SHORT COMMUNICATION

Greenhouse gas emissions from pig slurry applied to forage legumes on a loamy sand soil in south central Manitoba

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Received 1 December 2013, accepted 11 February 2014. Published on the web 5 May 2014.

Gao, X., Tenuta, M., Buckley, K. E., Zvomuya, F. and Ominski, K. 2014. **Greenhouse gas emissions from pig slurry applied to forage legumes on a loamy sand soil in south central Manitoba**. Can. J. Soil Sci. **94**: 149–155. Information regarding the greenhouse gas (GHG) emissions resulting from the application of pig slurry to forage in western Canada is limited. This study examined the effects of addition of pig slurry and soil water content with landscape position on nitrous oxide (N_2O) and methane (CH_4) emissions from forage legumes [sainfoin (*Onobrychis viciifolia*) and alfalfa (*Medicago sativa*)] on a sandy loam soil in Brandon, Manitoba, over two growing seasons. Pig slurry was surface applied with a rolling aerator-type tine at a rate of 35 000 L ha^{-1} and 38 000 L ha^{-1}, providing 62–15–50 and 205–45–86, actual N–P–K kg ha^{-1}, in 2006 and 2007, respectively. Emissions were measured on and between surface bands of the slurry applied to soil. Soil concentrations of NH_4^+-N and NO_3^--N, moisture, and temperature were also monitored. In both years, slurry application increased growing season cumulative N_2O emissions. Net increase in cumulative N_2O-N emissions with slurry treatment ranged from 0.04 to 0.05% of total N ha^{-1} applied in 2006 but from 0.7 to 0.9% in 2007. The coherence of rapidly increasing N_2O emissions following slurry application with decreasing soil NH_4^+ and increasing NO_3^- concentration, in combination with the fact that emissions continued even when soil NH_4^+ concentrations were undetectable, suggest nitrification and denitrification were sources of N_2O. Emissions of CH_4 were generally slightly negative and unaffected by addition of slurry. Higher soil water content at lower landscape position did not affect emissions of CH_4 but did increase those of N_2O in 2007. The current study was conducted at one field location. Examination of slurry additions to additional sites is required for reliable estimation of N_2O emissions from slurry applied to perennial legume forages in prairie Canada.

Key words: Forage legume, pig slurry, methane, nitrous oxide, soil moisture

Gao, X., Tenuta, M., Buckley, K. E., Zvomuya, F. et Ominski, K. 2014. **Émissions de gaz à effet de serre attribuables à l'application de purin de porc à un sable loameux du centre-sud du Manitoba employé pour la culture des légumineuses fourragères**. Can. J. Soil Sci. **94**: 149–155. On ne possède que des informations restreintes sur les dégagements de gaz à effet de serre (GES) résultant de l'application de purin de porc aux cultures fourragères dans l'Ouest canadien. Cette étude précise les conséquences de l'addition de purin de porc et de la teneur en eau du sol sur l'emplacement des émissions d'oxyde nitreux (N_2O) et de méthane (CH_4) venant de légumineuses fourragères [sainfoin (*Onobrychis viciifolia*) et luzerne (*Medicago sativa*)] cultivées sur un loam sableux à Brandon, au Manitoba, pendant deux périodes végétatives. Le purin a été appliqué en surface avec un rouleau aérateur à dents à raison de 35 000 L et de 38 000 L par hectare pour correspondre à un amendement réel de 62-15-50 et de 205-45-86 kg de N-P-K par hectare en 2006 et 2007, respectivement. Les dégagements ont été mesurés sur les bandes de sol qui avaient été bonifiées et entre celles-ci. Les auteurs ont aussi relevé la concentration de N-NH_4^+ et de N-NO_3^- dans le sol, la teneur en eau et la température. Les deux années, l'application de purin a accru les émissions cumulatives de N_2O durant la saison de croissance. La hausse nette des émissions de N-N_2O attribuable à l'amendement varie de 0,04–0,05 % du N total appliqué par hectare en 2006 à 0,7–0,9 % en 2007. Le fait que les émissions de N_2O augmentent rapidement après l'application du purin et que la teneur en NH_4^+ diminue dans le sol alors que celle de NO_3^- augmente, ajouté à celui que les émissions se poursuivent même quand il devient impossible de détecter le NH_4^+ dans le sol, laisse croire que la nitrification et la dénitrification sont à l'origine du N_2O. En général, les émissions de CH_4 étaient légèrement négatives et ne sont pas affectées par l'addition du purin. La teneur en eau plus élevée du sol aux endroits les plus bas du relief ne modifie pas les émissions de CH_4, mais a augmenté celles de N_2O en 2007.

