Available online at:
http://journal.unila.ac.id/index.php/tropicalsoil
DOI: 10.5400/jts.2012.17.2.105

Greenhouse Gas Emissions from Peat Soils Cultivated to Rice Field, Oil Palm and Vegetable

Abdul Hadi[1*], Luthfi Fatah[1], Syaifuddin[1], Abdullah[2], Dedi Nursyamsi Affandi[3], Rosenani Abu Bakar[4] and Kazuyuki Inubushi[5]

*[1]Faculty of Agriculture; [2]Faculty of Mathematics and Natural Sciences, Lambung Mangkurat University, South Kalimantan, Indonesia; [3]Indonesian Agricultural Environment Research Institute, West Java;Indonesia; [4]Faculty of Agriculture, Universiti Putra Malaysia, Selangor, Malaysia, [5]Faculty of Horticulture, Chiba University, Chiba, Japan. *: Corresponding Author: Abdul Hadi, Jl. A. Yani KM 37 Banjarbaru, South Kalimantan, Indonesia, e-mail: ahadi@faperta.unlam.ac.id*

Received 12 December 2011 / accepted 9 April 2012

ABSTRACT

Presently, about 20% of oil palm (*Elaeis guineensis* Jacq) fields in Indonesia are on peat soil, in addition to that other area of peat soil has been conventionally used for rice field and vegetables. To elucidate the global warming potentials of peat soils cultivated to oil palm, vegetable or rice field, field experiment has been carried out in South Kalimantan. Air samples were taken from rice field, oil palm and vegetable fields in weekly basis for six month period and analyzed for concentrations of N_2O, CH_4 and CO_2. The global warming potentials (GWP) of the three gases were calculated by multiplying the emission of each gas with their respective mole warming potential. This step was followed by the addition of the three gases' GWP to have the total GWP. The results showed that the emissions of greenhouse gases from peat soils changed seasonally and varied with the crops cultivated. Oil palm has resulted the highest GWP, mostly contributed by N_2O. There was no statistical different in total GWP of paddy and vegetable fields. The annual N_2O emission from oil palm field was 4,582 g N ha^{-1} yr^{-1}. Water, nutrients and organic matter managements are among the potential techniques to minimize gas emissions from oil palm field which need field trials.

Keywords: Global warming potential, methane, nitrification, nitrous oxide, oil palm (*Elaeis guineensis* Jacq)

INTRODUCTION

Peat soil comprises of 6% of earth surface but retains about 15%-30% of terrestrial carbon and nitrogen (Batjes 1996). This high C and N contents have lead peat soil to be thought as a sources of greenhouse gases (GHGs) such as nitrous oxide (N_2O), methane (CH_4) and carbon dioxide (CO_2) which have global warming potential 1, 23, and 296 in hundred year perspective, respectively (Bouwman 1990).

About 9 million ha of peat soil occurs in the coastal area of Borneo Island (Driesen 1981; Wahyunto *et al*. 2007) which belongs to three countries (*i.e.* Indonesia, Malaysia and Brunei). The peat soil in this island is formed from mixture of woody and grassy materials and has long time been used for paddy rice cultivation back to year 1969 (Sabiham 2010). Due to increased demand for bio-fuel, the peat soil has recently been used for development of oil-producing crops like oil palm (*Elaeis guineensis* Jacq). Presently, about 20% of oil palm fields in Indonesia and Malaysia are on peat soil (Noor 2010).

It has been estimated that peat and forest degradations contribute to about 45% of total GHGs emissions from Indonesia (Ridlo 1997). This considerable contribution of peat on total GHG emissions has put peat soil as a target for carbon emission reduction. Peat management is targeted to reduce 9.5-13% of GHGs emissions from Indonesia by year 2020 (Las and Surmaini 2010). To achieve this target, the government of Indonesia has suspended oil palm development on deep peat and will release a national action plan to minimize GHG emissions from peat (Noor 2010).

Apart from peat burning, about 75% of CO_2, N_2O and CH_4 are believed to be formed by microbial processes in peat soil (Hadi *et al*. 2001; Murayama and Zahari 1996). Methane is produced by a group of microbes known as methanogens under anaerobic conditions (Cahyani *et al*. 2004). Meanwhile, N_2O is produced by nitrifying microorganisms under aerobic conditions and by denitrifying microorganisms under anaerobic conditions (Hadi *et al*. 2012). The different conditions for these gases' formations may resulted a "trade off" effect (*i.e.* decreasing emission of one gas but at the same time increasing the emissions of other). The objective of present study was to elucidate the global warming potentials of peat soils cultivated to oil palm, vegetable or paddy rice.

MATERIALS AND METHODS

Site Locations

The study was carried out in South Kalimantan province (Indonesia), at the border of Hulu Sungai Utara, Hulu Sungai Tengah and Balangan districts covering an area of about 32,370 ha (Figure 1). The area was about 150 km from the Java ocean and surrounded by Meratus mountains, except for western side which was part of Nagara River basin. The site can be considered as ombrogenic peat where the water are mainly from rain. The peat soil in the area can be classified as a Haplohemist (PT. Saicle Jasa, 2006).

