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Short communication

Refining the New Zealand nitrous oxide emission factor for urea fertiliser and farm dairy effluent

T.J. van der Weerden[a,*], N. Cox[a], J. Luo[b], H.J. Di[c], A. Podolyan[c], R.L. Phillips[d], S. Saggar[e], C.A.M. de Klein[a], P. Ettema[f], G. Rys[f]

[a] AgResearch Invermay, Private Bag 50034, Mosgiel 9053, New Zealand
[b] AgResearch Ruakura, Private Bag 3123, Hamilton 3240, New Zealand
[c] Lincoln University, Department of Soil & Physical Sciences, Faculty of Agriculture and Life Sciences, Lincoln University, New Zealand
[d] Landcare Research, PO Box 69040, Lincoln 7640, New Zealand
[e] Landcare Research, Private Bag 11052, Manawatu Mail Centre, Palmerston North 4442, New Zealand
[f] Ministry for Primary Industries, PO Box 2526, Wellington 6140, New Zealand

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ABSTRACT

Applications of urea fertiliser and farm dairy effluent (FDE) to New Zealand pastures are the second and third largest sources of nitrous oxide (N_2O) emissions, after emissions from excreta deposited during grazing (urine and dung). New Zealand currently employs emission factors (EF_1) (percentage of N applied which is emitted as N_2O) of 0.48% and 1% for urea fertiliser and FDE, respectively, for calculating its national N_2O inventory. The country specific emission factors for urine and dung are 1% and 0.25% respectively. Because FDE has a higher organic nitrogen (N) content than urea, and because it is a diluted mixture of urine and dung, the mean FDE EF_1 is expected to be less than 1%. With a recent increase in research trials measuring EF_1 for FDE and urea, the objective of this study was to refine New Zealand-specific EF_1 values for these N sources. We analysed urea fertiliser and FDE N_2O emission data from 45 EF_1 field trials conducted in New Zealand. This meta-analysis yielded a combined (urea and FDE) EF_1 mean of 0.46% (95% confidence interval of 0.07% and 0.90%), with EF_1 means for urea and FDE of 0.59% and 0.25%, respectively. There was no statistical difference between urea fertiliser and FDE EF_1 values. However, we recommend separate country-specific EF_1 means of 0.6 and 0.3% for urea fertiliser and FDE, respectively, for New Zealand's agricultural soils N_2O emissions inventory due to the different origin and characteristics of these N sources.

1. Introduction

Nitrous oxide (N_2O) is the third most important anthropogenic greenhouse gas and the largest remaining anthropogenic stratospheric ozone depleting substance currently being emitted, with agriculture as its largest source, representing 66% of total emissions (Davidson and Kanter, 2014). The rapid global increase in synthetic nitrogen (N) fertiliser use and the intensification in livestock farming, resulting in growing volumes of animal excreta and manure, are contributing to the increasing atmospheric N_2O concentrations (Davidson, 2009). It has been estimated that global fertiliser use will increase 50% from 2006 to 2050 (Sutton and Bleeker, 2013).

In New Zealand's pasture-grazed livestock systems, excreta deposited by the grazing animal (i.e. urine and dung) is the largest source of N_2O emissions. However, following global trends, the amount of synthetic N fertiliser applied to agricultural soils has increased from 59 kt in 1990 to 359 kt in 2013, with 80% of the total represented as urea fertiliser (Ministry for the Environment, 2015). In addition, recent increase in the number of dairy animals has resulted in a doubling of the amount of farm dairy effluent (FDE) applied to land, from 18 kt in 1990 to 39 kt in 2013 (Ministry for the Environment, 2015). Farm dairy effluent is a mixture of excreta and water derived from the washdown of dairy cow milking sheds and associated yards. This is the most common form of animal manure collected and applied to New Zealand pastoral soils (Laubach et al., 2015).

Direct N_2O emissions following application of synthetic N fertiliser and animal manures to agricultural soils are included in national N_2O inventories, and are calculated by multiplying the amount of N applied by the direct N_2O emission factor EF_1

* Corresponding author. Fax: +64 3 4893739.
E-mail address: tony.vanderweerden@agresearch.co.nz (T.J. van der Weerden).

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(percentage of N applied which is emitted as N_2O). The IPCC (Intergovernmental Panel on Climate Change) recommend a "default value" of 1% for N fertiliser and manure EF_1 (IPCC 2006) which has an uncertainty range of 0.3 to 3.0% (Smith et al., 2012). However, there have been a number of international studies reporting lower EF_1 values for urea fertiliser compared to the IPCC default value (e.g. Misselbrook et al., 2014; Kuikman et al., 2006; Velthof and Mosquera, 2011; Galbally et al., 2005; Chen et al., 2010). New Zealand has recently adopted a country specific EF_1 value of 0.48% based on a statistical analysis of animal urine and dung and urea fertiliser field experiments conducted in New Zealand (Kelliher et al., 2014). This country-specific value is based on several studies (e.g. de Klein et al., 2004; Luo et al., 2007, 2010), with about two-thirds conducted in one region of New Zealand (Waikato). For FDE, New Zealand uses a value of 1% (Ministry for the Environment, 2015), which is the same as the current IPCC default value (IPCC, 2006). However, the EF_1 value for FDE could be expected to be lower than the one for urea, as the organic N in FDE is not readily available for nitrification and denitrification, which are the main processes for N_2O production in soil. Another reason why the FDE EF_1 is expected to be lower than 1% is that FDE is a mixture of urine and dung that have New Zealand specific emission factors of 1 and 0.25%, respectively.

