CHAPTER 7
EFFECT OF SUGARCANE FIELD BURNING ON GHG EMISSIONS FROM SOILS

The agricultural sector is one of the major anthropogenic sources of greenhouse gas (GHG) emissions. Three GHG associated with agriculture are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Other important GHGs include water vapor and many halocarbon compounds which are not considered to be influenced by agriculture (IPCC, 2006; Snyder et al, 2009). Agricultural soils are a major source of GHG emissions. The contribution of agricultural soils to GHG emissions depends on a biophysical process and a decomposition process of organic residue in soils (Munoz et al, 2010). In addition, management practices in agricultural areas are believed to affect on GHG emissions from soil. Burning of crop residue would be affected to change in soil emission because this activity has direct effect on changes in physical, chemical and biological properties of soils. A better understanding on the effect of open burning on GHG emitted from soil is still required to assess the change of GHG balance due to the conversion burning to no-burning system. In this context, this chapter described on estimation the annual GHG emission from soil under burned and unburned management systems. It focused on the exchange of CO_2, CH_4, and N_2O from sugarcane soil into the atmosphere over a one-year cycle of growing season.

7.1 Methodology

7.1.1 Experimental site

Field experiments were carried out on a sugarcane farm in Nakhon Sawan province, the northern region of Thailand. This site was 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 with the 10-15 months of plant ages. 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. The annual average of rainfall is about 1,100 mm, of which about 86% occur during the period running from May to October as shown in Fig. 7.1 (TMD, 2013).

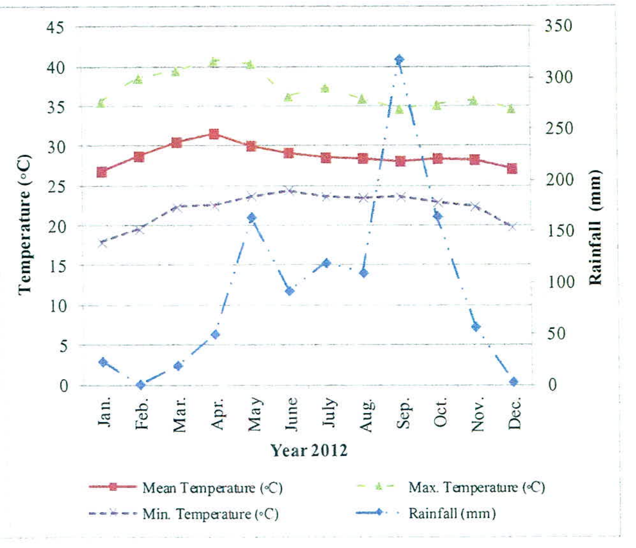


Figure 7.1 Climatic conditions at the experimental sites

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 the 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 Khon Kaen 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 as summaries in Table 7.1. The fertilizer application rates and timing was determined base on the typical practices of the local farmer.

The soil of this experimental site was a high activity clay soil type, classified as a Takhil soil series according to the classification of the Land Development Department, and Mollisols soil series according to the USDA classification. Basic soil properties determined from this site are shown in Table 7.2. The top 30 cm soil layer had a texture of clay soil with low organic carbon and moderate alkaline.

Table 7.1 Nitrogen fertiliser application at the experimental sites

Fertiliser applications	Day after planting	Application rate (kg N ha^{-1})
1) No. 1 (N-P-K: 16-20-0)	0	44
2) No. 2 (N-P-K: 15-7-18)	106	33
3) No. 3 (N-P-K: 46-0-0)	128	54
4) No. 4 (N-P-K: 46-0-0)	151	54

Table 7.2 Soil characteristics of the experimental sites. Standard errors are in parenthesis.

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)

7.1.2 Flux measurements and GHG emissions calculation

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 farming management practices were collected during the experimental 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 preventing 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 in turn for 20 minutes for CO_2 and CH_4 gases, and 30-60 minutes for N_2O gases. 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 (Fig. 7.2). 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).