Guided by a land-use map, survey had been carried out to find oil palm, vegetable and paddy rice fields. Considering the easy access for sampling, the sampling points were in radius about 100 meter from collector road. Oil palm was planted in year 2006 (three year old at the time of measurement). Ciherang rice variety was the common rice variety in the area and usually planted in June. Meanwhile, vegetable field was usually

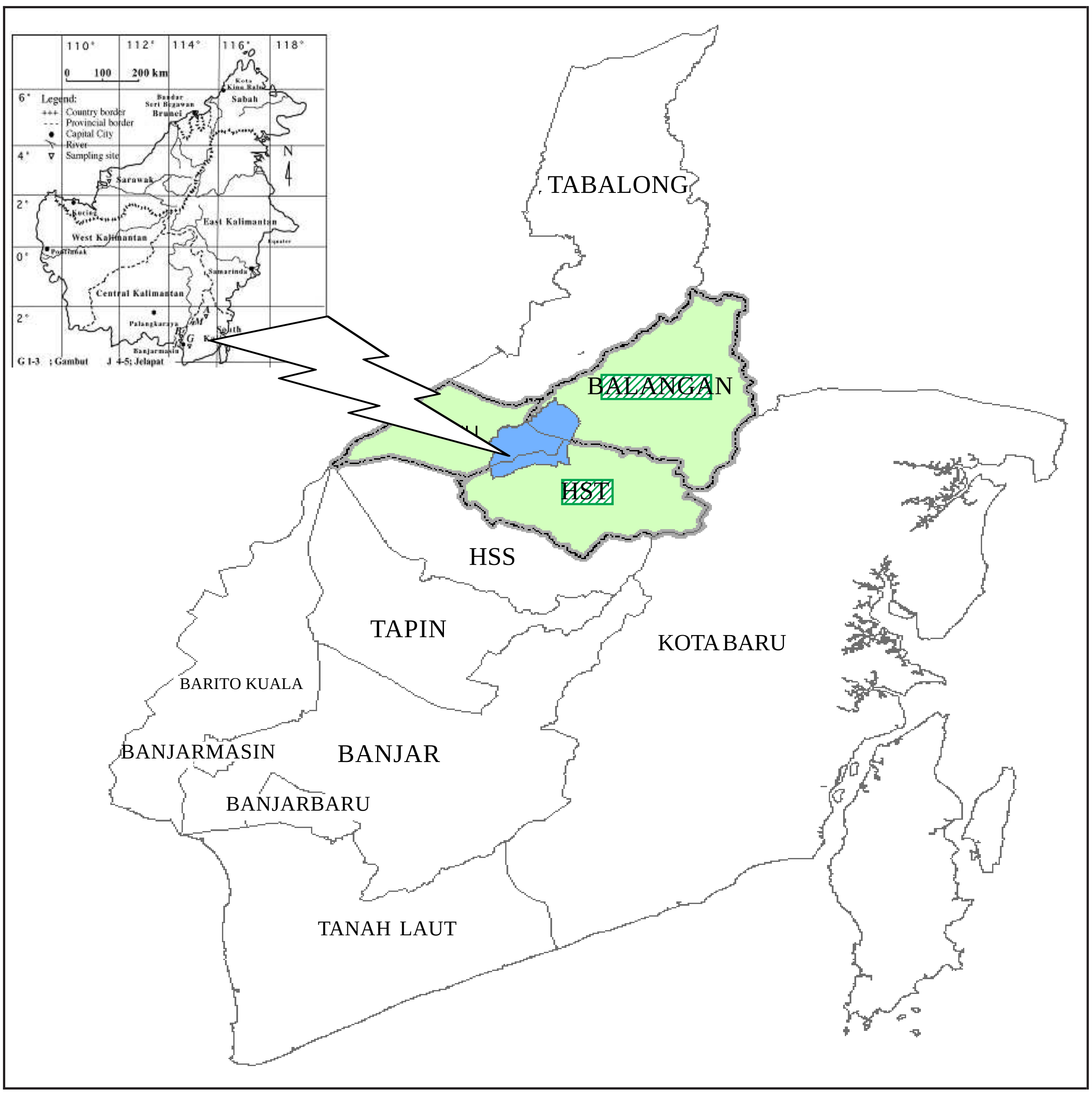


Figure 1. Map of study site.

cultivated during June to August. No fertilizer has been applied to the fields. The rice field can be considered as rain fed paddy field with zero tillage practice.

Field Settings and Measurements

Three imaginary plots which about nine meters apart from one to another in oil palm field, vegetable field or paddy field were selected and considered as replications. A piezometer was inserted at each point to reach the ground water table. Redox potential (*Eh*) electrodes were also inserted to a 10 cm soil depth at about 30 cm distanced from the pizometers.

Rectangular (length 50 cm × width 50 cm × height 50 to 200 cm) chambers were used to collect gas samples, depending on height of plants. The chambers had a capillary plastic tube inserted to one site of the chamber through a rubber septum in order to collect air. The chambers were also equipped with fan at the center of the chamber in order to mix the air inside the chamber prior to gas sampling. One oil palm trees (height 150-220 cm), four hills of paddy rice (height 45-82 cm), and two vegetable plants (tomato and sweet corn; height 0-233 cm) were enclosed into the chambers during gas sampling.

Chambers were inserted to beneath about five cm into the soil. Gas samples were taken by sucking the air inside the chambers through the tube and transferred into a vacuumed bottle (Parkin Elmer, Germany) until the time of analysis. Gas samplings were carried out in weekly basis for six months period (July-November 2009). At the same time, soil *Eh* was measured by an ORP meter (TOA Electronics Ltd, Japan) and the water table was measured manually by inserting a ruler into the pizometer.