A recent increase in the number of studies focusing on determining N_2O emissions and EF_1 values for FDE and urea fertiliser across New Zealand (Li et al., 2014, 2015; van der Weerden and Rutherford, 2015; van der Weerden et al., 2016) provides a timely opportunity to perform a meta-analysis to refine country-specific EF_1 values for these two N sources for New Zealand. Furthermore, Chadwick et al. (2011) suggested that, due to the varying amounts of organic N in animal manure applied to land (in New Zealand's case FDE), it may be more useful to express the N_2O emission factor as percentage of the inorganic N (rather than total N) applied.

The objectives of our study are therefore to firstly utilise the available FDE experimental data to determine the most significant variables influencing FDE EF_1 and to assess the efficacy of expressing the EF1 for FDE as percentage of inorganic N applied; and secondly refine the New Zealand country-specific emission factors for urea fertiliser and FDE.

2. Methodology

2.1. Drivers of FDE EF_1

Access to key soil, climatic and FDE characteristics from Bhandral et al. (2007),Li et al. (2014, 2015), van der Weerden and Rutherford (2015) and van der Weerden et al. (2016) allowed a best subsets regression analysis (Hocking and Leslie, 1967) of their influence on FDE EF_1. A natural log transformation of EF_1 was required due to its non-normal distribution. Because a large fraction of the total N is in the organic form, requiring mineralisation followed by nitrification to form an effluent-derived NO_3^- (Chadwick et al., 2011), we also converted EF_1 to an emission factor based on the readily available N applied, as determined by the total ammoniacal N (TAN) content of the FDE (EF_{1TAN}). The data for EF_{1TAN} was also log transformed (ln) prior to a best subsets regression.

The regression approach examines all possible combinations of variables to determine which combinations give the best prediction of FDE EF_1. Key variables included initial characteristics of the soil (soil pH, soil organic C content, soil total N, soil C:N ratio, soil bulk density), regional/environmental variables (region, season, cumulative rainfall in first 1 and first 3 months, average soil temperature (5 cm depth) in first 1 and first 3 months, average water filled pore space (WFPS) in the first 1 and first 3 months) and effluent characteristics (total solids, pH, Total C, Total N, C:N ratio, TAN content, TAN as a percentage of Total N, TAN and N load). We have used 1 and 3 month periods as we would expect a high proportion (ca 50–80%) of N_2O emissions from FDE to occur in the first month, while emissions can be expected to return to background levels 3–4 months following application (van der Weerden et al., 2016). All data from the studies by Li et al. (2014, 2015), van der Weerden and Rutherford (2015) and van der Weerden et al. (2016) was sourced directly from the publication or, where missing, was provided by the authors. Data from the Bhandral et al. (2007) study was taken directly from the publication's tables and text, or, for average soil temperature and WFPS, was estimated from their figures. Adjusted R^2 values are reported; this measure makes an allowance for the number of parameters used in the best subsets regression. The Akaike information criterion (AIC) was used to guide choice of the best model.

2.2. Meta-analysis of EF_1

Meta-analysis is a quantitative synthesis of results across multiple studies. Kelliher et al. (2014) conducted a meta-analysis of field experimental results to calculate a New Zealand country-specific EF_1 value for urea fertiliser and EF_3 values for cattle and sheep excreta. Their meta-analysis did not include FDE as a source of N_2O, as the available dataset relevant to an EF_1 calculation at that time was limited to a single study in New Zealand: Bhandral et al. (2007). However, the recent increase in field studies on FDE EF_1 (Li et al., 2014, 2015; van der Weerden and Rutherford, 2015; van der Weerden et al., 2016) resulting in the number of FDE EF_1 values increasing 6-fold from 4 to 25, justified a meta-analysis of EF_1 for FDE. For urea, an additional 4 values were available since the Kelliher et al. (2014) meta-analysis, which increased the total data set for urea EF_1 to 24 values. Unlike Kelliher et al. (2014), we did not include urine and dung data (EF_3) for this updated analysis, as the combined dataset of 49 values was considered sufficient for a separate meta-analysis of EF_1.

In total, 49 EF_1 data from 45 field trials were included in the meta-analysis. All field sites were classified according to 2 soil drainage classes (free versus poor), region and season. Trials were limited to four regions of New Zealand (Waikato, Manawatu, Canterbury and Otago), conducted from 2003 to 2015. Season for each trial was defined by determining which month the trial's 15th day occurred as follows: January, February and December for summer, March, April and May for autumn, June, July and August for winter and September, October and November for spring, as previously used by Kelliher et al. (2014).

For estimating EF_1, we used a natural log transformation with N source included as a fixed effect and other effects fitted as random effects within a model that retains any non-zero variance components. The estimated effects were back-transformed and bias corrected. The bias correction was done by scaling the back-transformed estimates by the amount required to get their weighted mean to be the same as the overall mean of the EF_1 values (Kelliher et al., 2014).

3. Results

3.1. Drivers of FDE EF_1

The best subsets regression revealed a significant multi-variable relationship between ln (EF_1) and region, season, soil bulk density, FDE TAN content and Total N load (Adj. $R^2 = 0.74$, $P < 0.001$). The analysis of ln (EF_{1TAN}) produced a similarly significant multi-variable relationship where up to 65% of the variance could be explained by four of the five same variables: