

## **NITROUS OXIDE EMISSION FROM FARM DAIRY EFFLUENT APPLICATION IN GRAZED GRASSLAND**

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### **ABSTRACT**

Intensification in dairying and increased production of farm dairy effluent (FDE) has raised concerns about gaseous nitrogen (N) losses and their environmental implications. This study was undertaken to monitor changes in mineral-N and soil water-filled pore-space (WFPS) in relation to N<sub>2</sub>O emission from application of FDE to dairy-grazed pasture. Pasture was irrigated with FDE in September 2003 (first irrigation) and January 2004 (second irrigation), preceded by grazing events. The N<sub>2</sub>O emission rate increased after application of FDE. Total amounts of N<sub>2</sub>O emitted from FDE application for first and second irrigation were 2% and 4.9%, respectively, of the total N added through effluents. Difference in emission rates between the two irrigation events were attributed to difference in time lapse between the grazing event and FDE application. When FDE was applied immediately after grazing (second irrigation) higher emissions were observed.

**Keywords:** Denitrification; mineral-N; Carbon; Oxygen diffusion rate

### **INTRODUCTION**

Intensification of dairy industry in New Zealand has led to increasing amounts of effluent being generated (Longhurst *et al.*, 2000) which has resulted in growing concerns about environmental impacts of land application of this farm effluent (Luo *et al.*, 2008a). One of the major concerns is loss of effluent nitrogen (N) through nitrate leaching, ammonia volatilization and denitrification, thereby resulting in environmental degradation. The problem is further aggravated if effluent is applied on grazed pastures that are subject to compaction and excretal deposition (Luo *et al.*, 2008b).

Nitrous oxide (N<sub>2</sub>O) is formed in soils during the microbiological processes of

nitrification and denitrification, which are affected by a number of soil and climatic factors, such as soil enzyme activities, nitrate concentrations, pH, available carbon, rainfall/irrigation, water-filled pore-space (WFPS) and temperature (Tiedje 1988, Bolan *et al.*, 2004a, Luo *et al.*, 2008c).

There have been very few comprehensive studies examining the emission of N<sub>2</sub>O from farm dairy effluent (FDE) application periodically to grazed paddocks as normally occurs on a commercial dairy farm. The combination of compaction caused by cattle treading during grazing and excretal deposition by grazing cattle is additional stimulants of

N<sub>2</sub>O emission that will occur subsequent to effluent irrigation on a commercial farm. One of the main factors that influence emission in pasture is the grazing event (Oenema *et al.*, 1997). Effluent irrigation immediately after the grazing event may enhance N<sub>2</sub>O emission from grazed pasture. This study was undertaken to examine the changes in mineral-N, dissolved organic carbon, oxygen diffusion rate (ODR) and WFPS in relation to N<sub>2</sub>O emission from application of FDE to dairy-grazed pasture.

## MATERIALS AND METHODS

Nitrous oxide emissions and related soil and environmental parameters were monitored for two weeks following applications of FDE in September 2003 (spring - 1<sup>st</sup> irrigation) and January 2004 (summer - 2<sup>nd</sup> irrigation).

### Experimental site and soil characteristics

The field site consisted of pasture grazed by dairy cows and was located on Massey University's N° 4 Dairy Farm in the Manawatu region of New Zealand (NZMS 260, T24, 312867). The site is located in a flat to easy rolling landscape (~ 3% slope), which receives an average annual rainfall of ~ 1000 mm supporting a mixed pasture of perennial ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*).

The soil type was Tokomaru silt loam classified as Argillic-fragic Perch-gley Pallic soil in the Soil Classification (Hewitt, 1998). The soil at the experimental site had a total N of 0.35%, organic matter of 6.2%, bulk density of 1.01 Mg m<sup>-3</sup> and cation exchange capacity of 22 cmol<sub>c</sub> kg<sup>-1</sup>.

Two 40m x 40m field sites were selected for the trial. The irrigated treatment site received two FDE applications and the control treatment did not receive any FDE. Both the sites have similar management practices and grazing events. The control plot which was about 200 m away from the irrigated plot was grazed at the same time and at same intensity as the irrigated plot. Two effluent irrigation events during 15<sup>th</sup> to 28<sup>th</sup> September 2003 (1<sup>st</sup> irrigation) and 28<sup>th</sup> January to 11<sup>th</sup> February, 2004 (2<sup>nd</sup> irrigation) were monitored for N transformations in soils and N<sub>2</sub>O emission.

