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รายงานวิจัยฉบับสมบูรณ์

โครงการ การศึกษาโมเดลทำนายการปล่อยมีเทน และ ไนตรัสออกไซด์จากนาข้าว

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รศ.ดร. สิรินทรเทพ เต้าประยูร
นางสาว เครือมาศ สมัครการ

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สัญญาเลขที่ BGJ4580027

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บัณฑิตวิทยาลัยร่วมด้านพลังงานและสิ่งแวดล้อม

มหาวิทยาลัยเทคโนโลยีพระจอมเกล้าธนบุรี

สนับสนุนโดยสำนักงานกองทุนสนับสนุนการวิจัย

(ความเห็นในรายงานนี้เป็นของผู้วิจัย สกว.ไม่จำเป็นต้องเห็นด้วยเสมอไป)

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Abstract

Project Code: BGJ4580027

Project Title: Study on models implementation on methane and nitrous oxide emissions from rice field.

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Project Period: 30 September 2002 – 29 September 2003

The objects of this study were 1) to study methane and nitrous oxide emissions from different fields drainage, and 2) to modify existing model relating methane emissions using field experiment from native rice fields. In order to achieve the objectives the field experiment was investigated to measure CH_4 and N_2O emissions and provides complete data inputs for models. The results from field observation was used to verify model and find out accuracy and possibility application for Thai rice fields.

It was observed that the mid season drainage and the multiple drainage, with slightly reduction of rice yield, shown the average CH_4 emission per crop 2 times lower that the continuously flooded and local drainage. The N_2O emission also shown the interesting information related to water drainage system.

The results from model validations shown estimated emissions using DNDC site mode are –30 to 30 % different from field observations. While estimated using empirical model are −50 to 153 % compared with field observations. To access more accuracy estimation using these models, some missing data and the complete database for Thailand need to be developed and model modifications need to study.

Key words: Methane/ Nitrous oxide/ Emissions/ Model/ Rice field

บทคัดย่อ

รหัสโครงการ: BGJ4580027

โครงการ: การศึกษาโมเดลทำนายการปล่อยมีเทนและไนตรัสออกไซด์จากนาข้าว

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การศึกษานี้มีวัตถุประสงค์เพื่อศึกษาข้อมูลการปล่อยก๊าซมีเทน และ ก๊าซไนตรัสออกไซด์จากนาข้าวที่มีการระบายน้ำที่แตกต่างกัน, และ เพื่อปรับปรุงแบบจำลอง 2 ประเภท คือ process base model และ Empirical model ในการคำนวณก๊าซมีเทนจากนาข้าว โดยใช้ข้อมูลจากนาข้าวในประเทศไทย เพื่อให้บรรลุวัตถุประสงค์ดังกล่าว โครงการนี้ได้ทำการทดลองภาคสนาม ณ นาข้าวจังหวัดสมุทรสาคร เพื่อสำรวจการปล่อยก๊าซทั้งสอง และเพื่อเป็นการจัดเตรียมข้อมูลเพื่อสนับสนุนการทำงานของแบบจำลอง นอกจากนี้ข้อมูลที่ได้จากการสำรวจภาคสนามได้ถูกนำมาเปรียบเทียบกับข้อมูลที่ประเมินได้จากแบบจำลองเพื่อศึกษาถึงความแม่นยำ และ ความเป็นไปได้ของการนำแบบจำลองดังกล่าวมาใช้ในประเทศไทย

จากการสำรวจภาคสนามพบว่านาที่มีการระบายน้ำกลางฤดูกาล 1 ครั้ง และ นาที่มีการระบายน้ำ 2 ครั้ง ซึ่งมีอิทธิพลให้ผลผลิตข้าวลดลงเล็กน้อย แต่ให้ปริมาณการปล่อยก๊าซมีเทนน้อยกว่าแปลงนาที่ไม่มีการระบายออกตลอดฤดูกาล และ นาที่มีการจัดการตามแบบเกษตรกรท้องถิ่น ถึง 2 เท่า สำหรับปริมาณการปล่อยก๊าซไนตรัสออกไซด์นั้นพบว่ามีความสัมพันธ์กับการระบายเช่นกัน

การศึกษาเปรียบเทียบข้อมูลภาคสนามกับข้อมูลจากแบบจำลองพบว่า process base model ประเมินค่าการปล่อยก๊าซมีเทนแตกต่างจากการสำรวจ ประมาณ –30 ถึง 30 % ส่วน empirical model มีความแตกต่างจากการสำรวจถึง 50 ถึง 153 % ดังนั้นจำเป็นต้องมีการศึกษาเพื่อพัฒนาโมเดล และสร้างฐานข้อมูลที่สมบูรณ์เพื่อให้การประเมินถูกต้องแม่นยำมากขึ้น

คำหลัก: มีเทน/ ไนตรัสออกไซด์/ การปล่อยก๊าซ/ โมเดล/ นาข้าว

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The authors would like to express their sincere thanks to Thailand Research Fund for the financial support. Sincere thanks to Miss Saipin Poonkaew and Mr. Pin Pol-In for their distributions. We thank Prof. Yao Huang empirical model and Prof. Chang Shang Li for Denitrification-Decomposition model.

Chapter I

Introduction

1.1 RATIONALE

One of the current's environment concerns is the global warming caused by anthropogenic gases release of carbon dioxide, methane, nitrous oxide and ozone, which absorb solar radiation and trap the remaining heat energy in the lower temperature, warms the earth. Atmospheric methane and nitrous oxide are recognized as the most important greenhouse gases. It has been reported that methane and nitrous oxide emission to the atmosphere contributes 21 and 310 times of carbon dioxide's effect for global warming [Houghton 1995].

Agriculture soil store great amount of organic carbon, it is on of the sinks of atmosphere carbon dioxide. Methane is an end product of the biological reduction of carbon dioxide or organic carbon under anaerobic conditions. Methane fluxes are strongly controlled by soil carbon content, soil redox potential (Eh), and soil temperature. In addition, nitrous oxide could be emitted during the drainage period of rice fields. Nitrous oxide is produced during the transformation of soil N by the microbial processes of nitrification and denitrification and from abiotic reactions. Nitrous oxide emission from agriculture soils correlated positively with fertilizer N inputs.

The linkage among microbial process and influence factors related still uncertain for Thai rice fields and estimated methane and nitrous oxide from rice fields are large range and depend on high variability in flooded soil and methodologies. For accuracy estimated of these two gases from rice field, the process based model and empirical model are helpful in order to understand linkage of environment factors on methane and nitrous oxide emission and possibly to prediction. In addition the modifications of existing model will be required to account for the effects of field drainage, a normal management practice used by farmers and a potential strategy for mitigation of methane and nitrous oxide emissions.

This study will apply existing process based model and empirical model to estimate methane and nitrous oxide emissions uses field experiments data from Thai rice fields in order to compare the accuracy estimation. The field experiment will be investigated in order to fulfill insufficient data for the models. However, the existing models developed base on data from other country, therefore modification of existing models in order to apply suitable condition for Thai rice fields need to study. In addition the database for agricultures sector will be developed in order to estimate emissions for whole country.

1.2 MODEL

The DNDC model site mode and regional mode [Li, C.S. 1992] and empirical model [Huang et al. 1998] were used for this study.

1.2.1 PROCESS BASE MODEL: denitrification-decomposition [Li, C. S. 1992]

This model was developed for predicting trace gases emissions from agriculture ecosystems. The model containing fundamental biochemical and geochemical processes. The DNDC was constructed to include two components. The first component predicts the soil environmental forces driven by the ecological drivers, and the second component predicts the rates of nitrification, denitrification and chemo-denitrification based on the soil environmental forces. The model runs on a personal computer and uses commonly available climate, soil, land use and agriculture practices data input. Daily mean air temperature and daily rainfall/irrigation data are compiled into a climate scenario. Additional input data include soil properties such as texture, initial temperature and moisture, density, pH, initial organic residue content, organic carbon and nitrate concentrations, crop type, tillage practices, amendments, and fertilizer applications. The DNDC model provides site mode and regional mode in order to convenience simulations and validations for specific site and large scale, respectively.

1.2.2 EMPIRICAL MODEL [Huang et al. 1998a]

The empirical model [Huang et al., 1998] is a semi-empirical model that developed to predict methane emissions from flooded rice fields. This model focused on the contributions of rice plants to the processes and also the influence of environmental factors. The hypothesis of this model was the methanogenic substrates are primarily derived from rice plants and added organic matter. Rates of methane production in flooded rice soils are determined by the availability of methanogenic substrates and the influence of environmental factors. The fraction of methane emission was controlled by the rice growth and its development. The amount of methane transported from the soil to the atmosphere is determined by the rates of production and the emitted fraction. The important influences environmental from model validation are rice net productivity, cultivars character, soil texture, soil temperature, and organic matter amendments.

1.3 OBJECTIVES

1.3.1 To record methane and nitrous oxide emissions from different fields drainage.

1.3.2 To modify existing model relating methane emissions using field experiment from native rice fields.

1.4 SCOPE OF WORKS

Methane fluxes are strongly controlled by soil carbon content, soil redox potential (Eh), and soil temperature. In addition, nitrous oxide could be emitted during the drainage period of rice fields. Nitrous oxide is produced during the transformation of soil N by the microbial processes of nitrification and denitrification and from abiotic reactions. Nitrous oxide emission from agriculture soils correlated positively with fertilizer N inputs.

Water management (irrigation and drainage) is one of major importance factor in rice production and has a major impact on CH_4 and N_2O emissions. Submergence and drainage of the rice field controls oxygen available in the rice soil. The existing model was not concerned of field drainage and the field data or previous experiment focused on field drainage was not available. The field experiment need to investigate in order to modify model for Thai rice fields.

1.4.1 Investigate fields experiment in order to measure methane and nitrous oxide emission and provides complete data inputs for models. The field experiment investigates in native rice fields with in irrigate area, which drainage and water managements has been controlled.

1.4.2 Verify model using results from fields experiment in order to find out accuracy and possibility application for Thai rice fields.

Chapter II

Methodology

2.1 Field description and water management

The field experiment was performed in Samutsakorn province located in the central plain of Thailand [Figure 1], it located at longitude 100.20 E and latitude 13.20 N . This area had been cropped continuously since last 20 years. The field measurements were taken from the second rice-growing season of 2002. Rice soil in this field experiment was Bangkok soil series and soil classified as Typic Tropaquepts. The physicochemical properties of Bangkok soil series are shown in Table 1.

Table 1: The physical and chemical characteristics of soil in the Samutsakorn rice fields.

