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Monitoring soil thermal properties and CO_2, CH_4 and NO_2 emissions in a corn field in central Missouri

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ABSTRACT

We monitored Carbon Dioxide (CO_2), Methane (CH_4) and Nitrous Oxide (N_2O) emissions and soil thermal properties in a corn field. The study was conducted from 2008 to 2012 at Lincoln University's Freeman farm in Jefferson City, Missouri. Static and vented chambers were used to collect soil air samples for the determinations of gas concentrations. Analysis of CO_2, CH_4 and N_2O from air samples was done with a Shimadzu GC-14. Soil temperature (T), thermal conductivity (K), resistivity (R) and diffusivity (D) were directly measured with KD_2 probe. Results showed that the corn field was a source for CO_2 and N_2O from 2008 to 2012 as follows: for CO_2: 2008<2009>2010<2011>2012 and N_2O: 2008>2009>2010<2011>2012. It was a sink (2008>2009) but also a source (2010<2011>2012) for CH_4. Soil thermal properties were both positively and negatively correlated with gases fluxes with correlation coefficients ranging from 0.20 to 0.95. More significant correlations were found in 2008 and 2012 for N_2O and in 2011 for CO_2 and CH_4. More studies are needed for a better understanding of the relationships between soil thermal properties and gases emissions.

Keywords: Greenhouse gases fluxes--soil thermal properties--controlling factors

1. INTRODUCTION

Gaseous emissions from the earth continually occur from natural and manmade sources. Certain gases are quantified as greenhouse gases because they contribute to the greenhouse gas effect (Ramanathan and Feng, 2009; Snyder et al., 2009). According to US Environmental Protection Agency (USEPA), without the greenhouse effect the *earth’s surface temperature would be* approximately 15.55°C *co*oler than the average surface temperature (USEPA, 2010). While greenhouse gases are emitted during natural processes, human activities have caused a large rise in these emissions, causing a larger effect to be seen (USEPA, 2010). Industrial processes are the main sources of man driven greenhouse gases emissions, but agricultural activities also contribute to the problem. In fact, agricultural related greenhouse gas emissions accounted for approximately 6.5% of overall greenhouse gas emissions in the United States in 2010 and approximately 14% of emissions globally (Cooper et al, 2011). Agriculturally important greenhouse gases include carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4). Carbon dioxide (CO_2) emissions are mainly due to the burning of fossil fuels while the two largest sources of CH_4 are natural gas systems and enteric fermentation (Johnson et al., 2011). Most N_2O emissions come from agricultural activities. In 2010, it was approximated that the total N_2O emissions in the United States was 325.7 Tg CO_2 equivalent. Of this total, 223.8 Tg CO_2 equivalent (67%) were from agricultural soils (USEPA, 2010). Greenhouse gases emitted from soils are affected by soil properties and management practices such as the use of fertilizers and other soil amendments. Several authors have sought to identify the properties controlling gas emissions from soil (Johnson et al., 2011; Ball et al., 1999; Ginting et al., 2003). Soil temperature and moisture were suggested as the main controlling factors for greenhouse gases emissions from soil (Mosier et al., 1998; Ball et al, 1999), but the results are not always consistent among ecosystems. Soil thermal properties which relate to the ability of a soil to absorb, transfer, and retain heat have not extensively studied as potential controlling factors (Usowicz et al., 1996;, Abu-Hamdeh, 2003). Among the few short-term studies, Nkongolo et al (2010) reported correlations between soil thermal properties and gases fluxes in a pasture while Johnson et al (2007) suggested that soil thermal properties related to greenhouse gases emissions in a secondary forest. The objective of this study was therefore to assess the relationships between soil thermal properties and greenhouse gases fluxes over a 5years period in a corn field.

