CHAPTER 3

GHG EMISSIONS FROM RICE FIELDS WITH DIFFERENT CULTIVATION PRACTICES

3.1 Introduction

Thailand is an agricultural country and among other agricultural crops, rice is the most important one. The paddy fields account for 10 million hectares or 50 % of agricultural area. Production from rice farming is not only rice grains but also huge amounts of rice straw. About 48% of rough rice straw produced is burnt in the field (DEDE, 2003). Therefore the suitable rice straw management is necessary to avoid the effects of air pollution from rice straw burning. In practical, rice straw is burned in the field after harvesting as it is the most economic and convenience way to clear the land for the next cultivation. The open field burning releases several air pollutants such as smoke, particulate matter, ash and greenhouse gases (CH_4 and N_2O). The approximate air pollutant emissions from open field burning of rice straw in Thailand are 12,207, 10 and 1 Gg/yr in term of CO_2 CH_4 and N_2O, respectively (Gadde et al., 2009). Recently, the government concerns over the negative air quality effects of the traditional practice of rice straw burning, has led to new legislation set up along with the national master plan for open burning control. The incorporation of rice straw into field improves soil fertility and soil organic carbon storage (Singh et al., 2004). Therefore, incorporated of rice straw has been promoted for the attractive choice of rice straw management. However, the incorporated activity increased organic carbon and decomposition rate and influence on the pattern of methane formation in the rice field. Generally, addition of rice straw enhances methane production (Neue et al., 1996; Chidthaisong and Watanabe, 1997; Bossio et al., 1999; Ma et al., 2009) and amount of rice straw incorporation linearly increases methane emission from paddy soil (Shang and Hsiu, 1998). Another significant effect of rice straw incorporated before transplanting has been associated with decreases in rice yield (Sass et al., 1991) because the production of organic acids which reduce seedling root growth.

The future of rice cultivation practice is to reduce greenhouse gas emissions from paddy fields with avoidance of air pollution from open field burning. Based on percent of global distribution of rice area, irrigated rice is the largest source of CH_4 emission of all rice ecologies (Buendia et al., 1997). Water management is one of the most important factors in rice cultivation. The mitigation option of water drainage in irrigated rice fields (Towprayoon et al., 2005) presented the possibility of reduction of average methane emission. Yagi et al., (1996) reported that CH_4 emission with intermittent irrigation decreased to 45% of continuous flooding. Therefore, these experiments focused on sustainable cultivation practices with rice straw and water management under the constraint of greenhouse gases reduction and avoidance of air pollution.

3.2 Methodology

The field experiment consisted of the study of soil temperature and soil water content changing in rice fields in real-time when the rice straw was burned and the optimization of rice straw management under drainage system with the aim to reduce greenhouse gases emission.

3.2.1 Site study

Field studies were carried out during the rice cultivation periods of 2007 and 2008 in the experimental paddy field at Samutsakorn, Thailand (Figure 3.1). This area is located in the central plain of Thailand (100° 20′ E, 13° 20′ N). The site study was an irrigated rice field cultivated two times per year. Normally, the rice plants (*Oryza sativa* L. ssp. *indica*) were modern varieties that can be harvested in 120 day after scattering seed. Normally, the rice straw was burned in rice field after harvest. Rice field was 25 year continuously grown using conventional practices of the area as listed in Table 3.1.

The paddy soil of the field experiment is classified as Typic Tropaquepts in Bangkok soil series. Soil texture is clay with a percentage composition of sand: silt: clay of 22:24:54 (Smakgahn, 2003). The soil samples were collected from the experiment field before 2nd harvesting time. Summary of physical and chemical soil properties are listed in Table 3.2. This soil contained 2.94% of total carbon and 0.08% nitrogen content under an initial soil pH of 5.71. The properties of soil samples in depth 1-10 cm show height level of fertility with organic matter, total carbon, total nitrogen and available K, while available P show intermediate values. Content of iron and manganese are height values. The annual precipitation is about 1,128 mm and mean temperature is about 28.5°C. The relative humidity is between 70–75%. The rainy season starts in May and usually lasts until

October. Mostly soil temperature regime of Thailand is Isohyperthermic Soil Temperature Regime that the average temperature of site study shows in the range of 22-32 °C.

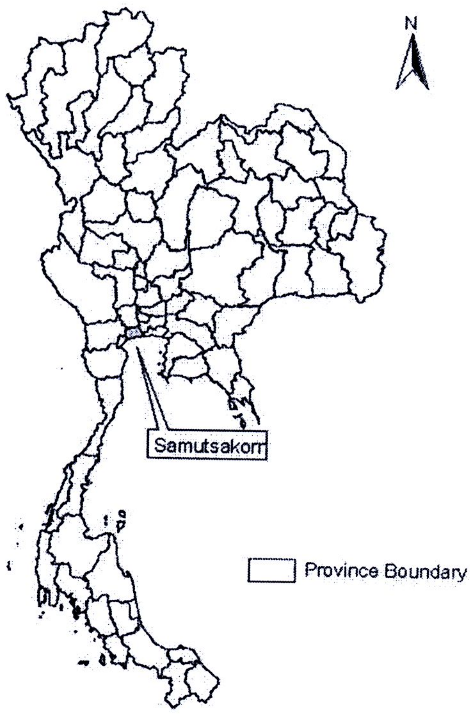


Figure 3.1 Map of Thailand with location of study site (▒)

Table 3.1 Field conventional practices of site study

Agricultural practice	Period/ Quantity
1. Open field burning for land preparation	After 2-3 days rice harvest
2. Fallow period	2-4 weeks
3. Scattering seed	25 kg/rai
4. Drainage	Before fertilizer or pesticide application
5. Fertilizer apply	a. 16-20-0 (about 15 DAS* / 25 kg/rai) b. 30-0-0 (about 50 DAS* / 10 kg/rai)
6. Pesticide apply	Upon pest
7. Final drainage	Before harvest about 2 weeks
8. Machinery harvest	1 day

*DAS means days after seed sowing.

Table 3.2 The physical and chemical properties of the paddy soil

Soil property	Value
pH(1:1)	5.71
Organic matter (%)	3.57
%C (w/w)	2.94
%N (w/w)	0.08
P (mg kg-1), Bray II	9.72
K (mg kg-1), Extract by NH_4OAc	351
Fe (mg kg-1)	29.32
Mn (mg kg-1)	163.75
EC $_{(1:5)}$ dS m-1	1.18

3.2.2 Experimental design

This field experiment determined the effect of burned rice straw, incorporated rice straw and field drainage on CH_4 emissions under the same cultivar type, Suphan Buri 2, and agricultural practices in order to find suitable cultivation practices for methane mitigation and rice production. Six treatments with an individual size of 100 m^2 in the measurements field were carried in a split plot. There were designed with water management that consist of mid-season drainage plots (M) and local drainage plots (L). The Local drainage refers to draining by local farmer considering rice plant health when water weed and acidity water occur or fertilizer application. More over the Mid-season drainage is three days draining during early rice flowering stage. Therefore, in M treatment were drained 2-3 times per crop while, L treatment were drained 1-2 times per crop. Inside the water management plots were separated with three rice straw treatments. The rice straw managements consist of stubble incorporated (S), rice straw burning (B), and rice straw and stubble incorporated (I) as show in Table3.3. After rice harvesting by machine, the rice plants were separated to rice straw and stubble. This study defined the "stubble" in S plots as a part of stem above ground 20-30 cm height that stand in the field, the other part is "rice straw" that was cut and removed from field. Stubble is usually combination of below and above ground biomass of rice plant. The rice straw and a part of stubble were burned on field and the residue from field burning was incorporated into soil as B plots. Burning fraction in this study was measured by Kanokkanjana (2010) to be 78.8%. On the other hand, whole rice straw and stubble in I plot were incorporated into soil as show in Figure 3.2. The above ground biomass of rice plants was measured with regardless the below ground biomass.

Table 3.3 Experiment design for water management and rice straw management

		Rice straw management		
		Burn	rice straw & stubble **Incorporate**	**Stubble** incorporate
Water management	**Mid-season drainage**	MB	MI	MS
	Local drainage	LB	LI	LS

The first cultivation was started in the middle of April and continued until harvest in August (wet season) and the second cultivation was conducted from September until December (dry season). The paddy field was left on short fallow period between rice cultivation about two weeks. We defined the fallow period as the interval from after harvest until finish land preparation. That means the rice field was dry in early period and wet in land preparation time. The first fallow period included dry condition on 10-17 August and wet condition on 18-30 August. The second fallow period included dry condition on 26 December, 2007 – 17 January, 2008, after that, the rice field was in intermittently flooded as wet condition on 18-22 January, and 23-29 Febuary, 2008.

After the harvest of the previous cultivation, the rice straw was removed from S plots, remaining approximately one-third of the aboveground biomass of the rice plants (stubbles) as approximately 300-500 g/m^2. The rice straw was burned for burn plots as a cultural practice in irrigation rice field. In the incorporated plots, the whole rice straw was soaked for few days, after that rice straw was incorporated into the soil at an amount of approximately 500-600 g/m^2. Normally, wetland tillage is traditional practice for this region. The advantages of puddling land preparation are impervious to water, limited weed growth and increasing nutrient transformation.

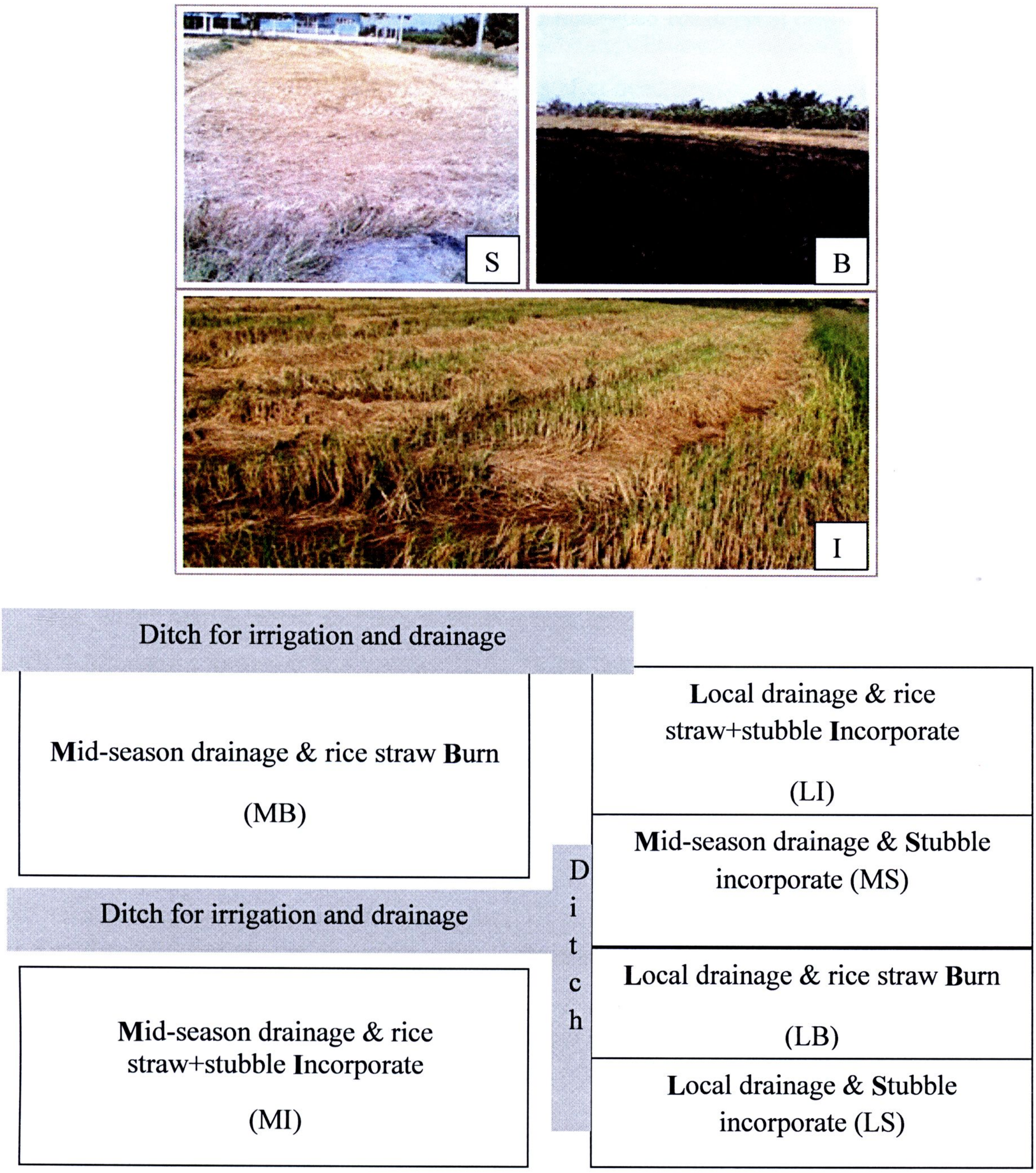


Figure 3.2 Schematic illustrations of the experimental plots

The fields were flooded about half month in fallow period. After land preparation, wet seeding with 25 kg of seed/rai was applied. Before spreading seeds, the rice field was drained and the rice field soil was kept in saturated condition by drainage the field with enough water to make rice field wet. The fields were re-flooded on 15 days after seed sowing and the water level in each plot was controlled approximately 5-15 cm throughout the growing period, except for during drainage periods. Last drainage was performed at 2 weeks before harvest in order for farmers to use the machines for harvest easily.

The fertilizer was applied during 15-20 days after seed sowing as the basal fertilizer as N-P-K: 16-20-0 (25 kg/rai). Nitrogen as urea fertilizer was applied as the top dressing fertilizer (30-0-0) during 50-56 days after seed sowing. Finally, the rice was harvested on 114 days in first cultivation and 106 days in second cultivation. The planting calendar of rice cultivation in experiment field was shown in Table 3.4.

The outline of the water management of the L treatment during the rice cultivation period was based on conventional practices of continuous flood irrigation, drainage and subsequent intermittent floods as shown in Table 3.4. In M treatment, the field was flooded and re-flooded similar with L treatment, except during mid-season drainage to start the flowering stage.

The water management in the wet season was locally drained two times in 45 and 55 DAS. Mid-season drainage was conducted in 81-84 DAS during flowering stage of rice plant. On the contrary, the mid-season drainage in dry season was conducted in 63-66 DAS during the heading stage of rice plant and the local drainage was conducted only one time in 13 DAS for pesticide application.

Table 3.4 Planting calendar of rice cultivation in Samutsakorn, 2007

Cultivation practice		1stcrop (wet season)		2ndcrop (dry season)	
		Date	Das*	Date	Das*
1.	Fallow period (flood)	12 March-5Apr		18-19August	
2.	Soil preparation (flood)	6–10 April		20-30 August	
3.	Scattering soaked seed (Local drainage)	13 April	0	6 September	0
4.	Re flood	27 April	15	20 September	14
5.	Fertilizer application	9 May	27	26 September	20
6.	Start tillering stage	12 May	30	2 October	26

Cultivation practice		1st crop (wet season)		2nd crop (dry season)	
		Date	Das*	Date	Das*
7.	Pesticide application (Local drainage)	27 May	45	19 September	13
8.	Fertilizer application (Local drainage)	6 June	55	-	-
9.	Start flowering stage (Mid season drainage)	2 -5 July	81-84	8-12 November	63-66
10.	Local drainage before harvest	20 July	106	27 November	82
11.	Harvest	9 August	119	25 December	110
12.	Fallow period (dry)	10-17 August		Dec 07 – Mar 08	

*DAS means days after seed sowing. The gray rows perform the water drainage.

3.2.3 Study of physical property of soil in the initial period

In the burned plot, the paddy soil was measured for the physical property of soil at 0-30 centimeter depth (rhizosphere zone), before and after field burning. Parameters of physical soil property are bulk density, soil moisture, soil temperature and volumetric water content in soil. The experiments were accomplished in 2 sites during 13-20 February 2007 on nearly field (pre-test) and during 11-12 March 2007 on experiment field.

Bulk density (D_b) is the mass of a dry soil sample per unit bulk volume as compared to the mass of an equal volume of water. A soil core, 7.3 cm in diameter and 4 cm in height, was inserted to full height into the soil, broken out and the bottom cut neatly across with the end of the core so that the water could be retained. Three replicates were done at each depth of soil 0-10, 10-20 and 20-30 cm Bulk density of each soil samples was determined by weighting the sample after oven dry at 105 °C for 24 hours. Bulk density is expressed as grams per cubic meters and calculated in Equation 3.1 (Brady and Weil, 2002).

$$\text{Bulk density, } \rho_b \text{ (g cm}^{-3}\text{)} = \frac{\text{Weight of oven dry soil (g)}}{\text{Total volume of soil (cm}^3\text{)}} \qquad (3.1)$$

Soil moisture or soil water content is the amount of water present in the soil. Gaps between soil particles are called pore spaces or voids. These voids contain various amounts of either water or air. Soil moisture content can be expressed on different bases:

- Gravimetric Soil Moisture (θ_m): the mass of water/mass of solid material (g/g) This section the soil moisture represents in percentage (%) and calculated in Equation 3.2 (Brady and Weil, 2002). A sample of moist soil is weighed before and after complete drying, and the mass of water lost is divided by the dry soil mass to calculate grams of water per grams of dry soil.

$$\text{Soil moisture (\%)} = \frac{\text{Weight of wet soil} - \text{Weight of oven dry soil}}{\text{Weight of oven dry soil}} \times 100 \quad (3.2)$$

- Volumetric Soil Moisture (θ): the volume of water/volume of soil and gaps (cm^3/cm^3). The relationship between the mass and volume of soil water content can be summarized as: $\theta = D_b \times \theta_m$ (Brady and Weil, 2002)

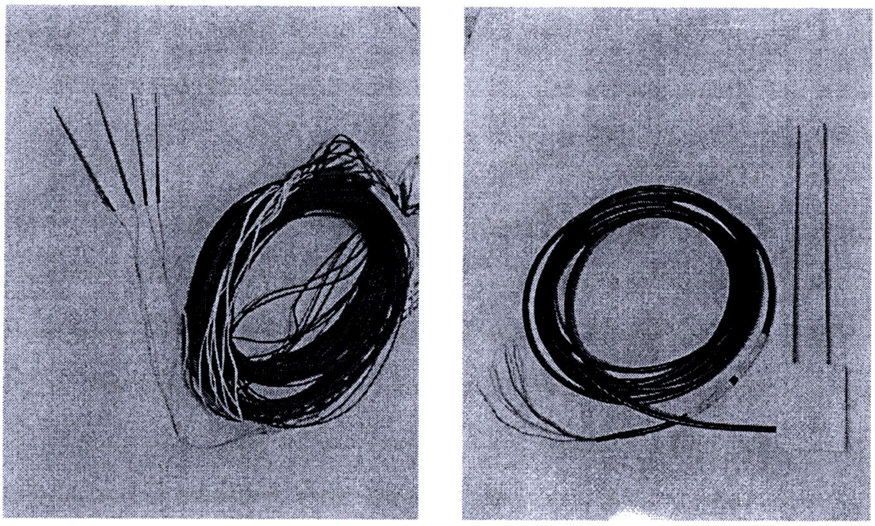
Soil temperature and volumetric water content in field burning period

In case of rice straw burning on farm, it is important to measure how the surface soil is damaged. This initial experiment in land preparation was conducted in order to determine the effect of open field burning on changes of soil physical that will disturb the soil microbe. Soil temperature and volumetric water content were measured continuous from one day early rice straw burning until open field burning. The burning period in pre-test field was 10.30 -12.00 a.m. on 15 Feb, 2007. Afterward, the MB and LB plots were burned on 5-6 p.m. 11 Mar, 2007 in experimental site.

