

SIMULATION OF NITROUS OXIDE EMISSIONS FROM DAIRY- GRAZED PASTURES AND ITS MITIGATION STRATEGIES

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ABSTRACT

Intensive chamber (~20 per ha) measurements of soil N₂O emissions were taken throughout the year to account for spatial and temporal variability from two highly productive grass/legume ungrazed and grazed dairy pastures, to assess the influence of soil moisture, temperature, and availability of N (NH₄⁺ and NO₃⁻) on N₂O emissions, and to calibrate a process-based model to simulate these emissions. The soils at these New Zealand pasture sites differed in texture and drainage characteristics. Our results showed that excretal and fertiliser-N input, and soil water-filled pore space (WFPS) were the variables that most strongly regulated N₂O fluxes, and the denitrification was the primary source of N₂O emissions from the grazed pastures. A process-based Denitrification-Decomposition (DNDC) model, modified to represent New Zealand grazed pasture systems ("NZ-DNDC"), was used to simulate the emissions. The NZ-DNDC model simulated effectively most of the N₂O emission pulses and trends from both the ungrazed and grazed dairy pastures, and fairly reproduced the real variability in underlying processes regulating N₂O emissions. The NZ-DNDC estimates of total yearly emission of N₂O from the grazed and ungrazed sites of both farms were within the uncertainty range of the measured emissions. Our model accounted for the climatic variations in rainfall, and was also able to pick up differences in emissions resulting from differences in soil texture. Results suggest the model's applicability to simulating N₂O emissions from a range of New Zealand grazed pastures. Our current research focuses on using NZ-DNDC to monitor the efficacy of mitigating urine-induced N₂O emissions from grazed pasture systems, using nitrification inhibitors.

1.0 INTRODUCTION

Nitrous oxide contributes about 16% (on a CO₂-equivalent basis) of New Zealand's greenhouse gas emissions. The N excreted by sheep and cattle onto grazed pastures provides high localised concentrations of available N and C in soils, and is the main source of anthropogenic N₂O emissions from New Zealand, contributing to about 85% of total N₂O emissions (Cameron et al. 2000).

New Zealand has ratified the Kyoto Protocol and is required to produce an annual inventory of N₂O emission from all anthropogenic sources to assess the magnitude and change in total emissions. New Zealand currently relies on the IPCC default methodology (New Zealand Climate Change Project 2002), and on animal population statistics for each region to estimate its N₂O emission inventory. Direct and indirect emissions from animal excreta (dung and urine) are estimated using N excreted by each animal type. IPCC default

methodology is only a first approximation, because of i) uncertainty in emission factors, ii) uncertainty in indirect emissions, iii) limited data on the type and amount of N excreted by grazing animals, and iv) spatial and temporal variability of N₂O emission. It, therefore, appears to be too simplistic and generalised, ignoring all site-specific controls. The IPCC methodology is also not sufficiently flexible to allow mitigation options to be assessed. Current emission rates from excretal input and from different soils in New Zealand are very uncertain, and uncertainty in New Zealand's N₂O emissions is $\pm 65\%$ (Sherlock et al. 2001), which must be reduced if changes since 1990 are to be reported internationally.

Accordingly, a more robust, process-based approach is required that is internationally acceptable and quantifies N₂O emissions at the field level more accurately than the IPCC methodology. Such an approach is needed to develop regional- and national-scale inventories with known levels of uncertainties. DNDC (DeNitrification DeComposition; Li et al. 1992) is a process-based model with reasonable data requirements that has been used to produce regional estimates for the US (Li et al. 1996), China (Li et al. 2001), Germany (Butterbach-Bahl 2001), Canada (Smith et al. 2002), and the UK (Brown et al. 2001, 2002). Although the model is suitable for simulation at appropriate temporal and spatial scales there were particular limitations in applying this model directly to New Zealand soils, which are distinctive and diverse within short distances, and have higher organic carbon contents than the world average (Saggar 2001). The New Zealand grazed pastoral system (grazing 24 hours a day) and climatic conditions are also different. The DNDC model has, therefore, to be modified to represent New Zealand grazed pastoral systems.