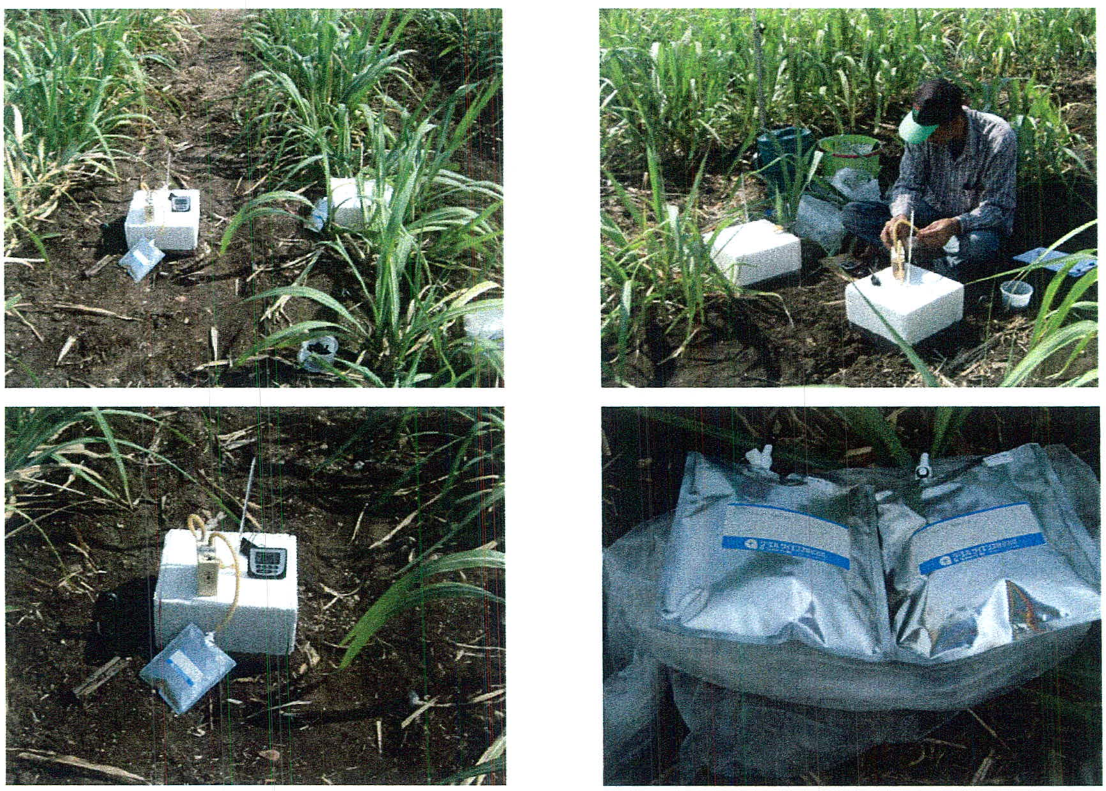


Figure 7.2 Soil GHG emissions measurement in the experimental sites

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 Eq. (7.1).

$$C_i = \frac{q_i M_i P}{RT} \qquad (7.1)$$

where C_i is the gas concentration in terms of mass per volume concentration (mg. m^{-3}), q_i is the gas concentration in terms 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 the 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 (Eq. 7.2).

$$F = \frac{V}{A} \cdot \frac{dC_i}{dt} \tag{7.2}$$

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}).

