Determination of the N_2O emission factor for animal dung applied in spring in three regions of New Zealand

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Jiafa Luo, Tony van der Weerden, Coby Hoogendoorn, Cecile de Klein

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1. Executive summary

Objectives

- To determine N_2O emission factors from dairy cow dung (cow dung), beef cow dung (cattle dung) and sheep dung on 6 different soil types in spring-summer in three regions of New Zealand.
- To determine the effects of DCD (a nitrification inhibitor) use on N_2O emissions from cow dung on two poorly-drained soils.

Context

Previous MAF-funded studies suggested that the N_2O emission factor (EF3) for animal dung ranged between 0.1 and 0.5%. This is lower than the current New Zealand-specific EF3 of 1% applied to all animal excreta N. Results from the autumn-winter study confirm that N_2O emissions decrease as follows: cow urine > cow or cattle dung > sheep dung. However, these autumn-winter results need to be verified under conditions that are likely to induce high N_2O emissions (i.e. warm and wet soils) in order to be fully confident that a disaggregation of the N_2O emission factor for urine and dung in the NZ inventory is warranted. We have therefore repeated the autumn-winter dung trial following a spring application to provide further evidence for disaggregation of the EF3 for urine and dung.

Approach

This report presents findings from a field study conducted to determine the N_2O emission factors from application of animal excreta, following application in spring 2008 in three regions of New Zealand. Excreta included dairy cow dung, beef cow dung, sheep dung and cow urine. Excreta was applied as a series of plot trials to 2 different soil types in each of the three regions (Waikato: Horotiu free draining silt loam and Te Kowhai poorly draining silt loam, Southern Hawkes Bay: Ngamoko free draining silt loam and Wilford poorly draining hill soil, Otago: Wingatui free draining silt loam and Otokia poorly draining silt loam) (Table 1). Another treatment, "cow dung + DCD (a nitrification inhibitor)", on the two poorly-drained

soils (Waikato Te Kowhai and Otago Otokia soils) was also included to determine the effects of the DCD use on N_2O emissions from application of cow dung.

Treatments were applied on 22 October 2008. Nitrous oxide emission measurements were made twice per week for the first month following the application. The measurements were then made once per week until background levels were reached in April 2009.

Table 1: Regions, soil types and treatments used for spring-applied excreta study

Region	Soil drainage class	N source
Waikato	Free and poorly draining	Cow dung
	Free and poorly draining	Sheep dung
	Free and poorly draining	Cow urine
	Poorly draining only	Cow dung + DCD
Southern Hawkes Bay	Free and poorly draining	Cattle dung
	Free and poorly draining	Sheep dung
	Free and poorly draining	Cow urine
Otago	Free and poorly draining	Cow dung
	Free and poorly draining	Sheep dung
	Free and poorly draining	Cow urine
	Poorly draining only	Cow dung + DCD

Outcomes

- The N_2O emissions from this spring application of animal dung were much lower than those from application of cow urine on all 6 soils, with most sampling occasions showing emissions from dung plots being similar to those from control (untreated) plots. The same findings were observed in the autumn-winter trial.
- Results from this spring-summer study confirmed that EF_3 decreases as follows: cow urine > cow or cattle dung > sheep dung. The average EF_3 for cow urine, cow dung and sheep dung were estimated to be 0.26%, 0.04% and -0.02% of excreta N applied, respectively. These EFs were similar to those found in the autumn-winter trial. The average EF_3 for cow urine, cow

dung and sheep dung for both the autumn-winter and the spring trials were 0.28%, 0.04% and 0.01% of excreta N applied, respectively.

- The EF_3 for cow urine was significantly higher ($P < 0.05$) than those for dung in this spring-summer study. There was no significant difference ($P > 0.05$) in EF_3 for cattle and sheep dung.
- EF_3 for urine in this spring-summer study was similar to that found in the autumn-winter trial, but lower than the average estimated from previous MAF EF_3 studies.
- As found in the autumn-winter trial, soil drainage class within regions did not have a consistent effect on EF3 values for different excreta types.
- EF_3 for cow dung was not significantly ($P > 0.05$) reduced with the application of DCD on the Otago Otokia soil. However, EF_3 for cow dung was significantly ($P < 0.05$) reduced by the application of DCD on the Waikato Te Kowhai soil.
- These results again support that a disaggregation of EF3PRP between dung and urine is warranted.
- It is recommended that the N_2O emission factor for urine remains at 1%, and the N_2O emission factor for dung is reduced to 0.5%.

2. Introduction

The aim of the proposed programme is to estimate the spring-summer N_2O emission factor for cattle and sheep dung and to compare this to the emission factor for cattle urine.

Direct and indirect N_2O emissions from animal excreta deposited during grazing contribute over 80% of the total agricultural N_2O emissions in New Zealand. In recent years, seasonal field studies have been conducted to estimate the N_2O emission factor (EF_3) for animal urine – mainly dairy cow urine – which confirmed a New Zealand specific value for EF3 of 1% (compared to the IPCC default value of 2%). However, these studies also included a limited number of dung treatments, with the results suggesting that EF_3 for cow dung ranged between 0.1 and 0.5%, while N_2O emissions from sheep dung were (close to) zero[1]. Yet, the current New Zealand-specific EF_3 of 1% applies to both animal urine and dung N. The partitioning of N in dung and urine largely depends on N intake from the herbage and can range from 50:50 (dung N: urine N) in animals on a low N diet to 25:75 in animals on a high N diet[2]. A disaggregation of EF_3 between urine N and dung N would therefore have a significant impact on the N_2O inventory. In addition, such a disaggregation would enable the effect of feeding strategies that partition more N in dung than urine (e.g. use of condensed tannins and maize silage) to be accounted for in our national inventory.

A MAF funded trial has been conducted following an autumn-winter application of dung in 2008[3]. Results from that trial confirm that N_2O emissions decrease as follows: cow urine > cow or cattle dung > sheep dung. However, these autumn-winter results need to be verified under conditions that are likely to induce high N_2O emissions (i.e. warm and wet soils) in order to be fully confident that a disaggregation of the N_2O emission factor for urine and dung in the NZ inventory is warranted.

[1] de Klein, C.A.M., Li, Z., Sherlock, R.R (2004) *Determination of the N_2O and CH_4 emission factors from animal excreta and urea following a winter application in 2 regions of New Zealand*. Report for MAF Policy, Wellington. Pp. 27

[2] Ledgard, S.F., Luo, J., Monaghan, R.M (2003). *Partitioning of excreta nitrogen from grazing animals into urine and dung nitrogen*. Report for MAF Policy, Wellington. Pp16

[3] Luo, J., van der Weerden, T., Hoogendorn, C., de Klein, C.A.M. (2009). *Determination of the N_2O emission factor for animal dung applied in late autumn in three regions of New Zealand*. Report for MAF Policy, Wellington. Pp. 26

We have therefore repeated the autumn-winter dung trial following a spring application of excreta to ascertain whether a disaggregation of the EF_3 for urine and dung is warranted in seasons other than autumn/winter.

3. Objectives

- To determine N_2O emission factors from application of dairy cow dung, beef cow dung and sheep dung on 2 different soil types in each of three different regions of New Zealand in the spring-summer period.
- To determine the effects of DCD (a nitrification inhibitor) use on N_2O emissions from cow dung on two poorly-drained soils.

4. Materials and methods

4.1 Study design

A series of plot trials were conducted to determine N_2O emission factors from dairy cow dung, beef cow dung and sheep dung in spring on 6 different soil types throughout New Zealand (Table 2). The application of animal dung and urine was carried out on 22 October 2008.

Although this study aimed to refine the N_2O emission factor for cattle and sheep dung, a dairy cow urine treatment was included as a 'reference' treatment to ensure that the dung results can be directly compared to the urine emission factor results from previous MAF funded NzOnet trials[4] and the autumn-winter dung trial[5]. Another treatment, "cow dung + DCD (a nitrification inhibitor)", applied to two poorly-drained soils (Waikato Te Kowhai and Otago Otokia soils) was also included to determine the effects of the DCD use on N_2O emissions from cow dung.

[4] de Klein C.A.M., Li, Z., Sherlock, R.R (2004) *Determination of the N_2O and CH_4 emission factors from animal excreta and urea following a winter application in 2 regions of New Zealand.* Report for MAF Policy, Wellington. Pp. 27

[5] Luo, J., van der Weerden, T., Hoogendorn, C., de Klein, C.A.M. (2009). *Determination of the N_2O emission factor for animal dung applied in late autumn in three regions of New Zealand*. Report for MAF Policy, Wellington. Pp. 26

Table 2: The study design for determining N_2O emission factors for animal dung

Region	Soil type	Drainage	Treatment	N application rate kg N ha^{-1}
Waikato	Horotiu silt loam	Free	Cow dung	900
			Sheep dung	317
			Cow urine	551
			Control	0
	Te Kowhai silt loam	Poor	Cow dung	900
			Cow dung + DCD	900
			Sheep dung	317
			Cow urine	551
			Control	0
Southern Hawkes Bay	Ngamoko silt loam	Free	Cattledung	671
			Sheep dung	290
			Cow urine	548
			Control	0
	Wilford Hill soil	Poor	Cattle dung	671
			Sheep dung	290
			Cow urine	548
			Control	0
Otago	Wingatui silt loam	Free	Cow dung	1084
			Sheep dung	273
			Cow urine	548
			Control	0
	Otokia silt loam	Poor	Cow dung	1084
			Cow dung + DCD	1084
			Sheep dung	273
			Cow urine	548
			Control	0

4.2 Approach

4.2.1 Waikato site

The Waikato soils were located on a flat dairy farm. Stock was excluded from the sites for at least one month before the commencement of this study. Dairy cow dung was applied at a rate of 900 kg N ha^{-1} and sheep dung at a rate of 317 kg N ha^{-1} (Table 2). Another treatment "cow dung + DCD (a nitrification inhibitor) applied to the poorly-drained Te Kowhai soil" was also included (Table 2), and DCD was applied at a rate of 10 kg ha^{-1}. A reference treatment with real dairy cow urine at an application rate of 551 kg N ha^{-1} was also used. The amount and method of urine N application were same to those used in the previous autumn-winter trial[6] and similar to those used in previous MAF funded NzOnet trials[7], allowing direct comparison with the results of those trials. Each treatment was replicated four times in a randomised block design. Plots with no dung and urine applied were also included (control) with four replicates. Thus, there were 36 plots at the Waikato study sites.

