Nitrous oxide emissions from farm effluents

Rita Bhandral[1], Surinder Saggar[2], Nanthi S.Bolan[3] and Mike Hedley[4]

[1]Soil & Earth Sciences, Massey University, New Zealand. www.massey.ac.nz Email: Rita.Bhandral.1@uni.massey.ac.nz
[2] Landcare Research, New Zealand. www.landcareresearch.co.nz Email saggars@landcareresearch.co.nz
[3]Soil & Earth Sciences, Massey University, New Zealand. www.massey.ac.nz Email: N.S.Bolan@massey.ac.nz
[4]Soil & Earth Sciences, Massey University, New Zealand. www.massey.ac.nz Email: Mike.Hedley@massey.ac.nz

Abstract
Effluent irrigation leads to increased emission of greenhouse gases, such as nitrous oxide (N_2O) and methane (CH_4). Massey University and Landcare Research have initiated a number of studies examining the effects of various factors, such as the nature of the effluent, hydraulic loading, time of application, soil type and compaction, on N_2O emissions from effluent irrigation. Here we compare the emissions from treated and untreated dairy effluents, and piggery and meat effluents applied to 2 m x 1 m plots for two periods (1st irrigation: February-April, 2003; and 2nd irrigation: July-September, 2003). In addition we examined N_2O emissions from the treated dairy effluent applied to a dairy farm during three periods (September 2003 and January and February 2004), and the residual effect of effluent irrigation and grazing on emissions in a field-scale trial. In the plot trial, the effluent irrigation resulted in higher emissions than the control and the highest N_2O emissions were observed from piggery effluent (1.4% of the applied N) and meat effluent (0.67%) after the first and second irrigation, respectively. In the field-scale trial, N_2O emissions increased immediately after the application of the dairy effluent and the total N_2O emitted from effluent application in the first, second and third irrigations were 2.0%, 5.8% and 2.5%, respectively of the total N added in the effluent. No residual effect of effluent irrigation on N_2O emissions was observed two months after the application.

Key Words
Denitrification, Farm effluents, Nitrous oxide flux, Pastures

Introduction
Over the last decade intensification of pastoral agriculture in New Zealand, has seen dairy cow numbers increase by 54% from 3.44 million in 1990 to 5.23 million in 2003 (National Inventory Report New Zealand 2004). In countries such as New Zealand, where open grazing is practised, a large amount of animal excreta is directly deposited onto pasture land. On dairy farms, however, approximately 6- 10 % of the excreta is deposited in the milking shed and collecting yards. When the yards and milking area are cleaned with high-pressure hoses, farm dairy effluent is generated at approximately 50 L per cow per day. It is estimated that annually in New Zealand about 70 million m^3 of effluent are being generated from dairy sheds, 4 million m^3 from piggery farms, and 50 million m^3 from meat processing plants (Saggar *et al*. 2004b). All these effluents contain significant quantities of valuable nutrients that could be applied onto land in order to improve soil fertility and increase the sustainability of farming systems. Bolan *et al.* (2004) estimated the value of effluents from dairy shed and piggery farms in New Zealand to be $21million per year.

Environmental concerns have been raised about the appropriate management of such farm effluents (Saggar and Bolan, 2003). In New Zealand, farm effluent management, is subject to regional council and dairy industry regulations. To date, most concern associated with land application of effluents has centred on the contamination of ground and/or surface water. Many regional councils encourage land irrigation of effluents, which is perceived to minimize their environmental impacts on groundwater and surface water. Moreover, due to their high nutrient content, land application of effluents is considered a move towards sustainable farming. There are regulations governing land application of effluents that are generally based on total N and/or P loading. But this policy has been made without due regard to its impact on the air quality. It has been reported that effluent irrigation leads to increased emission of greenhouse gases such as nitrous oxide (N_2O) and methane (CH_4) (Bhandral *et al*. 2003b; Bolan *et al*. 2004). Animal excreta, effluents and manure form a major part of N input to soil, which can lead to denitrification and release of N_2O (Figure 1).

The chemical composition varies between the various effluents and also varies with time and with treatment of the individual effluents (Roberts *et al*. 1992; Luo *et al*. 2004). Thus, effluents generated from

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different farming systems may lead to varied levels of gaseous emissions primarily due to their differences in chemical composition.