Effluent loading rate for each irrigation event was equal to the soil moisture deficit at the time of the effluent irrigation. The effluent was applied at hydraulic loadings of 25mm and 21mm the 1st and 2nd irrigation, respectively which resulted in N loading levels of 25.2 and 21.2 kg N ha<sup>-1</sup>, respectively. Effluent was applied with a spitfire Mark I oscillating irrigator traveling at the rate of approximately 2.7 mm min<sup>-1</sup>.

The characteristics of the effluent applied are presented in Table 1. The paddock was grazed 8 days before the 1st irrigation by 18 dairy cattle (112 cattle per hectare) for 12 hours and 1 day before the 2<sup>nd</sup> irrigation by 22 cattle (135 per hectare) for 12 hours. The grazing took place at time and intensity that was normally followed under the management practices for the farm. The whole project was part of the deferred irrigation practice followed at the farm (Houlbrooke *et al.*, 2004).

### Nitrous oxide measurement

The N<sub>2</sub>O emissions for the above mentioned periods for the two experiments were measured using the closed chamber technique (Saggar *et al.*, 2002, 2004a).

**Table 1.** Characteristics of the farm dairy effluent applied during two applications on the Tokomaru silt loam soil.

Properties	Irrigation 1	Irrigation 2
Total suspended solids (mg L <sup>-1</sup> )	245.2	268.6
pH	7.6	7.8
Total N (mg L <sup>-1</sup> )	95.6	101.4
NH <sub>4</sub> <sup>+</sup> -N (mg L <sup>-1</sup> )	68.2	75.4
NO <sub>3</sub> <sup>-</sup> -N (mg L <sup>-1</sup> )	0.6	0.4
Total carbon (mg L <sup>-1</sup> )	908.2	959.2
Dissolved organic carbon (mg L <sup>-1</sup> )	18.2	19.2
C:N ratio	9.5	9.5
Chemical oxygen demand (mg L <sup>-1</sup> )	95	97
Biochemical oxygen demand (mg L <sup>-1</sup> )	105	112
Total P (mg L <sup>-1</sup> )	18.4	18.0

Twenty chambers were installed per treatment in a zig zag pattern to cover the spatial variability in the field. During the monitoring of N<sub>2</sub>O flux immediately after a grazing event, installing chambers directly over the dung patch was avoided. The chambers, 25cm in diameter, were inserted about 10cm into the soil after the effluent application. Background N<sub>2</sub>O flux (grazed unirrigated control) was measured for the site one day before the effluent application. During the first week after the effluent application, measurements of the N<sub>2</sub>O emissions were made daily to capture major changes in N<sub>2</sub>O fluxes. This was followed by measurements on alternate days for rest of the experimental period till the fluxes decreased, approaching the background emission. The concentration of N<sub>2</sub>O in the gas samples taken at times t<sub>0</sub>, t<sub>30</sub> and t<sub>60</sub> (30-min intervals) from each chamber was determined using a Shimadzu GC-17A gas chromatograph equipped with a <sup>63</sup>Ni-electron capture detector, and N<sub>2</sub>O emission rate was calculated from the change in concentration in the chamber

over this time. Full descriptions of the calculation of N<sub>2</sub>O flux are presented elsewhere (Saggar *et al.*, 2002, 2004a).

#### Soil sampling

On all days of N<sub>2</sub>O measurement, four soil samples were collected randomly from each site (irrigated and control) at 0-5 cm depth to determine soil water content. Soil samples were also collected to measure DOC and mineral N.

#### Oxygen diffusion rate

The oxygen diffusion rate (ODR) measurements were made to examine the difference in the diffusion rate between the irrigated and control treatments for all the two irrigations using ten replicate platinum electrodes (Glinski and Stepniewski, 1985). The electrodes were left overnight after installation at 5 cm soil depth to equilibrate with the soil solution. A voltage of 0.65V was applied for 3min and then the current between each electrode and a brass anode was read against an Ag/AgCl reference electrode with a Jensen oxygen diffusion rate meter.

The ODR was calculated using the following equation (Eq. 1):

$$\text{ODR } (\mu\text{g O}_2 \text{ cm}^{-2} \text{ min}^{-1}) = 0.059 \times \text{MC } (\mu\text{A}) \quad [1]$$

where, MC is the observed microelectrode current. The ODR was monitored on the first and the last day of the N<sub>2</sub>O measurement period for each of the two effluent irrigations.