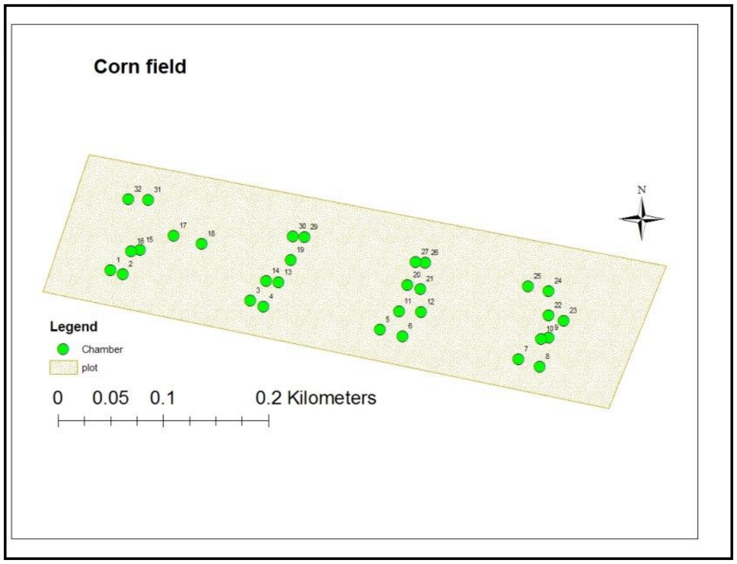


Figure 1 Experimental field

2. MATERIALS AND METHODS

2.1. Study area

The study was conducted from 2008 to 2012 at Freeman farm of Lincoln University in Callaway County, north of Jefferson City, Missouri. The experimental site is showed in Fig.1. Its geographic coordinates were 38°58′16″N and 92°10′53″W. The soil of the site was a Waldron silty-loam (Aeric Fluvaquents) with an average pH of 6.8. Mean annual air temperature and precipitation in the area was 12.5°C and 1083 mm, respectively. The corn field was conventionally tilled (moldboard plow) and received 81.65 kg/ha of NPK. Corn was planted in late May and harvested in October. After harvest, residues were left on soil surface and incorporated into soil during tillage for the next cropping season. The complete experimental procedure is described in Kladivko et al (2014).

2.2. Air sampling for measurements of CO_2, CH_4 and N_2O

A week after corn seedlings emergence, thirty two cylindrical polyvinylchloride (PVC) chambers of 0.30 m long and 0.20 m in diameter were permanently (for the duration of the growing season) inserted into the soil to a depth of 0.05 m. The design of the sampling chamber is a modified version of Hutchinson and Mosier (1998) and is showed in Fig. 2. The chambers were constructed with two ventilation holes on the sides as also showed in Nkongolo et al (2010). They had circular tops made from Plexiglas and containing two additional holes. One of the holes was covered by a stopper for the extraction of gases and while the other served for ventilation. Installation of these chambers for the entire growing season kept the soil undisturbed. In order to maintain an air tight seal, a groove was put on the bottom of the lid so that it would fit securely onto the sampling chamber. During sampling time, the groove was filled with Dow-Corning high vacuum grease. Soil air samples for gas analysis were collected as follows: (1) the two chamber ventilation holes were sealed off by rubber stoppers; (2) the greased (to seal the chamber) chamber tops were put on; (3) the chamber was allowed to fill up with air for thirty minutes; and (4) the soil air samples were collected with a 50 mL syringe and put into a 200 mL Tedlar bag for storage. An additional sample was collected from the ambient air at about 1.5 m height from soil surface at a location near each chamber for a total of 32 ambient air samples per sampling cycle. A total of 41 soil air samples were collected in 2008, 48 in 2009, 161 in 2010, 225 in 2011 and 192 in 2012. Analysis of CO_2, CH_4, and N_2O from soil air samples were conducted at Lincoln University's Dickinson Research Laboratory within 2 hours after samples collection. The concentration of each greenhouse gas was measured using a Shimadzu Greenhouse Gas Chromatograph (GC-14) with an Electron Capture Detector. The data were then transferred into an Excel data sheet where the gas fluxes were calculated. A positive value represents gas emission from the soil, while a negative value represents gas uptake. Fluxes were calculated using the following equation (Ginting et al., 2003).

$$F = \rho * (V/A) * (\Delta C/\Delta t) * (273/T) * \alpha$$

where, F is the gas production rate; ρ (kg/m^3) is the gas density under standard conditions; V (m^3) and A (m^2) are the volume and area of the chamber; $\Delta C/\Delta t$ is the ratio of change in the gas concentration inside the chamber (10^{-6}m^3/(m^3·h)); T is the absolute temperature; and α is the transfer coefficient (12/44 for CO_2, 12/16 for CH_4 and 28/44 for N_2O).

