NITROUS OXIDE EMISSIONS FROM DAIRY FARMLETS, AS AFFECTED BY USE OF A NITRIFICATION INHIBITOR AND A WINTER RESTRICTED GRAZING STRATEGY

Jiafa Luo, Stuart Lindsey, Bridget Wise and Stewart Ledgard

AgResearch, Ruakura Research Centre, Hamilton 3240, New Zealand
Email: Jiafa.Luo@agresearch.co.nz

Abstract
Experimental farmlets at DairyNZ's Prototype Farm near Hamilton were used to determine potential reductions in nitrous oxide (N_2O) emissions from use of a nitrification inhibitor and a restricted grazing regime. A control farmlet was managed under a conventional rotational grazing regime, while a "tight nitrogen" farmlet was managed under a similar grazing regime to that on the control farmlet, except during winter and early spring when cows grazed for about 6 hours per day on pasture with the remaining 18 hours spent in an animal shelter (e.g., a stand-off or restricted grazing regime). A nitrification inhibitor (dicyandiamide, DCD) was applied onto the "tight nitrogen" farmlet on 2-3 occasions immediately after grazing through winter and early spring. A soil chamber technique was used to measure N_2O emissions from each farmlet during three contrasting periods of each year for three years. In addition, the New Zealand IPCC inventory methodology was used to calculate total greenhouse gas emissions.

During winter/early spring in 2007, 2008 and 2009, N_2O emission rates were lower ($P<0.05$) in the "tight nitrogen" farmlet than in the control farmlet. The use of a restricted grazing regime and a nitrification inhibitor reduced N_2O emissions from the farmlet by 43-55%, 64-79% and 45-60% during the winter/early spring seasons, respectively. During late spring/summer and autumn periods, N_2O emission rates were generally similar between the two farmlets. The difference in the annual N_2O emission rates between the control and the "tight nitrogen" farmlets was not significant in the first year. However, in the second and third years the annual N_2O emission rate from the "tight nitrogen" farmlet was found to be between 39% and 50% lower than from the control. For the three study years, the average annual N_2O emission rate from the "tight nitrogen" farmlet was 20% lower than from the control. Total annual emissions for the sum of the three major greenhouse gases, N_2O, CH_4 and CO_2, were 11,524 and 10,871 kg CO_2-equivalent per hectare from the control and "tight N" farms, respectively. The total greenhouse gas emissions from the tight nitrogen dairy system were 6% lower than those from the control.

Keywords: Nitrous oxide, dairy, grazed pasture, nitrification inhibitor, restricted grazing

Introduction
Our previous PGGRC (Pastoral Greenhouse Gas Research Consortium) - funded studies have confirmed the advantages of instigating a winter restricted grazing strategy in reducing N_2O emissions (Luo et al. 2008). Currently, the use of nitrification inhibitors is being promoted in New Zealand for decreasing nitrogen leaching losses and N_2O emissions (e.g., Ledgard et al. 2008; Di et al. 2007; Luo et al. 2010). Integration of restricted grazing regimes with the use

of nitrification inhibitors, such as dicyandiamide (DCD), could perhaps further reduce environmental nitrogen emissions and consequently increase nitrogen use efficiency.

Future New Zealand dairy farm systems will aim to increase farm productivity and profitability whilst maintaining or increasing environmental efficiencies. This is only likely to be achieved through the use of best management practices and new technologies. DairyNZ has conducted a farmlet study to develop "Prototype farms for dairy farming's future". A key goal of this high profile industry study was to bring together the best available practices and technologies into dairy management systems, which together could deliver both the production and the environmental goals of farmers and the industry. The experimental programme for DairyNZ's Prototype farms was run as several farmlets, including a control farmlet and a "tight nitrogen" farmlet, on Scott farm near Hamilton. We used the DairyNZ farmlet trial to determine the potential reduction in N_2O emissions in the "tight nitrogen" farmlet, which involved the use of both an animal shelter (a restricted grazing regime with stand-off practices) over winter/early spring and application of DCD onto pasture.

In this paper, we summarise results from N_2O measurements on the farmlets during three contrasting periods of each year since spring 2006. The impact of the management practices undertaken in the Prototype farms on total greenhouse gas emissions (including CH_4 and CO_2) is also assessed.

