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Nitrous oxide emissions from urea fertiliser and effluent with and without inhibitors applied to pasture

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ABSTRACT

There is currently a limited number of New Zealand studies quantifying nitrous oxide (N_2O) emission factors (EF_1, N_2O emissions as a percentage of N applied) for farm dairy effluent (FDE) and urea fertiliser. Therefore, two experiments were conducted in four regions of New Zealand to determine EF_1 for FDE and urea fertiliser applied to pastures with contrasting soils and climatic conditions. Experiment 1 included urease and nitrification inhibitors to determine their effect on EF_1. Urea treatments included (i) standard urea; (ii) urea amended with the nitrification inhibitor dicyandiamide (DCD) at 0.02 kg DCD kg^{-1} nitrogen (N) and (iii) urea amended with the urease inhibitor *N*-(*n*-butyl) thiophosphoric triamide (*n*BTPT) at 250 mg *n*BTPT kg^{-1} urea, while FDE was applied with or without DCD, at 10 kg DCD ha^{-1}. Experiment 2 focused solely on FDE, which was applied to pastures that had either never received FDE or had a history of repeated application of FDE over several years. Urea fertiliser produced a large variation in EF_1 values, ranging from 0.03% to 1.52%. Application of FDE resulted in EF_1 ranging from 0.06% to 0.94% across both experiments. The urease and nitrification inhibitors had little or no effect on reducing EF_1 from urea fertiliser and FDE application. The history of repeated applications of FDE to pasture also had no effect on EF_1.

1. Introduction

Nitrous oxide (N_2O) is a potent greenhouse gas and contributor to stratospheric ozone depletion, making it a global pollutant of growing concern (Sutton et al., 2014). Agriculture is the largest source of anthropogenic N_2O emissions representing 60% of such emissions (Syakila and Kroeze, 2011), with increasing use of synthetic N fertiliser being one of the important factors, leading to the rapid increase of atmospheric N_2O concentration in recent decades (Davidson, 2009). Synthetic fertilisers and animal manure are applied to pastures to promote growth for livestock feed. In New Zealand, the amount of N fertiliser applied to agricultural soils increased from 59 kt in 1990 to 359 kt in 2013, urea representing more than 80% of all synthetic N fertiliser in 2013 (Ministry for the Environment, 2015). Farm dairy effluent (FDE), a mixture of excreta and water with a total solids (TS) content of less than 5% (Longhurst et al., 2012), is the most common form of animal manure collected and applied to New Zealand pastoral soils (Laubach et al., 2015). Derived from the washdown of dairy milking sheds and associated yards, FDE represented 6% of lactating dairy cattle excreta a decade ago (Ledgard and Brier, 2004). However, this proportion is steadily increasing with increased intensification of dairying in New Zealand, leading to greater use of off-paddock facilities such as feedpads (Laubach et al., 2015), which are now present on approximately one-quarter of New Zealand dairy farms (Luo et al., 2013).

Repeated application of FDE onto pastoral soils may influence the magnitude of N_2O production and emissions due to continued addition of organic manure elevating soil labile C supply. This may raise both background and FDE emissions following FDE application compared to pastoral soils with no effluent irrigation history. Furthermore, apart from labile C influencing substrate supply for

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denitrifiers, it is also possible that nitrifying and denitrifying microbial activity may be influenced by the repeated application of effluent over several years.

To mitigate N_2O emissions from urea- and ammonium-based fertilisers and animal slurries/effluent the nitrification inhibitor dicyandiamide (DCD) has been used for several decades to retain soil N in the ammonium form, thereby improving their N use efficiency, and reduce N losses via nitrate (NO_3^-) leaching and N_2O emissions (Halvorson et al., 2014; Cahalan et al., 2015). Studies have shown that DCD can be effective at reducing N_2O emissions from N fertiliser application (McTaggart et al., 1997; Dobbie and Smith, 2003; Misselbrook et al., 2014; Gilsanz et al., 2016) and slurry and effluent application to grassland soils (Li et al., 2014, 2015; Cahalan et al., 2015; Gilsanz et al., 2016). In addition, urease inhibitors, such as *N*-(*n*-butyl) thiophosphoric triamide (*n*BTPT) that slow the conversion of urea to NH_4^+ by inhibiting soil urease activity and reducing NH_3 emissions can reduce the rate of nitrification and potentially the associated N_2O emissions. However results on the efficacy of urease inhibitors to reduce N_2O emissions have been inconsistent (Saggar et al., 2013). For example, Sanz-Cobena et al. (2012) conducted a two-year study comparing standard urea with *n*BTPT-treated urea for maize production and observed a 54% reduction in N_2O emissions in the first year, but no reduction in the following year.

As the current country-specific values of EF_1 for FDE and urea are based on few studies, largely conducted in one region of New Zealand, we conducted two experiments across four regions to test the following hypotheses: (i) the nitrification inhibitor DCD can effectively reduce the EF_1 for FDE as well as urea, (ii) the urease inhibitor *n*BTPT can effectively reduce the urea EF_1, and (iii) repeated application of FDE will alter the FDE EF_1.