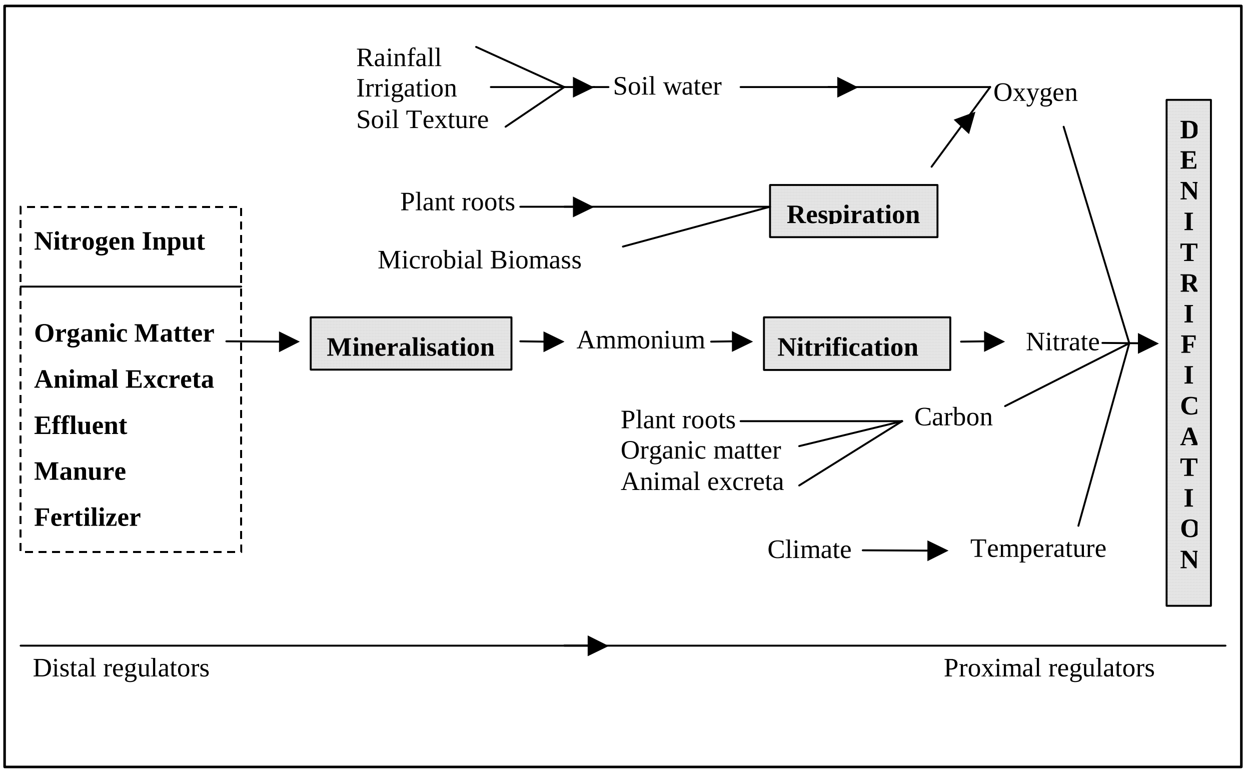

Figure 1. Factors affecting denitrification in grazed pastures.

In order to quantify N_2O fluxes arising from the irrigation of farm effluents to land, experiments were designed:

- To examine the effect of different effluent types on the rate of N_2O emission from pasture soil.
- To measure the rate of N_2O emissions from application of dairy effluent at a commercial dairy farm.
- To quantify the residual effect of effluent irrigation and grazing on N_2O emission.

Materials and Methods

Plot studies

To meet the first objective, N_2O fluxes from different effluents were compared. The experiment was conducted from 27th February to 9th June, 2003 (1st irrigation) and 9th July - 2nd September, 2003 (2nd irrigation) on sheep-grazed permanent legume-based pasture at Massey University's Frewens Research Block. Plots were fenced off six months prior to the commencement of the experiment to avoid further stock access during the experimental period and to eliminate the effect of grazing. The experiment had six treatments. Four different types of effluents namely, raw farm dairy effluent, dairy effluent after two pond treatment, piggery effluent and meat effluent were applied. Water only and a control treatment were included. Each of these treatments was applied to a 2m x 1m area strip. These strips were lined with 7.5 cm deep polythene sheet to contain the effluent within the plot. Total volume of effluent applied for each treatment was 50 L (i.e., 25mm depth). Each treatment was replicated four times.

Field studies

To meet the second objective, N_2O emissions and related soil and environmental parameters were monitored for two weeks following the application of treated dairy effluent in 3 periods (September 2003 and January and February 2004). Experiments were conducted at Massey University's Dairy 4 on areas described by Houlbrooke *et al*. (2003). The closed chamber technique described below was used for periodic measurement of N_2O emissions from two 80m x 40m blocks, one irrigated with effluent and grazed and the other grazed only. Each block had 20 chambers arranged in zig-zag fashion. Effluent was applied at 21mm, 21mm and 16mm irrigation depth during the 1st, 2nd and 3rd irrigation, respectively, depending on the soil water deficit prevalent in the field.

To meet the third objective, N_2O emissions were measured under fields conditions that reflected periods of effluent irrigation followed by grazing (irrigated grazed), normal grazing (unirrigated grazed) and periods of no grazing on non effluent plots. This enabled measurement of the residual effect of the previous effluent application (2 months after effluent irrigation) and of earlier grazing on emissions. These emissions were compared with a third site that was neither grazed nor irrigated. Each area had 20 chambers to cover the variability present in the field.

Nitrous oxide measurement

The N_2O fluxes were measured using the closed chamber technique. The chambers were modified PVC 'Sewer-hatch' attached to sections of PVC pipes (Saggar *et al*. 2002). The chambers, 250 mm in diameter, were inserted about 100 mm into the soil. Chamber heights were measured to calculate the volume of each chamber. During the first week measurements of N_2O emissions were made daily to capture major changes in N_2O fluxes. This was followed by measurements on alternate days for the rest of the experimental period as the fluxes decreased, approaching the background levels. Everyday after sealing the chambers with lids, three gas samples were taken from each chamber at times t_0, t_{30} and t_{60} (Time 0 minutes, 30 minutes and 60 minutes after closing of the chamber, respectively). The gas samples collected were then analysed using a Shimadzu GC-17A gas chromatograph with a ^{63}Ni-Electron capture detector and N_2O (mg m^{-2} hr^{-1}) flux was estimated from the measurements made at three time periods (t_0, t_{30} and t_{60}) as described in Saggar *et al*. (2002).To minimise the variation in the flux pattern, sampling was always carried out between 10am and 1pm.

Results and discussion

Plot studies

N_2O emissions were found to be affected by the application of different types of effluents (Figure 2a and 2b). Emissions were found to increase immediately after the application of each effluent for both the irrigation events. Peak emissions of 0.024, 0.028, 0.026 and 0.0206 kg N/ha/d for meat, untreated dairy effluent, piggery and treated dairy effluent, respectively during the first irrigation and 0.047, 0.021, 0.018 and 0.014 kg N/ha/d for meat, untreated dairy effluent, piggery and treated dairy effluent, respectively during the second irrigation were attained within 24 – 36 hours of the effluent application (Figure 2).During the first irrigation event a second peak was observed 30 days after effluent application for all treatments, which could be attributed to a significant rainfall event (23.4 mm) prior to that sampling period. Other studies have shown highly variable courses for peak response following animal waste application. Sharpe & Harper (1997) and Whalen *et al.* (2000) reported maximum responses in N_2O emission within several hours of swine-effluent applications. Nitrous oxide emission was found to decrease progressively from the time of application of various sources. Russell & Cooper (1987) also observed that following an effluent irrigation event, N_2O emission rate increased rapidly and reached a peak, which fell again to background levels as aerobic conditions re-establish.

Emissions were significantly higher from all effluent irrigation treatments compared to the control and water treatments for both the irrigation events. The overall emissions from the effluent treatments were 85-183% higher than that from the water treatment for the 1st irrigation and 1-183% higher during the second irrigation. This percentage was found to be much higher when compared with the control treatment (98-203% and 42-297% for first and second irrigation, respectively). Higher level of N_2O emissions from effluent treatments is attributed to the enhanced denitrification activity resulting from increased C availability and/or from decreased soil aeration. Petersen (1999) observed that lowering the C content of animal slurry had decreased N_2O emissions. Effluents have been shown to promote conditions conducive to microbial denitrification, creating an anaerobic environment abundant in inorganic N and readily oxidisable C (Comfort *et al*. 1988).

Figure 2a

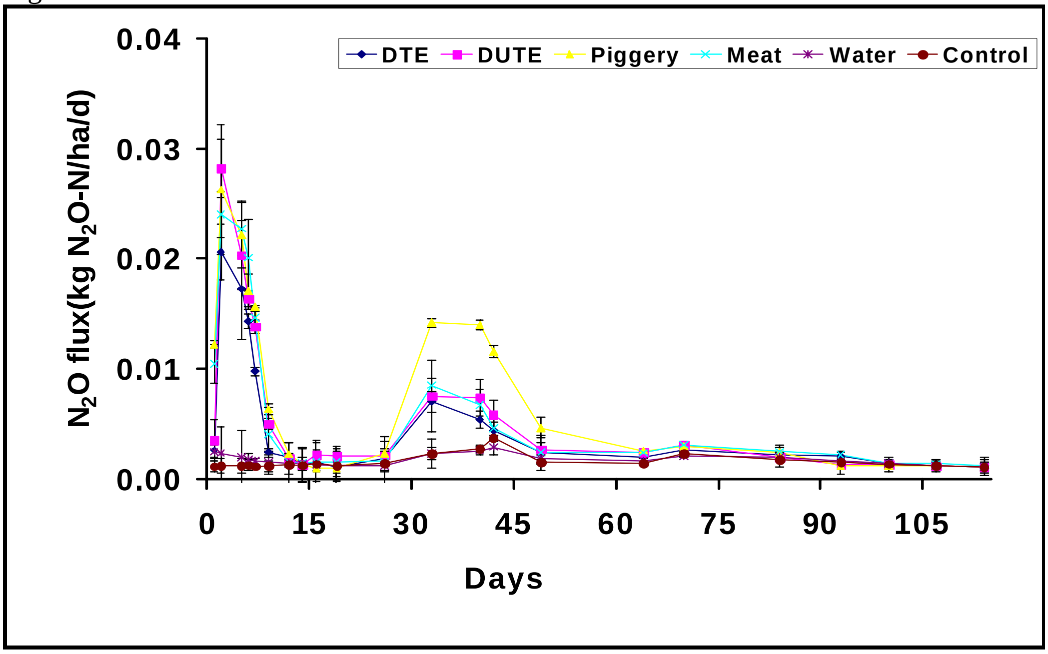

Figure 2b

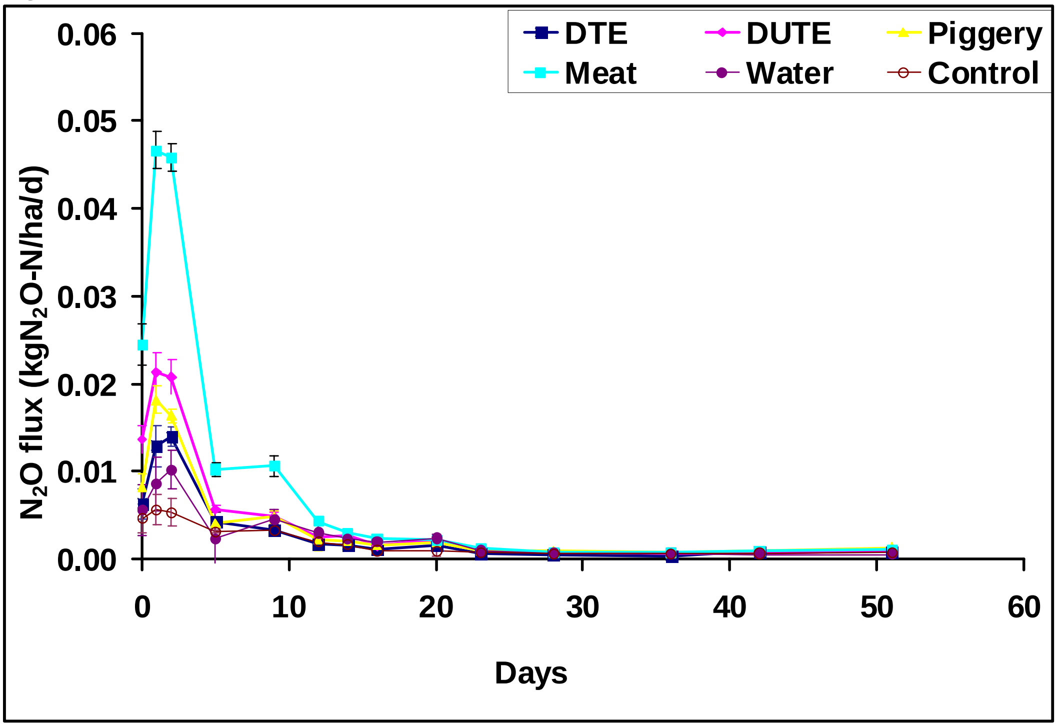

Figure 2. N_2O fluxes (kg N/ha/d) during (a) first (b) second application of effluents. Each value represents a mean of four replicates with standard deviation shown by vertical bars. DTE and DUTE in the legends stand for Dairy treated effluent and Dairy Untreated effluent, respectively.

Following the first irrigation, piggery effluent emitted the highest N_2O-N among the effluents used, with emissions of 0.59 kg N/ha or 2.17% of the total added effluent-N, over the experimental period (Table 1). It was found to be significantly higher than the other treatments. Emissions from untreated dairy effluent (0.45 kg N/ha) and meat effluent (0.46 kg N/ha) were not found to be significantly different. Untreated dairy effluent resulted in higher emissions (0.45 kg N/ha), compared with treated dairy effluent (0.38 kg N/ha), which gave the least emissions among the effluents. However, the proportion of effluent-N emitted was higher for the treated dairy effluent (2.04%) than for the untreated dairy effluent (0.73%). The percentage values of added N lost as N_2O are 2.17%, 1.15%, 0.73% and 2.04% for piggery, meat, untreated dairy effluent and treated dairy effluent, respectively. During second irrigation, meat effluent resulted in the highest N_2O emission of 0.29 kg N/ha, which is 0.84% of the total