#### Dry matter yield

To determine the pasture growth response to applied effluent, herbage was cut to a 2cm height prior to effluent application for both the irrigations. Herbage accumulation after the effluent application was recorded at the end of the measurement period using 30cm x 30cm cages, replicated 4 times.

The wet weight of herbage was recorded then oven dried at 70°C and dry matter (DM) recorded. The DM response to N input through effluent was calculated by the formula:

$$\text{DM response} = \frac{\text{DM from effluent irrigated plot} - \text{DM from control plot}}{\text{N added through effluent}}$$

#### Effluent, soil and plant analyses

The FDE was from the outlet of the aerobic pond of the dairy 4 farm of Massey University. Samples of effluent were analyzed for suspended solids, pH, total N, NH<sub>4</sub>-N, NO<sub>3</sub>-N, total carbon, dissolved organic carbon (DOC), chemical oxygen demand (COD), biological oxygen demand (BOD), total phosphorous and total potassium following the procedures published in standard methods (APHA, 1998).

Sub samples from each of the field moist soil samples were weighed ( $M_i$ ) and oven dried (105°C) to a constant final mass ( $M_s$ ) and weighed again. The final oven dry mass and the difference between the field-moist and final masses ( $M_w$ ) were used to calculate the gravimetric soil

water content (SWC) = ( $M_w/M_s$ ) × 100. The volumetric SWC was then calculated by multiplying the gravimetric SWC with the soil bulk density. Water-filled pore space (WFPS) was calculated as the ratio of the volumetric SWC to the total pore space (Saggar *et al.*, 2004b).

The sieved (< 4mm) field-moist sub sample (5g) was extracted with 0.5M K<sub>2</sub>SO<sub>4</sub> solution, by shaking it for 1 hr (1g soil: 4 ml extractant). The extracts were analysed for NO<sub>3</sub>-N and NH<sub>4</sub>-N by standard colorimetric methods (Keeney and Nelson, 1982) on an autoanalyser and for determining DOC by the dichromate oxidation (Tate *et al.*, 1988) method using a spectrophotometer.

The plant samples were analysed for total N following the Kjeldahl digestion method (Mckenzie and Wallace, 1954).

#### Statistical methods

The means and standard error of means were calculated for WFPS, ODR, N<sub>2</sub>O fluxes, DM, soil mineral N concentrations and soil DOC values for both the effluent irrigations. The experiment was pseudo-replicated with respect to treatments only. Total emission data was subjected to an analysis of variance using arithmetic mean to determine the statistical significance of different effluent sources, using SAS for the Windows software package. Calculated indices were analysed using a test of least significant difference (LSD). Regression and correlation analysis between N<sub>2</sub>O emission and various soil properties was conducted using the SAS package.

## RESULTS

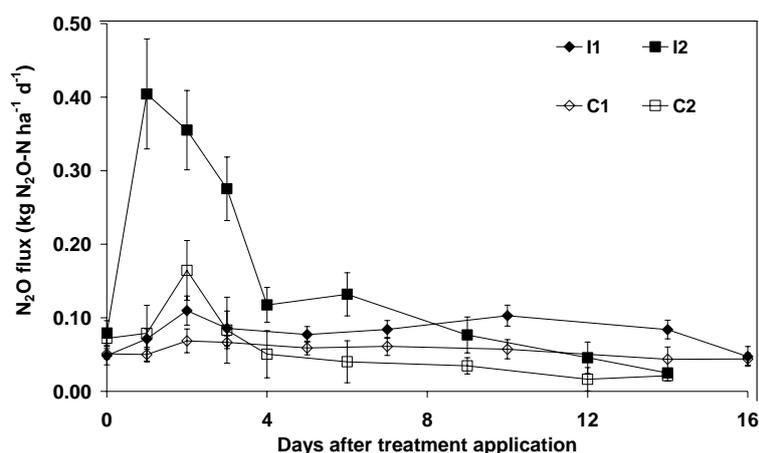
#### Properties of the effluent

The chemical composition of FDE used for the two applications varied slightly (Table 1), and the total solid and total N

contents were below the range reported in the literature (Wang *et al.*, 2004). This may reflect the reduction in the concentrations resulting from storage and effluent treatment. However, about 70 - 74% of N in NH<sub>4</sub>N form measured in the FDE used in our studies is typical of the effluent N distribution values found in New Zealand (Longhurst *et al.*, 2000).