Here we present seasonal variations in N₂O emissions from two dairy pastures with contrasting soils, and assess the influence of soil moisture, temperature, availability of N (NH₄⁺ and NO₃⁻) and soluble C on N₂O emissions. We then assess the ability of a modified DNDC model "NZ-DNDC" to simulate these emissions.

2.0 MATERIALS AND METHODS

2.1 EXPERIMENTAL SITES

The experimental sites were at Massey University, Turitea campus (40° 21' S, 175° 39' E). Average rainfall (1970–2000) at these sites is about 965 mm, which is fairly evenly distributed throughout the year with driest months being January–March. The mean annual sunshine is ~1900 h. The mean annual air temperature is 12.8°C, and the coldest and warmest months are July (6.8°C) and January (18.1°C). Soil temperature and rainfall data during the study period are illustrated in Fig. 1.

The two sites are part of Massey University's dairy-farm systems, which represent highly productive (~16 Mg DM ha⁻¹ y⁻¹) legume-based pastures on different soil types (Weathered Fluvial Recent, Karapoti fine sandy loam, and Argillic-fragic Perch-gley Pallic, Tokomaru silt loam). These sites were selected because their soils provide a contrast in texture and hydraulic properties. The pastures are regularly fertilised with N and P, and are 3 km apart. They were

rotationally grazed for periods of 12 to 48 hours at a time by dairy cattle. Intervals between grazing varied from 2 to 6 weeks, depending on herbage accumulation. A representative area of each farm (5 × 5 m) was fenced to exclude grazing, and excretal and fertiliser inputs, and was used as a control. The control areas were mown to 20 mm height at each grazing event, with clippings removed.

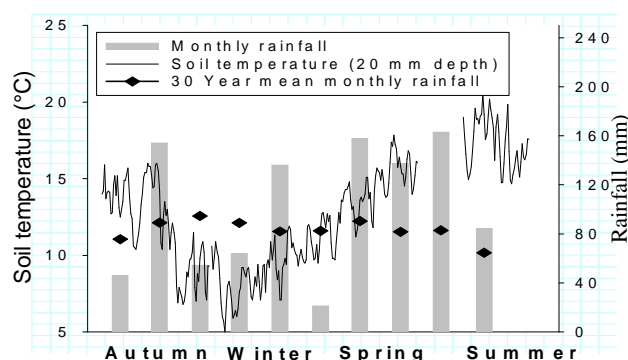


Figure 1. Distribution of daily soil temperature and monthly rainfall during the study period and 30-year mean monthly rainfall.

2.2 NITROUS OXIDE MEASUREMENTS

Nitrous oxide measurements were made periodically between April 2001 and February 2002 from the grazed and ungrazed areas at each site. To account for the spatial variability, 18 replicate chambers were randomly located c. 20 m apart along a Z-shaped transect to measure the fluxes of N₂O from the grazed area (~1 ha); two chambers were located in the ungrazed area (~0.005 ha). To protect the chambers from damage, they were removed from the sites while stock were present. Full descriptions of the chambers, collection and analyses of gas samples, calculation of N₂O flux, and soil sampling and analyses are presented elsewhere (Saggar et al. 2002, 2003).

2.3 ENVIRONMENTAL VARIABLES AND SOIL WATER CONTENT

At the Tokomaru site, an automated meteorological station was set up to monitor daily rainfall, wind velocity, soil temperature and volumetric soil water content (SWC), which was monitored using calibrated Delta-T theta probes (MLZx) at depths of 20, 50, 100 and 300 mm. For the Karapoti site, data were taken from an existing automated meteorological station 2 km away, and gravimetric SWC was measured at 0–50 and 50–100 mm depths, only on gas sampling days. Field-moist soil samples were weighed, oven-dried (105° C) to constant mass, and weighed again. The final mass M_s , and the difference between the field moist and dry masses M_w were used to calculate the gravimetric SWC = $(M_w/M_s) \times 100$. The volumetric SWC was then calculated by multiplying the gravimetric SWC with the soil bulk density. Soil temperature was measured at both sites with a thermocouple at 20 mm depth at 30-min intervals. Water-filled pore space (WFPS) was calculated as the ratio of the volumetric SWC to the total pore space.