Soil property	Analysis
pH	6.1
Organic matter (%)	2.3
K (mg/100g soil)	80
P (mg/100g soil)	0.7
Mg (mg/100g soil)	50.4
Soil texture	Clay
% Sand	22
% Silt	24
% Clay	54
NH_4^+ - N (mg/100g soil)	1.9.6

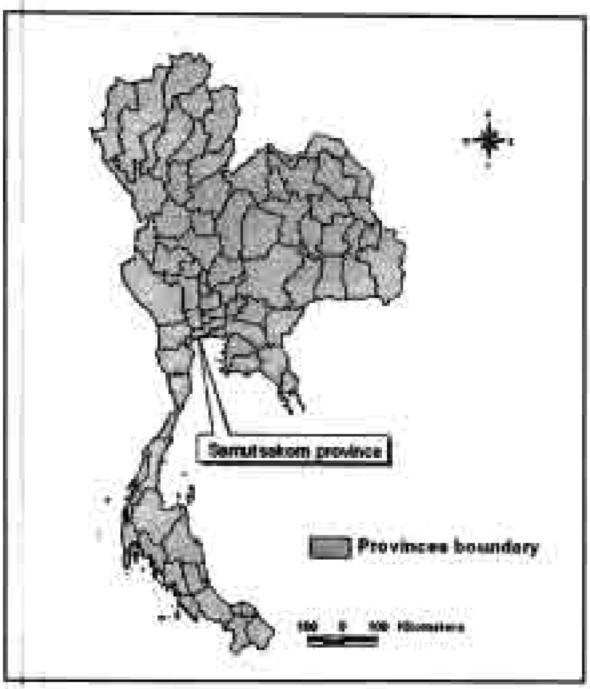

Figure 1 The location of experiment site Samutsakorn province located in the central of Thailand between longitude 100.20 E and latitude 13.20 N.

2.2 Experiment layout and treatment arrangements

The field experiments lay out with four treatments in the wet season. Four different field drainages has been conducted: local method, continuously flooded, mid season drained, and multiple aeration. The Local method: normal flooded following the local irrigation practice. The continuously flooded: field was flooded since the 10 days after plant to 18 days before harvested. Midseason drainage: 7 days drain at 75 days after plant (reproductive phase). Multiple drainage: 2 intermittent drained periods of 3 days duration, drain at 31 and 75 days after planted after initial flooding. The common rice irrigation practices in Samutsakorn province has been applied in this study. The fertilizer 16-20-0 was applied at 17 days after planted as the basal fertilizer which 50 kg/rai Nitrogen as urea 15 kg/rai was applied as the top dressing fertilizer at 29 days after planted and 20 kg/rai of 16-20-0 was applied at 47 days after planted. The cultivars plant was Suphanburi 1 (Table 3), the photoperiod insensitive non-jasmine rice cultivars that required 120-125 days from planting to maturity. Shoot length 125 cm and grain yield is approximately 5,000 kg/ha. The wet seedling with 187.5 kg of rice per ha was applied to field on August 12, 2002. The fields were flooded at 10 day after planted and water level in each field was controlled at the same level (5-10 cm) excepted draining periods. Planted calendar through the growing season are shown on Table 2.

Table 2 Planted calendars of experiments at Samutsakorn (2002)

Cultivation practice	Local practice	Continuously flooded	Mid season drainage	Multiple drainage
Soil preparation	23-Jul	23-Jul	23-Jul	23-Jul
Wet seedling	12-Aug	12-Aug	12-Aug	12-Aug
Weed eradicate	20-Aug	20-Aug	20-Aug	20-Aug
Flooding 5 cm. depth	25-Aug	25-Aug	25-Aug	25-Aug
Fertilizer application #1: 16-20-0	29-Aug	29-Aug	29-Aug	29-Aug
Fertilizer application #2: Urea	10-Sep	10-Sep	10-Sep	10-Sep
Fertilizer application #3: 16-20-0	28-Sep	28-Sep	28-Sep	28-Sep
Worm eradicate	29-Aug	29-Aug	29-Aug	29-Aug
Drain #1	14-Oct	-	25-Oct	11-Sep
Drain #2	-	-	-	25-Oct
Pesticide application	12-Sep	12-Sep	12-Sep	12-Sep
Re flood #1	17-Oct		1-Nov	14-Sep
Re flood #2	-	-	-	28-Oct
Drain field before harvest	14-Nov	14-Nov	14-Nov	14-Nov
Harvest	2-Dec	2-Dec	2-Dec	2-Dec

Table 3 Physiological characteristic of rice cultivars used in the experiment

Character	Suphan Buri 1 variety (*Oryza sativa L.*)
Photoperiod sensitive	Non
Shoot length (cm)	125
Period of growth (day)	120-125
Number of ear/m^2	230
Grain yield (t/ha)	5

2.3 Methane and nitrous oxide measurements

Methane and nitrous fluxes were usually measure once a week except during the draining periods where they were measured everyday other day. An acrylic chamber 0.6x0.6x0.85 (height) m. was used for methane measurements. An acrylic chambers made from 6 mm thick acrylic equipped with small fan (radian 3 inches) on the top of the chamber in order to air circulation inside the chambers. In addition, thermometer 0-100 °C was attached on the ceiling of the chamber for measure inside chamber temperature. In order to accomplish the close system during sample collections, the chamber was placed into 5 cm depth in flooded rice soil.

Sampling of gases from the acrylic chambers was done in a 2 hours cycle allowing four measurements of the gases sample inside each chamber, at 30 minutes intervals each measurement. Gases sample were collected during 12.00 to 2.00 p.m. because the maximum methane emissions from Thai rice fields was observed during the late afternoon 13:00 – 15:00 p.m. [Towprayoon et al. 1993, Katoh et al. 1999a]. Gas samples were collected with a syringe and transferred to the evacuated vial bottles stopped with butyl rubber septa.

Gases sample were measured 2 times after harvested in order estimates emissions during the fallow period. Methane concentrations were determined with gas chromatography model GC 14B (Shimadzu), with unibead-C column. Column temperature 100 °C, injection temperature 120 °C, FID detector temperature 300 °C, Carrier gas flow 65 ml/min, injection volume 0.5 ml.

Methane emissions were determined from the rate of change of concentration in a set of 4 samples taken over a 30 minutes sampling period. The samples sets of methane concentrations were plotted versus time, using linear regression. Methane fluxes were calculated from concentrations changes in the chamber with time at 30, 60, 90, and 120 minutes after the chamber was placed on the field, using the equation

$$F = 0.714\ S\ h\ (273/(273+T)) \quad \text{[Cai et. al. 2000]}$$

Where F is methane flux in $mgCH_4/m^2/h$, S is the linear increase of methane concentrations increase with time, h is the available height of the chamber, and T is the inside box temperature.

Nitrous oxide concentrations were determined with gas chromatography equipped with ^{63}Ni electron capture detector (ECD). Calibration was performed using nitrous oxide standard gas at the concentration 1 ppm (Scotty II co., Ltd.). Column temperature 65 °C, injection temperature 150 °C, ECD detector temperature 300 °C, carrier gas flow 60 ml/min, injection volume 1 ml.

Nitrous oxide emissions were determined from the rate of change of concentration in a set of 4 samples taken over a 30 minutes sampling period. The samples sets of nitrous oxide concentrations were plotted versus time, using linear regression. Fluxes were calculated from concentrations changes in the chamber on the field, using the equation:

$$F = \rho(V/A)\,(dC/dt) \qquad \text{[Watanabe et al. 2000]}$$

Where F is nitrous oxide flux in $mgN_2O/m^2/h$, ρ is the density of N_2O-N at the pressure and temperature measured inside the chamber, V is the above-ground surface volume of the chamber, A is the cross-sectional area of the chamber, and dC/dt is the increase in N_2O concentration inside the chamber with time. The dC/dt was determined from the linear regression of a set of the four data points obtained during a measurement period.

Data were analyzed with the analysis of variance (ANOVA) using statistic analyze system (SAS) software.

2.4 Other field properties and plant biomass measurements

Soil redox was measured using portable platinum electrodes (HANNA instruments model HI 9025). The electrode was inserted in the rice soil at approximately 5 cm depth. The electrodes was calibrate with redox solution for platinum electrodes, HANNA HI7020 before use and it was cleaned every time after use by electrode cleaning solution HANNA HI7061 and de-ionized water. Sufficient time (~ 5 min) was given for reading to get the stabilized before recording. The pH of the flooded soil and soil pH were measured using a portable pH meter (HANNA instruments model HI 9025). Soil and water temperature were measured using the thermometer (0-100 °C) at 5-10 depth, and recording temperature value in °C. Other properties such as water depth, biomass, grain yield etc. were measured and recorded throughout the growing season.

Chapter III

Results

3.1 Field experiment at Samutsakorn province

3.1.1. Seasonal methane and nitrous oxide emissions

Table 4 showed the daily average emissions and total seasonal emissions of methane and nitrous oxide from the four different drainage field. It was found that the nitrous oxide emissions from local method and continuous flooded field were at close proximity value but lower than mid season drainage field. The highest emission (61.26 mg/m2) from mid season drainage and lowest emission (36.14 mg/m2) was from local method. Methane fluxes varied with water management, showing the highest seasonal emission from continuous flooding (24.36 g/m^2) and the lowest from multiple aeration (15.68 g/m^2), which more than 35 % lower than continuous flooded. The emissions rate from local method treatment (23.96 g/m^2) and mid season drainage (17.36 g/m^2) showed 1.66 and ~ 29 % lower than continuously flooded fields.

Table 4 Methane and nitrous oxide emissions values

Treatments	Emissions				Grain yield (g/m2)
	Methane **		Nitrous oxide		
	Daily average (mg/m2/d)	Total seasonal (g/m2)	Daily average (ug/m2/d)	Total seasonal (mg/m2)	
Local method	213.88	23.96	322.68	36.14	438.00
Continuously flooded	217.50	24.36	331.68	37.15	435.00
Mid season drainage	155.02	17.36	546.93	61.26	408.00
Multiple drainage	139.99	15.68	343.60	38.48	388.00

** Significantly different at *P*=0.05

The seasonal patterns of methane emissions from Samutsakorn rice field are shown in Figure 2. Methane fluxes were significantly different at p = 0.05. The results from this field showed that mid--season drainage and multiple aeration treatments considerably affected methane emission. Figure 3 shown irregular pattern of nitrous oxide, which were different within the four treatments. However as water draining lead to the increasing of soil redox potential, an increasing trend of nitrous oxide emissions was observed.