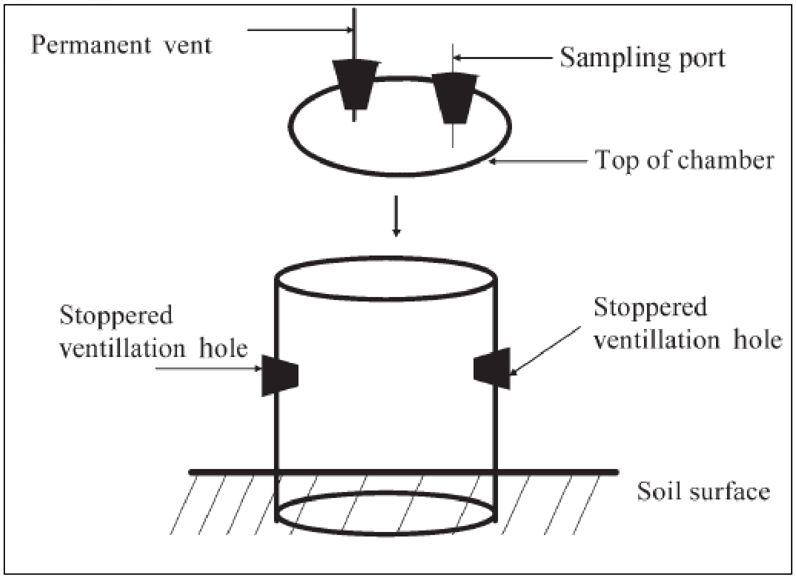


Figure 2 Soil air sampling chamber

2.3. Soil thermal properties

The soil thermal properties were measured *in-situ* in each chamber or on its neighborhood with a KD2-Pro thermal properties meter (Decagon) at 0.06 m depth. The KD2 thermal meter uses three sensors to measure thermal diffusivity (*D*), thermal conductivity (*K*), thermal resistivity (*R*) as well and soil temperature. KD2 takes measurements at one second intervals during a 90 sec measurement cycle by using the transient line heat source method. The soil thermal properties were measured during every sampling date.

2.4. Mapping and statistical analysis

Statistix 9.0 was used to calculate simple statistics, Pearson correlation matrix and to run a linear regression analysis for CO_2, N_2O, and CH_4 and the soil properties. ARCGIS 10 Spatial Analyst Extension was used to produce maps portraying the spatial distribution of greenhouse gases fluxes across the field.

3. RESULTS

3.1. Summary of simple statistics

Summaries of simple statistics of the entire study period (2008-2012) are showed in Tables 1 and 2 for greenhouse gases emissions and soil thermal properties, respectively. The average fluxes were 101.45 mg C-CO_2 m^2h^{-1}, 7.20 ug C-CH_4 m^2h^{-1}, and 52.81 ug N-N_2O m^2h^{-1} for CO_2, CH_4 and N_2O, respectively. The coefficient of variation (CV) ranged from 61.79 to 919.03 %, indicating strong variability in fluxes, especially for CH_4 (highest) and N_2O while CO_2 emissions had the lowest variability. High spatially variability of greenhouse gases fluxes have been reported by other authors (Smith et al., 2003). For soil thermal properties (Table 2), the mean values were 22.74ºC; 0.76 W/m°C; 1.59 m°C/W and 0.33 mm^2/sec for T, K, R and D, respectively. The coefficient of variation ranged between 33.99 to 49.09, implying moderate variability in comparison to greenhouse gases fluxes. T has the lowest coefficient of variability followed by D.

