Temporal and spatial patterns of N_2O and CH_4 emissions on an agricultural field containing ephemeral wetlands

Sheng Li[A,B], Tom Goddard[C], Anthony Brierley[D], Len Kryzanowski[C] and Kerrianne Koehler-Munro[C]

[A]Soil Science Department, University of Manitoba, MB, Canada.
[B]Semiarid Prairie Agricultural Research Centre, Agriculture and Agri-Food Canada, Swift Current, SK, Canada.
[C]Alberta Agriculture and Food, Edmonton, AB, Canada.
[D]Land Resource Unit, Agriculture and Agri-Food Canada, Edmonton, AB, Canada.

Abstract
It has been recognized that both N_2O and CH_4 emissions vary with land use and slope positions. In various parts of the world, wetlands are imbedded in the agricultural landscapes. However, to date, no study has been carried out to examine the N_2O and CH_4 emissions from agricultural fields containing ephemeral wetlands. In this study, gas samples were collected for four consecutive years (2003 to 2006) from different slope positions along three transects from a No-Till cropped upslope through the riparian area to the wetland. Additionally, gas samples were taken from three adjacent cropped depressions for a two-year period. Although the daily fluxes of N_2O and CH_4 emissions were highly variable, there were distinctive temporal and spatial patterns. These patterns reflect the effects of the hydrological regime and land management practice which are related to the land use and slope positions. Overall, on an annual basis, the total non-CO_2 GHG emission rates from the wetland basin were much greater than those from the cropped area. The riparian zone served as a transition zone with the highest variability of N_2O and CH_4 emissions. These findings suggest that the N_2O and CH_4 emissions from ephemeral wetlands imbedded in the agricultural landscapes must be taken into account.

Key Words
Green house gas, N_2O, CH_4, agricultural field, ephemeral wetlands.

Introduction

In an agricultural field, both N_2O and CH_4 emissions are highly variable, temporally and spatially. The distributions of N_2O and CH_4 emissions are often skewed with so-called spatial "hot spots" and also temporal "hot periods" (Yates *et al.* 2006, Dalal *et al.* 2008). Field studies of N_2O and CH_4 emissions have focused on the cropland. In the Prairie Pothole Region (PPR), wetlands are imbedded in the agricultural landscapes. The area is extensively farmed with more than half of the wetlands drained or altered for agriculture. Some big or deep wetlands are remained uncultivated but the upland areas around these wetlands are cropped. To date, no study has been conducted to examine both N_2O and CH_4 emissions from complex landscapes containing both wetlands and cropland. Due to the lack of studies, in regional or national GHG inventories report, the N_2O and CH_4 emissions from the cropped depressions usually were not distinguished from other cropped areas and those from the in-field wetlands have been ignored, not being accounted for in either the inventory of the wetland or that of the cropland (e.g., Gregorich *et al.* 2005). The objectives of this study were to examine the temporal and spatial patterns of the N_2O and CH_4 emissions from agricultual fields containing ephemeral wetlands.

Methods

Study site and sample collection

The field site of this study is the 260 ha Parkland Agriculture Research Initiative demonstration farm located near the town of Mundare in central Alberta near the northern extent of the Prairie Pothole Region (Fig. 1). The farm has been farmed for about 100 years and contains cropped uplands and depressions and some uncultivated in-field wetlands. The in-field wetlands were all ephemeral wetlands ─ inundated after spring snowmelt but water receded in the summer. A stratified transect method was used in this study for the sample collection. Three adjacent in-field wetlands ─ referred to as East (E), Central (C) and West (W) wetland, respectively ─ were selected (Fig. 1). Each transect was stratified into different slope positions, each with a sampling point (Fig. 1c showing the central transect as an example). After the first year, three cropped depressions (CD) were also selected in the upland areas adjacent to the wetlands and a sample point was established in the middle of each depression. Locations of all sampling points were determined using a DGPS unit. Gas samples were collected using the chamber method at each sampling point in each year from before spring snowmelt near the end of March to after freeze up at the end of November. The sampling

interval varied but averaged about one sample per week. The gas samples were taken using a 20 ml syringe from the chambers 30 minutes after the chamber installation. At least three ambient samples were taken at the time of gas sampling in the proximity of the chamber top to serve as a time-zero sample. All gas samples were taken between 10:00 and 14:00 at the sampling dates. The gas samples were analyzed for CH_4 and N_2O simultaneously using a Varian 3600 gas chromatograph (GC) with manual injection and Varian Star Workstation version 5.3 software. Sample chamber gas flux was calculated from the measured concentrations using the ambient air concentration next to the chamber as the value at time-zero.

