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NITROUS OXIDE EMISSIONS DURING FORAGE BRASSICA CROPPING AND GRAZING

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Abstract

The objective of this study was to conduct field measurements of changes in nitrous oxide (N_2O) emissions through various stages during the establishment and utilisation of a forage rape (Brassica *napus* subspecies *biennis*) crop on land that had been in permanent pasture. This work was carried out on a free-draining volcanic soil at the site of the former Ruakura Number 1 Dairy Research Farm, Hamilton.

N_2O emissions during the establishment, growth and management of the forage rape crop, followed by re-establishment of permanent pasture by direct-drilling, were evaluated and compared with that from established permanent pasture. Treatments on the rape and pasture plots were nitrogen (N) fertiliser application (0 versus 80 kg N ha^{-1}) and management (grazing versus cutting). N_2O emissions were measured using a closed chamber technique.

Production of a forage rape crop resulted in higher N_2O emissions compared with leaving the area in pasture. The total N_2O emission from the forage rape, including fertiliser and grazing, was 5.59 kg N_2O-N ha^{-1} over the 10 month measurement period. This compares with 0.64 kg N_2O-N ha^{-1} from the adjacent fertilised and grazed permanent pasture over the same period.

Application of urea-N at 80 kg N ha^{-1} on the forage rape crop significantly ($P<0.05$) increased the N_2O emissions from 0.45 kg N_2O-N ha^{-1} to 1.45 kg N_2O-N ha^{-1}. Application of urea-N on the permanent pasture increased the N_2O emissions from 0.14 kg N_2O-N ha^{-1} to 0.21 kg N_2O-N ha^{-1}, but this increase was not statistically significant ($P>0.05$).

Grazing of the forage rape or the permanent pasture significantly ($P<0.05$) increased total N_2O emissions, compared with those from the ungrazed forage rape or pasture controls. The largest contribution to N_2O emissions from the forage rape crop system (approximately 75% of total) was from the 6 weeks following the grazing of the forage rape.

Introduction

In New Zealand, agriculture is predominantly based on grazing systems using permanent pastures. Pastoral production systems can benefit from the incorporation of forage crops to mitigate feed shortages at key times of year. Forage brassicas (*Brassica* spp.) are widely used for grazing during winter due to their fast growth rates, high dry matter yield and high nutritional value (Belesky et al., 2007) compared to perennial grass pastures. Additionally, there are differences in plant composition and nutrient concentrations of brassicas that could affect animal productivity and environmental impacts. Forage brassicas have more non-structural carbohydrates and less neutral detergent fibre than perennial ryegrass (*Lolium perenne* L.) (Sun et al., 2012). The higher readily fermentable carbohydrate content of brassicas compared to ryegrass has the potential to improve the efficiency of nitrogen (N) utilisation in the rumen and consequently reduce N losses (Pacheco and Waghorn, 2008). However, planting and growth of brassicas may affect nitrous oxide (N_2O) emissions, as the amount of N_2O emitted is affected by many soil factors e.g. mineral N content, soil aeration, soil water and availability of degradable organic material (Choudhary et al., 2002). These factors are all affected by soil cultivation for planting brassicas. Greater N_2O fluxes have been measured from cultivated soil compared to permanent pasture (Choudhary et al., 2002). However, it has also been suggested that cultivation increases aeration, thereby potentially reducing soil N_2O fluxes (Choudhary et al., 2001). There has been little research which has examined N_2O emissions as affected by the cultivation of permanent pasture for growing of brassica crops. The objective of this research was to determine N_2O emissions through various stages during the establishment, N fertilisation and utilisation of a forage rape (Brassica *napus* subspecies *biennis*) crop and compare it with that from permanent pasture.

Materials and Methods

Site Description and Preparation

The trial was located at the site of the former Ruakura Number 1 Dairy farm, near Hamilton, on a free-draining volcanic soil (Horotiu silt loam). The site was formerly used for grazing dairy cows, but more recently it had been used for grazing young dairy replacement stock. It contained permanent pasture, which consisted predominately of perennial ryegrass and white clover (*Trifolium repens* L.).