Table 1 Summary of simple statistics for CO_2, CH_4 and N_2O fluxes

	CO_2	CH_4	N_2O
	mg CO_2-C/[m^2·h]	ug CH_4-C/ [m^2·h]	ug N_2O-N/[m^2·h]
N	665	665	665
Mean	101.45	7.20	52.81
SD	61.85	66.20	166.76
C.V.	60.96	919.03	315.76
Minimum	3.10	-344.03	-49.94
Median	94.70	0.21	13.88
Maximum	464.16	800.47	1980.80
Skew	1.44	3.17	6.64
Kurtosis	4.33	33.44	53.58

Table 2 Summary of simple statistics for soil thermal properties

	T	K	R	D
	ºC	W/m°C	m°C/W	mm^2/sec
N	665	665	665	633
Mean	22.74	0.76	1.59	0.33
SD	7.73	0.36	0.78	0.12
C.V.	33.99	47.83	49.09	35.81
Minimum	4.70	0.10	0.20	0.10
Median	24.80	0.71	1.41	0.34

Maximum	38.60	4.92	10.21	0.79
Skew	-0.63	3.65	2.98	0.38
Kurtosis	-0.58	32.56	22.67	0.09

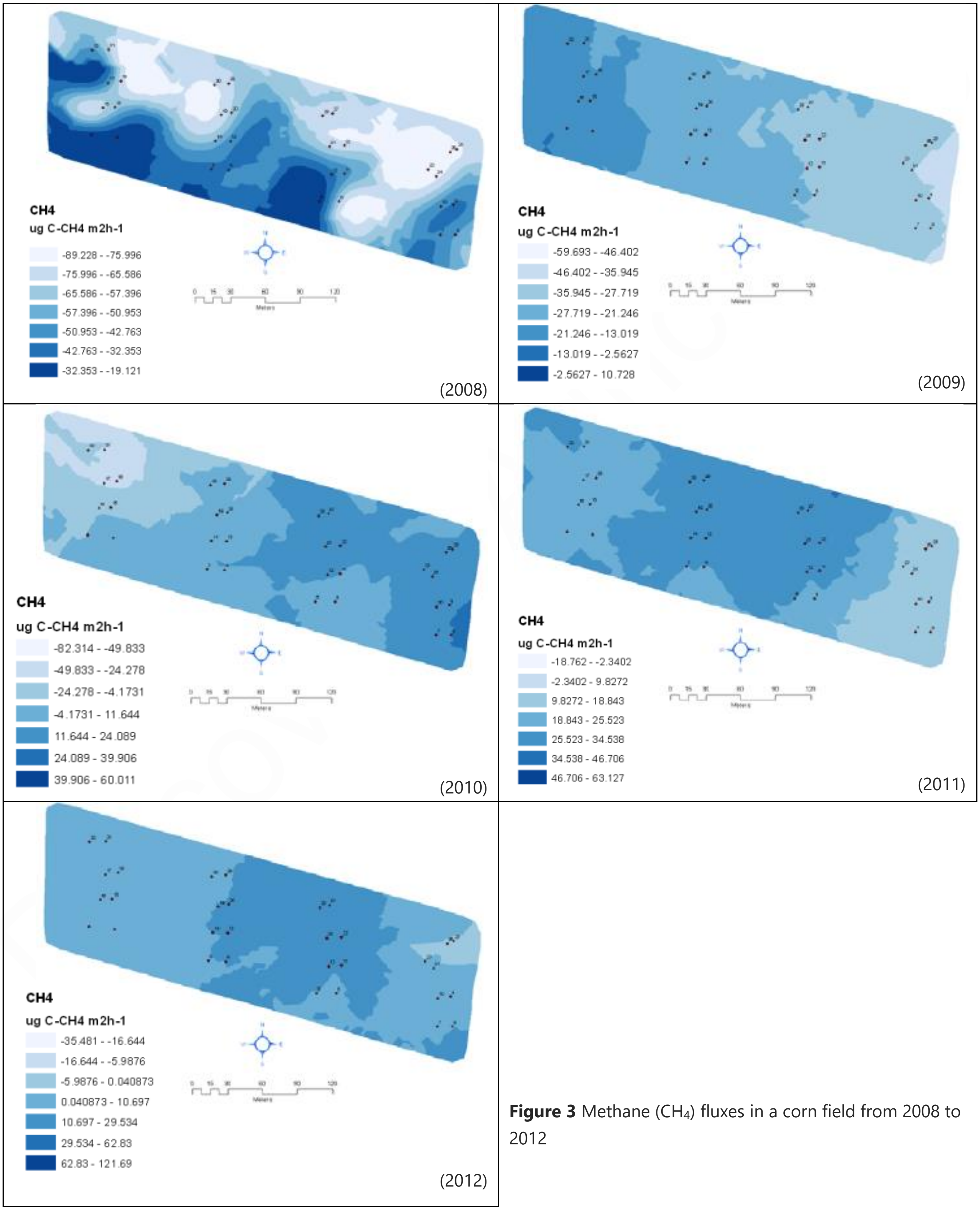
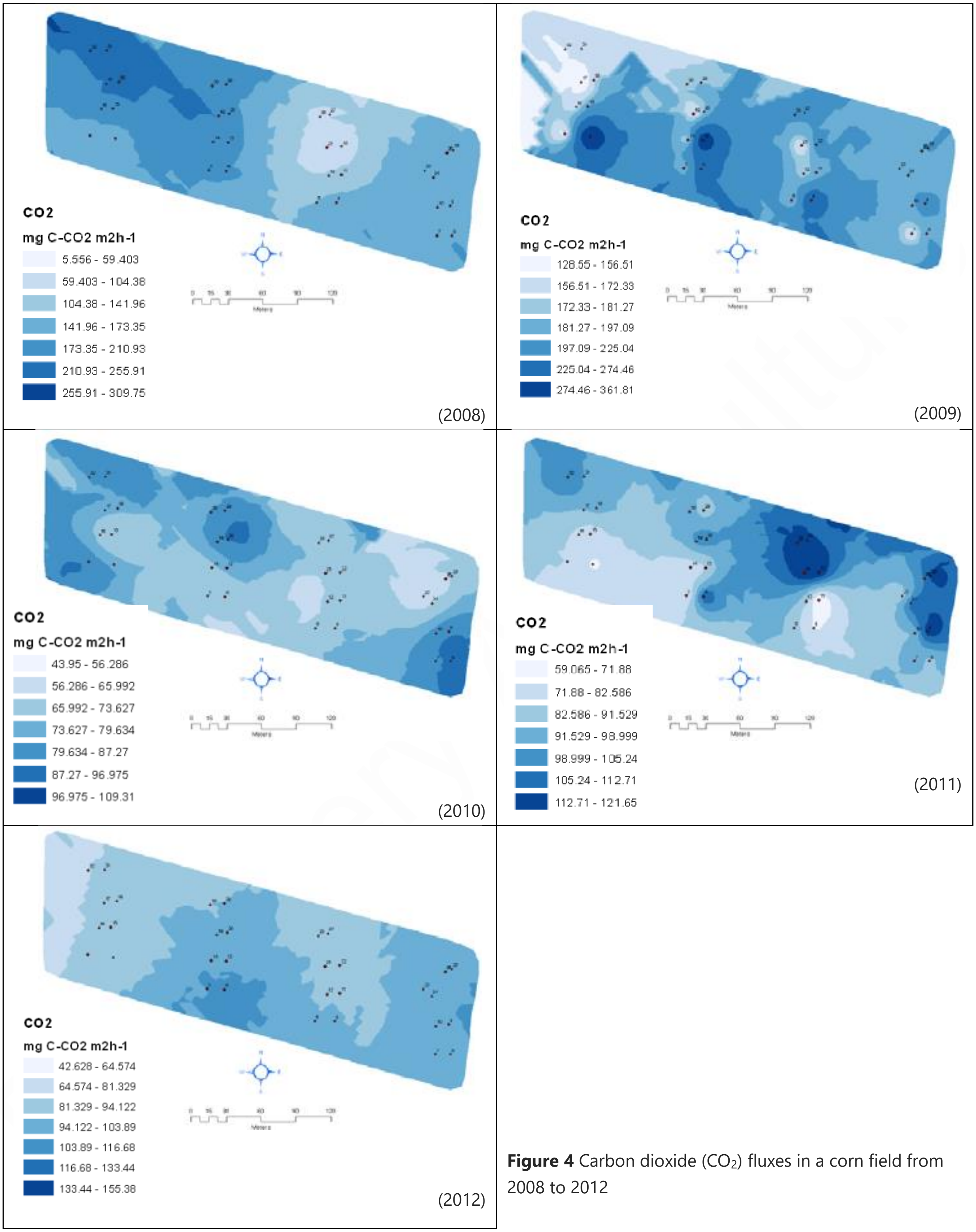


