Adhikari, K. P., Saggar, S., Luo, J., Giltrap, D., Berben, P., Palmada, T., Sprosen, M., Lindsey, S., & Dando, J., 2020. Nitrous oxide emissions and emission factors from urine-deposited 'hot-spots' in dairy pastures – winter trials. In: *Nutrient Management in Farmed Landscapes.* (Eds C. L. Christensen, D.J. Horne and R. Singh). http://flrc.massey.ac.nz/publications.html. Occasional Report No. 33. Farmed Landscapes Research Centre, Massey University, Palmerston North, New Zealand. 9 pages.

NITROUS OXIDE EMISSIONS AND EMISSION FACTORS FROM URINE-DEPOSITED 'HOT-SPOTS' IN DAIRY PASTURES – WINTER TRIALS

Kamal P. Adhikari[1], Surinder Saggar[1], Jiafa Luo[2], Donna Giltrap[1], Peter Berben[1], Thilak Palmada[1], Mike Sprosen[2], Stuart Lindsey[2] & John Dando[1]

[1]Manaaki Whenua – Landcare Research, Palmerston North, New Zealand

[2]AgResearch, Hamilton, New Zealand

(Email: adhikarik@landcareresearch.co.nz)

Abstract

In dairy-grazed farm systems, total nitrous oxide (N_2O) emissions could be dominated by relatively large emissions within small areas termed 'hot-spots' – areas with high stocking density resulting in proportionally high excretal nitrogen (N) deposition and soil compaction. The objective of this study was to determine N_2O emissions and emission factors from urine (EF_3) applied to potential hot-spot areas (i.e. water troughs, gateways and raceways) to improve our understanding of N_2O emissions within a dairy-grazed farm. Two field studies were conducted during winter at two typical dairy farms, one on a poorly drained Tokomaru soil (Manawatu) and the other on a well-drained Otorohanga soil (Waikato). Gas sampling chambers were placed at various locations in potential hot-spot areas as well as in the surrounding 'typical' pasture area. Soil was either treated with cow urine or remained untreated. Overall, N_2O emissions at the Manawatu site were higher than at the Waikato site. However, there was no clear trend for higher emissions and EF_3 values from applied urine in hot-spot areas compared with those from the 'typical' pasture area at either farm. The winter N_2O emissions measurement results suggest that changes in soil physical and chemical parameters of the areas around the water troughs and gateways, possibly influenced by disproportionate excreta deposition, and soil compaction resulting from stock movements and subsequent elevated water-filled pore space, slightly influenced the total emissions from deposited urine but also affected the background emissions and so had little impact on N_2O EF_3 values when compared with EF_3 values from cattle urine deposited in a 'typical' pasture area.

Introduction

Total nitrous oxide (N_2O) emissions from dairy-grazed farm systems can be dominated by large emissions within a small area ('hotspots'). Typically, N_2O hotspots are areas with high stocking density, high excretal inputs (resulting in high soil N), and situations when soil water-filled pore space (WFPS) are elevated. Potential N_2O hotspot areas within a dairy-grazed farm can be compacted land with a potential for concentration of excretal N, such as gateways, feeding and water trough sites, and raceways. High input systems can lead to a greater potential for N_2O emission hotspots. These N_2O emissions hotspots have a potentially large environmental footprint, yet only represent a small portion of the total farm area. The effect of hotspots on N_2O emissions is not currently included in the New Zealand greenhouse gas (GHG) inventory. Identifying N_2O emissions hot spots in the dairy-grazed farm is required for monitoring and mitigating the emissions of this potent GHG. Preliminary research has shown that the N_2O emissions and the magnitude of N_2O emissions factor (EF_3) from hot-spot locations (water troughs and gateways) are significantly greater than from the rest of the paddock. In a study when the effects of increased EF_3 for urine were considered, gateways with 3.2% of the farm area contributed 9.4% of the total farm N_2O emissions (Luo et al. 2016b, 2017). Further information is needed not only to understand the impact on N_2O emissions from key hotspot

locations but also to understand the effect of different soil types and seasons on emissions. These data can be used to further refine N_2O EF_3 for the national GHG inventory calculations. In addition, such data could also help identify the potential to mitigate emissions by targeting hot spots. The objective of this study was to determine N_2O emissions and calculate EF_3 from cattle urine applied in winter to potential physical hot-spot areas within dairy-grazed farms (i.e. water troughs, gateways, and raceways) in two contrasting soils.

