Nutrient Cycling in Agroecosystems **71:** 93–99, 2005.
DOI 10.1007/s10705-004-5283-8

Factors influencing methane emission from peat soils: Comparison of tropical and temperate wetlands

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Key words: Global warming, Methane, Peat soil, pH, Substrates

Abstract

Methane (CH_4) emissions from peat soils in tropical and temperate wetlands were compared. Annual CH_4 emission rates in Ozegahara, the largest wetland on Honshu main island, Japan, were higher than in drained forest wetland areas examined in Indonesia. Methane emissions from the lowland paddy fields examined in Indonesia were higher than those of peaty paddy fields in Japan. There was generally a positive correlation ($r^2 = 0.09$; $P < 0.1$) between CH_4 emissions and CH_4 production activities in wetland soils. In Ozegahara, there was a positive relationship ($r^2 = 0.80$; $P < 0.01$) between CH_4 production activities and soil pH, but there was no such relationship in Indonesia. The range of soil pH in Ozegahara was 5–7, while pH values in the Indonesian sites were lower than 5. There was a positive response of CH_4 emission with respect to groundwater level in all of these areas. In Indonesia, land-use change from swamp and drained forest to cassava or coconut field lowered groundwater levels and decreased CH_4 emission, while change to lowland paddy raised the groundwater level and increased CH_4 emission. Addition of acetate generally inhibited CH_4 production during the early period (until 2 weeks) of incubation, then enhanced it afterward in both Ozegahara and Indonesian wetland soils. Addition of hydrogen mostly enhanced CH_4 production. From the results of this study, CH_4 fluxes from peat soil to the atmosphere were positively correlated with CH_4 production activities, and CH_4 production activity in peat soil was regulated by soil pH, while land-use change from wetland to upland crop lowered groundwater level and thus reduced CH_4 production and enhanced CH_4 oxidation.

Introduction

Methane (CH_4) is one of the most important greenhouse gases, which has a global warming potential per molecule about 20–30 times that of carbon dioxide (CO_2). It is currently thought to contribute ca. 20% of global warming, which is the second highest contributing gas following CO_2 (IPCC 1996). Wetlands are estimated to contribute about 20% of global CH_4 to atmospheric loading. Paddy fields and termites are also considered to be biogenic sources of atmospheric CH_4. However, ranges of CH_4 emission estimates from wetlands are still wide, 55–150 Tg CH_4 $year^{-1}$. It is unclear what are main controlling factors and how this variation in the emissions will respond to global climate change. Therefore, more detailed research in this area is highly demanded.

Previous studies indicate that the amount of CH_4 emitted from wetlands in South Kalimantan, Indonesia, is lower than from the Ozegahara wetland, in central Japan (Wada et al. 1998; Hadi 2001). These results imply that the amounts of atmospheric CH_4 from wetlands in the tropical region may be lower than those from the temperate region. In this study, we measured CH_4 emissions from tropical wetland in Jambi, Sumatra, and in South Kalimantan, Indonesia,

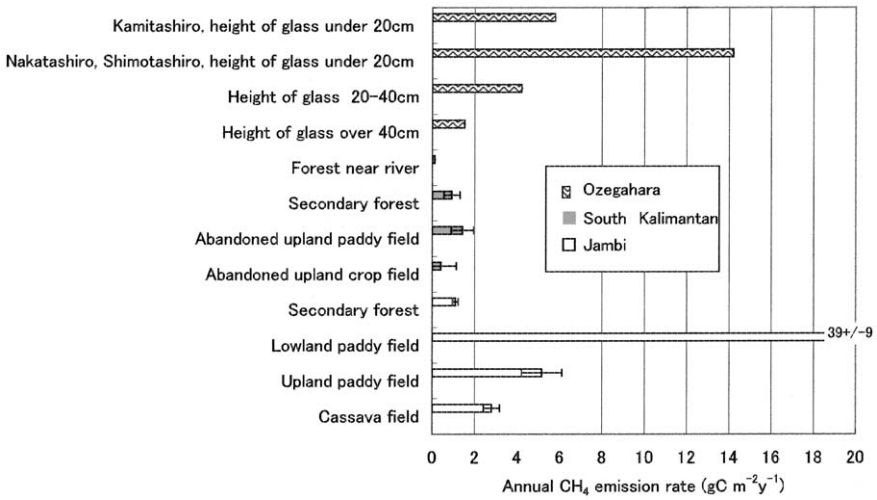

Figure 1. Annual CH_4 emission rate from peat soil in Ozegahara, Japan, and South Kalimantan and Jambi, Indonesia. Bars indicate 1 standard deviation from the mean.

