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Hotspot Areas of Nitrous Oxide Emissions from Pasture Grazed by Dairy Cows

SLMACC Final Report for MPI

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Executive summary

This report fulfils Milestone 4 of Objective 2 of the Sustainable Land Management and Climate Change (SLMACC) funded project, entitled "Identification of problem areas within farming systems and approaches to mitigate nitrous oxide (N_2O) hotspots".

Previous milestones were:

- Milestone 1: A review to identify potential hotspots for N_2O emissions in New Zealand dairy farm systems (Luo et al., 2014).
- Milestone 2: Development of a framework for determining total emissions from dairy farms and estimating the significance of the potential hotspot areas at the farm scale (Luo et al., 2015b).
- Milestone 3: Quantification of N_2O emissions from hotspots that have been identified as significant but for which there is no existing data (Luo et al., 2016).

Milestone 4 is to determine the importance of potential significant hotspots identified in the previous milestones, the most important of which are gates and troughs (Luo et al., 2015b).

As presented in the Milestone 3 report (Luo et al., 2016), a field trial was set up in a paddock, previously grazed by dairy cows, on a farm in the Waikato region, involving the measurement of N_2O emissions along transects radiating from the gate and from the water-trough. Small-plot areas on the transects were either treated with cow urine or remained untreated, with gas measurements made and emission factors for urine (EF_3) calculated. There were elevated background N_2O emissions from the areas around water-troughs and gateways within the paddock. High background N_2O emissions relate to effects of previous urine patches or, possibly, to other localised soil factors such as higher water filled pore space (WFPS). However, the IPCC N_2O inventory methodology doesn't account for these higher background emissions when N_2O emission factors (EF_3, N_2O-N emitted as % of excreta N applied) are used to calculate total farm emissions. Therefore, to include all the effects on emissions related to the hotspots, background emissions were accounted for by including them using an adjusted EF_3 (adjEF_3). This was calculated by subtracting an average background emission from non-hotspot areas in the paddock instead of the background emission at that measured point.

The extent of the hotspot areas were estimated from the elevated N_2O emissions. The hotspot area around the water-trough was found to be considerably smaller than the hotspot area around the gateway (3.2% compared to 0.3% of paddock area, respectively). When the background N_2O emissions from the average paddock were considered, the likely magnitude of adjEF_3 values for the gateway and water-trough areas would be about 5 times that of the rest of the paddock. The limited set of results from this single study indicate that the appropriate EF_3 values to use for urine in the New Zealand national greenhouse gas inventory calculation would be 5% for the gate and water-trough areas, compared to the current national inventory value of 1%. However, we recommend further studies in different regions and times of year to validate this result.

A subsequent survey was conducted in 7 different paddocks of case-study dairy farms in 3 regions (Waikato, Canterbury and Southland) of New Zealand to determine whether the excreta N deposition onto the gateway and water-trough areas was greater than that onto the rest of the paddock. Results indicated that there was no obvious increase in excreta deposition in the gateway or water-trough areas.

This data was used to test and confirm the significance of water-trough and gateway affected areas as potential hotspots for N_2O emissions. The three case-study farms and the framework model developed in Milestone 2 (Luo et al., 2015b), were used to recalculate the case-study farm emissions using the size of affected areas and EF_3 values derived from the measurements obtained from Milestone 3 (Luo et al., 2016). The relative contributions of the water-trough and gateway affected areas to total farm N_2O emissions were subsequently assessed.

The analysis suggests that water-trough affected areas are unlikely to contribute more than 1% of total farm N_2O emissions. Therefore, water-trough areas cannot be considered a significant hotspot for the farm. However, our analysis suggests that gateways could be significant hotspots for N_2O emissions on dairy farms. When the effects of increased EF_3 values are considered, gateways contribute between 2 and 9% of the total farm N_2O emissions. The highest contribution from gateways was found on the Waikato case-study farm, due to the smaller average paddock size resulting in more gateways per hectare of the farm. On this farm 3% of the farm was covered by gateway areas, contributing 9% of the total farm N_2O emissions. The effect of the number of gates on dairy farm emissions was shown to be potentially important. However, these results are based on only one field site measurement and more data is required to understand the significance of paddock size, hotspot areas and EF_3 values.

If it was assumed that the area affected by each gateway and the associated $adjEF_3$ are constant, increasing the paddock sizes to reduce the number of gateways required, may help mitigate this hotspot and reduce total farm N_2O emissions. Other mitigation options to reduce emissions from gateways include locating gateways on well-drained soil, applying materials (such as gravels, carbon-rich products, zeolite, lime, or nitrification and urease inhibitors) around gateways, or improving drainage, and avoiding N fertilisers and farm effluent/manure application near the gates. To reduce physical damage to soils around gateway areas, situations that result in animals gathering around gateways should be avoided. Placing troughs near gateways should also be avoided.

1. Background

This report fulfils Milestone 4 of Objective 2 of the Sustainable Land Management and Climate Change (SLMACC) funded project, entitled "Identification of problem areas within farming systems and approaches to mitigate nitrous oxide (N_2O) hotspots". Hotspots are deemed to be areas of the farm which potentially produce a higher proportion of the total N_2O emitted from the whole farm. The overall aims of this programme were to: 1) identify N_2O hotspots within farms and farming systems, and 2) recommend parameters for updating the New Zealand greenhouse gas inventory, if applicable.

The following milestones have been completed:

- Milestone 1: A review to identify potential hotspots for N_2O emissions in New Zealand dairy farm systems (Luo et al., 2014).
- Milestone 2: Development of a framework for determining total emissions from dairy farms and estimating the significance of the potential hotspot areas at the farm scale (Luo et al., 2015b).
- Milestone 3: Quantification of N_2O emissions from hotspots that have been identified as significant but for which there is no existing data (Luo et al., 2016).

Summaries of the major findings from the above milestones are presented in the following sections (Sections 2, 3 and 4).

The final milestone of this project (Milestone 4), presented in this report, is to determine the importance of gateway and water-trough areas as N_2O hotspots and recommend potential mitigation options to reduce N_2O emissions from these hotspots.

2. Identification of potential hotspots

In a review report produced for **Milestone 1** (Luo et al., 2014), we identified a number of areas in dairy farm systems which could be potential N_2O hotspots. Typically, N_2O hotspots (Figure 1) are areas with high stocking density, high excretal inputs (resulting in high soil N) and situations when soil water filled pore space (WFPS) is elevated.

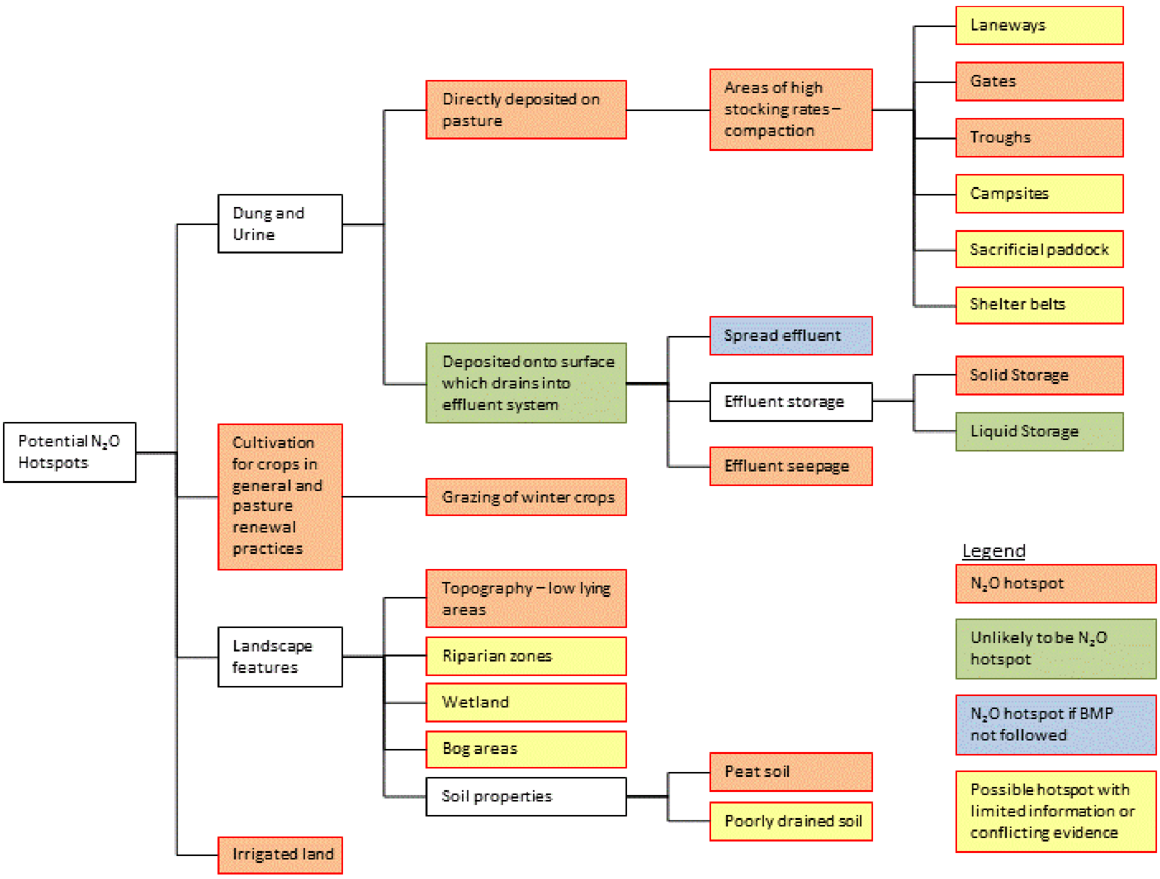


Figure 1: Potential N_2O hotspots and driving factors from dairy farm systems.

