Measurement of Greenhouse Gas Emissions from Sugarcane Plantation Soil in Thailand

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Abstract—Continuous measurements of greenhouse gases (GHGs) emitted from soils are required to understand diurnal and seasonal variations in soil emissions and related mechanism. This understanding plays an important role in appropriate quantification and assessment of the overall change in soil carbon flow and budget. This study proposes to monitor GHGs emissions from soil under sugarcane cultivation in Thailand. The measurements were conducted over 379 days. The results showed that the total net amount of GHGs emitted from sugarcane plantation soil amounts to 36 Mg CO_{2eq} ha^{-1}. Carbon dioxide (CO_2) and nitrous oxide (N_2O) were found to be the main contributors to the emissions. For methane (CH_4), the net emission was found to be almost zero. The measurement results also confirmed that soil moisture content and GHGs emissions are positively correlated.

Keywords—Soil, GHG emission, Sugarcane, Agriculture, Thailand.

I. INTRODUCTION

CLIMATE change continues to be a topic of considerable scientific debate and public concern. The concentration of greenhouse gases (GHG) including carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) in the atmosphere has been significantly increased due to human activities. This has given rise to growing concern about the consequences of such increase on global warming and climate change [1], [2]. Agricultural production plays an important role on atmospheric greenhouse gas concentration [3], [4] and agricultural soils are also viewed as a large contributor to GHG emissions, especially CH_4 from wetland fields [5], and CO_2 and N_2O for upland field [2]. The contribution of agricultural soils to CO_2, CH_4, and N_2O emissions depends on a biophysical process and a decomposition process of organic residue in soils. CO_2 is produced in the aerobic condition, while CH_4 is produced in the anaerobic condition, and N_2O produced naturally in the soil through microbial processes of nitrification and denitrification [6]. Also, emissions of GHG are significantly influenced by environmental factors such as temperature and rainfall, and by farm management practices. On the other hand, agricultural soils play an important role in the GHG global budget, with 3.5% of total carbon reserve of the earth [7]. A better understanding the emissions from agricultural soils is therefore a key issue for an effective quantification and of assessment of the overall change in the soil carbon flow and budget.

In Thailand, sugarcane cropping accounted for 1.28 million ha in Thailand in 2012 [8], with two different residue management systems; burning and no-burning sugarcane residue in the field. The cultivation of sugarcane is expected to expand during the next decades to support food and especially bioethanol production to meet the national energy need of the region. Currently, data on carbon flow and budget in sugarcane plantation system are still very scarce or inexistent, and consequently any evaluation of GHGs emissions from sugarcane plantation is difficult. On the other hand, an accurate and reliable quantification of soil emissions is required to better understand the agro-ecosystem response to global change. The objective of this study is to quantify the CO_2, CH_4, and N_2O emissions from sugarcane plantation soils over the whole growing seasons. Monitoring of GHGs conducted at experimental sites under burned and unburned sugarcane cultivation areas is described and discussed. GHGs emissions from sugarcane plantation are then analyzed and assessed.

II. MATERIALS AND METHODS

A. Experimental Site

Field experiments were carried out on a sugarcane farm in Nakhon Sawan province, northern region of Thailand. This site has been cropped for over 20 years with sugarcane. The cropping system is consisted of sugarcane plant crop in rotation with 2-3 years ratoon. The sugarcane is harvested annually. The climate of this province is classified as a tropical monsoon climate, i.e. warm and wet conditions in summer and cool in winter. The mean annual temperature of the study area is 28.8°C. Regarding the rainfall, the annual average is about 1,100mm, of which about 86% occur during the period running from May to October as shown in Fig. 1 [9].