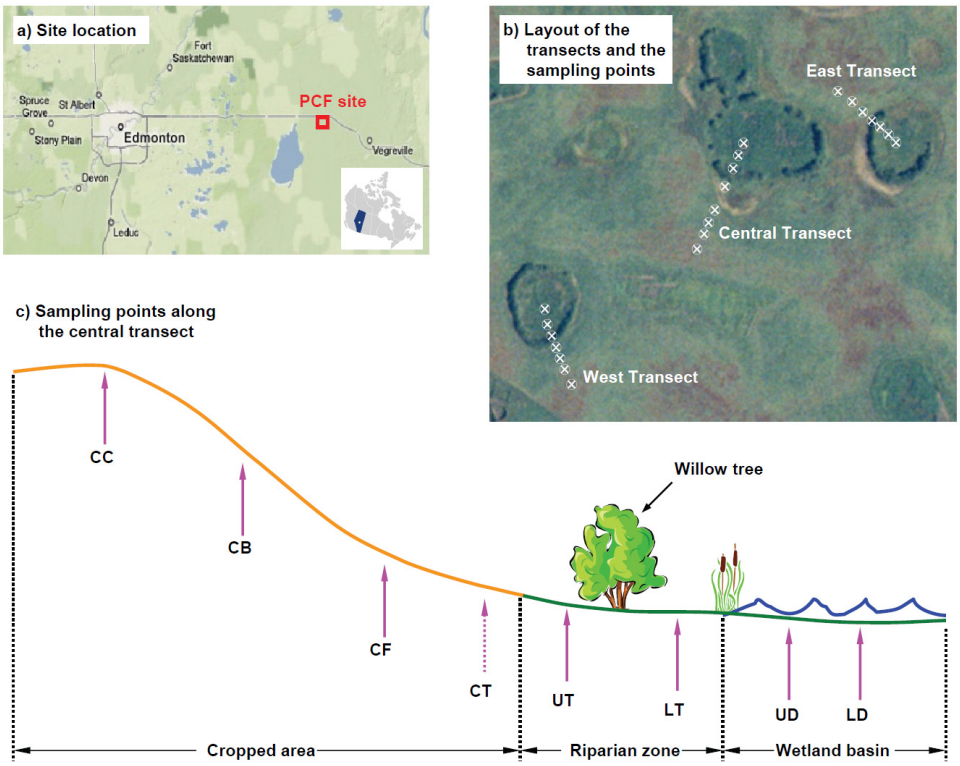

Figure 1. The location of the field site and the layout of the sampling points.

Data processing and statistical analyses

Daily N_2O and CH_4 fluxes between March 1st and December 1st in each year were calculated using a linear interpolation of the flux data measured at the sampling dates. Each year was divided into six periods based on the seeding date. The 35-day period before the seeding date was defined as the late-spring period (LSP) and the period from March 1st to the beginning of the LSP was defined as the early-spring period (ESP). The 35-day period immediately after the seeding date was defined as the early-summer period (ESM) and the two consecutive 35-day periods were defined as the mid-summer period (MSM) and late-summer period (LSM), respectively. The period after the LSM until December 1st was defined as the fall period (FAL). Cumulative N_2O and CH_4 emissions within these periods (referred to as period cumulative data, herein) were calculated as the sums of the daily N_2O and CH_4 fluxes in each period in each year, respectively. Annual cumulative N_2O and CH_4 emissions were calculated as the sums of the daily N_2O and CH_4 fluxes in each year (assuming no emissions between Dec 1st and March 1st), respectively. The annual cumulative data for these two gases were converted to the CO_2-equvalent (CO_2-eq) values using the global warming potential factors over a 100-yr cycle (25 and 298 for N_2O and CH_4, respectively) proposed by the IPCC (2006). The converted values of the two gases were added up and used as the annual cumulative total non-CO_2 GHG emission.

The period cumulative data were divided into sub-datasets based on the land use. The group means of the N_2O and CH_4 emissions (data log-transformed) for each slope position and each period in each land use were calculated. The differences between the group means of the slope position (GM_s) and the period (GM_p) were tested using the Duncan's Multiple Range Test (DMRT, $P = 0.05$). Similar approach was taken for the analyses of the annual cumulative data except that one major factor was changed from the period to the year (GM_y). The group means were then back transformed to their original units.