2.4 MODELLING

DNDC was modified to better represent New Zealand's grazed pasture systems. Modifications were made to version 6.7 of the model, the most recent version at the time the research was begun [a newer version has been released that may address some of the deficiencies found in version 6.7]. Details of the modifications are given in Saggar et al. (2003). The modified model, hereafter named "NZ-DNDC", was then used to simulate N₂O emissions from the pastures grazed by dairy cattle.

3.0 RESULTS AND DISCUSSION

3.1 SEASONALITY OF N₂O FLUXES

Figures 2a and 2b show measured N₂O emissions for each site. Large spatial and temporal variations were observed in the N₂O fluxes measured from the grazed area in both the pastures studied (Figs 2a, b). Large fluxes were generally observed after each grazing and rainfall event, and were followed by a decline. The spatial variations in N₂O fluxes observed for the grazed sites throughout the year were large (Figs 2a, b), with coefficient of variation values ranging between 56 and 262%. The N₂O fluxes and their spatial variability at both ungrazed sites were low, with coefficient of variation values ranging between 35 and 59%. Spatial variability in N₂O emissions is naturally large in most soils (Folorunso and Rolston 1984; Choudhary et al. 2002) because of soil heterogeneity and the episodic nature of N₂O emissions, and variability increases as a result of animal grazing and unevenly distributed excretal returns (Carran et al. 1995; Saggar et al. 2002).

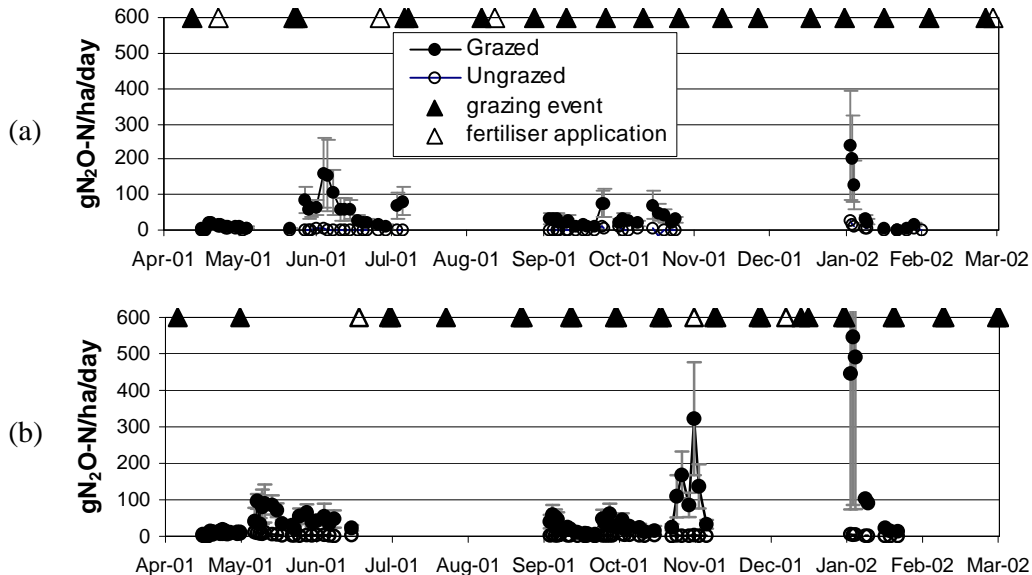


Figure 2. Measured means and ranges of nitrous oxide emissions from grazed and ungrazed pastures from (a) Karapoti and (b) Tokomaru soils.