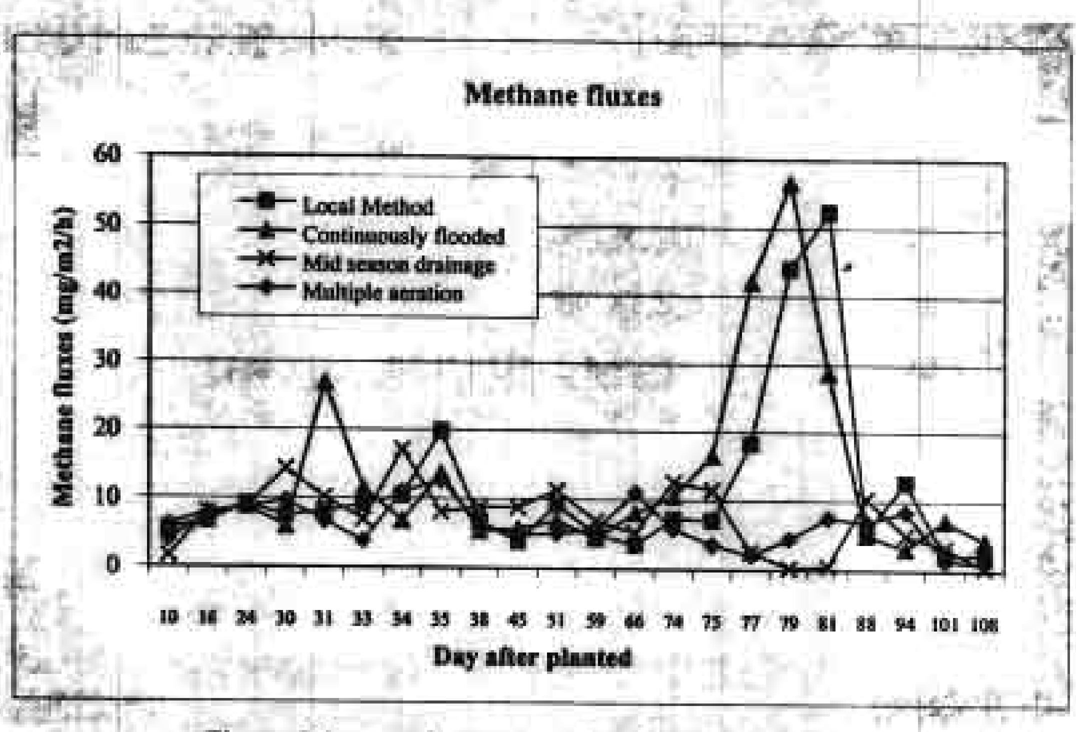

Figure 2 Seasonal patterns of methane emissions

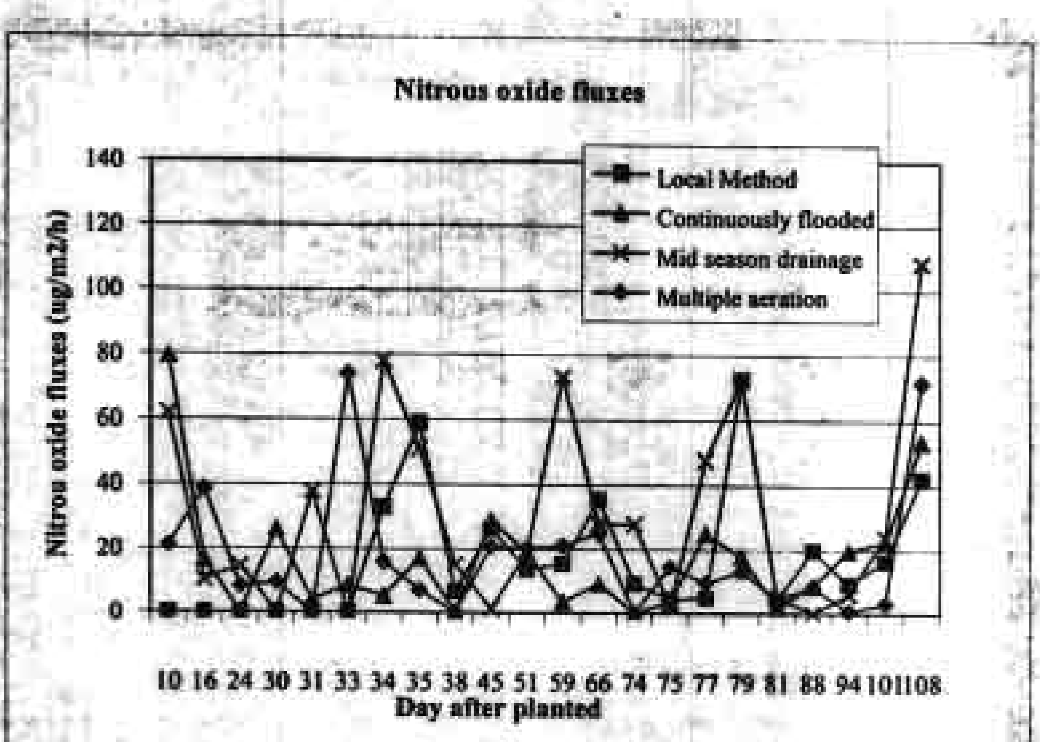

Figure 3 Seasonal nitrous oxide emissions

3.1.2. Field characteristics
3.1.2.1 Soil redox potential

Soil redox potentials (Eh) during the growing period ranged from – 178 to + 85 mV [Figure 4]. Eh increased when the field was drained and decreased again when the field was re-flood. Average soil Eh decreased gradually after beginning of season until the field was drain and increased slowly when re-flooded. The minimum soil Eh presented at 10 day after planted from the local method treatment. The first partial drain of local method resulted in an increased of soil Eh from –139.2 to –114.2 mV. Long period of mid season drainage (7 days drain) resulted in an increased of soil Eh from –150.30 to –98.4 mV. The first draining period from multiple aeration resulted in an increased of soil Eh from –156.6 to –132.3 mV, while the second draining period increased from –153.3 to –100.6 mV.

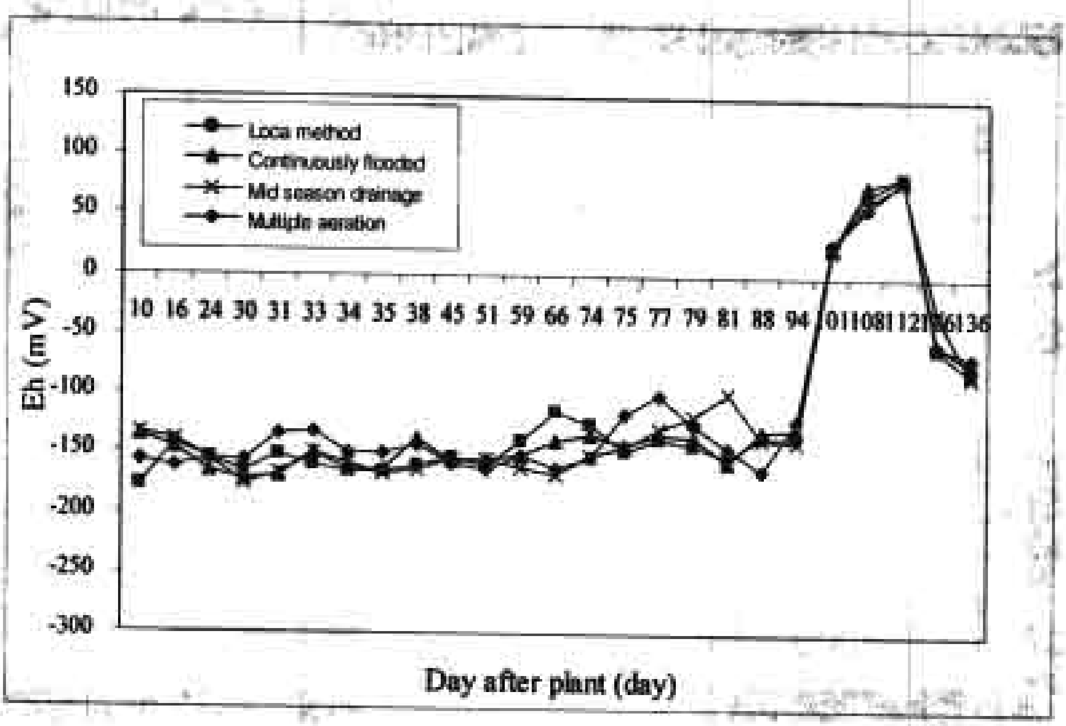

Figure 4 Soil redox potential at the 5-cm. depths.

The relationship between soil Eh and methane emissions from rice field was the negative correlation [Figure 5]. This results agree with previous research that the methane emission begun to increase with the decrease of soil Eh [Minami 1994]. In order to consider the effect of field drainage on methane fluxes-the Eh values were plotted versus methane fluxes and the correlations between these parameters followed a negative exponential curve. This relationship agrees with previous research [Wang et al 1993]. Soil redox potential during the draining period between normal flood and drainage treatments (mid season drainage and multiple aeration) was significantly different at p=0.05.

The seasonal methane emissions correlated with soil redox potential and growing stage of rice plant. The seasonal methane emissions increased gradually within two short periods at tillering stage and panicle initiation stage. Methane emissions decreased rapidly after field was drained. This is due to the dry conditions in rice soil and increasing of soil redox potential. In the continuously flooded treatment, methane emissions increased with plant growth and gradually increased to the highest emission at the almost panicle initiation stage (79 Day after planted), and then decreased rapidly. At the end of growing season, the fields were drain cause the dry conditions in rice fields and methane emissions decreased rapidly.

Highest methane emissions from rice fields presented in the reproductive period (80 day after planted approximately) because the environmental condition in this period such as soil pH ~ 6.0, strong anaerobic condition in flooded field suitable for microorganism activities and organic matter decomposition. In addition, rice plant in reproductive period require high nutrient than other growing period in order to seed productive, therefore nutrient uptake through root systems such as root exudation is also higher than other periods. Not only root exudate useful for plant growth but it is an energy source for methanogenic bacteria around rice root also.

Multiple drainage, with low methane emission also showed low nitrous oxide emission when compare to other treatments. In general, drainage system introduces aeration to soil and promote nitrous oxide formation. In the case of multiple drainage, although two short drainage times (3 days) were employed, but the emission was lower than the midseason drainage with one drainage time of 6 days. We believed that, as seen by the redox potential increment, the drainage time play the important role in introducing nitrous oxide emission. Shorter drainage time might not be sufficient for nitrous oxide to development. Therefore multiple drainage showed the lowest nitrous oxide emission and methane emission despite the lowest grain yield.