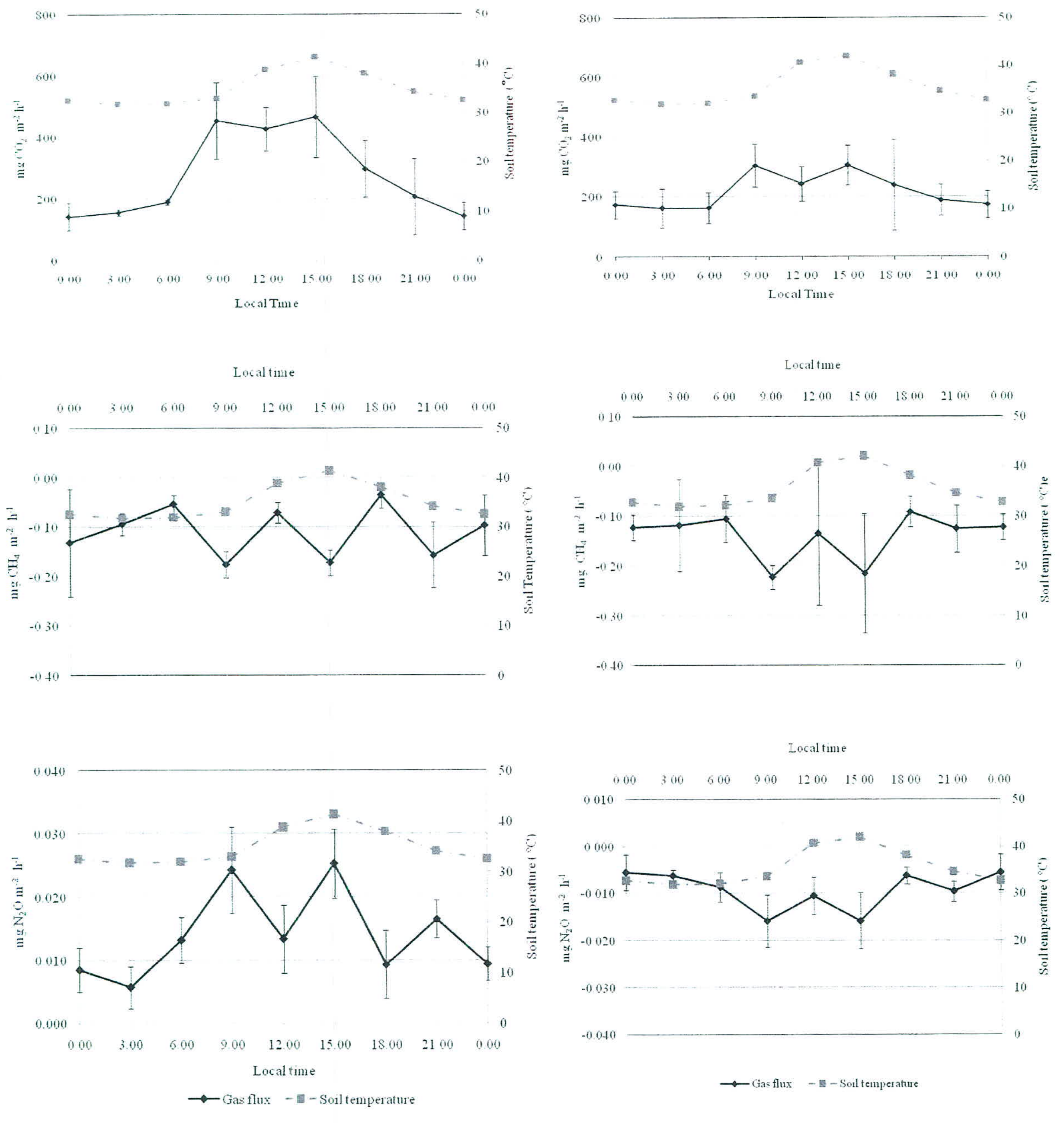
Daily average CO_2, CH_4, and N_2O fluxes and their standard errors were calculated based on the original data measured in the field. In addition, all values of GHG emissions were converted to CO_2 equivalent following the individual global warming potential for a period of 100 years for each gas using 1 for CO_2, 21 for CH_4, 310 for N_2O (IPCC, 2007).

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 the gas samplings. 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).

7.2 Results and discussion

In this study, the diurnal cycles of CO_2, CH_4, and N_2O fluxes were measured two times during the dry and wet seasons for evaluating the daily fluxes. During the dry season, the 24-hour measurement of CO_2, CH_4, and N_2O fluxes showed clear diurnal cycles in the daily emissions with high values during daytime and low values during night time, as shown in Figure 7.3. Soil temperature and high soil aeration during the day influence gas diffusion. This is in line with findings from the study by Denmead et al. (2010).

The observed daily patterns of GHGs flux variations are probably linked to temperature change during daytime, i.e. when soil temperature increases, soil effluxes also increase.

