THE FATE OF URINE NITROGEN: A GRASSLAND LYSIMETER STUDY IN IRELAND

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Abstract

In grazed pasture systems, the nitrogen (N) contained in a cattle urine patch may be up to 1200 kg N ha^{-1}. The majority of this N is in excess of plant requirements and is vulnerable to environmental loss. In this study, cattle urine was applied at five rates of nitrogen, 0, 300, 500, 700 and 1000 kg N ha^{-1} to soil monolith lysimeters in late autumn in Ireland. Measurements of gaseous N emissions, nitrate (NO_3^-) leaching and pasture N uptake were made for a calendar year following urine application in two consecutive experiments. Increasing the rate of urine N applied increased the cumulative nitrous oxide (N_2O) emissions, NO_3^- leaching and pasture N uptake in years one and two, and the relationships were curvilinear with N recovery diminishing at the higher N rates.

Introduction

Nitrogen is returned to the pasture by grazing animals in urine and dung. The amount of N returned in a urine patch varies from 200-1200 kg N ha^{-1} (Haynes and Williams, 1993), depending mostly on the amount of N consumed. As the N content in the diet increases, the proportion of the N excreted in the urine increases, whereas the proportion in the dung remains relatively constant (Barrow and Lambourne, 1962). Pasture diets contain a high N content relative to other feed sources (Tamminga, 1996), so urine N loading rates are likely to be higher from a 100% pasture diet. The N loading rate in a urine patch exceeds the pasture requirement for N, particularly during autumn and winter when the temperature is low and the pasture is not growing. During the autumn and winter, N deposited in the urine patch is vulnerable to environmental loss (Decau *et al.*, 2003; van Groenigen *et al.*, 2005). Of particular concern are the environmental losses nitrous oxide (N_2O) emissions (as a potent greenhouse gas) and nitrate (NO_3^-) leaching (water quality) (Stark and Richards, 2008). With the exception of Di and Cameron (2007), few studies have quantified the effect of urine N loading rate on N loss and pasture N uptake from the urine patch. The objective of this study was to quantify the effect of urine nitrogen loading rate on cumulative N_2O emissions, NO_3^- leaching and pasture N uptake from a grassland soil.

Materials and methods

Soil monolith lysimeters (0.5 diameter x 0.7 m deep) were collected in autumn 2009 and 2010 from a free-draining sandy loam soil in County Cork Ireland, following the method of Cameron *et al.* (1992) and transported to a facility in County Wexford. Urine was collected during milking from a mixed age Holstein-Friesian dairy herd grazing a pasture diet in late autumn. The urine total N concentration was diluted with water or fortified with urea to produce total N concentrations of 3, 5, 7 and 10 g N L^{-1}. When applied to the lysimeters, these concentrations corresponded to urine N loading rates of 300, 500, 700 and 1000 kg N ha^{-1}. The control was a nil urine treatment. Four replicates of each treatment were arranged in a randomised block design. Treatments were applied to the lysimeters on 15 December 2009 and repeated 28 December 2010 on a new set of lysimeters. Drainage water was analysed for mineral N, including total oxidised N (NO_2^- and NO_3^-) and ammonium (NH_4^+), using standard methods (Aquakem 600A, Thermo Electron, Finland) and for total N using a TOC-N analyser (Shimadzu Inc., Tokyo). The dissolved organic N (DON) was calculated as the difference between the total N and the mineral N. Cumulative N leaching was calculated by summing the N recovered in each drainage event, for each lysimeter. Nitrous oxide was sampled using static chambers and analysed using gas chromatography (Varian 3800 GC with ECD detector). A linear slope calculation provided the hourly N_2O flux, which was then used to estimate the daily flux, assuming it represented the average hourly flux of the day (de Klein *et al.*, 2003). Cumulative N_2O emissions were calculated by integrating the calculated daily N_2O fluxes and linearly interpolating between measurement points for each lysimeter. The measurement period for N_2O was 80 days in year one and 360 days in year two, in order to compare cumulative N_2O emissions from the typical sampling duration with those calculated for a full calendar year. Pasture was harvested approximately monthly, dry matter content calculated and analysed for N content. The apparent N recovery (or emission factor for N_2O) for NO_3^- leaching and N uptake was calculated as the cumulative N recovered in each pathway net of the control, as a percentage of the urine N applied. Climatic variables daily rainfall (mm) and mean daily air temperature (°C) were obtained from a meteorological station situated adjacent to the lysimeter facility. For the cumulative N recovered in each year, an analysis of variance (ANOVA) was carried out on the $\log_{10}$-transformed N recovery to determine the difference between the two blocks, as well as the between treatment effects. The ANOVA included an examination of linear and quadratic orthogonal contrasts for the five urine rates 0, 300, 500, 700 and 1000 kg N ha^{-1}.