Results

Within-year variations of the N_2O and CH_4 emissions

The daily N_2O and CH_4 emissions were highly variable with time and across the landscape. However, the

grouped means of the period cumulative data for each sampling point showed the distinctive within-year temporal patterns for different land uses on different slope positions (Table 1). In cropped area, the N_2O was mainly produced in the early-spring and early-summer, associated with the snowmelt and the seeding and fertilizing events. The CH_4 emission was low and was not greatly affected by these two events. Overall, there was a low level of CH_4 consumption in the cropped area, especially after the mid-summer. In the wetland basins, the N_2O was mainly produced after mid-summer and CH_4 was produced year round but the hottest periods were the late-spring to the mid-summer. In the riparian zones, there were large differences between the two slope positions, indicating the high variability of N_2O and CH_4 emissions in these areas, probably due to the fact that the riparian zones are the transition zone from the cropped area to the wetland basin.

Table 1. Group means of the period cumulative N_2O and CH_4 emissions.

			Cropped area							Riparian zone				Wetland basin			
			CC	CB	CF	CT	CD	GM_p	N_p	UT	LT	GM_p	N_p	UT	LT	GM_p	N_p
	Days	n	3	3	3	1	3			3	3			3	3		
N_2O emission (N_2O-N, g ha^{-1} period^{-1})																	
ESP	52	4	196	220	340	593	694	**292 a**	**43**	89	-1	**37 a**	**24**	20	17	**19 b**	**24**
LSP	35	4	33	38	67	87	383	**62 c**	**43**	44	-1	**19 a**	**24**	8	-2	**3 b**	**24**
ESM	35	4	229	254	182	453	605	**272 a**	**46**	58	11	**32 a**	**24**	33	55	**43 ab**	**24**
MSM	35	4	169	92	95	204	191	**131 b**	**46**	49	29	**39 a**	**24**	106	172	**137 a**	**24**
LSM	35	4	10	1	17	21	20	**12 d**	**46**	1	5	**3 ab**	**24**	28	106	**62 ab**	**24**
FAL	60	3	14	26	21	11	23	**20 d**	**33**	-6	-19	**-13 b**	**18**	140	125	**133 a**	**18**
GM_s			**92**	**87**	**100**	**167**	**212**			**37**	**4**			**46**	**66**		
			B	**B**	**B**	**A**	**A**			**A**	**B**			**A**	**A**		
CH_4 emission (CH_4-C, g ha^{-1} period^{-1})																	
ESP	52	4	-43	-8	-41	232	291	**14 ab**	**43**	121	394	**253 b**	**24**	534	273	**400 c**	**24**
LSP	35	4	7	-33	20	-19	520	**29 a**	**43**	525	4017	**1898 a**	**24**	10286	8600	**9412 ab**	**24**
ESM	35	4	28	-24	59	-43	-49	**6 ab**	**46**	115	4617	**1741 a**	**24**	13362	28504	**19647 a**	**24**
MSM	35	4	-107	-193	-28	-57	-26	**-95 c**	**46**	-64	2052	**801 ab**	**24**	5219	10716	**7581 b**	**24**
LSM	35	4	-168	-113	-119	-57	-88	**-121 c**	**46**	-185	294	**41 b**	**24**	523	1242	**860 c**	**24**
FAL	60	3	-125	-91	-129	176	56	**-75 bc**	**33**	-107	410	**136 b**	**18**	1208	948	**1075 c**	**18**
GM_s			**-67**	**-77**	**-37**	**29**	**52**			**62**	**1651**			**3639**	**4928**		
			BC	**C**	**ABC**	**AB**	**A**			**B**	**A**			**A**	**A**		
N_s			**69**	**69**	**69**	**23**	**27**			**69**	**69**			**69**	**69**		

Table 2. Group means of the annual cumulative N2O and CH4 emissions.

	Cropped area					Riparian zone		Wetland basin			
	CC	CB	CF	CT	CD	UT	LT	UD	LD	GM_y	N_y
n	3	3	3	1	3	3	3	3	3		
N_2O emission (CO_2-eq, kg ha^{-1} yr^{-1})											
2003	83	74	113	392	—	88	78	94	61	**91 b**	**22**
2004	428	422	384	329	—	53	-9	159	170	**166 ab**	**22**
2005	457	374	412	892	854	274	-6	223	693	**318 a**	**25**
2006	721	609	710	2049	1380	94	-20	479	484	**374 a**	**25**
GM_s	**347**	**308**	**346**	**708**	**1088**	**110**	**1**	**206**	**263**		
	ABC	**ABC**	**ABC**	**AB**	**A**	**C**	**D**	**BC**	**BC**		
CH_4 emission (CO_2-eq, kg ha^{-1} yr^{-1})											
2003	-5	10	23	39	—	20	72	1139	2741	**136 a**	**22**
2004	-35	-30	0	21	—	-12	333	1330	1668	**98 a**	**22**
2005	-11	-27	-33	-14	18	-3	633	5328	5066	**150 a**	**25**
2006	-9	-15	-11	-7	30	33	621	2162	1786	**137 a**	**25**
GM_s	**-17**	**-18**	**-9**	**7**	**24**	**7**	**338**	**2053**	**2541**		
	C	**C**	**C**	**C**	**C**	**C**	**B**	**A**	**A**		
Total non-CO_2 GHG emission (CO_2-eq, kg ha^{-1} yr^{-1})											
2003	86	85	138	431	—	122	152	1234	2870	**288 b**	**22**
2004	401	395	384	350	—	25	480	1517	1939	**467 ab**	**22**
2005	454	341	379	878	868	321	692	5811	6256	**919 a**	**25**
2006	714	593	700	2042	1407	145	566	2996	2766	**910 a**	**25**
GM_s	**342**	**301**	**353**	**733**	**1107**	**125**	**420**	**2401**	**3137**		
	BCD	**CD**	**BCD**	**BC**	**AB**	**D**	**BCD**	**A**	**A**		
N_s	**12**	**12**	**12**	**4**	**6**	**12**	**12**	**12**	**12**		