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Abbreviations: **DOY**, day of the year; **GHG**, greenhouse gas; **GMC**, gravimetric moisture content

Cette étude a été réalisée sur un seul terrain. Il faudrait examiner l'application de purin à d'autres endroits pour estimer de façon fiable les dégagements de N_2O attribuables à cette forme d'amendement sur les cultures de légumineuses vivaces fourragères dans les Prairies canadiennes.

Mots clés: Légumineuses fourragères, purin de porc, méthane, oxyde nitreux, teneur en eau du sol

In Canada, the agricultural sector contributes approximately 10% of the total national anthropogenic greenhouse gas (GHG) emissions, with nitrous oxide (N_2O) and methane (CH_4) contributing 72 and 24%, respectively (Environment Canada 2012). Both gases can be emitted from soils receiving manure. In general, manure application increases N_2O emissions through enhanced denitrification and nitrification, and has the potential to stimule CH_4 production due to the addition of labile carbon in the slurry (United States Environmental Protection Agency 2011).

In Manitoba, Canada, it is a common practice to apply pig manure in the form of slurry to perennial forages. Generally, manure slurries emit more N_2O and CH_4 compared with solid manures because of higher levels of water content, labile carbon and ammonium (Gregorich et al. 2005). On tame grassland, where the water table seasonally reaches near to the soil surface, in southeastern Manitoba, Tenuta et al. (2010) reported pig slurry application increased both N_2O and CH_4 emissions relative to the no-pig-slurry control, with a split application resulting in lower emissions compared with a single high application rate in spring. Furthermore, emissions of N_2O occurred in relatively drier and CH_4 in wetter locations within the study site. There is a lack of information for N_2O emissions in response to manure application to forage legumes.

Soil water content, which is often related to topography, is one of the most important regulators governing the production and consumption of GHG in soils. Pennock et al. (2010) studied the effect of slope positions on N_2O emissions in the pothole region of the Black Soil Zone near Saskatoon and found higher N_2O emissions on lower slope positions. At a research site in a prairie pothole region in Manitoba, we also found the moist depressions emitted more N_2O than the higher and drier locations and, further, increased soil moisture led to anaerobic conditions conducive to methanogenesis and CH_4 production (Dunmola et al. 2010). Therefore, knowledge of the impact of landscape position on GHG emissions is necessary to provide reliable estimates of the contribution of western Canadian agricultural soils to emissions.

The objectives of this study were, therefore, to determine N_2O and CH_4 emissions from pig slurry applied to forage legumes in western Manitoba and characterize the effect of soil water content, as influenced by landscape position, on N_2O and CH_4 emission variability within forage lands receiving pig slurry.

MATERIALS AND METHODS

The experiment was conducted during the growing seasons of 2006 and 2007 at the Agriculture and Agri-Food Canada Research Centre in Brandon, Manitoba (lat. 49°88′N, long. 100°0′W). The experimental site is mapped as Orthic Black Chernozem with loamy sand texture (Fitzmaurice et al. 1999). The soil (0–30 cm) was characterized as follows: pH (1:2 soil:water) 7.8, electrical conductivity 0.48 dS m^{-1}, organic matter 26 g kg^{-1}, particle size distribution of 780 g sand kg^{-1}, 140 g silt kg^{-1} and 80 g clay kg^{-1}, $CaCl_2$-extractable NO_3^--N 6 mg kg^{-1}, and $NaHCO_3$-extractable P (Olsen) 18 mg kg^{-1}.

The field was divided into a northern and southern block: the north block was planted to alfalfa (*Medicago sativa*) and the south block was planted to sainfoin (*Onobrychis viciifolia*). Treatment levels [with manure (Slurry) and no manure (Control)] were randomly assigned to each block, giving a total of four plots. Each plot was 350 m long by 4.6 m wide and decreased in elevation from 406.25 m at the west end to 404.65 m at the east end of the plot. Five locations, referred to as A to E, were selected along the west–east toposequence of each plot for measurement of gas emissions and soil conditions. The locations were 70 m apart and had elevations of 406.22 (A), 406.23 (B), 405.71 (C), 405.04 (D) and 404.72 m (E). The elevations were determined from a digital elevation model created from light detection and ranging (Lidar) flight data of the Research Centre by Altus Geomatics (Brandon, MB). At each position, N_2O and CH_4 emissions and soil conditions were monitored between May 23 and Sep. 20 in 2006 and between May 08 and Aug. 22 in 2007.