Materials and methods

Experimental set up and treatments

Two field sites, representing a poorly drained Tokomaru soil (Manawatu) and a well-drained Otorohanga soil (Waikato) were established during the winter season at typical dairy farms, growing predominantly perennial ryegrass and white clover. The details of experimental set up and treatments are given in Saggar et al. (2019) and briefly described here. Gas sampling chambers were placed at various locations in potential hot-spot areas (water troughs, gateways and raceways) and in the surrounding 'typical' pasture. The selected areas for the experiments were fenced off for 6–12 weeks before the start of the field trials to avoid interference from fresh dung and urine inputs and reduce spatial variability from the previous N fertiliser inputs and uneven deposition of dung and urine. The layout of gas sampling chambers in Manawatu and Waikato farms are presented in Figure 1. Area inside the chamber was either treated with cow urine (10 L m^{-2}) or remained untreated (control).

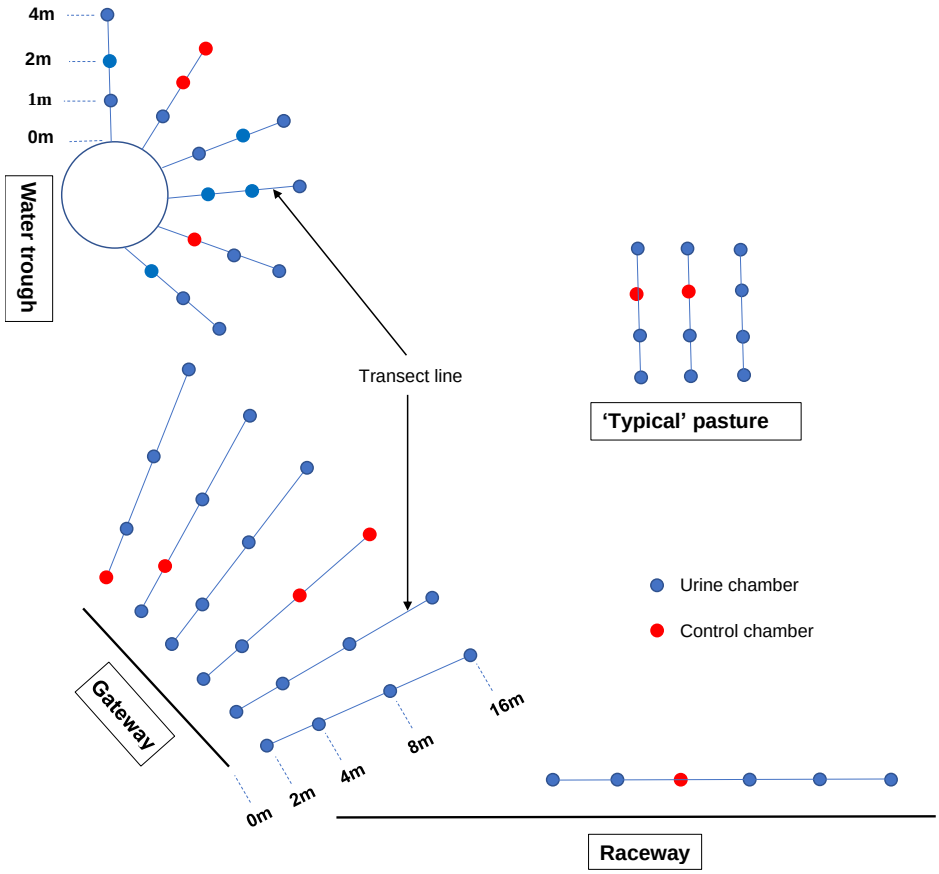


Figure 1. Schematic layout of gas sampling chambers at Manawatu and Waikato farms (not to scale with some variations in the distances in the gateway and 'typical' pasture sampling areas).

Meteorological data

Daily rainfall and soil temperatures were recorded throughout the duration of the trial with monitoring equipment at the trial sites. Rainfall and temperature data were also obtained from a nearby meteorological station.