Results and discussion

Climate

In year one the daily air temperature ranged from -1.2 to 20.2 °C, with an average of 9.6 °C. Year two temperatures ranged from -2.5 to 17.7 °C with an average of 10.3 °C. The average air temperature in the first 100 days after urine application was 4.2 °C in year one compared to 6.2 °C in year two, both of which were lower than the long-term average for the area of 6.3 °C, over the same period. Total rainfall inputs and drainage losses in year one were 763 and 435 mm respectively, and 864 and 435 mm respectively, in year two. The lysimeter soil was close to field capacity when urine was applied in both years.

The effect of urine nitrogen rate on nitrogen leaching

The cumulative NO_3^--N leaching loss was 7, 108, 140, 184 and 193 kg N ha^{-1} in year one, where urine was applied at 0, 300, 500, 700 and 1000 kg N ha^{-1}, respectively, which corresponded to 31, 24, 23 and 17% of the N applied (Figure 1a). In year two, the cumulative NO_3^--N leaching loss was 13, 93, 103, 125 and 207, where urine was applied at 0, 300, 500, 700 and 1000 kg N ha^{-1}, respectively, which corresponded to 25, 17, 16 and 18% of the N applied. The relationship between urine N rate and the cumulative amount of NO_3^--N leached was quadratic ($P < 0.001$) and was described by the following equations in year one ($y = -0.0002x^2 + 0.3466x + 7.9338$) and in year two ($y = 4E\text{-}06x^2 + 0.1634x + 19.702$) (Figure 1a). These results were similar to the linear relationship with cumulative NO_3^--N leached where urine was applied at 0, 300, 700 and 1000 kg N ha^{-1}, respectively, reported by Di and Cameron (2007) from lysimeters of a free-draining silt loam soil.

Whereas the cumulative NO_3^--N leached was similar in year one and year two, the cumulative total N leached was markedly different (Figure 1b). In year one, the total N leached was 11, 206, 352, 417 and 409 kg N ha^{-1}, and in year two was 15, 128, 165, 197 and 274 kg N ha^{-1}, where urine was applied at 0, 300, 500, 700 and 1000 kg N ha^{-1}, respectively in each year. The difference between the total N leaching loss in year one and two was mostly due to the leaching of a large amount of DON in year one, which was 4, 68, 163, 136 and 83 kg N ha^{-1}, where urine was applied at 0, 300, 500, 700 and 1000 kg N ha^{-1}, respectively. Although urea was not measured, most of the DON was leached within the first 25 mm of drainage, suggesting leaching by preferential flow. Interestingly, despite the large difference in total N leached, and preferential flow occurring soon after urine application in year one, the cumulative NO_3^--N leached was very similar in year one and year two. Cumulative NO_3^--N leached in year one was expected to be lower than in year two if a large proportion of the applied N was leached soon after urine application. These findings suggest that native soil N was leached in addition to the applied N, either initially by preferential flow (conflicting the suggestion above) or later in the season as NO_3^-. Solubilisation of native soil N following urine application has also been found in other studies (Monaghan and Barraclough, 1993; Wachendorf *et al.*, 2005).