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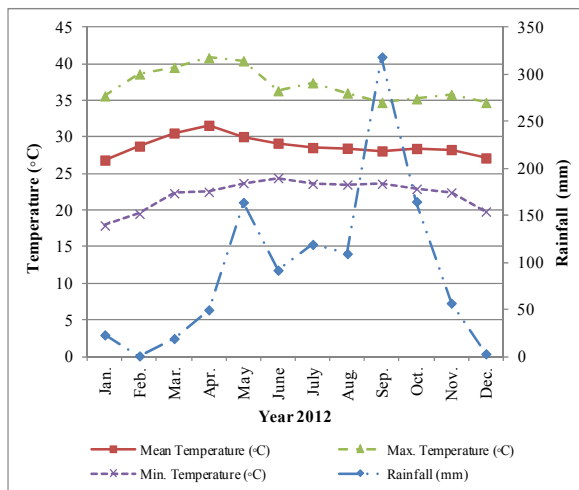
Fig. 1 Weather conditions at the experimental site

Emission measurements were made in blocks of sugarcane plant crop. Two treatments, i.e. with and without field burning, were implemented over a one year cropping cycle during January 2012-January 2013. Each of treatments was applied at a plot of 12m x 50m. For the treatment with burning, the selected area has been burned annually over the past 20 years. The area without burning was set in a plot which had not been burned for more than four years before the experiment, and located in the adjacent site of the area with burning. The soil was tilled in December 2011, after harvesting the ratoon crop. During the dry season, sugarcane variety KHONKEN 3 was planted in January 2012 with three times of irrigation. About 185 kg N ha^{-1} were applied annually, including 44 kg N ha^{-1} as a basal fertilizer at the planting time, and 141 kg N ha^{-1} in slits cut to a depth of 10-15 cm on each side of planted row and then covered with soil. The fertilizer application rates and timing was determined base on the typical practices of the local farmer.

TABLE I
SOIL CHARACTERISTICS OF THE EXPERIMENTAL SITE

Depth (cm)	Texture	pH	Organic matter (%)	Total nitrogen (g kg^{-1})	Phosphorus (mg kg^{-1})	Exchangeable K (mg kg^{-1})
Burned area						
0-10	Clay	7.87 (0.15)	1.75 (0.06)	2.07 (0.03)	4.00 (1.15)	171.33 (9.53)
10-30	Clay	7.93 (0.07)	1.30 (0.06)	1.87 (0.07)	2.67 (1.67)	143.67 (11.41)
30-55	Clay	8.13 (0.12)	0.47 (0.07)	1.47 (0.15)	<1.00 (0.00)	37.33 (9.36)
55-72	Clay loam	8.13 (0.12)	0.57 (0.09)	1.17 (0.07)	<1.00 (0.00)	52.33 (13.87)
72-100	Clay loam	8.20 (0.06)	0.43 (0.03)	1.03 (0.03)	<1.00 (0.00)	32.33 (6.89)
Unburned area						
0-10	Clay	7.83 (0.09)	2.23 (0.03)	2.27 (0.18)	<1.00 (0.00)	171.67 (1.20)
10-30	Clay	8.00 (0.17)	1.40 (0.12)	1.80 (0.12)	<1.00 (0.00)	145.67 (16.59)
30-55	Clay	8.10 (0.20)	0.47 (0.04)	1.33 (0.09)	<1.00 (0.00)	46.33 (13.98)
55-72	Clay loam	8.00 (0.21)	0.57 (0.05)	1.23 (0.07)	<1.00 (0.00)	51.67 (6.57)
72-100	Clay loam	8.03 (0.15)	0.48 (0.02)	1.17 (0.12)	<1.00 (0.00)	57.00 (10.58)

The area can be classified as high activity clay soil type with low organic carbon. It is described locally as a Takhil and Mollisols soil series according to the USDA classification. The soil characteristics of the experimental site located in the burned and unburned areas are reported in Table I.