Figure 3 Methane (CH_4) fluxes in a corn field from 2008 to 2012



(2008)

(2009)

(2010)

(2011)

(2012)

Figure 4 Carbon dioxide (CO_2) fluxes in a corn field from 2008 to 2012

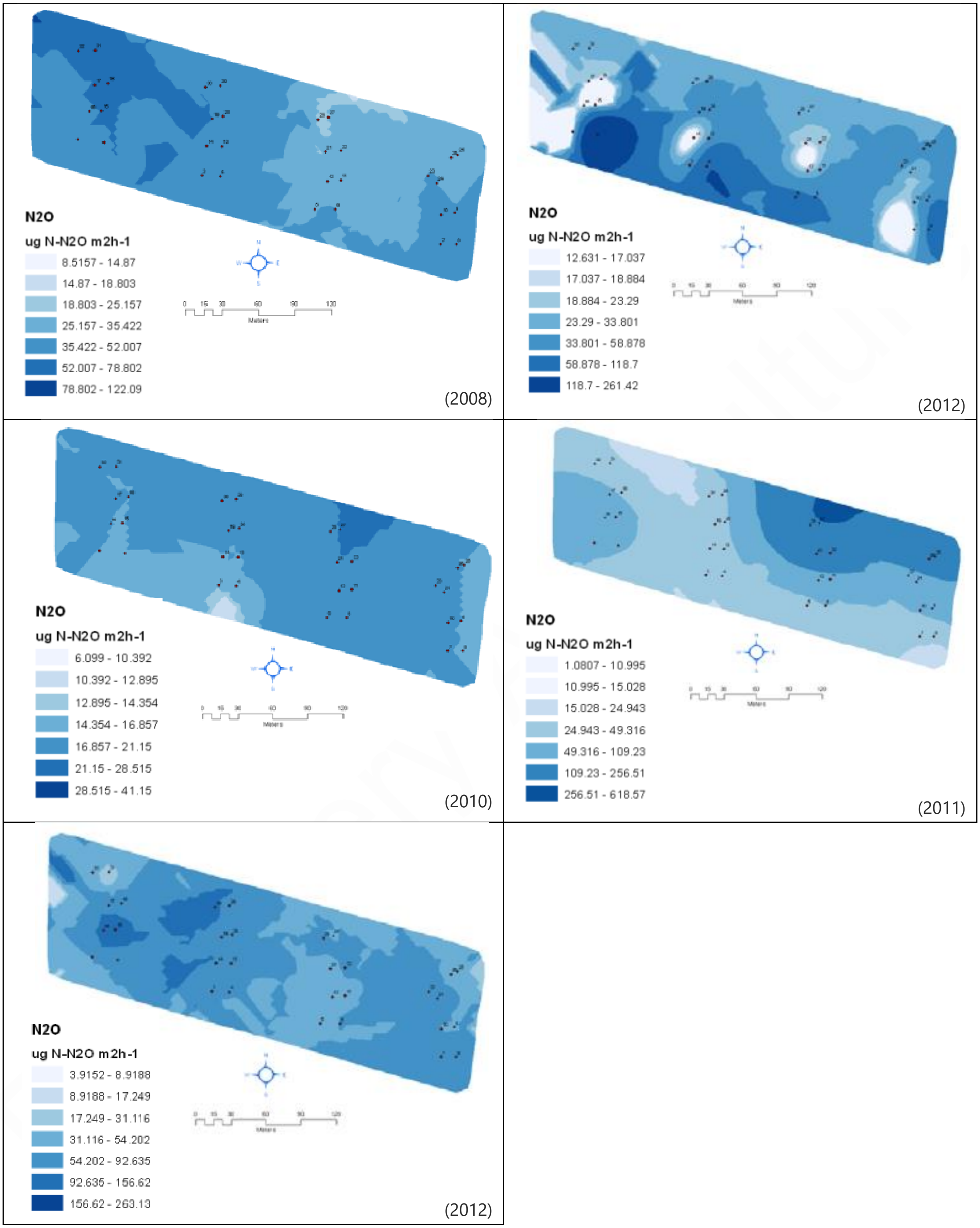


Figure 5 Nitrous oxide (N_2O) fluxes in a corn field from 2008 to 2012

3.2. Mapping the spatial distribution of greenhouse fluxes

Interpolated maps showing the spatial distribution of greenhouse gases fluxes across the corn field from are showed in Figures 3, 4 and 5 for CH_4, CO_2, and N_2O, respectively. CH_4 fluxes (Fig.3) were roughly divided into two zones of uptake: a zone of low uptake in northern portion of the field and spots high CH_4 uptake in the southern portion of the corn field. In 2009, a large spot of CH_4 emission was observed in the western side of the field while the remaining portion of the field kept its CH_4 (uptake). For the remaining years, CH_4 was again distributed into two zones, a zone of emission in the middle of field in 2011 and 2012 and in the eastern portion of the field in 2010. For CO_2 (Fig. 4), the maps showed zones of highest and lower emissions with inconsistent patterns. Finally, for N_2O fluxes (Fig.5), the map also showed zones of high and low emissions with non repeating patterns as for CO_2.