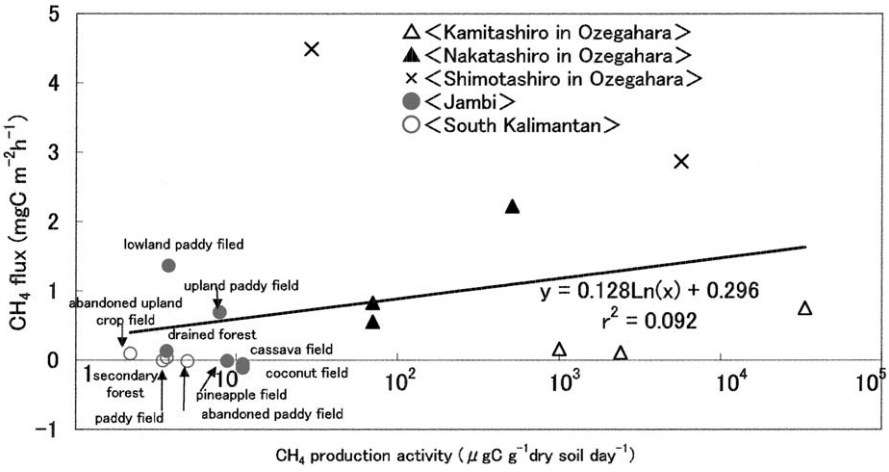

Figure 2. Relationship between CH_4 production activity and CH_4 emission. The formula indicates regression and significant level for Ozegahara samples (except Shimotashiro).

to compare with temperate data and to find controlling factors of CH_4 emission. We examined the difference in CH_4 production and oxidation activities between tropical and temperate sites, in relation to various factors such as soil pH, water table level and response to addition of substrates for CH_4 production. Acetate and hydrogen were substrates selected, since CH_4 is produced in anaerobic soil either by reduction of CO_2 by H_2 or by decomposition of acetate (Takai 1970). These factors are likely to be important regulators of CH_4 emission, because CH_4 emission is affected by the balance of CH_4 production and oxidation.

Materials and methods

We used peat soil samples made mainly of *Sphagnum* materials from Ozegahara in Nikko National Park, which is the largest (7.6 km^2) and most well-preserved wetland in Honshu (main island of Japan). This wetland is located at 36°55-57′N 139°12-15′E, about 1400 m above sea level in the boundary of Gunma, Fukushima and Niigata Prefectures, surrounded by mountains. Mean annual temperature is 4.6 °C and during the time of this investigation (June–September) was 12–18 °C. We collected samples from the Kamitasiro, Nakatashiro and Shimot-

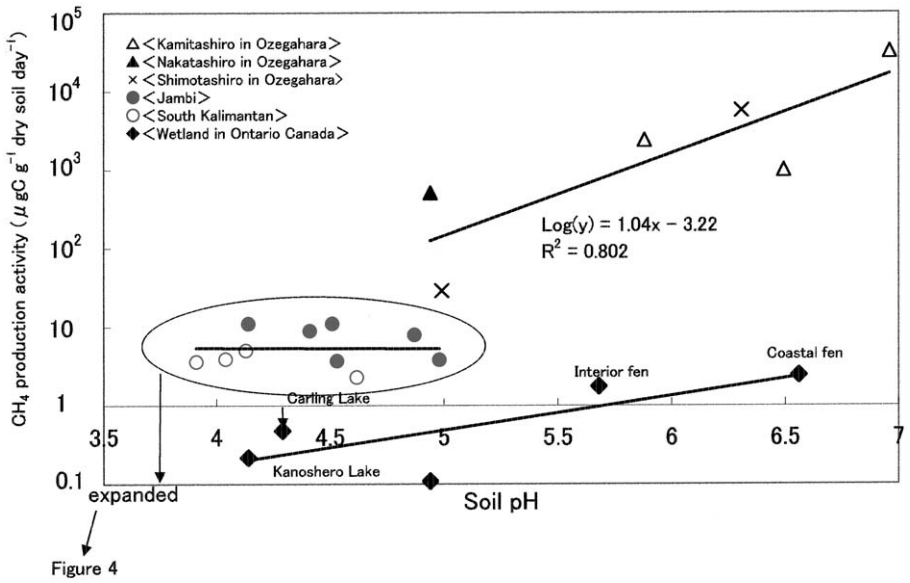

Figure 3. Relationship between soil pH and CH_4 production activity. The formula indicates regression and significant level for Ozegahara samples. Data for wetland in Ontario, Canada were taken from Valentine et al. (1994).

