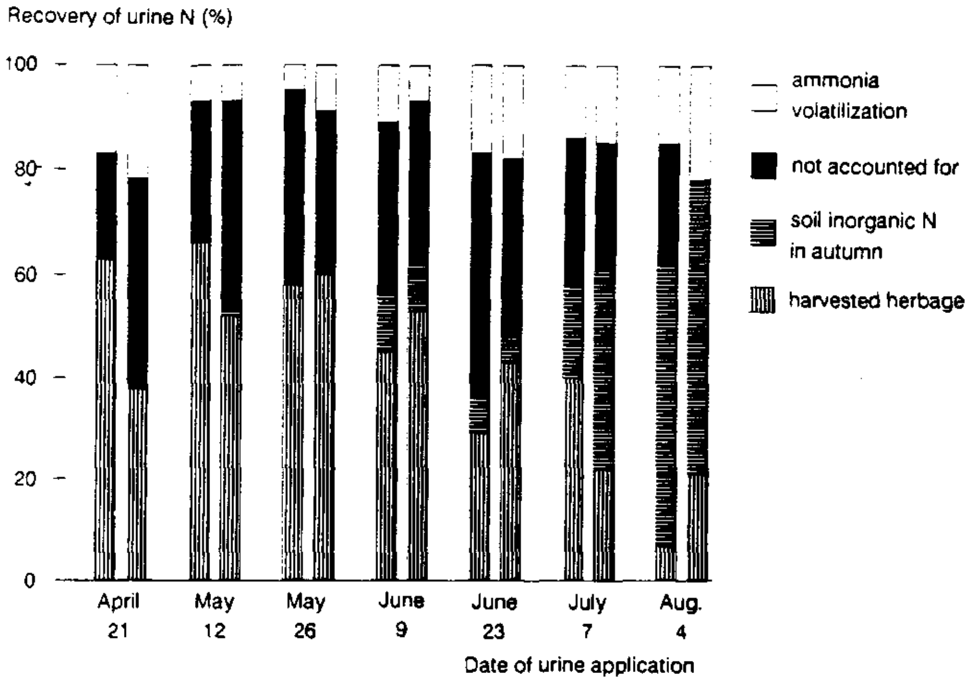

Figure 2. Recovery of N from artificial urine in the season of application (1986) to grassland on a sandy soil near Wageningen. For each date of application and experimental treatment, values are shown for N loss by volatilization of ammonia, N recovery in the harvested herbage, inorganic N in the soil profile (0-60 cm) at the end of the growing season (late October), and unrecovered N. For each date there were 2 treatments, listed for left and right columns respectively:

21 April : (a) urine with 6 g N l^{-1}; (b) 12 g N l^{-1};
12 May : idem;
26 May : (a) 12 mm simulated rain immediately after urine application; (b) 4 daily portions of 3 mm;
9 June : (a) no rain; (b) 12 mm immediately after urine application;
23 June : (a) sward clipped to 2 cm at the start of the experiment; (b) normal sward;
7 July : (a) low fertilizer N pretreatment of the sward; (b) high N pretreatment;
4 August: both with addition of the nitrification inhibitor DCD (but unintentionally: (a) severely scorched sward; (b) lightly scorched sward).

All treatments, except 2, received 5 l artificial urine with 12 g N l^{-1} per m^2. The swards used in the experiments of 21 April, 26 May, and 23 June had a low N pretreatment (25 kg N $ha^{-1}month^{-1}$); those used on 12 May, 9 June, and 4 August had a high N pretreatment (80 kg N $ha^{-1}month^{-1}$).

Recovery of nitrogen from cattle dung

Table 2 presents the results from 2 Dutch experiments carried out to study the fate of faecal N on grassland. The average proportion of faecal N lost by ammonia volatilization was about 13 %. Sugimoto and Ball (1990) reported ammonia losses ranging from 2.8 to 8.1 % of the N content in cattle dung. In preliminary experiments at Hurley, ammonia volatilization from dung amounted to only about 2 % of the N over 14 days.

Uptake of dung N by the planted grass was rather high in the autumn after dung application (Table 2). However, it was low in the second year, in particular on the plot with simulated rain in the first 12 days after dung application. The low recovery of dung N in the second year indicates that most of the faecal N is rather stable organic N. No explanation is available for the difference in N recovery in 1988 between the wetted and the dry "dung pat".

Table 2. Recovery of N from fresh cattle dung applied to grassland at a rate of 32 kg m^{-2} (125 g N m^{-2}) on 1 July 1987. One "dung pat" was wetted 2 times per day during the first 12 days with 2.8 mm water; the other received no water and became dry.

Process or pool	% recovery of applied dung N	
	wetted "dung pat"	dry "dung pat"
Volatilization of ammonia		
1-12 July	10.3	9.4
13-29 July	4.3	2.5
Recovery in harvested herbage		
27 August-29 October	6.3	9.1
Soil inorganic N		
29 October	4.1	7.1
Recovery in harvested herbage		
growing season 1988	0.5	8.8
Not accounted for	74.5	63.1

CONCLUSIONS

There is good agreement between the results from 2 series of experiments, conducted in The Netherlands and the United Kingdom, to assess volatilization of ammonia from cattle urine applied to grassland. On average, 13 % of the urine N was lost as ammonia in the Dutch experiments, and 14 % in the British experiments.

In the Dutch experiments with artificial urine, evidence was obtained of rapid N losses associated with nitrification. More research is required to assess the nature of these losses and their magnitude under different conditions.

After urine applications in April, May and early June, a maximum of about 60 % of the urine N was recovered in the harvested herbage. With later applications of urine (and/or additional applications of fertilizer N), N recovery by the grass decreased and residual inorganic N in the soil in autumn increased. In general, a varying part of this residual inorganic N will be lost by denitrification or leaching. In the experiment with ^{15}N labelled urine at Hurley, about 13 % of the N from an application in August was taken up into plant components of the sward. Evidence was obtained that substantial nitrate leaching and some denitrification occuured during late autumn and winter.

Ammonia volatilization from cattle dung also amounted to approximately 13 % of the N applied in the Dutch experiments (compared with only about 2 % at Hurley). Only a small proportion of dung N was recovered in the harvested herbage. This indicates that a large part of faecal N was added to the organic N pool in the soil.

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