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Urine patch and fertiliser N interaction: Effects of fertiliser rate and season of urine application on nitrate leaching and pasture N uptake

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ABSTRACT

Urine patches are the primary source of N loss from pastoral systems due to the high N loading that occurs over a relatively small area. However, few studies have sought to determine the effect of concurrently deposited urine and fertiliser on the fate of N in pastoral systems, even though the application of fertiliser soon after grazing is commonly practised, while no studies have examined seasonal effects of any interaction.

The objective of this study was therefore, to understand how the combination of fertiliser-N and urine affected fertiliser-associated NO_3^- leaching losses and plant uptake of N. A two year lysimeter study was undertaken with urine (800 kg N ha^{-1}) applied in either autumn or spring. Urea fertiliser enriched with ^{15}N was applied to these lysimeters at rates equivalent to 200 or 400 kg N ha^{-1} per year according to the standard regional practice.

Urine and fertiliser at the 400 kg N ha^{-1} rate increased total NO_3^- leaching by up to 58 kg ha^{-1} ($P < 0.001$), from urine applied in either autumn or spring. Fertiliser applied at 200 kg N ha^{-1} did not increase N leaching from urine patches. Fertiliser ^{15}N recovery in drainage was <2.2% and was not affected by fertiliser rate. Pasture uptake accounted for up to 52% of the fertiliser ^{15}N recovery and this increased with increasing fertiliser rates, even in the presence of urine. Recovery of fertiliser ^{15}N in the soil at the end of the experiment averaged 22% with the majority of this in the top 10 cm soil.

These results indicate that the potential for leaching of fertiliser N, applied to a urine patch, is low, and that avoiding fertiliser application over urine patches, reduces leaching losses of fertiliser-N by <2%, which is minimal in terms of total N loss mitigation. However, at high fertiliser application rates to urine patches (i.e. 400 kg N ha^{-1}), the total N leaching from non-fertiliser (non ^{15}N-enriched) sources can increase. Further work is required to quantify these effects at the paddock scale. The results also show that NO_3^- leaching losses were greater from autumn applied urine compared to spring applied urine by up to 306 kg NO_3^--N ha^{-1}.

1. Introduction

The mitigation of nitrate (NO_3^-) leaching is a significant challenge facing the New Zealand agricultural industry, and it has been a focus of research over the past two decades. Loss of nitrogen (N), as NO_3^-, reduces soil fertility and potential productivity, while also posing an environmental threat (Cameron et al., 2013). Nitrate leaching may accelerate eutrophication of surface water bodies, resulting in water quality deterioration and subsequent effects on aquatic habitats, recreational use and aesthetics (Sutton et al., 2011).

Ruminant urine deposition and the application of urea fertiliser in dairy farming systems contributes to N leaching losses from pastures (Cameron et al., 2013). Urine-N is the dominant NO_3^- leaching source in grazed dairy pastures because the urine-N rate exceeds the pasture's ability to utilise it. Urine-N induced NO_3^- leaching losses are more likely in late autumn, winter and early spring, when temperatures are cooler, plant N demand is low and soil drainage occurs due to rainfall exceeding evapotranspiration (Wild and Cameron, 1980). Conversely, fertiliser-N leaching losses can be low, if timing of fertiliser-N application and rates match plant demand (Di and Cameron, 2002b; Cameron et al., 2013).

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Despite numerous suggestions that fertiliser application onto urine-affected areas (i.e. grazed pasture) will lead to an increased risk of N leaching and decreased fertiliser N use efficiency (Silva et al., 1999; de Klein et al., 2001; Silva et al., 2005; Mackenzie et al., 2011; Cameron et al., 2013), few studies have quantitatively investigated the interaction between concurrent mineral fertiliser-N application and urine-N deposition with respect to N leaching (Silva et al., 1999; Leterme et al., 2003; Decau et al., 2004; Silva et al., 2005). Furthermore, no studies have partitioned the fertiliser contribution to N leaching under concurrently applied urine and fertiliser. Understanding the relative contributions of fertiliser-N and urine-N is crucial if N leaching is to be successfully mitigated.

Various mitigation strategies to reduce N leaching from pastoral systems have been proposed (Addiscott, 1996; Di and Cameron, 2002b), including developing precision technology for applying fertiliser-N while avoiding urine and dung patches (Yule and McVeagh, (2011); Mackenzie et al. (2011). Such technologies would, theoretically, increase fertiliser-N use efficiency in pastoral systems if fertiliser-N was preferentially lost under urine patches. However, knowledge of the urine patch-fertiliser-N interaction and the respective contributions to N leaching is extremely limited, and by default so are the economic and environmental benefits such technologies may provide.

Thus, the primary objective of this study was to understand how fertiliser-N interacted with urine to affect NO_3^- leaching losses and plant uptake of N, when fertiliser was applied following urine deposition in either autumn or spring, and to determine to what extent, if any, fertiliser-N enhanced leaching of N from under a urine patch. It was hypothesised that (i) increased fertiliser associated leaching would occur under urine patches with increasing rates of fertiliser application, and (ii) that leaching would be greatest under an autumn deposited urine patch when compared to a spring deposited urine patch.