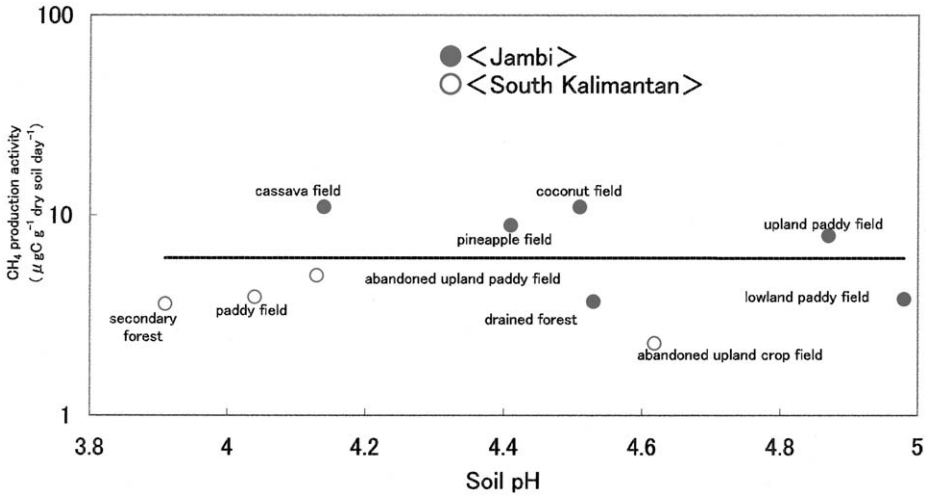

Figure 4. Relationship between soil pH and CH_4 production activity in Indonesian soils.

ashiro areas, three dominant parts of Ozegahara, which correspond to different elevation levels. The areas are categorized as higher, medium and lower, respectively, within about 5 m of elevation difference between each area. Characteristics of bank and hollow complexes in the area have been described in detail (Sakaguchi and Sohma 1982). To estimate an annual CH_4 emission rate, vegetation in Ozegahara was classified into four categories: three categories were defined according to height of grass; below 20 cm, 20–40 cm and over 40 cm, and the fourth category was riparian forest (forest near river) (Wada et al. 1998).

Peat soil samples mainly made of woody materials were collected in coastal regions in Indonesia as described by Hadi et al. (2000) and Inubushi et al. (2003). In South Kalimantan, an abandoned crop field and an abandoned paddy field were selected at Gambut; a paddy field and a drained forest were selected at Barambai (Hadi et al. 2001a). Six sites with different land-use (drained forest, cassava field, upland paddy field, paddy field, coconut field and pineapple

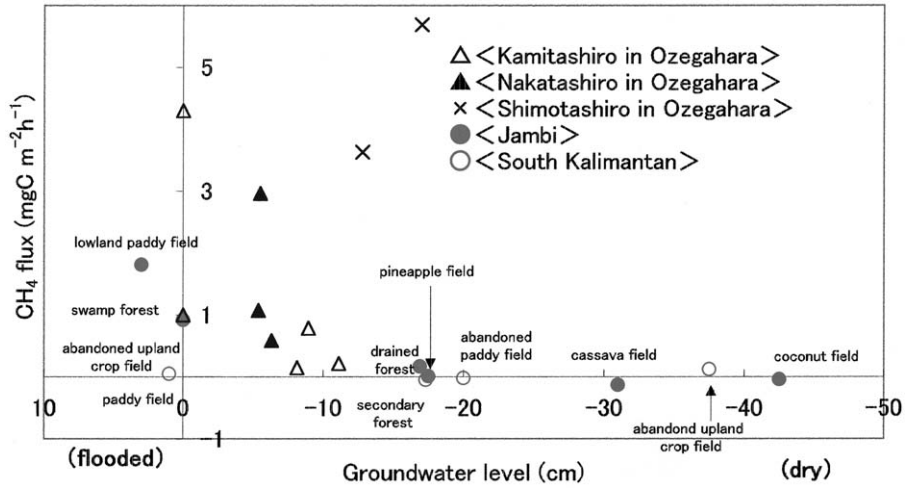

Figure 5. Relationship between groundwater level and CH_4 emission.

field as S-1 to S-5 and T-1, respectively) were selected in Jambi, Sumatra island, Indonesia. Additionally, a swamp forest site (S-7) located about 2.3 km from the drained forest site (S-1) was also compared with other sites sampled (Furukawa et al. 2004).