Soil sampling

Soil samples for chemical properties such as pH, mineral N (NH_4^+ and NO_3^-), total C and N, and Olsen P were collected before the trials began. Soil cores were collected approximately 150–200 mm from each chamber. The cores were bulked together by sampling distance to obtain a composite sample from each treatment category, which was sieved through a 4-mm sieve. However, intact cores were collected to measure bulk density, total porosity, macroporosity, field capacity, and air permeability using a soil sample liner about 250 mm from the chamber (between the chambers of same treatment category). The physical and chemical properties of soils were measured following established methods. Soil water content at the Manawatu site was measured throughout the experimental period using a calibrated moisture probe (Moisture probe meter MPM-160-B, ICT International Pty Ltd, Australia), however gravimetric method was followed at Waikato site.

Nitrous oxide measurement

A static chamber technique was used to measure N_2O emissions, and the methodology was based on that the previously published studies on N_2O emissions (Luo et al. 2015; Hoogendoorn et al. 2018). The measurements were continued till the N_2O flux values for treatment plots reached similar levels to the background measured in the control plots. The N_2O concentrations of gas samples were analysed using a Shimadzu GC-17a gas chromatograph equipped with a 63Ni-electron capture detector using oxygen-free N as a carrier gas and connected to an automatic sampler capable of handling up to 120 samples (de Klein et al. 2003; Saggar et al. 2004; Hedley et al. 2006). Chamber temperatures were recorded at the beginning and end of the cover period and the average of the two readings was considered the chamber temperature for calculating the gas flux. The increase in N_2O concentration within the chamber headspace, for the gas samples collected at t_0, t_{30} and t_{60} was generally linear (R^2 >0.90). Therefore, the hourly N_2O fluxes (in mg N_2O-N m^{-2} hr^{-1}) were calculated using linear regression and the ideal gas law according to Mosier & Mack (1980) Eqn. 1:

$$N_2O\ flux = \frac{\delta N_2O}{\delta T} * \frac{M}{Vm} * \frac{V}{A} \qquad \textit{Eqn. 1}$$

where, δN_2O is the increase in head space N_2O over time (μL L^{-1}); δT is the enclosure period (hrs); M is the molar weight of N in N_2O (g mol^{-1}); Vm is the molar volume of gas at the sampling temperature (L mol^{-1}); V is the headspace volume (m^3); and A is the area covered (m^2).

For each chamber, the hourly flux data were assumed to be representative of the mean daily flux. Cumulative emissions were calculated via trapezoidal integration of the daily fluxes on measurement dates to estimate the total emissions over the measurement period. Emission factors (N_2O-N emitted as % of urine N applied) were calculated following the IPCC (2006) methodology, using Eqn. 2:

$$EF_3 = \frac{Total\ treatment\ N_2O - N - Total\ control\ N_2O - N}{Total\ N\ applied} \times 100\% \qquad \textit{Eqn. 2}$$

where, EF_3 is emission factor; total treatment N_2O and total control N_2O are the cumulative N_2O emissions from the urine treatment and control plots, respectively (kg N ha^{-1}); and N applied is the rate of treatment N applied (kg N ha^{-1}).

The EF_3 values were calculated by subtracting the total control N_2O-N at each sampling distance from the emissions from urine at that distance.

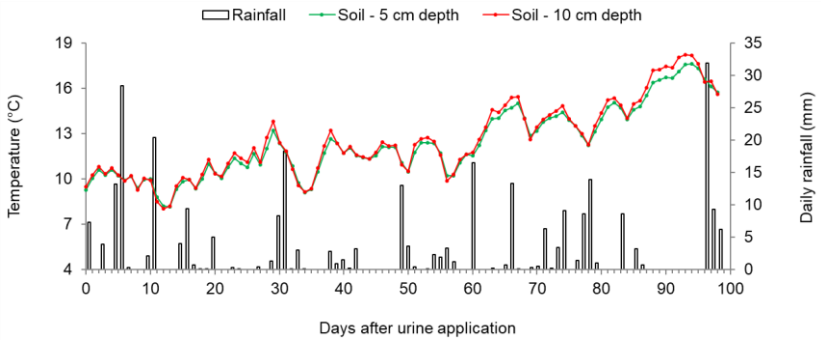
Statistical methods

The data for total N_2O emissions and EF_3 and soil physical properties were analysed using an analysis of variance (ANOVA), and treatment means were compared using Tukey's Studentized Range (HSD) Test. Log transformations were performed when necessary to meet the requirements for normality and homogeneity of variance. All the analyses were conducted using the Genstat statistical software (Genstat 64-bit Release 18.2, VSN International Ltd, $P < 0.05$).