effluent-N added. There was no significant difference in N_2O emissions from piggery and untreated dairy effluent. Emissions from treated dairy effluent, piggery and water were found to be in the same range. The percentage values of the added N lost as N_2O are 0.78, 0.31, 0.56 and 0.84% for treated dairy effluent, untreated dairy effluent, piggery and meat effluent, respectively. Khan (1999) in his field study also reported higher emissions from piggery effluent than from treated dairy effluent being 1.9% and 0.1–0.3% of the applied N as N_2O emissions from piggery effluent and treated dairy effluent, respectively.

Table 1. N added and N_2O emitted from various effluents.

Type of Effluent	N added through effluent (kg N/ha)		N emitted (kg N/ha)		% of added N emitted	
	1st Irrigation	2nd Irrigation	1st Irrigation	2nd Irrigation	1st Irrigation	2nd Irrigation
Dairy Treated	18.75	13.02	0.38	0.10	2.04	0.78
Dairy Untreated	61.00	49.33	0.45	0.15	0.73	0.31
Piggery	27.50	23.11	0.59	0.13	2.17	0.56
Meat	39.50	33.75	0.46	0.29	1.15	0.84
Water	0.12	0.00	0.21	0.10	---------	--------
Control	---------		0.19	0.07		
LSD (0.05%) n = 4			0.02	0.03		
LSD (0.01%); n = 4			0.03	0.05		

Field Study

Compared to the plot study, similar sized N_2O peak emissions of 0.11, 0.40 and 0.17 kg N/ha/d occurred from three consecutive dairy farm effluent irrigations. N_2O emissions increased immediately within a few hours to 24 hours of the effluent application, and subsequently dropped. It took 1–2 weeks for the emissions to return to a lower level similar to the control treatment (Figure 3a, 3b and 3c). The increased denitrification rates after effluent application can be attributed to the presence of large quantities of inorganic N together with high organic C levels and increased soil water content (Rice *et al*. 1988). The total N_2O emitted from effluent application after the first, second and third irrigation were 2.0%, 5.8% and 2.5% respectively of the total N added through effluent (Table 2). Emissions were observed to be higher during second effluent irrigation (Table 2) because of the high soil moisture content during the measurement period. Moreover effluent was applied immediately after the grazing event leading to greater N input in the soil. The study shows that the emissions varied greatly depending on soil water filled pore space (WFPS) and the climatic conditions.