The water content reflectometer method using probe model CS616, Campbell Scientific for measuring soil water content is an indirect measurement that is sensitive to the dielectric permittivity of the material surrounding the probe rods. The output of CS616 probe is period in milliseconds (τ). The conversion τ to volumetric water content was shown in relative equation (3.3). Multiply a fraction basis by 100 to express in percentage of volumetric water content.

$$\theta_v(\tau) = -0.187 + 0.037\tau + 0.335\tau^2 \quad (3.3)$$

The temperature and volumetric water content were measured continually in column dimension at depth of 5, 10, 20 and 30 cm Temperature probes (chromelconstantan thermocouples) and water content reflectometers were inserted to 4 level depths of paddy soil. Both measurements were taken every 10 seconds and stored values in datalogger (model CR23X, Campbell Scientific) as shown in Figure 3.3, 3.4.



(a) (b)

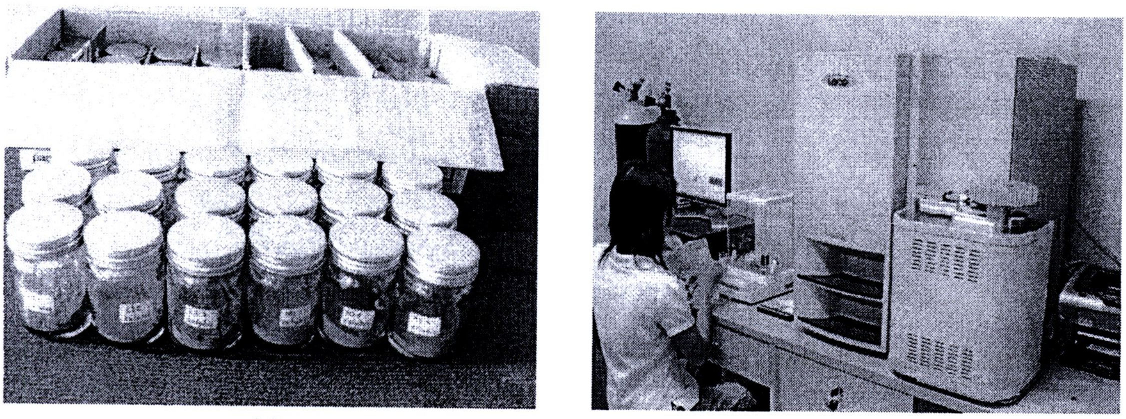
Figure 3.3 Represent (a) Temperature probes, (b) water content reflectometers

Figure 3.4 Represent probes position in paddy soil and datalogger (model CR23X, Campbell Scientific) on field during fallow period

Chemical property of soil

The soil samples at a depth of 0-10 cm were taken from three cores in each field. The soil samples were air-dried in a laboratory. After that, the samples were milled and screened through a 250 μm mesh sieve. The soil sieved was contained in bottle with date and plot marked, Figure 3.5(a).

Total amount of carbon and nitrogen in the soil were analyzed with CN soil analyzer, Leco model TruSpec CN, as show in Figure 3.5(b). Soil sample 0.25 g packed in tin foil cup was burned in furnace at 850 – 950 °C. The homogeneous combustion gases in the ballast are then purged through the CO_2 infrared detector (IR) and the 3 CC aliquot loop. Once the gases have equilibrated, carbon is measured as CO_2. The gases in the aliquot loop are transferred to the helium carrier flow, swept through hot copper to remove O_2 and change NO_x to N2 and then flow through Lecosorb and Anhydrone to remove CO_2 and H_2O. Finally, a thermal conductivity (TC) cell is used to determine the nitrogen content in unit of percentage by weight.



(a) (b)

Figure 3.5 Represent (a) Soil samples were collected in bottles, (b) CN soil analyzer model TruSpec CN, Leco.

Microbial analysis of soil

Three replicates of soil sample from I plot and B plot were collected before 2nd crop harvesting at a depth of 0-10 cm. After air drying, soil samples were sent to laboratory of Max Planck Institute for Terrestrial Microbiology, Marburg, Germany in order to analyze the methanogen community and quantity of Archaea. There are (1) the T-RFLP (terminal restriction fragment length polymorphism) pattern and (2) the qPCR bumbers of archaeal

16S rRNA genes. Both results are based on the extraction of DNA from each soil sample. The detail of methodology can be found in Conrad et al. (2008) and Penning and Conrad (2006).

3.2.4 Gas sampling and analysis

Methane (CH_4) and nitrous oxide (N_2O) fluxes were measured twice a week. The closed chamber method was used to trap gas emitted from plant and soil into atmosphere throughout the investigation period. The opaque chamber was used for avoid photosynthesis effect in daytime. Chamber base (0.3x0.3x0.1 m: width x length x height) was inserted and left permanently in the field throughout the study period, so that the equilibrium of gas in soil was not disturbed at the gas sampling time. When measurement, an opaque acrylic chamber, size 0.3x0.3x0.5 m, placed gently onto the chamber base and left for at least 15-30 minute while the gas inside the chamber was sampling at 0, 10, 20 and 30 minute during fallow period until before tillering stage of rice plants and 0, 5, 10 and 15 minute when the plants growing to vegetative stage as chamber size 0.3x0.3x0.8 m. Gas samples (20 ml) were collected with a syringe and transferred to evacuated vial bottles and wrap with parafilm. The temperature inside the chamber was measured by thermometer (0 - 100 °C) at the top of the closed chamber and record every time for sampling as show in Figure 3.6 and 3.7.

In the laboratory, gas samples was analyzed for methane and carbon dioxide concentrations using Gas Chromatography (Shimadzu model GC 14B, Japan) equipped with Flame Ionization Detector (FID) with a unibead C column and connect with Methanizer. The GC operating conditions are: FID detector temperature: 300°C, Injection temperature: 120°C, Column temperature: 100°C, with carrier gas: Helium flow rate of 65 ml/min. Sample injection volume was 1 ml.

Nitrous oxide concentrations were determined with gas chromatography equipped with a 63Ni Electron Capture Detector (ECD). The GC operating conditions are: Column temperature: 65°C, ECD detector temperature: 300°C, Injection temperature: 150°C, Carrier gases flow rate of 60 ml/min and a sample injection volume of 1 ml.

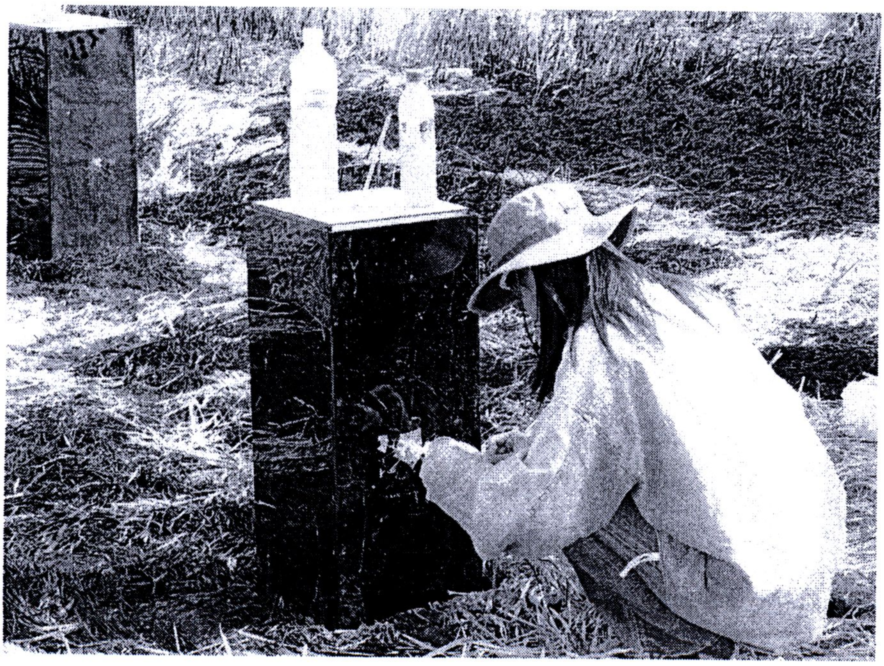


Figure 3.6 Gas sampling in paddy field after open field burning

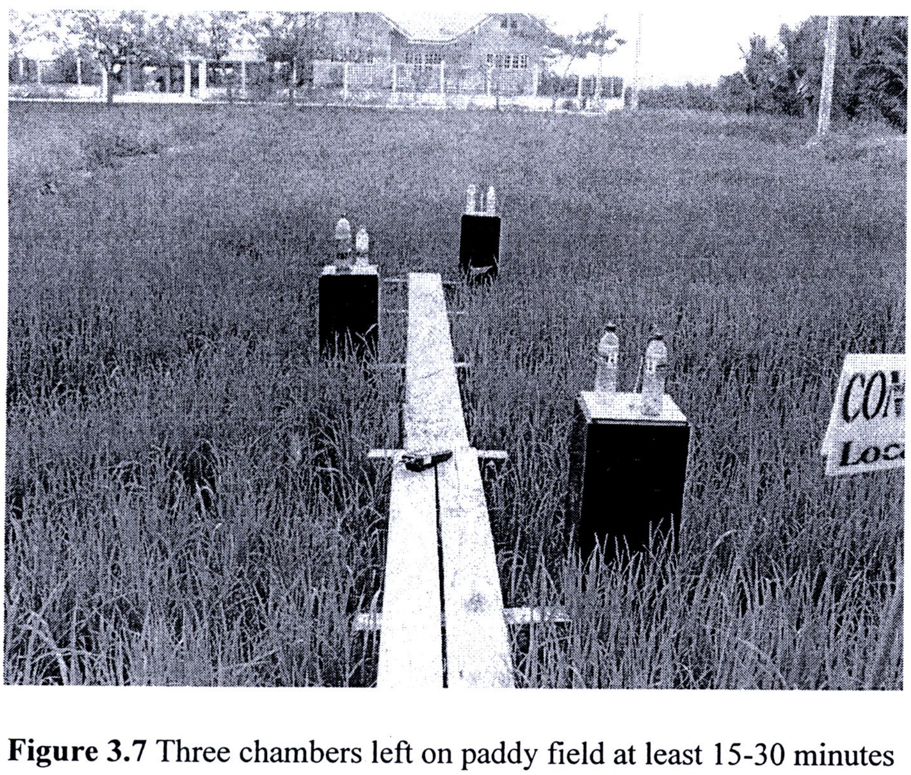


Figure 3.7 Three chambers left on paddy field at least 15-30 minutes

Flux calculations (Watanabe et al., 2000)

Greenhouse gas fluxes are expressed in terms of mass per unit area per unit of time (e.g. mg CH_4 m^{-2} h^{-1}). Firstly, the concentration obtained from the chamber headspace must be converted to a mass or molecular basis using the ideal gas law, thus, depending on temperature and pressure of the enclosed air as shown in Equation (3.4).

$$Ci = \frac{qi \times Mi \times P}{RT} \tag{3.4}$$

Where Ci = Mass/volume concentration (g/m^3)

Mi = Molecular weight (g) of CH_4 (16g), N_2O (44g) and CO_2 (44g)

qi = Volume/volume concentration (e.g. ppmv)

P = Pressure

T = Temperature (K)

R = Universal gas constant (0.082058 L.atm/ K.mol)

Soil methane, N_2O and carbon dioxide effluxes were calculated using the linear portion of the gas concentration inside the chamber change over the 20 minute sampling time step from the following Equation (3.5).

$$F = \frac{dc}{dt}\frac{V}{A} \tag{3.5}$$

Where; F = flux on the aerial basis (mg m^{-2} hr^{-1})

V = volume of the chamber's headspace (m^3)

A = area of soil enclosed by the chamber (m^2)

$\frac{dc}{dt}$ = rate of CH_4 or CO_2 concentration increase with time (ppm CH_4 or CO_2 min^{-1}). The dc was determined from the linear regression of four concentration points obtained during a measurement period.

Environment data measurement

The data set of air temperature inside the chambers was recorded at each time of gas sampling. The redox potential (Eh) of paddy soil was measured by using portable platinum electrodes (HANNA instruments model HI 9025). The electrodes were inserted in the rice soil to a depth of approximately 5 cm. The electrodes were calibrated with redox solution for platinum electrodes, HANNA HI7020. Sufficient time (~5 min) was given for measurement. The pH of flooded water and soil were measured using a portable pH meter (HANNA instruments model HI 9025). Soil temperature were measured using a portable thermo copper (HANNA instruments model HI 9025). The water table level of the flooding water and plant height in each plot was recorded throughout the cultivation periods.

3.3 Results

3.3.1 Study of physical and chemical property of soil on the initial period

3.3.1.1 Soil temperature on open burning period

Four temperature detectors were inserted into rice field one day before rice straw burning for measuring the diurnal pattern of soil temperature. Figure 3.8 shows the diurnal patterns of soil temperatures in four levels of depth soil in pre-test field on 14 Feb, 2007. The ambient temperature (blue line) ranged from 23 to 37 °C, the distance from probes to datalogger about 5 meters. The highest air temperature occurred on 2.30 p.m. at 37°C in account of diurnal effect the lowest air temperature appeared in early morning. The gradation of soil temperature at depth soil 5, 10, 20 and 30 cm showed clearly daily effects when the increasing of soil temperature delayer than air temperature. Soil temperature fluctuates annually and daily affected mainly from variations in air temperature and solar radiation. However, temperature at 20 and 30 cm soil depth showed stable in ranged 26 - 27 °C.

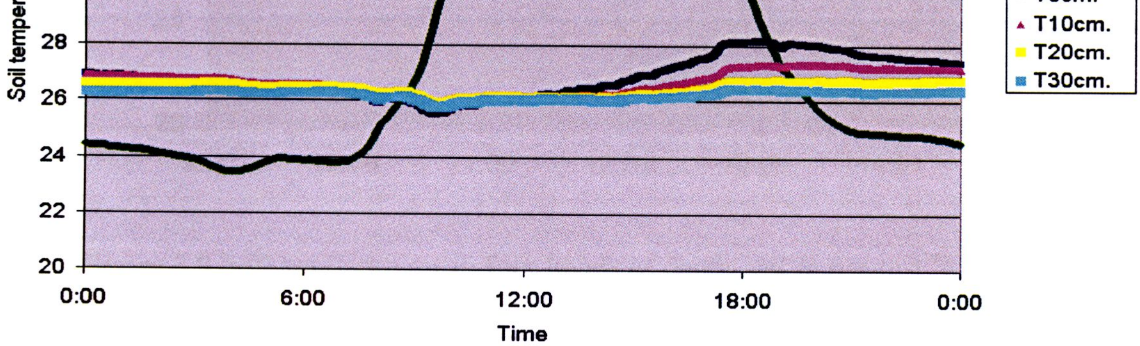


Figure 3.8 Diurnal effects of soil temperatures in four level of depth soil in pre-test field (14Feb, 2007)

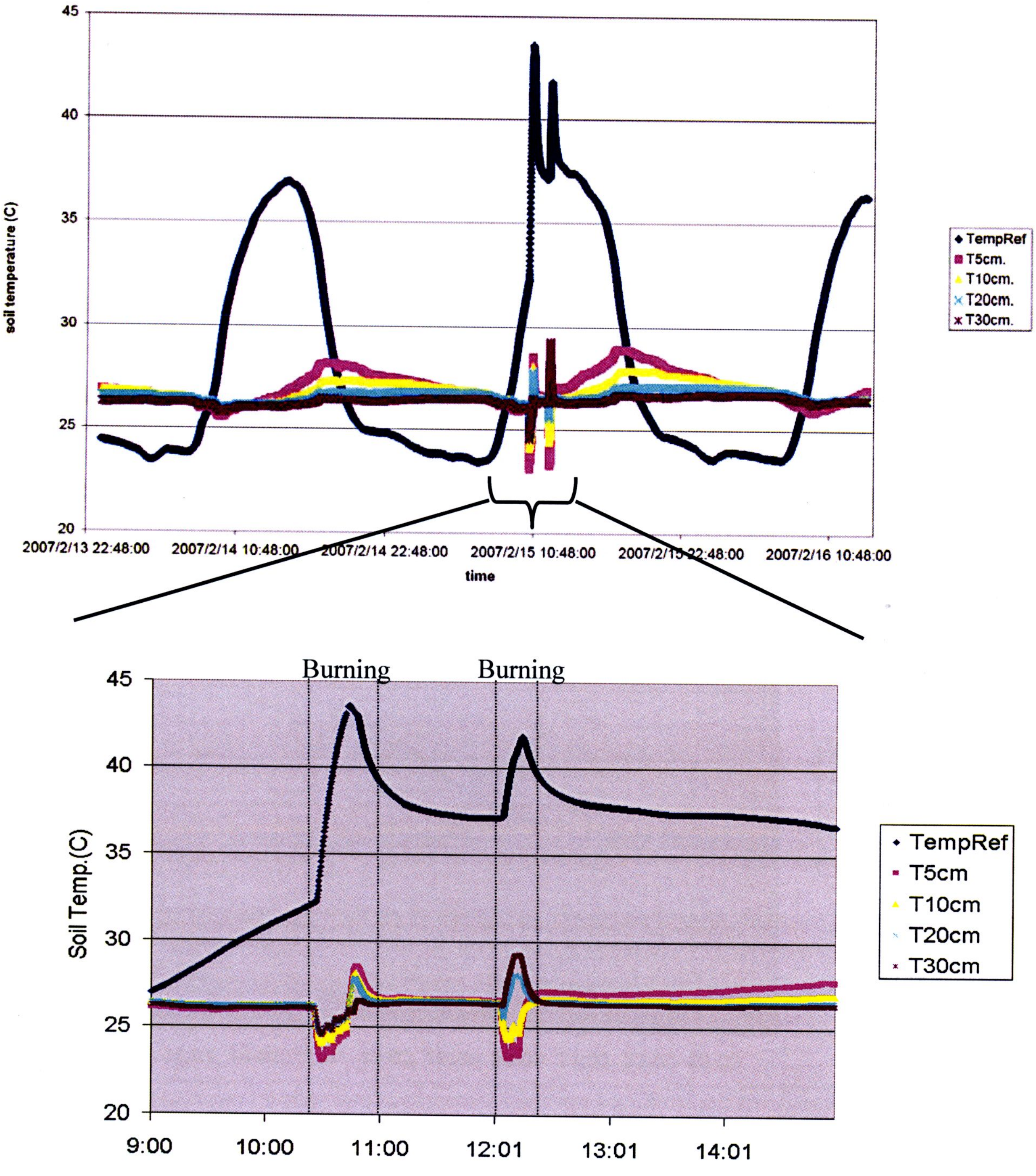


Figure 3.9 Soil temperatures in four levels of depth soil in pre-test field (burning on 15 Feb, 2007)

Rice straw was open field burned nearly noon on 15 Feb, 2007. The result presents highest peak of soil temperature on 10.48 a.m. and 12.12 a.m. as shown in Figure 3.9. The immediately change of temperature induced endothermic reaction from soil to water in order to water evaporate. In addition, the soil water in depth moved up to soil surface by capillary force that result soil temperature dropped in initial of burning. After that, the increment of soil temperature was increased up to 28 °C occurring at 5, 10 and 20 cm depth of soil on account of heat transfer from soil surface to soil depth by heat conduction process. At 12.12 a.m. the clinch burn was performed. The results of temperature change were repeated in 5 and 10 cm soil depth. However, the temperature in 20 and 30 cm of soil depth varied with air temperature.