In May 2005, alfalfa 'AmeriStand 401Z' was seeded at 13.4 kg ha^{-1} to the northern half of the field and sainfoin 'Nova' was seeded at 64.8 kg ha^{-1} on the southern half of the field. The pig slurry was obtained from a feeder/finisher barn at Brandon Research Centre in 2006 and a farrow-to-finish barn in 2007. In 2006, the manure was composed of 987 g H_2O kg^{-1} as is weight with a total N, P, K content of 1.5, 0.4, 1.2 g L^{-1}, respectively. In 2007, the manure contained a greater content of nutrients, and was composed of 969 g H_2O kg^{-1} as-is weight with a total N, P, K of 4.5, 1.0, 1.9 g L^{-1}, respectively. Ammonium concentration of the slurry was 1.4 and 3.5 g N L^{-1} in 2006 and 2007, respectively. The slurry application volume was kept relatively constant between years, at 41 000 L ha^{-1} and 45 000 L ha^{-1}, providing 62–15–50 and 205–45–86, total N, P and K kg ha^{-1}, in 2006 and 2007, respectively. On 2006 May 17 [DOY 137 (day of year)] and 2007 May 07

(DOY 127), slurry applications were performed with a rolling aerator-type tine applicator using a 4.6 m AerWay® SSD (Holland Equipment Ltd., Norwich, ON) mounted with a chopper-distributor, which delivered manure slurry to equal length hoses with attached emitters positioned 2 cm above the soil surface. The tines penetrated approximately 16 cm into soil fracturing it horizontally. The emitters were positioned directly behind three gangs of aeration units. Each of the 24 aeration units was made up of four 20-cm tapered tines mounted at 90° angles from one another. The slurry dropped into slots created by four tines resulting in slurry bands spaced about 19 cm apart.

Mechanical harvest removal was not performed in 2005, which was the forage establishment year. A mechanical harvest removal for hay was done with two cuts on Jun. 15 and Jul. 22 in 2006, and Jun. 18 and Aug. 02 in 2007, respectively. In 2006, dry matter yields were 3.7, 4.5, 4.0, and 5.6 Mg ha^{-1} for sainfoin–Control, sainfoin–Slurry, alfalfa–Control, and alfalfa–Slurry, respectively. In 2007, dry matter yields were 6.4, 7.4, 5.5, and 5.4 Mg ha^{-1} for sainfoin–Control, sainfoin–Slurry, alfalfa–Control, and alfalfa–Slurry, respectively.

Emissions of N_2O and CH_4, as well as soil respiration (CO_2) from on-band and between-band positions were measured using the vented, two-piece (collar and lid), static cylindrical chambers (Tenuta et al. 2010). The collars measured 20.3 cm internal diameter by 10 cm height. The collars were centered on either on-band or between-band rows, inserted 5 cm into the soil, and left open throughout the experimental periods, except during gas collection periods. Plants were clipped to 5 cm height inside collars.

Emissions were monitored every 1–3 d for the first 3–4 wk following slurry application, and every 5–15 d later in the growing season. On each sampling date, headspace gas was collected from chambers at intervals of 0, 15, 30, and 45 min from placement of the lid. All gas flux measurements were initiated between 0900 and 1200. Gas emission rate was estimated from the rate of increase in gas concentration in chamber headspace, amount of gas in headspace using the Ideal Gas Law (PV = nRT), molecular mass of N or C in N_2O or CH_4, chamber area and headspace volume, air temperature and atmospheric pressure at sampling. The increasing rate of gas concentration with deployment time was estimated by linear regression because non-linear patterns were not evident from inspection of time by concentration plots. As a result, emissions for a chamber were estimated by fitting a linear regression model, using the program Microsoft Excel, through at least three of the four sample times, removing occasional outliers to achieve a minimum model R^2 of 0.85 and $P < 0.001$ (Petersen et al. 2006).

At each sampling date, soil temperature was measured at a 5-cm depth beside each chamber using a Traceable Longstem Thermometer (Fisher Scientific Canada, Nepean, ON). Soil samples were collected on the same day just after gas sampling. In each plot, 10 soil cores (5 cm internal diameter by 5 cm height) were randomly collected and composited to make one sample. Samples were then analyzed for gravimetric moisture content (GMC) and concentrations of NH_4^+ and NO_3^-. Details on analysis are available in Tenuta et al. (2010).

Growing season cumulative N_2O (ΣN_2O) and CH_4 (ΣCH_4) emissions for each position were averaged from on-band and between-band locations, by the summation of daily estimates of N_2O and CH_4 emissions obtained by linear interpolation between sampling dates over a 120-d (2006) and 106-d (2007) period. Analysis of variance was performed on data from each year using the mixed procedure for repeated measures in SAS 9.3 (SAS Institute, Inc. 2011) to determine the main and interaction effects of slurry treatment and position elevation on ΣN_2O and ΣCH_4 emissions. In the model, slurry treatment was a fixed effect and elevation was the repeated measurement. The spatial power [SP (POW)] covariance structure (Littell et al. 2006) was implemented in the model to account for spatial correlation among measurements taken at different elevations. Although the two blocks were cropped to different forage legumes, block was considered a random effect in the mixed model, since the primary objective was to assess the effect of manure application regardless of crop species, thus allowing for generalization of conclusions across forage species. In any case, there was no effect of forage species on ΣN_2O and ΣCH_4 emissions measured in the study. For example in 2007, in which N_2O emissions were greater than 2006, ΣN_2O with Slurry treatment was 1.71 ± 0.30 (1 standard error) and 2.05 ± 0.38 kg N ha^{-1} for sainfoin and alfalfa, respectively.

The relationships between the soil parameters (temperature, moisture, and soil NO_3^- and NH_4^+ concentrations) and N_2O and CH_4 emissions were evaluated by Pearson's correlation analysis using SAS 9.3. Treatment differences were considered significant if $P < 0.05$ using the Tukey–Kramer method.

RESULTS AND DISCUSSION

Weather Conditions

Average air temperature May through October in both 2006 and 2007 was 14°C, being similar to the long-term normal. Total precipitation May through October was 296 mm in 2006 and 317 mm in 2007, compared with 350 mm to the long-term normal. In 2006, precipitation was greatest in June and heavy rainfall events (> 30 mm) had occurred on Jun. 30 (DOY 181), Aug. 24 (DOY 236) and Sep. 17 (DOY 260). In contrast, precipitation May through October in 2007 was more evenly distributed (Fig. 1).