Composite soil samples were taken in monthly basis at two soil depths (0-10 cm and 10-30 cm) and about 50 cm from the center of the chambers. The soil samples from all fields (72 samples) were analyzed for soil pH and soil moisture content. Soils taken in September, October and November (32 samples) were used for determinations of nitrate and water extractable-carbon.

Concentrations of CH_4 and N_2O were quantified by using gas chromatographs. Type, detectors, and working conditions of gas chromatographs were as those given by Hadi *et al*. (2005). Concentrations of nitrate, and water extractable-C were determined by method described by Hayashi *et al*. (1997) and Hadi *et al*. (2000), respectively.

Calculation and Statistical Analysis

The fluxes (mg C m^{-2} h^{-1} CH_4 or mg N m^{-2} h^{-1} for N_2O) were calculated according to the following equation (Hadi *et al*. 2005):

$$F = k \cdot h \cdot dc/dt\ (273/T)$$

where: k = constant for conversion from volume to weigh (N_2O = 1.250; CH_4 = 0.536), h = height of chamber (meter), dc/dt = change in concentration (ppmv) per unit time (hour) and T = air temperature inside the chamber (°K). The annual emissions of greenhouse gases were calculated by multiplying the weighed mean of gas fluxes with time (*i.e.* one year). Global warming potential of the three gases was calculated by multiplying the annual emissions with the mol warming potential of the gases (*i.e.* 1, 23 and 296 for CO_2, CH_4 and N_2O, respectively) (Bouwman 1990).

The frequency distributions of all gas data were first tested for normality using Lilliefors Test. If normally distributed, differences between treatments were determined by analysis of variance (ANOVA) and least significant differences (LSD) test. All statistical analyses were performed using the "SYSTAT 8.0" statistical package (SPSS, 1996) and were based on $P < 0.05$ significant level.

RESULTS AND DISCUSSION

Environmental Conditions

Site descriptions and their soil properties prior to experiment were summarized in Table 1. The oil palm field was situated at peat dome with elevation 17 m from mean sea level (MSL), while the vegetable field situated at slop of peat dome with mountain orientation with elevation 15 m from MSL. The paddy field was at the swamp-orientated slop of the dome with elevation 11 m from MSL. Peat depths of the three sites ranged from 180 cm in paddy field to more than 300 cm in oil palm field. Soil pHs were about five for all sites. Soil C and N ranged from 12-31% and 0.1 to 1.3%, respectively. Number of bacteria was one or two order of magnitude higher than number of fungi in the three sites.

Ground water tables in the three crop fields varied and changed seasonally. The ground water tables in paddy and vegetable fields fluctuated around 30-77 cm from ground surface, while the ground water table in oil palm field fluctuated deeper (*i.e.* > 120 cm from soil surface). Ditches had been constructed by heavy equipment at oil palm field in order to develop aerobic conditions at root zone of oil palm. Due to high data variability, the *Eh* was

Table 1. Site descriptions and soil properties prior to the experiment.

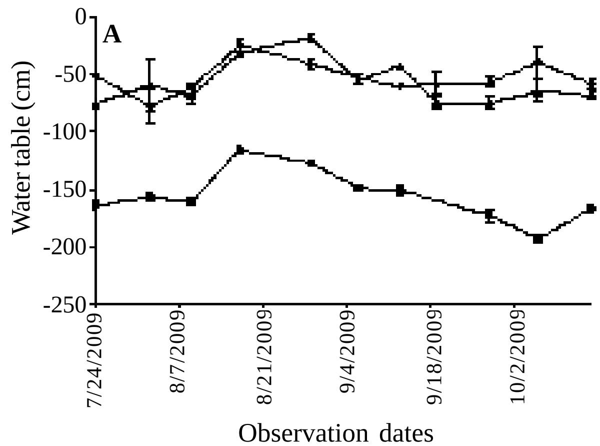
Site location		Elevation (m from MSL)	Peat thickness (cm)	pH (1:5)	C-organic	Total N	Total bacteria (× 10^5 cfu g^{-2} soil)	Total fungi (× 10^4 cfu g^{-2} soil)
					%			
Crop	GPS							
Paddy	2°24'54.65"-54.85"S; 118°40'20.43"-20.66"E	15	180	5.48	12.3	0.09	9.4	7.4
Oil Palm	2°25'41.69"-42.01"S; 118°38'14.09"-14.77"E	17	>300	4.52	14.6	0.15	5.5	5.1
Vegetable	2°26'29.28"-29.41"S; 118°37'21.91"-22.29"E	11	190	4.60	31.1	1.26	170.0	20.2

considered unchanged during the observation period (Figure 2).

Soil Properties

The pH in paddy field increased during the first two weeks of the experiment (*i.e.* 24 July to 9 August) and remained high onward, but the pH in oil palm field decreased during the first three weeks of experiement and remained low onward (Figure 3). The soil moisture contents did not statistically differ during the observation period, except that was observed in oil palm field taken from 10-30 cm depth where the soil moisture content decreased and reached minimum on 15 October 2009.

Water extractable-C and NO_3^- contents varied in the three fields and changed seasonally (Figure 3).