In the experimental plot (MB), the rice straw was burned at 5.10 to 6 p.m. on 11 Mar, 2007. In the evening, with high humidity, so soil temperature during field burning had not changed much. The result of soil temperature in four depths of soil showed similar patterns with pre-test field. The soil temperature dropped about 0.5 °C before increase to 30 °C in 5 cm soil depth and gradient as shown in Figure 3.10.

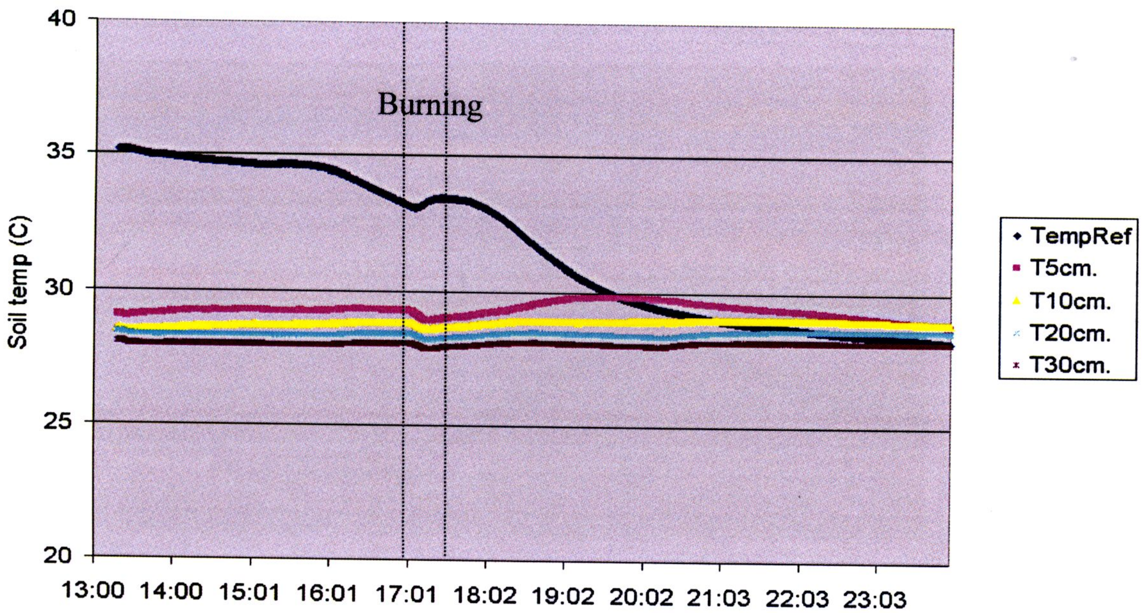


Figure 3.10 Soil temperatures in four level of depth soil in experiment field (burning on 11 Mar, 2007)

3.3.1.2 Volumetric water content on field burning period

Figure 3.11 shows the diurnal patterns of volumetric water content in four levels of depth soil on 14 Feb, 2007 one day before burning. The volumetric water content at 5 and 10 cm of depth soil showed obvious the diurnal effects which increase on daytime and fall down on nighttime. Simultaneously, volumetric water content at 20 and 30 cm depth levels showed stable around 16%. In soil depths of 5 and 10 cm soil water content relate with soil temperature because of water evaporation from soil with effects of air temperature, solar radiation and air moisture. Normally, water in lower soil moves up to soil surface by capillary force. In burning period, the water evaporation involved with the increasing of temperature. The strength of water evaporation induced the moving of water in lower soil to shallow soil, as shown in Figure 3.12. We found the increasing of water content in 10 cm soil depth and the reducing of soil water content at soil depth 20 and 30 cm. However, the change of volumetric water content did not shown clearly when the field burning was done in evening. In Figure 3.13, the volumetric water content in experiment field increased after rice straw burning (8 p.m.) because of water drainage into the field for land preparation in next step.

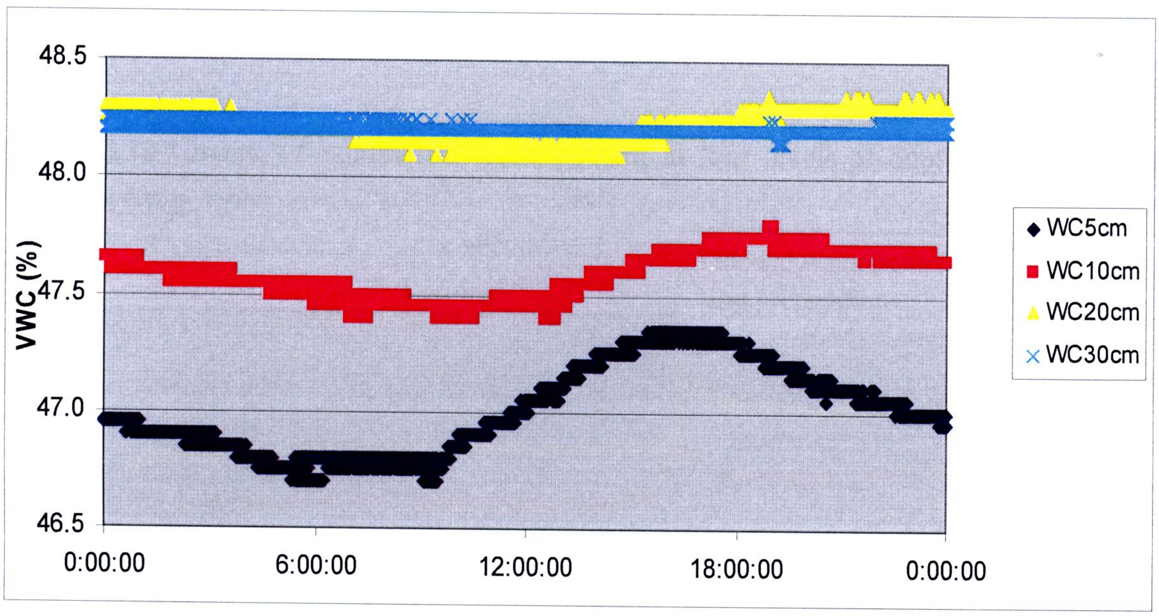


Figure 3.11 Diurnal effects of volumetric water content in four levels of depth soil in pre-test field

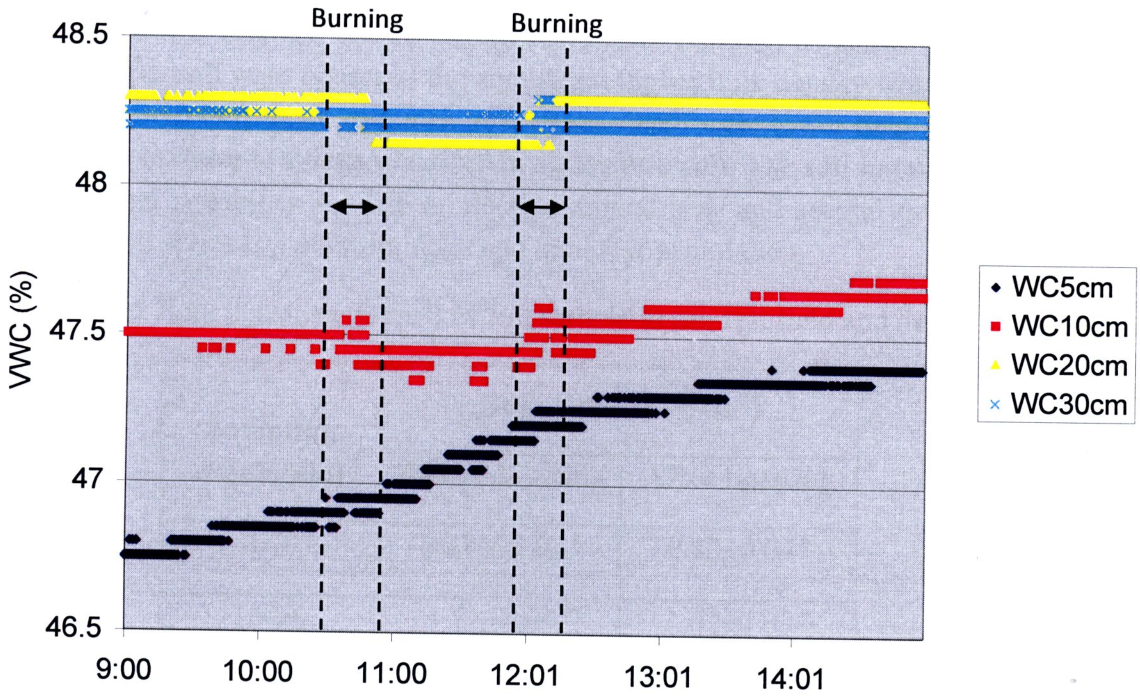


Figure 3.12 Change of volumetric water content in four levels of depth soil in burning field on 15 Feb, 2007.

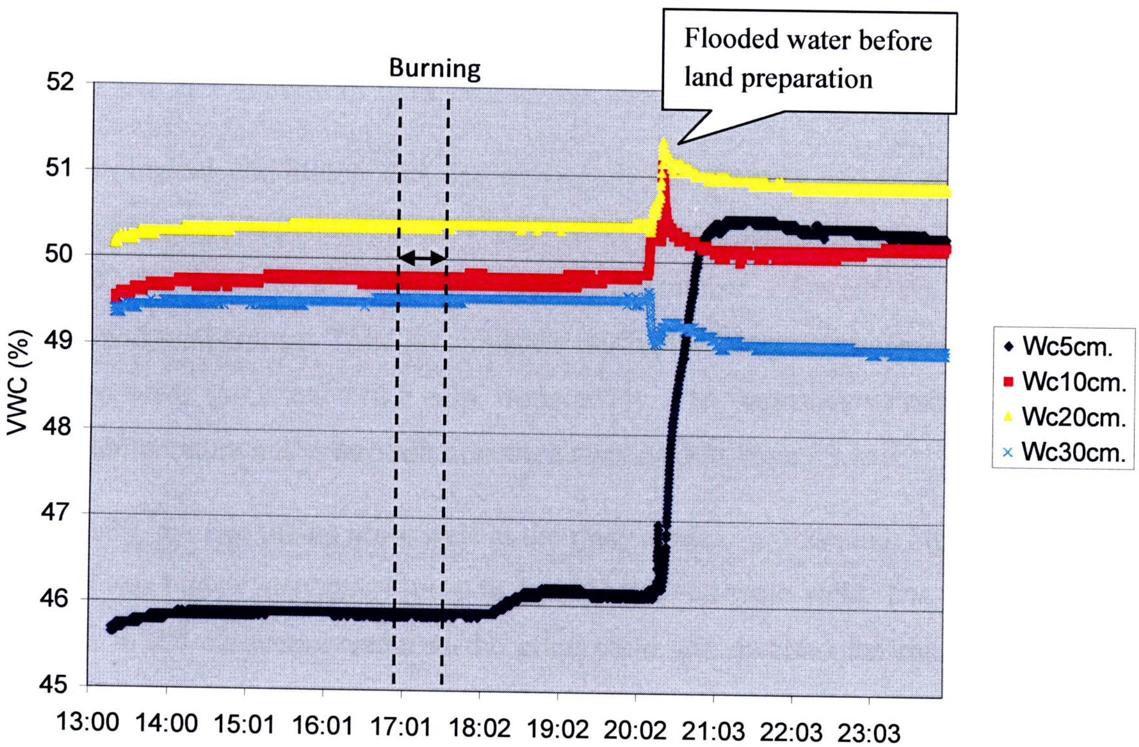


Figure 3.13 Change of volumetric water content in four levels of depth soil in burning field on 3 Mar, 2007.

The rice field burning did affect the bulk density of the soil which had no significant difference between before burning and after burning, as shown in Table 3.5. However, in depth soil were observed the significant higher bulk density which is compare to soil surface (0-10 cm). Bulk densities at 0-10 cm depth were lower than 10-20 cm and 20-30 cm depth in order to tillage practices in agriculture soil. The soil in this field is clay which actual land suitability for rice or flooded annual crop and second rice cultivation. The Bangkok soil series is a poor drainage and hardness percolation.

Table 3.5 Bulk densities (g/cm^3) of soil sample in pre-test field and designed field

Sampling depth (cm)	Bulk Density (g/cm^3)	
	Before burning	After burning
0-10	0.87 ± 0.02^{a}	0.80 ± 0.04^{a}
10-20	1.11 ± 0.09^{b}	1.02 ± 0.03^{b}
20-30	1.31 ± 0.06^{c}	1.23 ± 0.03^{c}

Values after ± indicate SD. Values of total seasonal within a column followed by the same letter are not significantly different at $P < 0.05$ using LSD test.

3.3.2 Climate and rice growth in field experiment 2007

Meteorological conditions and rice growth in the growing season are shown in Table 3.6.. Average air temperature from 1st crop (wet season, mid of April - August) was higher by 1.02 °C than the 2nd crop (dry season, September - December), which was similar to the soil temperature. Total precipitation during the study period from wet season and dry season were 850.9 and 218.8 mm, respectively. The frequency of rainy days, the annual of air temperature and solar radiation were displayed in Figure 3.14.

Normally, the rice plants grow well in the rainy season. In this study, the rice plant in the 1st crop was higher than the 2nd crop in good health and grain yield. The interference of weedy rice in 2nd cultivation reduced the grain yield and dwarfed the rice plant. The plant height increased gradually and reached approximately 110-120 cm as shown in Figure 3.14.

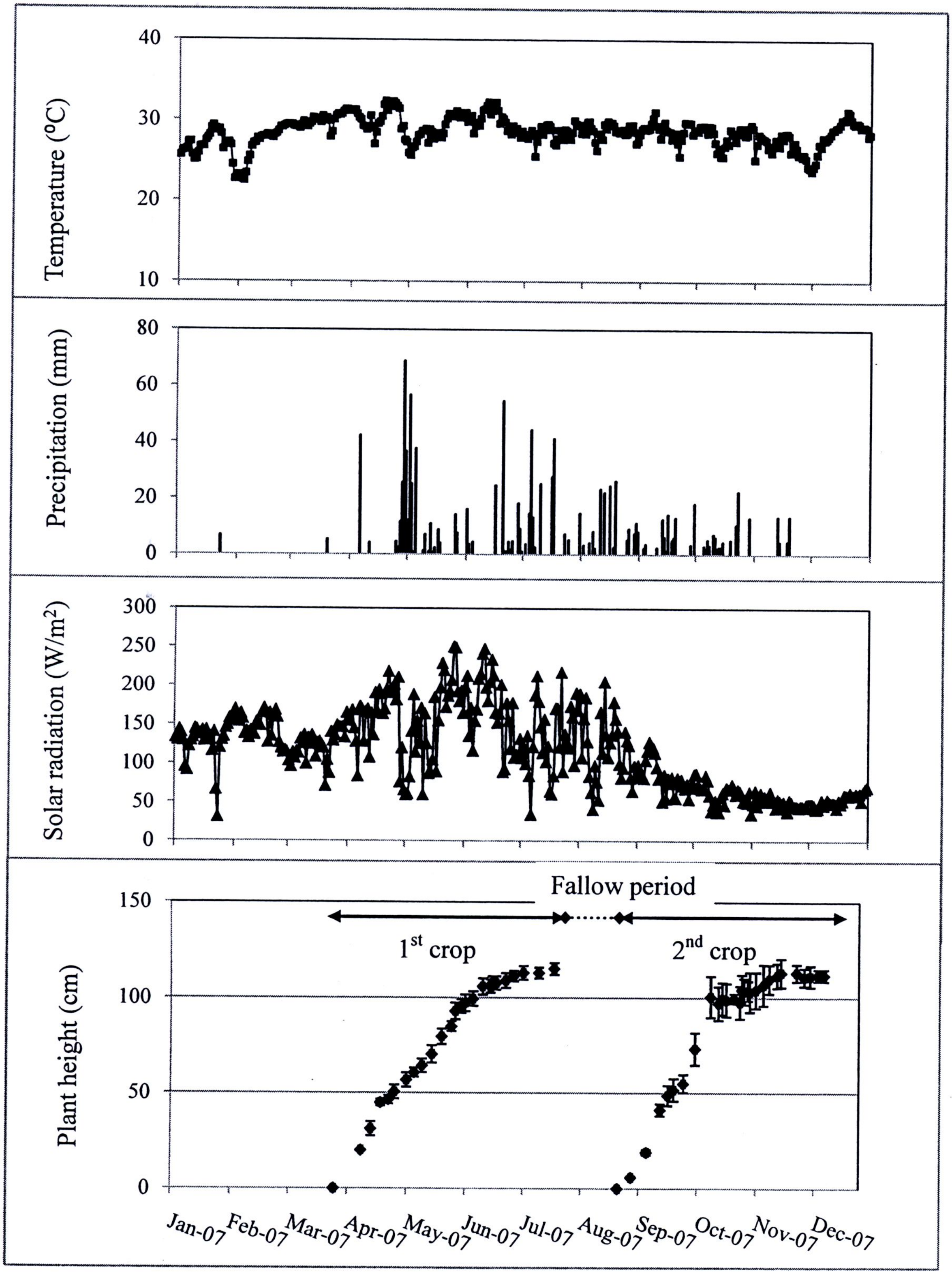


Figure 3.14 The seasonal courses of meteorological and vegetative variables at experimental site in Samutsakorn.