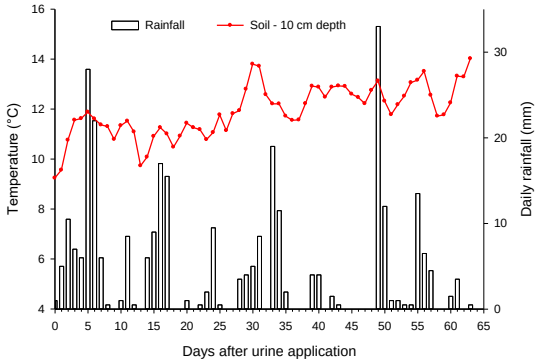
Results and discussion

Meteorological data

The daily rainfall and soil temperatures during the experimental period at the Manawatu and Waikato sites are presented in Figure 2. Rainfall and soil temperatures during the trial were normal for the measurement time of year at the Manawatu site. However, both rainfall and soil temperatures were higher than normal for the time of year at the Waikato site.



a)



b)

Figure 2. Rainfall events, and soil temperatures during the experimental period at a) Manawatu and b) Waikato sites.

Soil data

The physical and chemical properties of the soil at the Manawatu and Waikato site are presented in Tables 1 and 2, and Tables 3 and 4, respectively. Soil measurements confirmed more compaction and reduced soil air permeability within 8 m of the gateway compared with 'typical' pasture area at both sites. However, in the trough, a greater area was affected by compaction at the Waikato site (within 4 m from the trough) than at the Manawatu site (within 2 m from the trough). The initial soil total mineral N was generally higher in the area closer to the trough and gate relative to a 'typical' pasture area. These differences could be attributed to stock movements and disproportionate excreta deposition. The coarse-textured materials used within 8 m from the gateway to fill holes created during stock movement also partly contributed to higher bulk density in these areas.

Table 1. Physical properties of hot-spots areas of the Manawatu site soil from 0 to 75 mm depth (mean ± s. e., (n = 5, but n = 9 for 'Typical' pasture) before the trial begins

Paddock Area	Bulk density ($Mg\ m^{-3}$)	Total porosity (%)	Macro-porosity (%)	Field capacity (%)	Air permeability (m^2*10^{-13})
Distance from water trough (m)					
1	1.23 ± 0.03^{abc}	52.1 ± 1.4^{abc}	6.5 ± 1.2^{a}	43.7 ± 0.8^{ab}	60 ± 43^{ab}
2	1.35 ± 0.05^{ab}	47.2 ± 2.0^{bc}	5.5 ± 1.6^{a}	40.4 ± 0.5^{bc}	18 ± 6^{b}
4	1.14 ± 0.03^{c}	54.4 ± 1.2^{a}	7.6 ± 1.4^{a}	45.0 ± 0.7^{ab}	134 ± 29^{ab}
Distance from gateway (m)					
2	1.42 ± 0.03^{a}	44.9 ± 1.1^{c}	6.4 ± 2.3^{a}	36.8 ± 1.7^{c}	74 ± 31^{ab}
4	1.41 ± 0.02^{a}	45.4 ± 0.4^{bc}	7.1 ± 1.5^{a}	36.7 ± 1.6^{c}	97 ± 34^{ab}
8	1.21 ± 0.07^{bc}	52.5 ± 2.4^{ab}	7.5 ± 1.1^{a}	43.4 ± 1.7^{ab}	39 ± 20^{ab}
16	1.07 ± 0.04^{c}	57.8 ± 1.4^{a}	9.9 ± 1.4^{a}	45.8 ± 0.7^{a}	136 ± 43^{ab}
'Typical' pasture	1.10 ± 0.02^{c}	56.3 ± 0.7^{a}	7.6 ± 0.3^{a}	46.8 ± 0.5^{a}	138 ± 18^{a}

Means followed by different lower-case letters in a column are significantly different (Tukey HSD, $P < 0.05$)

Table 2. Chemical properties of hot-spots areas of the Manawatu site soil from 0 to 100 mm depth (bulked samples) before the trial begins