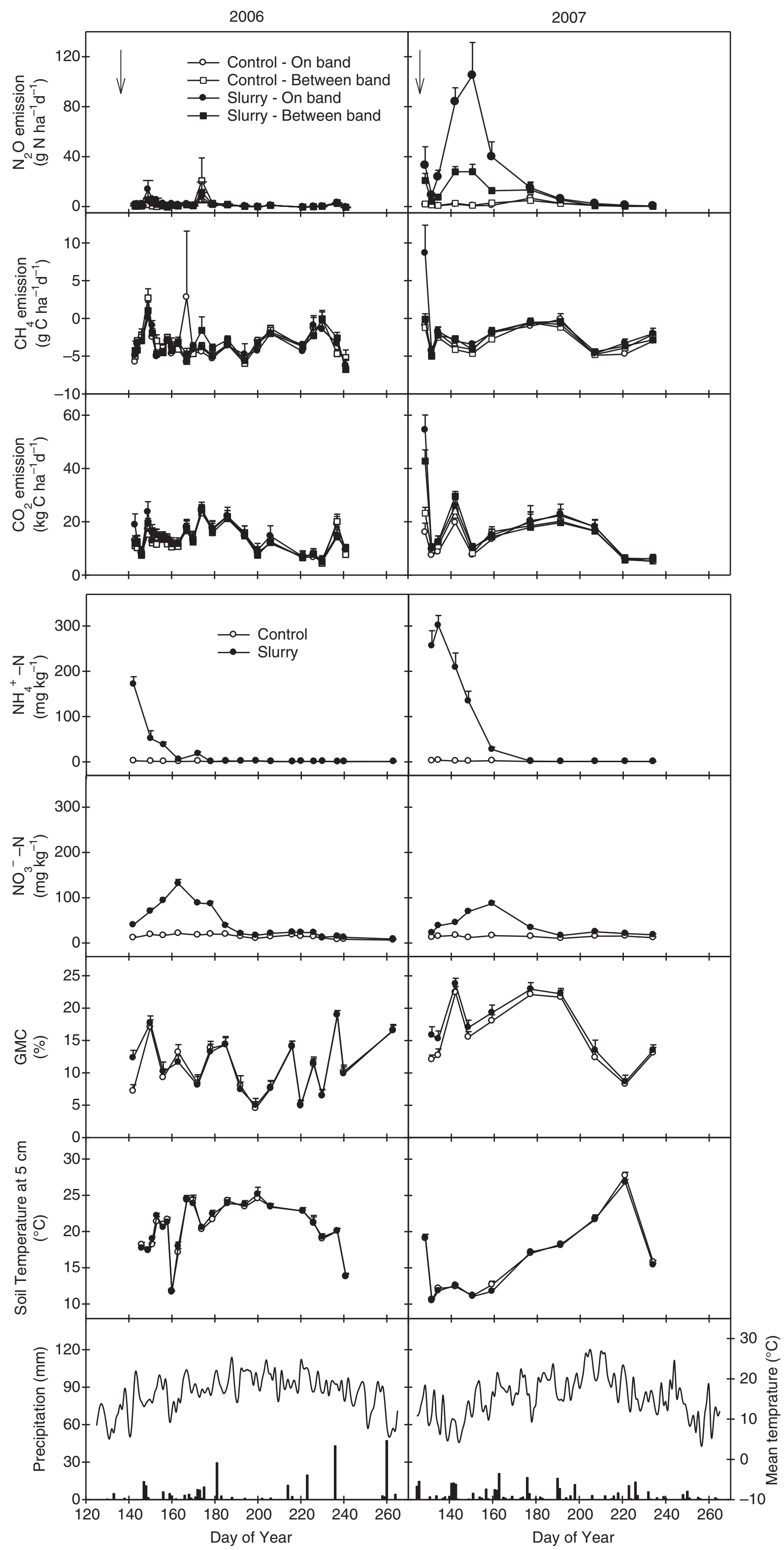

Fig. 1. Mean daily greenhouse gases (N_2O, CH_4, CO_2) emissions from the on-band (Slurry) and between-band positions, soil concentrations of NH_4^+ and NO_3^-, soil gravimetric moisture content (GMC), and soil temperature at 5 cm for pig slurry treatments (Control and Slurry). Also shown are the average daily air temperature and daily precipitation during the growing season. Positive 1 standard error of the mean of landscape positions are shown ($n = 5$). Arrows indicate date of pig slurry application.

Emissions of N_2O

In 2007, application of manure resulted in an immediate increase in N_2O emissions from on-band but not between-band positions (Fig. 1). The greater emission from on-band position is likely associated with high levels of moisture and NH_4^+ concentration. Growing season ΣN_2O was increased by slurry application in both years with values being 11.2 times greater in 2007 (1.88 ± 0.24 kg N ha^{-1}) than 2006 (0.15 ± 0.07 kg N ha^{-1}). Further, net increase of N_2O emissions by slurry treatment was only 0.04–0.05% of total slurry N applied in 2006 compared with 0.7–0.9% in 2007. The difference between years may be attributed to difference in NH_4^+ and total N concentration in the manure. Jarecki et al. (2009) and Rochette et al. (2000) reported that a larger fraction of N was lost as N_2O as rate of N application of pig slurry increased. Other researchers have reported comparable cumulative emissions. Tenuta et al. (2010) reported cumulative N_2O emissions ranging from 0.29 to 0.51% of total surface-applied pig slurry N applied to a coarse-textured grassland soil over a measurement period comparable to the current study. Smith et al. (2008) reported N_2O emissions ranging from 0.0008 to 0.23% of total surface-applied pig slurry N over a 20-d measurement period.