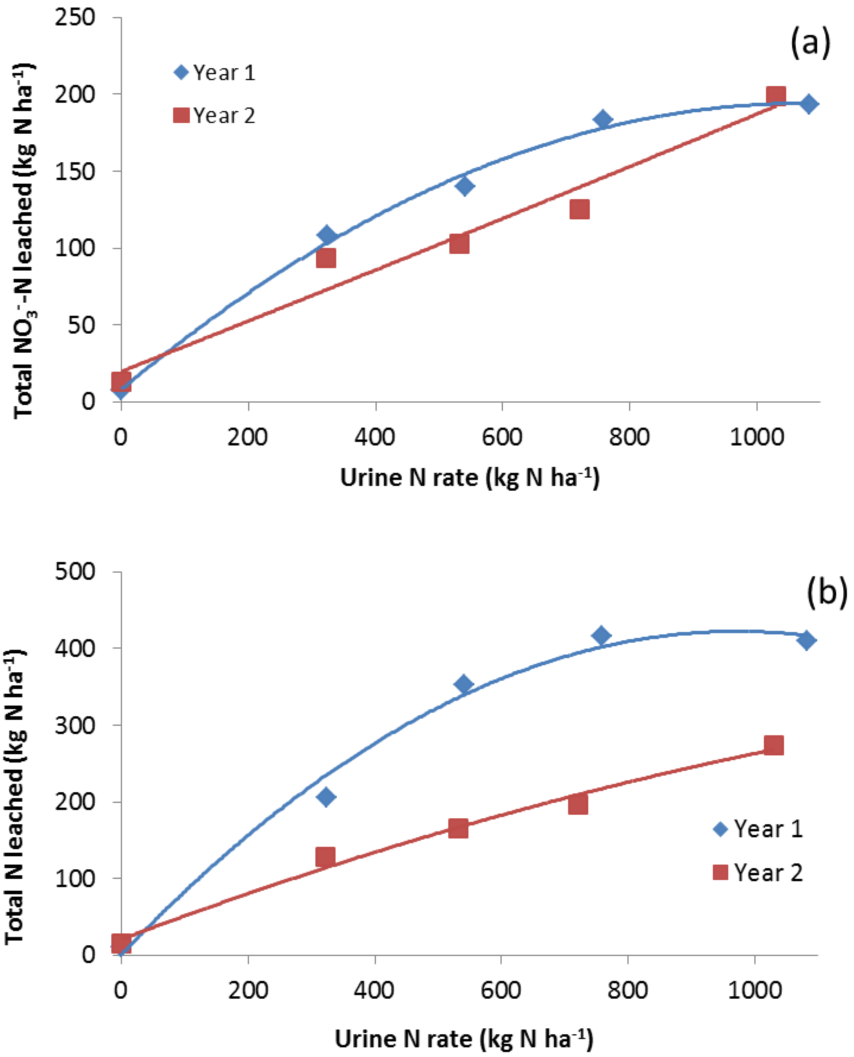

Figure 1: The effect of urine nitrogen loading rate on (a) cumulative nitrate leaching, and (b) cumulative total nitrogen leaching.

The effect of urine nitrogen rate on nitrous oxide emissions

Cumulative nitrous oxide emissions following urine application were similar in year one and year two over the same 80 day measurement period (Figure 2). The cumulative N_2O emissions were higher for the longer measurement period (360 days) in year two. Despite this, the emission factor (EF_3) remained consistently below 0.4%, regardless of the period of measurement or amount of urine N applied. The relationship between urine N rate and cumulative N_2O emissions followed a quadratic function in year one and year two ($P < 0.001$). The quadratic functions were described by the following equations in year one ($y = -5E\text{-}07x^2 + 0.0041x + 0.1828$), year two after 80 days ($y = -2E\text{-}06x^2 + 0.0058x + 0.1743$) and after 360 days ($y = -2E\text{-}06x^2 + 0.0094x + 0.5933$) where y is the total N_2O-N emissions and x is the urine N rate applied (Figure 2). The highly significant quadratic relationship indicated diminishing emissions at the higher urine N rates, which must have been due to a factor other than N availability limiting N_2O production. One possible explanation was nitrification inhibition by the high N loading rate reducing the pool of NO_3^- available for denitrification (Clough *et al.*, 2003). Another possibility is the availability of a labile carbon (C) source limiting N_2O production at the higher N rates. Further discussion on the effect of urine N rate on N_2O emissions is provided in Selbie *et al.* (2014). A third explanation may have been an alternative pathway of N removal such as immobilisation, volatilisation or complete denitrification (to N_2).