4.2.2 Southern Hawkes Bay site

The Southern Hawkes Bay soils were located in hill country. Stock was excluded from the sites for at least 6 weeks before the commencement of the study. The treatments and measurement procedures for the hill country soils were the same as those for the Waikato soils, except that in this trial fresh beef cow dung instead of dairy cow dung was used (Table 2). The lower N content of the beef dung, compared to dairy cow dung, meant that the beef cow dung N application rate was approximately 75% that of the dairy cow dung applied at the Waikato site (see 4.2.1). The "cow dung and DCD" treatment used at the Waikato site was not included. Sheep dung was applied at a rate of 290 kg N ha^{-1}, which was approximately 90% of the N application rate of the sheep dung applied at the Waikato site. There were 32 plots at the southern Hawkes Bay study site.

[6] Luo, J., van der Weerden, T., Hoogendorn, C., de Klein, C.A.M. (2009). *Determination of the N_2O emission factor for animal dung applied in late autumn in three regions of New Zealand.* Report for MAF Policy, Wellington. Pp. 26

[7] de Klein C.A.M., Li, Z., Sherlock, R.R (2004) *Determination of the N_2O and CH_4 emission factors from animal excreta and urea following a winter application in 2 regions of New Zealand*. Report for MAF Policy, Wellington. Pp. 27

4.2.3 Otago site

The Otago soils were located on a flat sheep farm and stock was excluded from the sites for at least one month before the commencement of the study. The treatments (including the dung and DCD treatment) and measurement procedures for the Otago soils were the same as those for the Waikato soils (Table 2). The N content of the dairy cow dung was higher than that at the Waikato site and thus dairy cow dung at the Otago site was applied at a higher N rate than that at the Waikato site. Sheep dung was applied at a rate of 273 kg N ha^{-1}, which was approximately 86% of the N application rate of the sheep dung applied at the Waikato site. There were 36 plots at the Otago study site.

4.2.4 Animal dung and urine collection

On 20 and 21 October 2008, fresh dung from dairy cows, beef cows and sheep was collected from local commercial farms in Waikato, Southern Hawkes Bay and Otago. The fresh dung was stored in cool-rooms at 4^{o}C and applied on 22 October 2008. Subsamples of each dung type were taken for chemical analysis (Table 3).

For the cow urine treatment, fresh cow urine was collected at the AgResearch Ruakura No. 1 Dairy farm. The dairy cow urine from this farm was used for all three sites. Immediately after collection, the urine was stored overnight at 4^{o}C or transported overnight as refrigerated airplane cargo to Southern Hawkes Bay and Otago. The dairy cow urine was applied at all study sites on 22 October 2008. A dairy cow urine sample was taken immediately after collection for chemical analysis (Table 3) at AgResearch and NZlabs at Ruakura.

Table 3: Characteristics of animal dung and urine used in the trials. Characteristics were analysed at the time of application

	Total N (%)	NH_4^+ (mg N L^{-1})	Organic C (%)	Dry matter (%)	pH
Waikato					
Dairy cow dung	0.318	395	3.39	9.1	7.5
Sheep dung	0.634	894	7.46	17.7	7.2
Dairy cow urine	0.551	984			8.1
Southern Hawkes Bay					
Beef cow dung	0.237	338	3.97	10.6	7.8
Sheep dung	0.580	957	10.2	17.2	7.3
Dairy cow urine	0.551	984			8.1
Otago					
Dairy cow dung	0.383	459	4.22	9.9	7.2
Sheep dung	0.546	843	4.60	14.1	7.4
Dairy cow urine	0.548	882			7.7

4.2.5 Animal dung and urine application

The cow dung was applied in 20 cm diameter "pats" for gas sampling. Fresh dung (0.89 kg) was evenly spread to the entire circle (equivalent to 28.3 kg m^{-2}). The gas measurements were made from the entire dung pat plus a small area of un-amended soil. The gas emission rates were corrected to adjust for this un-amended area during calculation, employing the correction method used previously in a MAF study for treatments that are smaller than the chamber area[8]. Adjacent to this circular plot, two separate areas (0.2 $\times$ 0.5 m each area, leaving 0.1 m buffer in between) were used for soil sampling, and 2.83 kg of fresh dung was applied to each area. For the "dung and DCD" treatment a 1 g L^{-1} solution of DCD was applied onto the cow dung at a rate of 10 kg DCD ha^{-1}.

At the Waikato and Otago sites, the sheep dung was also applied in 20 cm diameter "pats" for gas sampling. Fresh dung (0.157 kg) was evenly spread to the entire circle (equivalent to 5 kg m^{-2}). Adjacent to this circular plot, 1.25 kg of fresh sheep dung was applied to a plot (0.5 $\times$ 0.5 m) which was used for soil sampling.

[8] de Klein, C.A.M., Li, Z., Sherlock, R.R (2004) *Determination of the N_2O and CH_4 emission factors from animal excreta and urea following a winter application in 2 regions of New Zealand*. Report for MAF Policy, Wellington. Pp. 27

At the Southern Hawkes Bay site, the sheep dung was applied to 0.25 × 1 m plots. Fresh sheep dung (1.25 kg) was evenly distributed over the entire plot (equivalent to 5 kg m^{-2}). Gas samples were taken in the middle of each plot and soil samples were taken from the rest.

At all three sites, the dairy cow urine was evenly spread onto 0.5 x 1 m plots at a rate of 10 L m^{-2} which is a typical urination rate for cattle[9]. Gas samples were taken in the middle of each plot and soil samples were taken from the rest.

4.3 N_2O measurements and calculations

A static soil chamber technique was used to measure N_2O emissions and the methodology was based on that from the previous MAF funded NzOnet studies on excreta N_2O emissions[10].

Gas samples were taken on one occasion several days before the treatments were applied to determine if there was any pre-existing between-plot variability. Following treatment application on 22 October 2008, gas samples were collected twice per week for the first month and then once per week until background levels were reached in April 2009.

On each sampling day, N_2O measurements were carried out once between 12 noon and 2 p.m. Two headspace gas samples were taken during a cover period of 60 minutes at times $t_0$and t_{60} from each chamber with syringes and 12 ml of the gas sample was transferred into a 6 ml septum-sealed screw-capped glass vial.

Gas samples were analysed for N_2O concentrations by gas chromatograph at Landcare research, Palmerston North, and at the Analytical Services laboratory, Lincoln University. At Landcare research, analysis was conducted using a Shimadzu GC-17a gas chromatograph equipped with a ^{63}Ni-electron capture detector with oxygen-free N as a carrier gas. At Lincoln University, a SRI 8610 automated gas chromatograph was used.

[9] Haynes, R.J., Williams, P.H. (1993) Nutrient cycling and soil fertility in the grazed pasture ecosystem. *Advances in Agronomy* 49: 119-199

[10] de Klein, C.A.M., Li, Z., Sherlock, R.R (2004) *Determination of the N_2O and CH_4 emission factors from animal excreta and urea following a winter application in 2 regions of New Zealand*. Report for MAF Policy, Wellington. Pp. 27

The hourly N_2O emissions were calculated for each chamber from the increase in head space N_2O concentrations over the sampling time. The hourly N_2O emissions (mg N m^{-2} h^{-1}) were calculated as follows:

$$N_2O\,flux = \frac{\delta N_2O}{\delta T} * \frac{M}{Vm} * \frac{V}{A} \quad (1)$$

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

Hourly emissions were integrated over time, for each enclosure, to estimate the total emission over the measurement period.

Total emissions from dung treatments in this study were often very low: in several cases, lower than the total emissions measured from control treatments, resulting in net negative emissions from specific treatments (suggesting N_2O deposition had occurred). Consequently, the previous method used for calculating average Emission Factors, where the geometric mean of the emission factors for each excreta type is presented[11], could not be employed here as it is not possible to calculate the log of a negative number.

An alternative method was employed in this study, where total emissions were transformed using the *log(a+x)* transform, with *a* = 0.76 estimated by optimizing the Anderson-Darling statistic for normality. Transformed data were analysed by residual maximum likelihood, with plot within block within location as random effects, and the factorial interaction of region, soil drainage class and excreta treatments as fixed effects. Each cell in the resulting table of estimates of fixed effects then had $\sigma^2/2$ added to it, as the variance inflation appropriate for the lognormal distribution, and was then back-transformed using the exponential function. Emission factors were then calculated from the difference in total emissions from each excreta treatment and the control treatment, divided by the rate of urine N or dung N applied, as described by equation 2:

[11] de Klein, C.A.M., Li, Z., Sherlock, R.R (2004) *Determination of the N_2O and CH_4 emission factors from animal excreta and urea following a winter application in 2 regions of New Zealand.* Report for MAF Policy, Wellington. Pp. 27

$$EF = \frac{N_2O \text{ total (urine/dung)} - N_2O \text{ total (control)}}{\text{Urine/Dung N applied}} \times 100\% \qquad (2)$$

where EF is emission factor (N_2O-N emitted as % of urine-N or dung-N applied), N_2O total (urine/dung) and N_2O total (control) are the cumulative N_2O emissions from the urine/dung and control plots, respectively (kg N ha^{-1}), and Urine/Dung N applied is the rate of urine N or dung N applied (kg N ha^{-1}). Standard errors were calculated using the variance of function formulae as in Kendall and Stuart, Volume 1 (1969) [12].