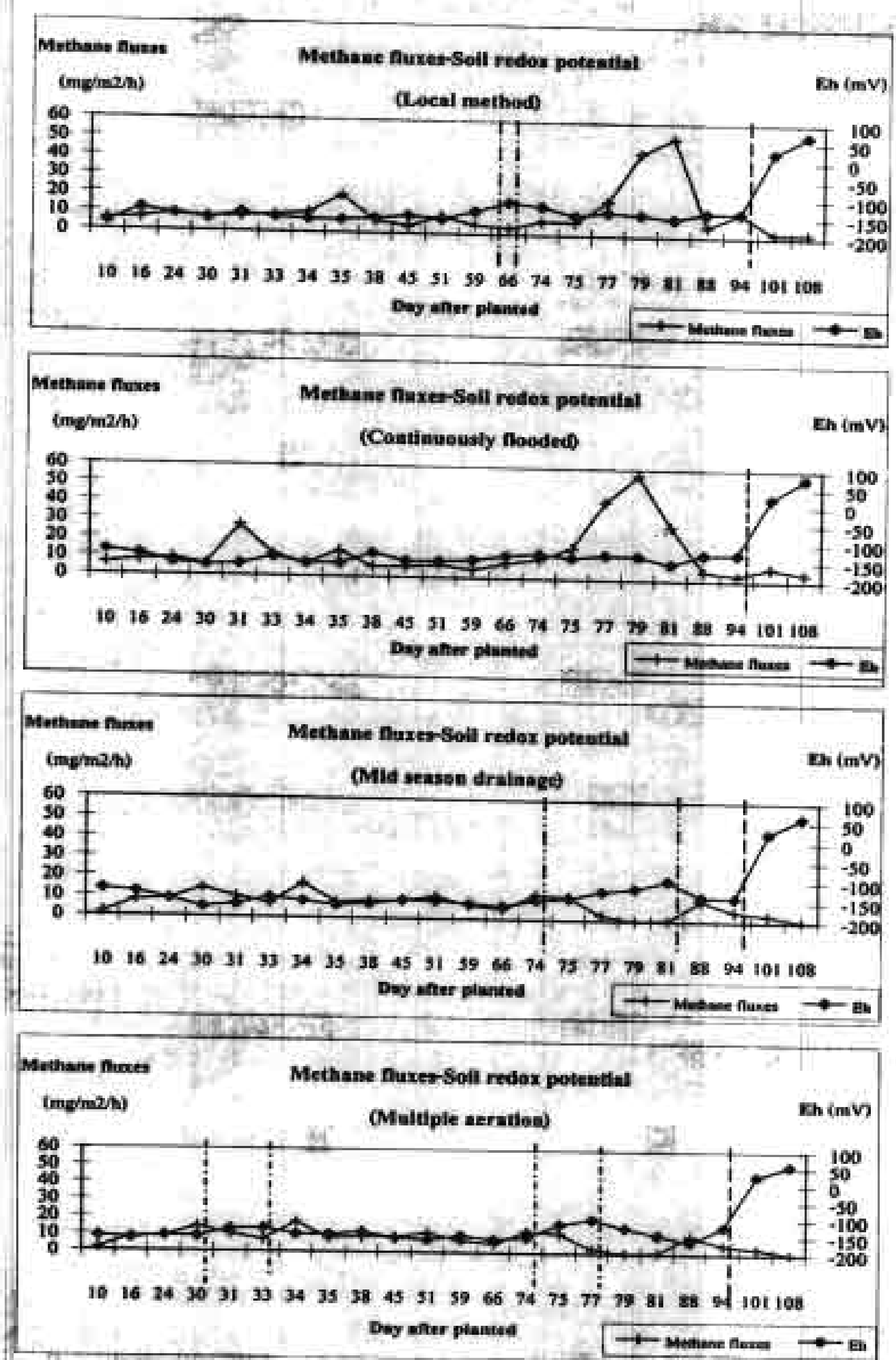

Figure 5 Soil redox potential and methane emissions throughout the growing period.

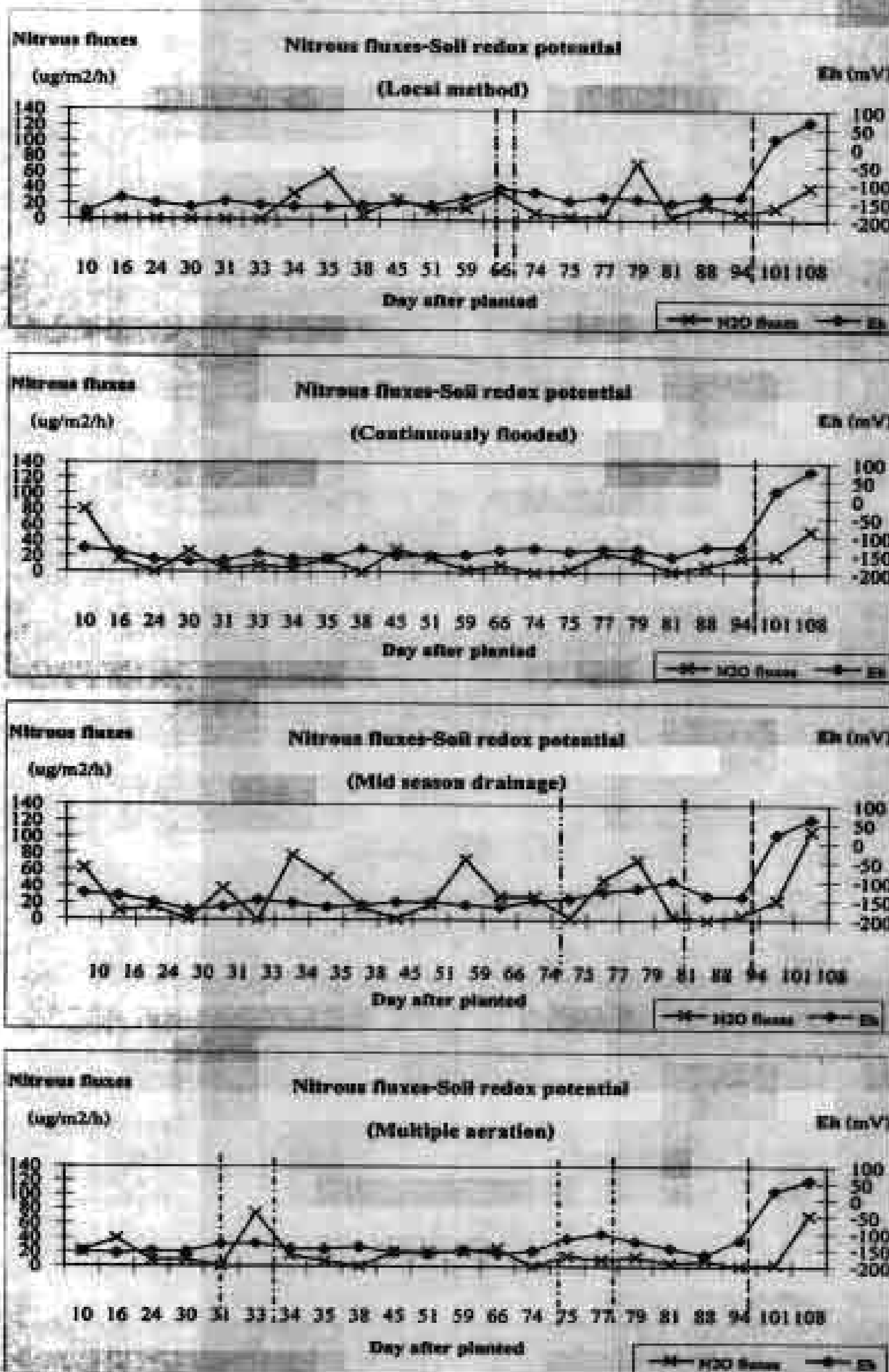

Figure 6 Soil redox potential and nitrous oxide emissions throughout the growing period.

3.1.2.2 Soil pH and water pH

Soil pH of growing season range from 6.43 – 7.49 and it does not significantly different. The minimum soil pH presented at the 101 day after planted from multiple aeration treatment, and the maximum from mid season drain at the 24 day after planted. Where as the average minimum of soil pH is 6.94 presented at the 108-day after planted and the average maximum 7.37 at the 24-day after plant (Figure 8). The results from this experiment shown soil pH is always higher then water pH from all treatments but both of data are similar pattern. The water pH range from 6.90 – 7.95, and the average minimum is 6.94 presented at the 75-day after plant, the average maximum 7.86 at 16 day after planted.

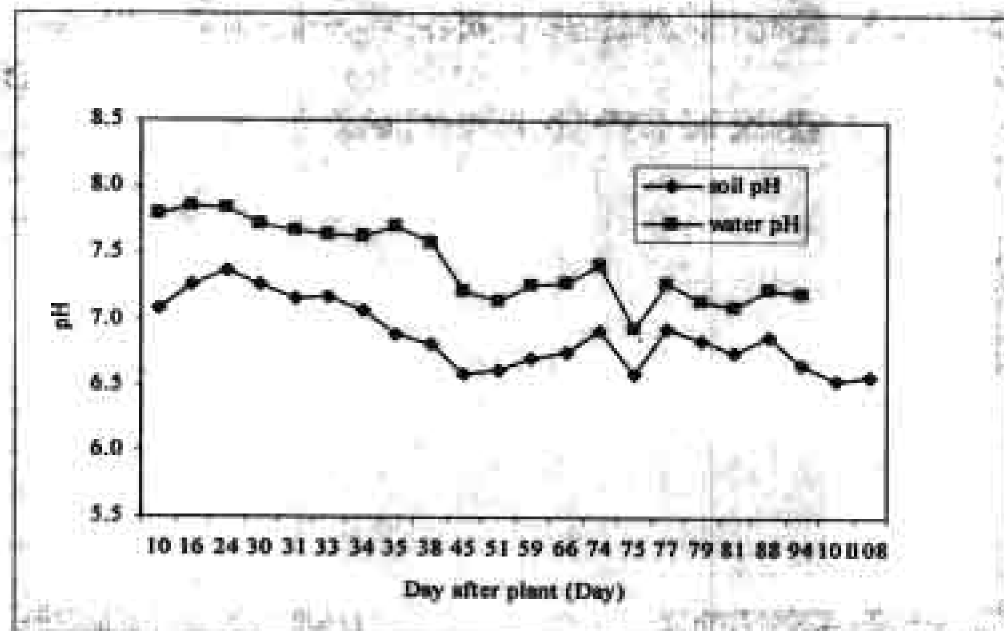

Figure 7 Average soil and water pH throughout the growing period.

3.1.2.3 Plant Biomass and Grain Yield

Table 5 Plant biomass and grain yield.