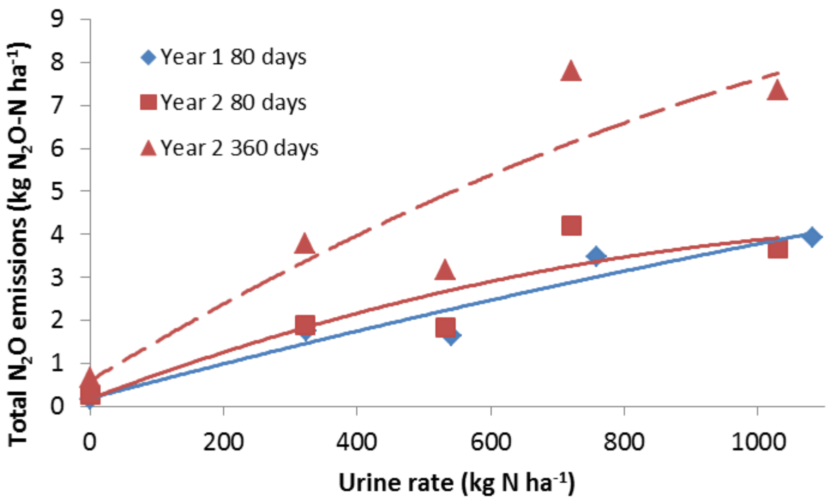

Figure 2: The effect of urine nitrogen loading rate on cumulative nitrous oxide emissions over 80 days in year one and over 80 and 360 days in year two.

The effect of urine nitrogen rate on pasture nitrogen uptake

Pasture N uptake in year two was between two and four times higher than in year one (Figure 3). In year one, the pasture growth was slow, which was more likely to have been a result of over-cutting of the pasture during a particularly harsh winter (to ~2 cm), than to a urine scorch effect or nutrient deficiency. The pasture N uptake in year two was similar to that found on under similar conditions on a free-draining stony soil by Di and Cameron (2007), who reported cumulative N uptake of 133, 361, 451 and 632 kg N ha^{-1}, where urine was applied at 0, 300, 700 and 1000 kg N ha^{-1}, respectively, in a lysimeter study. A significant quadratic function described the relationship between the rate of urine N applied and the amount of N taken up by the pasture, in year one ($P < 0.01$) and year two ($P < 0.05$) (Figure 3). The relationships were described by the following equations in year one ($y = 0.0002x^2 - 0.0384x + 59.832$) and year two ($y = 0.0002x^2 + 0.1931x + 149.94$) where y was the pasture N uptake and x was the urine N rate applied (Figure 3).