Excreta deposition and soil compaction cause elevated N_2O emissions in their own right. However, combining the two in areas such as stock campsites, gateways, and laneways, around water-troughs and pugged winter-damaged paddocks is likely to further increase emissions from these areas. The full magnitude of these emissions and the associated area these features occupy on a farm are not fully understood and require further investigation.

Effluent management is also a factor influencing the source and magnitude of N_2O hotspots. Application of effluent to land is unlikely to be a hotspot if best management practices are followed, e.g. low application rates and avoiding application to saturated or compacted soils. Due to anaerobic conditions, which result in a low nitrate concentration, liquid effluent storage is unlikely to be an N_2O hotspot. However, stored solid manure and the processes which separate solid and liquid material may be potential N_2O hotspots, due to aerobic and anaerobic zones allowing coupled nitrification and denitrification to occur. Further work is required to improve our understanding of the processes responsible for N_2O emissions from these potential hotspots.

Cultivation of permanent pasture and grazing summer and winter forage crops are likely to result in hotspots of N_2O production. Large amounts of soil N are mineralised following herbicide-spraying of pasture and tillage. The amount of mineral N is usually supplemented by fertiliser N applied to crops and new pasture. In-situ grazing of the crops, especially during winter, increases the risk of high N_2O emissions when large amounts of excretal N are deposited onto soils that are wet and remain wet during the following fallow period. In wet conditions the risk of soil compaction and structural damage from animal treading increases, especially when crops are established using cultivation, further increasing the likelihood of N_2O emissions.

Topography influences soil moisture content, which results in low-lying areas being potential N_2O hotspots. Riparian zones in the landscape are typically saturated and often receive N rich waters, making them potential N_2O hotspots, but they can also be sinks for N_2O. There is a lack of information regarding N_2O emissions from riparian zones on New Zealand dairy farms and international studies present a range of emission values, meaning it is difficult to draw conclusions on the status of riparian zones as N_2O hotspots. Peat soils with high moisture and available carbon status are potential N_2O hotspots. Some research has indicated that poorly drained soils are also hotspots, yet other work has indicated this is not the case.

3. Development of framework

For **Milestone 2**, a framework was developed using the knowledge and information gained from the review for Milestone 1 in order to attempt to quantify the effects of potential N_2O hotspots on whole-farm N_2O emissions (Luo et al., 2015b). This framework was based on the equation:

$$N_2O_{\text{Dairy farm}} = \sum_i (\text{Ninput}_i \times EF_i)$$

Where,

Ninput_i = amount of N mineralised, applied or deposited in the feature “area” i; EF_i = N_2O emission factor for feature area i.

A spreadsheet model was developed, according to this framework to calculate emissions from all features of the farm, such as pasture paddocks, water-trough areas, effluent storage, winter and summer cropping areas, pasture renewal areas etc., to help identify the hotspot areas. For this model, estimates were made, based the literature review conducted for Milestone 1, of the area covered by these zones, the potential increases in N inputs to these zones and the possible increases in N_2O emission factor.

“Typical” farms from three regions of New Zealand (Waikato, Canterbury and Southland) were used as case studies to apply the developed framework. A sensitivity analysis was then conducted using the framework, by altering the magnitude of N input rates and emission factors, to estimate changes in total N_2O emissions from the case study farms. The relative contributions of the different farm features to total farm N_2O emissions were subsequently assessed.

The sensitivity analysis suggested that gateway and water-trough areas could be the most significant N_2O hotspots on dairy farms. When the effects of increased N loading and potential increase in EF_3 were combined, these features resulted in a total contribution of 50% or more of the total farm emissions from the Southland and

Waikato case-study farms. Therefore, confirmation of the likely magnitudes of N input and EF values for the gateway and water trough areas were the priority for subsequent field experiments in this project.

The other farm feature highlighted as a potential hotspot for N_2O emissions was winter cropping on both Southland and Canterbury farms, with the contribution of this feature to the total farm emissions being estimated at just under 50% when the effects of increased N loading and increased EF for this feature were combined. The framework suggested that other features, such as laneways, pasture renewal areas and stand-off pads, are unlikely to be hotspots for N_2O generation and emission. However, the results for these features strongly depend on the accuracy of estimates for amounts of N input and associated EFs. The potential for specific landscape areas, such as gully aspects and riparian zones, to be hotspots depends on the proportion of the farm that is occupied by these features, which is likely to be highly variable between farms. Irrigation applied at high frequency (e.g. centre pivot irrigators on short rotations of 3 days) is likely to have a higher EF compared to lower frequency irrigations. Because of the large area irrigated in Canterbury this can have a large effect on the whole farm emissions.

4. Quantification of N_2O emissions from hotspots

For **Milestone 3**, measurements of EF_3 values were made in gateway and water-trough areas (hotspots as identified in Milestones 2) in order to increase the reliability of the framework estimates (Luo et al., 2016).

A field trial was set up in a paddock (1.4 ha) on AgResearch's Tokanui dairy farm, located about 45 km south of Hamilton, involving the measurement of N_2O emissions along transects radiating out from the gate and from the trough (Figure 2). Small-plot areas on the transects were either treated with cow urine or remained untreated ('nil urine'), with gas measurements being made over an 82-day period and emission factors for urine (EF_3) calculated.

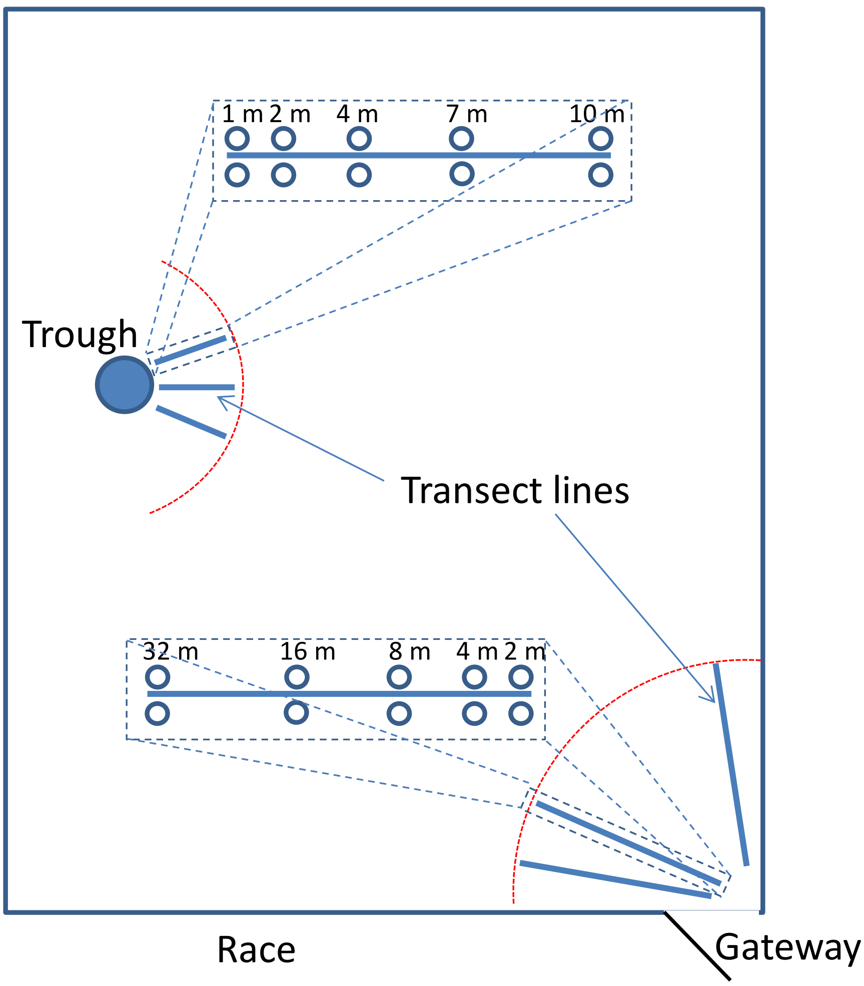


Figure 2: Layout of gas sampling chamber transects (not to scale). Cow urine was randomly applied to one of each pair of gas sampling chambers.

