A BOUNDARY LINE APPROACH FOR ESTIMATING THE RISK OF N_2O EMISSIONS FROM SOIL PROPERTIES

Iris Vogeler[1], Tony van der Weerden[2], Rogerio Cichota[1], Siva Ganesh[1], and Jiafa Luo[3]

[1]AgResearch, Palmerston North
[2]AgResearch, Invermay
[3]AgResearch, Ruakura
Email: iris.vogeler@agresearch.co.nz

Abstract

To reduce agricultural nitrous oxide (N_2O) emissions, a better understanding of the factors driving emissions, and an evaluation of mitigation strategies is required. We linked a boundary line approach (BLA) with outputs from the Agricultural Production systems SIMulator (APSIM) and Dairy NZ's Whole Farm model (WFM) to identify the risk periods of N_2O emissions from urine patches in animal grazing systems. The BLA was based on the soils' water filled pore space (WFPS) and the soil temperature (SoilT), and provided limits for low, medium, and high risk of N_2O emissions. Results presented here are for a Horotiu silt loam in the Waikato Region of NZ. These boundary lines were then used to estimate the likely risk of N_2O emissions from urine depositions during grazing for a typical farm in this region. Estimated paddock scale N_2O emissions were 3.3 kg N_2O/ha/yr. Mitigation by using duration controlled grazing (DCG) at high risk periods for N_2O emissions reduced paddock scale emissions by one third.

Introduction

Agriculture is the largest contributor to New Zealand's (NZ's) total greenhouse gas (GHG) emissions. Nitrous oxide (N_2O) emissions represent approximately one-third of agricultural GHG, with animal excreta being its main source. For inventory purposes N_2O emissions are currently estimated based on a Tier 2 methodology that employs disaggregated emissions factors (EFs) for deposited dung and urine from grazing, with emissions from urine being greatest due to N being deposited in a quickly available form. However, such EFs are insensitive to soil and climate factors that influence emissions. To reduce N_2O emissions, a better understanding of the factors driving emissions and an evaluation of mitigation strategies is required. While deterministic models can be used to evaluate how heterogeneity in climate and soil affect these emissions and identify mitigation options, site specific validation and parameterisation of such models is often lacking, limiting the accuracy of the models. An alternative is to consider empirical models, which are based on more easily available input data, as the one developed by Conen et al. (2000) for estimation of N_2O emissions. Their approach is based on a boundary line (BLA) and using the soils' water filled pore space (WFPS), temperature (SoilT) and mineral nitrogen content (nitrate and ammonium).

In this paper we describe the BLA for estimating limits for low, medium, and high risk periods for N_2O emissions based on WFPS and SoilT. The analysis was done for a Horotiu soil in the Waikato Region. Based on the BLA, and the use of APSIM and the WFM, paddock scale N_2O emissions were calculated and mitigation practice by avoiding grazing during high risk periods was evaluated.

Methods and Materials

Boundary Line Analysis

Data from the N_2O database for New Zealand (Vogeler et al., 2012) were used. The data were restricted to the Waikato Region, the Horotiu soil and N_2O emissions following dairy urine depositions at different times (Figure 1). Following Conen *et al*. (2000) N_2O emissions were categorised into low (<10 g N_2O/ha/d), medium 10-100 g N_2O/ha/d and high (>100 g N_2O/ha/d) emissions. Daily values for the WFPS and SoilT and soil nitrate (NO_3) content were obtained using the APSIM model, a detailed simulation setup has been reported previously (Vogeler et al., 2013b). Only data with NO_3 contents ≥ 10 kg/ha in the upper 200 mm soil profile were used for the BLA as lower NO_3 contents showed low emissions.