4.4 Soil and climatic parameters

Soil samples (7.5 cm deep, 25 mm diameter) were taken from all plots for determination of soil nitrate-N, ammonium-N and water content. Immediately after sampling the hole was back-filled with sealed PVC tubes to minimise any effects on soil aeration. Back in the laboratory on the same day or the following day, the samples were thoroughly mixed and about 15 g of fresh soil (about 10 g dry soil equivalent) was extracted for 1 hour in 50 mL of 0.5 *M* K_2SO_4. The filtered (using filter paper No 42 or equivalent) solutions were then frozen until analysed for nitrate-N (plus nitrite-N) and ammonium-N in the Ruakura laboratory. The remainder of the mixed soil was dried at 105ºC for 24 hours, to determine gravimetric soil water content. Water-filled pore space (WFPS) was calculated by dividing volumetric water content by total porosity (Linn and Doran, 1984)[13]. Total porosity is calculated as follows: 1–(bulk density/particle density). Volumetric water content is calculated by multiplying gravimetric water content by bulk density.

Air and soil temperatures (at 5 cm depth) and rainfall were monitored on each sampling day at the study sites.

[12] Kendall, M.G., Stuart, A. (1969) *The Advanced Theory of Statistics*, Volume 1, Third Edition. Griffin: London

[13] Linn, D.M., Doran, J.W. (1984) Effect of water-filled pore space on carbon dioxide and nitrous oxide production in tilled and non-tilled soils. *Soil Science Society of American Journal* 48: 1267-1272

5. Results and discussion

5.1 Hourly N_2O emission rates

- The hourly N_2O fluxes for the various treatments at the different sites are given in Figures 1-6. Please note the difference in scale of the Y-axis between these figures. Soil and climatic conditions are also shown in these figures.
- For each site, the N_2O fluxes from the individual plots were similar prior to treatment application and thus pre-existing between-plot variability was not evident.
- Following excreta application, N_2O fluxes were greater than that of control plots for up to 161-173 days, depending on the site.
- Dairy cow urine treatments resulted in the largest fluxes, followed by dung and control treatments.
- The single largest flux was 2.41 mg N_2O-N m^{-2} hr^{-1}, measured from dairy cow urine applied to the poorly drained Te Kowhai soil at the Waikato site.
- The single largest fluxes measured in South Hawkes Bay and Otago sites were substantially less than this, at 0.14 and 0.46 mg N_2O-N m^{-2} hr^{-1}, respectively, both from dairy cow urine.
- As found in the autumn-winter trial, on all 6 soils N_2O fluxes from application of animal dung were much lower than those from dairy cow urine application.
- N_2O fluxes were greater from cow dung compared to sheep dung on the Horotiu, Te Kowhai and Otokia soils, with N_2O fluxes from sheep dung plots being similar to control (untreated) plots at these sites. However, emissions from sheep and cow dung were similar from the other three soils.
- During the first month on the Te Kowhai soil in the Waikato, DCD applied to cow dung significantly reduced the N_2O emission. This is somewhat reflected in the soil mineral N data, where DCD application resulted in lower nitrate-N levels in the first 2 weeks compared to the non-DCD dung plots. However, the DCD application also appeared to reduce the soil ammonium content over this same period, although this was not significant.

- There was no effect of DCD on N_2O fluxes from dung in Otago. This may have been due to fluxes from dung at this site being more than a magnitude less than those measured from the Te Kowhai soil in the Waikato. Soil mineral N data also suggest no inhibition of nitrification by DCD occurred in the soil beneath the dung pats, as ammonium-N levels were similar for the "cow dung" and "cow dung + DCD" treatments.
- As in the autumn-winter trial, initial N_2O peaks from the urine treatments from both the Horotiu and Te Kowhai soils were observed. This was possibly due to an increase in soil pH immediately following urine application resulting in the mineralisation of soil N and release of available C. This could increase nitrification and denitrification rates. Following the initial peak, N_2O fluxes from both soils at the Waikato sites were generally similar to those measured from urine applications[14,15,16]. The N_2O fluxes were higher from the poorly-drained Te Kowhai soil than from the well-drained Horotiu soil.
- As for the Waikato site, the sites in the Southern Hawkes Bay also produced low N_2O fluxes. This may have been due to the relatively low soil WFPS resulting from the low rainfall during the duration of the trial. The N_2O fluxes from cow urine were greater from the poorly drained Wilford hill soil than from the well drained Ngamoko. Despite the soil nitrate levels being consistently higher for the Ngamoko than Wilford soils, the Wilford soils had slightly higher WFPS throughout the trial.
- N_2O fluxes measured from cow dung-amended soil at the Otago site in the current spring study are comparable to those found in past studies[8,9,10] . However, N_2O fluxes from urine-amended soil in the current study are generally lower than those previously found. This is most likely due to the relatively low WFPS over the course of the trial, as the soil never reached field capacity (~60%) during the first four months. N_2O peaks from the urine-amended soil were observed from both soils during the first two

[14] Sherlock, R.R., de Klein C.A.M., Li, Z. (2003a) *Determination of the N_2O and CH_4 emission factors from animal excreta, following a summer application in 3 regions of New Zealand*. Report for MAF Policy, Wellington. pp. 27

[15] Sherlock, R.R., de Klein C.A.M., Li, Z. (2003b) *Determination of the N_2O and CH_4 emission factors from animal excreta, following a spring application in 3 regions of New Zealand.* Report for MAF Policy, Wellington. pp. 28

[16] de Klein, C.A.M., Li, Z., Sherlock, R.R. (2004) *Determination of the N_2O and CH_4 emission factors from animal excreta and urea following a winter application in 2 regions of New Zealand.* Report for MAF Policy, Wellington. Pp. 27

months following rainfall events. Over this period soil mineral N levels were generally above those measured from the control treatment.

- The Otokia soil resulted in lower N_2O fluxes compared to the well-drained Wingatui; this is possibly due to the lower WFPS in the former, which has been observed to drain more rapidly following rainfall events, possibly due to a greater number of very large pores. The overall average WFPS for the Otokia soil was found to be 5% less than that measured from the Wingatui soil. Higher fluxes from the well drained Wingatui soil compared to poorly drained Otokia soil were also observed in the autumn-winter dung trial[17] and a previous MAF funded study (summer trial)[18].

5.2 N_2O emission factors

- Table 4 provides an overview of estimates of the N_2O emission factors for spring-applied dung and urine. Also shown in Table 4 are emission factors for dung and urine, as calculated in the autumn-winter trial. Table 5 presents the results on an excreta type basis from the present spring-summer trial, with averages between the spring-summer and the autumn-winter trials and annual averages from previous MAF funded NzOnet studies also shown.

Key points about N_2O emission factors:

- Results showed that average EF_3 decreases as follows:

  Cow urine > cow or cattle dung > sheep dung

  0.26 > 0.04 > -0.02

- These EF3 values for each excreta type were generally similar to those found in the autumn-winter trial. The EF_3 values for sheep dung were below zero, indicating that uptake of N_2O by the soil may have taken place. The EF_3 values for cow urine, cow or cattle dung and sheep found in the autumn-winter trial were 0.30, 0.05 and 0.04, respectively.

[17] Luo, J., van der Weerden, T.J., Hoogendoorn, C., de Klein, C.A.M., (2009) *Determination of the N_2O emission factor for animal dung applied in spring in three regions of New Zealand.* Client report for MAF Policy, Pp. 26

[18] Sherlock, R.R., de Klein C.A.M., Li, Z. (2003a) *Determination of the N_2O and CH_4 emission factors from animal excreta, following a summer application in 3 regions of New Zealand*. Report for MAF Policy, Wellington. pp. 27

- The average EF_3 for cow urine, cow dung and sheep between the winter-autumn and the spring-summer trials were 0.28%, 0.04% and 0.01% of excreta N applied, respectively. Previous NzOnet seasonal EF_3 studies[19] showed the same trend of EF_3: cow urine (0.9) > cow dung (0.2) > sheep dung (0.0).
- The EF_3 for cow urine was significantly higher ($P < 0.05$) than those for dung in this spring-summer study. As expected, the readily available N in urine (urea-N + ammonium-N) was greater than that applied in dung pats, resulting in significantly higher soil ammonium- and nitrate-N levels under urine patches. In addition, urea hydrolysis following urine application to the soil potentially increased the soil pH, releasing organic matter into a soluble form available as a microbial food supply for denitrifying bacteria.
- EF_3 for urine in this spring-summer study was similar to that found in the autumn-winter trial, but lower than the average estimated from previous MAF EF_3 studies. This could be due to relatively dry soil conditions during this study period.
- The EF_3 for urine was largest in Waikato, presumably due to soil WFPS being greater than for the other regions, which were relatively dry for the spring-summer.
- Urine EF_3 from the poorly drained soils were higher than those of the well drained soils in the Waikato. However, the reverse was found in Otago. This was also found in the autumn-winter study.
- There was no significant difference ($P > 0.05$) in EF_3 for cattle and sheep dung, which was close to zero.
- The results for EF_3 for dung from the Waikato soils in the present spring-summer study were similar to values found in previous studies, where dung was also applied in the spring, while the results from Otago were lower in the present study to previous studies where dung was applied in the winter and spring.
- As found in the autumn-winter trial, soil drainage class within regions did not have a consistent effect on EF_3 values for different excreta types. Therefore, the results again suggest that pooling data into drainage class

[19] Kelliher F.M., de Klein, C.A.M., Li, Z., Sherlock, R.R. (2005) *Review of nitrous oxide emission factor (EF3) data*. Report for MAF Policy, Wellington. Pp. 20

alone is not sufficient, due to the variation between regions. Therefore, disaggregation of urine EF_3 will need to be on a 'region' x drainage class basis, where 'region' is represented by local climatic conditions (soil temperature, rainfall).

- EF_3 for cow dung was not significantly ($P > 0.05$) reduced with the application of DCD on the Otago Otokia soil. However, EF_3 for cow dung was significantly ($P < 0.05$) reduced by the application of DCD on the Waikato Te Kowhai soil.