The trial area was fenced to exclude cattle grazing in November 2013. On 19 December 2013, lime (2 T ha^{-1}) was applied to the site. Through the spring and summer the area was mown regularly. Plot areas for pasture and for the crop were identified and pegged out on 24 January 2014. The adjacent pasture area was designated as a control. On 3 February 2014 the areas designated for sowing the forage rape crop were sprayed with a combination of Roundup herbicide (4 L ha^{-1}) and Pulse Penetrant (0.8 L ha^{-1}) to kill pasture plants. This spraying was repeated four weeks later to remove weed regrowth and seedlings. On 10 March 2014, basal fertiliser containing phosphorus (P), potassium (K) and sulphur (S) were applied to the entire trial area.

The forage rape area was cultivated on 12 March to a depth of between 150 and 200 mm (rototill, grub, rototill). Crop sowing took place on 13 March (light hand raking, hand sowing of seed and light rolling with quad bike tyres). Because of very dry conditions the trial area was irrigated with 10 mm per day on 10 and 11 March 2014 (before cultivation) and 5 mm after sowing on 13 March 2014. Both the forage rape area and the pasture area were irrigated with the same amounts of water.

Field Trial Layout

The study was split into 2 periods, where period 1 covered the forage rape establishment and growth period and period 2 covered the subsequent grazing and new pasture establishment period. This was to ensure that, although the effect of the fertiliser applied at the start of the trial was no longer present, the grazing activity was randomly assigned across the trial areas.

Forage rape establishment - Period 1

A randomised block design was used with 2 treatments forage rape or permanent pasture, replicated 6 times (Table 1). Each individual pasture plot measured 2.0 m × 2.0 m, and each forage rape plot measured 3.0 m x 3.0 m. The chambers for gas sampling were located near the centre of each plot with the remainder of the plot area allocated to sampling for analysis of forage yield, soil mineral N and soil moisture levels.

Table 1: Details of treatments applied to the pasture and forage rape areas. N fertiliser was applied as urea.

Forage rape establishment and growth period – Period 1

	Cultivation and rape sowing	Urea (kg N ha^{-1})	
	13 Mar 2014	13 Mar 2014	23 Apr 2014
Permanent pasture	no	0	0
Permanent pasture +N	no	40	40
Forage rape	yes	0	0
Forage rape +N	yes	40	40

Grazing of forage rape crop and new pasture establishment period – Period 2

	Grazing	New pasture establishment
	1 Jul 2014	9 Sep 2014
Permanent pasture	no	no
Permanent pasture	yes	no
Forage rape to new pasture	no	yes
Forage rape to new pasture	yes	yes

Grazing, new pasture establishment and growth period - Period 2

The plots were reassigned new treatments (Table 1) and a randomised block design was again used with 2 treatments for either permanent pasture or forage rape area, replicated 6 times. Grazing took place for 24 hours on both the permanent pasture (116 cows ha^{-1}equivalent) and the forage rape plots (144 cows ha^{-1}equivalent) on 1 July 2014. Control plots, without grazing, for both the permanent pasture and the forage rape areas were also included and the herbage was cut and removed from these plots manually. New pasture (ryegrass and white clover) was established by direct drilling seeds on all forage rape plots on 9 September 2014. No N fertiliser was applied during Period 2.

Gas, soil and forage sampling and analysis

Nitrous oxide emissions were measured on the permanent pasture and on the forage rape area during the forage rape establishment and growth period and then on the permanent pasture and on the newly established pasture in the area where the forage rape had previous grown. The measurements were first made on one occasion on 10 March 2014 (3 days before the permanent pasture soil was cultivated for planting forage rape), then on 27 occasions for Period 1 over the 100 day forage rape growing period and on 23 occasions for Period 2 after the forage rape crop was grazed and the new pasture established. Measurements were conducted more frequently immediately after cultivation, urea fertiliser application and grazing.

A static soil chamber technique was used to measure N_2O emissions using a methodology based on previous studies on N_2O emissions (Luo et al., 2015). Briefly, stainless steel chamber bases were inserted 100 mm into the soil. On each sampling day, between 11a.m. and 1p.m, insulated aluminium chamber tops were fitted to the bases and gas samples were collected at 0, 30 and 60 minutes. The samples were analysed for N_2O concentration using a gas chromatograph fitted with an electron capture detector. The hourly emissions were integrated over time, for each chamber, to estimate the total emission over the measurement period. From these results, N_2O emission rates and emission factors (% of applied fertiliser-N lost as N_2O, EF_1) were calculated.

Soil samples were taken at every gas sampling event. The sampling depth was 75 mm in the permanent pasture plots and 150 mm for the forage rape due to the greater root depth. Soil moisture was determined on each occasion and soil ammonium-N (NH_4^+-N) and nitrate-N (NO_3^--N) were determined on each alternate occasion (2M KCl extraction followed by analysis using a Skalar SAN^{++} segmented flow analyser).

Climate parameters

Rainfall was measured at the Ruakura meteorological station, which is within 1 km of the trial site. Soil temperature, at 5 cm depth, was measured on site using a hand probe during each N_2O sampling occasion.

Statistical analysis

Analysis of variance (ANOVA) for total N_2O emissions and N_2O emission factors was carried out using the statistical software package GenStat (13th edition) (Payne et al., 2010). The integrated emissions of N_2O per chamber were log-transformed before the ANOVA analysis. Standard error of the mean was calculated for N_2O flux, water filled pore space (WFPS) and soil mineral N (NH_4^+-N and NO_3^--N) at each sampling date.

Results and discussion

Climatic conditions

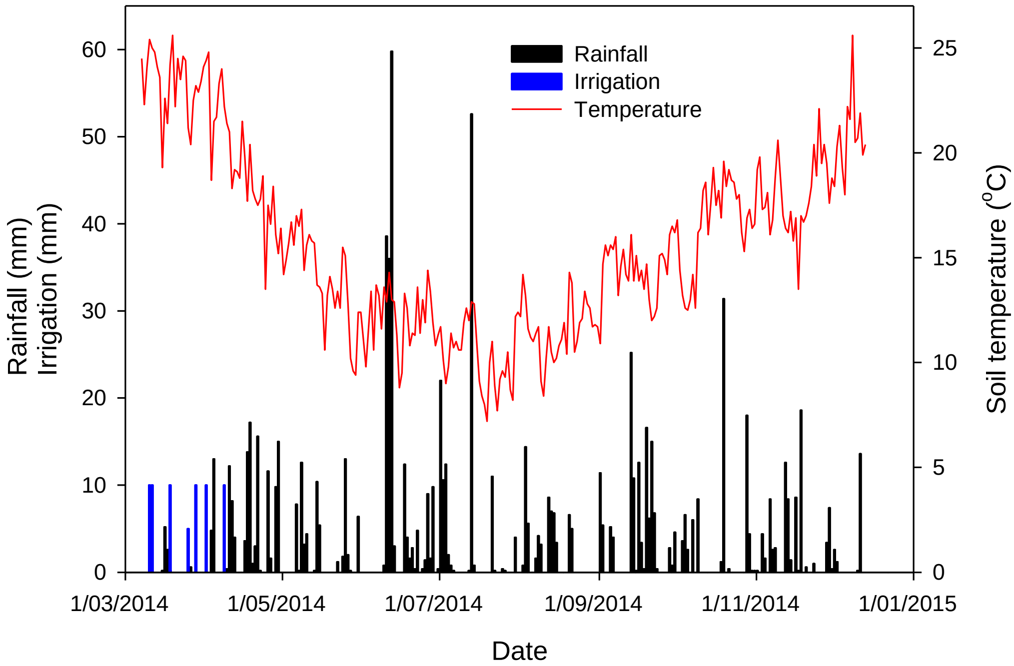

Figure 1: Daily rainfall and soil temperature (at 12 noon) for the trial period. Soil temperature (5 cm depth) was measured on site and rainfall was measured at the Ruakura meteorological station.

Peak soil temperature (5 cm depth) was about 26°C, which occurred in March and again in December 2014, while the minimum soil temperature was about 7°C in early August 2014 (Figure 1). These were within the normal temperature range of the trial site. At the beginning of the trial period, very little precipitation fell from March to mid April 2014, with only two rainfall events during this period. This meant that treatments were applied when the soil was relatively dry. Hence, irrigation was applied several times during this dry period to ensure establishment of the forage rape crop (Figure 1).