Table 3.6 The meteorological and vegetative variables in experimental field, Samutsakorn during the growing period, 2007

Parameter	1^{st} crop	2^{nd} crop	Parameter	1^{st} crop	2^{nd} crop
Precipitation (mm)	850.9	218.8	High of rice plant (cm)	117±5	111±18
Frequency of rainy (day)	59	30	Density of plant (shoot/m^2)	352±48	385±43
Air temp. (°C)	29.1±1.4	28.1±1.5	Grain yield (g/m^2)	473±38	307±50
Soil temp. (°C)	31.1±1.6	28.1±2.1	Weight of straw and stubble (g/m^2)	490	610
pH of flood water	6.9±0.1	7.1±0.1			
pH of soil	6.6±0.05	6.9±0.1			

3.3.3 Methane emissions

The methane flux, water table and Eh data obtained in six plots with two different water management systems with three different rice straw management systems during the rice cultivation periods of wet and dry season, 2007 are shown in Figures 3.15 - 3.18.

3.3.3.1 Pattern of methane fluxes during 1^{st} cultivation

Seasonal variations in the CH_4 flux from the experiment field measured in wet season, April-August 2007 are shown in Figure 3.15. The measurement of CH_4 flux was started on April 27, 15 days after seed sowing (DAS). Field observations revealed that the seasonal variation of CH_4 emission in Local drainage and Mid-season drainage plots during the crop-growing season were almost similar patterns except in mid-season drainage period. Normally, at the beginning of rice cultivation, CH_4 fluxes were slightly increased because of the lower gas transport capacity of the rice plant into the atmosphere, ebullition and vertical movement in the bulk of the soil is the main transfer mechanism (Le Mer and Roger, 2001).

In stubble plot with local drainage (LS plot) the methane emission began to increase early with the decrease of the soil Eh at high negative value (Eh ~ -380 mV) as shown in Figure 3.15 and 3.16, respectively. Two prominence emission peaks were found during 46 days after seed sowing in tillering stage and 93 days after seed sowing in flowering stage. While methane flux in stubble plot with midseason drainage (MS plot) was increased gradually after flooding as time elapsed, and showed the highest peak of methane in 93 DAS. The first peak in the period during 20-40 day after flooding (DAF) occurred from degradation of easily-decomposable portions of rice straw (Chidthaisong and Watanabe 1997).

Seasonal emission of CH_4 during the rice cultivation in wet season was 22.70 gm^{-2} in LS plot and 11.15 gm^{-2} in MS plot. There were significant differences between the fluxes of the MS and LS plot at P value = 0.05 and the cumulative CH_4 from LS plot was approximately 50 % higher than MS plot.

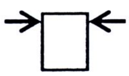
The results of methane emission in rice straw burning treatment showed similar patterns in both local and midseason drainage plots. The emission rates of CH_4 in the early stage began 2 weeks after flooding in LB and MB plots and increased gradually from 46 days until 66 days after planting. The strongest CH_4 emission peak (26.5 $mgCH_4\ m^{-2}\ hr^{-1}$) during the growing season was found in MB at 93 DAS within ripening phase. Seasonal emission of CH_4 during the cropping period was 15.63 gm^{-2} in LB plot and 14.40 gm^{-2} in MB plot. There was no significant difference between the total seasonal methane emission of the M and L treatment in burning plot, while emission rates from straw and stubble incorporate plot increased after flooding as time passed. Rice plants were branched in 40 days after seed sowing and methane emission was increased sharply until the reproductive stage. The strongest CH_4 emission peak (47.83$mgCH_4\ m^{-2}\ hr^{-1}$) was found in LI at 93 DAS in ripening phase. In addition, although the pattern of methane emission in MI plot was similar with LI plot but, as the result of mid-season drainage, the increasing of methane was separated into two peaks, as shown in Figure 3.15. Seasonal CH_4 emission in LI was 18.03 g m^{-2} which is close proximity to seasonal flux from MI (17.56 g m^{-2}). The daily average CH_4 during the growing season was 158.16 mg $m^{-2}day^{-1}$ in LI and 154.00 mg $m^{-2}day^{-1}$ in MI (Table 3.7).

Several studies have shown that the redox potential (Eh) demonstrated the biological reactions. Redox status is commonly indicated by measurements of Eh, which can be easily done but difficult to interpret in terms of specific redox processes (Bartlett, 1999). Several investigated observed the relations between the Eh and anaerobic metabolisms in flooded paddy field. The sequential reduction in waterlogged paddy soils, after end of respiration in the presence of O_2 and NO_3^- were MnO_2/Mn^{2+}, Fe_2O_3/Fe^{2+}, SO_4^{2-}/H_2S and CO_2/CH_4 respectively due to the efficient energy-yielding processes (Kimura, 2000). The Eh of the soil decreased sequentially, according to the respective metabolic processes after submergence, for methane production Eh arranged between -0.2 to -0.3 V. The relations between methane emission and soil Eh appeared to be negatively exponential (ZP et al., 1993).

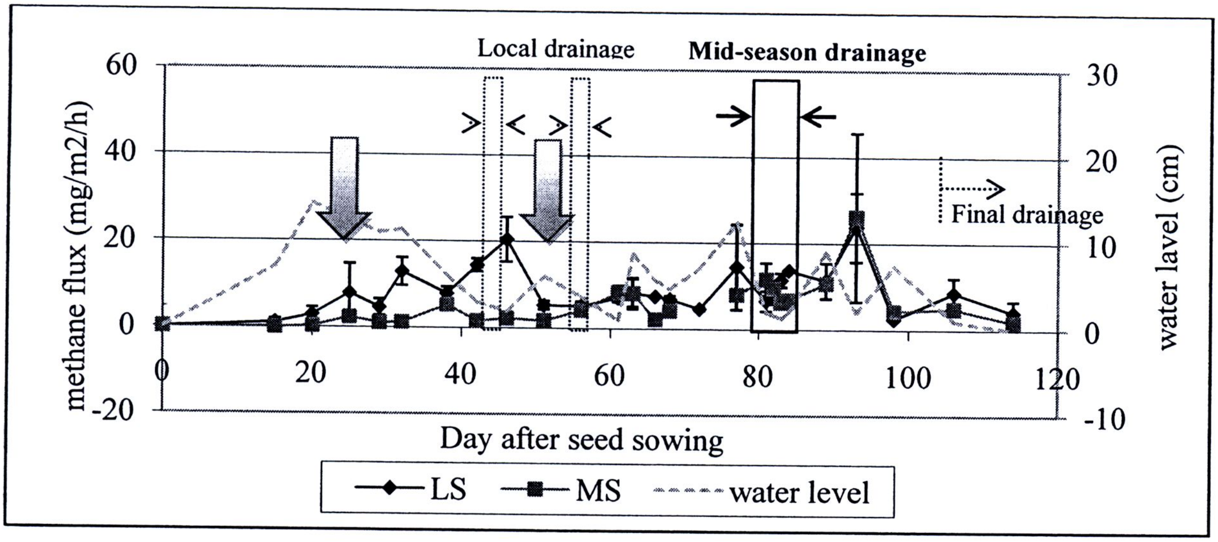
The variation of Eh in paddy soil fluctuated between -150 to -500 throughout the cultivation period. After flooded the trend of Eh sharply dropped down to -500 in S and I plots. Tanji et al. (2003) investigated the characterizing redox status of paddy soil with incorporated rice straw and the results showed that straw-incorporated and straw-rolled treated soils developed more reducing condition than the straw-burned plot. The clearly effect of mid-season drainage was shown in S and B plots. The Eh in MS and MB treatment rise up when water drain-out, as show in Fig 3.16. The result of Eh shows consistent with methane emission in negative correlation. After final drainage, the plow soil returns to aeration and Eh in all plots rise up closely to -100 mV. Figures 3.16 – 3.18 consist of arrows indicating agricultural practices:

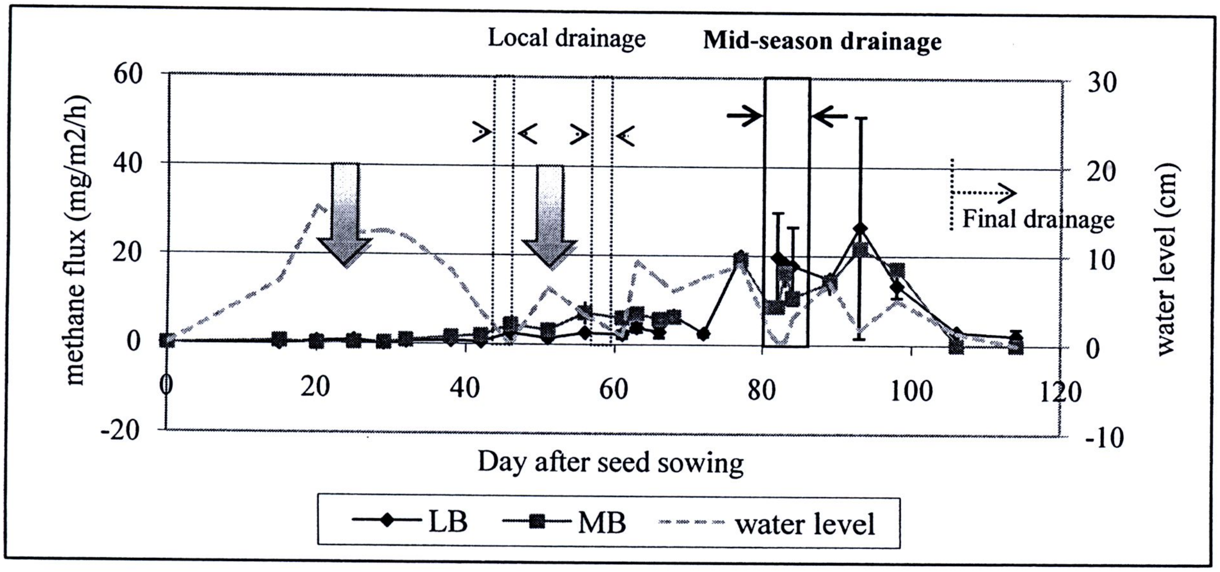
 represents the chemical fertilizer addition,

 represents the water drainage during rice cultivation (local drainage only one day),

 represents the water drainage during rice cultivation (midseason drain 3 day),

 represents the final drainage before machinery harvest 2 week and dotted line is water level during rice cultivation.





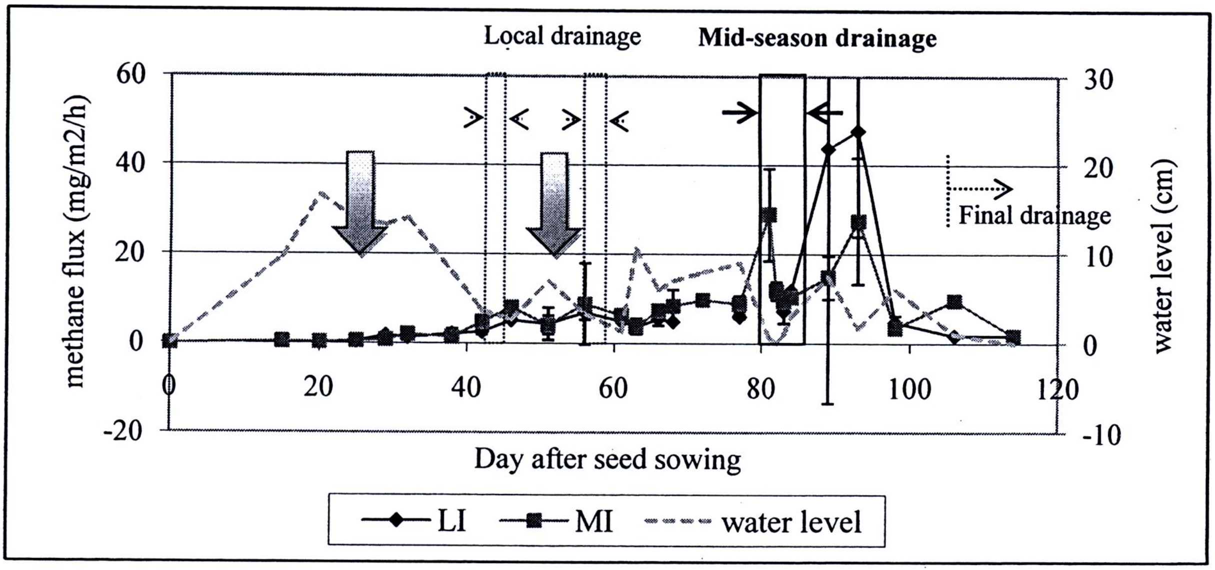
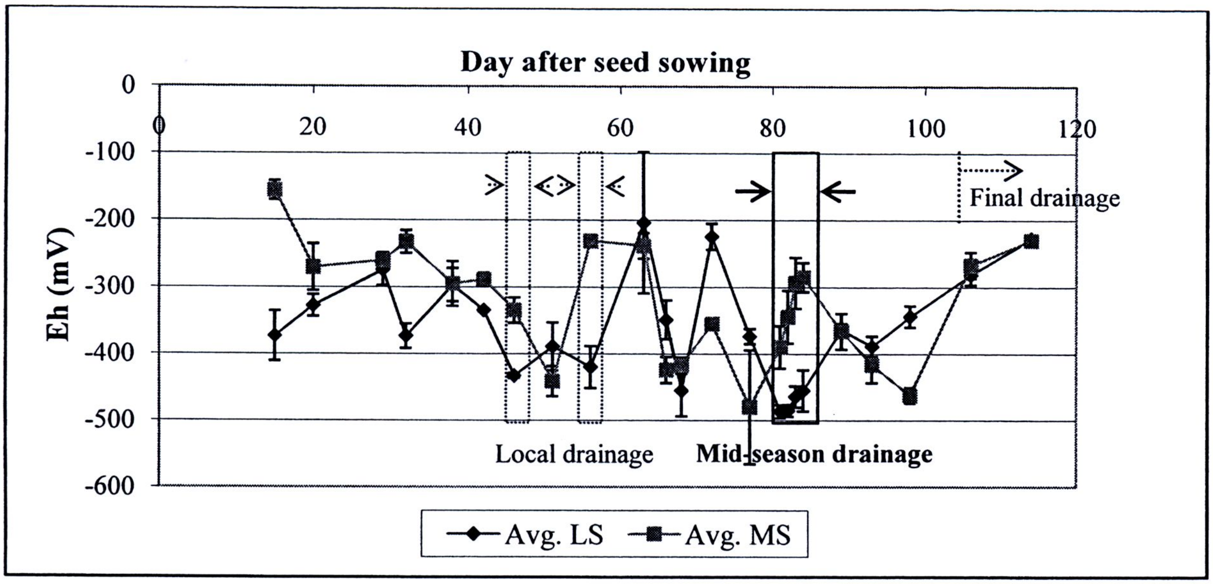
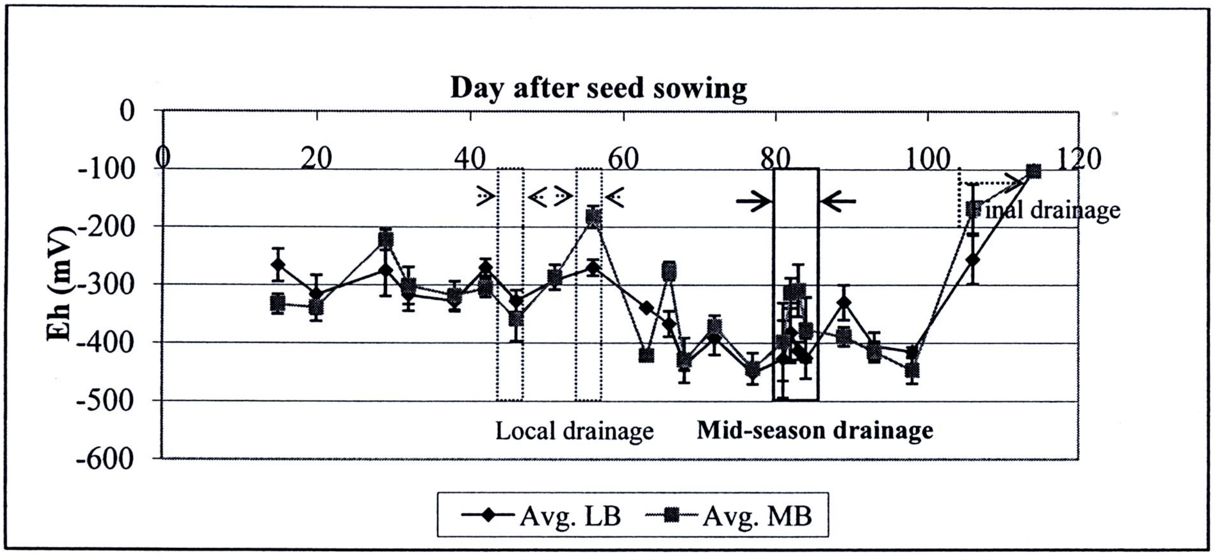