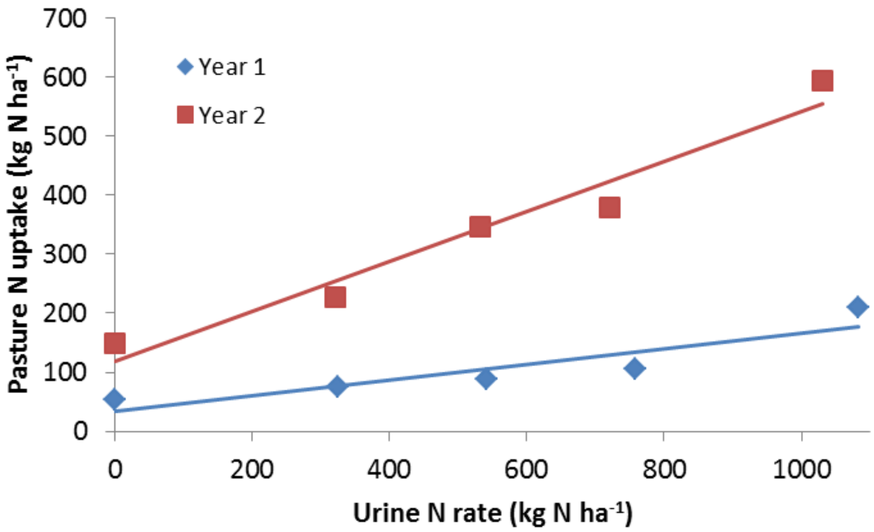

Figure 3: The effect of urine nitrogen loading rate on the cumulative nitrogen uptake by pasture in year one and year two.

The relationship between total N leaching and pasture N uptake in a urine patch

Comparison of the N recovery in each fraction indicates that there was a strong relationship between the total N leached and the pasture N uptake from each lysimeter, regardless of urine N rate or the difference between measurement years (Figure 4). Moir *et al.* (2012) also reported a strong relationship (R^2 of 0.70-0.74) between N leaching and plant N uptake from 13 temperate grass species treated with urine in a glasshouse pot study. Although there are several other competing processes for N in the urine patch, these results highlight the importance of N uptake as a sink for urine N. There is potential for mitigation methods to reduce N leaching beneath urine patches by enhancing N uptake, for example by over-sowing to maintain a productive sward, or the use of winter active or deep-rooting grass species (Malcolm *et al.*, 2014).

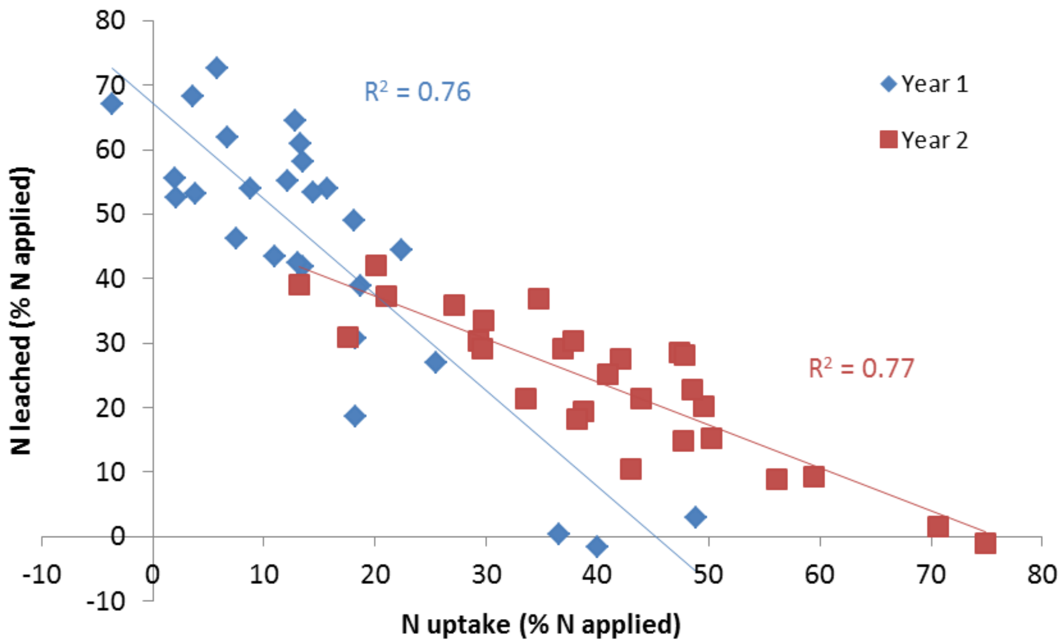

Figure 4: The relationship between cumulative total N leached and cumulative N uptake from each lysimeter in year one and year two.