Nitrous oxide fluxes during the forage rape establishment and growth period – Period 1
Cultivation and seeding on 13 March 2014 for forage rape establishment sharply increased soil N_2O fluxes to 0.299 mg N m^{-2} hr^{-1} in the absence of N fertiliser (Figure 2). The N_2O fluxes then sharply decreased to levels similar to those of the permanent pasture plots within a month. During this month, most of the N_2O fluxes from the forage rape plots were higher ($P<0.05$) than those from the pasture plots.

The addition of fertiliser N as urea on 13 March further increased the maximum N_2O flux to 0.333 from 0.299 mg N m^{-2} hr^{-1} in the forage rape plots (Figure 2). The increased fluxes lasted for about 2-3 weeks. The application of urea also enhanced the N_2O fluxes from pasture. However, application of urea on 23 April 2014 did not lead to an immediate increase in N_2O fluxes from either the forage rape or the pasture plots. Nitrous oxide fluxes from the forage rape plots receiving urea increased after the middle of May 2014 and were higher ($P<0.05$) than the fluxes from the forage rape plots where urea was not applied.

Soil NH_4^+-N and NO_3^--N levels increased after initial soil cultivation and urea application in both the permanent pasture and the forage rape plots (Figure 2). Cultivation alone also had a significant ($P<0.05$) effect on soil NO_3^--N levels (as evident from the nil-N-fertilised crop treatment), probably due to enhanced mineralisation and nitrification activity as a result of soil aeration. A second application of urea in late April also increased soil NH_4^+-N and NO_3^--N levels. Changes in soil NH_4^+-N and NO_3^--N levels affected the initial N_2O fluxes; however, low soil moisture at that time could have limited the duration of this effect.