Materials and methods

Experimental site

The experimental site was located in the Waikato region of New Zealand and consisted of white clover (*Trifolium repens* L.) and perennial ryegrass (*Lolium perenne* L.) pasture on a Te Kowhai silt loam soil (Typic Ochraqualf, Soil Survey Staff 1990). The soil was poorly drained with compact subsoil and slow permeability. The soil properties of the upper 75 mm of the soil profile were: total N of 0.45%, total C of 5.0%, organic matter of 8.8%, pH of 5.5, bulk density of 0.92 Mg m^{-3} and cation exchange capacity of 14 me/100g soil. The site has a mean annual rainfall of about 1200 mm and mean annual temperature of 14^{o}C. Winter and spring at the study site are relatively wet with cool temperatures, whereas summer and early autumn are generally dry and warm.

Farmlet treatments

We used the following two established farmlets in the "Prototype farms for dairy farming's future" trial:

- Control farm – The farmlet had a stocking rate of 3.0 cows ha^{-1} (this is a common stocking rate for dairy farms in the Waikato region) and was managed under a typical rotational grazing regime (i.e. cows graze on a paddock for a day and are then moved to fresh paddocks to allow pasture to regrow).
- "Tight nitrogen" farm – The farmlet also had a stocking rate of 3.0 cows ha^{-1}. The grazing regime on this farmlet was similar to that on the control farmlet, except during the winter and early-spring (up to about 3 months per year) when cows grazed for about six hours (generally between 9 a.m. and 3 p.m.) per day on pasture with the other 18 hours per day spent in an animal shelter. A nitrification inhibitor (eco-n^{TM}, containing dicyandiamide, DCD) was applied to the farmlet paddocks, following best practice guidelines, at a rate of 10 kg active ingredient ha^{-1} on 2-3 occasions immediately after grazing during winter and early spring.

Measurements

In order to determine annual N_2O emissions, detailed measurements of N_2O emitted from the control and "tight nitrogen" farmlets were made within one grazing interval on two or three replicated paddocks during 3 typical grazing patterns/seasons in each year for three years between November 2006 and October 2009 (Table 1). On two or three occasions during each period, two paddocks were selected (one from each farmlet). Immediately after grazing, 6 replicate chambers were randomly inserted in each paddock. Different paddocks from each farmlet were used on each occasion. Measurements of N_2O emission were made simultaneously on the two paddocks until the return of cows to the paddocks (6 measurement times on each of the three occasions in the late spring/summer or autumn measurement periods and about 12 measurement times on each of the two occasions in the winter/early spring measurement period each year).

A closed soil chamber technique was used to measure N_2O emissions and the methodology was based on the NzOnet studies on excreta N_2O emissions (de Klein et al. 2003) and the previous PGGRC studies on N_2O emissions (Luo et al. 2008). The hourly emissions were integrated over time to estimate the total emission over the measurement period. An analysis of variance (ANOVA) was performed to identify differences between treatments. Seasonal emissions from the grazed pastures were estimated by multiplying the means of the N_2O emissions over one grazing interval by the number of the grazing events during the season (Table 1). Annual N_2O emissions were then calculated by adding all the seasonal emissions.

New Zealand IPCC calculations

The New Zealand IPCC inventory methodology (Ministry for the Environment 2008) was used to calculate total emissions of CH_4 to estimate total greenhouse gas emissions from the farm systems. The methodology was also used to calculate N_2O emissions from sources that were not included in the field measurements. These sources included leached nitrogen, land-applied dairy effluent nitrogen and volatilised ammonia nitrogen. Farm emissions of CO_2 were estimated using fuel and electricity data. Estimates of greenhouse gas emissions also included indirect contributions associated with production of fuel, electricity and fertilisers.

Table 1. Timing of N_2O emission measurement periods and animal grazing information.

Measurement period	Grazing interval (days)	Pairs of paddocks measured	Seasons represented	Number of grazing events in the season
Nov-Dec 06	23	3	Spring/summer (Nov 06-Feb 07)	5.3
Mar-Apr 07	21	3	Autumn (Mar-Jun 07)	5.7
Jun-Sep 07	60	2	Winter/early spring (Jul-Oct 07)	2.0
Nov 07-Jan 08	21	3	Spring/summer (Nov 07-Feb 08)	5.8
Mar-Apr 08	21	3	Autumn (Mar-Jun 08)	5.7
Jun-Oct 08	60	2	Winter/early spring (Jul-Oct 08)	2.0
Nov-Dec 08	21	3	Spring/summer (Nov 08-Feb 09)	5.8
Mar-Apr 09	21	3	Autumn (Mar-Jun 09)	5.7
Aug-Oct 09	60	2	Winter/early spring (Jul-Oct 09)	5.7