Conclusions

Increasing the loading rate of urinary nitrogen significantly increased the cumulative N_2O emissions, NO_3^- leaching and pasture N uptake, due to an increasing supply of N. The relationship between the increasing urine N rate and N recovery was, in all cases, curvilinear ($P < 0.001$), with the N recovery diminishing at the higher N rates. This diminishing relationship was likely due to a limiting factor other than N, such as C availability, however the exact mechanism was not able to be identified in this study. Additional findings included a strong relationship between N leaching and N uptake beneath the urine patch, and the evidence of solubilisation of native soil N.

References

Barrow, N.J., Lambourne, L.J., 1962. Partition of excreted nitrogen, sulphur, and phosphorus between the faeces and urine of sheep being fed pasture. Australian Journal of Agricultural Research 13, 461-471.

Cameron, K.C., Smith, N.P., McLay, C.D.A., Fraser, P.M., McPherson, R.J., Harrison, D.F., Harbottle, P., 1992. Lysimeters without edge flow: an improved design and sampling procedure. Soil Science Society of America Journal 56, 1625-1628.

Clough, T.J., Sherlock, R.R., Mautner, M.N., Milligan, D.B., Wilson, P.F., Freeman, C.G., McEwan, M.J., 2003. Emission of nitrogen oxides and ammonia from varying rates of applied synthetic urine and correlations with soil chemistry. Australian Journal of Soil Research 41, 421-438.

de Klein, C.A.M., Barton, L., Sherlock, R.R., Li, Z., Littlejohn, R.P., 2003. Estimating a nitrous oxide emission factor for animal urine from some New Zealand pastoral soils. Australian Journal of Soil Research 41, 381-399.

Decau, M.L., Simon, J.C., Jacquet, A., 2003. Fate of urine nitrogen in three soils throughout a grazing season. Journal of Environmental Quality 32, 1405-1413.

Di, H.J., Cameron, K.C., 2007. Nitrate leaching losses and pasture yields as affected by different rates of animal urine nitrogen returns and application of a nitrification inhibitor - a lysimeter study. Nutrient Cycling in Agroecosystems 79, 281-290.

Haynes, R.J., Williams, P.H., 1993. Nutrient cycling and soil fertility in the grazed pasture ecosystem. Advances in Agronomy 46, 119-199.

Malcolm, B.J., Cameron, K.C., Di, H.J., Edwards, G.R., Moir, J.L., 2014. The effect of four different pasture species compositions on nitrate leaching losses under high N loading. Soil Use and Management 30, 58-68.

Moir, J.L., Edwards, G.R., Berry, L.N., 2012. Nitrogen uptake and leaching loss of thirteen temperate grass species under high N loading. Grass and Forage Science 68, 313-325.

Monaghan, R.M., Barraclough, D., 1993. Nitrous-oxide and dinitrogen emissions from urine-affected soil under controlled conditions. Plant and Soil 151, 127-138.

Selbie, D.R., Cameron, K.C., Di, H.J., Moir, J.L., Lanigan, G.J., Richards, K.G., 2014. The effect of urinary nitrogen loading rate and a nitrification inhibitor on nitrous oxide emissions from a temperate grassland soil. Journal of Agricultural Science (IN PRESS).

Stark, C.H., Richards, K.G., 2008. The continuing challenge of nitrogen loss to the environment: Environmental consequences and mitigation strategies. Dynamic Soil, Dynamic Plant 2, 41-55.

Tamminga, S., 1996. A review on environmental impacts of nutritional strategies in ruminants. Journal of Animal Science 74, 3112-3124.

van Groenigen, J.W., Velthof, G.L., van der Bolt, F.J.E., Vos, A., Kuikman, P.J., 2005. Seasonal variation in N_2O emissions from urine patches: Effects of urine concentration, soil compaction and dung. Plant and Soil 273, 15-27.

Wachendorf, C., Taube, F., Wachendorf, M., 2005. Nitrogen leaching from N-15 labelled cow urine and dung applied to grassland on a sandy soil. Nutrient Cycling in Agroecosystems 73, 89-100.