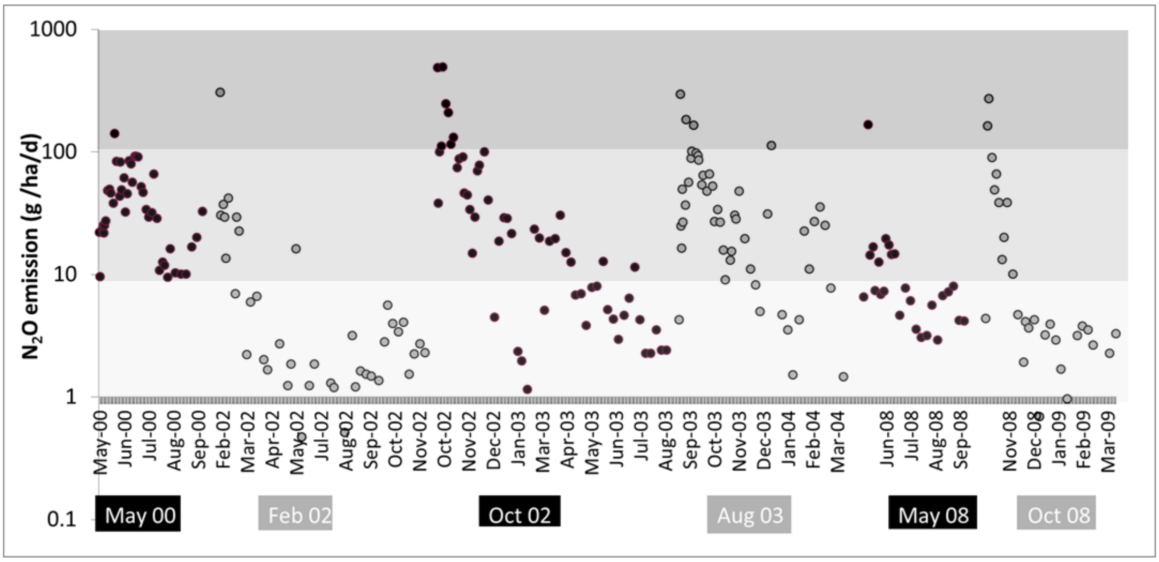

Figure 1. Measured N_2O emissions (N_2O-N) following urine depositions at different times to the Horotiu soil in the Waikato Region of NZ.

Estimation of Long Term Risk of N_2O Emissions

For estimating the average and variability of N_2O emissions over the year APSIM simulations were set up over a period of 20 years (1993-2012) with daily weather data from the Virtual Climate Station database from Ruakura from the NIWA Virtual Climate Station (VCS) dataset (Tait and Turner, 2005). Separate simulations runs were done for each year, the ryegrass/clover sward was harvested every three weeks, and N fertiliser was applied at an annual rate of 200 kg/ha. Model outputs used for the estimation of risk of high N_2O emissions were used are daily values of SoilT and WFPS in the upper 200 mm.

Estimation of Paddock Scale Emissions

To estimate paddock scale N_2O emission results from the BLA were linked with outputs from the WFM and long term modelling using APSIM. The WFM provided urinary N loads deposited during individual grazing events, while the APSIM simulations supplied daily values for WFPS and SoilT.

Results and Discussion

Boundary Line Analysis

The categorised data of N_2O emissions were plotted against WFPS and SoilT to determine boundary lines (or limits) for medium and high risk of N_2O emissions (Figure 2). Boundary lines (parallel lines) were obtained by splitting the data into 8 equidistant segments according to the X-axis (SoilT), selecting the lowest 1% of Y (WFPS) values, and then fitting a regression model to the chosen 1% data.

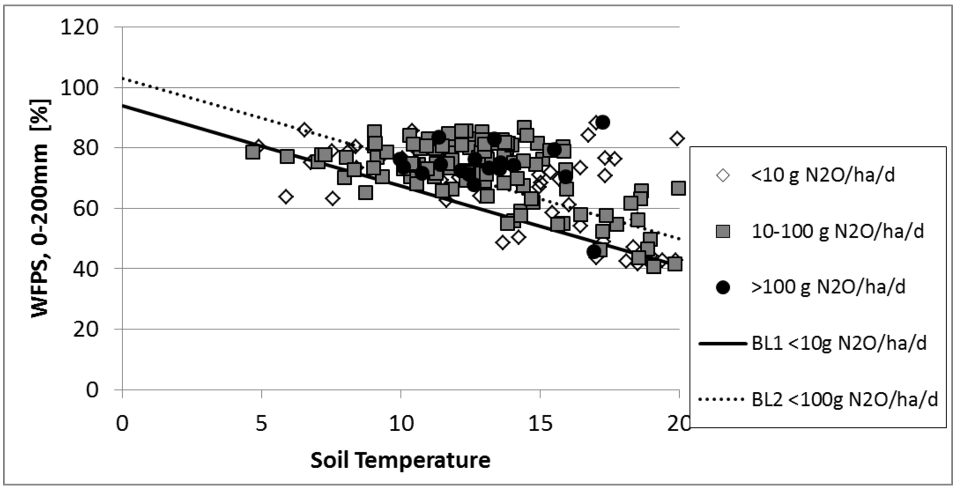

Figure 2. Boundary lines (limits) to WFPS and SoilT below which N_2O emissions were limited to < 10 g/ha/day (solid line) or 100 g/ha/d (broken line). Symbols show measured N_2O emissions (N_2O-N) of <10 (◇), 10-100 (■) and >100 (●), when NO_3 contents in the upper soil profile were non-limiting (> 10 kg/ha).