Treatments	Grain yield g/m2	Average plant density (plant/ft2)	Average plant height (cm)	Average Shoot dry weight (g/plant)	Average root dry weight (g/root)	Average root length (cm)
Local method	438.00	34.73	66.49	5.71	2.63	14.60
Continuously flooded	435.00	34.32	68.30	5.68	2.35	14.71
Mid season drainage	408.00	32.45	68.54	5.87	2.35	13.57
Multiple drainage	388.00	30.64	68.57	5.48	2.36	13.61

Table 5 shown grain yields, plant density and biomass measured from Samutsakorn rice fields (Figure 8, 9, and 10). The maximum grain yield was observed from local method, which closed to grain yield from, continuously flooded. While the minimum grain yield was from multiple drainage, which ~ 11 % lower than local method. Average plants density from multiple drainage and mid season drainage were ~ 12 and ~7 % compared with local treatment. The results from statistical analysis shown shoot dray weight, root dry weights were not significant different.

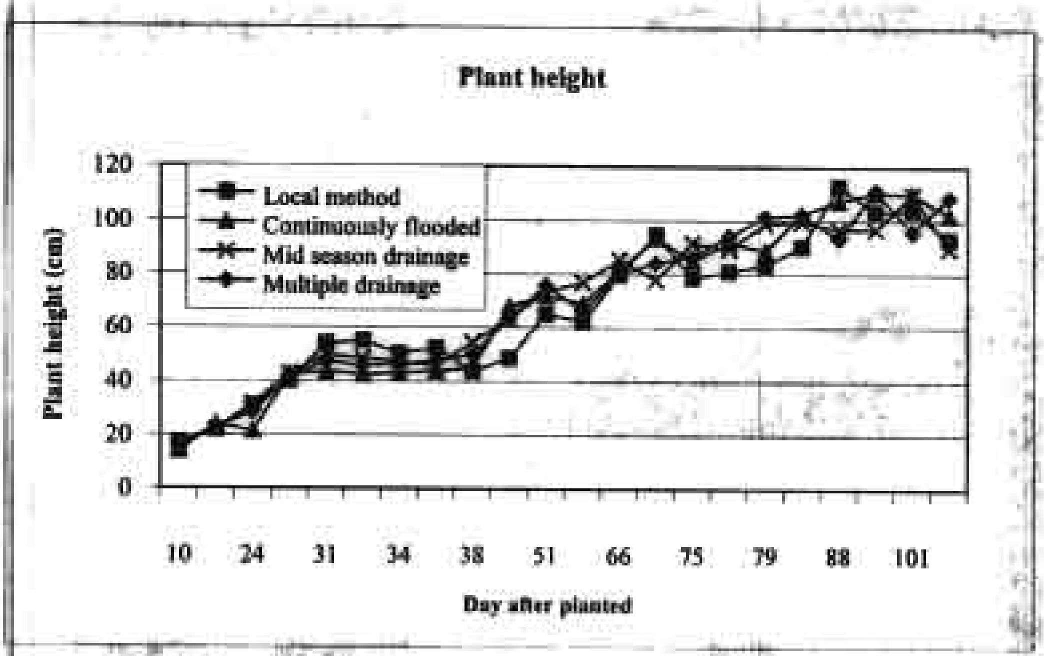

Figure 8 Plants height

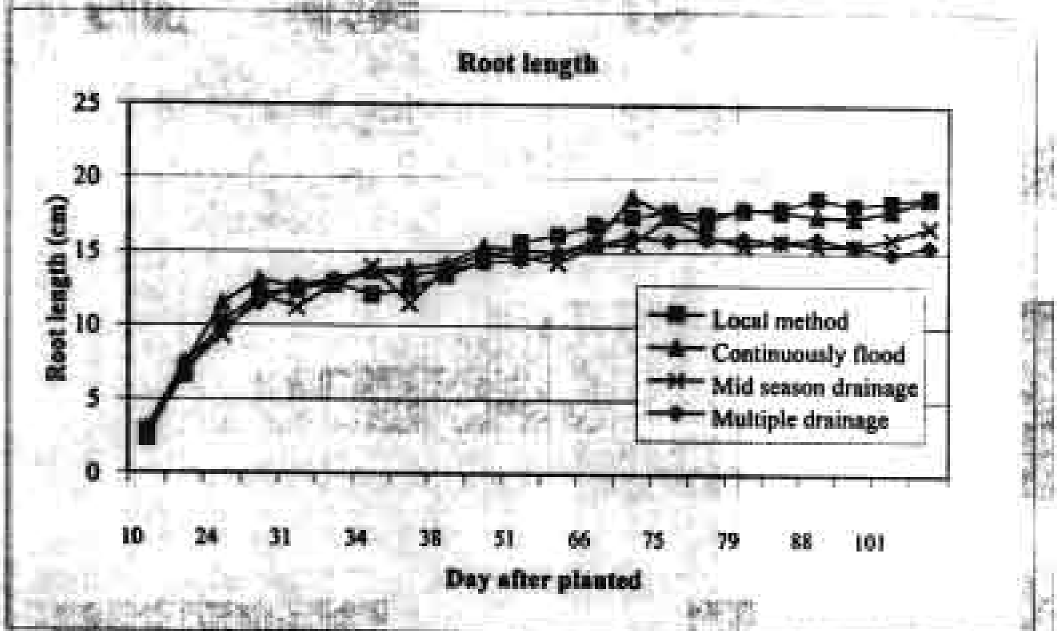

Figure 9 Root lengths

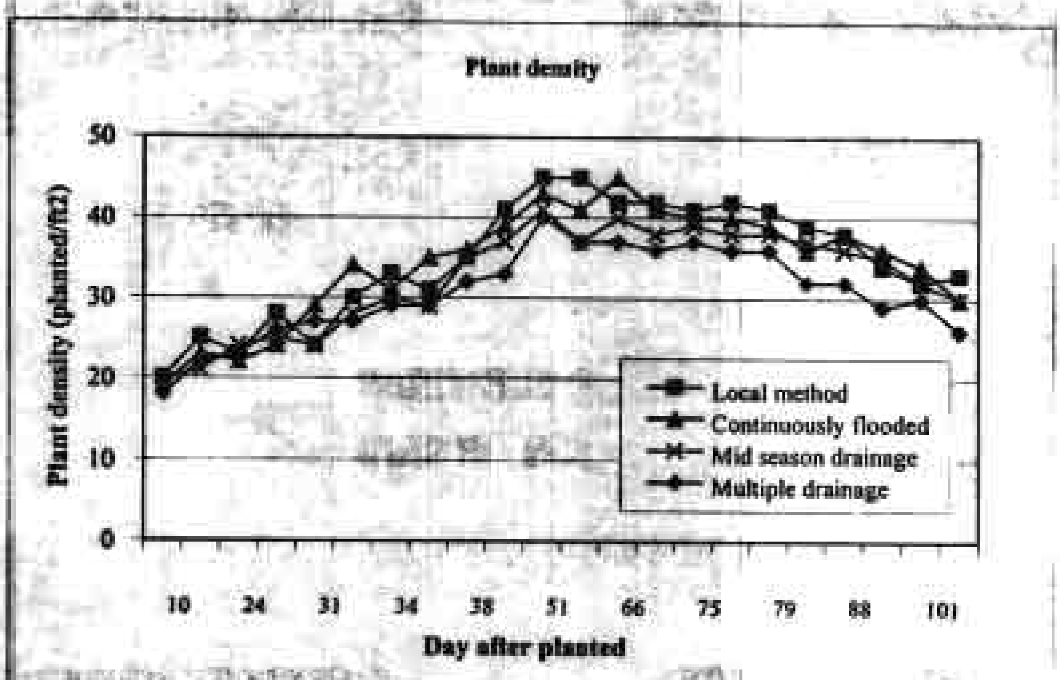

Figure10 Plant density

3.1.2.4 Emissions per grain yields

Table 6 Emissions per grain yields

Treatment	Product	Emissions		Emissions per Grain yields	
		CH_4	N_2O	CH_4	N_2O
	kg/ha/crop	kg/ha/crop	kg/ha/crop	g CH_4/kg product	ug N_2O/kg product
Local Method	4,375	239.55	0.36	54.75	82.61
Continuously flooded	4,350	243.60	0.37	56.00	85.40
Midseason drainage	4,075	173.62	0.61	42.61	150.32
Multiple aeration	3,875	156.79	0.38	40.46	99.31

Methane emissions per grain yield from the continuously flooded was highest and the lowest ratio was observed from multiple drainage, which ~ 24 % lower than continuously flooded. While nitrous oxide emissions per grain yield from mid season drainage was highest and higher than the minimum ratio from local treatment ~55 %.

Table 7 shown the global warming potential as carbon dioxide from field observation. Total global warming potential from continuously flooded was maximum (5,230.29 kg CO_2), while the minimum value was multiple drainage (3,410.29 kg CO_2). The multiple drainage can be reduced global warming potential around 35 % compared with rice cultivation with out drainage.

Table 7 Global warming potential

Treatment	Emissions		Emissions		GWPs Net GHGs*		
	CH_4	N_2O	CH_4	N_2O	CH_4	N_2O	Total
	mg/m2/day	ug/m2/day	kg/ha/crop	kg/ha/crop			
Local Method	213.88	322.68	239.55	0.36	5,030.54	111.60	5,142.14
Continuously flooded	217.50	331.68	243.60	0.37	5,115.59	114.70	5,230.29
Midseason drainage	155.02	546.93	173.62	0.61	3,646.12	189.10	3,835.22
Multiple aeration	139.99	343.60	156.79	0.38	3,292.49	117.80	3,410.29

* GWPs CH4 = 21 and GWPs N2O = 310 times of CO_2 [Houghton et al. 1996]

3.2 Model validation using field data

Table 8 Comparison of methane emissions from field observation and models

Field/Treatments	Methane emissions		
	Field observed g/m2/yr	DNDC model g/m2/yr	Empirical model g/m2/yr
Local method	23.96	18.42	44.11
Continuously flooded	24.36	19.99	25.09
Mid season drainage	17.36	15.51	13.72
Multiple drainage	15.68	22.88	24.76

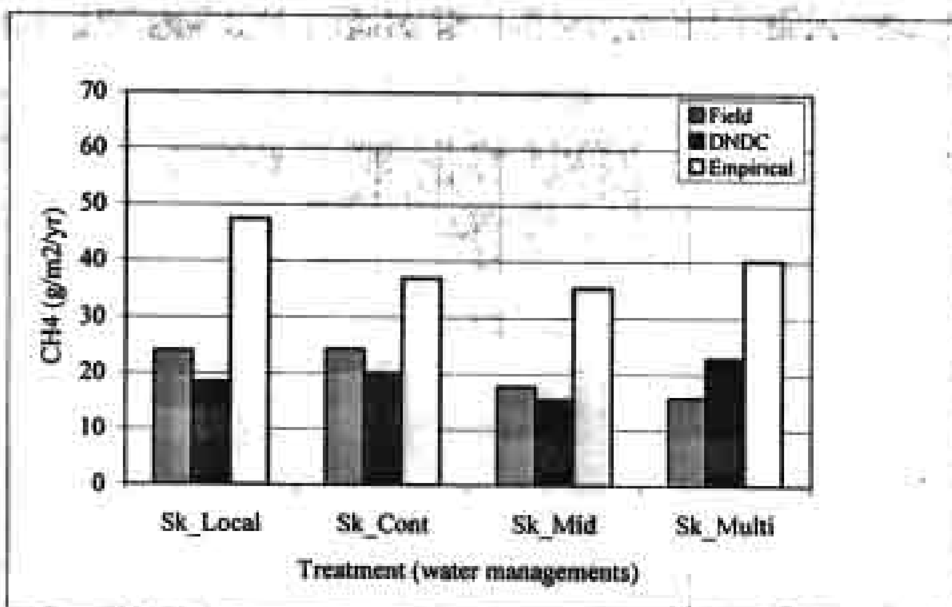

Figure 11 Comparison of methane emissions from field observation and models

The estimated emissions using DNDC site mode are –30 to 30 % different from field observations. While estimated using empirical model are ~50 to 153 % compared with field observations. The lowest emissions estimated from two model were mid season drainage, while multiple drainage emitted lowest from field observed. The results from this study shown both process base model and empirical model shown the possibility to be use for estimated methane emissions from irrigated rice fields in Thailand. However, to access more accuracy estimation using these models, some missing data and the complete database for Thailand need to be developed and model modifications need to study.