B. Emission Measurement

A one-year experiment was conducted at the farmer's field in the first year of planting, called the plant crop. Soil CO_2, CH_4, and N_2O fluxes were measured, and information on the local weather conditions, soil and faming management practices was collected during the experiment period. Gas samples were collected using static chamber method over 379 days of growing seasons (January 2012-January 2013). Six manual chambers were installed in the burned and unburned plots. Three chambers were placed at the middle of a row and the other three chambers at the between-row spacing over the fertilizer slit. To monitor the net GHG exchange through soil respiration while prevent the effect of photosynthesis, 0.25m x 0.25m x 0.15m size opaque chambers were used and installed in the area without plants. Gas samples were collected twice a

month during the growth period, between 9 am to 12 pm. Each chamber was monitored by turn for 20 minutes for CO_2 and CH_4 emissions, and 30-60 minutes for N_2O emissions. Gas samples were extracted using a mini air pump (Mini Pump MP-2N, Sibata, Japan) at a flow rate of 2.5 L m^{-1} to inject into an aluminum Tedlar bag. Then, they were analyzed for CO_2, CH_4, and N_2O at the laboratory within 2-3 days after sampling. The concentrations of CO_2 and CH_4 in the gas samples were determined by gas chromatography (GC) using a flame ionization detector (FID), and N_2O by GC using ^{63}Ni electron capture detector (ECD).

For assessment, the gas concentrations obtained from the chamber headspace were converted to mass or molecular basis using the ideal gas law depending on the temperature and pressure of enclosed air as shown in (1):

$$C_i = \frac{q_i M_i P}{RT} \tag{1}$$

where, C_i is the gas concentration in term of mass per volume concentration (mg. m^{-3}), q_i is the gas concentration in term of

volume per volume concentration (ppmv), M is molecular weight of each trace gas (g mol^{-1}: 44 for CO_2, 16 for CH_4, and 44 for N_2O), P is the atmospheric pressure (1 atm), T is air temperature inside the chamber (K), and R is universal gas constant (0.08205 atm.m^3. kmol^{-1}. K^{-1}).

Gas fluxes were calculated based on the slope of the gas concentration in the five samples taken at the measurement periods (2):

$$F = \frac{V}{A} \cdot \frac{dC_i}{dt} \qquad (2)$$

where: F is gas flux (mg. m^{-2}. h^{-1}), V is chamber volume (m^3), A is the surface area covered by the chamber (m^2), $\frac{dC_i}{dt}$ is the increase/decrease rates of gas concentration (mg. m^{-3} h^{-1}).

Daily average CO_2, CH_4, and N_2O fluxes and their standard error were calculated based on the original data measured in the field. In addition, all values of GHG emissions were converted to CO_2 equivalent following the individual global warming potential for a period of 100 years for each gas using 1 for CO_2, 21 for CH_4, 310 for N_2O [10].

The ambient air temperature and rainfall data were collected from the local meteorological station near the experimental site. The air temperatures within the chambers were also recorded during each of gas sampling. Soil volumetric moisture content and soil temperature at the top soil (0-5 cm) near the soil chamber were measured using the soil moisture meter (ThetaProbe-HH2, Delta-T Devices Ltd., UK).

III. RESULTS AND DISCUSSION

The 24-hour measurement period of CO_2, CH_4, and N_2O fluxes indicated that there was a clear diurnal cycle in the daily emission with high values during the daytime and low values at the nighttime as shown in Fig. 2. The influence of soil temperature and high soil aeration during the day are indeed affected by the gas diffusion in line with the study by Denmead et al. [11]. The observed daily pattern of GHG flux variation was probably due to the temperature change during the daytime, i.e. when the soil temperature increased, the soil effluxes also increased.

Regarding the daily flux, the GHGs fluxes of the burned and unburned sugarcane cropping systems were determined over 379 days during growing season. Weighted contribution to the total area of the sugarcane plant-rows (61.37%) and spaces between-rows (38.27%) were used to estimate the gas flux per hectare basis for both treatments. Hourly fluxes were scaled up to daily fluxes with correction of the diurnal variation for each gas emission.

From Fig. 3, the soil CO_2 emissions from the sugarcane plant-row area were significantly higher than that emission from the spaces between-rows area. The trend of CO_2 emissions was found to increase with the plant age. On the other hand, no significant difference of CO_2 emission was observed between the burned and unburned sites. The total CO_2 fluxes over 379 day of planting (DAP) were about 35.56 ± 0.73 and 35.99 ± 1.20 Mg ha^{-1} for burned and unburned areas, respectively. The soil CO_2 emission rates of the growth season were 93.84 ± 1.94 kg ha^{-1} day^{-1} for burned plot, and 94.96 ± 3.16 kg ha^{-1} day^{-1} for unburned plot.