### Nitrous oxide emission

Effluent applications at both events resulted in an increase the N<sub>2</sub>O emission over the unirrigated control. The emissions from FDE peaked within a few hours of application and subsequently dropped to reach the background level after 1-2 weeks of application (Figure 1).



**Figure 1.** N<sub>2</sub>O fluxes (kg N ha<sup>-1</sup> d<sup>-1</sup>) during the two effluent application events. Each value represents a mean of twenty replicates with standard deviation shown by vertical bars. I1 and I2 represent the irrigated treatment and C1 and C2 represent the control treatment for the 1<sup>st</sup> and 2<sup>nd</sup> effluent application, respectively.

Peak emissions of 0.110 and 0.404 kg N ha<sup>-1</sup> d<sup>-1</sup> were attained within 4-24 hours of the effluent application for the 1<sup>st</sup> and 2<sup>nd</sup> irrigation, respectively.

A small second peak was observed only for the 1<sup>st</sup> irrigation on day 10. The emissions then declined to the base level within 16 and 14 days for the 1<sup>st</sup> and 2<sup>nd</sup> irrigations, respectively.

Nitrous oxide emission from the FDE treated pasture ranged from 0.047 to 0.110 and 0.025 to 0.404 kg N<sub>2</sub>O-N ha<sup>-1</sup> d<sup>-1</sup> for the 1<sup>st</sup> and 2<sup>nd</sup> irrigations, respectively. The results indicate that 44 and 78% of the total emission were

emitted within a week for the 1<sup>st</sup> and 2<sup>nd</sup> irrigation, respectively.

The total amounts of N<sub>2</sub>O emitted from effluent application for the 1<sup>st</sup> and 2<sup>nd</sup> irrigation were 2.0% and 4.9%, respectively, of the total N added through effluents (Table 2). Cumulative emissions from the irrigated site were 1.5, and 2.8 times higher than that from the unirrigated control for respective irrigation events. The N<sub>2</sub>O flux from the control treatment remained almost stable with daily emission ranging from 0.0436 to 0.069 and 0.0164 to 0.164 kg N<sub>2</sub>O-N ha<sup>-1</sup> d<sup>-1</sup> for the 1<sup>st</sup> and 2<sup>nd</sup> irrigations, respectively.

**Table 2.** Amount of N applied through farm dairy effluent irrigation and N<sub>2</sub>O emitted during the two fresh applications on the Tokomaru silt loam.

Irrigation	Treatment	Emission period *	N added (kg ha <sup>-1</sup> )	Peak emission rate	N <sub>2</sub> O-N emitted (kg ha <sup>-1</sup> )	Emission factor (%) **
First	Irrigated	17	23.9	0.110	1.357	2.0
	Control		Nil	0.069	0.886	–
Second	Irrigated	14	25.2	0.404	1.922	4.9
	Control		Nil	0.164	0.679	–

\*Emission period = Number of days for emission to reach the background level

\*\*Emission factor =  $\frac{N_2O \text{ emitted (effluent treated plot)} - N_2O \text{ emitted (control plot)}}{N \text{ added through effluent}} \times 100$

A slight increase in the emission was observed for the 2<sup>nd</sup> irrigation, which coincided with the rainfall event (Fig. 1).

#### Water filled pore space

Soil WFPS for the irrigated and control treatment are shown in Figure 2. The calculated WFPS during the measurement period for both events was above the soil field capacity. Overall, WFPS was lower in the control treatments than the irrigated treatment. The WFPS values generally higher during the 2<sup>nd</sup> than the 1<sup>st</sup> irrigation. The range in WFPS values for the 1<sup>st</sup> and 2<sup>nd</sup> irrigation was 0.61 to 0.90 and 0.69 to 0.94, respectively. The mean WFPS values for the entire measurement period for the irrigated treatment were 4.1 and 5.5% higher than the mean value of the control treatment for the respective irrigation events.