There were elevated N_2O emissions from the ‘nil urine’ treatment close to the water trough and gateway within the paddock. The rate from ‘nil urine’ at the distance of 32 m from the gate can be regarded as a typical background emission rate, as this was in the range of the emissions measured from a similar soil type on the same farm (Ledgard et al., 2014; Luo et al., 2015a). Emissions from ‘nil urine’ at distances closer to the gate (4 to 16 m) were about 10 times higher than the background rate, except for the area 2 m from the gate, which was about 5 times the typical background emission rate. A much higher emission rate was measured 1 m away from the trough than at the other locations, showing that the affected area around the trough was smaller than that around the gateway.

The emissions were integrated over time to estimate the total emission over the measurement period. The N_2O emission factors (EF_3, N_2O-N emitted as % of N applied) were then calculated for each urine treatment using the following equation:

$$EF_3\ (\%) = \frac{N_2O\text{-N total (urine)} - N_2O\text{-N total (control)}}{\text{Urine N applied}} \times 100$$

where, EF_3 is emission factor (N_2O-N emitted as % of urine-N applied), N_2O-N total (urine) is the cumulative N_2O-N emissions (kg N ha^{-1}) from the urine plots at each sampling point in the transects, N_2O-N total (control) is the average of all the cumulative background emissions measured 32 m from the gate and 10 m from the trough, and Urine N applied is the rate of urine N applied (kg N ha^{-1}).

In Milestone 3, EF_3 values were calculated by subtracting the background emissions at each sampling point from the emissions from urine at that point (Luo et al., 2016). However, as previous discussed, the background N_2O emissions from the hotspot areas were elevated, which must be considered when calculating the emission factor at each point. For use in the framework, in order to capture this increased background emission in the calculation of total farm emissions resulting from the presence of these hotspots, EF_3 values were recalculated using the average background (‘nil urine’) emissions measured from the unaffected areas 32 m from the gate and 10 m from the trough, as these represented more typical background emissions (Ledgard et al., 2014; Luo et al., 2015a). This is not technically correct, as EF_3 is intended to be the actual increase in N_2O emissions associated with the specific urine patch and should be relative to the background emissions at that sampling point. These high background emissions relate to effects of previous urine patches or, possibly, to other localised soil factors such as higher WFPS. However, the IPCC N_2O inventory methodology doesn’t account for these higher background emissions when N_2O emission factors (EF_3, N_2O-N emitted as % of excreta N applied) are used to calculate total farm emissions since they are determined by the specific N inputs, such as from excreta. Therefore, to include all the effects on emissions related to the hotspots, the increase in background emissions were accounted for by including them using an adjusted EF_3 (adjEF_3). This was calculated by subtracting an average background emission from non-hotspot areas in the paddock instead of the background emission at that measured point; in this study areas 32 m from the gate and 10 m from the water-trough were used.

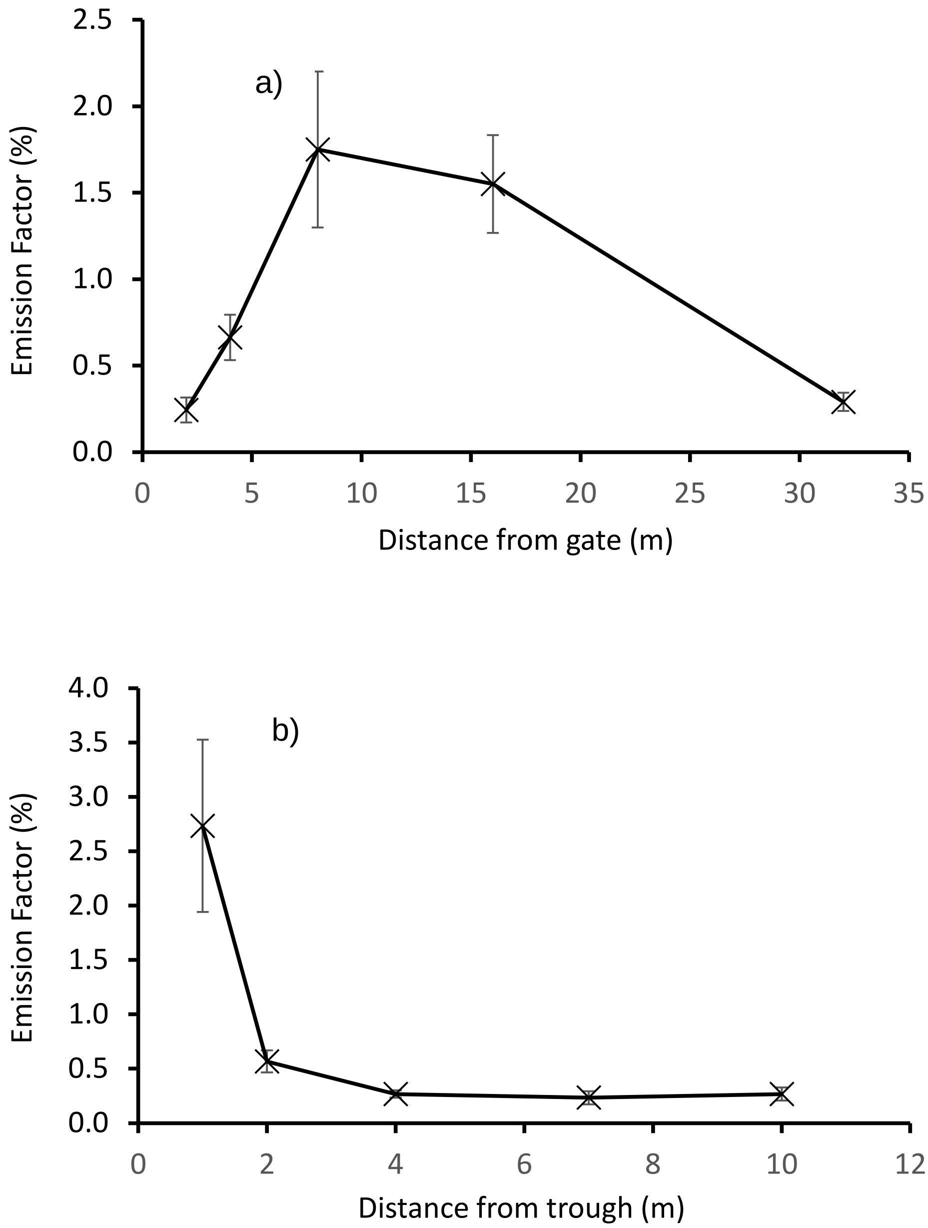


Figure 3: Adjusted nitrous oxide emission factors for cow urine at increasing distance from the gate (a) and water-trough (b), relative to background control levels at 32 and 10 m from gate and trough, respectively (Error bars represent standard error of the mean).

Average adjusted N_2O emission factors ($adjEF_3$) for urine, recalculated using typical background emission values, were 0.24, 0.66, 1.75, 1.55 and 0.29% at the distances of 2, 4, 8, 16 and 32 m from the gate over the 82-day measurement period (Figure 3a). The adjEF_3 values at the distances of 8 and 16 m from the gate were about 5-6 times the base level EF_3 value. The deposited gravel around the gateway (within 2-3 m from the gate) may have had lower soil microbial activity, which led to a lower N_2O emission rate and a lower adjEF_3. If it is assumed that the affected area finishes half way between the 16 m and 32 m distances from the gate, then the spatially weighted average EF_3 for the gateway hotspot is 1.35%.