Cross-year variations of the N_2O and CH_4 emissions

There are cross-year variations of N_2O and CH_4 emissions (Table 2), which could be explained by the different climate conditions and managements (e.g., crop type and fertilizer application) among the experimental years. Among different slope positions, the annual cumulative N_2O emission rates from the wetland basin were lower than but at a comparable level as those from the cropped area (Table 2). The annual cumulative CH_4 emission rates from the wetland basin were orders of magnitude greater than those from the cropped area. Consequently, the total non-CO_2 GHG emission rates from the wetland basin were much greater than those from the cropped area. The riparian area served as a transition zone and the N_2O and CH_4 emissions from the riparian area appeared to have the highest variability. The overall annual total non-CO_2 GHG emissions from the riparian area may be much lower than but could also be higher than those of the cropped area. Within the cropped area, significant differences in N_2O and CH_4 emissions were also found on different slope positions, with the lower slope positions being the "hot spot" for both N_2O and CH_4 emissions. These observed temporal and spatial patterns can largely be explained by the different hydrological regimes and in-field soil and nutrient transportations. which are determined by the land use and the slope position in the field scale.

Implications

The high variability of N_2O and CH_4 emissions observed in this study imply that in an agricultural landscape containing wetlands, large errors may exist when the average emission rates measured on random selected points (or plot data) at random dates are used for the upscaling of GHG emissions. Due to the skewness of the emission rates, the field inventory may be overestimated when the "hot spots" (e.g., the cropped depression or wetland basin points) or "hot periods" (e.g., snow-melt period) are included or may be underestimated when they are excluded. This also requires that the sampling design must take the temporal and spatial variation into account. More accurate results can be obtained by using a landscape stratification procedure (e.g., Pennock *et al.* 2005; Izaurralde *et al.* 2004) and through multi-year or long term monitoring.

Conclusion

The N_2O and CH_4 emissions vary across the landscape and with time. However, there were distinctive temporal and spatial patterns for given periods, land uses and slope positions. Our findings suggest that it is necessary to take into account the temporal and spatial variability of the N_2O and CH_4 emissions in the upscaling procedure, sampling design and the development of GHG mitigation strategies.

References

Dalal RC, Allen DE, Livesley SJ, Richards G (2008) Magnitude and biophysical regulators of methane emission and consumption in the Australian agricultural, forest, and submerged landscapes: a review. *Plant Soil* **309**, 43-76.

IPCC 2006 (2006) IPCC Guidelines for National Greenhouse Gas Inventories. In 'The National Greenhouse Gas Inventories Programme'. (Eds HS Eggleston, L Buendia, K Miwa, T Ngara, K Tanabe). (Published: IGES, Japan).

Izaurralde RC, Lemke RL, Goddard TW, McConkey B, Zhang Z (2004) Nitrous oxide emissions from agricultural toposequences in Alberta and Saskatchewan. *Soil Sci. Soc. Am. J.* **68**, 1285-1294.

Gregorich EG, Rochette P, VandenBygaart AJ, Angers DA (2005) Greenhouse gas contributions of agricultural soils and potential mitigation practices in Eastern Canada. *Soil Tillage Res.* **83**, 53-72.

Yates TT, Si BC, Farrell RE, Pennock DJ (2006) Probability distribution and spatial dependence of nitrous oxide emission: temporal change in hummocky terrain. *Soil Sci. Soc. Am. J.* **70**, 753-762.

Pennock DJ, Farrell RE, Desjardins R, Pattey E, MacPherson JI (2005) Upscaling chamber-based measurements of N_2O emissions at snowmelt. *Can. J. Soil Sci.* **85**, 113-125.