In each site, CH_4 emission was measured from soil surface and surface layer soils (0–10 cm) were taken for chemical and microbial measurements. Detailed site descriptions have been given by Wada et al. (1998) and Hadi et al. (2000, 2001a).

Emissions of CH_4 from the soil surface were measured in November 2001 in Indonesia and periodically during June–September 1997 in Ozegahara by inserting three chambers made of polyvinyl chloride (ϕ21 cm$\times$14 cm height) for each site. Annual CH_4 emission rates were estimated by considering seasonal variation of each CH_4 emission measured almost monthly in each site. Gas samples were analyzed by gas chromatograph (Shimadzu, GC-14B) equipped with a Porapak-R (80–100 mesh) column and a flame ionization detector (FID) for CH_4. The temperature of the column was set at 50 °C and that of the injector was set at 100 °C.

We measured pH(H_2O) and CH_4 production and oxidation activities of soil samples at 16 sites, which are located in Ozegahara, Jambi, and South Kalimantan. Soil pH(H_2O) was measured in soil : distilled water suspension (1:5) with a glass electrode. CH_4 production activity was measured by the anaerobic incubation method by placing 5 g wet soils and 25 ml oxygen-free water into 50 ml vials which were then sealed under N_2 gas flow with a double stopper and incubated at 30 °C for 4 weeks (Inubushi et al. 2001). We measured headspace CH_4 concentration once per week. The effect of adding substrates on CH_4 production was also measured by incubating soil in the above vials with either pure H_2 gas (2 ml in headspace) or sodium acetate (5 ml of 30 mM solution). CH_4 oxidation activity was determined from the decrease of CH_4 concentration in the headspace in vials using 5 g wet soils, and incubated at 30 °C for 9 h under aerobic conditions, and measuring CH_4 gas concentration in the headspace of the vial every 3 h (Watanabe et al. 1995).

Results and discussion

Annual CH_4 emission rates in Ozegahara were higher than from tropical drained forest wetland areas that we examined (Figure 1). Emissions from the lowland paddy in Jambi were higher than from the peaty paddy fields in Japan (12–31 gC $m^{-2}y^{-1}$; Soil Association 1996) due to high CH_4 emission during the flooded rice period in Jambi. CH_4 emissions from Jambi were generally higher than those from South Kalimantan.

There was generally a positive correlation (r^2 = 0.09; $P < 0.1$) between CH_4 emissions and CH_4 production activity in wetland soils (Figure 2), except for Shimotashiro samples in Ozegahara. In Ozegahara, there was a positive relationship (r^2 = 0.802; $P < 0.01$) between CH_4 production activity and soil pH (Figure 3), but there was no such relationship in Indonesia (Figure 4). The range of soil pH in Ozega-