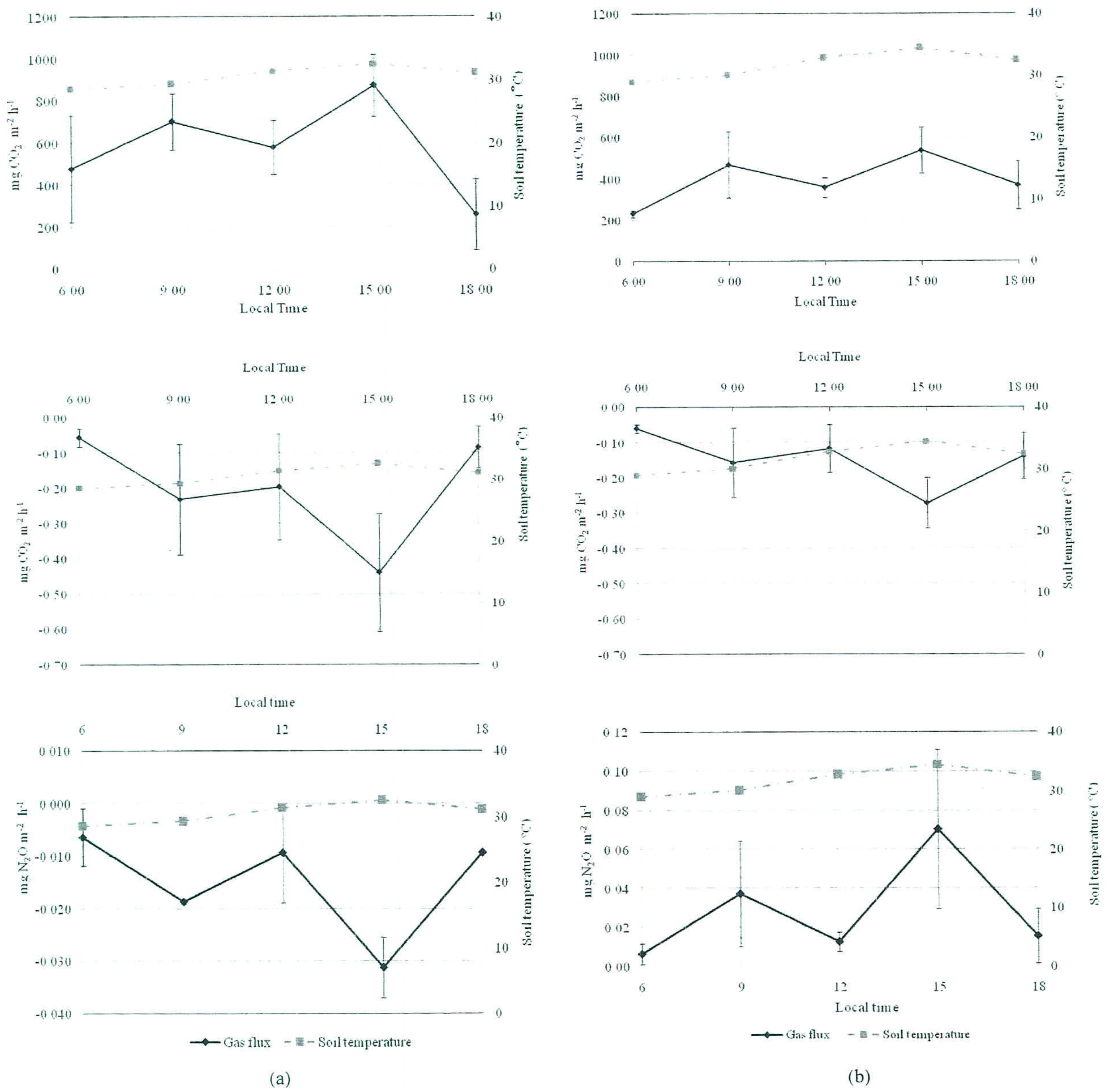


(a) (b)

Figure 7.3 Examples of diurnal cycles of soil CO_2, CH_4, and N_2O fluxes at (a) the middle of sugarcane plant-rows and (b) the spaces between-rows of the burned area (measurements on 23 March 2012, i.e. during the dry season).