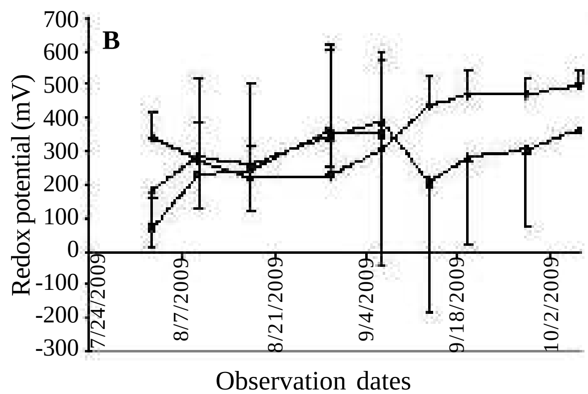


Figure 2. Seasonal changes in water table (A) and redox potential (*Eh*) (B) in the tree crop fields. No *Eh* measurement was carried out in oil palm field on 19 September, 2009 onward. An increase or a decrease bigger than the LSD value of respective crop field was considered as change. In A : —♦— paddy (LSD = 25.2), —■— oil palm (LSD = 25.1), and —▲— = vegetables, in B: —♦— paddy (LSD = 329), —■— oil palm (LSD = 371), and —▲— = vegetables (LSD = 455).

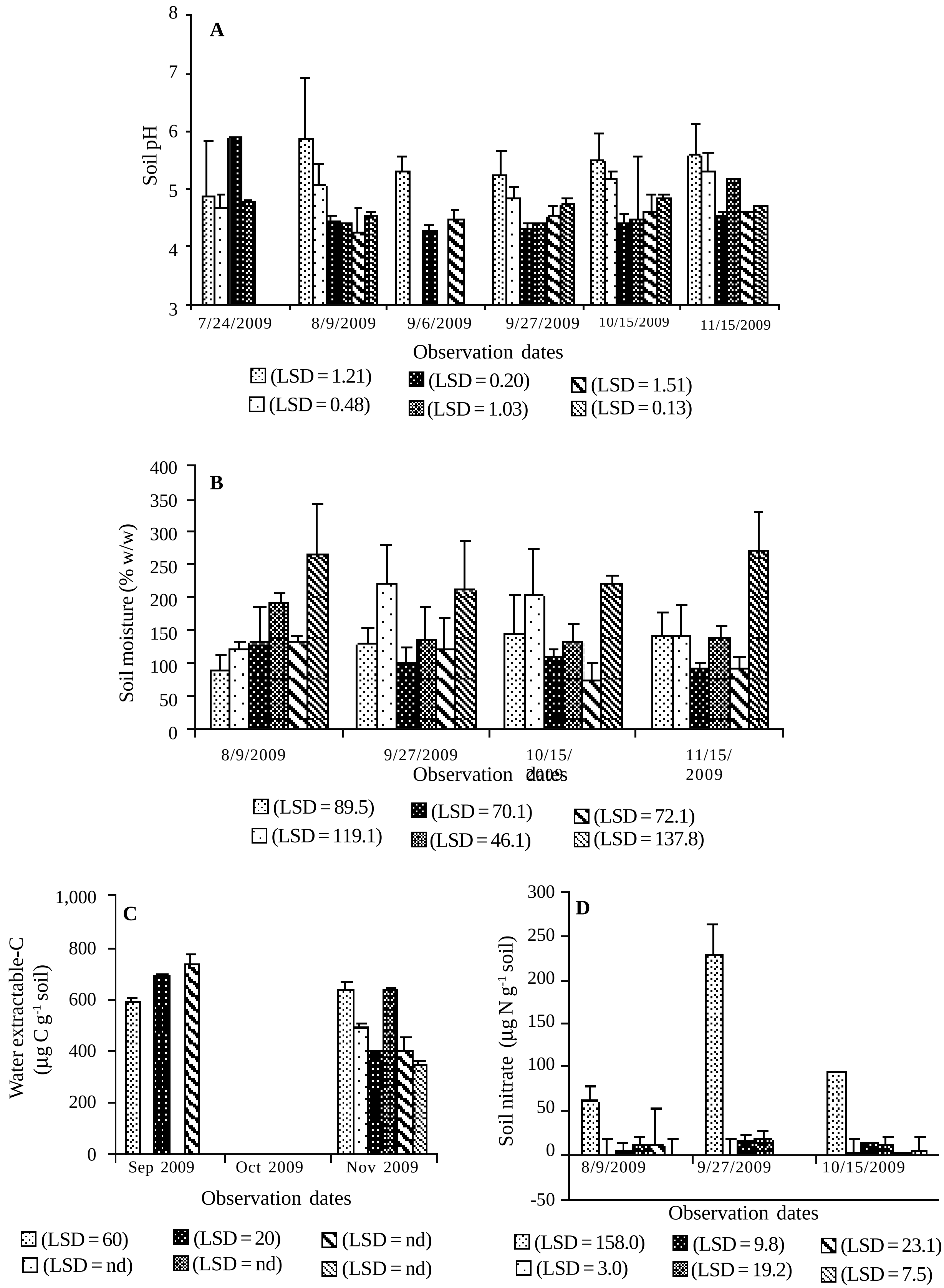


Figure 3. Seasonal changes in soil pH (A), soil moisture (B), and water extractable-C (C) and soil nitrate (D) concentrations taken from 0-10 cm or 10-30 soil depths in paddy, oil palm and vegetable fields. An increase or a decrease bigger than the LSD value of respective crop field was considered as change. ▨ = paddy 0-10 cm, □ = paddy 10-30 cm, ■ = oil palm 0-10 cm, ▩ = oil palm 10-30 cm, ◪ = vegetables 0-10 cm, and ▧ = vegetables 10-30 cm.