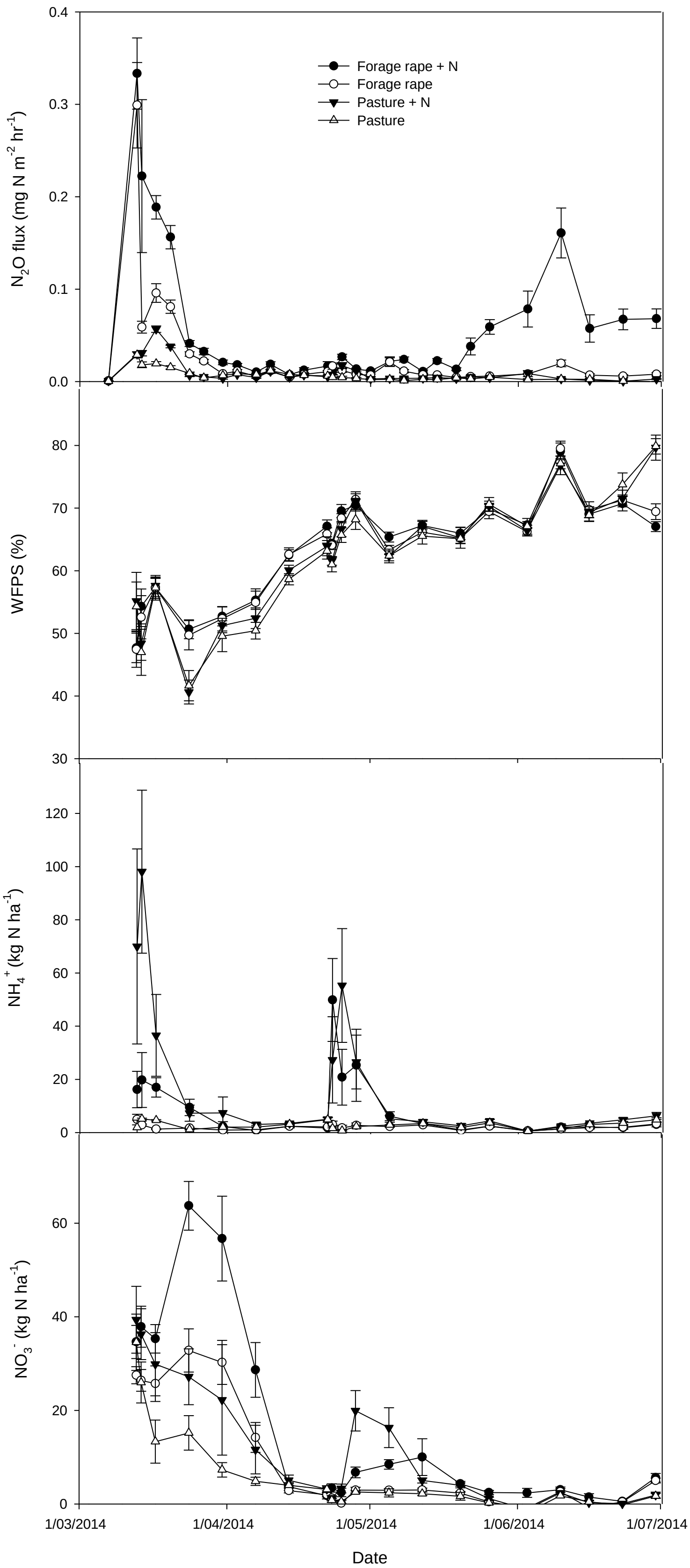

Figure 2: Nitrous oxide flux, soil WFPS, NH_4^+-N and NO_3^--N levels in forage rape and pasture plots during the period between cultivation/crop-establishment and prior to grazing (Period 1).