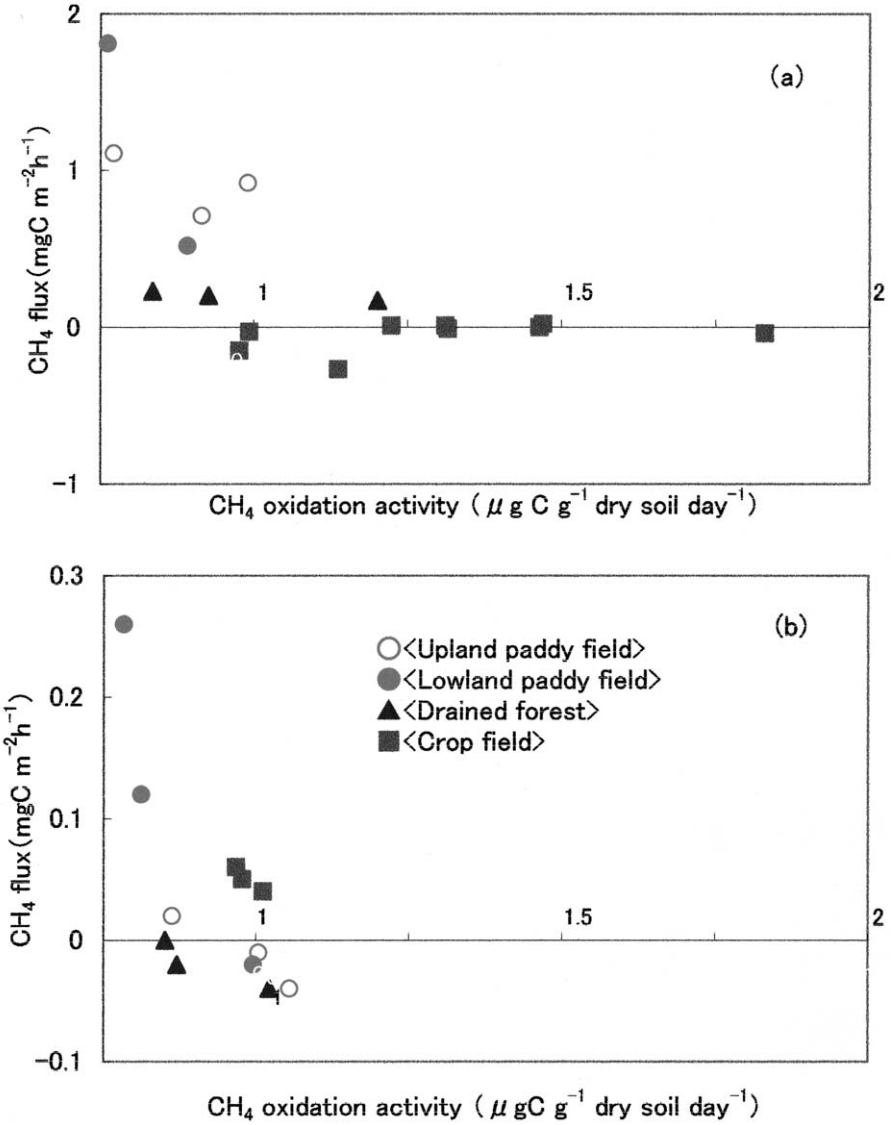

Figure 6. Relationship between CH_4 oxidation activity and CH_4 emission from peat soil in (a) Jambi, and (b) South Kalimantan, Indonesia.

hara was 5–7, while pH values in the Indonesian sites were all lower than 5. Neutral conditions are best for CH_4 production (Wang et al. 1999), so, where the range of pH was 5–7 as in Ozegahara, pH gave a positive effect on CH_4 production. A similar relationship was found in wetland in Ontario, Canada (Valentine et al. 1994), although the slope was different from those in Ozegahara because of low CH_4 production activity in Canada, probably due to a lower incubation temperature (20 °C) to compare with Ozegahara samples.

There was a positive response of CH_4 emission with respect to groundwater level in all five sites (Figure 5). The higher the groundwater level, the higher the CH_4 fluxes. In Ozegahara, microtopography also influenced the relationship between groundwater level and CH_4 flux. In Indonesia, land-use change from swamp and drained forest to cassava or coconut field lowered groundwater level and decreased CH_4 emission, while change to lowland paddy raised the groundwater level and increased CH_4 emission, as described by Furukawa et al. (2005). CH_4 oxidation activities in tropical peat soils were negatively correlated with CH_4 fluxes in Indonesia (Figure 6).