The NO_3^- concentrations in the three fields generally increased during the half period of the observation and decreased onward. The NO_3^- concentrations in surface soils of paddy field were higher than the sub-surface soil (10-30 cm soil depth) or the other crop fields.

Greenhouse Gas Emissions

Seasonal changes in N_2O and CH_4 fluxes are shown in Figure 4. The N_2O emission from oil palm field had many peaks and reached maximum on 17 August. The N_2O emission from vegetable field was maximum on 17 August and remained low at the rest of observation period. The N_2O emission from paddy field were low or even some times negative. Due to high data variability, no statistical different has been identified in CH_4 emissions from the three fields. Similarly, no statistical difference has been identified in CO_2 emissions from the three fields (data not shown).

The annual N_2O emission from oil palm field was the highest (4,582 g N ha^{-1} yr^{-1}) among the three crop fields studied, but no statistical difference was identified in N_2O emissions from paddy and vegetable fields (Table 2). No statistical difference was identified in CH_4 emissions from paddy, oil palm and vegetable fields. Carbon dioxide emissions were the highest in paddy field, but no statistical difference in CO_2 emissions from oil palm and vegetable fields has been identified.

Similar patterns of the global warming potential of three gases with that of emissions were observed. In total, the global warming potential was the highest in oil palm field (1.551 kg C-CO_2 equivalent ha^{-1} yr^{-1}). No statistical different has been identified in global warming potentials in paddy (285.8 kg C-CO_2 equivalent ha^{-1} yr^{-1}) and vegetable (401.2 kg C-CO_2 equivalent ha^{-1} yr^{-1}) fields (Table 2).

Discussion

Peat, organic soil or Histosols are technically all soils which contain appreciable quantities of organic matter (OM) that is considered to dominate the soil properties (Mathur and Farham 1985). Peat soils are formed when the rate of OM accumulation exceeds the rate of decomposition and can be categorized as deep, medium and shallow peat (Radjagukguk 1990). Peat soil in present study ranged from medium peat in paddy and vegetable fields (200-300 cm) and deep peat in oil palm field (> 300 cm) (Table 1). The pH and nutrient contents of presented in Table 1 were higher than that average peat (Radjagukguk 1990), probably due to the position of the sites those were far from the ocean hence less influences of pyrite.

Peatlands in South East Asia are naturally submerged and are drained by constructing drainage ditches prior to establishment of crops on them (Sabiham 2010). The depth of drainage ditches depends on the type of crops to be established, which is commonly width and deep for estate crops like oil palm and narrow and shallow for food crops like rice paddy. The differences in dimensions of the ditches result on the variability of ground water table in different crop fields. These practices of crop establishments were also occurred in the study area, where ground water tables in oil palm field were deeper than those in paddy or vegetable fields (Figure 2).

The redox potential reflects the strength of oxidation and reduction reactions in soil (Hesse 1972). Oxygen (O_2) acts as the electron acceptor in aerobic conditions and will be substituted by oxygenuous compounds like NO_3^- in anaerobic conditions. Organic matter acts as electron donor at both conditions. The Eh values in present experiment were positive because the Eh electrodes were

Table 2. Emissions of N_2O, CH_4 and CO_2 from paddy, oil palm and vegetable fields and their global warming potentials.

	Parameter	Paddy	Oil Palm	Vegetables
N_2O	Emission (g N ha^{-1} yr^{-1})	-681.6 (521.0)	4585.2 (1842.4)	927.0 (1333.8)
	GWP (kg C-CO_2 equ ha^{-1} yr^{-1})	-201.8 (125.9)	1357.2 (445.3)	274.4 (322.4)
CH_4	Emission (g C ha^{-1} y^{-1})	16263.4 (5916.3)	9841 (16510)	1754.1 (6286.3)
	GWP (kg C-CO_2 equ ha^{-1} yr^{-1})	374.1 (136.1)	226.4 (379.7)	40.3 (144.6)
CO_2	Emission (g C ha^{-1} yr^{-1})	113505.1 (73695.7)	-33271.6 (22995.4)	86446.4 (42445.0)
	GWP (kg C-CO_2 equ ha^{-1} yr^{-1})	113.5 (60.2)	-33.2 (18.8)	86.5 (34.7)
Total GWP (kg C-CO_2 equ ha^{-1} yr^{-1})		285.8 (356.2)	1550.9 (463.3)	401.2 (376.0)

Numbers in parenthesis indicate standard deviations (n=3). Mean followed by the same letters in the same row are not different according to LSD test ($P<0.05$).