Table 3 Correlation matrix between soil thermal properties and CO_2, CH_4 and N_2O in 2012

	CO_2	CH_4	N_2O	T	K	R
CH4	-0.0537					
	0.4597					
N2O	0.3335	0.0565				
	0.0001	0.4366				
T	0.3914	0.1428	0.1905			
	0.0001	*0.0482*	*0.0081*			
K	0.0065	0.0851	0.247	-0.0316		
	0.9282	0.2406	*0.0006*	0.663		
R	0.0391	-0.1189	-0.1982	0.0752	-0.9445	
	0.5905	0.1005	*0.0059*	0.2998	0.0001	
D	0.258	0.1881	0.2931	0.4754	0.526	-0.5056
	0.0003	*0.009*	*0.0001*	*0.0001*	*0.0001*	*0.0001*

Table 4 Correlation matrix for soil thermal properties and CO_2, CH_4 and N_2O for entire sampling period (2008-2012)

	CO_2	CH_4	N_2O	T	K	R
CH_4	-0.1075					
	0.0068					
N_2O	0.1896	0.0414				
	0.0001	0.298				
T	0.1488	0.1245	0.2057			
	0.0002	*0.0017*	*0.0001*			
K	0.1757	-0.132	-0.0004	-0.1392		
	0.0001	*0.0009*	0.9916	0.0004		
R	-0.1091	0.0855	-0.0218	0.1575	-0.7149	
	0.006	*0.0316*	0.5842	0.0001	0.0001	
D	-0.2756	0.2031	0.1033	0.2066	0.0451	-0.2087
	0.0001	*0.0001*	*0.0093*	0.0001	0.2573	0.0001