In both study years, slurry application resulted in rapid nitrification, as indicated by a decline in soil NH_4^+ with concurrent increase of NO_3^- concentration. Soil GMC was greater in 2007 than 2006, resulting in favorable conditions for nitrifier-denitrification and denitrification in the former. Indeed, N_2O emission rates were greatest soon after the slurry application in 2007, when NH_4^+ was decreasing, but still occurred to a lesser extent when nitrification ended, as indicated by undetectable soil NH_4^+ concentrations and decreasing NO_3^- concentration. There was a weak but positive relationship between soil moisture and daily N_2O emission rate ($r = 0.35$, $P < 0.001$). In the current study, increasing soil GMC up to 25% (soil water-filled pore space of approximately 50%) could enhance both nitrification and denitrification (Granli and Bockman 1994). Similarly, Rochette et al. (2000) proposed that a portion of the N_2O emissions observed after slurry applications to soil were due to an increase in denitrification stimulated by the addition of available carbon in the slurry. Thus, both nitrification and denitrification should have been responsible for N_2O emissions following slurry application in the current study.

Emissions of CH_4

Emissions of CH_4 were generally negative in all treatments except for the first sampling occasion in 2007, when CH_4 emissions occurred at a rate of 8–12 g C ha^{-1} d^{-1} at on-band positions immediately following slurry application (Fig. 1). Such short-duration CH_4 emissions following slurry application to soil have been reported in other studies (Dittert et al. 2005; Fangueiro et al. 2012) and were attributed to the release of CH_4 already present in slurry and formed during storage, rather than the newly produced CH_4 by methanogenesis after application to soils.

The generally negative CH_4 emissions clearly showed that soil was a sink for CH_4. With the exception of the first sampling date in 2007 (when CH_4 emissions may have been driven by degassing from applied slurry), ΣCH_4 emissions for the first 3 wk following slurry treatment were -0.06 ± 0.01 kg C ha^{-1}, which was not significantly different from the control treatment (-0.07 ± 0.01 kg C ha^{-1}). The absence of a positive effect from the slurry treatment, although it increased soil NH_4^+ concentrations up to 130 mg N kg^{-1}, was unexpected because others have reported that elevated soil NH_4^+ following fertilizer and manure application could suppress CH_4 consumption (Lessard et al. 1997).

Respiration

Emissions of CO_2 were generally not affected by slurry treatments except for the previously noted increase on the first sampling date in 2007 (Fig. 1). Over the 2-yr experimental period, daily emission rates of CO_2 correlated positively with soil moisture ($r = 0.59$, $P < 0.001$). A similar correlation of CO_2 emission with soil moisture has been previously reported in another study of the impact of liquid manure on soil GHG emissions (Sistani et al. 2010), highlighting the importance of soil water content in affecting soil respiration.

Effect of Landscape Position and Soil Moisture on N_2O and CH_4 Emissions

For control and slurry treatments in 2006, and the control treatment in 2007, the greatest N_2O emission rates were observed at position E, which also had the most soil moisture (Fig. 2). Positions C and E had greater growing season ΣN_2O than position A in 2007 (Table 1). Wetter soil in the lower position elevations may have stimulated nitrification and/or denitrification (Granli and Bockman 1994). This assertion is supported by the correlation analysis, which showed that N_2O emission rate was positively correlated to soil moisture ($r = 0.35$, $P < 0.001$). It is interesting to note that in 2007, N_2O emission rates for the slurry treatment were highest at positions of relatively intermediate soil water content rather than those with the greatest soil water content (Fig. 2). It is likely that the high availability of labile carbon from slurry, soil NO_3^- concentrations and soil water content in the lowest position could have reduced N_2O to N_2 during denitrification (Sylvia et al. 1998). Accordingly, though no labile carbon was added, Dunmola et al. (2010) found that N_2O emissions following application of inorganic N fertilizers were higher at lower slope positions compared with upper slope positions due to higher soil moisture and C availability. These results confirm the importance of considering landscape position in estimating field N_2O emissions in prairie Canada (Rochette et al. 2008).