Results and discussion

N_2O emission rates

During late spring/summer and autumn periods, N_2O emission rates were generally similar between the two farmlets (Table 2). During winter/early spring in 2007, 2008 and 2009, N_2O emission rates were lower ($P < 0.05$) in the “tight nitrogen” farmlet than in the control farmlet. The use of a restricted grazing regime and a nitrification inhibitor reduced N_2O emissions from the dairy farmlet by 43-55%, 64-79% and 45-60% during the winter/early spring seasons of each year over the three years, respectively. It is expected that the lower N_2O emission rates on the “tight nitrogen” farmlet during the winter/early spring would be due to the use of a restricted grazing regime and the nitrification inhibitor DCD (de Klein et al. 2006; Di et al. 2007). However, the combined effect of both the restricted grazing and DCD use was not necessarily greater than the individual effect either from “stand-off” or DCD use observed in some other studies (e.g. de Klein et al. 2006; Luo et al. 2008; 2009;

Smith et al. 2008). In practice, both technologies are targeting the same key nitrogen source at the same time (i.e. cow urine-N over winter) and therefore the effects would not be expected to be simply additive.

Table 2. Nitrous oxide emission rates on grazed pastures.

Season	Average rate over one grazing interval (kg N_2O-N ha^{-1} grazing interval^{-1})		Estimated rate per season (kg N_2O-N ha^{-1} season^{-1})	
	Control	Tight N	Control	Tight N
Spring/summer (Nov 06-Feb 07)	0.62	0.82	3.29	4.35
Autumn (Mar-Jun 07)	0.21	0.34	1.20	1.94
Winter/early spring (Jul-Oct 07)	1.27	0.63	2.54	1.26
Nov 06- Oct 07			***7.03***	***7.55***
Spring/ summer (Nov 07-Feb 08)	0.11	0.11	0.64	0.64
Autumn (Mar-Jun 08)	0.22	0.17	1.25	0.97
Winter/early spring (Jul-Oct 08)	1.26	0.28	2.52	0.56
Nov 07-Oct 08			***4.41***	***2.17***
Spring/ summer (Nov 08-Feb 09)	0.14	0.14	0.81	0.81
Autumn (Mar-Jun 09)	0.11	0.10	0.63	0.57
Winter/early spring (Jul-Oct 09)	0.67	0.16	1.33	0.32
Nov 08-Oct 09			***2.77***	***1.70***
Average rate over 3 years (kg N_2O-N ha^{-1} year^{-1})			**4.74**	**3.81**

The overall N_2O emission rates on the control farm during different periods in 2006/2007 were in the following order: "winter/early spring, 2007 ≥ late spring/summer, 2006/2007 > autumn, 2007" (Table 2). The overall N_2O emission rates on the control farm in 2007/2008 were in the following order: "winter/early spring, 2008 > autumn, 2008 ≥ late spring/summer, 2007/2008". The overall N_2O emission rates on the control farm in 2008/2009 were in the following order: "winter/early spring, 2009 > late spring/summer, 2008/2009 ≥ autumn, 2009". In 2007/2008 and 2008/2009, the difference in the overall N_2O emission rates between the late spring/summer and autumn was not significant ($P > 0.05$). However, in 2007/2008 and 2008/2009, the overall N_2O emission rates were higher during the winter/early spring (Jul-Oct) than the late spring/summer (Nov-Feb) or autumn (Mar-June) (Table 2).

Animal excreta nitrogen combined with frequent rainfall were the principal causes of enhanced N_2O production. Our previous studies (e.g. Luo et al. 1999; Luo et al. 2007; 2008) have contributed much to our current understanding of the magnitude and temporal variability of N_2O emissions from grazed pasture. These studies showed that, of all measured variables, soil moisture content had the strongest influence on N_2O emissions from excretal nitrogen input following a grazing event on pasture (data not shown). Generally, N_2O emissions were high when soil water filled pore space (WFPS) was above soil field capacity during the winter/early spring seasons.

Total annual N_2O emissions

The calculated overall annual N_2O emission rates were higher ($P < 0.05$) during the first study year (November 06 – October 07) than during the second (November 07 – October 08) or third study year (November 08 – October 09) on the two measured farmlets (Table 2). This was probably due to higher rainfall frequency and volume during the late spring/summer in the first year than during the same period in the second or third year, thereby creating soil moisture conditions more conducive to N_2O production.

Although N_2O emission rates were found to be lower ($P < 0.05$) in the "tight nitrogen" farmlet than in the control farmlet in the winter/early spring measurement periods in 2007, emissions were greater from a "tight nitrogen" farmlet paddock during November 2006 (Table 2). Consequently, the differences in the total annual N_2O emission rates between the control and the "tight nitrogen" farmlets were not significant ($P > 0.05$) in the first study year (2006-2007) (Table 2).