Table 4: Estimates of spring-summer N_2O emission factors (N_2O-N emitted as % of dung or urine-N applied). Values in brackets are the SEM. Emission factors (& SEM) from the autumn excreta trial are also presented[20]

Location	Soil (description)	Treatment	**Current spring trial**	Autumn trial
Waikato	Te Kowhai	Dairy Cow dung	**0.11** **[0.05]**	0.07 [0.03]
	(poorly draining)	Dairy Cow dung + DCD	**0.00** **[0.04]**	0.03 [0.09]
		Sheep dung	**-0.24** **[0.09]**	0.04 [0.05]
		Dairy cow urine	**0.95** **[0.18]**	0.50 [0.09]
	Horotiu	Dairy Cow dung	**0.16** **[0.04]**	0.03 [0.02]
	(free draining)	Sheep dung	**0.06** **[0.07]**	0.03 [0.05]
		Dairy cow urine	**0.41** **[0.09]**	0.10 [0.05]
Southern Hawkes Bay	Wilford	Beef Cow dung	**0.00** **[0.02]**	0.01 [0.02]
	(poorly draining)	Sheep dung	**0.00** **[0.05]**	0.01 [0.06]
		Dairy Cow urine	**0.09** **[0.04]**	0.07 [0.04]
	Ngamoko	Beef Cow dung	**0.00** **[0.02]**	0.05 [0.03]
	(free draining)	Sheep dung	**0.02** **[0.05]**	-0.01 [0.06]
		Dairy Cow urine	**0.05** **[0.03]**	0.14 [0.04]
Otago	Otokia	Dairy Cow dung	**0.01** **[0.02]**	0.0 [0.01]
	(poorly draining)	Dairy Cow dung + DCD	**0.01** **[0.02]**	0.0 [0.01]
		Sheep dung	**-0.06** **[0.06]**	0.03 [0.05]
		Dairy cow urine	**0.21** **[0.06]**	0.49 [0.08]
	Wingatui	Dairy Cow dung	**0.04** **[0.03]**	0.17 [0.03]
	(free draining)	Sheep dung	**0.11** **[0.10]**	0.12 [0.05]
		Dairy cow urine	**0.42** **[0.10]**	0.91 [0.12]

[20] Luo, J., van der Weerden, T.J., Hoogendoorn, C., de Klein, C.A.M., (2009) Determination of the N_2O emission factor for animal dung applied in spring in three regions of New Zealand. Client report for MAF Policy, Pp. 26

Table 5: Estimates of N_2O emission factors (N_2O-N emitted as % of urine or dung-N applied) from spring-summer trial. Also shown are the autumn-winter[21] and annual average emission factor[22] for each excreta type, as reported previously

Excreta type	Region	Drainage class (soil type)	Season		Average of spring & autumn studies	Annual Average (previous research)
			Spring	Autumn (previous study)		
Dairy Cow urine	**Waikato**	Poor (Te Kowhai)	0.95	0.50	**0.28**	**0.90**
		Free (Horotiu)	0.41	0.10		
	Hawkes Bay	Poor (Wilford)	0.09	0.07		
		Free (Ngamoko)	0.05	0.14		
	Otago	Poor (Otokia)	0.21	0.49		
		Free (Wingatui)	0.42	0.91		
Average			**0.26**	**0.30**		
Dairy Cow dung* **Hawkes Bay used Beef Cow Dung*	**Waikato**	Poor (Te Kowhai)	0.11	0.07	**0.04**	**0.18**
		Free (Horotiu)	0.16	0.03		
	Hawkes Bay	Poor (Wilford)	0.00	0.01		
		Free (Ngamoko)	0.00	0.05		
	Otago	Poor (Otokia)	0.01	0.00		
		Free (Wingatui)	0.04	0.17		
Average			**0.04**	**0.05**		
Sheep dung	**Waikato**	Poor (Te Kowhai)	-0.24	0.04	**0.01**	**0.00**
		Free (Horotiu)	0.06	0.03		
	Hawkes Bay	Poor (Wilford)	0.00	0.01		
		Free (Ngamoko)	0.02	-0.01		
	Otago	Poor (Otokia)	-0.06	0.03		
		Free (Wingatui)	0.11	0.12		
Average			**-0.02**	**0.04**		

[21] Luo, J., van der Weerden, T.J., Hoogendoorn, C., de Klein, C.A.M., (2009). Li, Z., Sherlock, R.R. (2005) *Determination of the N_2O emission factor for animal dung applied in spring in three regions of New Zealand*. Client report for MAF Policy, Pp. 26

[22] Kelliher, F.M., de Klein, C.A.M., Li, Z., Sherlock, R.R. (2005) *Review of nitrous oxide emission factor (EF3) data*. Client report for MAF Policy, Wellington. Pp. 20

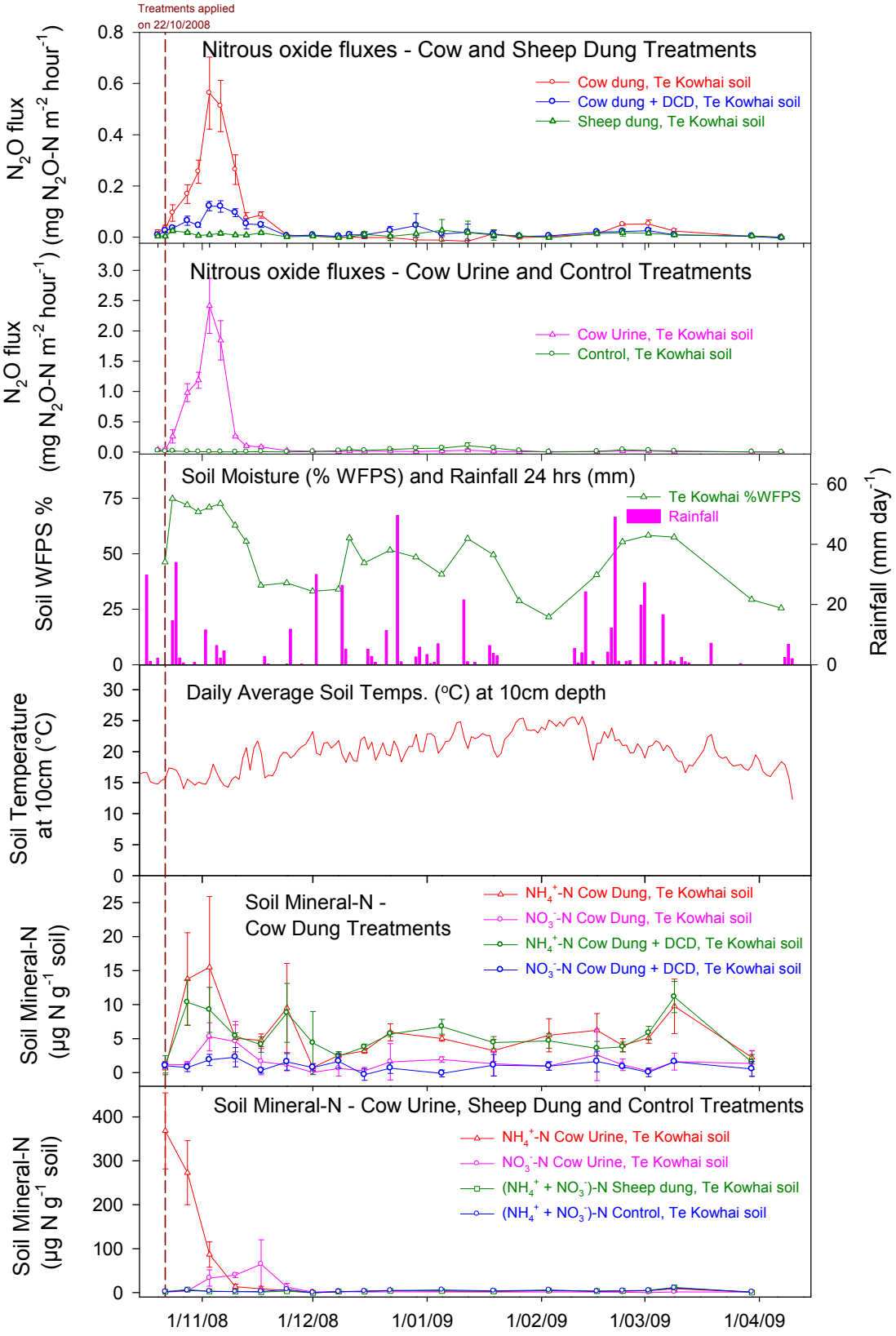

Figure 1: N_2O emissions and soil and climatic conditions for excreta amended Te Kowhai soil in Waikato. For N_2O flux and mineral N the data points represent arithmetic mean values ± SE (n=4)