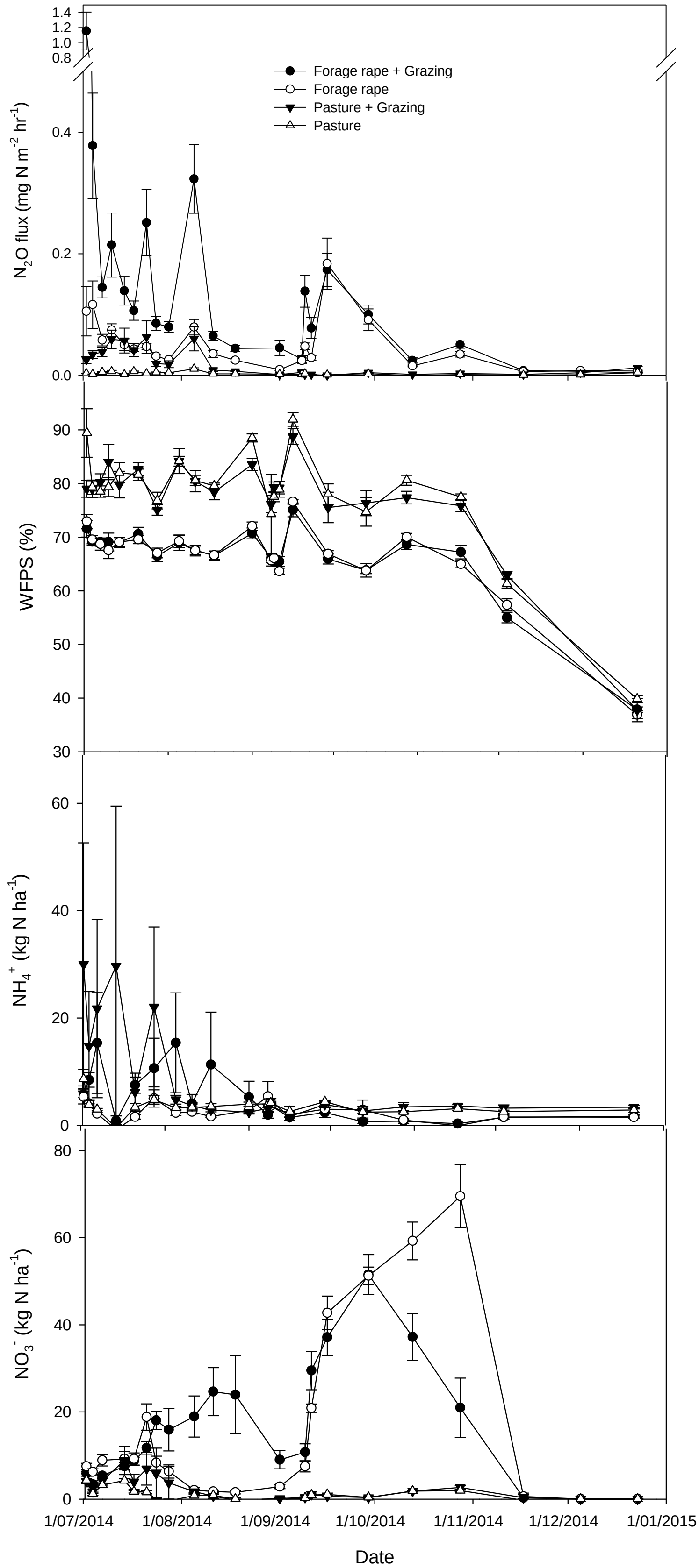

Figure 3: Nitrous oxide flux, soil WFPS, NH_4^+-N and NO_3^--N levels in forage rape and pasture plots during the period after grazing and new pasture establishment (Period 2).

Nitrous oxide fluxes after grazing and during the new pasture establishment and growth period – Period 2

Nitrous oxide fluxes increased immediately after grazing of forage rape on 1 July 2014, with a maximum flux of 1.15 mg N_2O-N m^{-2} hr^{-1} (Figure 3). For about six weeks, N_2O fluxes from the grazed forage rape plots were significantly ($P<0.05$) higher than those from the ungrazed forage rape plots. This initial increase was probably due to pugging of the wet soil, which was observed after the intensive grazing. At the beginning of September 2014 soil NO_3^--N levels increased, which resulted in a second peak of N_2O flux (Figure 3). This second peak of N_2O flux also corresponded with increased soil moisture. Seed drilling for establishing pasture may also have contributed to the increase in N_2O flux. After mid-November 2014 the N_2O fluxes from the grazed and ungrazed forage rape plots were not significantly different ($P>0.05$). This coincided with decreased WFPS and low levels of soil NH_4^+-N and NO_3^--N levels.

Grazing of pasture also increased N_2O fluxes, but the maximum flux only reached 0.063 mg N_2O-N m^{-2} hr^{-1}, which was much lower than the maximum flux from the grazed forage (Figure 3). The N_2O fluxes from the grazed permanent pasture plots were significantly ($P<0.05$) higher than those from the ungrazed plots for about two weeks in early-July. As with the forage rape plots, the increase in the N_2O fluxes corresponded with soil pugging; however, this effect was not as great as in the forage rape plots (Figure 3). The WFPS was lower for the cropped soil throughout, indicating that this was not the only factor affecting N_2O fluxes, although WFPS levels of all treatments were high (>70%) for all plots through to the end of October. When WFPS is over 70%, moisture is not considered to be a limiting factor for emissions (Luo et al., 2008b).

Total nitrous oxide emissions during the forage rape establishment and growth period – Period 1

Integration of the measured N_2O fluxes resulted in total N_2O emissions of 0.45 kg N_2O-N ha^{-1} over the forage rape establishment and growth period (Table 2). When urea (a total of 80 kg N ha^{-1}) was applied to the forage rape, the total emission was significantly ($P<0.05$) increased to 1.45 kg N_2O-N ha^{-1} over the same period. This resulted in an N_2O emission factor (EF_1) value of 1.28% for urea. The EF_1 value found during the forage rape growth period in this study is higher than the default IPCC guideline value of 1% for N_2O emissions from applied N fertiliser (de Klein et al., 2006).

The average total N_2O emission from the permanent pasture over the same period was 0.14 kg N_2O-N ha^{-1}, much lower than that from the forage rape (Table 2). Application of urea (a total of 80 kg N ha^{-1}) to pasture increased the total emission to 0.21 kg N_2O-N ha^{-1}, but the increase was not statistically significant ($P>0.05$). The N_2O emission factor (EF_1) value was 0.09% for urea, lower than the default IPCC guideline value of 1% for N_2O emissions from applied fertiliser (de Klein et al., 2006).