For the wet season, the daily flux was monitored over a 12-hour period on 7 August 2012 to identify differences in diurnal cycles between the dry and wet seasons. Figure 7.4

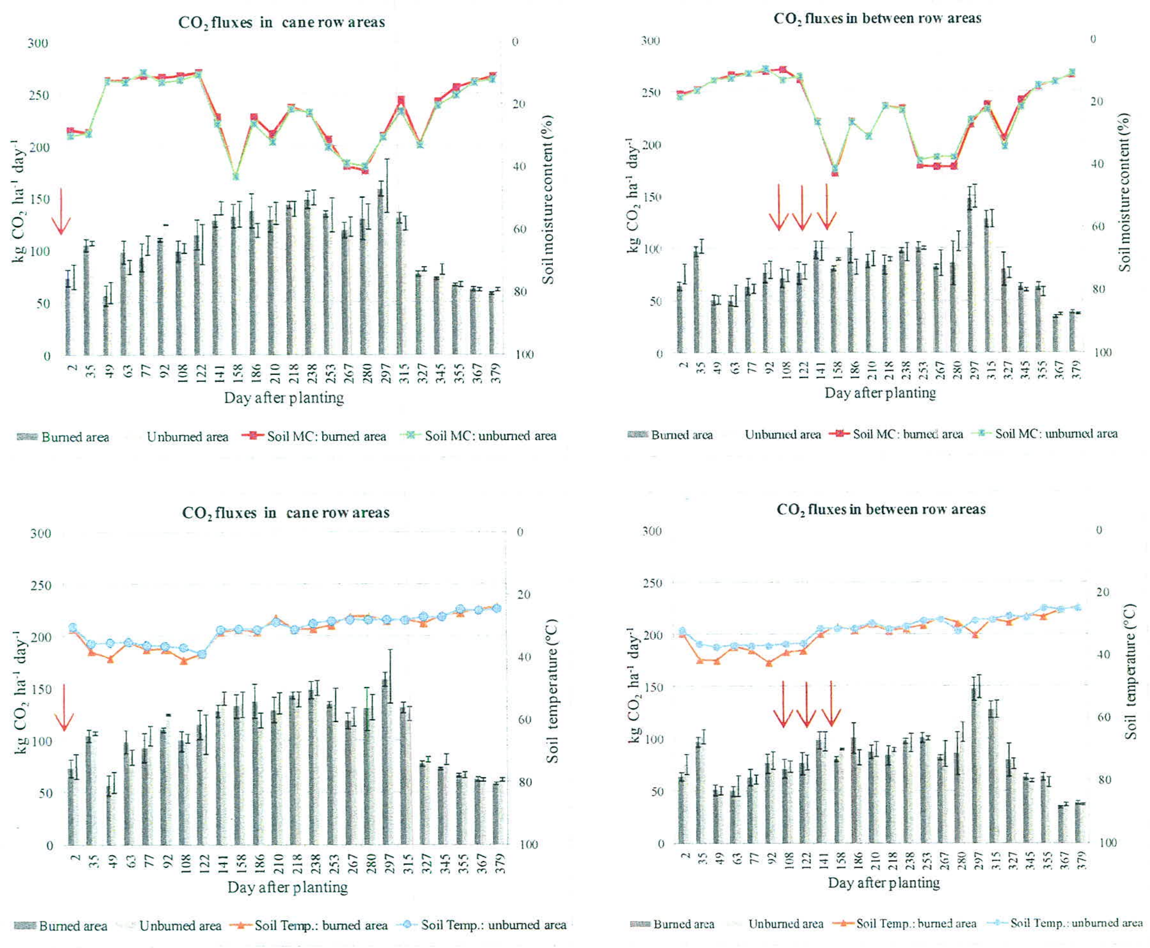
shows the diurnal cycles of CO_2, CH_4, and N_2O during the daytime in the wet seasons. The results show similar patterns of daily fluxes between the dry and wet season. The different values of gas fluxes recorded at each site are probably due to specific conditions of soil moisture content, soil temperature, root distribution in soil, and farm management practices followed, i.e. amount of fertilizer applied over the growing season of sugarcane.



(a) (b)

Figure 7.4 Diurnal cycles of soil CO_2, CH_4, and N_2O fluxes measured over 12-hour measurement periods during wet season in (a) cane-row and (b) between-row positions of sugarcane.