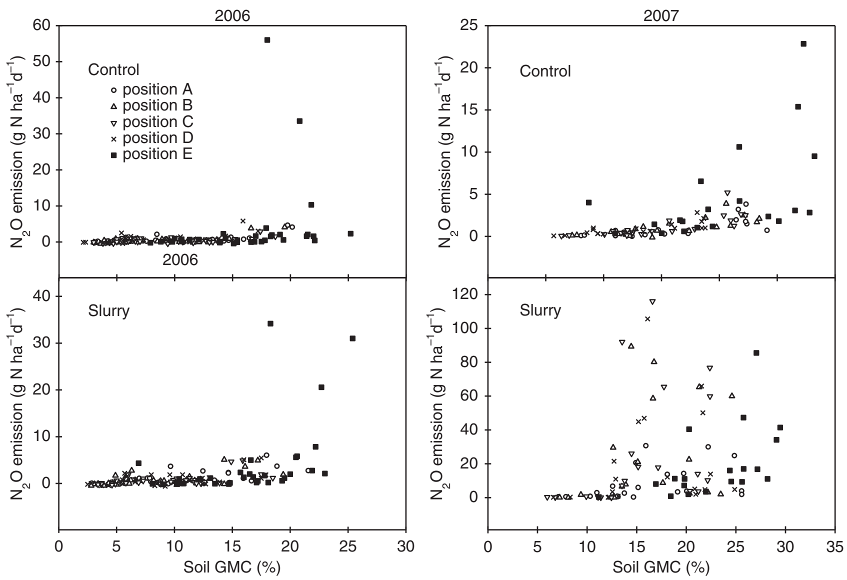

Fig. 2. Relationships between soil gravimetric moisture content (GMC) and N_2O emissions of five field elevation positions (A to E), as affected by pig slurry applications in 2006 and 2007.

It is important to note that the current study was conducted at one field location. Further examination of slurry addition to other perennial forage legume sites is required for reliable estimation of N_2O emissions from slurry on this forage type in prairie Canada. In summary, greater slurry application of N resulted in increased N_2O emissions in 2007 than in 2006. The absence of an N_2O emission episode soon after slurry application in 2006 was likely due to low soil moisture and low available-N concentration in the manure. Net increase in cumulative N_2O emissions with slurry treatment ranged from 0.04 to 0.05% of total N applied in 2006 but from 0.7 to 0.9% in 2007. Emissions of CH_4 were generally slightly negative and unaffected by slurry treatment, except being higher on the first sampling following additions. Lower landscape positions with greater soil moisture tended to have more N_2O emissions, reaffirming the importance of considering the impact of landscape position on estimating soil N_2O emissions in the Canadian prairies.

Table 1. Growing season cumulative N_2O emissions (ΣN_2O) by position elevation (A to E) for the 2 study years without (Control) and with pig slurry (Slurry) addition

	ΣN_2O (kg N_2O-N ha^{-1})		
	2006	2007	Average
Manure treatment			
Control	$0.124 \pm 0.071b$	$0.217 \pm 0.067b$	$0.170 \pm 0.049b$
Slurry	$0.154 \pm 0.068a$	$1.881 \pm 0.236a$	$1.017 \pm 0.231a$
Position elevation (m)			
A (406.22)	0.074 ± 0.012	$0.440 \pm 0.193b$	0.257 ± 0.101
B (406.23)	0.063 ± 0.012	$1.163 \pm 0.614ab$	0.613 ± 0.315
C (405.71)	0.055 ± 0.009	$1.342 \pm 0.728a$	0.698 ± 0.372
D (405.04)	0.081 ± 0.009	$0.991 \pm 0.558ab$	0.536 ± 0.277
E (404.72)	0.423 ± 0.196	$1.309 \pm 0.411a$	0.866 ± 0.241
Repeated measurement analysis		$P \geq F$	
Manure	<0.001	<0.001	<0.001
Position	NS	0.04	NS
Manure × Position	NS	NS	NS

a, b Means ± standard errors within a column followed by the same letter are not significantly different (Tukey-Kramer) at $P < 0.05$, manure treatment $n = 10$, position elevation $n = 20$.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the financial support of the Government of Canada programs for Environmental Technology Assessment for Agriculture, the Agricultural Greenhouse Gas Program, the Information Gaps in Water Quality and Nutrients Program of Agriculture and Agri-Food Canada, the Canada Research Chair Program in Applied Soil Ecology, and the Natural Sciences and Engineering Council of Canada Discovery Grants. Field and laboratory technical assistance from Mervin Bilous, Glen Lelyk, Brad Sparling, Clayton Robins, Rhonda Thiessen, and Randy Westwood is greatly appreciated. We also thank Dr. Alan Moulin for helpful suggestions for improvement of statistical analysis.

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