3.3. Correlations between soil thermal properties and greenhouse gases fluxes

Correlation matrices for the relationship between soil thermal properties and greenhouse gases fluxes are showed in Table 3 for 2012 only. Yearly correlations are discussed where necessary but their results are not showed except for 2012. An analysis for the entire sampling period is also showed in Table 4. All greenhouse gases correlated among themselves in 2008 with CO_2 and N_2O showing the high correlation ($p = 0.0001$, $r = 0.71$). The correlation was positive, indicating that the same controlling factor acted on both gases. Soil temperature (T) was not a controlling factor for CO_2 and CH_4, but only N_2O to which it correlated negatively. However, soil thermal conductivity (K) positively correlated CO_2 and N_2O and negatively with CH_4.Thermal resistivity (R) negatively correlated with N_2O while thermal diffusivity (D) positively correlated with CO_2 and N_2O. In 2009, only two correlations persisted when the entire data was considered: CO_2 vs N_2O and R vs N_2O. However, the strength the later correlation was lowered and its direction shifted. In 2010, soil temperature was negatively correlated with CH_4 and N_2O while D also negatively correlated with CO_2 and CH_4. In 2011 and 2012, T again acted as the controlling factors for CO_2, CH_4 and N_2O as did D in 2012 (Table 3). The trend found in 2011 and 2012 was also confirmed when all the data was combined (Table 4) for all 5 year of this study. The month to month analysis (not discussed) had more significant correlation between greenhouse gases fluxes and between gases and soil thermal properties. In fact, the highest correlations were found in the month to month analysis, such as the correlation between CO_2 and N_2O in September 2008 (Fig. 6) or that between CO_2 and soil thermal conductivity (Fig. 7).

4. DISCUSSION

Overall, the relationships between and amongst greenhouse gas fluxes and soil thermal properties were extremely variable throughout the five years of study. The relationship between CO_2 and N_2O fluxes was consistently positive during all the five of the years of the study. The reoccurrence of this relationship suggests the possibility of similar controlling factors for CO_2 and N_2O. No flux-thermal property correlation was found to have as many years of supporting relationship. Another strong relationship was a positive relationship between T and both CO_2 and CH_4 emissions. This relationship occurred during 3 years of study. Consistent positive relationships between D and all three gas fluxes were also found for two years of data, D also correlated sporadically with gas fluxes in other years, except in 2009. A positive relationship between R and both CO_2 and N_2O fluxes was also supported by two years of study. Most of the correlations found among the soil thermal properties are supported by several years of data. The negative relationship between R and K is supported by all six years. This understandable since R is the opposite of K. D and K were also found to have positive relationship in four of the years. The relationship with T and the other thermal properties was more variable, suggesting that T does control K, D and R. This can also explain the fact that K, D and R correlated with gas fluxes while T did not. The implication of this fact being that all thermal properties should always be measured to identify the best controlling factor. It is evident that the thermal properties do have an impact on the greenhouse gas fluxes. The variability of the relationships indicates that there are other controlling factors that impact the flux of greenhouse gases from the soils and studies need to be pursued.

5. CONCLUSION

Greenhouse gases (CO_2, CH_4 and N_2O) emissions were monitored in a corn field at Lincoln University's Freeman farm from 2008 to 2012. Results showed that greenhouse gases correlated among themselves and with soil thermal properties. Significant correlation between CO_2, CH_4 and N_2O and soil K, R and D were found even when these gases could not correlate with T, the most studied soil controlling factor for greenhouse gases emissions from soil. Therefore, these results confirm that soil thermal properties are also controlling factors for greenhouse gases emissions from soil and should be included in studies assessing the relationship between soil properties and gases emissions. However, more investigations are still needed to understand the sporadic shifts in the relationship between these properties and gases emissions: correlation vs no correlation, positive vs negative correlation for the same thermal property with a same gas.

CONFLICT OF INTERESTS

The authors declare that there is no conflict of interests regarding the publication of this paper.

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