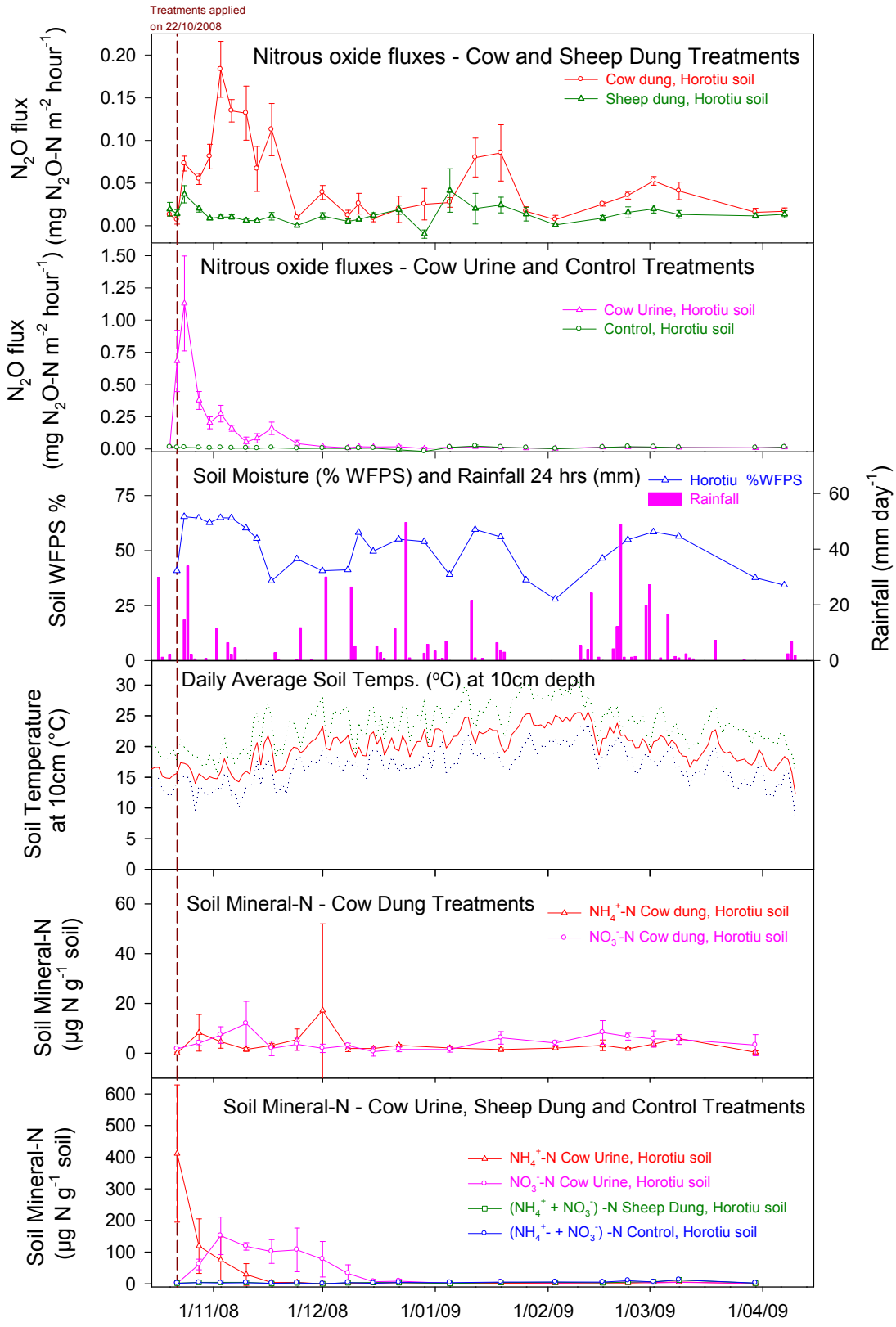

Figure 2: N_2O emissions and soil and climatic conditions for excreta amended Horotiu soil in Waikato. For N_2O flux and mineral N the data points represent arithmetic mean values ± SE (n=4).

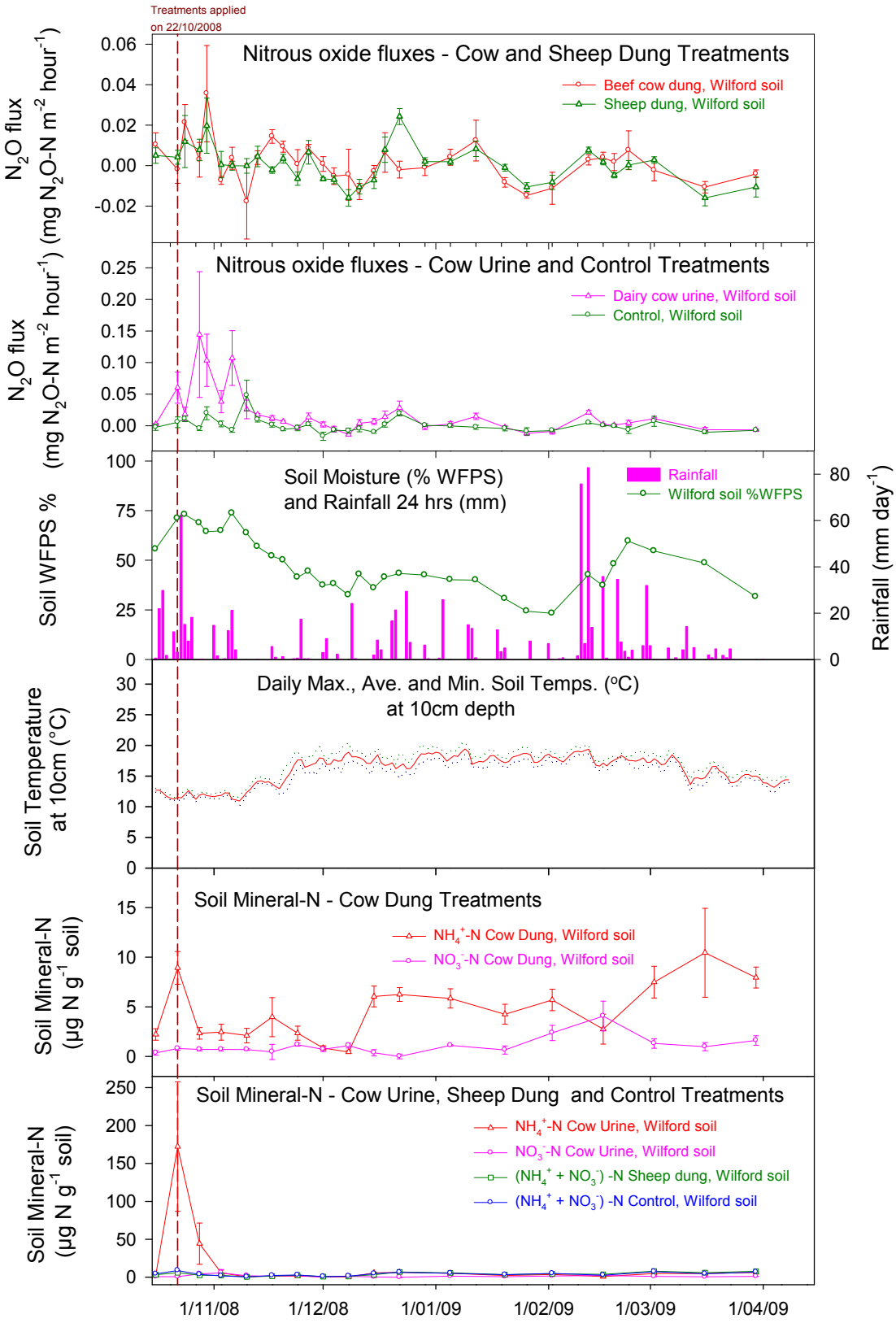

Figure 3: N_2O emissions and soil and climatic conditions for excreta amended Wilford soil in Southern Hawkes Bay. For N_2O flux and mineral N the data points represent arithmetic mean values ± SE (n=4)

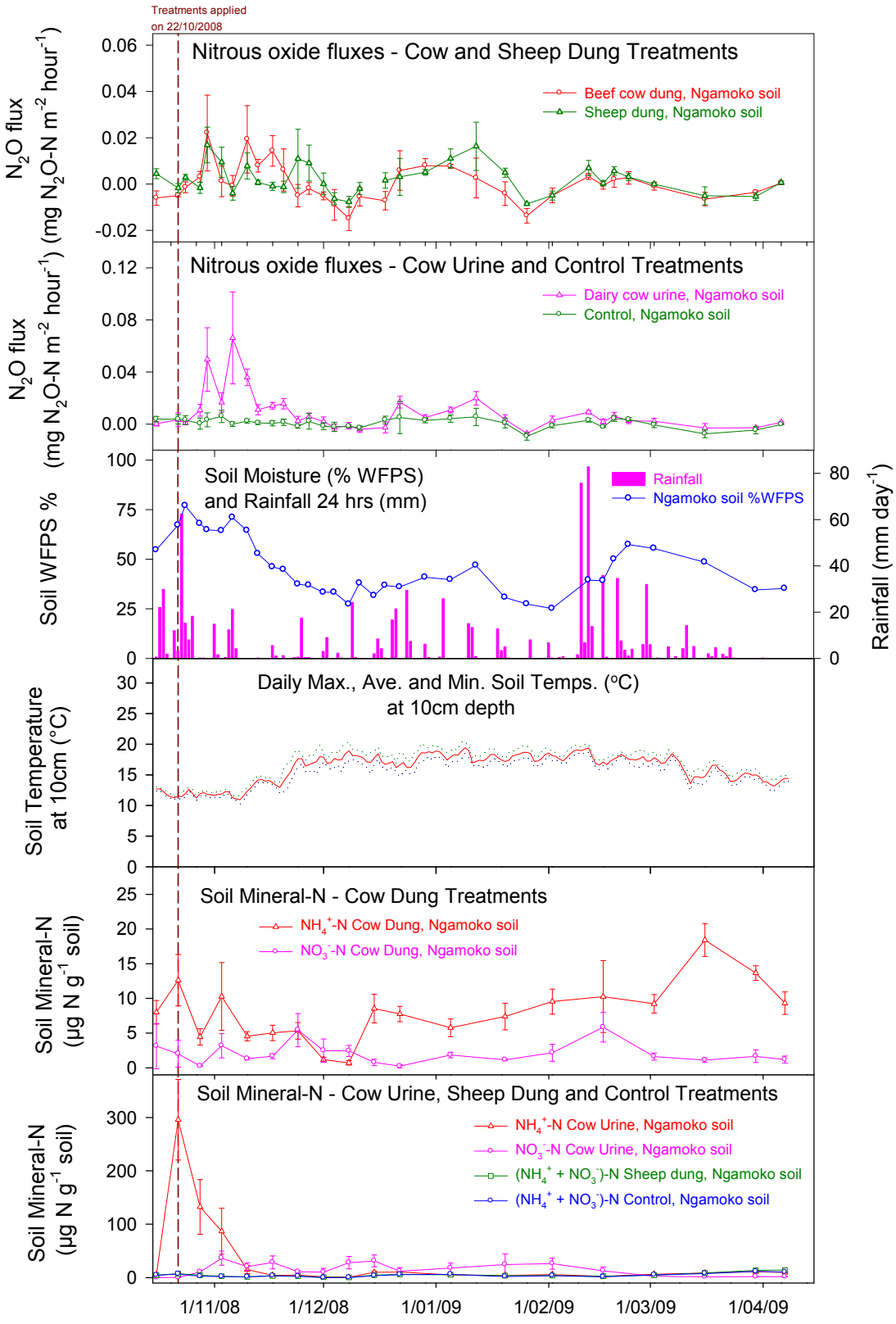

Figure 4: N_2O emissions and soil and climatic conditions for excreta amended Ngamoko soil in Southern Hawkes Bay. For N_2O flux and mineral N the data points represent arithmetic mean values ± SE (n=4)