Table 2. N applied as dairy effluent and N_2O emitted (kg N_2O/ha) during the three irrigations.

Irrigation	Time of application	Days for emissions to reach background levels	N applied (kg N/ha)	N emitted (kg N_2O-N/ha)	% of added N emitted	**WFPS range**
First	Sep 2003	17	23.9	0.493	2.0	**0.61-0.86**
Second	Jan 2004	14	25.2	1.433	5.8	**0.69-0.94**
Third	Feb 2004	9	18.0	0.449	2.5	**0.56-0.77**

Two months after dairy farm effluent application no difference in the N_2O flux was observed between the irrigated and unirrigated sites (Figure 4). High spatial variability was observed within the sites, which is one of the features in the measurement of N_2O emission, especially under field conditions. Large differences were observed between the grazed (both irrigated and unirrigated) and ungrazed sites (Figure 4). High input of N from animal excreta leads to higher emissions from grazed pastures. High N_2O fluxes in grazed pastures, often associated with N and C from the deposition of animal excreta to the soil by grazing animals, have also been reported by Ryden (1986) and Saggar *et al.* (2002, 2004). Grazing is known to introduce additional spatial variability to N_2O fluxes because of the uneven excretal returns of N (Saggar *et al*. 2002, 2004) and animal treading to the soil (Bhandral *et al*. 2003a).