Paddock Area	pH water	NH_4^+-N (mg kg^{-1})	NO_3^--N (mg kg^{-1})	Olsen P (mg kg^{-1})	Total C (%)	Total N (%)
Distance from water trough (m)						
1	5.7	5.9	7.1	48.3	3.0	0.3
2	5.7	0.9	24.4	59.8	3.0	0.3
4	5.7	2.3	8.1	89.7	4.3	0.4
Distance from gateway (m)						
2	5.7	3.1	8.8	134.5	4.3	0.4
4	5.7	1.4	8.1	133.9	3.8	0.3
8	5.8	2.7	9.1	121.7	4.1	0.4
16	5.8	0.1	7.5	86.6	4.1	0.4
Raceway	5.7	0.6	4.7	28.1	3.6	0.3
'Typical' pasture	5.7	1.0	4.2	62.3	3.7	0.3

Table 3. Physical properties of hot-spots areas of the Waikato site soil from 0 to 75 mm depth (mean ± s. e., n = 5, but n = 6 for 'Typical' pasture) before the trial begins

Paddock Area	Bulk density (Mg m^{-3})	Total porosity (%)	Macro-porosity (%)	Field capacity (%)	Air permeability (m^2*10^{-13})
Distance from water trough (m)					
1	1.3 ± 0.1 ^{a}	51.7 ± 1.6 ^{a}	5.0 ± 0.3 ^{a}	45.8 ± 1.3 ^{a}	43.4 ± 32.9 a
2	1.1 ± 0.0 ^{ab}	54.7 ± 1.1 ^{ab}	5.5 ± 0.5 ^{ab}	47.9 ± 0.9 ^{a}	14.2 ± 5.7 ^{a}
4	1.1 ± 0.0 ^{b}	57.0 ± 1.3 ^{b}	7.3 ± 0.9 ^{b}	48.3 ± 0.5 ^{a}	65.6 ± 7.9 ^{a}
Distance from gateway (m)					
2	1.0 ± 0.0 ^{b}	58.0 ± 1.5 ^{a}	6.9 ± 2.3 ^{a}	49.1 ± 1.3 ^{ab}	72.5 ± 28.7 ^{a}
8	1.1 ± 0.0 ^{b}	56.6 ± 0.6 ^{a}	8.9 ± 1.0 ^{a}	45.9 ± 1.6 ^{a}	77.8 ± 35.1 ^{a}
14	0.9 ± 0.0 ^{a}	64.0 ± 0.7 ^{b}	10.1 ± 0.7 ^{a}	51.4 ± 0.9 ^{b}	163.6 ± 25.2 ^{a}
24	0.9 ± 0.0 ^{a}	63.4 ± 1.3 ^{b}	8.5 ± 1.4 ^{a}	52.8 ± 0.9 ^{b}	96.2 ± 32.8 ^{a}
'Typical' pasture	0.9 ± 0.1 ^{a}	62.7 ± 2.3 ^{b}	10.0 ± 1.2 ^{a}	50.7 ± 1.3 ^{b}	109.9 ± 28.6 ^{a}

Means followed by different lower-case letters in a column are significantly different (Tukey HSD, $P < 0.05$)

Table 4. Soil inorganic N (0–75 mm) sampled at each distance prior to treatment application and after the final gas sampling from the actual chambers at the hot-spots areas of the Waikato site (bulked samples)

Paddock Area	Pre-treatment		Final no-urine		Final with urine	
	NH_4^+-N (mg kg^{-1})	NO_3^--N (mg kg^{-1})	NH_4^+-N (mg kg^{-1})	NO_3^--N (mg kg^{-1})	NH_4^+-N (mg kg^{-1})	NO_3^--N (mg kg^{-1})
Distance from water trough (m)						
1	10.5	2.7	1.2	2.1	2.5	1.8
2	1.4	0.9	2.6	3.6	2.6	2.7
4	8.1	5.1	2.7	5.5	3.4	3.9
Distance from gateway (m)						
2	18.1	0.9	1.3	4.3	3.9	7.8
8	2.2	1.0	1.0	3.4	2.4	4.1
14	2.1	0.8	2.0	4.5	1.9	3.7
24	1.9	0.7	1.8	5.0	3.5	3.8
'Typical' pasture	1.2	0.9	2.6	2.8	2.1	2.2

Overall, soil WFPS (data not presented) were higher (80–110% during most of the measurements) at Waikato site compared with Manawatu site which reflects very wet soil conditions at the Waikato site. The WFPS were generally higher in the area closer to the water troughs than in the 'typical' pasture area. This could be associated with higher soil compaction reduced pore volume and air permeability in those areas of trough (Tables 1 and 3).