2. Methods and materials

2.1. Soil description and lysimeter collection

Thirty six large, undisturbed soil monolith lysimeters (50 cm diameter × 70 cm deep) were collected on 14 December 2010 from the AgResearch No. 1 Dairy Farm, at the Ruakura Research Centre, Hamilton, New Zealand (latitude 37.779°S, longitude 175.315°E). The soil at the collection site was a moderately permeable, well drained Horotiu silt loam (Typic Orthic Allophanic Soil) (Singleton, 1991; Hewitt, 1998). The soil was under a ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens*) pasture and had a history of regular cattle grazing and fertiliser application. The site was fenced off 4 months prior to lysimeter collection to prevent animal access. Basic soil properties (0–7.5 cm depth) are listed in Table 1.

Lysimeter collection followed the procedure of Cameron et al. (1992) with steel cylinder casings (50 cm diameter × 70 cm deep) inserted into the soil to a depth of 70 cm, while avoiding soil compaction. The soil monolith was then cut at the base and steel base plates were affixed and sealed. Liquefied petroleum jelly was used to prevent preferential flow between the soil and the casing (Cameron et al., 1992). Dry soil bulk density was determined using cylindrical soil core samplers at the lysimeter collection site for the purpose of calculating soil pore volume. Completed lysimeters were transported to a purpose built field trench facility where they were installed at the same level as the surrounding pasture surface to maintain normal pasture growing conditions. Following installation (10 weeks prior to the start of the experiment) pasture within the lysimeters received 25 kg N ha^{-1} as urea followed by 10 mm of water to stimulate pasture growth.

Table 1
Basic soil properties (0–7.5 cm).

Soil properties	Value
pH	5.9
Total C (g kg^{-1})	55
Total N (g kg^{-1})	6.7
Olsen P (mg kg^{-1})	30
Sulphate sulphur (mg kg^{-1})	6
Potassium ($cmol_c$ kg^{-1})	0.65
Calcium ($cmol_c$ kg^{-1})	8.1
Magnesium ($cmol_c$ kg^{-1})	1.57
Sodium ($cmol_c$ kg^{-1})	0.14
Cation exchange capacity ($cmol_c$ kg^{-1})	23
Total base saturation (%)	45

2.2. Experiment design and treatments

Prior to treatment application, the lysimeters each received 800 mm of tap water (>1 pore volume) over a 10 day period to leach antecedent NO_3^--N. Nine treatments were arranged in a 3 × 3 factorial design with four replicates. Three treatments consisted of ^{15}N enriched (5 atom%) urea fertiliser rates (0, 200 and 400 kg N ha^{-1} $year^{-1}$) applied as 8 annual, evenly split, applications of 0, 25 and 50 kg N ha^{-1}, respectively, without any urine application and are subsequently referred to as F0U0, F2U0 and F4U0 (Table 2). A further three treatments had the same fertiliser treatments but with a single bovine urine-N treatment (applied 15 min prior to the fertiliser), in spring, at a rate of 800 kg N ha^{-1} subsequently referred to as F0US, F2US and F4US (Table 2). The final three treatments also had the same fertiliser and urine treatments but the urine was applied in autumn, and these are subsequently referred to as F0UA, F2UA and F4UA (Table 2).

The 200 kg N ha^{-1} $year^{-1}$ fertiliser rates represented standard fertiliser practice for dairy farms in the Waikato region, while the 400 kg N ha^{-1} $year^{-1}$ rate represented a rate for a more intensive dairy production system. The split fertiliser-^{15}N dressings were applied evenly, in a powder form, over the whole area of the lysimeters and immediately washed in using 10 mm of deionised water to reduce NH_3 volatilisation (Black et al., 1987).

Fresh dairy cow urine was collected from the AgResearch dairy farm at Tokanui for each urine application. The concentration of the fresh autumn and spring urine was 8.2 and 13.1 g N L^{-1}, respectively. The urine was standardised to a concentration of 8.0 g N L^{-1} using distilled water. A total of 1.8 L of urine was applied over the entire surface area of the urine-treated lysimeters on either the 4th May 2011 (autumn) or 31 August 2011 (spring). Urine concentration and volume were selected based on previously reported studies from cows grazing pasture (Petersen et al., 1956; Davies et al., 1962; Richards and Wolton, 1976; Safley et al., 1984; Haynes and Williams, 1993). The urine was washed in with 10 mm of water to reduce NH_3 volatilisation. When water was applied to wash in fertiliser and/or urine, the same amount of water (10 mm) was applied to all lysimeters, including controls. The treatments and timing of their application are outlined in Table 2 and Fig. 1, respectively. The experiment began on 21 February 2011 and continued until 28 August 2012 (554 days).

2.3. Sample collection: leachate, pasture and soil

Leachates from the lysimeters were collected regularly, after rainfall induced drainage ceased, refrigerated (4 °C) and analysed within 24 h for inorganic-N and dissolved organic-N (DON). Sub-samples were frozen (−20 °C) until ^{15}N analysis.

Pasture was cut and removed every 2–4 weeks to a height of 3 cm (*c.* 1600 kg DM ha^{-1} residual) to imitate a grazing regime typical of a Waikato dairy system. Harvested DM was dried (55 °C)