Figure 3.15 Seasonal variations of CH_4 flux in wet season (1st cultivation)





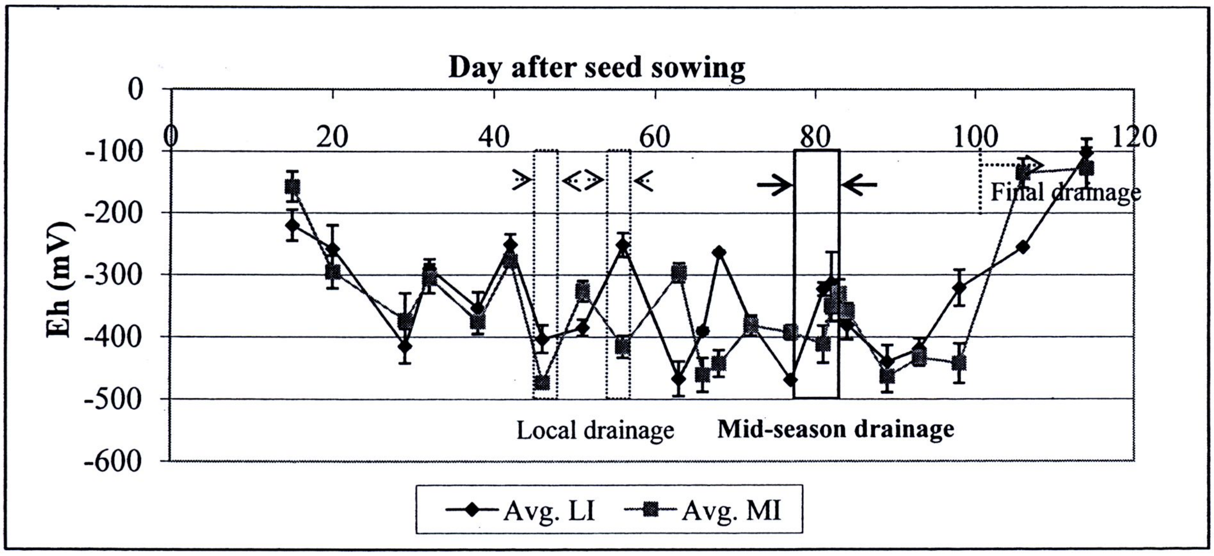


Figure 3.16 Soil Eh at 10 cm depth in the experiment field in wet season (1st cultivation)

3.3.3.2 Pattern of methane fluxes in 2nd cultivation

Two days after the first harvest, the rice straw on both burn plots were burned. While the stubble plots were collected rice straw and stubble were left on field. Thereafter, all plots were flooded 2 weeks before land preparation. The paddy field was left on short fallow period between rice cultivation about two weeks. Several times plow for incorporated the rice straw and stubble were performed in incorporate plots. Simultaneously, two times plow were conducted for burn plots and stubble plots.

The CH_4 emission fluxes in dry season and soil Eh (6 September - 25 December 2007) were presented in Figure 3.17 and 3.18. The CH_4 emissions began to increase with the decrease of soil Eh nearly 30 DAS. The period of CH_4 emissions from the rice field to the atmosphere corresponded closely to the period of low redox potential at a depth of 5 cm in the paddy soil (Yagi, 1997). Although the magnitude of the flux was different among the plots of straw and stubble incorporate (I) and stubble incorporate (S) treatment. They are two dominant peaks, the first peak appeared in 30-40 DAS in tillering stage of rice plants at begin of October and the second peak appeared during the middle of November in the beginning of flowering stage (65-75 DAS). Before flowering period, the methane flux value exceeded 50 $mg/m^2/hr$ in LI plot and 21 $mg/m^2/hr$ in LS plot. In contrast, the methane flux in burning (B) treatment showed only one peak in the beginning of flowering stage at the flux value 5 $mg/m^2/hr$. After the maximum tiller number stage, the rhizosphere of waterlogged rice becomes reductive, which was the reason why the highest peak of methane will shows in the flowering stage (Kimura, 2000). Moreover, the carbon source from rice plant such as root exudates enhances methane production. In addition the gas transfer pass aerenchyma is the dominant process, when rice plants develop. Chidthaisong and Watanabe (1997) attributed for CH_4 peak after 80 DAF occurred from the release of organic material from rice plants and the application of rice straw also indirectly enlarged CH_4 emissions.

The methane fluxes were in correspondence with water management practices such as drainage. The flux minima were observed during the local drainage. Furthermore, the flux rapidly dropped in M plots after continuous irrigation was interrupted with mid-season drainage.

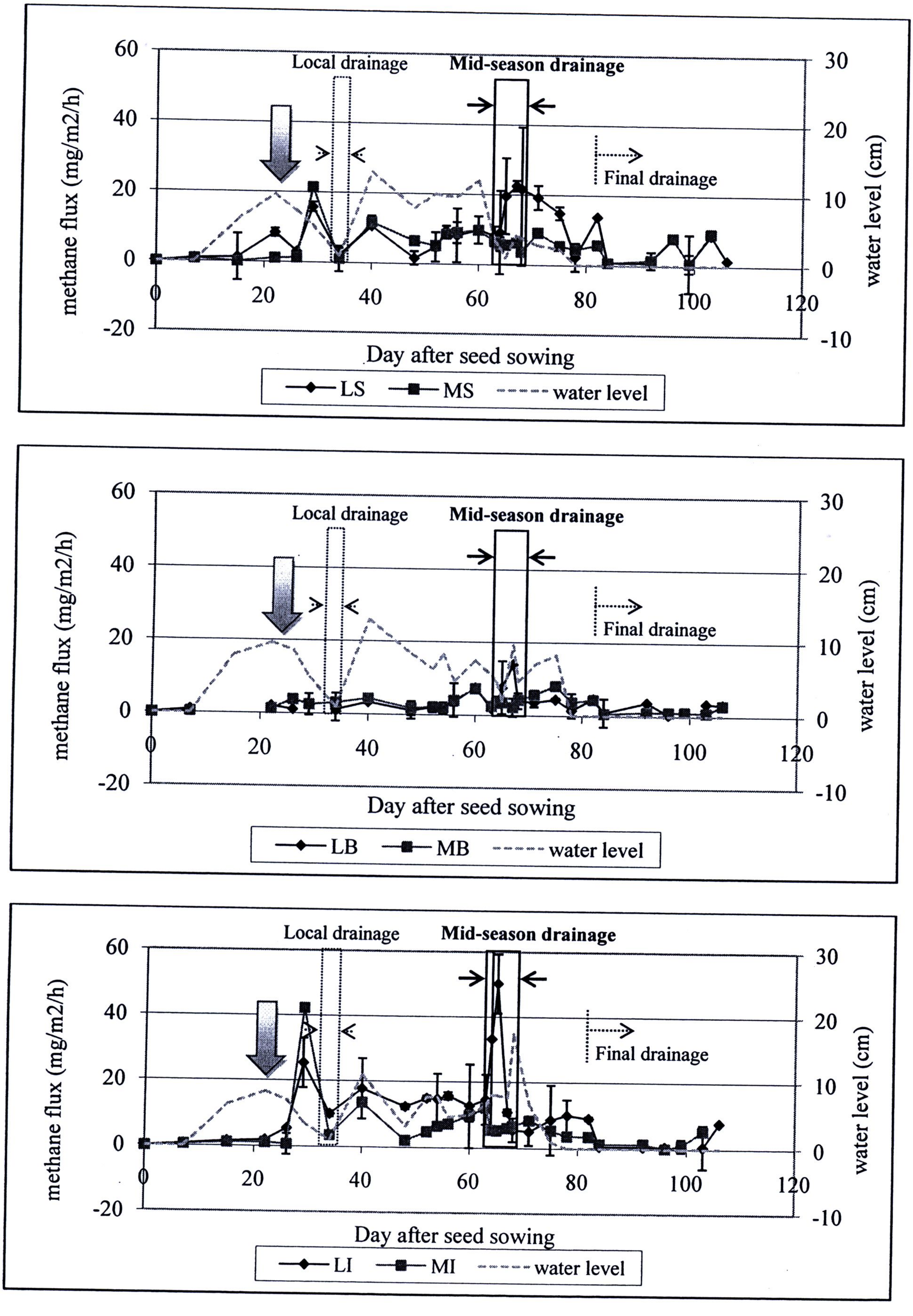


Figure 3.17 Seasonal variations of CH_4 flux in dry season (2nd cultivation)

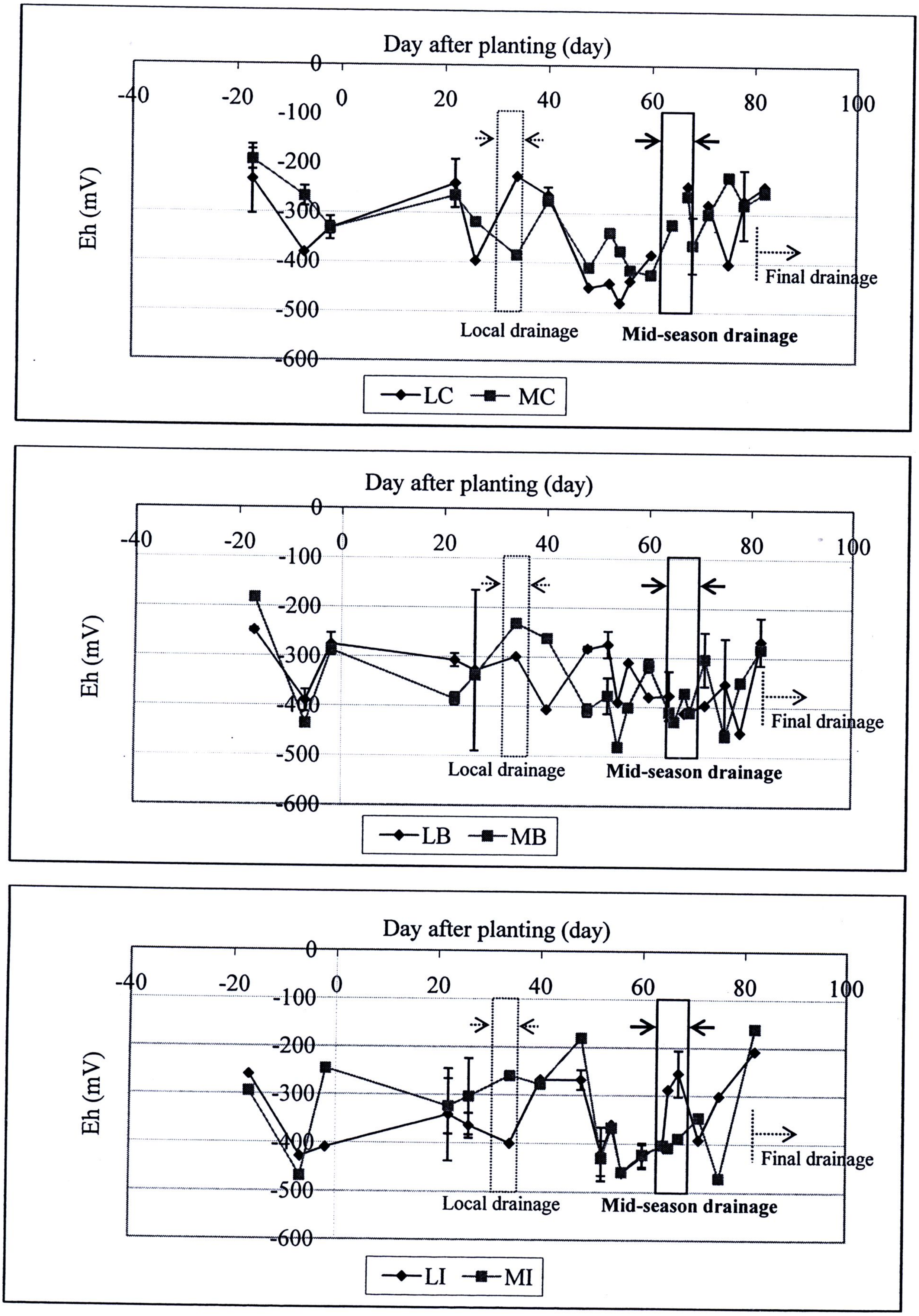


Figure 3.18 Soil Eh at 10 cm depth in the experiment field in dry season (2nd cultivation)

3.3.3.3 Average and total of methane emissions per season

Table 3.7 shows the comparison of methane emissions during rice cultivation period in wet and dry season. There are significant differences between the total seasonal variations in wet and dry season at P value = 0.05. The seasonal emission rates were estimated by multiplying the average flux by the length of rice cultivation. The average emission rates of CH_4 from wet season higher than those from dry season. The average soil temperature at a depth of 5 cm during the rice cultivation was 31 °C and 28 °C in wet and dry season, respectively. The higher temperature may accelerate methane production in soil. Another possibility reasons are the difference in period of water drainage, amount of fertilizer in each season and the rice plant growth.

This field study was conducted during the mid-season drainage on 81-84 DAS during the flowering stage of rice plant in 1st crop, and 63-66 DAS or during the heading stage of rice plant in 2nd crop. In first crop, the effect of the mid-season draining practices on CH_4 emission showed in stubble plots as 22.70 and 11.15 g/m2 in LS and MS plot, respectively. The average daily CH_4 flux in stubble plots with local drainage and mid-season drainage were 0.20±0.01 $gm^{-2}day^{-1}$ and 0.10±0.01 $gm^{-2}day^{-1}$, respectively. Contrary, the emission of wet season showed no significant difference between mid-season drainage (M) and local drainage (L) treatment in straw and stubble incorporate (I) plot and burn (B) plot. However, CH_4 emissions from mid-season drainage treatment were slightly lower than local drainage treatment. In second crop, the seasonal methane emission from straw application treatments shows the effective of mid-season drainage as mitigation option. Total seasonal emission in MS plot was 12.81 g/m^2 or 23% reduction when compare with LS plot (16.69 g/m^2). The mitigation option also shows the effect in I plot that could reduce CH_4 emission from 20.07 g/m^2 in LI plot to 12.92 g/m^2 in MI plot or 35% reduction. In the other hand, the rice straw burning treatments were not got the effect from mid-season drainage in both seasons.

The application of rice straw to the paddy fields significantly increased the methane emissions at both seasons ($P < 0.05$). It is well known that the addition of organic materials increase methane production in paddy soil under anaerobic condition (Yagi, 1997; Le Mer and Roger, 2001). In this study, the rice straw addition also enhance the CH4 emissions in S and I treatments. The CH_4 efflux in LS, LI and MI were higher than LB and MB plots by using LSD test at $P < 0.05$ as show in wet season cumulative flux. The effect of rice straw incorporated on CH_4 emission was repeated in dry season.

Table 3.7 Daily average and total seasonal CH_4 emission during the rice cultivation period

Treatments	CH_4 emission in wet season		CH_4 emission in dry season	
	Daily average ($g/m^2/day^1$)	Total seasonal (g/m^2)	Daily average ($g/m^2/day^1$)	Total seasonal (g/m^2)
Local drainage-stubble (LS)	0.20±0.01	22.70±1.52^{c}	0.16±0.04	16.69±4.88^{d}
Mid-season drainage-stubble (MS)	0.10±0.01	11.15±0.89^{a}	0.12±0.01	12.81±0.60^{e}
Local drainage-burning (LB)	0.14±0.01	15.63±0.90^{ab}	0.06±0.01	6.84±1.02^{e}
Mid-season drainage-burning (MB)	0.13±0.02	14.40±1.71^{ab}	0.06±0.01	6.64±0.82^{e}
Local drainage - straw&stubble incorporate (LI)	0.16±0.02	18.03±2.96^{b}	0.19±0.04	20.07±5.10^{d}
Mid-season drainage - straw&stubble incorporate (MI)	0.15±0.02	17.56±2.49^{b}	0.12±0.01	12.92±1.58^{e}

Values after ± indicate SD. Values of total seasonal within a column followed by the same letter are not significantly different at $P < 0.05$ using LSD test.

3.3.3.4 Methane emissions in fallow period

Normally, the rice cultivation in central plain grew two crop cycles per year. Traditional straw management is open field burning after left dried in the field around two day. In this study the fallow period including from after rice harvest until finish of land preparation. Therefore, the rice field was left to dry until the land preparation start in flooded condition about one week. The first fallow period was 27 days (dry condition 9 days and fields flooded 18 days) and the second fallow period was 94 days (dry condition

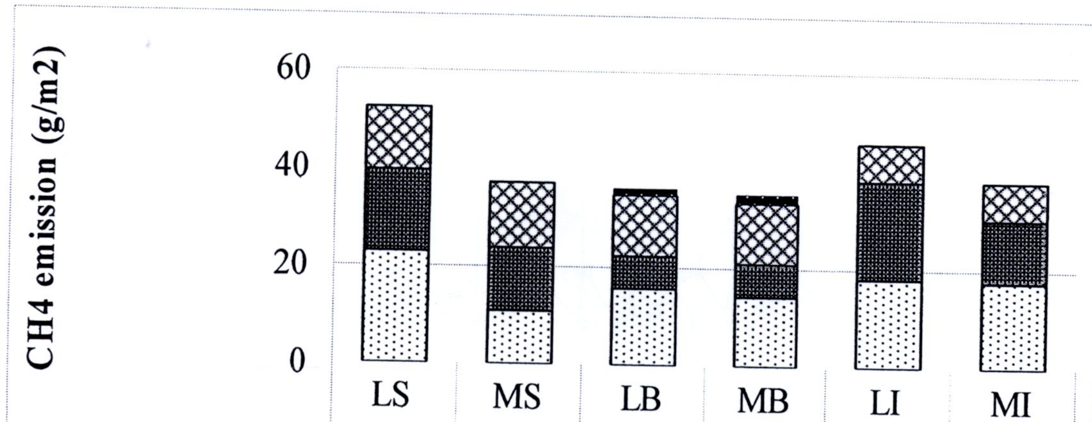
75 days and fields flooded 19 days). The rice straw and stubble in 1st fallow period was managed as the experiment design in S, B and I plots. Unfortunately, the 2nd cultivation was disturbed by the weedy rice. Therefore, in 2nd fallow period, the farmer burned the rice straw and stubble in all plots in order to destroy the seed of weedy rice. In addition, the rice fields were alternated wet dry conditions, and the weedy rice was eradicated by soil plow around 2-3 times in two month during fallow period. The CH_4 emissions in fallow period are indicated in Table 3.8.