Regarding CH_4 emissions, they were close to zero as what could be expected for dry crop soil. In addition, for both burned and unburned areas, there was no significant difference between the sugarcane plant-row and spaces between-row areas as shown in Fig. 3. The CH_4 emission rate for the unburned treatment was -1.24 ± 0.20 g ha^{-1} day^{-1}, and -1.28 ± 0.17 g ha^{-1} day^{-1} for the burned area. Likewise, there was insignificant difference in the total CH_4 emission over the measurement period between the two sites, -0.48 ± 0.07 and -0.47 ± 0.08 kg ha^{-1} for the burned and unburned system, respectively.

For N_2O, the emission from sugarcane plant-rows soil was significantly lower than that from spaces between-row soil (Fig. 3). The N_2O emission rate mean daily value under the burned system was 4.86 ± 1.16 g ha^{-1} day^{-1}, and 4.73 ± 0.99 g ha^{-1} day^{-1} for the unburned one. The total emission of N_2O of the whole growth period was 1.84 ± 0.42 and 1.79 ± 0.38 kg ha^{-1} for burned and unburned system, respectively. No significant difference in N_2O emissions was observed between the two sites.

For soil volumetric moisture content and soil temperature, the difference between burned and unburned sugarcane areas was insignificant. Also, it was found that soil moisture content was positively correlated with GHGs emitted from soil, while none correlation was between soil emission and soil temperature.

TABLE II
GHGs EMISSIONS FROM SUGARCANE PLANTATION SOILS OVER 379 DAP OF THE FIELD EXPERIMENT

GHG emissions	Burned system		Unburned system	
	Mg ha^{-1}	Mg CO$_{2eq}$ ha^{-1}	Mg ha^{-1}	Mg CO$_{2eq}$ ha^{-1}
1. CO_2	35.56	35.56	35.99	35.99
2. CH_4	-0.00048	-0.0102	-0.00047	-0.00990
3. N_2O	0.00184	0.3865	0.00179	0.37641
Total		35.94		36.36