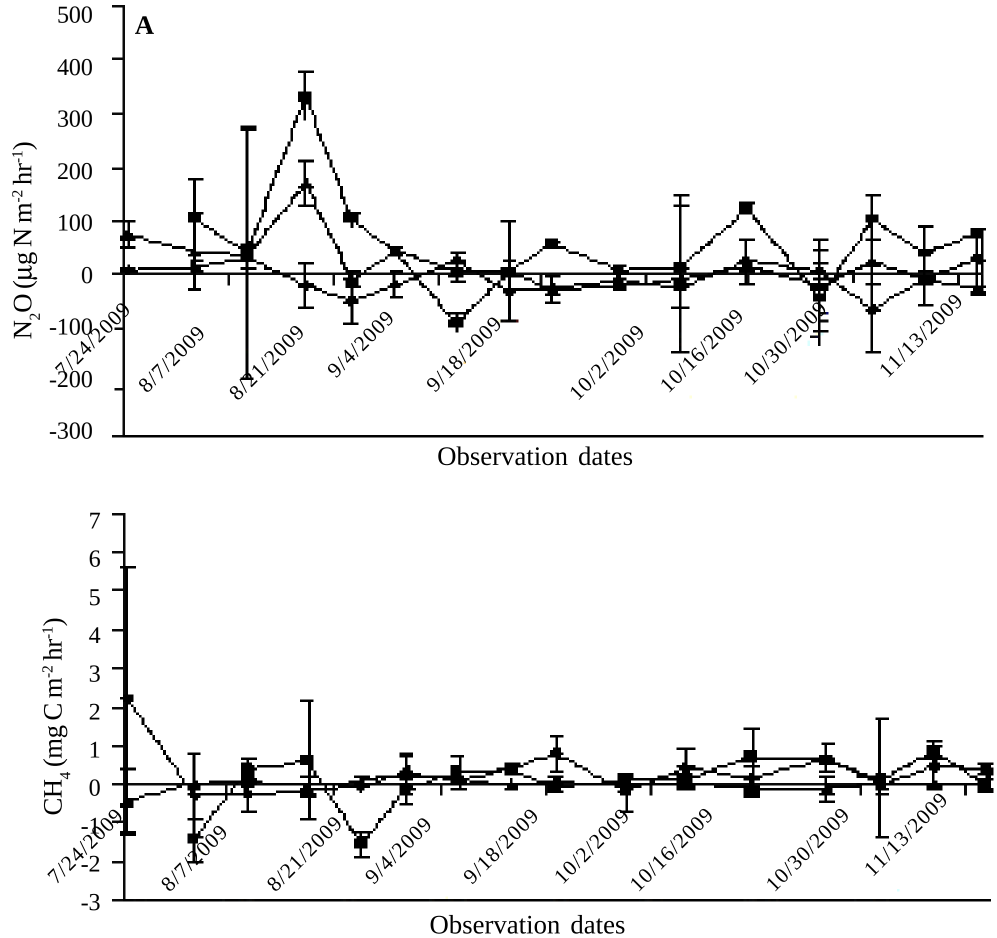


Figure 4. Seasonal changes in N_2O (A) and CH_4 (B) emissions from paddy, oil palm and vegetable fields. An increase or a decrease bigger than the LSD value of respective crop field was considered as change. In A : —◆— paddy (LSD = 61.6), —■— oil palm (LSD = 137.2), and —▲— = vegetables (LSD = 86.3), in B: —◆— paddy (LSD = 1.6), —■— oil palm (LSD = 1.6), and —▲— = vegetables (LSD = 0.5).

inserted to the 10 cm soil depth in the three crop fields those were above ground water table, hence at aerobic conditions. (Figure 2). The Eh values in the three fields tended to be similar due the same reasons as mentioned above (*i.e.* all were in aerobic conditions).

The patterns of soil pH in paddy field followed the general trend of wetland soils where the pH increased in the first two week of submergence of dry soil (Yulius *et al*. 1985) and were opposite with that occurred in oil palm field (Figure 3). Increase in pH in paddy field is achieved by the increase of OH^- concentrations during the reduction of $Fe(OH)_3$ to form $Fe(OH)_2$, $Fe_4(OH)_8$ or other ferro hydroxides (Yulius *et al*. 1985), while the pH decrease in oil palm field was probably due to the H^+ formed during the aerobic decomposition of OM. These arguments were also supported by the soil moisture contents in oil palm field where the soil moisture decreased in the early period of observation (Figure 3).

The water extractable-C and NO_3^- in present study were generally higher than those reported by Hadi *et al*. (2000) in Sarawak, Malaysian side of Borneo island. This indicated the intensive soil OM decomposition in Indonesian side of Borneo (*i.e.* decomposition level was hemic) as compared to the Malaysian side of Borneo (*i.e.* decomposition level were generally fibric) where the water table in oil palm fields were shallower (40-60 cm). This high OM decomposition process may also have contributed to the high release of N_2O in the oil palm field presently studied (which will be discussed later).

The N_2O more fluctuated than the other two gases in the three fields (Figure 4), indicating that N_2O was more responsive to the soil and environmental conditions. Hadi *et al*. (2000) reported N_2O response to changes in soil water in which the N_2O was more from soil with 100% water holding capacity (WHC) than that from soils with 60% WHC or submerged conditions. Furukawa *et al*. (2005)

also reported a negative correlation between precipitation and N_2O emission from peat soil in Sumatera island. No differences in CH_4 emission from the three fields may indicate that the formations of CH_4 were not optimum at aerobic conditions prevailed the three fields. Carbon dioxide was released in paddy and vegetable fields, but was fixed in oil palm field (Table 2).

Emission of N_2O from oil palm field was high (nearly five kg N ha^{-1} yr^{-1}) (Table 2), though no fertilizer had been applied to the fields. This amount was in the same order of magnitude with those reported by Melling *et al*. (2007) or Takakai *et al*. (2006) and ought to be increased if N-fertilizer had been applied (Akiyama *et al*. 2006). This amount of N is equal to amount that emitted from fertilized mineral soil (Hadi *et al*. 2008). This big amount of N loss may contribute to increase in farming cost. Moreover, the N_2O emission particularly meaningful when we consider its global warming potential which was nearly 1.4 Mg C-CO_2 equivalent ha^{-1} yr^{-1} in case of oil palm (Table 2).