2. Methodology

2.1. Field sites

Two field experiments were conducted in 4 regions (Waikato, Manawatu, Canterbury and Otago) of New Zealand. The first experiment started in September 2013 and the second in September 2014. All the regions have temperate climates, with mean annual rainfall of 1240 mm and mean annual temperature of 14 °C in Waikato, 970 mm and 13 °C in Manawatu, 680 mm and 11.5 °C in Canterbury and 700 mm and 9 °C in Otago.

Table 1 describes soil characteristics at each site in Experiments 1 and 2. All of the sites support a predominately ryegrass (*Lolium perenne*)/white clover (*Trifolium repens*) pasture which is grazed. Animals were excluded from the experimental sites for at least two months prior to treatment application, based on previous experience (Luo et al., 2007).

2.2. Experimental design and treatments

Each experiment was laid down as a completely randomised block design, with 6 replicates of each treatment. Experiment 1 included five N treatments; (i) urea (50 kg N ha^{-1}), (ii) urea + DCD (0.02 kg DCD kg^{-1} N) (iii) urea + *n*BTPT (250 mg *n*BTPT kg^{-1} urea) (iv) FDE (52–58 kg total N ha^{-1}) and (v) FDE +DCD (10 kg DCD ha^{-1}) (Table 2), as well as an untreated control (C). Each experimental site included 36 plots of 2 × 2.5 m, within which an area of 2 × 2 m was treated for soil sampling, to ensure there was sufficient soil available for 12 months of field sampling. The remaining 0.5 × 2 m area was used for siting N_2O gas chambers. A single application of each treatment was made on 4 or 5 September 2013, depending on the region. In New Zealand urea application to pasture is typically split 75:25 between spring and autumn (Jeff Morton, Ballance Agri-Nutrients, pers. comm.). The majority of stored FDE is typically applied from spring through to mid-summer, with less applied in the latter half of the lactation season up to the end of autumn to ensure storage ponds are empty by the beginning of winter (Dave Houlbrooke, AgResearch, pers. comm.). In this study the rate of urea applied was the same for each treatment and similar to the typical rate used for pasture (30–50 kg N ha^{-1}; Roberts and Morton, 2012) while FDE was typically applied at between 30 and 150 kg N ha^{-1} (maximum N load; Houlbrooke et al., 2013). For the FDE-DCD treatment, DCD was dissolved in deionised water at a rate of 10 kg DCD (containing 0.7 kg N kg^{-1}) per 800 L and sprayed on to the pasture plots immediately before FDE application, resulting of addition of 7 kg DCD-N ha^{-1}. Because

Table 1
Soil characteristics and locations of each site used for Experiments 1 and 2. For paddock FDE history, the number of years each site had received FDE is shown in brackets.

Region	Soil order	Soil type	Paddock FDE history (number of years receiving FDE)	Soil properties					
				Olsen P (mg L^{-1})	pH	Organic C (g kg^{-1} soil)	TKN (g kg^{-1} soil)	Bulk density (Mg m^{-3})	Total porosity (m^3 m^{-3})
Experiment 1: September 2013									
Waikato	Typic, orthic allophanic	Horotiu silt loam	No FDE history	44	6.0	59	6.7	0.84	0.68
Manawatu	Weathered, fluvial, recent	Karapoti fine sandy loam	No FDE history	27	5.7	25	2.6	1.08	0.59
Canterbury	Immature pallic	Templeton fine sandy loam	No FDE history	25	6.5	28	2.2	1.16	0.56
Otago	Mottled-weathered fluvial recent	Wingatui deep silt loam	No FDE history	32	6.0	49	4.8	0.90	0.66
Experiment 2: September 2014									
Waikato	Typic orthic allophanic	Horotiu silt loam	No FDE history	97	6.1	67	6.7	0.85	0.63
			FDE history (20)	114	6.4	72	7.3	0.83	0.64
Manawatu	Typic fluvial recent	Recent sandy[a]	No FDE history	53	6.9	14	1.4	1.26	0.52
			FDE history (25[b])	57	5.9	25	2.6	1.16	0.55
Canterbury	Immature pallic	Templeton fine sandy loam/silt loam.	No FDE history	26	5.8	37	3.5	1.12	0.56
			FDE history (14)	20	6.0	37	3.3	1.06	0.59
Otago	Acidic orthic gley	Koau deep silty clay loam	No FDE history	21	6.2	93	8.3	0.75	0.69
			FDE history (10)	65	6.5	108	9.9	0.73	0.69

[a] The 'No FDE history' site was classified as a sandy loam soil, whilst the 'FDE history' site was classified as a loamy silt soil.
[b] Estimated by the farmer as "20–30 years", therefore we have assumed a mid-point of 25 years.