The boundary line above which N_2O emissions can exceed 10g N/ha/d is given by:

$$WFPS + 2.65\ SoilT = 93.8 \qquad [1]$$

And the boundary line above which N_2O emissions can exceed 100g N/ha/d is given by:

$$WFPS + 2.65\ SoilT = 103 \qquad [2]$$

Risk of High N_2O Emissions

To evaluate the average and variation of the risk of N2O emissions from urine patches over the year daily values of SoilT and WFPS in the upper 200 mm soil profile from 1993 to 2012 were used. Using equations (1) and (2), the risk of N_2O emissions above 10 g N/ha/d and 100 g N/ha/d is shown in Figure 3. The highest risk of N_2O emissions being above 10 g N/ha/d over 20 years occurs in May and August to October, with more than 90% of the days being at high risk. N_2O emissions exceeding 100 g N/ha/d are most likely in May and October, with more than 70% of the days at risk. To mitigate N_2O emissions, grazing at those high risk periods should be avoided or restricted. However there is also a large year to year variability due to the variability in the controlling environmental conditions, here namely WFPS and SoilT. While for example in general the risk of high N_2O emissions in February is low, in some years all days in February are at high risk.

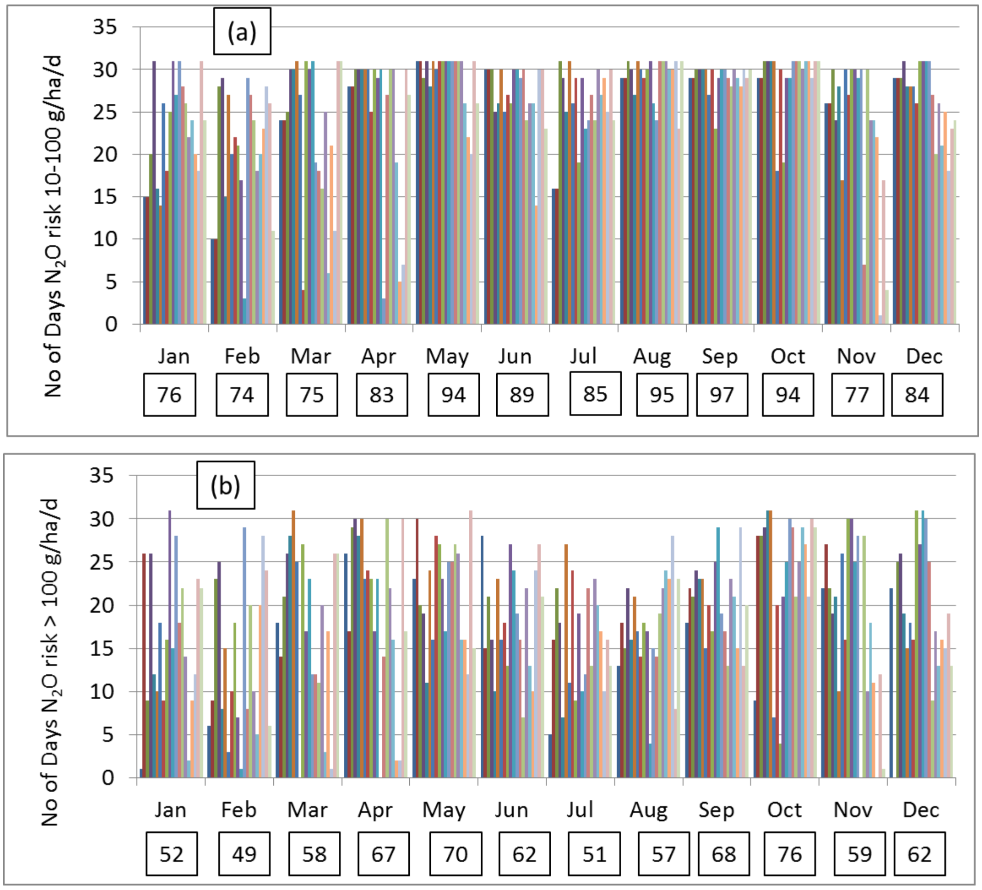

Figure 3. Risk of N_2O emissions (number of days/month) above (a) 10 g/ha/d and (b) 100 g/ha/ based on boundary line analysis for a period of 20 years on a Horotiu silt loam in the Waikato Region. The numbers in the boxes represent the average percentage of days at risk.