In both soils, the N₂O emissions for the grazed areas in winter were higher than those in spring. The emissions were lower by about one-third in autumn. However, highest emissions (almost 5 to 10 times of those in winter) were measured in both soils for about a week after a heavy rainfall in January

following a grazing event. The emissions dropped rapidly to the levels observed in autumn as the soils dried out. These highest summer N₂O fluxes could be attributed to a combination of high WFPS and very high soil temperature (~20°C), and high mineral-N. Significant N₂O fluxes occur at higher temperatures, our temperature response being similar to that of Dobbie and Smith (2001). The high N₂O fluxes observed during the winter could have been due to a combination of WFPS exceeding 0.60, a high soil mineral-N content and low plant uptake of N. The low rainfall in autumn resulted in low soil water content (WFPS <0.60), and the lowest N₂O emissions. The spring season was characterised by significant rainfall events, rapidly fluctuating soil water content (WFPS between 0.40 and 0.95), mild temperatures, and increased plant growth that resulted in medium levels of N₂O emissions. This seasonal pattern of N₂O fluxes is consistent with the data of Ruz-Jerez et al. (1994) and Carran et al. (1995). The lowest emissions were obtained during the periods when WFPS was <0.60.

Overall, N₂O emissions were slightly lower in the well-drained fine sandy loam soil compared with the poorly drained silt loam soil. The emissions from the ungrazed pastures were <20% of those from the grazed pastures. These results suggest that in grazed pastures it is the animal excreta deposited in the form of dung and urine that provide high concentrations of available N and C, and are the principal source for N₂O production.

3.2 EFFECT OF SWC, MINERAL N AND EXTRACTABLE C

The SWC was expressed as WFPS, which normalises for differences in bulk density and particle density between soils. Our results show that, of the measured variables, WFPS was the most strongly influential on N₂O fluxes at both grazed sites. Generally, N₂O emissions at the grazed sites were high in both soils when the WFPS was above 'field capacity' (Saggar et al. 2002, 2003), indicating that formation of anaerobic sites following rainfall, a fundamental requisite for denitrification, was mainly responsible for these high N₂O fluxes. The field-capacity WFPS values appear to be the critical levels above which conditions were sufficiently anaerobic to enhance N₂O emissions significantly in the grazed sites. Although both nitrification and denitrification may have contributed to the emissions, the very high fluxes associated with WFPS values, >0.60, were more likely to have come mainly from denitrification. Davidson (1991) showed that nitrification was the dominant source of N₂O when WFPS was <0.60 and denitrification was the predominant source at WFPS >0.60. Dobbie and Smith (2001) suggested the exponential increase in N₂O flux with WFPS above 0.60 pointed to denitrification being responsible for N₂O production in Scottish soils. Further indication of the importance of WFPS in controlling denitrification, and hence N₂O emission, is the abrupt increase in N₂O fluxes when the WFPS increased above 0.66 or 0.62 after a significant rainfall event (data not reported).

Changes in WFPS above field capacity had no discernible effect on emissions at the ungrazed sites, where NO₃⁻ and extractable C levels were very low, indicating the emissions also depended on the supply of mineral N and soluble C substrate from animal excreta. These results show N₂O emissions at the ungrazed sites are obviously limited by the lack of substrate.

3.3 COMPARISONS OF MODELLED WITH MEASURED EMISSIONS

NZ-DNDC simulated well the average daily N_2O fluxes from the control and grazed plots (Figs 3a, b). However, it slightly overestimated spring (October) emissions and also underestimated the very high emissions observed at both the grazed sites in summer (January) due to high temperature and moisture after a rainfall event but simulated well the following low emissions that dropped quickly as the soils dried out.