#### Oxygen diffusion rate

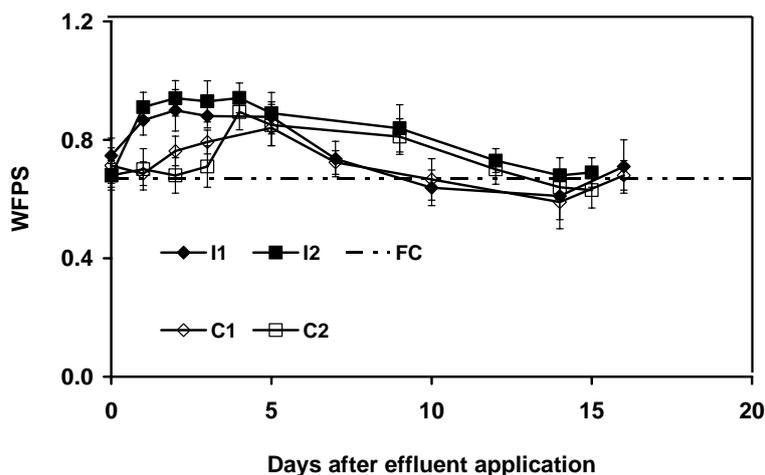
The ODR values declined immediately after the FDE application (Figure 3). Immediately after the 1<sup>st</sup> and 2<sup>nd</sup> irrigation

ODR values were 29.2 and 32.8% lower than the unirrigated control treatment. By the end of the measurement period of both the irrigation events ODR values increased to those observed in the control treatment. Overall, ODR values were slightly lower for the 2<sup>nd</sup> than 1<sup>st</sup> irrigation event, though the difference was not significant.

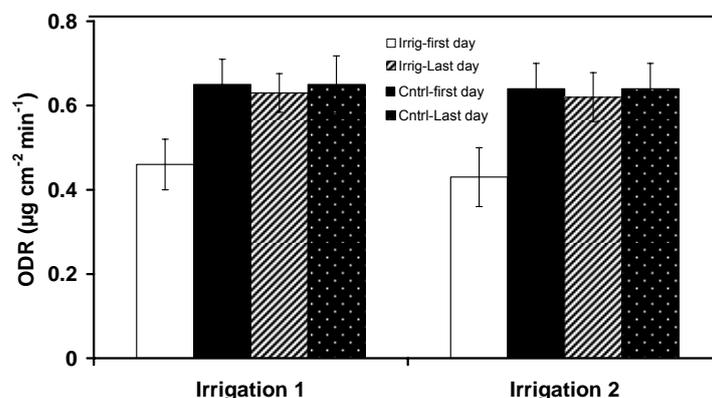
#### N transformation in soil

Application of FDE increased soil mineral N concentration (Figure 4a and b). In general the trend in mineral-N distribution was same for both the irrigation events, with NH<sub>4</sub>-N concentration increasing immediately after FDE application and then decreasing progressively with time.

Nitrate concentration on the other hand showed an initial lag period before starting to increase. The highest NH<sub>4</sub>-N concentration of 22.7 mg kg<sup>-1</sup> soil was reached within two days of the 1<sup>st</sup> effluent application. The concentration then decreased to a minimum of 5.1 mg kg<sup>-1</sup> soil on the last day of the measurement period.



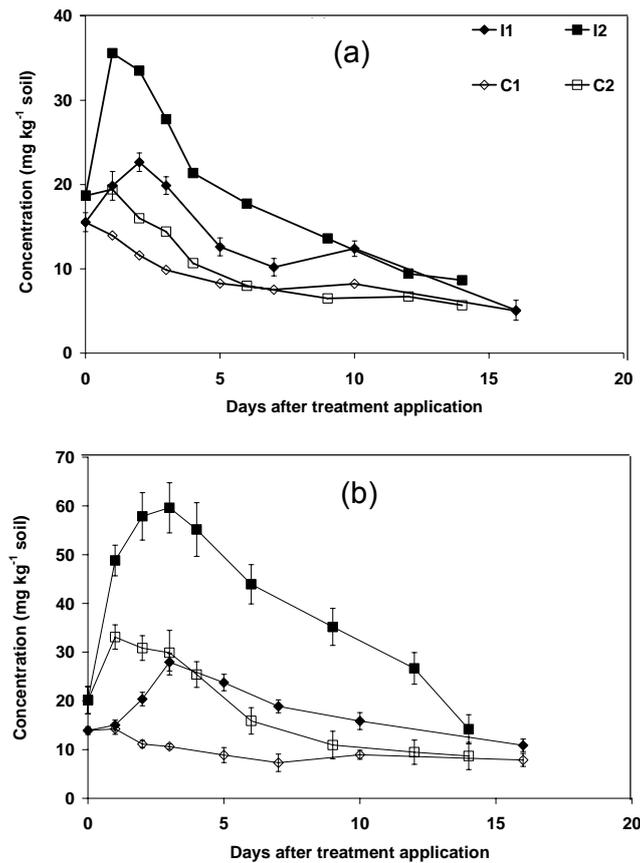
**Figure 2.** WFPS distributions for two freshly irrigated and corresponding control treatment (unirrigated). I1 and I2 represent the irrigated treatment and C1 and C2 represent the control treatment for the 1st and 2nd effluent application, respectively. Each value represents a mean of twenty replicates with standard deviation shown by vertical bars. FC=Field capacity.