In the second (2007-2008) and third (2008-2009) study years, N_2O emission rates were found to be lower ($P < 0.05$) in the "tight nitrogen" farmlet than in the control farmlet in the winter/early spring measurement periods. However, N_2O emission rates were generally similar between the "tight nitrogen" farmlet and the control farmlet in the other two measurement periods. Overall, annual N_2O emission rates from the "tight nitrogen" farmlet were found to be between 39% and 50% lower than those from the control in these two years.

Over all the three study years (2006-2009), the average annual N_2O emission rate from the "tight nitrogen" farmlet was 20% lower than from the control farmlet (Table 3). These measurements confirmed differences in N_2O emission rates between the "tight N" and control farmlets, demonstrating the effectiveness of using the nitrification inhibitor DCD and the winter restricted grazing regime on reducing N_2O emissions.

Total greenhouse gas emissions from the whole farm system

In this calculation, the basic farm information for Dairy NZ's prototype farms was used, including:

- a stocking rate of 3.0 cows ha^{-1}
- average N fertiliser of 170 kg urea-N ha^{-1} yr^{-1} for the control farmlet
- average N fertiliser of 150 kg urea-N ha^{-1} yr^{-1} for the tight nitrogen farmlet
- farm dairy effluent and manure from the wintering stand-off facilities applied onto the farms
- average milk production of 1,137 kg milksolids ha^{-1} $year^{-1}$ for both farms.

Table 3. Reduction of greenhouse gas emissions through using the DCD and restricted grazing option in the "tight nitrogen" farm system.

	Control	Tight N (Restricted grazing with use of DCD)
Total N_2O-N emissions from grazed pastures (kg N_2O-N ha^{-1} yr^{-1})	4.74	3.81
N_2O change from control (%)		-20
Total greenhouse gas emission including CH_4, N_2O and CO_2 (kg CO_2-equivalent ha^{-1} yr^{-1})	11,524	10,871
Total greenhouse gas emission change from control (%)		-6
Carbon charge (\$ ha^{-1} yr^{-1})[1]	288	272
"Carbon gains" relative to control (\$ ha^{-1} yr^{-1})		16

[1] based on \$25 t^{-1} CO_2-equivalent.

Total calculated annual emissions for the sum of the three major greenhouse gases, N_2O, CH_4 and CO_2, from the control and "tight N" dairy farms were 11,524 and 10,871 kg CO_2-equivalent per hectare, respectively (Table 3). The total greenhouse gas emissions from the tight nitrogen dairy system were 6% lower than that from the control system. Schils et al. (2006) estimated that reduction of N fertiliser use and grazing times could reduce N_2O emissions from intensive dairy systems in the Netherlands by 50%. However, these practices could only reduce total greenhouse emissions by 26%. Clough et al. (2007) estimated that use of nitrification inhibitors could reduce N_2O emissions from NZ dairy farm systems by 29-53%, but only reduce total greenhouse gas by approximately 2-18%.

Reducing emissions can potentially have economic benefits when C costs are imposed. Potential savings (assuming US\$25 per tonne of CO_2 equivalent) associated with a reduction of N_2O emissions as a result of the use of the DCD and restricted grazing mitigation options are presented in Table 3. These savings are dependent on the cost attributed to emissions and will need to be considered in relation to the cost of application of the individual mitigation practices.

Conclusions

The annual N_2O emission rates on DairyNZ's Prototype farmlets were higher during the first study year (November 06 – October 07) than those during the second or third study year (November 07 – October 08 or November 08 – October 09). During the winter/early spring periods, N_2O emission rates were lower from the "tight nitrogen" farm paddocks than those from the control farm paddocks. It is calculated from these results that the use of a restricted grazing regime (e.g., use of an animal shelter) and the nitrification inhibitor DCD reduced N_2O emissions from the dairy farmlet by 43-79% during the winter/early spring measurement periods. For the three study years, on average, the annual N_2O emission rate from the "tight nitrogen" farmlet was observed to be 20% lower than from the control. Total calculated annual emissions for the sum of the three major greenhouse gases, N_2O, CH_4 and CO_2, were 11,524 and 10,871 kg CO_2-equivalent per hectare from the control and "tight nitrogen" dairy farms, respectively. The total greenhouse gas emissions from the "tight nitrogen" dairy system were 6% lower than those from the control system. Reducing emissions can potentially have economic benefits when C costs are imposed.

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