Average N_2O adjEF_3 values were 2.73, 0.57, 0.27, 0.23 and 0.27% for urine at the distances of 1, 2, 4, 7 and 10 m from the water-trough over the 82-day measurement period (Figure 3b). The adjEF_3 values measured 1 to 2 m away from the water-trough were higher than those at the other locations. As discussed earlier, the area around the water-trough, affected by cattle congregation, was smaller than the affected area around the gateway. If it assumed that the affected area finishes half way between the 2 m and 4 m distances from the water-trough, then the spatially weighted average adjEF_3 for the water-trough hotspot is 1.29%.

Elevated adjEF_3 values for urine were measured in the area up to 16 m from the gate and 2 m from the trough (Figure 3). A distinct border for the hotspot area is hard to determine from this data. However, if it assumed that the hotspot areas finished half-way between these distances and the next measurement points, then the hotspot areas around the gateway could be up to 24 m and around the trough are within about 3 m. This gives values of 452 m^2 and 42 m^2 for the gateway and water-trough hotspot areas, respectively, for the 1.4 ha paddock. Using these values, the areas of the hotspot zones can be calculated as a percentage of the whole paddock area (i.e. 3.2% and 0.3% for the gateway and water-trough hotpots, respectively).

When the background N_2O emissions from the average paddock were considered, the likely magnitude of adjEF_3 values for the gateway area would be 4.8 times that of the rest of the paddock and for water-trough areas 4.6 times that of the rest of the paddock. Thus, it is possible that the appropriate EF_3 values to use for urine in the New Zealand national greenhouse gas calculation inventory would be 4.8% and 4.6% for the gate and trough areas, respectively, as the current national inventory value is 1%. However, further studies in other regions and times of year are required to validate these values.

These increased EF_3 values and potential sizes of gateway and water-trough areas were incorporated into the framework to calculate total farm N_2O emissions. N inputs to relevant areas of individual farm features have also been determined by surveying dairy farm paddocks around the country (Section 5 in this report).

In Section 6 of this report, total emissions from the “typical” case farms from three regions of New Zealand, used to develop the framework, were recalculated to take account of the measured affected land area of the gateway and water-trough hotspots and the refined EF_3 values. The N inputs to these features determined in Section 5 were also considered. The significance of gateway and water-trough areas as N_2O hotspots was re-assessed and potential mitigation options for reducing N_2O emissions from these hotspots are discussed.

In an attempt to identify possible contributing factors to the differences in EF_3 at different distances from the gate and water-trough, soil bulk density and penetration resistance measurements were taken. Approximately 2 months after the completion of the N_2O sampling, soil cores (10 cm dia. x 5 cm depth) were taken in duplicate at each sampling distance along the three transects from the gate and trough. The soil was dried at 105˚C, cooled and weighed. Bulk density was calculated as the weight of dry soil divided by the core volume (SSSA, 1986). A cone penetrometer was used to take duplicate readings of soil penetration resistance to a depth of 5 cm at each point (SSSA, 1986). The results of these measurements are given in Figure 4.

In the gateway area the bulk density was highest at 1.1 g/cm^3 nearest the gate and steadily decreased to 0.8 g/cm^3 at 16 m from the gate. At 32 m from the gate the value was higher again at 0.95 g/cm^3. Penetration resistance was highest nearest the gate at 0.47 kN and 0.44 kN at 1 m and 2 m, respectively. At all the other sampling distances around the gate the value was reasonably consistent at approximately 0.3 kN.

In the water-trough area the bulk density was highest at 1.2 g/cm^3 1 m from the water-trough. At all the other distances around the trough the value was reasonably consistent at approximately 1.0 g/cm^3. Penetration resistance around the trough varied between 0.28 kN and 0.42 kN.

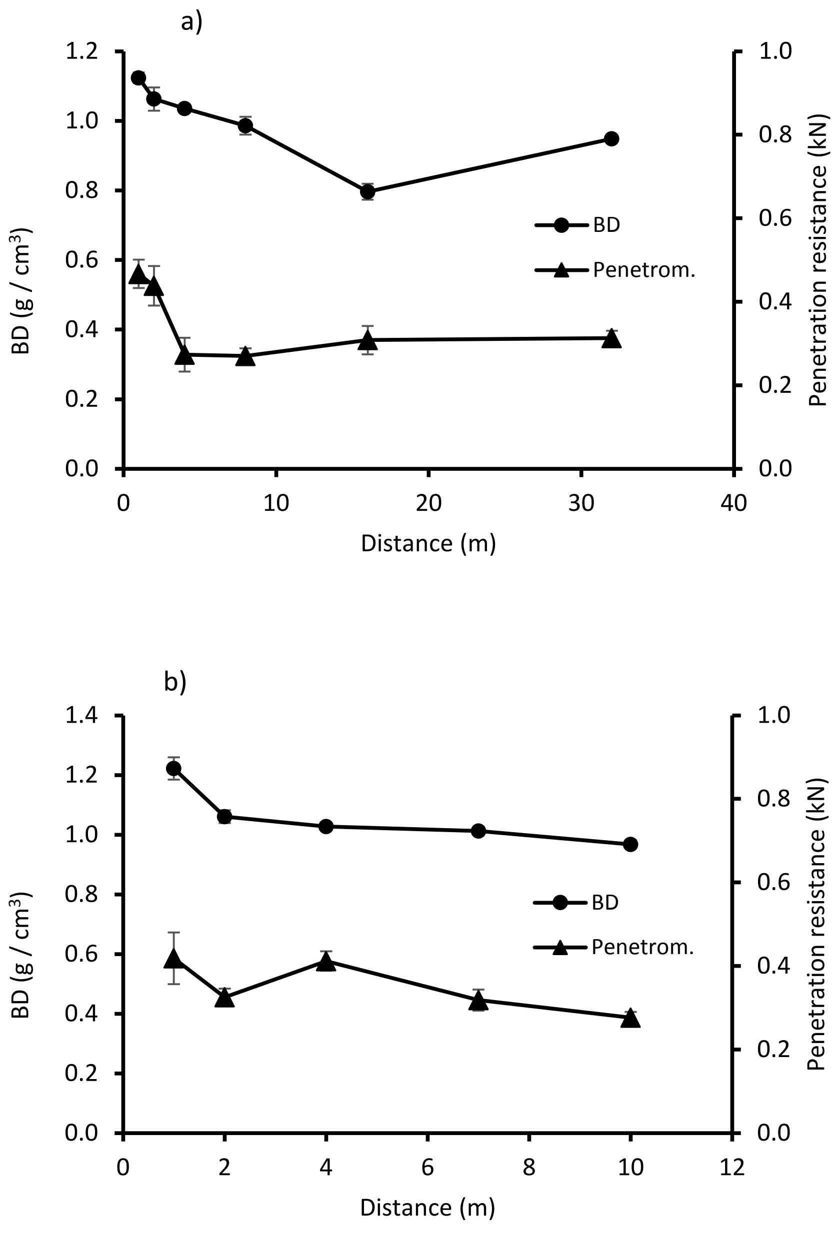
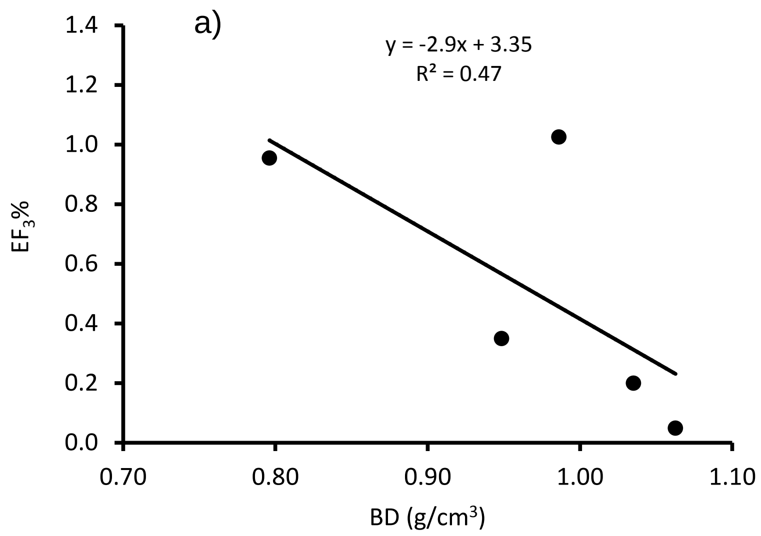


Figure 4: Soil bulk density (g/cm^3) and penetration resistance (kN) at different distances from the gate (a) and trough (b).

The relationships between EF_3 and bulk density and EF_3 and penetration resistance in the gateway area are shown in Figure 5. There was a tendency for EF_3 to be lower with both higher bulk density and higher penetration resistance; however, the correlations were not significant. The presence of gravel at the measurement sites near to the gate confounded interpretation of these measurements.