**Figure 3.** ODR ( $\mu\text{g cm}^{-2} \text{min}^{-1}$ ) for the experiments on the first and last day after treatment application for the two irrigation events. Each value represents a mean of four replicates with standard deviation shown by vertical bars. Irrig and Cntrl stand for irrigated and control.

The  $\text{NO}_3\text{-N}$  concentration was found to peak to a concentration of  $27.9 \text{ mg kg}^{-1}$  soil on the third day after the 1<sup>st</sup> effluent application. Decreases in both the  $\text{NH}_4\text{-N}$  and  $\text{NO}_3\text{-N}$  concentration were measured from the beginning to the end of the

measurement period for the control treatment. The changes in the concentrations of the mineral N in the control treatment could be attributed to the excretal input from the grazing event a week before monitoring started.



**Figure 4.** Distribution of (a)  $\text{NH}_4\text{-N}$  concentration, and (b)  $\text{NO}_3\text{-N}$  concentration during the 1<sup>st</sup> and 2<sup>nd</sup> effluent irrigation events. Each value represents a mean of four replicates with standard deviation shown by vertical bars. Please note the difference in the scale of Y axis. I1 and I2 represent the irrigated treatment and C1 and C2 represent the control treatment for the 1<sup>st</sup> and 2<sup>nd</sup> effluent application, respectively.

The pre-effluent irrigation mineral N concentration in the soil was higher for the 2<sup>nd</sup> than 1<sup>st</sup> event. A relatively large pool of both  $\text{NH}_4\text{-N}$  and  $\text{NO}_3\text{-N}$  existed in the soil, that was grazed a day before the application of the 2<sup>nd</sup> irrigation. This could be attributed to the rapid transformation of the excretal (urine) N in the soil. The highest  $\text{NH}_4\text{-N}$  concentration of  $35.6 \text{ mg kg}^{-1}$  soil was 133% of the  $\text{NH}_4\text{-N}$  concentration added through the

effluent, indicating some priming effect resulting from effluent application and from the excretal deposition. The  $\text{NO}_3\text{-N}$  concentration also showed a similar trend with the levels being far higher than could be accounted for from all added  $\text{NH}_4\text{-N}$  mineralised.

The range of the  $\text{NH}_4\text{-N}$  concentration for the irrigated and the control treatment were  $6.7$  to  $15.2 \text{ mg kg}^{-1}$  soil and  $5.3$  to  $7.7 \text{ mg kg}^{-1}$  soil, respectively. During the

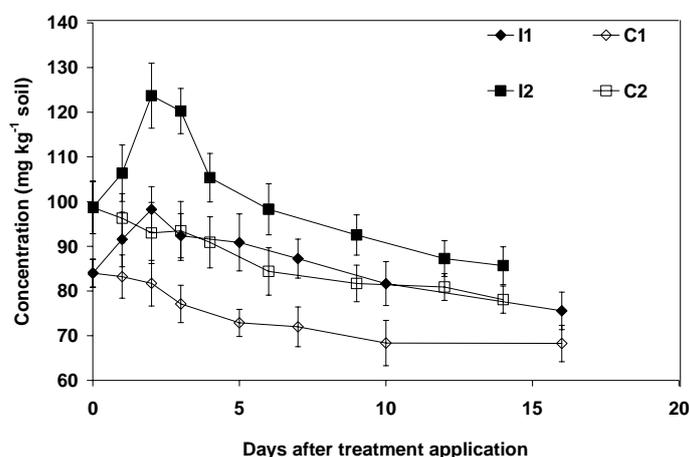
entire measurement period, the soil NO<sub>3</sub>-N concentration was higher in FDE irrigated site than the unirrigated control site (Figure 4b). The NO<sub>3</sub>-N ranged from 5.4 to 15.9 mg kg<sup>-1</sup> soil and from 5.9 to 9.4 mg kg<sup>-1</sup> soil for the irrigated and control treatments, respectively.