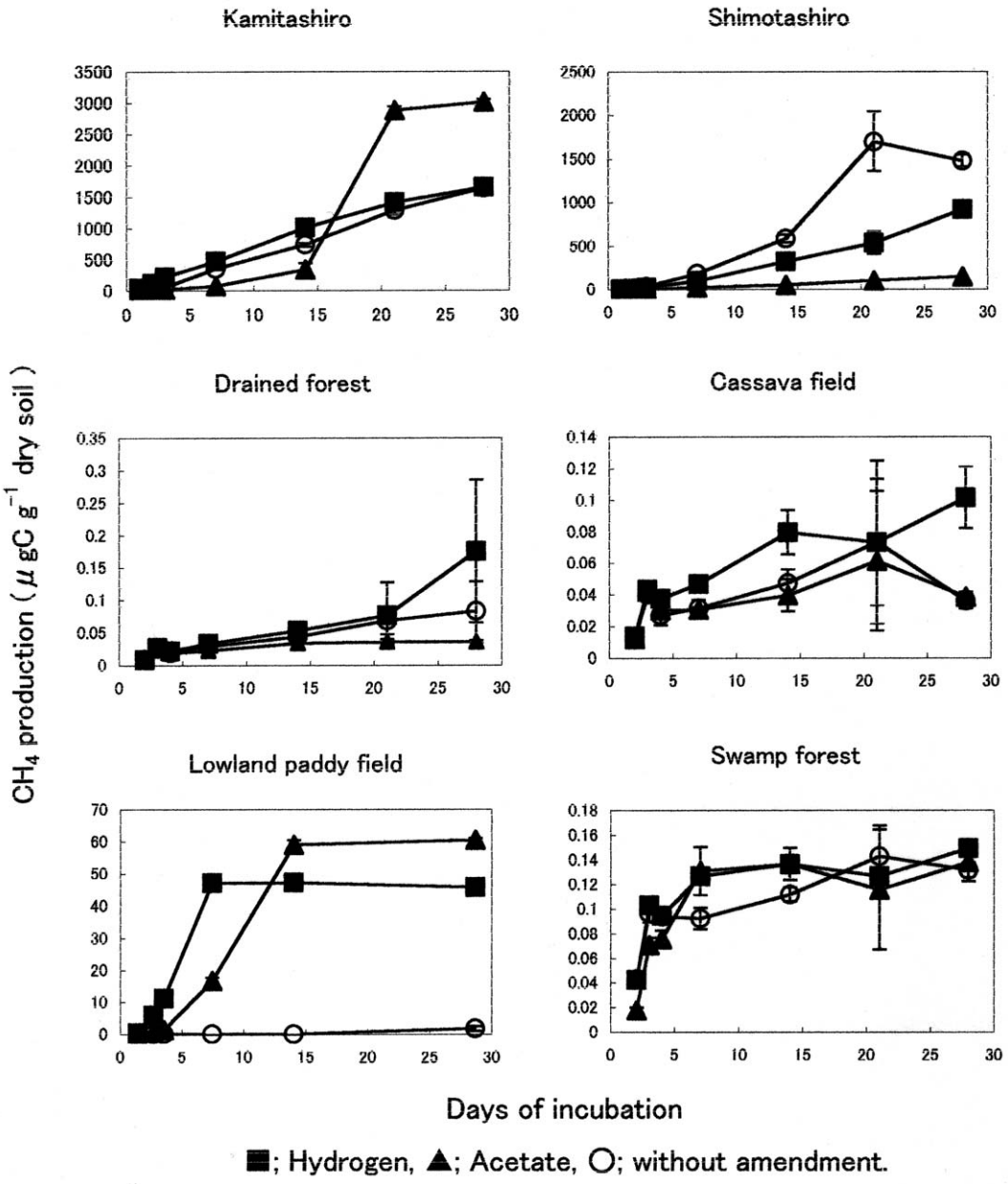

Figure 7. Effect of substrate additions on CH_4 production in laboratory incubation experiment. Bars indicate 1 standard deviation of the mean.

Addition of acetate generally inhibited CH_4 production during the early portion (until 2 weeks) of the incubation period in both Ozegahara and Indonesian soils, then enhanced production during the second two weeks of incubation, except in three sites: Shimotashiro, Ozegahara and drained forest and cassava field soils from Indonesia. Acetate addition enhanced CH_4 production in lowland paddy field soil from Indonesia, just as reported by many researchers in temperate paddy soil (i.e., Takai 1970) (Figure 7). Addition of hydrogen enhanced CH_4 production except at Shimotashiro. These tendencies are similar to those reported by Williams and Crawford (1984) for Minnesota peatlands. It seems that hydrogen is utilized by methanogens in peat soil, while acetate is not a dominant substrate, so that response of metha-

nogenic microorganisms to acetate might require several weeks. Sugimoto and Fujita (1997) measured the $\delta\ ^{13}C$ value of CH_4 in *Sphagnum* peat soil in Mizorogaike, Kyoto and found that CO_2 and H_2 were the dominant substrates for CH_4 production through the year, except midsummer. We measured organic acids in peat soils, but acetate levels were below the detection limit, which is unusual for paddy soils where acetate is typically a dominant organic acid (Inubushi et al. 1986). These differences in the mechanism of CH_4 production are attributed to different soil pH, substrate availability or microbial flora, but further investigation is essential using various substrates with different concentrations.

From the results of this study, it can be concluded that CH_4 fluxes from peat soil to the atmosphere are positively correlated with CH_4 production activities. CH_4 production activity in peat soil was regulated by soil pH, especially under neutral conditions, while land-use change from wetland to upland crop could lower groundwater level and thus reduce CH_4 production and enhance CH_4 oxidation. However, the regulation of CH_4 production by soil pH and changes in microbial activity by land-use change and their influences on CH_4 dynamics in the long run are still unknown.

Acknowledgements

This study was supported by the Global Environmental Research Funds of the Ministry of the Environment, Japan and by the Oze Preservation Foundation.

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