The relationships between EF_3 and bulk density and EF_3 and penetration resistance in the area around the water-trough are shown in Figure 6. There was a tendency for EF_3 to be higher with both higher bulk density and higher penetration resistance. The relationship with bulk density was significant. This is likely to be due to greater soil compaction caused by animal treading closer to the trough. This would decrease soil oxygen content which enhances N_2O production in soil (Bhandral et al., 2003; Beare et al., 2009). Compaction also reduces the plant growth leading to more surplus N available for N_2O production (Pal et al., 2014).



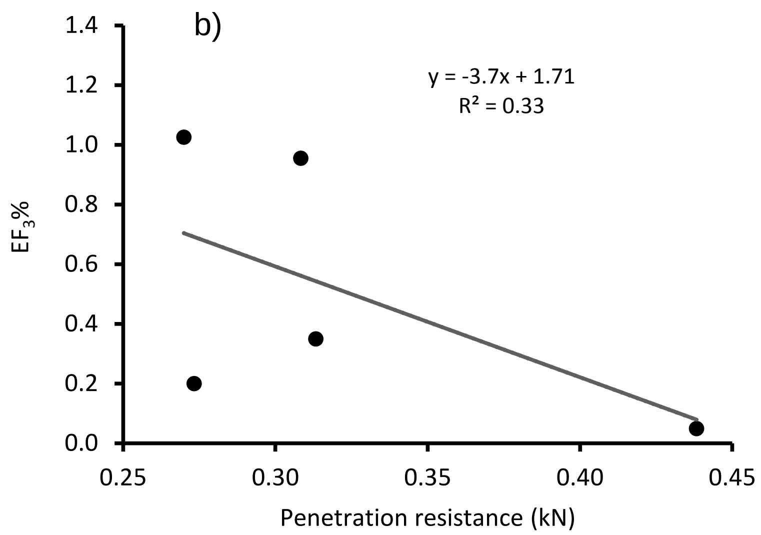


Figure 5: Relationships between site-specific EF_3 and soil bulk density (a) and site-specific EF_3 and soil penetration resistance (b) in the gateway area.

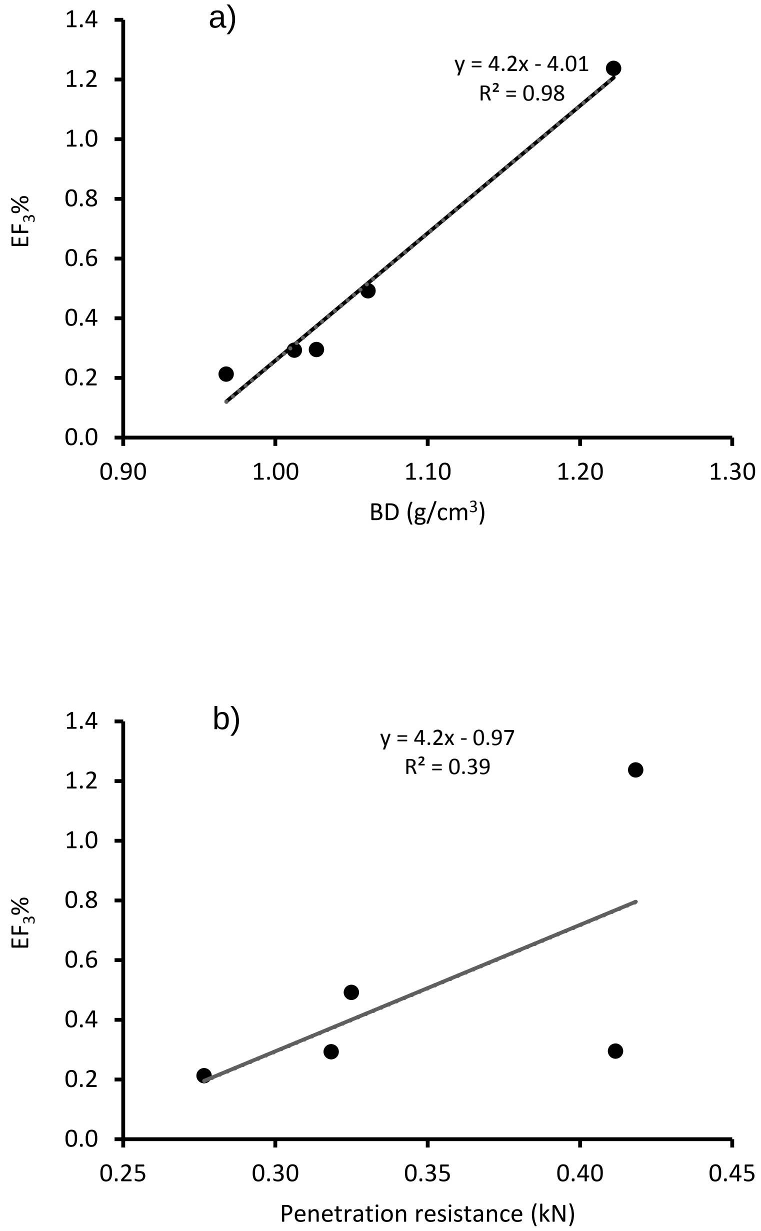


Figure 6: Relationships between site-specific EF_3 and soil bulk density (a) and site-specific EF_3 and soil penetration resistance (b) in the area around the water-trough.

5. Excreta N input survey

In order to increase the reliability of the N input estimates used in the framework, surveys were carried out in Milestone 4 to determine the typical distribution of excreta in a paddock to ascertain the percentage of excreta that is deposited in hotspot zones. This section reports the results of those surveys.

The surveys were carried out in the Waikato, Canterbury and Otago areas using GPS units to log the geographic location of fresh dung spots following a grazing event. It was assumed that urine and dung would be similarly distributed. Soon after cows were removed from each paddock, a hand held GPS device was used to map each dung patch by saving its location as a waypoint. Each patch was marked with flour to avoid duplication, and where dung had been deposited erratically, an attempt was made to assign it to a single deposition event. The GPS files were uploaded to Google earth and a map produced showing the distribution of the dung patches. A visual assessment was made of the distribution pattern with particular reference to zones around gateways and water-troughs.

In the Waikato the survey was carried out on Feb 26, 2016 after 170 cows had grazed a 1.25 ha paddock for 12.5 hours (Figure 7). In Canterbury the survey was carried out on March 17, 2016 after 180 cows had grazed a 1.58 ha paddock for about 24 hours (Figure 8). In Otago the survey was carried out on March 17, 2016 after 300 cows had grazed a 1.4 ha paddock for about 12 hours (Figure 9).

Figure 7: Waikato paddock dung patch location.

Figure 8: Canterbury paddock dung patch location.

Figure 9: Otago paddock dung patch location.

The surveys showed that the dung was randomly distributed around the paddocks with no greater or lesser concentration of dung patches around troughs or gateways. There appeared to be a higher frequency of dung patches in the corners and along the fence line of the Otago paddock where gateways were situated but this did not occur when the surveys were repeated (Figure 10). An error in one of the GPS units for the repeated Waikato survey caused an offset of several metres; however, the random distribution of the dung patches is still discernible. A further large 2.7 ha paddock, grazed by 500 cows, was surveyed on a different farm in the Waikato and this also showed no increase in the concentration of dung patches around the water-trough or gateway (Figure 10a).

Mathew et al. (2010) and MacDonald et al. (2011) suggested that water-trough areas and gateways could be zones that cows may spend more time in, resulting in increased excreta deposition in these areas, as reported in Milestones 1 and 2 of this project. However, although Draganova et al. (2015) provided evidence using urine sensors with GPS capability fitted to cows, that the time spent by cows in a particular location was a factor affecting the distribution of excreta, in that study, as in our study, no increase in excreta deposition was found around gateways or water-troughs.

Current management practices on New Zealand dairy farms result in cows having adequate pasture allocation and therefore less likelihood of congregating around gates prior to leaving the paddocks for milking. Moisture in the pasture consumed by cows could also have provided enough water, so that cows did not need to visit the water-trough as often. It could be possible that different results may be found in especially warm or dry conditions. Further work could be done to assess the effects of temperature variation and pasture availability on the distribution of excreta.

As a result of these surveys there appears to be no justification for using N input values for the water-troughs or gateways that are higher than the average paddock values when using the framework developed in Milestone 2 to calculate the total farm N_2O emissions.