### Dissolved organic carbon

Increases in the DOC concentration of the soil occurred with FDE application (Figure 5). This was as anticipated, because the FDE added soluble carbon to the soil. The increase in the DOC concentrations varied between the two irrigation events, but for both the events, an initial increase in DOC after the effluent application was followed by a decrease with time (Figure 5).

After the 1<sup>st</sup> irrigation, DOC levels increased rapidly within two days to the peak level of 98.3 mg kg<sup>-1</sup> soil, and then declined immediately, reaching 75.6 mg kg<sup>-1</sup> soil after 16 days of the FDE application. The DOC concentration in the soil under the control treatment fluctuated with time and the concentration varied by 18.7% between the first and the last day of the measurement period. The effect of effluent was observed throughout the measurement period with significant differences observed between the two treatments.

The DOC concentration measured during the 2<sup>nd</sup> irrigation were higher than first irrigation event. The concentration on day 1 of this irrigation was 25.9 mg kg<sup>-1</sup> and 43.2% higher than the 1<sup>st</sup> irrigation.



**Figure 5.** Distribution of soil DOC concentration (mg kg<sup>-1</sup> soil d<sup>-1</sup>) during the monitoring period for the 1<sup>st</sup> and 2<sup>nd</sup> effluent application event. Each value represents a mean of four replicates with standard deviation shown by vertical bars. I1 and I2 represent the irrigated treatment and C1 and C2 represent the control treatment for the 1<sup>st</sup> and 2<sup>nd</sup> effluent application, respectively.

The concentrations during the entire measurement period ranged from 85.7 to 123.7 mg kg<sup>-1</sup> soil for irrigated and 78.1 to 98.7 mg kg<sup>-1</sup> soil for the control. The

peak concentration for the irrigation treatment was 4.4 times higher than the total DOC added through effluent irrigation, indicating that FDE irrigation

induced the mobilization of some of the excretal C input from the grazing a day before irrigation and native soil carbon. At the end of the two weeks 87.7 mg kg<sup>-1</sup> soil of the DOC remained in the soil which was still significantly higher than that remaining in the control.

Over the entire measurement period the DOC values for the irrigation treatment ranged from 76.2 to 86.4 mg kg<sup>-1</sup> soil and for the control treatment from 71.9 to 78.3 mg kg<sup>-1</sup> soil. The effect of FDE application on DOC concentration in the soil was observed only for a week.

#### Dry matter yield

The FDE irrigation increased the pasture DM yield (Table 3) and the yields in the FDE treatments were 2.0 and 2.2 times higher than those obtained for the respective unirrigated control. The yield response, expressed as kg DM kg<sup>-1</sup> N was the higher for the 2<sup>nd</sup> irrigation.

#### DISCUSSION

The addition of the FDE to dairy pastures, under normal farming conditions, resulted in significant increases in the N<sub>2</sub>O emissions for both irrigation events. A 1.5 and 2.8 fold increase in the emission was observed during the 1<sup>st</sup> and 2<sup>nd</sup> irrigation over the unirrigated treatment. The magnitude of increases in N<sub>2</sub>O emissions observed in our studies is in the same range as found with the application of animal wastes in Europe (Lowrance *et al.*, 1998; Chadwick *et al.*, 2000).

The FDE-induced increases in N<sub>2</sub>O have been attributed to the supply of soluble C, N and water (Barton and Schipper, 2001). In our study, addition of water through FDE increased soil WFPS (Figure 2), resulting in anaerobic conditions and enhanced denitrification.

Denitrification typically is thought to proceed at optimal rates above 0.60 WFPS (Linn and Doran, 1984). Saggarr *et al.* (2004a) showed that WFPS most strongly influences N<sub>2</sub>O fluxes in grazed pastures. They found generally high N<sub>2</sub>O emissions from grazed pasture sites when WFPS was above field-capacity (0.62-0.66). Over the entire measurement period, WFPS exceeded 0.60 for both effluent applications. This shows that most of the N<sub>2</sub>O emission might have been derived from the denitrification process rather than the nitrification process.

A significantly higher rate of denitrification at higher soil moisture levels has been observed in soils amended with liquid manure (Loro *et al.*, 1997). However, in this study the WFPS in the two irrigation events was >0.70 in the unirrigated control and thus the addition of the water through FDE would have little effect on the N<sub>2</sub>O emission. Therefore, N and DOC from FDE would have a greater role in increasing emission.