Table II summarizes the GHGs emissions from soils in the burned and unburned areas during the whole growth period. There was no significant difference in the annual GHGs emission between burned and unburned soils. The total GHGs emission from sugarcane soils in this experiment was about 35.94 – 36.36 Mg CO$_{2eq}$ ha^{-1}. As expected, the emission of CO_2 was found to be the highest comparatively to others, and accounted for 99% of the total GHGs emission. Only 0.38 – 0.39 Mg CO$_{2eq}$ ha^{-1} were emitted as N_2O and non-emission was from CH_4.
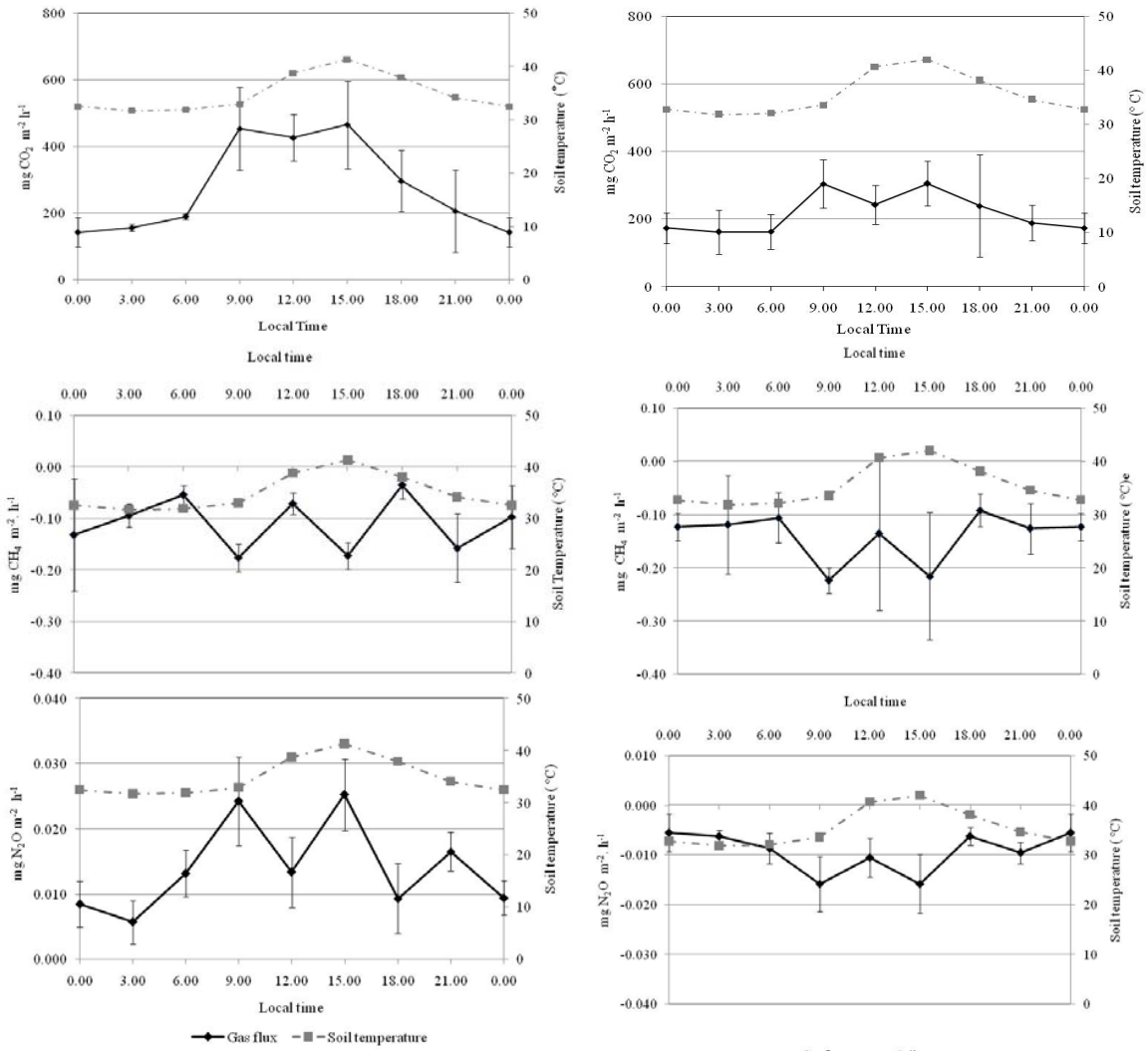
(a)   (b)