Table 3.8 The CH_4 emission in fallow period

treatment	First fallow period		Second fallow period	
	Daily average (g m-2 day-1)	Cumulative flux (g m-2)	Daily average (g m-2 day-1)	Cumulative flux (g m-2)
S	0.11	3.04	0.11	10.09
B	0.05	1.24	0.12	11.15
I	0.07	1.83	0.06	5.83

3.3.3.5 Annual methane emissions

The summation of methane emissions from two cultivations, fallow periods and CH_4 from burned was shown in Figure 3.19. The highest annual CH_4 emissions occur in the rice straw incorporated treatments with local drainage, LS plot was 52.5 g/m^2 and LI plot was 45.8 g/m^2. In rice straw burned treatments and rice straw incorporated with mid-season drainage treatments indicated similar annual CH_4 emissions, in range 35-38 g/m^2.



	LS	MS	LB	MB	LI	MI
CH4 from burn			1.22	1.60		
Fallow period	13.13	13.13	12.39	12.39	7.66	7.66
2nd crop	16.69	12.81	6.84	6.64	20.07	12.92
1st crop	22.70	11.15	15.63	14.40	18.03	17.56

Figure 3.19 Annual methane in 6 plots with different rice straw management and water drainage

3.3.4 Nitrous oxide emissions

3.3.4.1 Pattern of N_2O fluxes

N_2O flux was observed simultaneously with methane flux throughout the rice cultivation. Figures 3.20 and 3.21 show the N_2O efflux in six plots of two different water management that within three different rice straw management during the rice cultivation periods of wet and dry season, 2007. The N_2O fluxes did not show the exactly pattern. It generally showed negligible fluxes in the early cultivation, increase small fluxes when local drainage in short time and the large fluxes in the mid-season drainage. When the soil was drained, the redox potential rises, the nitrification-denitrification process occur which N_2O was produced. The nitrogen fertilizer dressing time and rate and the duration of aeration in paddy field are the key factor which control the N_2O and CH_4 emission (Guo and Lin, 2001). The direct N_2O emission during the rice growing season relates with dry-wet alternation in soil that stimulated N_2O generation and emission (Yan, et al. 2000).

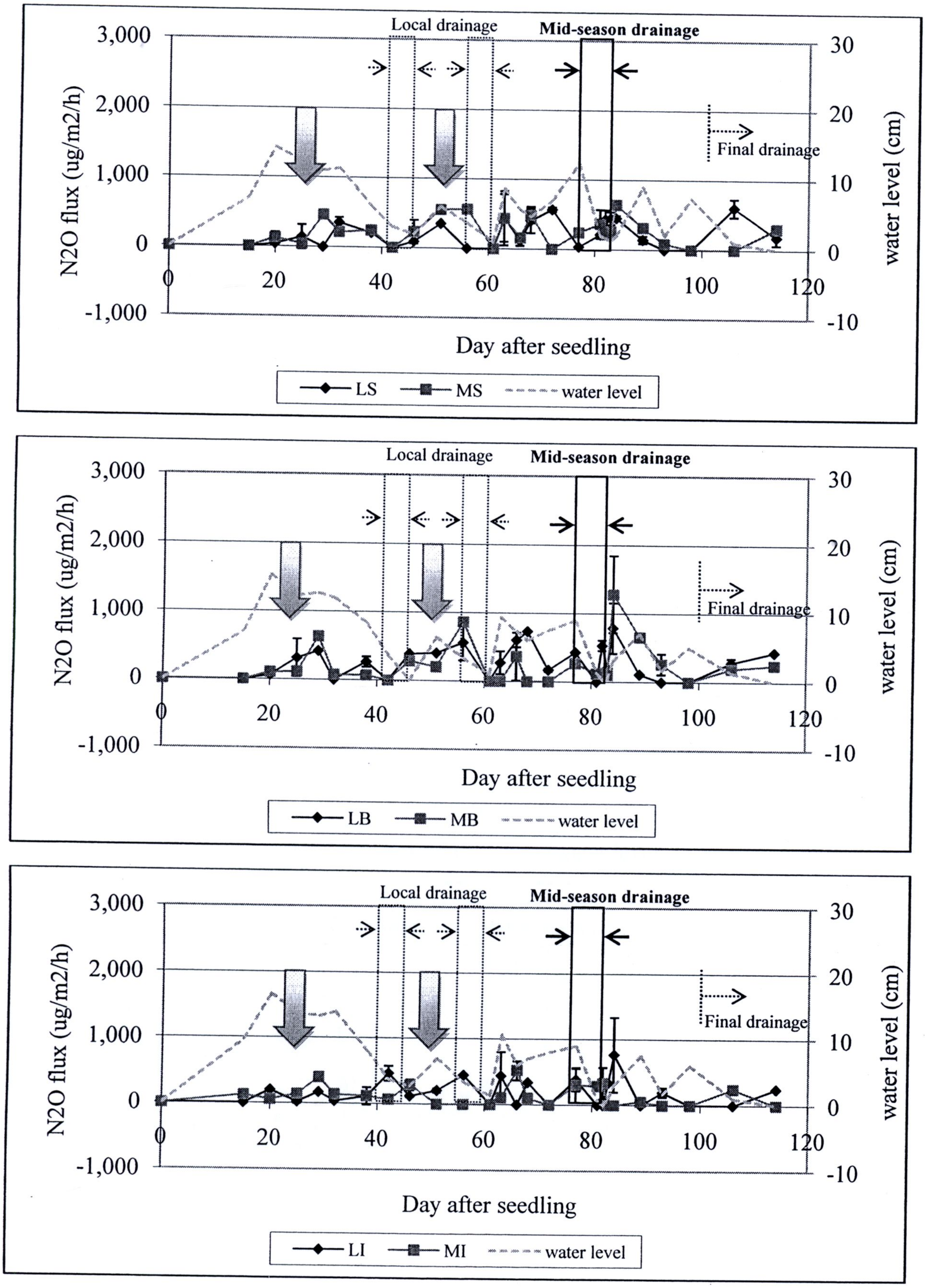


Figure 3.20 Seasonal variations of N_2O flux in wet season (1st cultivation)

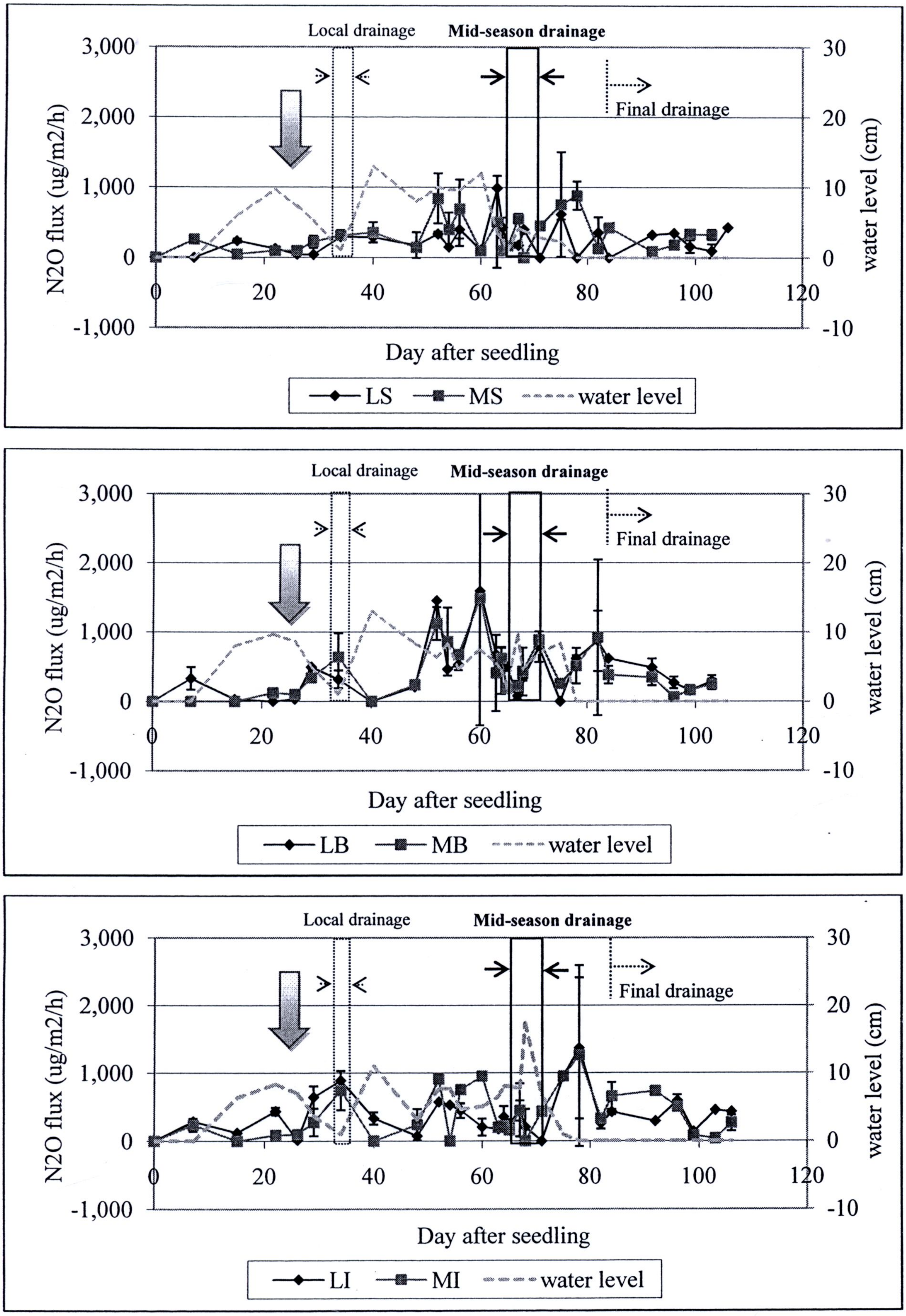


Figure 3.21 Seasonal variations of N_2O flux in dry season (2nd cultivation)

3.3.4.2 Average and total of nitrous oxide emissions per season

Table 3.9 shows the comparison of N_2O emissions during rice cultivation period in wet season and dry season. The seasonal emission rates were estimated by multiplying the average flux by the length of rice cultivation. The average emission rates of N_2O from dry season higher than those from wet season. There are significant differences between the total seasonal variations in wet and dry season at P value = 0.05. Seasonal emission of N_2O during the rice cultivation in wet season was highest in burn plot (LB; 0.49 gm^{-2}) while the smallest N_2O emission was found in whole rice straw incorporate treatment (0.27 and 0.33 gm^{-2}). There were significant differences between the fluxes of the rice straw burning with local drainage plot and rice straw incorporate plots at P value = 0.05, as shown in Table 3.9. In dry season, the highest N_2O emission was still found in rice straw burning with local drainage plot (0.87 gm^{-2}). There are double of N_2O emission from stubble incorporate with local drainage plot.

Table 3.9 Daily average and total seasonal N_2O emission during the rice cultivation period

Treatments	N_2O emissions in wet season		N_2O emissions in dry season	
	Daily average ($mg/m^2/day^1$)	Total seasonal (g/m^2)	Daily average ($mg/m^2/day^1$)	Total seasonal (g/m^2)
Local drainage-stubble (LS)	3.80±0.62	0.43 ± 0.07^{ab}	3.76±1.42	0.40 ± 0.1^{a}
Mid-season drainage-stubble (MS)	3.50±0.40	0.40 ± 0.05^{abc}	6.08±0.41	0.64 ± 0.04^{ab}
Local drainage-burning (LB)	4.29±0.61	0.49 ± 0.07^{a}	8.22±0.42	0.87 ± 0.04^{b}
Mid-season drainage-burning (MB)	3.49±0.63	0.40 ± 0.07^{abc}	7.01±1.35	0.74 ± 0.14^{b}
Local drainage -straw&stubble incorporate (LI)	2.91±0.13	0.33 ± 0.02^{bc}	7.15±0.55	0.76 ± 0.06^{b}
Mid-season drainage - straw&stubble incorporate (MI)	2.38±0.48	0.27 ± 0.05^{c}	7.57±2.99	0.80 ± 0.12^{b}

Values after ± indicate SD. Values of total seasonal within a column followed by the same letter are not significantly different at $P < 0.05$ using LSD test

3.3.4.3 N_2O emissions in fallow period

In this study, the fallow period including from after rice harvest until finish of land preparation. The rice field was left to dry until the land preparation start in flooded condition about one week; accordingly, the first fallow period was 27 days (dry condition 9 days and fields flooded 18 days). The rice straw and stubble in 1st fallow period was managed as the experiment design in S, B and I plots. Unfortunately, the 2nd cultivation was disturbed by the weedy rice. Therefore, in 2nd fallow period, the farmer burned the rice straw and stubble in all plots in order to destroy the seed of weedy rice. In addition, the rice fields were alternated wet dry conditions, and the weedy rice was eradicated by soil plow around 2-3 times in two month during fallow period. The second fallow period was 94 days (dry condition 75 days and fields flooded 19 days). The N_2O emissions in fallow period are indicated in Table 3.10.

Table 3.10 N_2O emissions in fallow period

treatment	First fallow period		Second fallow period	
	Daily average (mg m^{-2} day^{-1})	Cumulative flux (g m^{-2})	Daily average (mg m^{-2} day^{-1})	Cumulative flux (g m^{-2})
S	0.42	0.01	3.50	0.33
B	0.65	0.02	3.99	0.38
I	0.37	0.01	2.46	0.23

3.3.4.4 Annual nitrous oxide emissions

The summation of nitrous oxide emissions from two crops, fallow periods and N_2O from burned was demonstrated in Figure 3.22. The highest annual N_2O emissions occur in the rice straw burned treatments, LB plot was 1.78 g/m^2 and MB plot was 1.57 g/m^2. In rice straw incorporated treatments (LS, LI and MI), annual N_2O emissions were about 1.3 g/m^2.

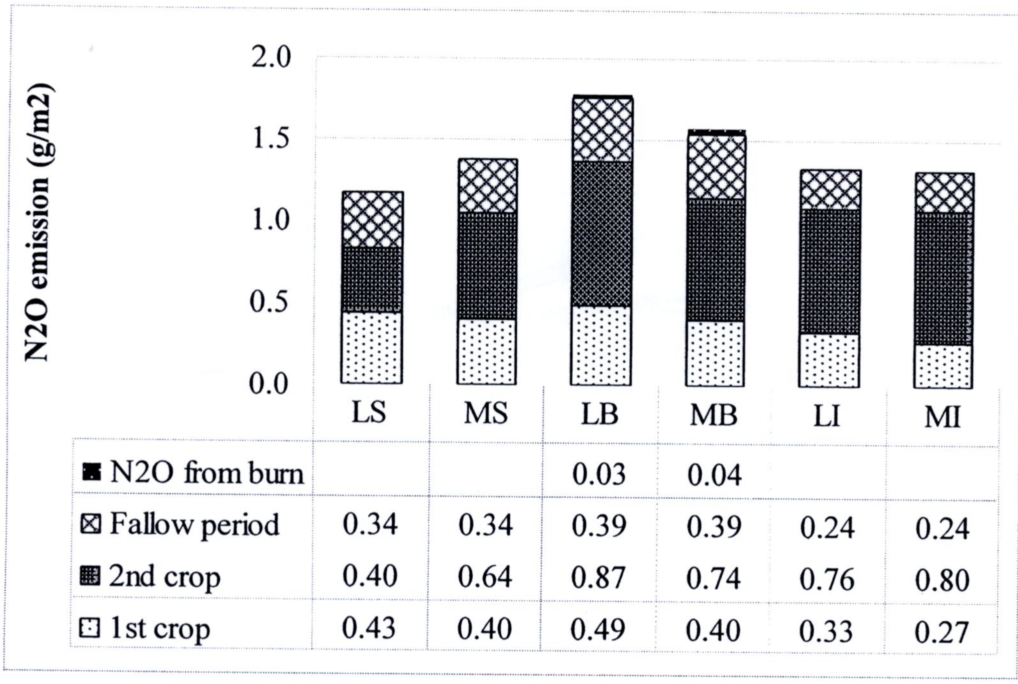


Figure 3.22 Annual nitrous oxide in 6 plots with different rice straw management and water drainage

3.3.5 Physical, chemical and biological property of soil

3.3.5.1 Summary of soil properties in the plowed layer of the study site

Table 3.11 Soil properties

plot	bulk density (g/cm3)	soil moisture (%by mass)	soil moisture (%by volume)	pH	OM(%)	P (mg/kg)	K (mg/kg)
LS	0.82 ± 0.03	70.49 ± 4.57	58.01 ± 2.35	5.5±0.1	4.3±0.30	8±1.73	430±10
MS	0.89 ± 0.06	60.20 ± 5.37	53.43 ± 0.97	6.0±0.2	2.77±0.15	4.67±1.53	363±23
LB	0.86 ± 0.02	65.70 ± 1.25	56.38 ± 0.30	5.8±0.2	3.13±0.06	6.33±1.53	353±15
MB	0.76 ± 0.05	71.82 ± 7.77	54.04 ± 3.72	5.7±0.3	3.83±0.65	12.67±2.52	333±25
LI	0.88 ± 0.04	63.77 ± 2.75	56.00 ± 3.80	6.0±0.2	3.33±0.38	14.67±13.32	300±53
MI	0.86 ± 0.10	64.66 ± 6.68	55.57 ± 3.99	5.3±0.3	4.07±0.32	12±4.36	326±45

