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The effect of nitrogen concentration in synthetic cattle urine on nitrous oxide emissions

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ABSTRACT

This study determined a relationship between N concentration in synthetic cattle urine and the nitrous oxide (N_2O) emission factor (EF_3; N_2O-N emitted as % of urine N applied) under field conditions. The results will improve the assessment of the efficacy of N_2O mitigation options that affect urinary N concentration and deposition rates. Field studies on two free draining soils and one poorly draining soil were conducted using synthetic urine with N concentrations of 0, 2, 4, 6, 8, 10 and 12 g N L^{-1} (equivalent to application rates of 0 to 1200 kg N ha^{-1}). The study on the poorly draining soil also included a urine N concentration of 14 g N L^{-1} (1400 kg N ha^{-1}). N_2O emissions were measured for up to 18 weeks after urine application using a static chamber methodology. The EF_3 values ranged from 0.03 to 0.34% of urine N applied on the free draining soils and from 0.5 to 0.9% on the poorly draining soil. There was a statistically significant ($p < 0.05$) trend of increasing EF_3 with increasing N application rate on the free-draining soils, with EF_3 increasing 3- to 4-fold between the lowest and highest N rate. No such trend was found on the poorly draining soil, indicating that for this soil the N_2O emission factor was independent of the N application rate. These results suggest that the urine N concentration only affected the N_2O emission factor when values were very low. We therefore conclude that mitigation strategies which reduce the urine N concentration in individual urination events, but not the overall total amount of urine N excreted over the whole farm system, may have limited impact on reducing total direct N_2O emissions.

1. Introduction

Pastoral agriculture is New Zealand's dominant industry and land-use, and is characterised by year-round grazing of grass-clover pastures. As a result, urine patches deposited by grazing animals are the single largest source of the potent greenhouse gas (GHG) nitrous oxide (N_2O), contributing c. 80% of total N_2O emissions (Ministry for the Environment, 2012).

New Zealand is committed to reduce its GHG emissions and current strategies for reducing N_2O emissions from urinary nitrogen are to either reduce the total amount of urine N deposited or to reduce the N_2O emission factor of urinary N ($EF_{3\text{-urine}}$). Options to reduce the total amount of urine N deposited include reducing the N intake of animals or reducing stocking and/or animal replacement rates, while options to reduce $EF_{3\text{-urine}}$ include using nitrification inhibitors, adjusting the timing grazing and fertiliser management to avoid high N_2O loss risk conditions, or reducing the N concentration of individual urination (Beukes et al., 2010; de Klein and Eckard, 2008; de Klein and Monaghan, 2011; Di and Cameron, 2006; Luo et al., 2010). Hoogendoorn et al. (2010) reported that the urine N concentration of grazing animals on less intensively grazed rolling hill country can vary widely both between and within animal species, with mean (and range) values for single urinations of 7.9 (1.4–17.8) and 4.4 (0.9–13.2) g N kg^{-1} fresh urine for sheep and beef cattle, respectively. For dairy cattle on more intensive lands urine N concentrations of 5–10 g N kg^{-1} fresh urine have been reported (de Klein et al., 2003; Di and Cameron, 2007; van der Weerden et al., 2011). At typical urination volumes of 4 and 10 L m^{-2} for sheep and cattle, respectively (Haynes and Williams, 1993) these urine N concentrations are equivalent to 50–700 kg N ha^{-1} (sheep) 100–1300 kg N ha^{-1} (beef cattle) and 500–1000 kg N ha^{-1} (dairy cattle). The within-species variability suggests that there is indeed scope for manipulating the urine N concentrations of individual urinations. For example, Ledgard et al. (2007) showed that supplementing the animals with salt reduced the urine N concentration of each urination, as it increased their water intake, and

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urination frequency, but did not affect the volume of urine excreted per event.

To calculate its annual N_2O emissions, New Zealand adopts the Intergovernmental Panel on Climate Change (IPCC) inventory calculation method with New Zealand-specific emission factors (N_2O emitted as % of N applied) for a range of N sources. The current NZ emission factors for animal excreta deposited to pasture are 1% of urine-N applied ($EF_{3\text{-urine}}$) and 0.25% for dung-N applied ($EF_{3\text{-dung}}$; Ministry for the Environment, 2012), and are based on research trials conducted on the past two decades (Carran et al., 1995; de Klein et al., 2003; de Klein et al., 2004; Muller et al., 1995; Sherlock et al., 2003a, 2003b; van der Weerden et al., 2011). These emission factors are applied to the total amounts of urine- and dung-N applied annually. As a result of using a constant value of $EF_{3\text{-urine}}$, the current inventory calculations cannot account for any mitigation strategies that could reduce the N concentration of animal urine but not the total amount of urinary N returned to pasture, such as salt supplementation. As $EF_{3\text{-urine}}$ is the amount of N_2O loss per unit of N applied, a constant $EF_{3\text{-urine}}$ value implies a linear relationship between N application rate and cumulative N_2O emissions. However, some studies have shown that cumulative N_2O emissions can increase exponentially with increasing N application rate suggesting that the N_2O emission factor is not constant (e.g. Cardenas et al., 2010; Hoben et al., 2011; MacKenzie et al., 1997; McSwiney and Robertson, 2005; Peng et al., 2011; Rochette et al., 2010). In a recent meta-analysis of studies on the effects of N application rate on N_2O emissions, Kim et al. (2013) suggest a three phase response of EF_3 to increases in N rate additions based on differences in competition for N between vegetation and soil microbes. However, the studies reviewed by Kim et al. (2013) used inorganic fertiliser N rather than urine N and at N application rates of up to 400 kg N ha^{-1} only. Although Clough et al. (2003) measured N_2O emissions following urine N application at different rates up to 1000 kg N ha^{-1} their study was conducted using sieved soils in laboratory conditions. In addition, they could not fully determine the effect of urine-N rate on the $EF_{3\text{-urine}}$ as they measured emissions for only 21 days following urine application and N_2O emissions from the urine treatments were still significantly higher than the non-urine treatment. This study therefore aimed to determine the relationship between urine N application rate and the N_2O emission factor ($EF_{3\text{-urine}}$) under field conditions. Our null hypothesis was that cumulative N_2O emissions increase linearly with urine N application rate and that $EF_{3\text{-urine}}$ is constant and can be calculated by the slope of the relationship.