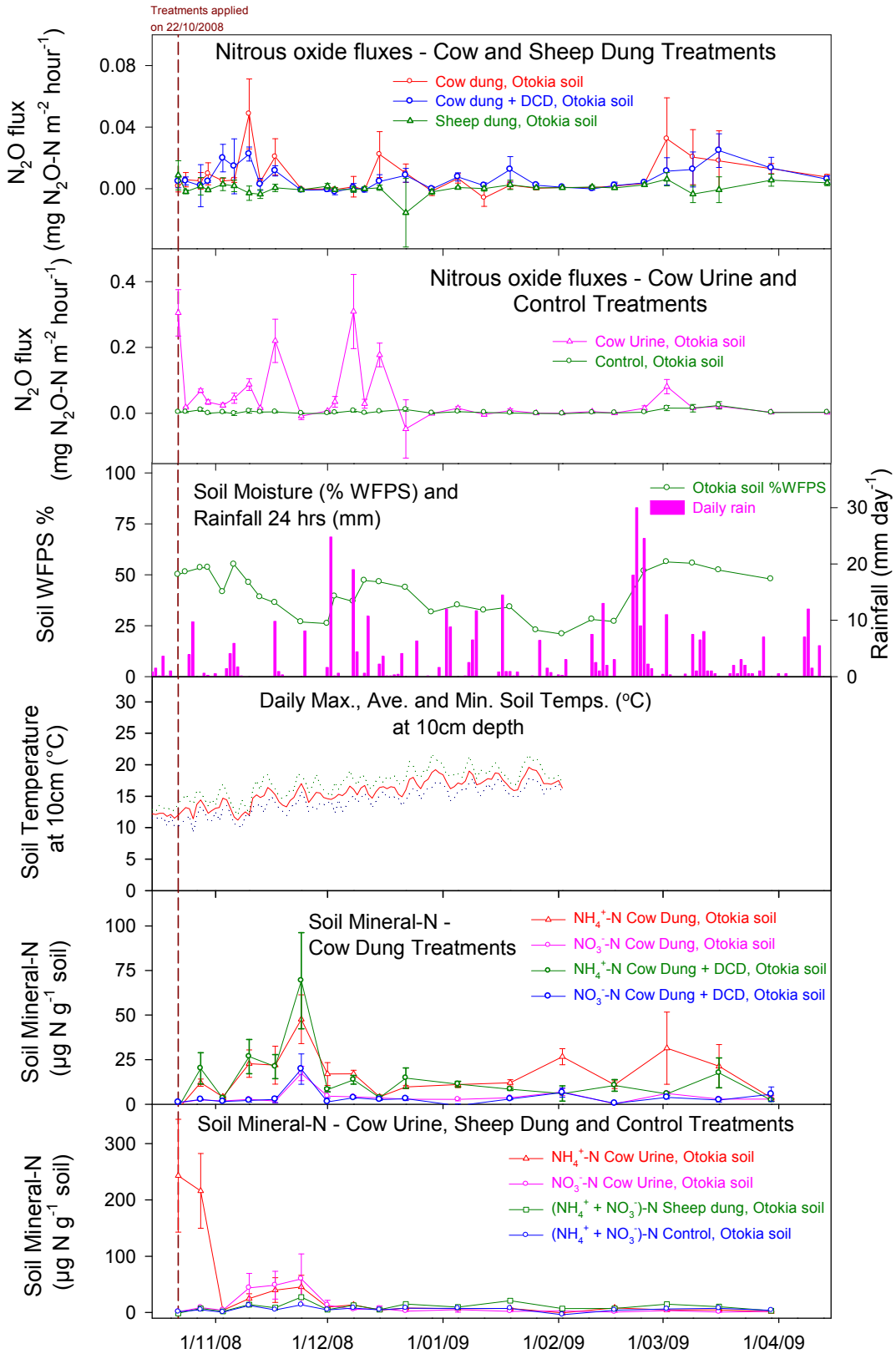

Figure 5: N_2O emissions and soil and climatic conditions for excreta amended Otokia soil in Otago. For N_2O flux and mineral N the data points represent arithmetic mean values ± SE (n=4). Soil temperature data from 1 February 2009 are unavailable

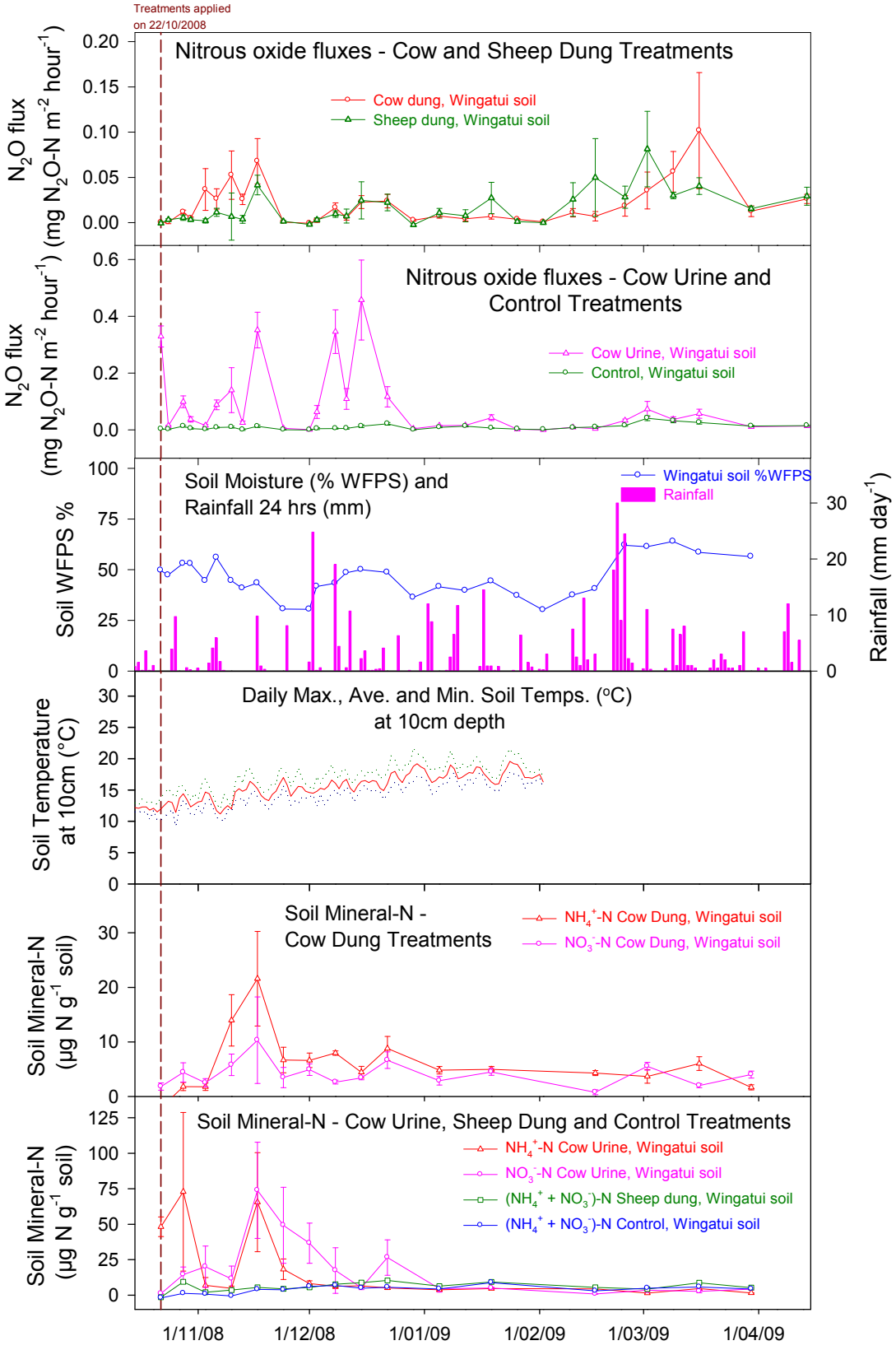

Figure 6: N_2O emissions and soil and climatic conditions for excreta amended Wingatui soil in Otago. For N_2O flux and mineral N the data points represent arithmetic mean values ± SE (n=4). Soil temperature data from 1 February 2009 are unavailable

6. Recommending a country specific EF_3 values for urine and dung for NZ

A second objective of the spring-summer dung trial was to review all New Zealand and international data on N_2O measurement comparisons between urine and dung and to recommend country specific EF_3 values for dung for NZ's N_2O inventory.

In 2003 a detailed literature review of EF_3 values was conducted to inform the revision of the 2006 IPCC N_2O inventory methodology. This review was updated with more recent results. In addition, the NZ specific results from previous NzOnet trials and the more recent MAF autumn-winter and spring-summer dung trials were summarised and an assessment was made of the direct comparison of the EF_3 from urine and dung from these trials.

The full EF_3 literature review is attached in Appendix 1, but a summary of the N_2O emission factors for different excreta types is presented in Table 6.