3.3.5.2 Total carbon, total nitrogen and C/N ratio

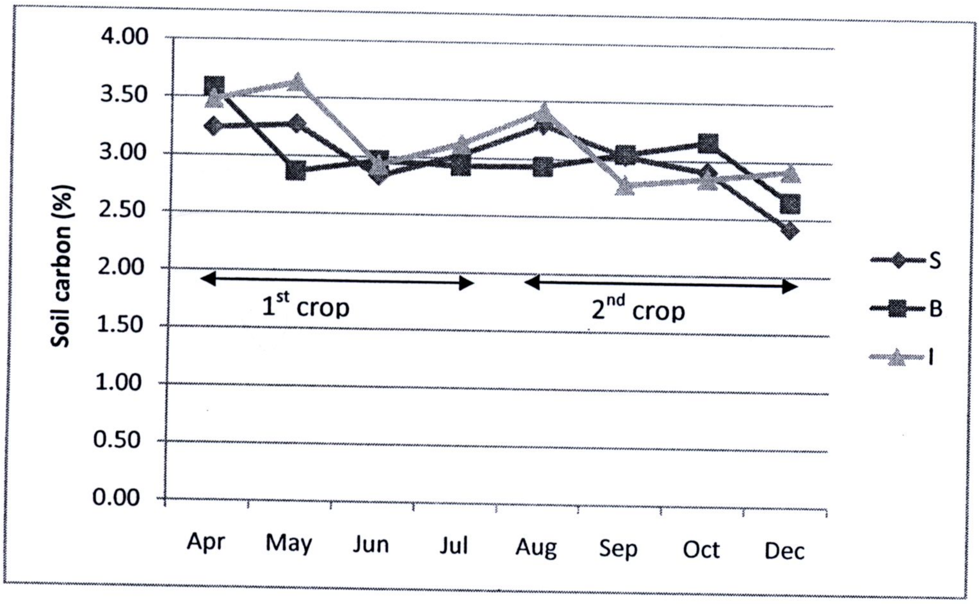


Figure 3.23 Soil carbon in 6 plots at experimental site

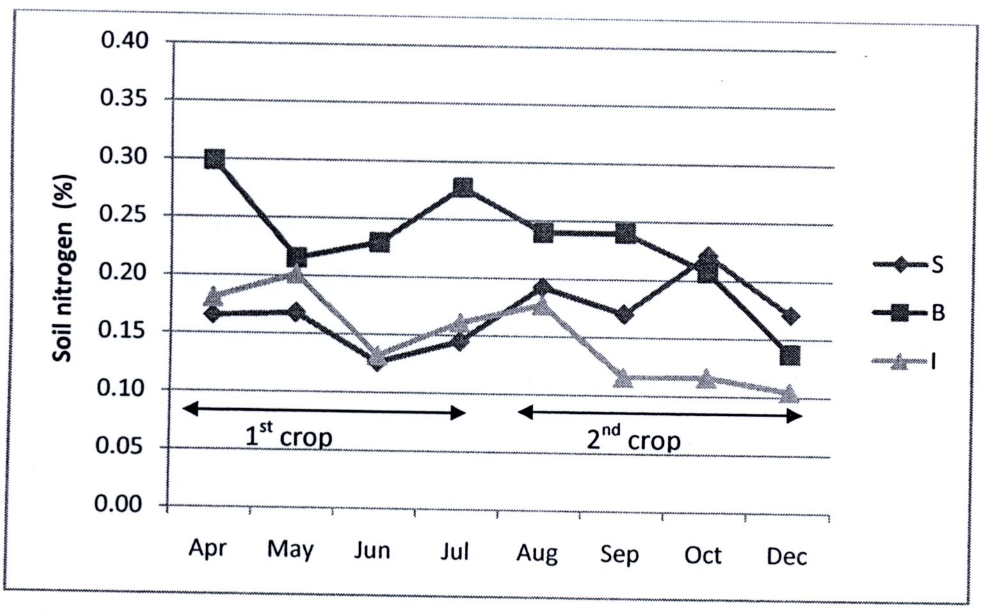


Figure 3.24 Soil nitrogen in 6 plots at site experiment

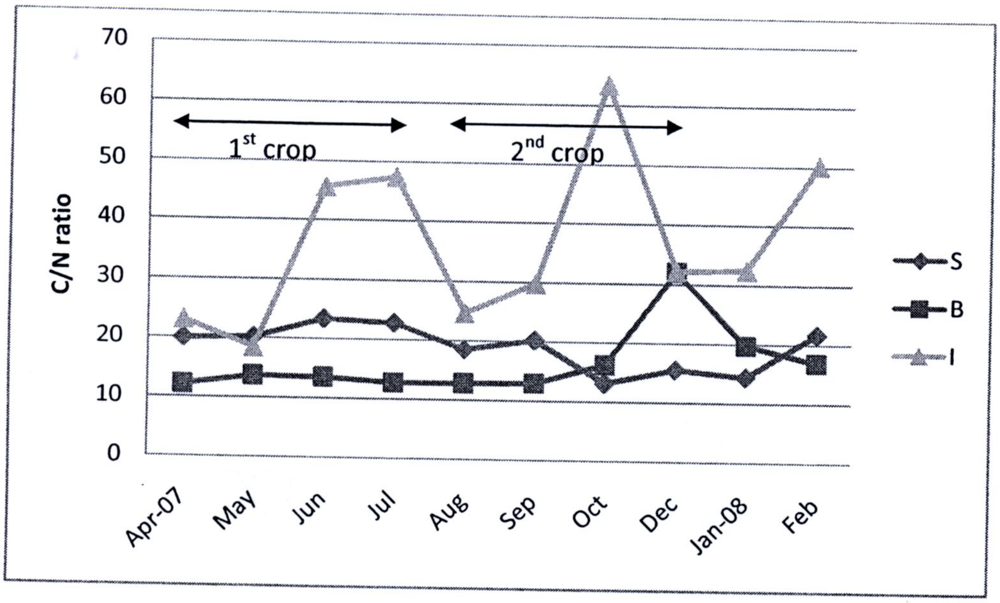


Figure 3.25 C/N ratio of paddy soil in 6 plots at site experiment

3.3.5.3 Methanogen in paddy soil

The soil sample was collected from rice field on 14 Dec, 2007 during 10 days before second rice harvest. Three replicate was random sampling from LB and LI plots in order to compare the effect of rice straw management to Archaea. Figure 3.26 shows the portion of Archaea in paddy soil between rice straw burning (LB) and rice straw incorporated (LI). Dominance Archaea in both plots are the Order Methanomicrobiales consist of Methanosarcinaceae, Methanocellales (RC-I), Methanomicrobiales and Methanosaetaceae. They use acetate as the major source to produced CH_4. The methyl carbon of acetate is reduced to CH_4 and the carboxyl carbon is oxidized to CO_2. The data show the usual diversity of archaeal 16S rRNA genes with presumably Methanomicrobiales, Methanosarcinaceae, Methanosaetaceae and Rice Cluster I. No evidence for Methanobacteriales so far. The numbers of 16S rRNA gene copies is with about $1.5*10^8$ copies per gram dry soil also in the usual range (Figure 3.27). In conclusion, the rice straw management in fallow period compared between rice straw burning and rice straw incorporated do not effect to Archaea community in paddy soil.

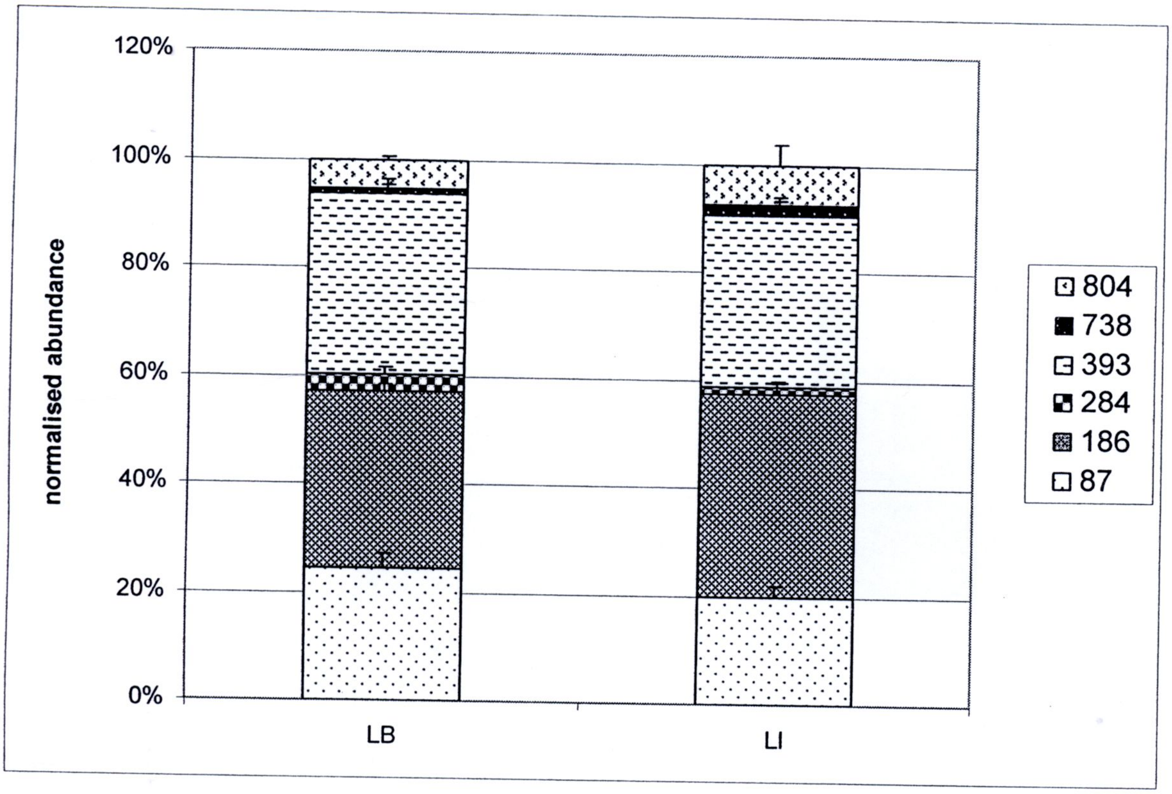


Figure 3.26 Mean of normalised relative abundance of Archaea [%] in paddy soil (LB: Burn plot with Local water management, LI: Incorporate plot with Local water management)

Each color represents a terminal restriction fragement with a characteristic length (in base pairs) obtained from PCR targeting archael 16S rRNA genes retrieved from the soil samples. The following four T-RFs are normally due to characteristic methanogens:

87 bp = Methanomicrobiales

186 bp = Methanosarcinaceae (somtimes also Crenarchaea)

284 bp = Methanosaetaceae

393 bp = Methanocellales (RC-I) or Methanomicrobiales

The other T-RFs are usually Crenarchaea

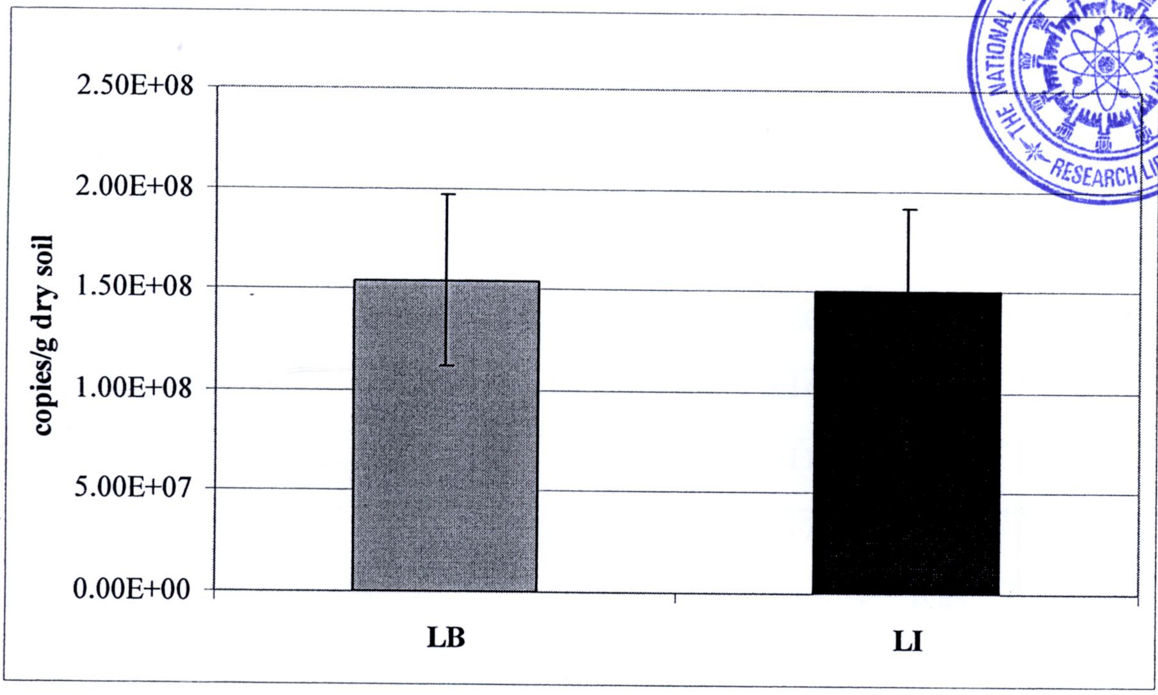


Figure 3.27 Mean and SD of Archaea [16S rRNA gene copies/ g dry soil] in rice soil (LB: Burn plot with Local water management, LI: Incorporate plot with Local water management)

3.3.6 Rice plant and grain yield

Average grain yield from six plots are 473±38.62 and 306.84±50.33 g/m^2 in first and second crop, respectively. In 2nd crop, the rice fields in this area were influenced by weedy rice, therefore the yield decreased. Normally, the means of rice production in irrigation system is 422 g/m^2 or 675 kg/rai (OAE, 2007). Recently, the irrigate rice fields have expanded in every region of Thailand in order to great rice yield per area. Although, the rice straw burning plots produced higher yield than stubble and straw incorporated plots but there are no significant different in statistic test. Moreover, there were no significant differences on the water management plots. This implies that the mid-season drainage was not reducing the grain yield. However, grain yield in burned plot was higher than yield in stubble plot, straw and stubble incorporated plot which may attribute to the effect of acidity in soil occurred from straw degradation at early period of cultivation.

Table 3.12 Vegetative variables from six plots in 1st and 2nd crop

Plot	Plant density (shoot/m²)		Plant height (cm)		Grain yield (kg/m²)	
	1st crop	2nd crop	1st crop	2nd crop	1st crop	2nd crop
LS	383±7	422±17	117±0.7	97.97±15.4	0.44	0.29
MS	367±9	344±4	114±2.1	90.00±20.7	0.46	0.27
LB	317±9	433±6	117±0.7	80.13±14.1	0.55	0.36
MB	250±7	400±9	120±1.4	84.71±11.6	0.46	0.35
LI	467±5	322±1	114±3.5	93.56±17.9	0.47	0.23
MI	333±6	389±11	111±1.4	84.08±8.8	0.45	0.34

3.4 Discussion

3.4.1 Rice straw management affects greenhouse gas emissions from rice cultivation

3.4.1.1 The open field burning at the beginning of rice cultivation

The hypothesis of this experiment is the rice straw burning for land preparation would affect the physical and chemical properties of soil. The field experiment was performed before the first crop land preparation. Temperature and water content in soil are the key properties. Therefore, the sensors were inserted in soil at depth 5, 10, 20 and 30 cm in order to observe the change during field burning. The immediately change of temperature induced endothermic reaction from soil to water in order to water evaporate. In addition, the soil water in depth moved up to soil surface by capillary force that result soil temperature dropped in initial of burning. After that the increment of soil temperature up to 28 °C occurred at 5, 10 and 20 cm depth of soil on account of heat transfer from soil surface to soil depth by heat conduction process. However, the few change of soil temperature (±2°C) did not effect to methanogen in term of community and quantity, as show in Figure 3.26, 3.27. In addition, timing of burn is the key to control the violence of impact. Normally, the highest of soil temperature is on 1-2 pm. at 29 °C in April. If the burning was done in other time, the change of soil temperature should not be effect to microbe in surface soil.

3.4.1.2 The effect of rice straw management on GHG emissions

The seasonal variation of GHG flux in the experimental field was observed during the wet season (middle of April - August) and dry season (September - December). The different of temperature, precipitation and climate were influenced the rice growth and microbe which induced the higher methane emission in wet season.

3.4.1.2.1 Enhanced CH_4 emissions

Low land rice fields are unique environments for soil microorganisms. Flooding rice soil has a marked affect on gaseous exchange between the atmosphere and soil. Therefore, the most dramatic changes in soil physico-chemical and biological conditions are important for methane emissions. In flooded soil, the drop of O_2 content level and the development of anaerobic condition favor CH_4 production. There were very large differences in CH_4 emission from rice straw management between burn (burn plot with local drainage; LB) and un-burn treatments (stubble incorporate with local drainage; LS and rice straw and stubble incorporate with local drainage; LI). The impact of rice straw incorporated on CH_4 was apparent in both seasons. Two prominence emission peaks were found in tillering stage about 40 days after seed sowing; DAS and flowering stage about 90 DAS in both crop of stubble incorporate with local drainage plot (LS) and 2nd crop of rice straw and stubble incorporate with local drainage plot (LI). It is previously study that incorporation of fresh rice straw into paddy soils increase methane production and emission from paddy soil under anaerobic condition (Yagi, 1997; Le Mer and Roger, 2001; Zou et al., 2005; Ma et al., 2009). Naser et al., 2007 found that a significant correlation between rice straw carbon application rate and total CH_4 emission during the rice growing season in continuously flooded fields. However, the seasonal CH_4 emission in wet season from LI did not highest as we had hypothesized may be due to unusually high emissions during the first two weeks in LS plot. The first peak in the period during 20-40 day after flooding occurred from degradation of easily-decomposable portions (Chidthaisong and Watanabe, 1997). Moreover, previous this experiment, the carrion was left in LS plot. In the other hand, CH_4 fluxes from burning plot (LB) showed dominant peak only in repoductive phase. The cumulative methane emissions from two rice growing season of rice straw application into paddy fields were significantly increased double of burn fields.

3.4.1.2.2 Reduced of N_2O emission

The previous studies demonstrated that the effect of rice straw application on N_2O emissions in rice fields was negatively related to the straw application rate (Jiang et al., 2003; Ma et al., 2009; Xing et al.,2009). A small decrease in N_2O emission due to rice straw incorporation in rice paddies was occurred because decomposition of straw accelerates O_2 consumption in the rhizosphere and in the aerobic soil layer, which favoring N_2O transformed to N_2 by denitrification. The decomposition of straw with high C/N ratio stimulated net immobilization of N that may result in limit N available to nitrification and denitrification (Bronson et al., 1997). In this experiment, we found that the effect of rice straw incorporation reduced N_2O emission but the reduced rate did not relate with amount of rice straw application. The highest of N_2O emissions was also found in burning plots in both rice growing seasons; however, there were not significantly different from those in incorporated rice straw. Seasonal N_2O emissions from three of rice straw management were consistent with total soil N which was highest in burn plots throughout rice growing period.