Chapter IV

Conclusions and discussions

Drainage system influence methane emissions as well as nitrous oxide emission from rice field. Methane emissions from paddy soil are correlated with soil redox potential, thus a decrease of soil redox potential increases emission [Yagi and Minami 1990, Chairoj et al 1994]. Multiple drainage and midseason drainage at flowering period can help mitigate methane emission. Nevertheless the rice yield of these two irrigation systems were 6.8 and 11.4 percent reduction while more than 40 percent of methane can be reduced. Drainage day rather than number of draining influenced nitrous oxide emission. The study of field drainage on methane and nitrous oxide emissions from the drainage treatment shows that the field drainage is the option for reduces methane and nitrous oxide emissions from rice fields. To maintain high rice yield and low emission of methane and nitrous oxide, midseason drainage during flowering period with shorten draining time (3 days) is recommended.

To estimate methane emission from irrigation rice fields, model implementation is useful. The results from model validations from this study shown both process base model and empirical model shown the possibility to be use for estimated methane emissions from irrigated rice fields in Thailand. However, the accuracy estimation depends on many influencing factors during cultivation period. Field drainage is one important factor influence on soil Eh and methane emissions. On the basis of available information on rice cultivation, removing floodwater decreases methane emission because soil aeration inhibits methane production by methanogens. To access more accuracy estimation using these models, some missing data and the complete database for Thailand need to be developed and model modifications need to study.

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Output

1. Towprayoon, S., PoonKaew, S., and Smakgahn, K., Mitigation of methane and nitrous oxide emission in the rice field using drainage system, *Proceedings of 3rd International Methane & Nitrous Oxide Mitigation Conference, Beijing,* China November 17-21, 2003 (In press)

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Appendix

MITIGATION OF METHANE AND NITROUS OXIDE EMISSION IN THE RICE FIELD USING DRAINAGE SYSTEM

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ABSTRACT

One of the important cultural practices in the tropical rice plantation is the application of water drainage system. The drainage of water in the rice field during cultivation served to improve aeration in the soil as well as promote plant growth. In addition the induced aeration during drainage effected the soil redox potential and interfere soil ecosystem, which influenced on methane and nitrous oxide emission. In Thailand, although irrigation system was introduced, various patterns of the water drainage system were conducted throughout the country. In this study, 4 different water drainage systems were conducted in the rice field in central part of Thailand There were continuous flooding system, midseason drainage, multiple drainage and local drainage. Methane emission as well as nitrous oxide emission were observed and compared with rice yield and physical change of rice plant. It was observed that the mid season drainage and the multiple drainage, with slightly reduction of rice yield, shown the average methane emission per crop 2 times lower that the continuous flood and local drainage. The nitrous oxide emission also shown the interesting information related to water drainage system. Nevertheless, it was not clear that the change of redox potential involved in the reduction of methane and nitrous oxide as it was still in range of anaerobic activities.

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INTRODUCTION

Methane is an end product of the biological reduction of carbon dioxide or organic carbon under anaerobic conditions. Methane fluxes were strongly controlled by soil carbon content, soil Eh, and soil temperature. Wetland rice soils have been shown to be an important methane source at the global scale. Rice fields contribute 9-13 % to global methane emissions. [1].

Methane emissions from rice fields appear to be decreased by field drainage and some important cultivation practices. In general, field drainage trends to increase rice yield by increasing N-mineralization and by increasing root development in the rice plant. In addition drainage is conducted to improve aeration in the rice fields and results in a possible reduction of methane production and emissions.

Previously research shown the irrigated system have the highest potential for methane emissions because the assured or continuous water supply, and continuous flooded that cause anaerobic condition in the paddy soil [2]. Methane emissions have been shown to be higher with continuous flooding than intermittent irrigation [3,4]. Methane emissions decline during the drainage to near zero and increase after reflooding [5]. Methane emission rate also varies with the timing of flooding where a late flood (76 days post planting) treatment had the highest emission 1.6 times that observed during the normal water treatment and the multiple drainage aeration treatment emitted very low seasonal emission [6]. In contrast to methane, nitrous oxide emission was introduced by aeration occurred during draining water and reflooding. Lower methane emission due to water drainage may increase nitrous oxide emission. As nitrous oxide posses much higher global warming potential than methane, the relationship of these two greenhouse gases in different drainage system should be investigated in order to reveal the influence of water drainage system as the option of greenhouse gases mitigation.

MATERIALS AND METHODS

Experimental designed

The rice fields in Samutsakorn province with soil classified as Typic Tropaquepts were used as the studied area. (Longitude 100.20 E and latitude 13.20 N). This area had been cropped continuously since last 20 years. The field measurements were taken from the second rice-growing season of 2002. Four different field drainages has been conducted as followed: 1) local method drainage according to local irrigation practice, 2)continuously flooded represented long period flooded since the 7 days after plant to 15 days before harvested. 3)mid season drained, Midseason drainage: 6 days drain at 64 days after plant (flowering period and 4)multiple aeration 3 intermittent drained periods of 2 days duration, drain at 3, 6, and 9 weeks after initial flooding... .

The common rice irrigation practices in Samutsakorn province has been applied in this study. The fertilizer 16-20-0 was applied at 20 days after planted as the basal fertilizer which 156.25 kg/ha. Nitrogen as urea was applied as the top dressing fertilizer at 29 days after planted. The cultivars plant was Suphanburi 1, the photoperiod insensitive non-jasmine rice cultivars that required 120-125 days from planting to maturity. Shoot length 125 cm and grain yield is approximately 5,000 kg/ha. The wet seedling with 187.5 kg of rice per ha was applied to field on August 12, 2002. The fields were flooded at 7 day after planted and water level in each field was controlled at the same level (5-10 cm) excepted draining periods.

Methane measurement

Methane fluxes were usually measure once a week except during the draining periods where they were measured everyday other day. An acrylic chamber 0.6x0.6x0.85 (height) m. was used for methane measurements. An acrylic chambers made from 6 mm thick acrylic equipped with small fan (radian 3 inches) on the top of the chamber in order to air circulation inside the chambers. In addition, thermometer 0-100 °C was attached on the ceiling of the chamber for measure inside chamber temperature. In order to accomplish the close system during sample collections, the chamber was placed into 5 cm depth in flooded rice soil.

Sampling of gases from the acrylic chambers was done in a 2 hours cycle allowing four measurements of the methane inside each chamber, at 30 minutes intervals each measurement. Gas samples were collected with a syringe and transferred to the evacuated vial bottles stopped with butyl rubber septa.

Methane concentrations were determined with gas chromatography model GC 14B (Shimadzu), with unibead-C column. Column temperature 100 °C, injection temperature 120 °C, FID detector temperature 300 °C, Carrier gas flow 65 ml/min, injection volumn 0.5 ml.

Methane emissions were determined from the rate of change of concentration in a set of 4 samples taken over a 30 minutes sampling period. The samples sets of methane concentrations were plotted versus time, using linear regression. Methane fluxes were calculated from concentrations changes in the chamber with time at 30, 60, 90, and 120 minutes after the chamber was placed on the field, using the equation

$$F = 0.714\ S\ h\ (273/(273+T) \quad [7]$$

Where F is methane flux in $mgCH_4/m^2/h$, S is the linear increase of methane concentrations increase with time, h is the available height of the chamber, and T is the inside box temperature.

Nitrous oxide measurement

Nitrous oxide concentrations were determined with gas chromatography equipped with ^{63}Ni electron capture detector (ECD).

Calibration was performed using N_2O standard gas at the concentration 1 ppm (Scotty II co., Ltd.). Column temperature 65 °C, injection temperature 150 °C, ECD detector temperature 300 °C, carrier gas flow 60 ml/min, injection volume 1 ml.

Nitrous oxide emissions were determined from the rate of change of concentration in a set of 4 samples taken over a 30 minutes sampling period. The samples sets of nitrous oxide concentrations were plotted versus time, using linear regression. Fluxes were calculated from concentrations changes in the chamber with time at 30, 60, 90, and 120 minutes after the chamber was placed on the field, using the equation

$$F = \rho(V/A)\,(dC/dt) \text{ [8]}$$

Where F is Nitrous oxide flux in $mgN_2O/m^2/h$, ρ is the density of N_2O-N at the pressure and temperature measured inside the chamber, V is the above-ground surface volume of the chamber, A is the cross-sectional area of the chamber, and dC/dt is the increase in N_2O concentration inside the chamber with time. The dC/dt was determined from the linear regression of a set of the four data points obtained during a measurement period.

Soil Redox potential

Soil redox potential was measured using portable platinum electrodes (HANNA instruments model HI 9025). The electrode, calibrate with redox solution for platinum electrodes, HANNA HI7020, before use was inserted in the rice soil at approximately 5 cm depth.. Sufficient time (~ 5 min) was given for reading to get the stabilized before recording.

RESULT AND DISCUSSION

Methane Emission

It was found as shown in figure 1. that the methane emission from difference drainage methods showed difference pattern of emission . In local practice and continuous flooded fields, where the drainage period was applied during early flowering period(day 55-60) and after harvesting period, high methane emission peak was found during flowering period (day 75-88) . It was also noted that with midseason drainage and multiple aeration , where the drainage were applied during flowering period (day 73-79 and day 73-76) , high methane emission peaks were not observed . This finding lead to the lower overall emission of the two later drainage fields as shown in table 2. The deviation of the highest seasonal emission from continuous flooding (35.81 g/m^2) to the lowest from multiple aeration (16.91 g/m^2)was more than 52.8 percent . When compare to local practice, the seasonal emission of mid season drainage (18.76 g/m^2) and multiple drainage (16.91 g/m^2) were 40.2 % and 46.2 % lower than local practice field, respectively.