Fig. 2 Example of diurnal cycle of soil CO_2, CH_4, and N_2O flux at (a) the middle of sugarcane plant-rows and (b) the spaces between-rows of the burned area (measurements of 23 March 2012, i.e. during the dry season)
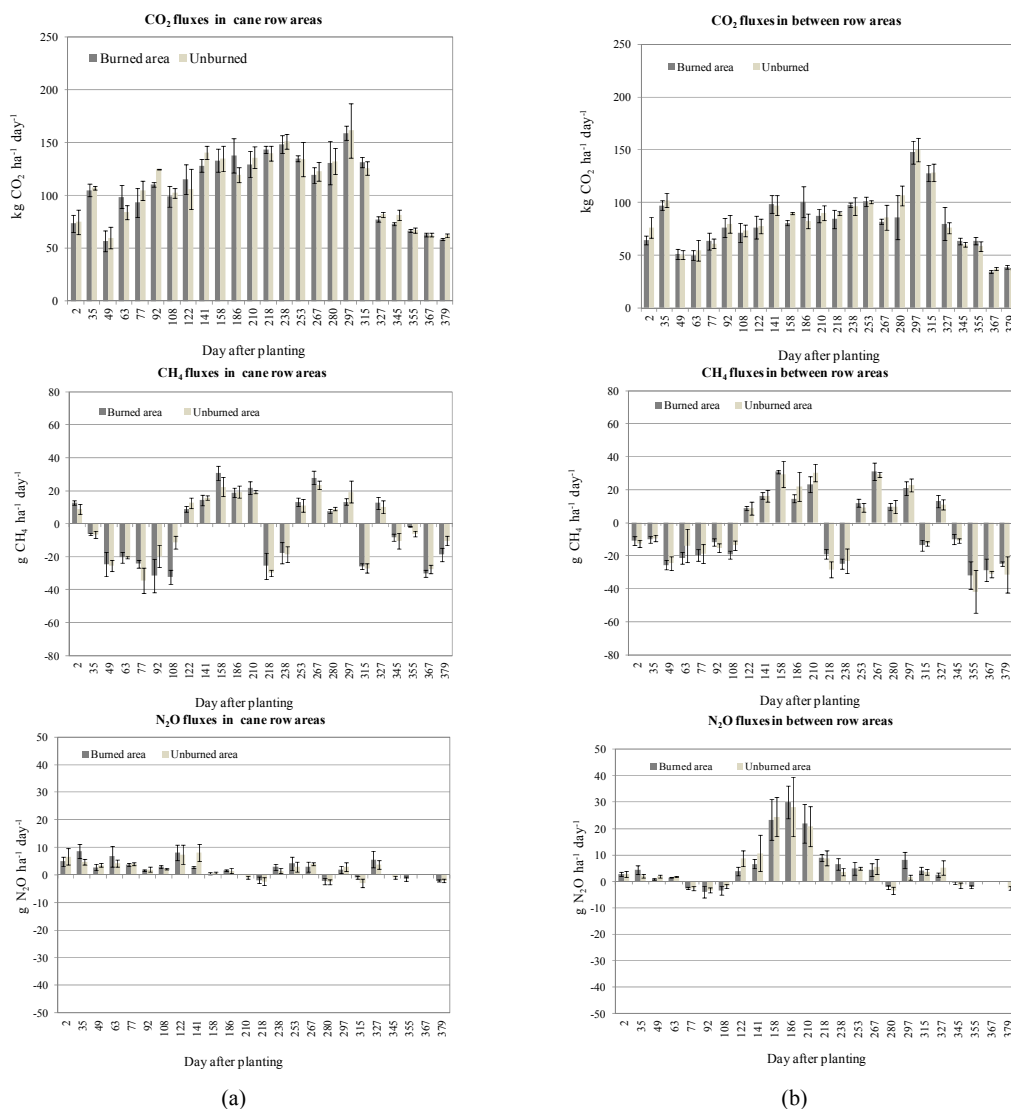
Fig. 3 Daily flux of CO_2, CH_4, and N_2O from (a) the sugarcane plant-row soil and (b) the spaces between-rows soils unburned the burned and unburned sugarcane plantation areas over 379 DAP

IV. CONCLUSIONS

The close chamber technique was used for monitoring GHG including CO_2, CH_4, and N_2O emitted from sugarcane plantation soils under burned and unburned systems in Thailand. The measurement was done over 379 days during the 2012/2013 growing season of a new plant crop. It was found that no significant difference in total GHGs emission from soils under the burned and unburned systems. The net emission for the season of one year cycle was 36 Mg CO_{2eq} ha^{-1}, of which 99% were reported as CO_2. Nearly none emission was observed for CH_4. The emission of N_2O from sugarcane plantation soils was very small, only 0.38 – 0.39 Mg CO_{2eq} ha^{-1}. In addition, it was found that the soil moisture content was an important factor in controlling GHGs fluxes from soil, especially for CH_4. The results obtained from this experiment were under site-specific conditions, e.g. new plant crop, one-year growing season only, etc., and therefore may not be representative of all sugarcane plantations in Thailand. To confirm the findings of this study, a multi-growing seasons continuous monitoring of at least three years at different regions of the country is highly recommended.

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