Table 6: Emission factors for different N sources (% of N applied)

N source	Range	Arithmetic mean	Median	Geometric mean	n
Sheep dung	-0.2 – 0.1	0.01	0.02	*	14
Cattle dung	0.0 – 4.0	0.34	0.10	0.03	27
Sheep urine	0.0 – 2.6	0.72	0.40	0.27	11
Pig urine	0.5	0.50	0.50	0.50	1
Cattle urine	0.0 – 14.0	1.77	0.90	0.40	52
Cattle urine + urea	1.5 – 2.2	1.94	2.09	1.91	3
Grazing sheep	0.2 – 1.7	1.02	1.00	0.84	5
Grazing beef cattle	1.0	1.00	1.00	1.00	1
Grazing dairy cattle	1.0 – 9.8	3.76	2.30	2.75	11
Synthetic urine	-0.4 – 16.3	1.76	0.99	*	102
Synthetic urine + dung**	0.1 – 9.7	4.41	4.40	2.79	15
Synth. urine + compaction	-0.6 – 10.8	3.29	1.87	*	22
Synth. urine + dung*+ compaction	0.6 – 3.2	1.66	1.70	1.44	8
Total	-0.6 – 16.3	1.82	0.91	*	261

* Unable to calculate geometric mean as negative values occurred

** The reported emission factor was corrected for the emissions derived from dung, and thus reflects urine derived N_2O emissions only.

These results clearly suggest a much lower emission factor for cattle or sheep dung compared to cattle urine. The reduction in EF_3 from dung was on average 81, 89 and 94% lower than the urine EF_3 when calculated based on the arithmetic mean, median or geometric mean, respectively.

Similar results were obtained when a direct comparison was made of dung and urine emission factors estimated in NzOnet trials (Table 7). Except for the results from the moderately drained soil in Canterbury in summer 2002, the EF3 for dung was always much lower than that for urine, ranging from 50 to 100% reduction, with an average reduction of 80%.

Table 7: A summary of EF_3 values from NzOnet trials where a direct comparison between cattle urine and cattle dung was made

Year	Season	Soil drainage	Region	Dung	Urine	% reduction
2002	Spring	Free	Waikato	0.20	1.20	83%
2002	Spring	Mod	Canterbury	0.20	0.40	50%
2002	Summer	Mod	Canterbury	0.20	0.20	0%
2003	Winter	Free	Otago	0.10	0.90	89%
2003	Winter	Poor	Otago	0.10	0.90	89%
2003	Winter	Poor	Waikato	0.50	2.60	81%
2008	Autumn	Free	Waikato	0.03	0.10	70%
2008	Autumn	Free	Otago	0.17	0.91	81%
2008	Autumn	Free	Manawatu	0.05	0.14	64%
2008	Autumn	Poor	Waikato	0.07	0.50	86%
2008	Autumn	Poor	Otago	0	0.49	100%
2008	Autumn	Poor	Manawatu	0.01	0.07	86%
2008	Spring	Free	Waikato	0.16	0.41	61%
2008	Spring	Free	Otago	0.04	0.42	90%
2008	Spring	Free	Manawatu	0	0.05	100%
2008	Spring	Poor	Waikato	0.11	0.95	88%
2008	Spring	Poor	Otago	0.01	0.21	95%
2008	Spring	Poor	Manawatu	0	0.09	100%

The results are also summarised by soil drainage class, region and season (Table 8A, B, C). There were only 2 pairs of results from the moderately draining soil in Canterbury and these results should therefore be reviewed with caution. The remaining results showed that the reduction was relatively similar for each drainage class, region and season (except summer where only one value was obtained).

The currently used NZ specific N_2O emission for animal excreta is 1%. This was initially based on 2 field trials but is supported by a range of further trials in different seasons and soil drainage classes (see Table 5). The reductions in EF_3 values for dung found in studies were a direct comparison was made between urine and dung, suggested a disaggregated emission factor for dung of 0.2%. However, given the potential effect of urine and dung overlaps on N_2O emissions (van Groenigen et al., 2005) [23], a conservative value of 0.5% is recommended.

Table 8: Average values of the N_2O emission factor for dung and urine by A) soil drainage class, B) region and C) season (n=18)

A)	EF3 (%)		
Soil drainage	Average of Dung	Average of Urine	Average of % reduction
Free (n=8)	0.09	0.52	0.80
Mod (n=2)	0.20	0.30	0.25
Poor (n=8)	0.10	0.73	0.91
Grand Total	0.11	0.59	0.79

B)	EF3 (%)		
Region	Average of Dung	Average of Urine	Average of % reduction
Canterbury (n=2)	0.20	0.30	0.25
Manawatu (n=6)	0.02	0.09	0.88
Otago (n=6)	0.07	0.64	0.91
Waikato (n=4)	0.18	0.96	0.78
Grand Total	0.11	0.59	0.79

C)	EF3 (%)		
Season	Average of Dung	Average of Urine	Average of % reduction
Autumn (n=6)	0.06	0.37	0.81
Spring (n=8)	0.09	0.47	0.84
Summer (n=1)	0.20	0.20	0.00
Winter (n=3)	0.23	1.47	0.86
Grand Total	0.11	0.59	0.79

[23] van Groenigen, J.W., Velthof, G.L., van der Bolt, F.J.E., Vos, A. Kuikman, P.J. (2005). *Seasonal variation in N_2O oxide emissions from urine patches: effects of urine concentration, soil compaction and dung*. *Plant and Soil* 273:15-27

7. Conclusions

- The N_2O emissions from application of animal dung in spring were much lower than those from application of dairy cow urine on all 6 soils, with most sampling occasions showing emissions from dung plots being similar to those from untreated plots.
- Results from this spring-summer study found that EF_3 decreases as follows: cow urine > cow or cattle dung > sheep dung. The average EF_3 for cow urine, cow dung and sheep dung were estimated at 0.26%, 0.04% and -0.02% of excreta N applied, respectively.
- The EF_3 for cow urine was significantly greater ($P < 0.05$) than those for dung in this spring-summer study. There was no significant difference in EF_3 for cattle and sheep dung ($P > 0.05$).
- As found in the autumn-winter study, EF_3 for urine in this spring-summer study was also lower than the average estimated from previous MAF studies.
- Soil drainage class within regions did not have a consistent effect on EF_3 values for different excreta types.
- Effects of DCD on EF_3 for cow dung were not consistent.
- These results confirmed that a disaggregation of EF_{3PRP} between dung and urine is warranted.
- It is recommended that the N_2O emission factor for animal urine remains at 1%, and the N_2O emission factor for animal dung is reduced to 0.5%.

8. Acknowledgements

Stuart Lindsay, Bridget Wise and Martin Kear for field and lab work at the Waikato Ruakura sites; Brian Devantier, Barry Rolle, Jill Walcroft and Phil Theobald for field and lab work at the Hawkes Bay Ballantrae sites; Jane Campbell, Alison Rutherford, Jim Paton and Sonya Walker for field and lab work at the Otago sites; Dr Roger Littlejohn for statistical analysis.

9. Appendix A: Review of N_2O emission factor for excreta deposited by grazing animals (EF_{3PRP})

Introduction

Excreta deposited by grazing animals are one of the sources of N_2O that are included in the IPCC methodology. The N_2O emission factor for this source (EF_{3PRP}) currently has a default value of 0.02 kg N_2O-N per kg N excreted, with an uncertainty range of -50%/+100%.

This default value is based on about 20 different values of N_2O emissions from animal excreta that were obtained in studies in 4 countries (The Netherlands, Germany, UK and New Zealand) prior to 1996. The values ranged from 0.02 kg N_2O-N per kg N excreted from well-drained unfertilised grassland in New Zealand, to 38 kg N_2O-N per kg N excreted from intensively grazed dairy pasture on peat soil in The Netherlands. Nearly all data pertain to temperate climate and intensively managed grasslands. There were no data from less intensively managed (sub) tropical grasslands.

Although the 1996 IPCC guidelines recognised that the N_2O emission factor for animal excreta is likely to vary with soil and climatic conditions, grazing intensity, animal type and diet, the default EF_{3PRP} was set for all regions of the world and for all animal types, due to the lack of experimental evidence.

This paper reviews the results of studies on the N_2O emission factor of excreta from grazing animals that were carried out after 1996. These are then linked with the earlier results to assess whether the current default value of EF_{3PRP} requires refinement, and whether enough information is available to disaggregate the emission factor based on climatic region, soil type, animal type, grazing intensity and/or animal diet.

Methods

Two recent review papers were the basis for this review: de Klein et al. (2001) and van Groenigen et al. (2005a). The studies and EF_{3PRP} values summarised in these papers overlapped substantially, but some studies were reported in only one of the papers. In addition, an in-depth literature search was conducted to find relevant

studies not included in either of the two papers. Finally, unpublished data from 8 New Zealand studies were also included.

The following information from each study was compiled in a spreadsheet:
Reference details
Region
Country
Climate
Season
System studied
Soil type
Water status/drainage class
N source
N rate
Measurement period
Cumulative N_2O emissions
Emission factor

Results

Climatic region

The review resulted in a total of 236 values for EF_{3PRP} from about 40 different studies (Table 1). The majority (> 90%) of these studies were conducted in a temperate climate in Europe (The Netherlands, UK, Germany and Belgium) and New Zealand. Two studies were conducted in a Continental climate (Colorado, USA and Japan) and one in a Mediterranean climate (Western Australia). Based on these results it is not possible to provide separate EF_{3PRP} values for different climatic regions.