Continuous flooded field with higher seasonal methane emission than the local practice field, produced closed proximity number of grain yield. While the midseason drainage and multiple drainage although showed half reduction of seasonal methane emission but the grain yield were lower , particularly with multiple drainage system. The percentage of yield reduction , compare to the local practice, were 6.8 % from midseason drainage and 11.4 % for multiple drainage, respectively.

Table 1 Methane emissions from 4 difference drainage rice fields.

	Methane emissions		Grain yield (g/m2)
	Daily average, (mg/m2/d)	Seasonal (total), (g/m2)	
Local method	277.40	31.43	438
Continuously flooded	318.19	35.81	405
Mid season drainage	176.37	18.76	408
Multiple drainage	143.12	16.91	388

Reduction-oxidation potential of the 4 treatment fields were also investigated during the experiment. The results showed that redox potential was increasing change when water was drained out and dropped again when the flooded water back to the field.

Nitrous Oxide Emission

The result in figure 2 showed irregular pattern of nitrous oxide which were different within the four treatments. However as water draining lead to the increasing of soil redox potential, an increasing trend of nitrouos oxide emission was observed Table 2 showed the daily average emission and the total seasonal emission of nitrous oxide from the four different drainage fields. It was found that the emission from local method and continuous flooded field were at close proximity value but lower than midseason drainage field. The lowest emission was from the multiple aeration field.

Multiple drainage, with low methane emission also showed low nitrous oxide emission when compare to other treatments. In general, drainage system introduce aeration to soil and promote nitrous oxide formation. In the case of multiple drainage, although two short drainage times (3 days) were employed, but the emission was lower than the midseason drainage with one drainage time of 6 days. We believed that, as seen by the redox potential increment, the drainage time play the important role in introducing nitrous oxide emission. Shorter drainage time might not be sufficient for nitrous oxide to development. Therefore multiple drainage showed the lowest nitrous oxide emission and methane emission despite the lowest grain yield.

Table 2 Nitrous oxide emissions from 4 difference drainage rice fields.

	Nitrous oxide emissions	
	Daily average, (ug/m2/d)	Seasonal (total), (ug/m2)

Local method	11.46	1.2
Continuously flooded	11.30	1.2
Mid season drainage	18.97	2.0
Multiple drainage	9.66	1.0

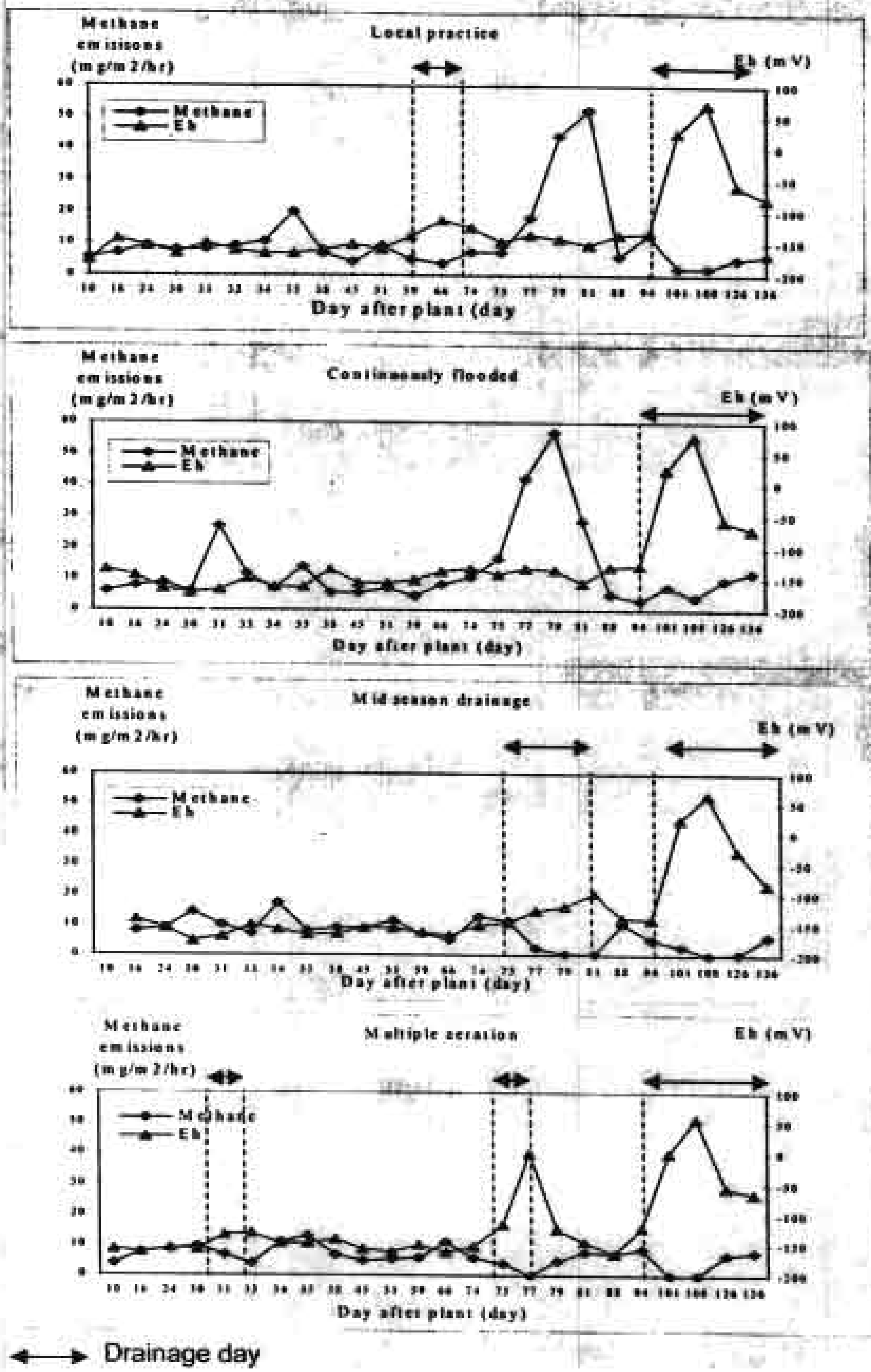
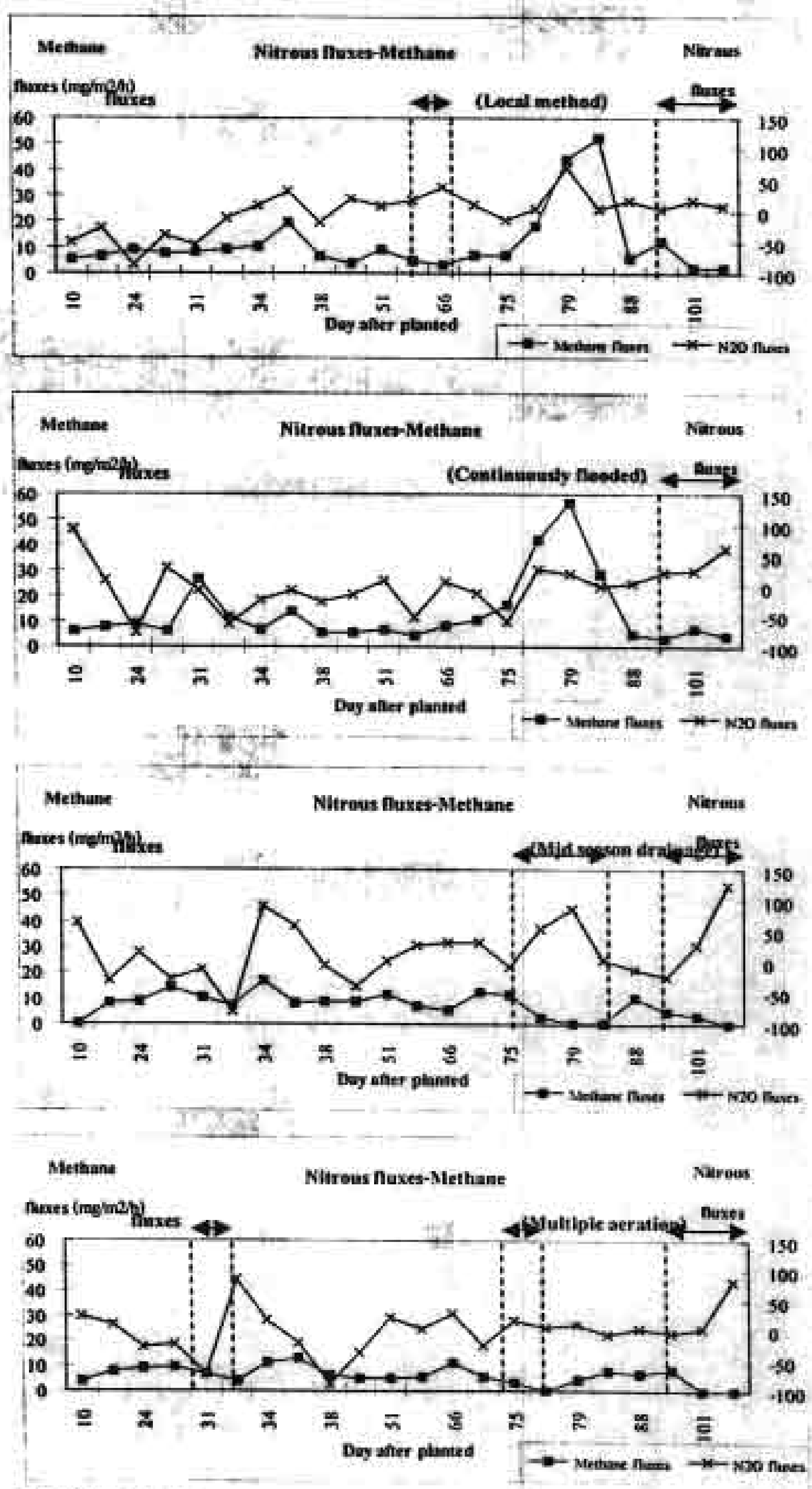


Figure 1. Methane emission and soil redox potential from 4 different drainage rice fields



⟷ Drainage time

Figure 2 . Methane emission and nitrous oxide emission from 4 different drainage rice fields

CONCLUSION

Drainage system influence methane emission as well as nitrous oxide emission from rice field. Multiple drainage and midseason drainage at flowering period can help mitigate methane emission . Nevertheless the rice yield of these two irrigation systems were 6.8 and 11.4 percent reduction while more than 40 percent of methane can be reduced. Nitrous oxide emission was influenced by drainage day rather than number of draining. Short drainage time lead to less methane emission. To maintain high rice yield and low emission of methane and nitrous oxide, midseason drainage during flowering period with shorten draining time (3 days) is recommended.