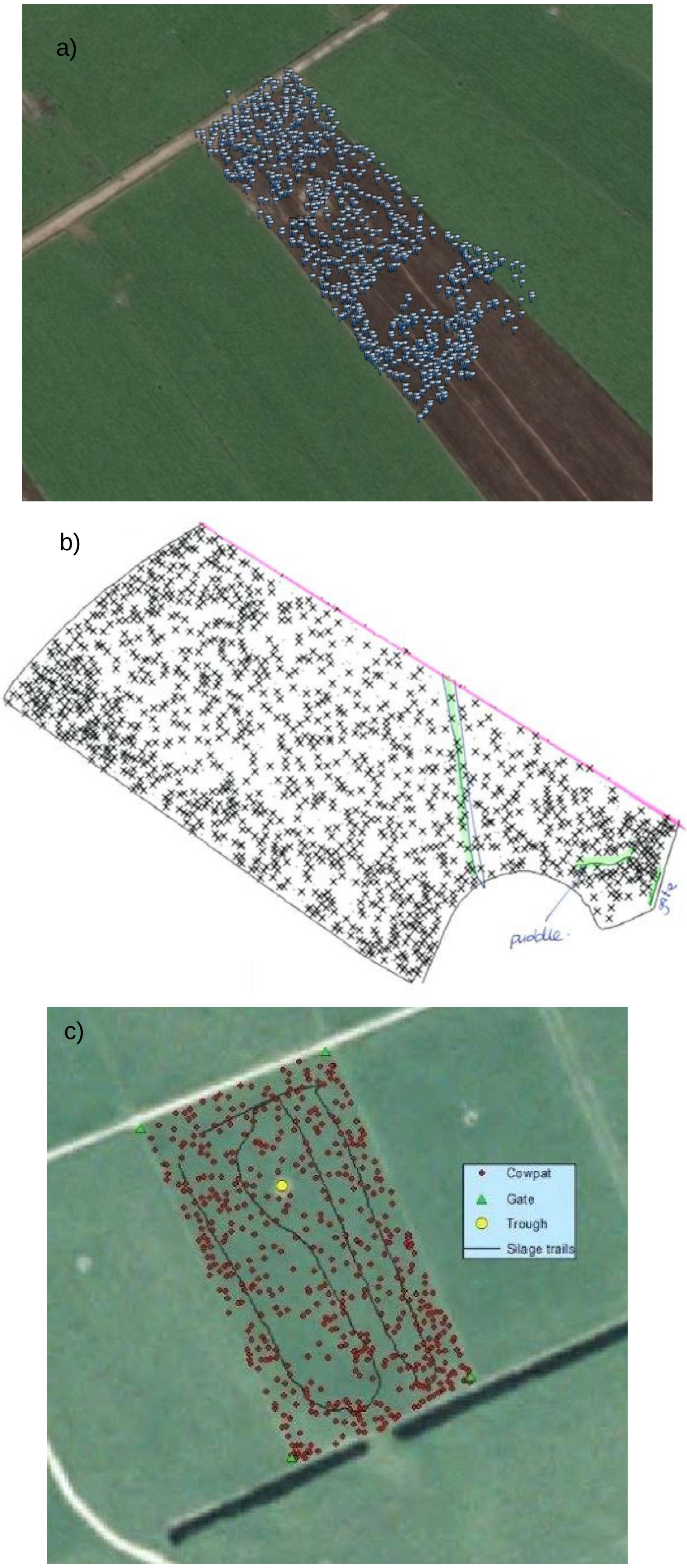


Figure 10: Repeat surveys of dung patches in newly-grazed paddocks in the Waikato (a), Canterbury (b) and Otago (c) regions.

6. Re-assessment of the significance of gateway and trough hotspots as contributors to total farm N_2O emissions

In this section the information and data obtained from the measurements in Sections 4 and 5 are used to refine the framework developed in the Milestone 2 report (Luo et al., 2015b). “Typical” farms from three regions of New Zealand were again formulated as case-studies to apply the modified framework.

6.1 Case-study farms

Waikato

The Waikato farm has a total effective grazing area of 180 ha, containing white clover (*Trifolium repens* L.) and perennial ryegrass (*Lolium perenne* L.) pasture on a Horotiu free draining soil. The farm has an average stocking rate of about 3.2 cows ha^{-1}. This farm supports 570 lactating cows, producing 420 kg MS cow^{-1} $year^{-1}$. The pasture is managed under a typical rotational grazing regime and received 175 kg urea-N ha^{-1} yr^{-1}. The total area of laneways is approximately 10 ha, with about 4% of dairy cow excreta deposited onto this surface. This area is in addition to the effective grazing area. The average paddock size is 1.4 ha with one water-trough and one gate per paddock.

Canterbury

The Canterbury farm has a total effective grazing area of 400 ha, comprising a 300 ha milking platform and a 100 ha block for wintering cows off the milking platform, all of which is irrigated. The milking platform is divided into a main block (210 ha) and an effluent block (90 ha). This farm supports 1050 lactating cows, producing 440 kg MS cow^{-1} $year^{-1}$. The stocking rate is 3.5 cows ha^{-1}. The total area of laneways is approximately 16 ha, with 5% of dairy cow excreta deposited onto this surface: this area is in addition to the effective grazing area. The average paddock size is 3.8 ha with one water-trough and one gate per paddock.

The farm is situated on a Lismore silt loam, which is a freely draining soil covering 100% of the farm. The wintering block is also located on a Lismore soil. Irrigation is applied by Rotorainer type overhead irrigators, at a frequency of no more than every 12 days from October to March.

Southland

The Southland farm has a total effective grazing area of 310 ha, comprising a 259 ha milking platform and a 44 ha wintering block, growing brassicas, for wintering cows on-farm. The milking platform is divided into a main block (186 ha) and an effluent block (70 ha). This farm supports 803 lactating cows, producing 350 kg MS cow^{-1} $year^{-1}$. The stocking rate is 2.7 cows ha^{-1}. The total area of laneways is approximately 16 ha, with 5% of dairy cow excreta deposited onto this surface: this area is in addition to the effective grazing area. The average paddock size is 3 ha with one water-trough and two gates per paddock.

The farm is situated on two main soil types. The first is a Makarewa silt loam, which is a naturally poorly drained soil and covers 50% of the farm supporting a large proportion of the main block only. The other soil is a Mataura silt loam, a generally well-drained soil, covering the remaining 50% of the farm, including the summer and winter crops and effluent block.

6.2 Total emissions from case-study farms

Baseline emissions

The N_2O emissions, and associated percentage contribution from each feature to the total N_2O emission loss, calculated from application of the framework based on New Zealand default emission factors, are shown in Table 1, along with the sizes used for each farm feature. The amounts of area allocated to the water-trough and gateway zones were derived from the measurements in Waikato in Section 3. The areas allocated to the rest of the farm were adjusted accordingly.

Table 1: Features of case-study farms and associated N_2O emissions using revised gateway and trough hotspot sizes. For all farm features, the New Zealand IPCC default emissions are used, i.e. EF_3 urine = 1%; EF_3 dung = 0.25%; EF_1 fertiliser or effluent = 1%.

Farm feature	Area (ha)	Total N input (including fertiliser, excreta and effluent) (kg N ha^{-1})	N_2O emission (kg N)	Contribution to total (%)	N_2O emission rate (kg N ha^{-1})
Waikato					
Main block on free draining soil	111	566	543	57	
Low-lying areas in gullies	36	566	178	18	
Effluent block on free draining soil	27	716	173	18	
Gateways	5.8	566	28	3	
Troughs	0.54	566	2.7	0.3	
Laneways	10	381	29	3	
Total	***190***		***953***	***100***	***5.02***
Canterbury					
Main block on free draining soil, largely on poorly draining soil (irrigated)	176	623	970	43.4	
Effluent block on free draining soil (irrigated)	89	638	504	22.6	
Pasture renewal area: pasture-summer crop-pasture (irrigated)	30	655 [170 (fert), 86 (N mineralisation inputs from pasture residues), 399 (excreta)]	173 [56 renewal, 117 summer crop]	7.8 [2.5 renewal, 5.2 summer crop]	
Winter crop on free draining soil	100	599	521	23.3	
Gateways – 1 per 3.8 ha paddock	3.2	606	17	0.8	
Troughs 1 per 3.8 ha paddock	0.3	606	1.6	0.1	
Laneways	16	373	48	2.1	
Total	***415***		***2236***	***100***	***5.50***
Southland					
Main block	180	426	670	50.6	
Effluent block on free draining soil	68	438	260	19.7	
Winter crop on free draining soil	43	920	324	24.4	

Gateways – 2 per 3 ha paddock	9.1	426	33.7	2.5	
Troughs – 1 per 3 ha paddock	0.4	426	1.6	0.1	
Laneways	16	276	35	2.7	
Total	***316***		***1325***	***100***	***4.19***

6.3 Effect of gateways and troughs to total emissions

In order to test and confirm the significance of water-trough and gateway areas as potential hotspots for N_2O emissions, calculations were conducted on the above three case-study farms using the framework model with the magnitudes of N input and EF_3 values derived from the Waikato measurements given in Sections 4 and 5. The relative contributions of the water-trough and gateway areas to total farm N_2O emissions were subsequently assessed (Tables 2 - 4).