Table 1: N_2O emission factors for animal excreta from grazing animals (EF_{3PRP}) in different climatic regions (% of N applied)

Climatic region	Range	Arithmetic mean	Median	Geometric mean	n
Mediterranean	0.00	0.00	0.00	0.00	1
Temperate	-0.6 – 16.3	2.07	1.08	1.20	233
Continental	0.6 – 5.0	2.80	2.80	1.73	2
Total	0.0 – 16.3	2.07	1.06	1.17	236

Soil type/drainage class

It is generally accepted that soil type or soil drainage class can have a large impact on N_2O emissions, with wetter soil generally emitting more N_2O than dryer soils. However, N_2O emissions from soils from very wet or saturated soils can be quite low as N_2O is often reduced to N_2 before being emitted from the soil. Recent studies have indicated that the optimum soil water pore space (WFPS) content for nitrification and denitrification is between 55-65% and 60-95% respectively (Luo et al. 2007; Phillips et al. 2007; Sagger et al. 2008). A recent study undertaken by Schils et al (2008) found that during the summer months only 4% of the annual N_2O emissions were released due to the lower WFPS. This has lead to suggestion that reducing animal urine deposition during winter months (for example on animal housing or standoff pads) can reduce the annual N_2O emission factor (Luo et al. 2008a).

Although clay and clay loam soils revealed a relatively high average emission factor, the range of emission factors found in sand, sandy silt loam and silt loam soils were similar to those from clay and clay loams. Phillips et al. (2007) found that after soil saturation (generally from irrigation or heavy rainfalls) irrespective of soil type short sharp N_2O emissions were released. The results obtained in this review are inconclusive with regard to the effect of soil type or soil drainage class (Table 2).

The largest number of studies was conducted in silt loam and sandy soils. Within these soil types, various soil water status or drainage class categories could be identified. Within the silt loam soils, no clear pattern of the effect of soil water status on EF_{3PRP} could be distinguished, as the median EF_{3PRP} values for well and poorly draining soils were very similar. A laboratory study by van Groenigen et al. (2005a) using sandy soil at different soil moisture status, suggested that moist sand had a higher emission factor than dry sand, particular if the moist soil was also compacted.

Table 2: EF_{3PRP} values for different soil types/drainage class (% of N applied)

Soil type		Range	Arithmetic mean	Median	Geometric mean	n
Silt loam		0.0 – 6.4	1.10	0.75	0.69	62
Sandy loam		0.1 – 5.0	1.53	0.95	0.93	8
Clay loam		0.0 – 14.0	2.89	1.20	1.05	24
Sandy silt loam		0.3 – 4.2	1.86	1.15	1.16	8
Peat		0.3 – 9.8	2.53	1.30	1.43	11
Sand		0.0 – 16.3	3.03	1.71	1.45	40
Loamy sand		-0.6 – 10.8	2.01	1.13	1.54	72
Loam		0.0 – 4.0	2.25	2.60	2.17	6
Clay		1.9 – 3.3	2.43	2.10	2.36	3
Acid brown		2.56	2.56	2.56	2.56	1
Coarse silt		7.0	7.00	7.00	7.00	1
Total		-0.6 – 16.3	2.07	1.06	1.17	236
Silt loam	- well draining	0.0 – 3.7	1.08	0.90	0.72	26
	- imperfectly draining	0.2 – 0.7	0.36	0.30	0.31	6
	- poorly draining	0.0 – 3.0	1.10	0.84	0.73	14
Sand *	- dry	0.2 – 1.9	0.72	0.38	0.47	7
	- moist	0.7 – 9.7	3.67	1.85	2.40	14
	- moist+compacted	0.6 – 6.9	2.76	2.01	2.07	14

* Results of a laboratory study using sieved and repacked soil (van Groenigen et al. 2005a)

Animal or excreta type

Table 3 summarises results from the studies using a variety of excreta types. The highest median emission factors were found in dairy grazed pastures and following the applications of cattle urine with urea fertiliser (cattle urine + urea) and of synthetic urine on soil with incorporated dung (Synthetic urine + dung). The results from the dairy grazed pastures were largely obtained by Velthof et al. (1995; 1996a,b) and included studies on peat soil. The three values for the cattle urine plus urea applications were obtained in a lysimeter study in New Zealand (Di and Cameron 2002, 2003), while the emission factors for synthetic urine + dung were measured in a laboratory with sieved and repacked soil (van Groenigen et al. 2005a) and in recent a field study on loamy sand (van Groenigen. 2005b). This latter study also included a mechanical compaction treatment (manual pounding of the soil with a wooden hammer). A recent study by Wachendorf et al. (2008) indicated that N_2O loss from dung-derived N was very low. Another study undertaken by Jones et al. (2007) showed that sewage sludge pellets had the highest annual N_2O emissions compared to poultry manure, cattle slurry, NH_4NO_3 fertiliser and urea (2.8%, 1.5%, 0.35%, 0.75% and 0.25% of the total N applied, respectively).

The results further indicated that the emission factors for sheep urine applications or in sheep grazing systems are lower than those following cattle urine applications or in dairy grazing systems. There was only one observation from a beef cattle grazing system and it is thus impossible to make a sound assessment of the EF_{3PRP} from these systems. They are however likely to be more similar to dairy grazing systems than to sheep grazing systems.

The median emission factor for cattle urine applications was lower than those obtained in dairy grazing systems, which could be a reflection of the fact that grazing animals also have other effects on N_2O emissions than depositing urine and dung. For example, they can cause soil compaction by trampling or increased turn-over of nitrogen from stubble and roots. Many of the 'cattle urine' studies used experimental plots with defined urine patches and did not include grazing animals. As mentioned, the compaction treatment reported by van Groenigen (2005b) was mechanical compaction.

The median EF_{3PRP} value for cattle dung was lower than that for cattle urine. All the 15 values for cattle dung were obtained in studies that included a direct comparison with cattle urine, and in only one occasion was the EF_{3PRP} form dung higher than the one for urine. In all other instances the emission factor for dung was equal to, or lower than, the one for urine.

Table 3: Emission factors for different N sources (% of N applied)

N source	Range	Arithmetic mean	Median	Geometric mean	n
Sheep dung	-0.2 – 0.1	0.01	0.02	*	14
Cattle dung	0.0 – 4.0	0.34	0.10	0.03	27
Sheep urine	0.0 – 2.6	0.72	0.40	0.27	11
Pig urine	0.5	0.50	0.50	0.50	1
Cattle urine	0.0 – 14.0	1.77	0.90	0.40	52
Cattle urine + urea	1.5 – 2.2	1.94	2.09	1.91	3
Grazing sheep	0.2 – 1.7	1.02	1.00	0.84	5
Grazing beef cattle	1.0	1.00	1.00	1.00	1
Grazing dairy cattle	1.0 – 9.8	3.76	2.30	2.75	11
Synthetic urine	-0.4 – 16.3	1.76	0.99	*	102
Synthetic urine + dung**	0.1 – 9.7	4.41	4.40	2.79	15
Synth. urine + compaction	-0.6 – 10.8	3.29	1.87	*	22
Synth. urine + dung*+ compaction	0.6 – 3.2	1.66	1.70	1.44	8
Total	-0.6 – 16.3	1.82	0.91	*	261

* Unable to calculate geomean as negative values occurred

** The reported emission factor was corrected for the emissions derived from dung, and thus reflects urine derived N_2O emissions only.

Based on their review of the literature on N_2O emission factors for animal excreta, Van Groenigen et al. (2005a) suggested that a lowering of the IPCC default value for EF_{3PRP} of 2.0 to 1.0% of N excreted is warranted. However, their review did not include the emission factors from sheep urine found in unpublished New Zealand studies (Muller 1995; de Klein et al. 2004; Sherlock et al. 2003b). Based on the results presented here it seems prudent to consider disaggregation of the EF_{3PRP} value for sheep and cattle grazing systems (e.g. 1.0 % for sheep excreta and 2.0% for dairy and beef cattle excreta).

A disaggregation of EF_{3PRP} for dung vs. urine N could also be considered. However, this is not easy to implement as the amount of N excreted in urine and dung widely varies with animal diet. In particular the amount of N excreted in urine will increase with increasing N content of the diet. It is unlikely that countries have the required information readily available to assess excretion rates in urine and dung. However, this approach should be considered by countries that use a higher tier methodology.

Grazing intensity and animal diet

Most of the data compiled in this review were from intensively managed systems. There were no published data on the N_2O emission factor from excreta from grazing animals in less intensive (sub) tropical grasslands. It is not possible to ascertain if the EF_{3PRP} for these less intensively managed systems is different from the ones summarised in this review. Similarly, the majority of the studies did not include any information on the diet of the animals that were used in the grazing studies or from which urine was collected. Recent work has shown that low N feed decreases the amount of N_2O emission. For example Luo et al. (2008b) showed that the N_2O emissions of dairy farms from control pasture [white clover (*Trifolium repens* L.) and perennial ryegrass (*Lolium perenne* L.) pasture] were slightly higher than on maize supplement feed (the average annual rate was 4.67 kg N_2O-N ha^{-1} and 4.03 kg N_2O-N ha^{-1} respectively). It was also found that the maize supplement feed decrease the whole farm N_2O emissions by 22% per kg of milk solid compared to the control pasture (Luo et al. 2008b). Le et al. (2009) however found that decreasing the crude protein for pigs from 15% to 12% did not change the amount of N_2O emission released. However, it is suggested that further work should be undertaken as the N_2O emission where low above the study site. It is suggested that decreasing the amount of N_2O released from the agriculture sector can been achieved by changing the urine composition through feed supplement (van Groenigen et al. 2006) or adding more salt to the animals diet to increase the amount of water needed which decrease the N concentration (de Klein and Eckard 2008).

Conclusion

There have been quite a number of new studies on the N_2O emission factor of excreta from grazing animals since the current IPCC default value of 2.0% of N excreted was determined in the 1996 Guidelines. A review of all these studies revealed a total of about 235 values from about 40 different studies. These indicate that the emission factor for sheep urine is lower than that for cattle urine and it is therefore proposed to reduce the N_2O emission factor for sheep excreta to 1% of N excreted, but maintain the N_2O emission factor for cattle excreta at the current 2% of N excreted. The results also suggest that the emission factor for dung is lower than that for urine. However, a disaggregation of EF_{3PRP} based on dung and urine is not straightforward to implement as the amount of N excreted in

urine and dung varies based on diet, and it is unlikely that countries have this information easily available. However, this approach should be considered by countries that use a higher tier methodology.

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