Nitrous oxide emissions

Total N_2O emissions from the urine treatments at the Manawatu site were higher than at the Waikato site (Fig. 3). This is likely due to very wet conditions at the Waikato site with well-drained soil which favour higher leaching losses of N and/or greater prevalence of complete denitrification to N_2 gas, leading to lower N_2O production. There was no clear trend for higher emissions from applied urine in hot-spot areas compared with those from the 'typical' pasture area at either farm. At the Manawatu site, the lowest emissions from urine applied observed at 8 m from the gateway were significantly lower than emissions from 'typical' pasture area and 1 m and 2 m from the trough. This could be partly attributed to the stoney materials used to fill the holes created during stock movement in the gateway area, which may result in more leaching losses of N (reduce the N available for nitrification and denitrification) or lower activity of denitrifiers and thereby reduced the emissions. The lower WFPS at 8 m from the gateway could have also contributed to these lower emissions. Generally, the controls at the trough area had the higher background emissions compared with background emissions from rest of the paddock.

Manawatu site

Waikato site

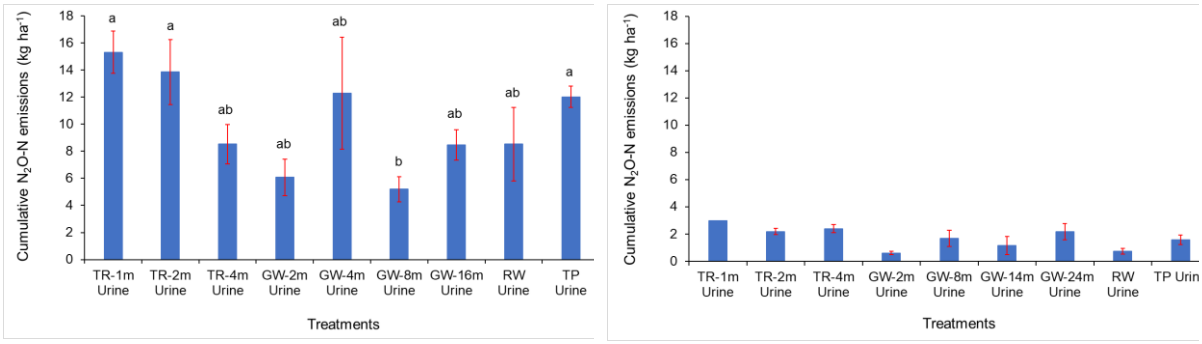


Figure 3. Cumulative N_2O-N emissions from urine applied at different areas of dairy-grazed pasture, vertical bars (± standard error values of means) with different letters indicate significant difference (Tukey HSD, $P < 0.05$), TR = water trough, GW = gateway, RW = raceway, TP = 'typical' pasture area (n = 5, but n = 4 for TR-1 m Urine at Manawatu site and GW-24 m Urine at Waikato site), no error bar for TR-1m Urine at Waikato site is due to lack of replication.

The EF_3 values for urine applied were slightly higher for some areas of hot-spots associated with soil compaction and subsequent elevated WFPS but these values were not significantly different from rest of the treatments, including 'typical' pasture area at both sites (Fig. 4).