Our present study considered three greenhouse gases together (i.e. presented as total GWP) (Table 2), which were not realized in previous studies (Hadi *et al*. 2005; Inubushi *et al*. 2003; Melling *et al*. 2007; Takakai *et al*. 2006). This may easy decision makers or policy makers to asses the benefit of a technology in minimizing greenhouse gas emissions. Difficulties encountered by separate consideration (Tsuruta *et al*. 1995) could be solved by this notion. By considering total GWP, Hadi *et al*. (2010) has proved the advantage of intermittent drainage in minimizing GHG emissions from peaty paddy fields in Indonesia and Japan.

In total, oil palm resulted the highest global warming (Table 2), suggesting that innovative technology to minimize N_2O emission from peat soil cultivated to oil palm should urgently be investigated. Water, nutrients and OM managements are among the potential techniques to minimize gas emissions from oil palm field. Current practice of water management in oil palm is to maintain water table at 50-75 cm (Singh, 2007). In the future, oil palm fields may be kept water-saturated since oil palm can adapt with submerged conditions (Soon 2007). Yanai *et al*. (2007) has reported the use of charcoal in reducing N_2O emission through nutrient sorption by the charcoal in a laboratory incubation experiment. Fresh OM incorporation to or dumping on peat soil should be avoided since it will promote GHG emissions (Hadi *et al*. 2000; Inubushi *et al*. 2007). Field trials to asses the effect of these mitigation options are needed if the peat soil are continually be used for oil palm cultivation.

CONCLUSIONS

It could be concluded that the emissions of greenhouse gases from peat soil in Borneo changed seasonally and varied with the type of crops cultivated. Oil palm has resulted the highest global warming potential, mostly contributed by N_2O. There was no statistical different in total global warming potential of paddy and vegetable fields. These findings indicated that innovative technology to minimize N_2O emission from peat soil cultivated to oil palm should urgently be investigated. Water, nutrients and OM managements are among the potential techniques to minimize gas emissions from oil palm field which need field trials.

ACKNOWLEDGEMENTS

We acknowledged the help of Ms. Normahrita and Ms. Dina Berlianti (Faculty of Mathematic and Natural Sciences, Lambung Mangkurat University) for the laboratory measurements. Field work was possible by the help of Mr. Bahtiar Rifai and Mr. Nanang Alfianto (Faculty of Agriculture, Lambung Mangkurat University). The cooperative effort of farmers at study sites were highly appreciated. This work was partly supported by Indonesian Minister of National Education through Grant for Foreign Collaborative Research and International Publication (contract no. 432/SP2H/PP/DP2M/VI/2010).

REFERENCES

Akiyama H, X Yan and K Yagi. 2006. Estimation of emission factors for fertilizer-induced direct N_2O emissions from agricultural soil in Japan: Summary of available data. *Soil Sci Plant Nutr* 52: 774-787.

Batjes NH. 1996. Total carbon and nitrogen in the soil of the world. *Eur J Soil Sci* 47: 151-163.

Bouwman AF. 1990. Introduction. In: Bourman AF (Ed) *Soils and the Greenhouse Effect*. John Wiley & Sons, New York. pp. 25-35.

Driesen PM. 1981. Peat soil. In: IRRI (Ed) *Soil and Rice*. IRRI, Los Banos, pp. 763-779.

Cahyani VR, K Matsuya, S Asakawa and M Kimura. 2004. Succession and phylogenetic profile of methanogenic archaeal communities during composting processes of rice straw estimated by PCR-DGGE analysis. *Soil Sci Plant Nutr* 50: 555-563.

Furukawa Y, K Inubushi, M Ali, AM Itang and H Tsuruta. 2005. Effect of changing ground water levels caused by land-use changes on greenhouse gas flux from Tropical peatlands. *Nutr Cycl Agroecosyst* 71**:** 81-91.

Hadi A, L Fatah, DN Affandi, RA Bakar and K Inubushi. 2012. Population and genetic diversities of nitrous oxide and methane related bacteria in peat soils of South Kalimantan, Indonesia. *Malaysian J Soil Sci* 16 (accepted).

Hadi A, O Jumadi, K Inubushi, K Yagi. 2008. Mitigation option for N_2O emissions from corn field in Kalimantan, Indonesia. *Soil Sci Plant Nutr* 54: 644-649.

Hadi A, K Inubushi, E Purnomo, K Yamakawa and H Tsurata. 2000. Effect of land-use changes on nitrous oxide (N_2O) emission from tropical peatlands. *Chemos Glob Changes Sci* 2: 347-358.

Hadi A, M Haridi, K Inubushi, E Purnomo, F Razie and H Tsuruta. 2001. Effect of land-use change in tropical soil on the microbial properties and emission of greenhouse gases. *Microb Environ* 16: 79-86.

Hadi A, K Inubushi, Y Furukawa, E Purnomo, M Rasmadi and H Tsurata. 2005. Greenhouse gas emission from tropical peatlands of Kalimantan. *Nutr Cycl Agroecosyst* 71: 73-80.