Paddock Scale Emissions

To estimate the paddock scale emissions from urine patches the boundary lines for medium (10-100 g N/ha/d) and high (>100 g N/ha/d) N_2O emissions were linked with outputs from WFM for a typical farm on a Horotiu soil in the Waikato Region, scaled to 25 ha. The WFM provided paddock specific grazing times as well as timing and coverage of urine patches (as a percentage of the paddock). Detail of the simulation setup and outputs have been published previously (Vogeler et al., 2013a). Here only the milking platform was considered, and an average year with respect to rainfall (a farming year from 1.6.2004 to 31.5.2005). APSIM outputs of daily values for WFPS and SoilT were used to estimate the risk of N_2O emissions. Results for one of the paddocks are shown in Figure 4a, where 29% of the paddock area receives urinations over the year. Of this area 6% is at low risk with N_2O emissions limited to <10 g/ha/day, 5% of the area is at medium risk with emissions limited to 100 g/ha/d, and 18% is at high risk where emissions can exceed 100 g/ha/d. This results in paddock averaged emissions of 3.3 kg N_2O-N/ha/yr.

Duration controlled grazing (DCG) has been shown as a suitable mitigation option for nitrate leaching from urine patches (Christensen et al., 2010). Here we used DCG to look at potential mitigation of N_2O emissions, and employed DCG at high risk periods (N_2O >100 g/ha/day) with the cows being restricted to 8hrs of grazing/day. This reduces the paddock area that receives urination during high risk periods to 9% (Figure 4b), and the total annual paddock averaged N_2O emissions to 2.2 kg N_2O/ha/year, a reduction of 33%.

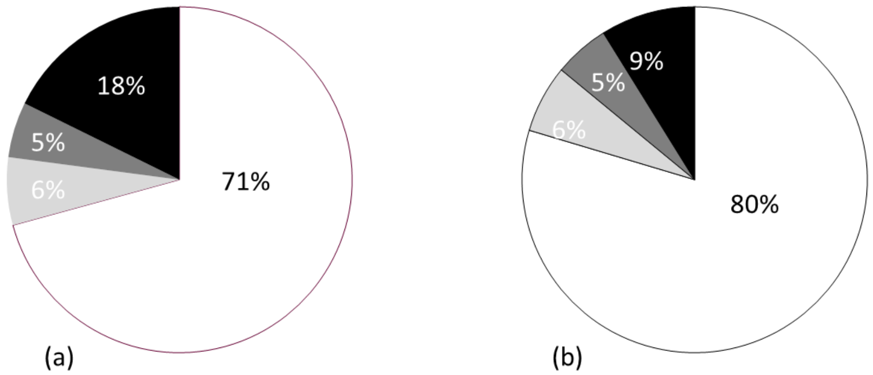

Figure 4. Percentage of a paddock on a typical farm on a Horotiu soil in the Waikato receiving (grey) or not receiving urinations (white) over the 2004/05 farming year. The different shades of grey representing different risk levels with having a risk of N_2O emissions <10 (◻) , between 10-100 (▩), and >100 g/ha/d (■), with (a) under typical management with cows having 16 hrs of active time on the paddock, and (b) under duration controlled grazing of 8 hrs/day during high risk periods.

Total average N_2O emission over the 25 ha milking platform were estimated to be 3.6 kg/ha/yr under typical grazing, and 2.3 kg/ha/yr when duration controlled grazing was employed at high risk periods, which were identified to be 64% of the time.

Conclusion

A boundary approach was used to assess the risk periods of N_2O emissions from urine patches, and linked with outputs from the WFM and APSIM to estimate N_2O emissions from a typical farm in the Waikato Region. Triggering duration controlled grazing during high risk periods reduced potential emissions by one third. Further work is required to extend the approach to other soils and regions, as well as to refine the approach by better accounting for the various sources for N_2O in the soil, mainly ammonium and nitrate.

Acknowledgements

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