Due to the variability associated with the measurements of the EF_3 values, a rounded figure of 5% was used for the affected areas around both the gateway and the water-trough. Hot spot areas of 452 m^2 and 42 m^2, calculated in Milestone 3 (Section 4), were used for each gateway and trough, respectively. As there was no discernible pattern found in the deposition of excreta surveyed for Milestone 3 (Section 5), average paddock values were assigned for N inputs to the hotspot areas.

Two different metrics were used for assessing the significance of water-trough and gateway affected areas as potential hotspots (Tables 2 - 4). One of these was a measure of their contributions to the total farm N_2O emissions. The other was a measure of the percentage increase in the contribution relative to the baseline contribution from these areas.

For the sensitivity analysis it was assumed that the area affected by each gateway and water-trough, and the associated $adjEF_3$, remains constant as the number of gates, troughs or paddocks is changed. However, the hotspot area may be proportional to the paddock area, e.g. if you halve the number of paddocks, the cows will spend twice as long in each paddock, going through the gates twice as often and possibly influencing a bigger area. There is currently insufficient data to confirm the relationship between water-trough and gateway affected area and paddock size. This could be the focus of future investigations.

Table 2: Assessment of the significance of trough and gateway affected areas (features) as potential hot-spots – Waikato case-study farm.

Scenario	**Feature size (ha)**	**Proportion of effective grazing area (%)**	**N Input to feature (kg ha^{-1})**	**Feature EF_3 (%)**	**Total farm emissions (kg N_2O-N)**	**Increase in total farm emissions from baseline (%)**	**Feature N_2O loss (kg N_2O-N)**	**Feature contribution to total emissions (%)**	**Increase in feature contribution to total emissions compared to baseline (%)**
Baseline (1.4 ha paddocks)									
Gateway	5.8	3.2	566	1	953		28	3.0	
Trough	0.54	0.3	566	1			2.7	0.3	
Increased EF_3									
Gateway (1 / paddock)	5.8	3.2	566	5	1027	7.8	96	9.4	213
Trough (1 / paddock)	0.54	0.3	566	5			8.9	0.8	167
Doubling the size of the paddocks (i.e. 2.8 ha paddocks)									
Gateway (equivalent 0.5 / paddock)	2.9	1.6	566	5	986	3.5	48	4.9	63
Trough (equivalent 0.5 / paddock)	0.27	0.15	566	5			4.5	0.5	66

Table 3: Assessment of the significance of trough and gateway affected areas (features) as potential hot-spots – Canterbury case-study farm.

Scenario	Feature size (ha)	Proportion of effective grazing area (%)	N Input to feature (kg ha^{-1})	Feature EF_3 (%)	Total farm emissions (kg N_2O-N)	Increase in total farm emissions from baseline (%)	Feature N_2O loss (kg N_2O-N)	Feature contribution to total emissions (%)	Increase in feature contribution to total emissions compared to baseline (%)
Baseline (3.8 ha paddocks)									
Gateway	3.2	1.2	606	1	2236		17	0.8	
Trough	0.3	0.1	606	1			2	0.1	
Increased EF_3									
Gateway (1 / paddock)	3.2	1.2	606	5	2273	1.7	53	2.3	187
Trough (1 / paddock)	0.3	0.1	606	5			5	0.2	100
Gateways, troughs x 2									
Gateway (2 / paddock)	6.4	2.5	606	5	2312	3.3	105	4.6	491
Trough (2 / paddock)	0.6	0.2	606	5			10	0.4	514
Halving paddock size (1.9 ha paddocks)									
Gateway (1 / paddock)	6.4	2.5	606	5	2312	3.3	105	4.6	491
Trough (1 / paddock)	0.6	0.2	606	5			10	0.4	514

Table 4: Assessment of the significance of trough and gateway affected areas (features) as potential hot-spots – Southland case-study farm.

Scenario	Feature size (ha)	Proportion of effective grazing area (%)	N Input to feature (kg ha^{-1})	Feature EF_3 (%)	Total farm emissions (kg N_2O-N)	Increase in total farm emissions from baseline (%)	Feature N_2O loss (kg N_2O-N)	Feature contribution to total emissions (%)	Increase in feature contribution to total emissions compared to baseline (%)
Baseline (3.0 ha paddocks)									
Gateway	9.1	3.0	426	1	1325		34	2.5	
Trough	0.4	0.1	426	1			2	0.1	
Increased EF_3									
Gateway (2 / paddock)	9.1	3.0	426	5	1402	5.8	108	7.7	202
Trough (1 / paddock)	0.4	0.1	426	5			5	0.4	202
Gateways, troughs x 2									
Gateway (4 / paddock)	18.1	6.0	426	5	1474	11.2	215	14.6	475
Trough (2 / paddock)	0.85	0.3	426	5			10	0.7	475
Halving paddock size (1.5 ha paddocks)									
Gateway (2 / paddock)	18.1	6.0	426	5	1474	11.2	215	14.6	475
Trough (1 / paddock)	0.85	0.3	426	5			10	0.7	475

Waikato

- 3.3% of the N emitted from the baseline farm comes from the combined water-trough and gateway affected areas, when N inputs are evenly distributed across the whole farm and New Zealand IPCC default EF values are used (Table 1).
- An increase in EF_3 for urine by a factor of 5, as measured in Section 3 of this study, increases total farm emissions by 7.8%. The contribution from the gateway increases from 3.0% to 9.4% and the contribution from the water-trough increases from 0.3% to 0.8% (Table 2).
- A sensitivity analysis showed that doubling the paddock size (i.e. halving the number of paddocks) increases total farm emissions by 3.5% and the combined contribution of these farm features increases from 3.3% to 5.4%
- In all these cases, the contributions from the gateway affected areas are far greater than those from the water-trough areas.

Canterbury

- 0.9% of the N emitted from the baseline farm comes from the combined water-trough and gateway affected areas, when N inputs are evenly distributed across the whole farm and New Zealand IPCC default EF values are used (Table 1).
- An increase in EF_3 for urine deposited in these affected areas by a factor of 5, as measured in Waikato in Section 3 of this study, increases total farm emissions by 1.7%. The contribution from the gateway affected area increases from 0.8% to 2.3% and the contribution from the water-trough affected area increases from 0.1% to 0.2% (Table 3).
- A sensitivity analysis showed that doubling the number of gates and water-troughs per paddock increases total farm emissions by 3.3% and the combined contribution of these farm features increases by a factor of 5, from 0.9% to 5%. Halving the paddock size has the same effect as doubling the number of gates and troughs per paddock.
- In all these cases, the effects of these farm features on total emissions are small. As well, the contributions from the gateway affected areas are much greater than those from the water-trough areas.

Southland

- 2.6% of the N emitted from the baseline farm comes from the combined water-trough and gateway affected areas, when N inputs are evenly distributed across the whole farm and New Zealand IPCC default EF values are used (Table 1).
- An increase in EF_3 for urine by a factor of 5, as measured in Waikato Section 3 of this study, increases total farm emissions by 5.8%. The contribution from the gateway increases from 2.5% to 7.7% and the contribution from the water-trough increases from 0.1% to 0.4% (Table 4).
- A sensitivity analysis showed that doubling the number of gates and water-troughs per paddock increases total farm emissions by 11% and the contribution of these farm features increases by a factor of 5, from 2.6% to 15.3%. Halving the paddock size has the same effect as doubling the number of gates and water-troughs per paddock.
- As for the other 2 case-study farms, in all these cases the contributions from the gateway affected areas are far greater than those from the water-trough areas.

The analysis suggests that water-trough affected areas are unlikely to contribute more than 1% of total farm N_2O emissions (Tables 2-4). Therefore, water-trough areas cannot be considered a significant “hotspot” for the farm.