Hadi A, K Inubushi and K Yagi. 2010. Effect of water management on greenhouse gas emissions and microbial properties from paddy fields of Indonesia and Japan. Paddy and Water Environment. *Paddy Water Environ* 8: 319-324.

Hayashi A, K Sakamoto and T Yoshida. 1997. A rapid method for determination of nitrate in soil by hydrazine reduction procedure. *Jpn J Soil Sci Plant Nutr* 68: 322-326.

Hesse PR. 1972. *A Text Book of Soil Chemistry Analysis*. William Clower and Sons, Limited, London. pp. 520.

Inubushi K, A Hadi, M Okazaki and K Yonebayashi. 1998. Effect of converting wetland forest to sago palm plantation on methane gas flux and organic carbon dynamics in tropical peat soil. *Hydrol Process* 12: 2073-2080.

Inubushi K, Y Furukawa, A Hadi, E Purnomo and H Tsuruta. 2003. Seasonal changes of CO_2, CH_4 and N_2O fluxes in relation to land-use change in tropical peatlands located in coastal area of south Kalimantan. *Chemosphere* 52: 603-608.

Inubushi K, A Pranoto, M Hashitani and H Kasai. 2007. Effect of empty fruit bunch dumping on greenhouse gas emissions in oil palm plantation. Proceedings of the Soil Science Conference of Malaysia, 17-19 April, 2007 Sarawak, Malaysia, pp. 1-41.

Las I and W Surmaini. 2010. Perlunya Pengembangan Teknologi Pertanian untuk Menekan Pemanasan Global. Paper on One Day Seminar for Alumni Gathering of Agricultural Faculty of Lambung Mangkurat University, Banjarbaru, March 11, 2010.

Mathur SP and Farham RS. 1985. Geochemistry of humic substances in natural and cultivated peatlands. In: Aiken (ed) *Humic Substances in Soil, Sediment, and Water*. John Wiley and Sons, Singapore, pp. 53-85.

Melling L, R Hatano and KJ Goh. 2007. Nitrous oxide emissions from three ecosystem in tropical peatlands of Sarawak, Malaysia. *Soil Sci Plant Nutr* 53: 792-805.

Murayama S and AB Zahari. 1996. Decomposition of Tropical peat soils: 1. Decomposition kinetics of organic matter of peat soils. *JARQ* 30: 145-151.

Noor M. 2010. Peatland productivity improvement and work opportunity enlargement. Proceeding Seminar Lokakarya Nasional Pemanfaatan Lahan Gambut Berkelanjutan untuk Pengurangan Kemiskinan dan Percepatan Pembangunan Daerah. Bogor, 28 October, 2010, pp. III-1-III-20 (in Indonesian).

PT Saicle Jasa. 2006. Feasibility study for oil palm plantation of swam area in Hulu Sungai Utara, Departement Pekerjaan Umum, Jakarta (in Indonesian)

Radjagukguk B. 1990. Management of peatland productivity for lowland rice. In: Taher (Ed) *Pengelolaan Sawah Bukaan Baru Menunjang Swasembada Pangan dan Program Transmigrasi*. Faperta Univ. Prasakti/Balittan, Sukarami, pp. 217-235 (in Indonesian with English summary).

Ridlo R. 1997. CO_2 emissions at peat reclamation for mega rice project in Central Kalimantan. *J Alami* 2: 57-58 (in Indonesian)

Sabiham S. 2010. Designing peatland management to support agriculture productions, lesson learned from the past three decades. Proceeding Seminar Lokakarya Nasional Pemanfaatan Lahan Gambut Berkelanjutan untuk Pengurangan Kemiskinan dan Percepatan Pembangunan Daerah. Bogor, 28 October, 2010, pp. III-1-III-20 (in Indonesian).

Singh G. 2007. Sustainable development of peatland in United Plantation Berhad for oil palm. Paper presented at Peatland Conference, Kuala Lumpur.

Soon CP. 2007. Soil resources and plantation agriculture in Malaysia. Proceedings of the Soil Science Conference of Malaysia, 17-19 April, 2007 Sarawak, Malaysia, pp. 1-41.

SPSS 1996. SYSTAT 8.0. SPSS Inc., Chicago, Illinois.

Takakai F, T Morishima, Y Hasihidoko, R Hatano, SH Limin, U Darung U and S Dohong. 2006. Effects of agricultural land-use change and forest fire on N_2O emission from Tropical peatlands, Central Kalimantan, Indonesia. *Soil Sci Plant Nutr* 52: 662-674.

Tsuruta H, K Yagi, K Kanda and K Hirose 1995. Nitrous oxide emission from rice paddy fields. In Program and Abstract of International Symposium on Soil-Source and Sink of Greenhouse Gases, Nanjing, China, p. 12.

Wahyunto, S Ritung, Suparto and H Subagjo. 2005. Sebaran Gambut dan Kandungan Karbon di Sumatera dan Kalimantan. Wetlands International-Indonesia Programmed and Wildlife Habitat Canada. Bogor (in Indonesian).

Yanai Y, K Toyota and M Okazaki. 2007. Effect of charcoal addition on N_2O emissions from rewetting air-dried soils in short-term laboratory experiment. *Soil Sci Plant Nutr* 53: 181-188.

Yulius AKP, JL Nanere, Arifin, SSR Somosir, R Tangkaisari, JR Lalapua, B Ibrahim, H Asmadi. 1985. Fundamental of Soil Science, BKS Intim (in Indonesian).