3.4.2 Water management affects greenhouse gas emissions from rice cultivation

With the local drainage or local irrigation, methane emission rates were sharply high at the active tillering stage and peaked at flowering and ripening stages. However, methane emission rate, of mid-season drainage, rose high at tillering stage and decreased gradually at the flowering stage when water in the field was drained out during mid season or early flowering stage. In local drainage treatment of 2nd crop, the total seasonal methane emissions were ranged from 6.63 to 20.20 g/m^2 for the crop period of 110 days. The flux was higher in incorporated plots than the burned plots. Although the higher methane emission was observed in both residue incorporated (I and S) plots (20.20 and 15.71 gCH_4 m^{-2}/crop, respectively), lowest emission were recorded from burning plots (6.63 gCH_4 m^{-2}/crop), when the application of water drainage was introduced during flowering period, the methane emission can be decrease about 49% and 32% in I and S plots, respectively (Figure 3.29). Draining with fewer drain days during the flowering period was recommended as a compromise between emissions and yield as reported, 27% and 35% of methane reduction in the mid-season drainage and the multiple drainage compared with local method (Towprayoon, Smakgahn and Poonkaew, 2005), the intermittent irrigation decreased 45% CH_4 emission of continuous flooding (Yagi et al., 1996).

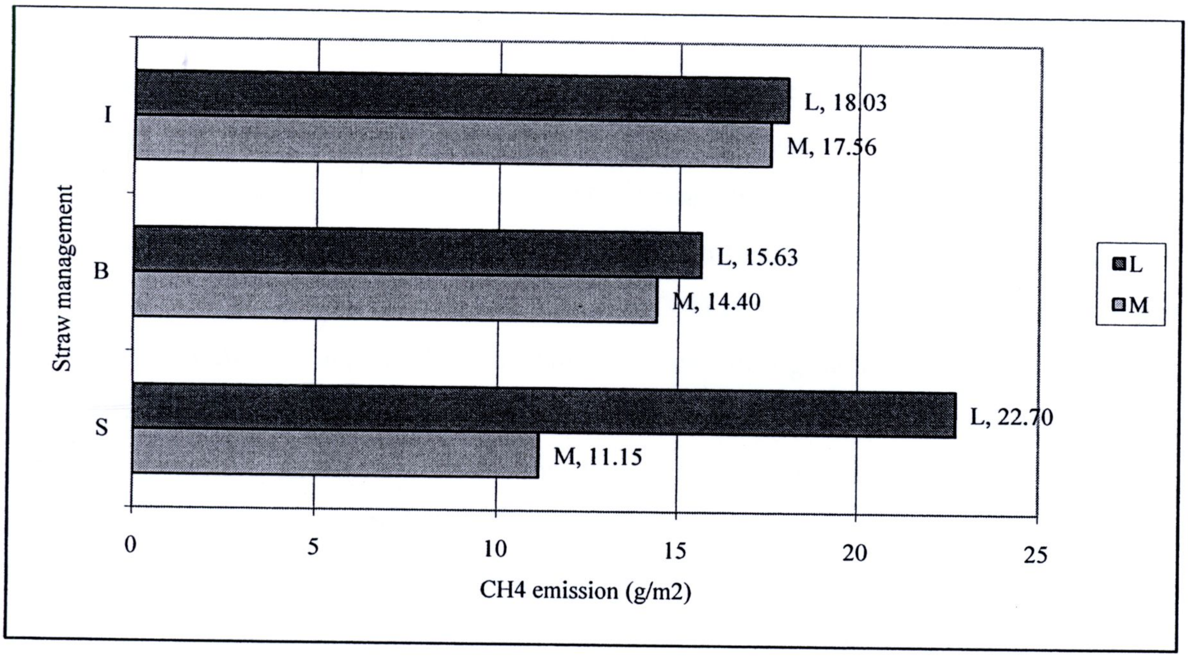


Figure 3.28 Total seasonal methane emissions in 1st crop: water management (L: Local, M: Mid-season drainage), rice straw management (S: stubble incorporate, B: burn, I: straw and stubble incorporate)

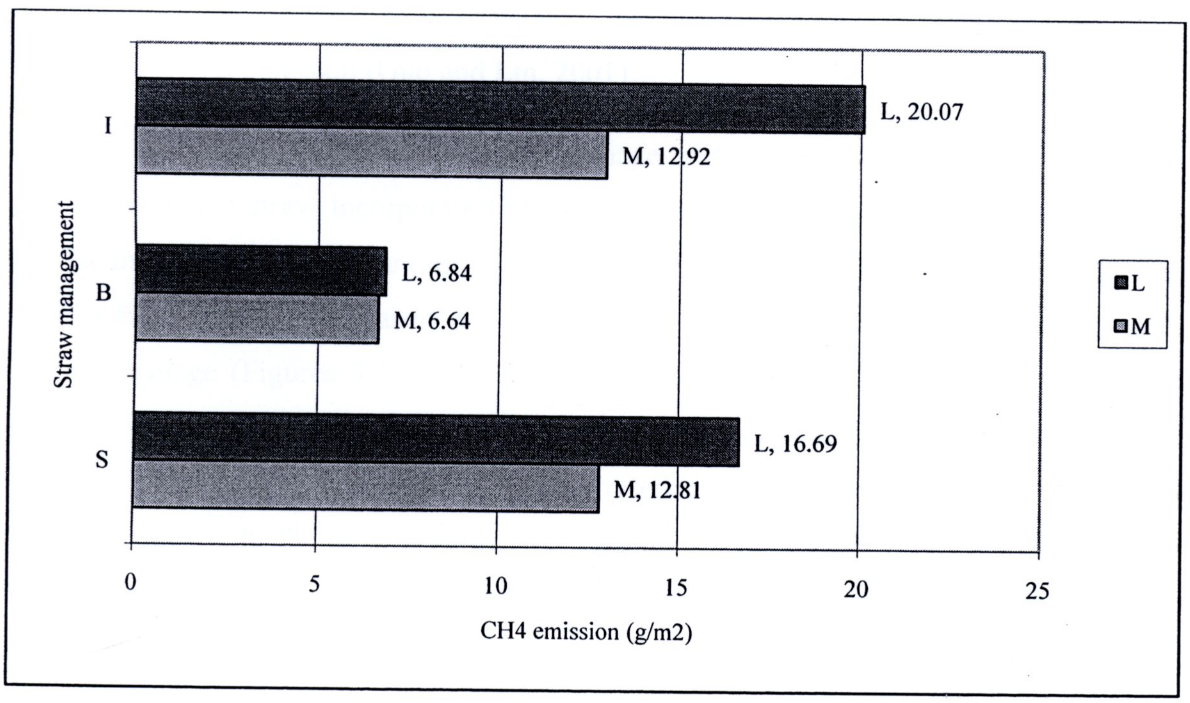


Figure 3.29 Total seasonal methane emissions in 2nd crop: water management (L: Local, M: Mid-season drainage), rice straw management (S: stubble incorporate, B: burn, I: straw and stubble incorporate)

N_2O fluxes generally showed negligible fluxes in the early cultivation, usually the small peaks of N_2O occurs after local drainage in short time and the large fluxes after the mid-season drainage. However, the mid-season drainage was not affect to seasonal N_2O emission in wet season. The quite clearly effect was shown only in un-burn plots in dry season that the N_2O fluxes in stubble plots were significantly different between the mid-season drainage and local drainage plots (Table 3.9). Later field research indicated that seasonal N_2O emission depends on water management during the rice growing season (Cai et al., 1999; Yan et al., 2000; Zou et al., 2003; Liu et al., 2010). When the soil was drained, the redox potential rises, the nitrification-denitrification process occur which N_2O was produced. The direct N_2O emission during the rice growing season relates with dry-wet alternation in soil that stimulated N_2O generation and emission (Yan et al., 2000). Zou et al. (2005) found that a great deal of N_2O was observed when the field was moist but not waterlogged by the intermittent irrigation. Thus N_2O emissions during intermittent irrigation periods depended strongly on whether or not water logging was present in the fields. The result of N_2O emission in this study informed that the mid-season drainage did not show clearly effect on N_2O emission because the local drainage often drained for fertilizer application and healthy of rice plants. Moreover, the nitrogen fertilizer dressing time and rate and the duration of aeration in paddy field are the key factor which control the N_2O and CH_4 emission (Guo and Lin, 2001).

In summary, the effect of water management on GHG emissions reduced CH_4 emissions in rice straw incorporate treatments (S and I) but enhanced N_2O emissions in stubble incorporate treatments (only S). The results in this study clearly show the pattern of CH_4 emission from two season rice fields which was significantly influenced by mid-season drainage (Figures 3.15, 3.17). The global warming potential (GWP) was used in order to estimate the potential future impacts of emissions of different gases upon the climate system in a relative sense. CO_2 is a reference gas to convert CH_4 and N_2O into CO_2-equivalents. In the present study, we calculated GWPs using IPCC factors to assess the combined climatic impacts from CH_4 and N_2O under coherence of rice straw and water management. The 100 year GWPs were revised by the Third Assessment Report (TAR), increasing the GWP of CH_4 to 23 and decreasing the GWP of N_2O to 296 (IPCC, 2001). In terms of GWP, methane emission from wet season is higher than the emission in dry season while the N_2O emission in dry season is higher than wet season (Figure 3.30).

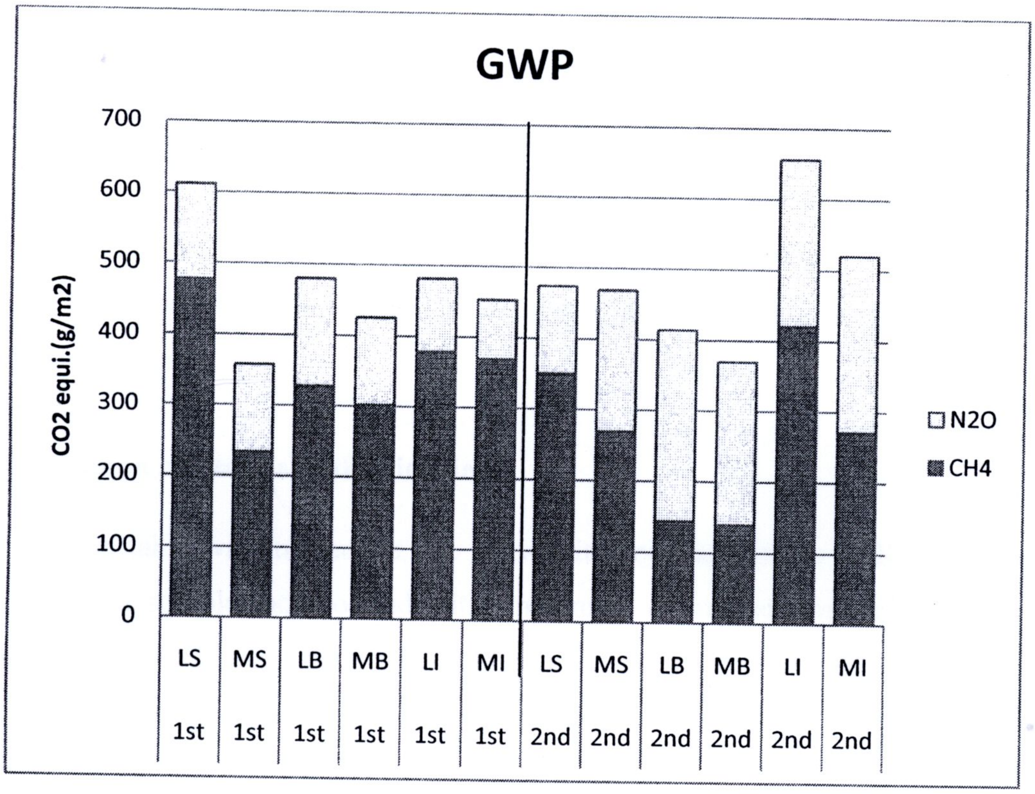


Figure 3.30 Comparison of GHG emissions from rice cultivation in wet and dry seasons

3.4.3 Rice straw and water management affect total of soil carbon and nitrogen, rice production

The soil carbon changed according to the cultivation practice, especially the rice straw management. In burning plot the total carbon trend to stable at 2.9-3.1 %, while the rice straw incorporated makes the fluctuation of total carbon in S and I plots (Figure 3.23). Soil nitrogen in burning plot was higher than nitrogen in rice straw and stubble plots throughout the rice cultivation (Figure 3.24). In terms of rice production, burn plot produced highest grain yields. Compared between burn and un-burn rice straw, the reduction of total grain yield in I plot and S plot were 13.22% and 14.69% compared to B plot. However, we found that no significant difference between local drainage and mid-season drainage in each treatment. The addition of rice straw which is a wide C/N ratio is supplemented as carbon source for soil organisms. A soil having C/N ratio wider than normal is not in the condition to support plant growth, due to the activity of the soil organisms will result a lack of available nitrogen. Doryland (1916) informed that the most favorable conditions for the consumption of ammonia or nitrates are an application of energy material, such as carbohydrates or straw. The work of Brown and Allison (1916) agrees with Doryland that an application of wide C/N ratio material caused decreased yields of oats whereas narrow ratio substances induced the yields. This knowledge concurs with this study that soil carbon in I and S plot was higher than soil carbon in B plot due to rice straw application. On the other hand, soil nitrogen was highest in burn plot and the soil C/N ratio steady between 12-13 results to the higher grain yield in burn plot (Figure 3.25).

3.4.4 Mitigation strategies in the rice field

The suitable way to manage rice straw with consideration to GHGs emission and air pollution is stubble incorporated with implement of mid-season drainage. The mid-season drainage in irrigated rice field could be using for reduce the GHGs emission when compare to the local drainage management as show in Figure 3.31. The GHG reduction were 23.83%, 14.51% and 10.98% in S, I and B plots, respectively.

In conclusion of this field experiment, the least greenhouse gases emissions from our experiment showed in MS and MB plots; however, the air pollution from open field burning should be taken into consideration. Therefore, the suitable cultivation practice for methane mitigation and rice production is stubble incorporate with mid-season drainage.

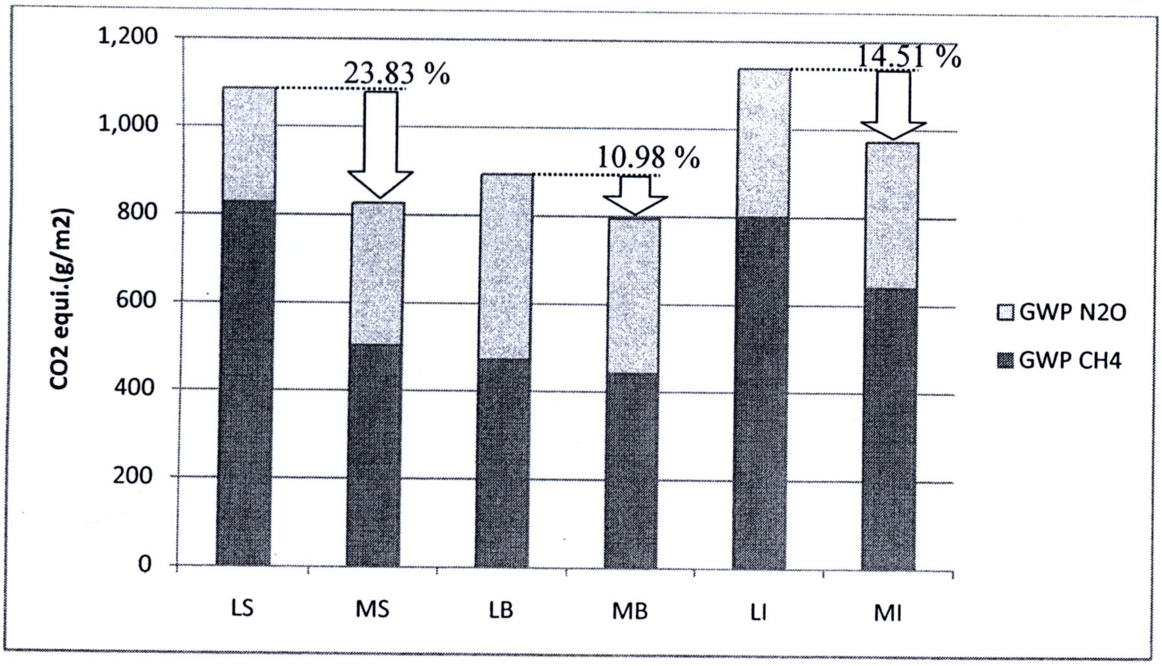


Figure 3.31 GHG emissions from two rice cultivation in Samutsakorn, 2007

3.5 Summary

Short-term burning effects soil temperature and soil volumetric water content in burning plot. The few change of soil temperature (±2^{0}C) due to heat capacity property of soil and heat transfer, therefore the field burning on short period did not affect the changes of soil temperature, water content and bulk density.

Different rice straw management did not affect the physical and chemical properties of soil. However, soil carbon and soil nitrogen changed according to rice straw management. In addition, the community of methanogen did not show clearly different between burned and unburned practice. Nevertheless, the unburn practice showed the dominant of Methanosarcinaceae in community while in burn plot showed the dominant of Methanomicrobiales.

Annual GHGs emissions consisted of CH_4 and N_2O from rice cultivation, fallow period and burning period. Percentage of CH4-rice cultivation, N_2O-rice cultivation, CH_4-fallow period, N_2O-fallow period, CH_4-burning and N_2O-burning are 46.92%, 26.28%, 17.97%, 7.78%, 0.79% and 0.27%, respectively. Methane emission from cultivation was high in incorporated plot and N_2O emission was high in burned plot. In rice cultivation, the mid-season drainage was implemented as GHGs mitigation option. The GHG reduction were 23.83%, 14.51% and 10.98% in S, I and B plots, respectively. The suitable cultivation practice for methane mitigation and rice production under rice straw management system is unburned rice straw with mid-season drainage.