The analysis also suggests that gateways could be significant hotspots for N_2O emissions on dairy farms. When the effects of increased EF_3 values are considered, gateways contribute between 2.3 and 9.4% of the total farm emissions (Tables 2-4). The highest contribution from gateways was found on the Waikato case-study farm due to the smaller average paddock size, resulting in more gateways per hectare of the farm. On this farm 3.2% of the farm is covered by gateway areas, contributing 9.4% of the total farm N_2O emissions. Increasing paddock sizes, to reduce the number of gateways required, could help mitigate this hotspot and reduce total farm N_2O emissions. On the Canterbury case-study farm, with a relatively larger paddock size, 1.2% of the farm is covered by gateway areas, which contribute 2.3% of the total farm N_2O emissions. Adding another gate to each of these larger paddocks increases the contribution from gateway areas to 4.6%. Increasing the number of gates for the

Southland case-study farm from 2 to 4 per paddock increases the contribution to the total farm N_2O emissions from 7.7% to 14.6%. This emphasises the potential effect of the number of gates on dairy farm emissions. For all these the sensitivity analyses, it was assumed that the area affected by each gateway and water-trough, and the associated $adjEF_3$, remains constant as the number of gates, troughs or paddocks is changed. However, the adjusted EF_3 values are based on a single paddock on a Waikato dairy farm. It is possible the adjusted EF_3 may differ for farms with more or less gates per paddock. It is also possible the results are influenced by soil type, region and time of the year.

7. Mitigation of N_2O emissions from gateways

As discussed above, the relatively small areas around gateways can emit a disproportionately larger amount of N_2O. Data presented in Section 5 of this report indicate that, as N input to these areas is similar to the rest of the farm, it is likely that this increase is related to soil physical changes caused by compaction due to animal treading.

Results from case-study farms presented in Section 6.2 indicate that reducing the number of gateways on a farm, by having larger paddocks or less gateways per paddock, could potentially reduce total emissions of N_2O, assuming that the affected area, and associated $adjEF_3$, of each gateway remains constant.

Where the option is available, locating gateways on well-drained soils could reduce N_2O emissions. This is because poorer-draining clay-textured soils generally have higher denitrification and N_2O losses (de Klein et al., 2003).

From measurements conducted for Section 4 of this report, the presence of gravel in the gateway area may partly or wholly explain the lower N_2O emissions.. Placing gravels or other inorganic materials could reduce N_2O emissions, although this could pose a greater risk of N leaching and run-off.

Placement of carbon-rich materials, similar to those used in stand-off pads could also reduce N_2O emissions by absorbing and immobilising excreta N (Luo et al., 2008a). However, this would require regular replacement of the material over time.

If practicality allows, altering soil conditions (e.g. applying zeolite, liming, improving drainage) could reduce emission of N_2O. For example, the addition of zeolite to soil treated with urea and urine under laboratory conditions was found to decrease N_2O emissions, while lime lowered $N_2O:N_2$ ratios and increased N_2 emissions (Zaman et al., 2007).

To reduce N loading to gateway areas, care should be taken, if possible, to avoid N fertilisers and farm effluent/manure application near the gates. Urease inhibitor, nitrification inhibitor, or a combination of both, could be used in gateway areas to reduce N loss and the availability of N for N_2O production.

Ensuring adequate pasture allocation could help reduce physical damage to gateway areas because as forage is depleted, dairy cows are more likely to gather near gateways in anticipation of transfer to fresh pasture. Timely opening of gates, allowing more freedom of movement for cows, could prevent congregation in gateways before milking and allow a steady stream of cows through the gateways.

Although water-trough areas were not found to be significant hotspots, very hot weather may induce more water consumption by cows and increase the frequency of visits to troughs. However, in very hot weather soils are likely to be drier and therefore less prone to treading damage. Dry soils are also less likely to cause increased N_2O emissions (Luo et al., 2008b).

8. Conclusions

When the background N_2O emissions from the average paddock were accounted for, the adjusted EF_3 values for the gateway and water trough areas were estimated at about 5 times that of the rest of the paddock. Potentially, the EF_3 values for urine in the New Zealand national greenhouse gas inventory could be 5% for the gate and water-trough areas, while the current national inventory average value is 1%. However, these results are based on only one field site measurement and more data is required to understand the significance of hotspot areas and associated EF_3 values. A survey of excreta distribution in 7 paddocks revealed that there was no clear indication of increased N input to gateway or trough areas.

Using the results of measurements made in Milestone 3 with the framework developed in Milestone 2, it was found that gateways could be significant hotspots for N_2O emissions. The highest contribution from gateways was estimated for the Waikato case-study farm, due to the smaller average paddock size resulting in more gateways per hectare of the farm. On this farm, 3.2% of the farm was covered by gateway areas, contributing 9.4% of the total farm N_2O emissions. Water-trough areas were considered unlikely to be significant hotpots due to their relatively small size (about 0.3% of the farm).

Mitigation options to reduce emissions from gateway areas include reducing the number of gates, locating gateways on well-drained soils, improving drainage, placing gravels or carbon rich materials around gateways, applying zeolite, liming, or avoiding N fertilisers and farm effluent/manure application near the gates and using N process inhibitors. To reduce physical damage to gateway areas, situations that result in animals gathering around gateways should be avoided. Placing troughs near gateways should also be avoided.

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10. References

Beare MH, Gregorich EG, St-Georges P 2009. Compaction effects on CO_2 and N_2O production during drying and rewetting of soil. Soil Biology & Biochemistry 41: 611-621.

Bhandral R, Saggar S, Bolan NS, Hedley MJ 2003. Nitrous oxide fluxes in soil as influenced by compaction. Proceedings of the New Zealand Grassland Association 65: 265 – 271.

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. Soil Research 41: 381-399.

Draganova I, Yule I, Stevenson M, Betteridge K 2015. The effect of temporal and environmental factors on the urination behaviour of dairy cows using tracking and sensor technologies. Precision Agriculture: in press.

Ledgard SF, Luo J, Sprosen MS, Wyatt J, Balvert S, Lindsey S 2014. Effects of the nitrification inhibitor dicyandiamide (DCD) on pasture production, nitrous oxide emissions and nitrate leaching in Waikato, New Zealand. New Zealand Journal of Agricultural Research 57: 294-315.

Luo J, Ledgard SF, Lindsey SB 2008a. A test of a winter farm management option for mitigating nitrous oxide emissions from a dairy farm. Soil Use and Management 24: 121-130.

Luo J, Lindsey SB, Ledgard SF 2008b. Nitrous oxide emissions from animal urine application on a New Zealand pasture. Biology and Fertility of Soils 44: 463-470.

Luo J, Wyatt J, Ghani A, Thomas S, van der Weerden T, de Klein C, Watkins N, Beare M 2014. Review of Potential Hot-spot Areas of Nitrous Oxide Emissions from Grazed Pasture. SLMACC Objective 1 Milestone 1. Report for the Ministry for Primary Industries. AgResearch Ltd. pp. 96.

Luo J, Ledgard SF, Wise B, Welten B, Lindsey S, Judge A, Sprosen M 2015a. Effect of dicyandiamide (DCD) delivery method, application rate and season on pasture urine patch nitrous oxide emissions. Biology and Fertility of Soils 51: 453-464.

Luo J, van der Weerden T, Thomas S, de Klein C, Rollo M, Lindsey S, Longhurst B 2015b. 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. pp. 25.

Luo J, Lindsey S, van der Weerden T, Thomas S, de Klein C 2016. Nitrous oxide emissions from gateway and water-trough areas - SLMACC Objective 2 Milestone 3. Report for the Ministry for Primary Industries. AgResearch Ltd. pp. 16.

MacDonald JD, Rochette P, Chantigny MH, Angers DA, Royer I, Gasser MO 2011. Ploughing a poorly drained grassland reduced N_2O emissions compared to chemical fallow. Soil & Tillage Research 111: 123-132.

Matthews RA, Chadwick DR, Retter AL, Blackwell MSA, Yamulki S 2010. Nitrous oxide emissions from small-scale farmland features of UK livestock farming systems. Agriculture, Ecosystems & Environment 136: 192-198.

Pal P, Clough TJ, Kelliher FM 2014. Sources of N_2O-N following simulated animal treading of ungrazed pastures. New Zealand Journal of Agricultural Research 57: 202-215.

SSSA 1986. Methods of Soil Analysis, 2nd ed. Part 1: Physical and Mineralogical Methods. Ed. A. Klute, Soil Science Society of America, Madison WN, USA.

Zaman M, Nguyen ML, Matheson F, Blennerhassett JD, Quin BF 2007. Can soil amendments (zeolite or lime) shift the balance between nitrous oxide and dinitrogen emissions from pasture and wetland soils receiving urine or urea-N? Soil Research 45: 543–553.