Regarding daily fluxes, the GHG fluxes of the burned and unburned sugarcane cropping systems were determined over 379 days (i.e. over the entire 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 gas fluxes on a per hectare basis for both treatments. Hourly fluxes were scaled up to daily fluxes with correction of the diurnal variation for each gas emission.



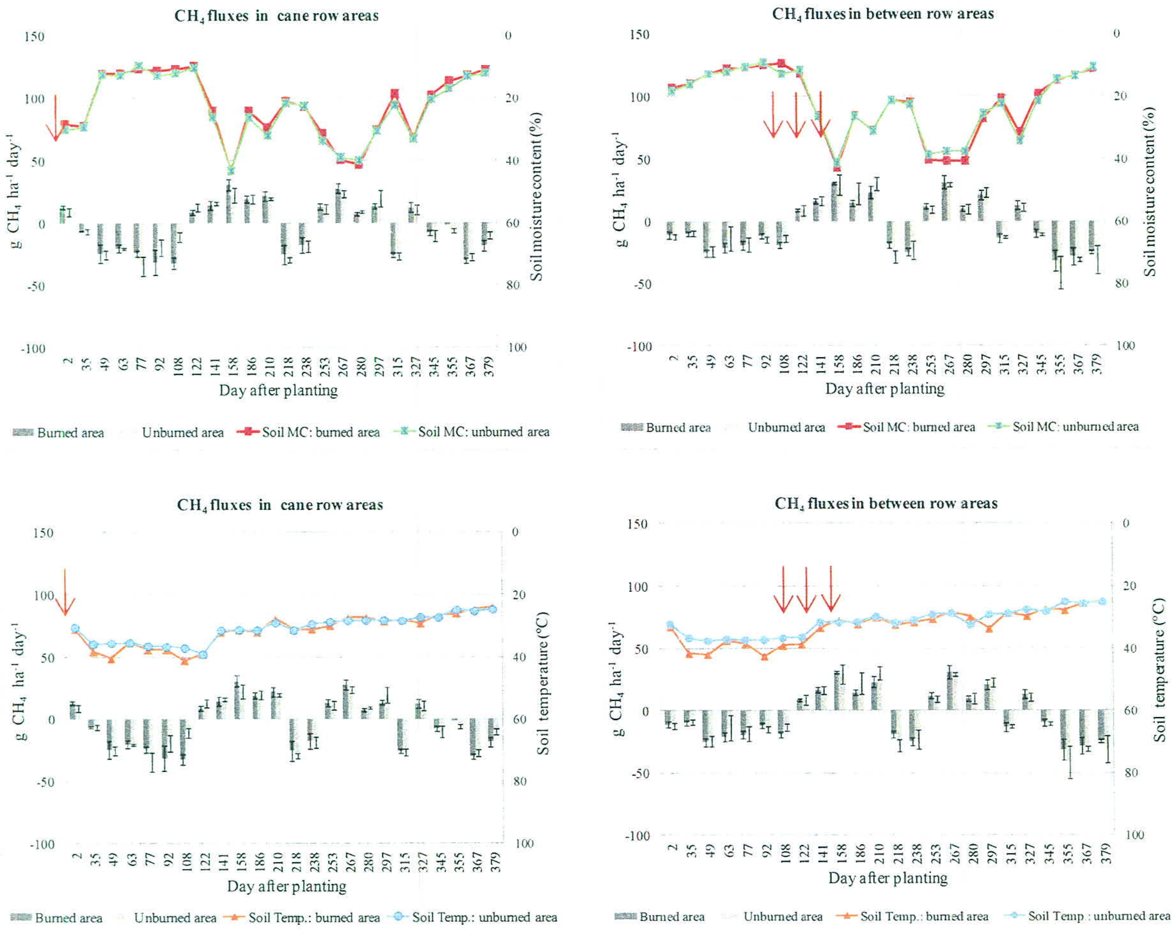
(a) (b)

Figure 7.5 Soil CO_2 flux, soil volumetric moisture content, and soil temperature from burned and unburned sugarcane areas over 379 DAP in (a) cane row and (b) between-row position of sugarcane. Arrows represent dates of N fertilizer application.