Manawatu site

Waikato site

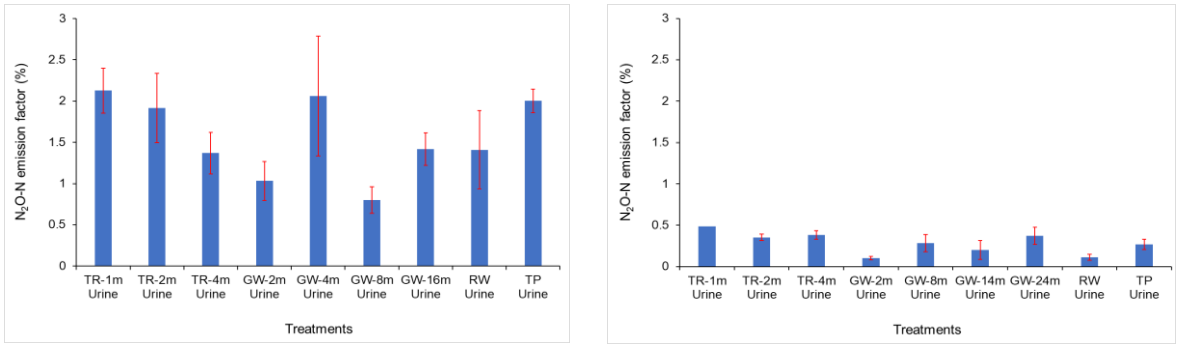


Figure 4. Nitrous oxide emission factor for urine (EF_3) applied at different areas of dairy-grazed pasture, vertical bars indicate ± standard error values of means, TR = water trough, GW = gateway, RW = raceway, TP = 'typical' pasture area (n = 5, but n = 4 for TR-1 m Urine at Manawatu site and GW-24 m Urine at Waikato site), no error bar for TR-1 m Urine at Waikato site is due to lack of replication.

Conclusions

The stock movements closer to the water troughs and gateways resulted in higher soil compaction and mineral N levels in these areas, which influenced the background N_2O emissions but this had little impact on winter season N_2O EF_3 values when compared with those from cattle urine deposited in a 'typical' pasture area.

Acknowledgements
This research was funded by New Zealand Ministry for Primary Industries (MPI) to support the objectives of the New Zealand Agricultural GHG Inventory (MPI SOW # 405819 Effect of "hotspots" on N_2O emissions).

References

de Klein CAM, Barton L, Sherlock RR, Li Z, Littlejohn RP 2003. Estimating a nitrous oxide emission factor for animal urine from some New Zealand pastoral soils. Aust. J. Soil Res. 41: 381–399.

Hedley CB, Saggar S, Tate KR 2006. Procedure for fast simultaneous analysis of the greenhouse gases: methane, carbon dioxide and nitrous oxide in air samples. Comm. Soil Sci. Pl. Analys. 37: 1501–1510.

Hoogendoorn C, Saggar S, Palmada T, Berben P 2018. Do nitrous oxide emissions from urine deposited naturally differ from evenly applied urine? In: Currie LD, Christensen CL eds. Farm environmental planning – Science, policy and practice. Occasional Report No. 31. Palmerston North, New Zealand: Fertilizer and Lime Research Centre, Massey University. Available at http://flrc.massey.ac.nz/publications.html

Luo J, van der Weerden T, Thomas S, de Klein CAM, Rollo M, Lindsey S, Longhurst B 2015. Framework to determine total farm nitrous oxide emissions and sensitivity analysis – SLMACC Objective 1 Milestone 2. Report for the Ministry for Primary Industries. AgResearch Ltd.

Luo J, Lindsey S, van der Weerden T, Thomas S, de Klein CAM 2016b. Nitrous oxide emissions from gateway and water-trough areas – SLMACC Objective 1 Milestone 3. Report for the Ministry for Primary Industries. AgResearch Ltd.

Luo J, Wyatt J, van der Weerden T, Thomas S, de Klein CAM, Li Y, Lindsey S, Ledgard S, Li J, Ding W, Qin S, Zhang N, Bolan N, Kirkham MB, Bai Z, Ma L, Zhang X, Wang H, Liu H, Rys G 2017. Potential hotspot areas of nitrous oxide emissions from grazed pastoral dairy farm systems. Adv. Agron. 145: 205 –268.

Mosier AR, Mack L 1980. Gas chromatographic system for precise, rapid analysis of nitrous oxide. Soil Sci. Soc. Am. J. 44: 1121–1123.

Saggar S, Andrew RM, Tate KR, Hedley CB, Rodda N, Townsend JA 2004. Modelling nitrous oxide emissions from dairy grazed pastures. Nutr. Cycl. Agroecosys. 68: 243–255.

Saggar S, Luo J, Adhikari KP, Berben P, Palmada T, Lindsey S, Sprosen M, Dando J 2019. Effect of 'hotspots' on nitrous oxide emissions – winter trials final report. Landcare Research Contract Report LC3659 for MPI. Client report number (not available yet). December 2019. 28 p.