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ESTIMATING OF METHANE EMISSION FROM RICE FIELD IN THAILAND USING DNDC MODEL

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ABSTRACT

Atmospheric methane is one of important greenhouse gases, with 21 times of global warming potential higher than CO_2. Wetland rice soils have shown to be an important CH_4 source at the global scale. However, to estimate the global change of methane, due to relation of soil properties to other environmental change such as cultivation practice, fertilizer application, emission at regional scale should be emphasized. Therefore this study focuses on application of existing process base model namely DNDC (Li C. 1992) to validate methane emission from Thailand in regional mode and site mode. The database for Thailand has been developed in order to estimate emissions using DNDC regional mode. The result from DNDC site mode and DNDC regional mode has been compared for considering the accuracy of methane emissions estimation.

In representation of the whole country, this study chose 12 provinces, which soil organic carbon content range from 0.0114 to 0.0143 % and clay content range from 0.231 to 0.288 %. Other condition such as cultivation practices, water management has been controlled in the same conditions for all cases. The estimated methane emissions from regional mode were higher than site mode in most cases. The relationship between site and regional mode has been found as linear regression with r^2 = 0.807. The regional mode showed perfectly clear relationship among rice cultivations area and methane emissions. High methane emission was estimated from province which high rice cultivation area and vice versa.

The results from the comparison between DNDC regional mode and site mode under the designated range of important factor such as soil organic carbon and clay content show a good relation but the gap estimation between them was 1.59 time. It is challenge for further this study to narrow gap estimation.

Keywords: Greenhouse gases/Methane/ Rice field/ Model/Database

1 INTRODUCTION

Methane is one of the most important greenhouse gases, with 21 times greater in infrared absorbing capability than CO_2 on a mass basis [1]. Methane is an end product of the biological reduction of CO_2 or organic carbon under anaerobic conditions. CH_4 fluxes were strongly controlled by soil carbon content, soil Eh, and soil temperature. At the global scale, wetland rice soils have been shown to be an important CH_4 source. The concentrations of this gas in the atmosphere are increasing on average at about 0.6 % per year [2]. Estimating emission is difficult because emission of this gas from rice fields is depending on various factors. Methane measurement in large scale and data interpretation are difficult because linkage among the microbial, physical, and chemical variables that influence in soils occur over many temporal and spatial scales. Therefore study with processes base model on methane emission is useful to understand linkage of influence environmental factors on methane emission and possible to methane prediction. However, the accuracy of estimation needs to be concerned.

This study used the DNDC (Denitrificaiton -Decomposition) model that developed based on the agricultural practice and the diversity of plants in China. In order to apply this model for Thai rice field, the database of agricultural practice and the diversity of plants in Thailand for DNDC regional mode has been developed, and site characteristic of Thai rice fields has been specific for DNDC site mode. The estimation using DNDC site mode and DNDC regional mode was compared in order to find out the accuracy estimation and the relationship between fine scale and extensive scale estimation.

2 MATERIALS AND METHODS

The DNDC model was used in this study. The DNDC model was a computer simulation model. This model was developed for predicting trace gases emissions from agriculture ecosystems. The model containing fundamental biochemical and geochemical processes. The DNDC was constructed to include two components. The first component predicts the soil environmental forces driven by the ecological drivers, and the second component predicts the rates of nitrification, denitrification and chemo-denitrification based on the soil environmental forces [3]. The DNDC model provides site mode and regional mode in order to convenience simulations and validations for specific site and large scale, respectively. To discover the relationship and possible applications of site mode and regional mode in unsuitable scale, the DNDC site mode and regional mode has been compared in this study.

This study casually chose 12 provinces over the country of Thailand, Chiangmai, Loei, Kanchanaburi, Songkhla, Mahasarakham, Saraburi, Chantaburi, Yala, Surin, Burirum, Sisaket, and Nakornsithammarat. These areas have been chosen under the narrow range of organic carbon and clay content in soil in order to controlled the distribution of the data. Soil organic carbon content in selected area range from 0.0114 to 0.0143 % and clay content range from 0.231 to 0.288 %. In addition, other conditions included cultivation practices; water management has been controlled in the same conditions for all cases. Such as two times plowing has been applied for soil preparation. Water management was controlled as the continuously flooded which 5-10 cm depth. The rice field was applied with 2 times fertilization.

The database for DNDC regional mode has been developed using available data from government agencies in the year 1999-2000. Crop data, agricultural practices, crop calendar, crop area, and the fertilizer statistic data derived from Office of Agriculture economics [4]. The livestock statistic data derived from the Department of Livestock [5]. The climate data included temperature and rainfall from the Department of Meteorology [6]. The soil properties, assumed unchanged by time, were derived from Department of Land Development and applied in the model. The PC computer was used for simulation. ARCVIEW 3.0a (ESRI) was used for display estimated methane emissions for whole country.

3 RESULTS AND DISCUSSIONS

The estimate of methane emissions using DNDC site mode from 12 selected province ranged from 73.15 – 715.88 kg/ha/year as shown in Table 1. The estimated methane emissions from site mode were lower than regional mode in most cases under the narrow range of organic carbon and clay content in soil. Estimate methane emissions using DNDC regional mode from 12 selected province range from 166.33 – 1265.18 kg/ha/year. These estimate emissions were around 0.99 – 2.27 times higher than site mode.

The highest methane emission, estimated in the whole country of Thailand using DNDC regional mode, was found at Ubonratchathani province (6.648E+10 gCH_4/year) in the North East region and the lowest emissions (2.411E+04 gCH_4/year) estimated from Phuket province in the South of Thailand. The estimated methane emissions for the whole country shown in Figure 1.

The regional mode showed close relationship among rice cultivations area and methane emissions. Estimated methane emissions for whole country using DNDC regional mode shown that high methane emission was estimated from province which high rice cultivation area and vice versa.

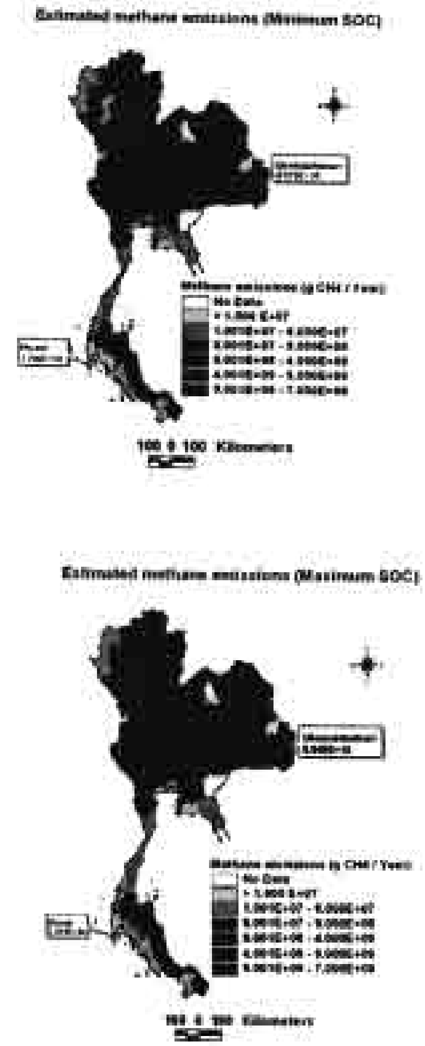

Fig 1 Estimated methane emissions using DNDC regional mode for whole country.

Total estimated methane emissions using the DNDC regional mode and local database were 0.468 Tg/year from minimum soil organic carbon scenario and 0.494 Tg/year from maximum soil organic carbon scenario. Our estimates of total methane emissions agree closely with Smakgahn et al. 2000; 0.459 Tg/year [7] and Matthew et al. 2000; 0.14-0.32 Tg/year [8] although different in methodology and technique of estimation.

The estimated methane emissions from regional mode were higher than site mode in most cases and the relationship between site and regional mode has been found as linear regression (r^2=0.807, n=12) with the slope of 1.59 as shown in Figure 2. The estimated methane emissions from regional and site mode shown in table 1. Although linear relationship was found but the slope of 1.59 indicated the gap estimation between site mode and regional mode. It is challenge for further study to narrow this gap estimation. The data inputs for site mode are complicated and need more details for soil properties and agricultural practice, this mode is useful for fine scale estimation. While in regional mode with large-scale illustration less complicated data inputs were found. As such the key important factor that shows relation on regional mode are the spatial factors i.e. cropping area. For site mode, local and site factors such as soil properties and some agricultural practices are important on the estimation.

Table 1 Estimated methane emissions from DNDC regional mode and site mode.

[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	715.88	1265.18	1.77
[illegible]	331.88	387.26	1.21
[illegible]	71.17	166.11	2.37
[illegible]	344.11	383.10	1.13
[illegible]	300.22	341.47	1.09
[illegible]	431.89	490.88	1.18
[illegible]	332.29	332.89	1.00
[illegible]	287.89	341.22	1.20
[illegible]	306.05	379.82	1.23
[illegible]	307.71	408.51	1.32
[illegible]	287.89	381.80	[illegible]
[illegible]	360.73	532.80	1.47

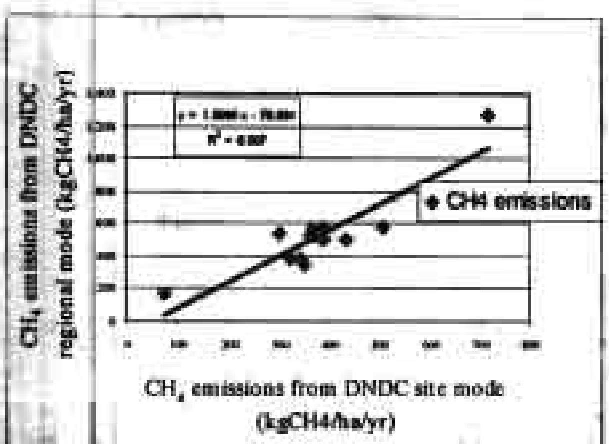

Fig 2 The relationship between estimated methane emissions between site and regional mode.

4 CONCLUSIONS AND DISCUSSIONS

The results from the comparison between DNDC regional mode and site mode under the designated range of important factor such as soil organic carbon and clay content show a good relation but the gap estimation between them was 1.59 time. The regional mode is useful for the estimation in broad scale, however to apply instead of site mode, more accuracy of rice cultivations area and narrow range of soil properties should be taken in to account.

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