Figure 7.5 shows that soil CO_2 fluxes from the sugarcane plant-row areas were significantly higher than those from the spaces between row areas. The higher emissions observed from plant-row areas may have been influenced by root respiration. On the other hand, no significant differences in terms of CO_2 fluxes were observed between the burned and unburned sites. The total CO_2 fluxes over 379 days 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 flux rates over the growing season were found to amount to 93.84 ± 1.94 kg ha^{-1} day^{-1} for the burned plot, and 94.96 ± 3.16 kg ha^{-1} day^{-1} for the unburned plot. This value is quite close to the daily flux value of 111 kg ha^{-1} day^{-1} reported for sugarcane soil by Denmead et al. (2010). However, previous studies have shown that daily CO_2 fluxes can vary largely, in the range 34 to 156 kg ha^{-1} day^{-1} (Yuttitham, 2009; Denmead et al., 2010), possibly because of different soil conditions, farm management practices and climatic conditions.

Regarding seasonal variations in CO_2 flux, the higher rates observed during the first period of measurements (over 35 DAP) may be explained by soil disturbances from farm machinery used to prepare the soil. It is also related to the high decomposition rate of sugarcane residues returned to the soil around that time (Yuttitham, 2009). During the growing season, CO_2 fluxes are observed to increase with the plant age, during the young seedling stage, and to decrease over the last period of the growing cycle (over 327 DAP). One of the factors that might contribute to this reduction could be the low moisture content observed in the soil at that time. Soil moisture content might be a one of the important factors influencing CO_2 emission from soils. The CO_2 flux tended to increase when soil moisture content increase but with much less significance (R^2 = 0.2). For soil temperature, the results indicated that no significant influence of soil temperature on CO_2 emission fluxes. This finding is in good agreement with results from Panosso et al (2009) and Epron et al. (2004) who mentioned that soil temperature had no effect on soil CO_2 emissions.

CH_4 fluxes are close to zero as expected for dry crop soil. This result is confirmed by another previous work from Yuttitham (2009) who stated that there are no CH_4 emissions from sugarcane in Thailand. This is also similar to other works from Denmead et al. (2010) who showed that there is no net flux of CH_4 from sugarcane under rainfed areas in Australia, while high emissions of CH_4 were found for a sugarcane plantation grown in an estuary flood plain. It was suggested that the source of CH_4 emissions in the experiment under an estuary flood plain was likely the result of anaerobic production in the many drains in the vicinity of the site. 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. 7.6. CH_4 flux 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 (Figure 7.6). Likewise, there was insignificant difference in the total CH_4 fluxes 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 soil moisture content, this study found that soil moisture content is a major influencing factor of CH_4 emissions. High soil moisture content caused on increase in CH_4 flux as shown in Figure 7.6. On the other hand, soil temperature was found to have no significant influence on soil CH_4 emission fluxes. Similarly, Denmead et al. (2010) reported that there was no dependence between CH_4 emissions and soil temperature.



(a) (b)

Figure 7.6 Daily CH_4 flux, soil volumetric moisture content, and soil temperature from burned and unburned sugarcane areas over 379 DAP in (a) cane row and (b) between-row position of sugarcane. Arrows represent dates of N fertilizer application.

In Figure 7.7, it is observed that soil N_2O emission fluxes from the areas between-rows are significantly higher than that those from the cane-row areas. This could be due to the high amount of nitrogen fertilizer applied in the area between-rows. The mean daily N_2O emission flux rate for the burned system amounts to 4.86 ± 1.16 g ha^{-1} day^{-1}, and to 4.73 ± 0.99 g ha^{-1} day^{-1} for the unburned system. The total flux of N_2O over the whole growing period for the burned and unburned systems are 1.84 ± 0.42 and 1.79 ± 0.38 kg ha^{-1}, respectively. No significant differences in N_2O fluxes are observed between the two sites.

(a) (b)

Figure 7.7 Soil N_2O flux, soil volumetric moisture content, and soil temperature from burned and unburned sugarcane areas over 379 DAP in (a) cane row and (b) between-row positions of sugarcane. Arrows represent dates of N fertilizer application.