Figure 3a

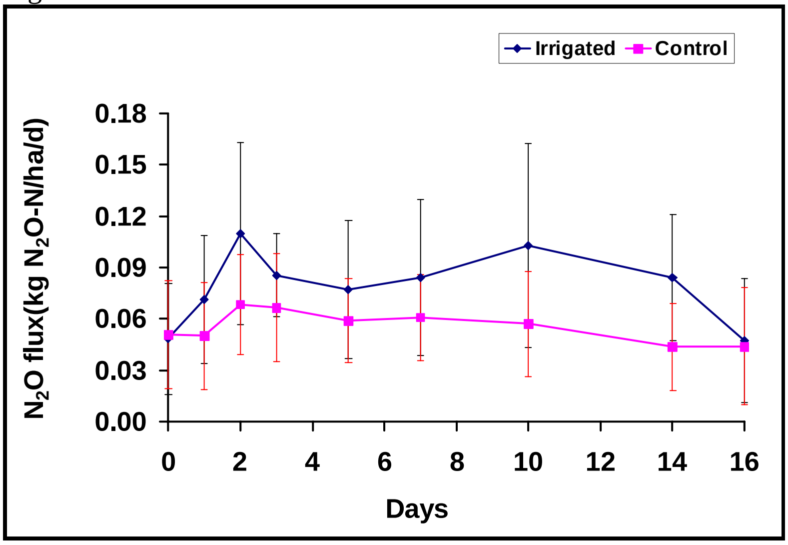

Figure 3b

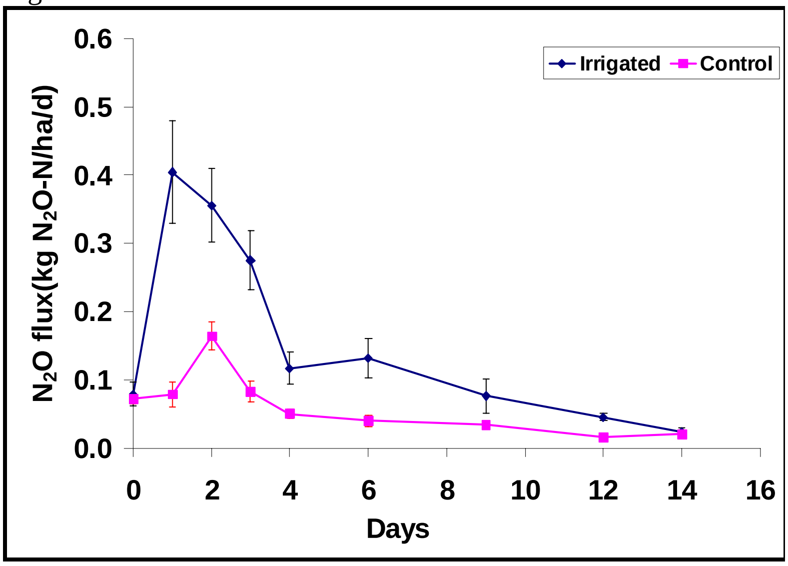

Figure 3c

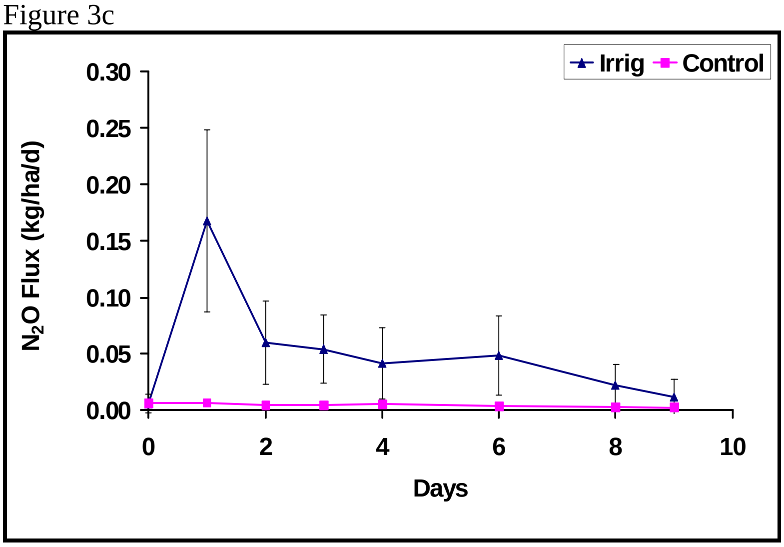

Figure 3a, b & c. N_2O fluxes (kg N/ha/d) during the (a) first (b) second and (c) third irrigation event. Each value represents a mean of four replicates with standard deviation shown by vertical bars.

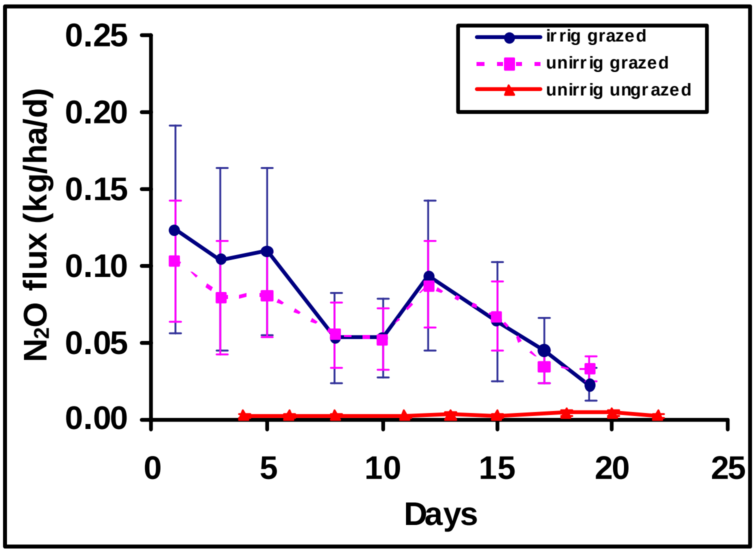

Figure 4. Residual effect of dairy farm effluent irrigation on nitrous oxide emissions.

Conclusion

- Emissions varied with the type of effluent, which could be attributed to the differences in the amount of available N and C in the effluent.
- Effluent irrigation increased N_2O emissions for a short duration. No long-term residual effect of effluent irrigation on emissions was observed.
- High spatial variability in emissions was observed due to uneven distribution of animal excreta.

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