2. Materials and methods

2.1. Soil and site description

The study was conducted in two temperate climate regions of New Zealand: Waikato and Otago. The Waikato region is warm and moist, with annual rainfall and average air temperatures of 1240 mm and 14 °C, respectively, while the Otago region is cooler and drier, with annual rainfall and average air temperatures of 700 mm and 9 °C, respectively. At the Waikato site, the study was conducted on a porous-textured free draining Horotiu soil (Typic Orthic Allophanic; Hewitt, 1998) and a heavy-textured poorly draining Te Kowhai soil (Typic Ochraqualf) (175° 36′ 37° 76′). The soil of the Otago site (170° 23′ 45° 50′) was a well-structured free draining Wingatui soil (weathered fluvial recent soil).

The soils supported mixed swards of perennial ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*) intensively grazed by dairy cattle (Waikato) or sheep (Otago). Before measurements began, the plots were fenced off to exclude stock for at least a month to reduce the risk of variability caused by previously deposited urine patches.

2.2. Experimental set-up

The experiments were carried out to measure cumulative N_2O emissions following synthetic urine application to soils and were intended to enable comparisons of the relative differences in EF_3 between urine with different N concentrations. In a previous study de Klein et al. (2003) showed that the N_2O emission patterns of synthetic urine were very similar to those of fresh urine and concluded that synthetic urine could be used for comparative treatment studies. Synthetic urine N rate treatments were applied in a randomised block design (5 replicates per treatment) in June 2010 (free draining Horotiu and Wingatui soils) or May 2011 (poorly draining Te Kowhai soil). While the same volume of urine was applied to each plot, the N application rate was varied by adjusting the N concentration in the urine.

The synthetic urine (Clough et al., 1996) contained $KHCO_3$ (13.8 g L^{-1}), KSO_4 (1.36 g L^{-1}), KCl (4 g L^{-1}), and $CO(NH_2)_2$ (urea) and $C_2H_5NO_2$ (glycine) at varying N concentrations depending on treatment (ranging from 2 to 12 or 14 g N L^{-1}). The N content of the urine was adjusted by altering the amount of both urea and glycine added to the mixture, with the ratio of glycine and urea as percentage of total N being kept constant at 9 and 91%, respectively. At the start of each experiment, 0.5 L of synthetic urine was slowly and evenly applied to the soil surface in each stainless steel ring (0.05 m^2) to represent a typical urination rate of 10 L m^{-2} (Haynes and Williams, 1993). As mentioned, the volume of urine applied was not varied in our study as the volume of single urination events of dairy cows is generally constant. For example, Ledgard et al. (2007) showed that supplementing dairy cows with salt to encourage them to drink more increased the urination frequency but not the volume each urination event. In our study we therefore solely focussed on investigating the effects of the urine N concentration and included concentration levels equivalent to 200 to 1200 kg N ha^{-1} in 2010 and 200 to 1400 kg N ha^{-1} in 2011 (Table 1). A 'Control' treatment, receiving no urine or water, was also included at each site.

2.3. N_2O emission measurements

A non-vented closed chamber technique was used to measure N_2O emissions (de Klein et al., 2003), with PVC chambers at the Waikato site and stainless steel chambers at the Otago site. Although the configuration of the chambers and the deployment protocols were slightly different at each site, they both conformed to criteria set out in recent guidelines for N_2O chamber methodologies (de Klein and Harvey, 2013). A week before the measurements commenced, stainless steel base rings were inserted into the soil at both sites, to approximately 10 cm depth. At the soil surface, the rings were fitted with a 2 cm-tall 'water-trough' flange. Otago site: On each sampling day, the stainless steel chambers were inserted into the 'water-trough' flange (25 cm diameter) which was filled with water to provide an airtight seal around the chamber. The chambers (270 mm in diameter and 100 mm in height) were insulated with polystyrene foam and covered with self-adhesive aluminium foil to minimise temperature and pressure fluctuations in the enclosed gases. The chambers were also fitted with suba-seal sampling ports that were removed at the time of chamber placement into the water trough. Waikato site: The PVC chambers (240 mm in diameter and 200 mm in height) were modified sewer hatches with removable lids fitted with a sampling valve. The "sewer-hatch" rim had an internal half-turn locking system and a greased rubber O-ring, which formed a gas-tight seal. These chambers were also placed in a 'water-trough' base (23 cm diameter) throughout each individual measurement period. Chamber heights were measured and the volume calculated.