As shown in Figure 7.7, the flux of N_2O emissions increases significantly after fertilizer application and remains at high levels for nearly 2 months, before declining to almost zero. Similarly, Denmead et al. (2010) reported that N_2O flux under sugarcane farm in Australia increased rapidly in the first 2 weeks after N fertilizer application and remained at high levels for almost 5 months. Also, Allen et al. (2010) mentioned that the highest N_2O emissions were observed in the first 2 months after N fertilizer application. So, it should be noted that N fertilizer is an important source of N_2O emissions from sugarcane soil. The emissions of N_2O increase with the increasing N fertilization rates.

This study also found that N_2O emissions from soils represented about 0.32% of the N added to the soils. It is well within the range of the previous research reported that N_2O emissions from agricultural soil vary from 0.03% to 21% of the total N fertilizer applied (Eichner, 1990; Yan et al., 2001; Allen et al., 2010; and Denmead et al., 2010). Large variability in amplitude and temporal dynamic in N_2O emissions responding to N fertilizers have been reported in the literature, possibly due to the effects of fertilizer type, the method of N application, soil conditions, and climate conditions. As Allen et al. (2010) mentioned that the different N_2O emissions were observed in fields receiving different fertilizer types and application methods. However, it is cause not only by fertilizer characteristics but also impacted by climate, precipitation and soil type.

Furthermore, the observation data from the cane row areas shows that there is virtually no influence of soil moisture content on the flux of N_2O. This is opposite to what is observed for the case of between-row area of sugarcane. This difference may be explained by the fact that in the area of cane-row no nitrogen fertilizer was applied after planting. These results in low nitrogen availability in the soil minimizing therefore the impact moisture content may have on N_2O emissions. The study from Denmead et al. (2010), confirms this assumption also indicating that high soil moisture content seems to favour the production of N_2O as a result of nitrification and denitrification processes. For soil temperature, plots of emission flux rates against soil temperature showed that there is some relationship between the two parameters for the cane row area. This is the area where nitrogen fertilizer was applied at the beginning of planting during the dry season (the period during which soil moisture content is low and soil temperature is high). On the other hand, no clear relationship between the two parameters is observed for the area of between row where nitrogen fertilizer was applied during the wet season (the period during which soil moisture content is high and soil temperature is low). This may be explained by the effect nitrogen fertilizer application may contribute to soil N_2O emissions over all other effects.

Table 7.3 GHG fluxes from sugarcane soil under burned and unburned conditions

	Burned area		Unburned area	
GHG fluxes	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

To find the net GHG fluxes from soil, each gas was converted into a CO_2 equivalent value using global warming from the 100-year time horizon GWP equivalent factor, as mentioned previously. Table 7.3 summarizes the GHGs fluxes from soils in the burned and unburned areas during the whole growth period. There was no significant difference in the annual GHGs fluxes between burned and unburned soils. The total GHG fluxes from sugarcane soils in this experiment were about 35.94 – 36.36 Mg CO_{2eq} ha^{-1}. As expected, the CO_2 flux was found to be the highest comparatively to others and accounted for 99% of the total GHG flux. Only 0.38 – 0.39 Mg CO_{2eq} ha^{-1} were emitted as N_2O and non-emission flux was from CH_4.

7.3 Summary of findings

The close chamber technique was used to monitor GHGs flux from soils, including CO_2, CH_4, and N_2O, for sugarcane plantations in burned and unburned plots. The measurements were performed over 379 days, to cover the whole growing season cycle of a new sugarcane plantation. It was found that there are no significant differences in terms of total GHG emissions between burned and unburned plots. The net emission for a one year cycle was found to be 36 Mg CO_{2eq} ha^{-1}, which represents 99% of the total flux reported as CO_2. There were virtually no soil emission fluxes of CH_4 and low emission fluxes of N_2O in the range 0.38 – 0.39 Mg CO_{2eq} ha^{-1}. Also, it was found that soil moisture content is one of the important factors influencing GHG emission fluxes from soil especially CH_4. However, the results obtained from this experiment are site-specific and may not be applicable to other areas. To confirm further the findings of this research, muti-seasonal studies of at least three years at different locations would be necessary.