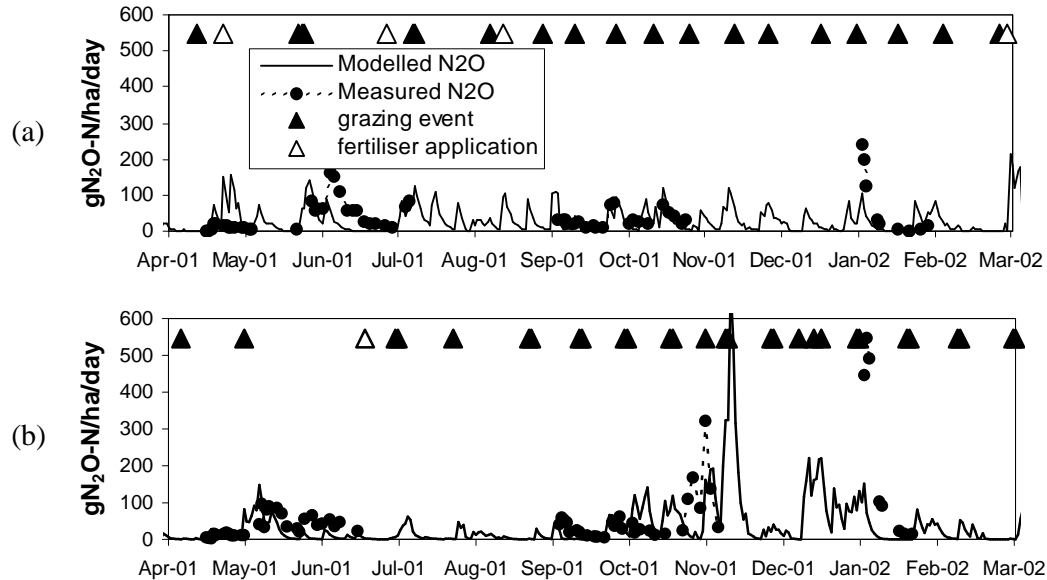


Figure 3. Comparison of modelled and measured nitrous oxide emissions from (a) Karapoti and (b) Tokomaru soils.

The modified NZ-DNDC model was able to predict the annual measured emissions from both the grazed and ungrazed farms very well (Fig. 4). NZ-DNDC estimated an annual net emission of 2.51 and 1.88 kg N_2O -N ha^{-1} (ungrazed areas), and 10.41 and 12.40 kg N_2O -N ha^{-1} (grazed areas) from the well-drained and poorly-drained soils, respectively. Grazing by dairy cattle markedly increased total N_2O emissions in both soils. The excretal plus fertiliser N inputs in the Karapoti and Tokomaru grazed pastures were 396 and 345 kg N ha^{-1} , respectively. The emissions were 1.99% of the excretal and fertiliser N in the well-drained soil, and 2.53% in the poorly drained soil. NZ-DNDC annual emission estimates for both farms were within 10% of the measured values, and are within the uncertainty range of the measured values. However, estimates based on New Zealand refined IPCC methodology (New Zealand Climate Change Project 2002) were about 25 to 60% lower than our modelled and measured values.

The overall comparisons of predicted and measured annual emissions (Fig. 4) indicate NZ-DNDC should be applicable to the simulation of N_2O emissions from a range of New Zealand grazed pastures. More testing is now needed on a range of different soils, and with sheep as well as other cattle-grazed pastoral systems. Our ultimate goal is to be able to estimate emissions accurately on a regional and national scale based on available climatic data, soil types, and numbers and types of grazing animals and their excretal N inputs.

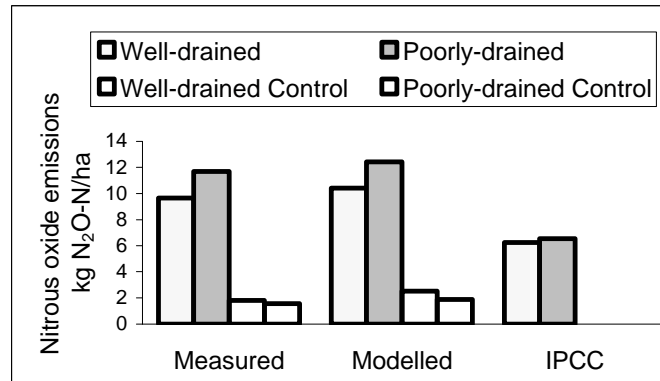


Figure 4. Annual-measured, model-predicted and IPCC-calculated nitrous oxide emissions from two ungrazed and dairy-grazed sites.

NZ-DNDC offers a solid beginning towards this goal and a base for future development. Our current research also focuses on using NZ-DNDC to monitor the efficacy of mitigating fertiliser- and urine-induced N₂O emissions from grazed pasture systems, using nitrification inhibitors, and on developing best management practices for efficient effluent application to reduce N₂O emissions.

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