Table 2: Total N_2O emissions and estimated emission factors for urea.

Forage rape establishment and growth period – Period 1

	N_2O emissions (kg N ha^{-1})	EF (%)
Permanent pasture (no cultivation, no N fertiliser)	0.14	
Permanent pasture (no cultivation, +N fertiliser)	0.21	0.09
Forage rape (cultivation, no N fertiliser)	0.45	
Forage rape (cultivation, +N fertiliser)	1.45	1.28
LSR (P<0.05)	*1.25*	

Grazing and new pasture establishment period – Period 2

	N_2O emissions (kg N ha^{-1})
Permanent pasture (no grazing)	0.11
Permanent pasture (grazing)	0.43
Forage rape (no grazing, new pasture establishment)	1.44
Forage rape (grazing, new pasture establishment)	4.14
LSR (P<0.05)	*1.65*

Total emissions from standard practice (combination of Period 1 and 2)

	N_2O emissions (kg N ha^{-1})
Permanent pasture (N fertiliser + grazing)	0.64
Forage rape (cultivation, N fertiliser + grazing + new pasture establishment)	5.59
LSR (P<0.05)	*1.44*

Total nitrous oxide emissions after grazing and during the new pasture establishment and growth period – Period 2

Grazing of the forage rape significantly (P<0.05) increased total N_2O emissions, compared with those from the plots where forage rape was cut and removed (Table 2). The total emissions, over the ~6 month measurement period after grazing, from the ungrazed and grazed forage rape plots were 1.44 and 4.14 kg N_2O-N ha^{-1}, respectively.

Grazing of the permanent pasture also significantly (P<0.05) increased total N_2O emissions, compared with those from the ungrazed pasture plots (Table 2). The total emissions, over the ~6 month period, from ungrazed pasture and grazed pasture were 0.11 and 0.43 kg N_2O-N ha^{-1}, respectively; lower than those from the forage rape plots.

Combined Period 1 and 2 total nitrous oxide emissions

The total N_2O emission from the forage rape, which was cultivated and fertilised using standard farm practices, including the establishment of new pasture after grazing, was 5.59 kg N_2O-N ha^{-1} over the 10 month measurement period (Table 2). This compares with 0.64 kg N_2O-N ha^{-1} from the adjacent fertilised and grazed permanent pasture over the same period. The largest contribution to the difference in the amounts of N_2O produced was from the 6 weeks following the grazing of the forage rape.

Conclusions and Implications

Total N_2O emissions over the forage rape growth period were 0.45 kg N_2O-N ha^{-1}. This increased to 1.45 kg N_2O-N ha^{-1} when urea was applied at the rate of 80 kg N ha^{-1}. This led to a N_2O emission factor (EF_1) value for fertiliser urea of 1.28%. Total N_2O emission from the permanent pasture over the same period was lower, with a value of 0.14 kg N_2O-N ha^{-1}. Application of urea to the permanent pasture at the rate of 80 kg N ha^{-1} increased the total emission to 0.21 kg N_2O-N ha^{-1}, resulting in the EF_1 value for the applied fertiliser urea of 0.09%.

The total emissions from ungrazed forage rape, grazed forage rape, ungrazed pasture and grazed pasture over the ~6 month period after grazing were 1.44, 4.14, 0.11 and 0.43 kg N_2O-N ha^{-1}, respectively. The total N_2O emissions from the forage rape, which was cultivated and fertilised using standard practice, including the establishment of new pasture after grazing, were 5.59 kg N_2O-N ha^{-1} over the 10 month measurement period. This compares with 0.64 kg N_2O-N ha^{-1} from the adjacent fertilised and grazed permanent pasture over the same period. These results show that the use of a forage brassica crop can result in a large increase in total N_2O emissions from soil. Previous research has shown that a forage brassica crop can result in reduced enteric methane emissions (Sun et al., 2012) and a lower amount of N excreted with a reduced urine EF (Luo et al., 2015) compared to that for a ryegrass/clover pasture. Thus, a full farm system analysis of all components of GHG emissions is required in order to determine the total effects from the integration of a forage brassica crop into a pastoral farming system.

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