SHORT COMMUNICATION

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

Xiaopeng Gao1,2, Mario Tenuta1,5, Katherine E. Buckley3, Francis Zvomuya1, and Kim Ominski4

1Department of Soil Science, University of Manitoba, Winnipeg, Manitoba, Canada R3T 2N2; 2State Key Laboratory of Desert and Oasis Ecology, Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi 830011, China; 3Agriculture and Agri-Food Canada, Brandon Research Centre, Brandon, Manitoba, Canada R7A 5Y3; and 4Department of Animal Science, University of Manitoba, Winnipeg, Manitoba, Canada R3T 2N2.

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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 (N2O) and methane (CH4) 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 NH4+–N and NO3–N, moisture, and temperature were also monitored. In both years, slurry application increased growing season cumulative N2O emissions. Net increase in cumulative N2O–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 N2O emissions following slurry application with decreasing soil NH4+ concentration and increasing NO3– concentrations, in combination with the fact that emissions continued even when soil NH4+ concentrations were undetectable, suggest nitrification and denitrification were sources of N2O. Emissions of CH4 were generally slightly negative and unaffected by addition of slurry. Higher soil water content at lower landscape position did not affect emissions of CH4 but did increase those of N2O in 2007. The current study was conducted at one field location. Examination of slurry additions to additional sites is required for reliable estimation of N2O 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. and 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 nitureux (N2O) et de méthane (CH4) 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-NH4 et de N-NO3 dans le sol, la teneur en eau et la température. Les deux années, l’application de purin a accru les émissions cumulatives de N2O durant la saison de croissance. La hausse nette des émissions de N-N2O 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 N2O augmentent rapidement après l’application du purin et que la teneur en NH4 diminue dans le sol alors que celle de NO3 augmente, ajouté à celui que les émissions se poursuivent même quand il devient impossible de détecter le NH4 dans le sol, laisse croire que la nitrification et la dénitrification sont à l’origine du N2O. En général, les émissions de CH4 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 CH4, mais a augmenté celles de N2O en 2007.

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

Corresponding author (e-mail: mario.tenuta@umanitoba.ca).
In Canada, the agricultural sector contributes approximately 10% of the total national anthropogenic greenhouse gas (GHG) emissions, with nitrous oxide (N₂O) and methane (CH₄) contributing 72 and 24%, respectively (Environment Canada 2012). Both gases can be emitted from soils receiving manure. In general, manure application increases N₂O emissions through enhanced denitrification and nitrification, and has the potential to stimulate CH₄ 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 N₂O and CH₄ 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 N₂O and CH₄ 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 N₂O occurred in relatively drier and CH₄ in wetter locations within the study site. There is a lack of information for N₂O 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 N₂O emissions in the pothole region of the Black Soil Zone near Saskatoon and found higher N₂O emissions on lower slope positions. At a research site in a prairie pothole region in Manitoba, we also found the moist depressions emitted more N₂O than the higher and drier locations and, further, increased soil moisture led to anaerobic conditions conducive to methanogenesis and CH₄ 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 N₂O and CH₄ 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 N₂O and CH₄ emission variability within forage lands receiving pig slurry.
(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 in 2007, respectively. In 2006, dry matter yields were 3.7, 4.5, 4.0, and 5.6 Mg ha⁻¹ in 2007, respectively. In 2006, dry matter yields were 6.4, 7.4, 5.5, and 5.4 Mg ha⁻¹ in 2007, respectively.

Emissions of N₂O and CH₄, as well as soil respiration (CO₂) 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 N₂O or CH₄, 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 R² 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 NH₄⁺ and NO₃⁻. Details on analysis are available in Tenuta et al. (2010).

Growing season cumulative N₂O (ΣN₂O) and CH₄ (ΣCH₄) emissions for each position were averaged from on-band and between-band locations, by the summation of daily estimates of N₂O and CH₄ 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 ΣN₂O and ΣCH₄ 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 ΣN₂O and ΣCH₄ emissions measured in the study. For example in 2007, in which N₂O emissions were greater than 2006, ΣN₂O 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 NO₃⁻ and NH₄⁺ concentrations) and N₂O and CH₄ 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 (N₂O, CH₄, CO₂) emissions from the on-band (Slurry) and between-band positions, soil concentrations of NH₄⁺ and NO₃⁻, 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 higher levels of moisture and $NH_4^+$ concentration. Growing season $Sigma N_2O$ was increased by slurry application in both years with values being 11.2 times greater in 2007 ($1.88 \pm 0.24$ kg N ha$^{-1}$) than 2006 ($0.15 \pm 0.07$ 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 application 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 $CH_4$ 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), $Sigma CH_4$ emissions for the first 3 wk following slurry treatment were $-0.06 \pm 0.01$ kg C ha$^{-1}$, which was not significantly different from the control treatment ($-0.07 \pm 0.01$ 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 $Sigma N_2O$ 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, Dummla 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).
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$_2$O emissions from slurry on this forage type in prairie Canada. In summary, greater slurry application of N resulted in increased N$_2$O emissions in 2007 than in 2006. The absence of an N$_2$O 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$_2$O 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$_2$O emissions, reaffirming the importance of considering the impact of landscape position on estimating soil N$_2$O emissions in the Canadian prairies.

### Table 1. Growing season cumulative N$_2$O emissions (ΣN$_2$O) by position elevation (A to E) for the 2 study years without (Control) and with pig slurry (Slurry) addition

<table>
<thead>
<tr>
<th>Position elevation (m)</th>
<th>ΣN$_2$O (kg N$_2$O-N ha$^{-1}$)</th>
<th>Control</th>
<th>Slurry</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manure treatment</td>
<td>2006</td>
<td>0.124 ± 0.071</td>
<td>0.154 ± 0.068</td>
<td>0.149 ± 0.076</td>
</tr>
<tr>
<td></td>
<td>2007</td>
<td>0.217 ± 0.067</td>
<td>1.881 ± 0.236</td>
<td>1.017 ± 0.231</td>
</tr>
<tr>
<td>A (406.22)</td>
<td>0.074 ± 0.012</td>
<td>0.440 ± 0.193</td>
<td>0.257 ± 0.101</td>
<td></td>
</tr>
<tr>
<td>B (406.23)</td>
<td>0.063 ± 0.012</td>
<td>1.163 ± 0.614</td>
<td>0.613 ± 0.315</td>
<td></td>
</tr>
<tr>
<td>C (405.71)</td>
<td>0.055 ± 0.009</td>
<td>1.342 ± 0.728</td>
<td>0.698 ± 0.372</td>
<td></td>
</tr>
<tr>
<td>D (405.04)</td>
<td>0.081 ± 0.009</td>
<td>0.991 ± 0.558</td>
<td>0.536 ± 0.277</td>
<td></td>
</tr>
<tr>
<td>E (404.72)</td>
<td>0.423 ± 0.196</td>
<td>1.309 ± 0.411</td>
<td>0.866 ± 0.241</td>
<td></td>
</tr>
<tr>
<td>Repeated measurement analysis</td>
<td>$P \geq F$</td>
<td>$&lt;0.001$</td>
<td>$&lt;0.001$</td>
<td>$&lt;0.001$</td>
</tr>
<tr>
<td>Manure</td>
<td>Position</td>
<td>NS</td>
<td>0.04</td>
<td>NS</td>
</tr>
<tr>
<td>Position</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td></td>
</tr>
</tbody>
</table>

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 $n = 20$.

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