As discussed earlier, the N<sub>2</sub>O emissions from effluent application to grazed pasture soils are highly dynamic. They vary with effluent quality and the period of effluent application (Sommer *et al.*, 1996) and also with the time after application. For example, Clough and Kelliher (2005) observed no increase in N<sub>2</sub>O emission with the FDE application that supplied very low levels of N (1.5 kg N ha<sup>-1</sup>).

Barton and Schipper (2001) found FDE application (50 kg N ha<sup>-1</sup>) increased N<sub>2</sub>O fluxes for only a short duration, with the flux returning to the background level within 3 to 48 hours. Studies by Watanabe *et al.* (1997), where the emissions were highest immediately after the application and then decreased with time are consistent with the post FDE application N<sub>2</sub>O emission rates reported in this study.

**Table 3.** Total DM yield, and DM response to the added N for the experiments.

Irrigation	Treatment	Monitoring period (Days)	Total DM (kg ha <sup>-1</sup> )	N added (kg ha <sup>-1</sup> )	DM response (kg DM kg <sup>-1</sup> N)
First	Irrigated	14	204 (±45)	23.9	4.4
	Control	14	102 (±35)	Nil	–
Second	Irrigated	15	251 (±56)	25.2	5.5
	Control	15	113 (±51)	Nil	–

Our results indicate higher emissions from the 2<sup>nd</sup> irrigation than from the 1<sup>st</sup> irrigation even though the FDE composition was more or less similar. This difference in the N<sub>2</sub>O emissions could be attributed to the difference in management and climatic factors preceding and during the effluent irrigation events. A grazing event immediately preceded the 2<sup>nd</sup> irrigation.

The excretal deposition and the soil compaction caused by the grazing cattle could have led to increased emission. The concentration of the mineral N (NH<sub>4</sub>-N and NO<sub>3</sub>-N) was higher in both the control and the irrigated treatments for the 2<sup>nd</sup> irrigation than for the 1<sup>st</sup> irrigation event. The combined effect of FDE and excretal substrates (C and N) and their mobilization from the soil must have led to an increase in emission.

Build up of NO<sub>3</sub>-N was higher than could be accounted for by the nitrification of NH<sub>4</sub>-N, indicating the excretal N added in the soil during the grazing must have undergone mineralization by the time the effluent was added. These results appeared to be consistent with the hypothesis (Sen and Chalk, 1993; Clough and Kelliher, 2005) that FDE and cattle urine application together cause a large scale priming effect in the soil N and C, either by the solubilisation of the soil organic matter due to increased pH from the hydrolysis of the urine urea, or due to

the N applied in the urine itself. Therefore, more NO<sub>3</sub><sup>-</sup> was built-up in the FDE treatment in our studies. It remains unclear, however, why this effect was not observed in the 1<sup>st</sup> irrigation where the site was grazed a week before the FDE application.

Farm effluent application commonly increases pasture yield (Bolan *et al.*, 2004b; Wang *et al.*, 2004). The increase in the dry matter yield with the application of the effluent can be attributed to the addition of both the water and the nutrients through effluent irrigation, and the level of response is influenced by the rate, method and time (season) of application, soil fertility, and climatic conditions (Ball and Field, 1982). For example, Goold (1980) recorded 43% increase in the pasture yield when irrigated with FDE (irrigated at 12 mm depth, every 27 days) with a total of 156 kg N ha<sup>-1</sup> year<sup>-1</sup>. Since our study did not include a control water treatment, it was not possible to isolate the effect of water from nutrients on the pasture DM yield response to effluent application.

Our results combined with another similar study (Saggar *et al.* 2005; Luo *et al.* 2008d) suggest that application of farm-dairy effluent during dry summer and autumn seasons can reduce N<sub>2</sub>O emissions. Our study also shows that delaying effluent application after grazing events could further reduce N<sub>2</sub>O emission

by reducing the levels of surplus excretal mineral N and carbon N inputs.

## CONCLUSIONS

Nitrous oxide emission from grazed dairy pasture was enhanced following application of FDE. Emission factor for the two irrigation events ranged from 2 to 4.9%. Higher N<sub>2</sub>O emission was measured when FDE was applied immediately after a grazing event. The excretal deposition from grazing animals adds high amount of substrate in soil for N<sub>2</sub>O to be produced by the micro-organisms. Application of effluent immediately after grazing event further creates conducive conditions for denitrification and also might cause priming effect in soil. Delaying effluent-irrigation after a grazing event could reduce emissions by reducing levels of surplus mineral-N.

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