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Effect of Sago Palm (*Metroxylon sagu* Rottb.) Plantation on CH_4 and CO_2 Fluxes from a Tropical Peat Soil

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Abstract: Methane (CH_4) and carbon dioxide (CO_2) fluxes from tropical peat soils were compared between sago palm *(Metroxylon sagu* Rottb.) cultivation blocks with different plant ages (3, 5, and 7 years old) and their neighboring secondary forests. No significant variations in CH_4 and CO_2 fluxes were observed during the daytime. The mean values of CH_4 flux from sago palm soils and secondary forest soils were 25 − 44 and 23 − 30 μg C m^{-2} h^{-1}, respectively. Methane emissions did not differ significantly between each sago palm block and the adjacent secondary forest. The number of years after sago palm transplantation and the development of sago palms were not major factors contributing to the spatial variation in CH_4 flux. The mean values of CO_2 flux from sago palm soils were 43 − 88 mg C m^{-2} h^{-1}, and those from the secondary forest soils were 44 − 64 mg C m^{-2} h^{-1}. The CO_2 emissions from a sago palm block with 3-year-old plants were larger than those from the adjacent forest soil. However, the CO_2 emissions from blocks with 5- and 7-year-old sago palms were smaller than those from the 3-year-old sago palm block and did not differ from the CO_2 emissions from the adjacent forest soils.

サゴヤシ栽培が熱帯泥炭土壌からのメタンおよび二酸化炭素フラックスに与える影響

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要約　熱帯泥炭土壌からのメタンおよび二酸化炭素（CO_2）フラックスを移植後年数の異なる（3、5、7年）サゴヤシ栽培区および各区に隣接する二次林において比較した。メタンおよびCO_2フラックス速度には日中有意な変化は認められなかった。サゴヤシ栽培土壌および二次林土壌からのメタンフラックスの平均値は25—44および23—30 μg C m^{-2} h^{-1}であった。サゴヤシ栽培各区と隣接二次林との間にはいずれもメタン発生量に差は認められなかった。また、移植後年数やそれに伴うバイオマスの違いは、サゴヤシ栽培区間におけるメタンフラックスの差の主原因ではなかった。一方、サゴヤシ栽培土壌および二次林土壌からの平均CO_2フラックスは43—88および44—64 mg C m^{-2} h^{-1}であった。移植後3年目のサゴヤシ栽培土壌からのCO_2発生量は隣接二次林土壌からのCO_2発生量を上回ったが、移植後5年目および7年目のサゴヤシ栽培土壌からのCO_2発生量は移植後3年目のサゴヤシ栽培土壌からのCO_2発生量よりも少なく、隣接二次林土壌からのCO_2発生量との間に差は認められなかった。

Introduction

Nowadays global warming is a most serious environmental problem that is assumed to be caused by an increase in the concentration of gases that absorb infrared radiation from the earth's surface and consequently prevent the atmosphere from cooling down. Such gases, including carbon dioxide (CO_2), methane (CH_4), nitrous oxide, and chlorofluorocarbons, are generally called greenhouse gasses. Natural wetlands including peatlands are recognized as the largest source of the tropospheric CH_4 (Denman et al. 2007).

Reported CH_4 emissions from natural peatlands in North America and Western Europe range widely from negative to >1 g m^{-2} d^{-1} (Nykänen et al. 1998; Shannon and White 1994). Environmental variables related to the activity of methanogens and CH_4 oxidizers, such as the temperature, reduction-oxidation potential, and amount of easily decomposable organic matter, and the type of vegetation are plausible important factors leading to the temporal and spatial variations in CH_4 flux from peatlands (Blodau 2002; Maljanen et al. 2001; Shannon and White 1994).

Clearance of the natural vegetation and the subsequent agricultural use of peatland influence greenhouse gas fluxes by changing the temperature, pH, and cycling of C and nutrients in soil. Drainage to facilitate plant root respiration dramatically mitigates CH_4 emission (Nykänen et al. 1995; Von Arnold et al. 2005), but accelerates organic matter decomposition, and as a result of which the CO_2 flux may increase (Blodau 2002; Martikainen et al. 1995). Plantation of sago palm (*Metroxylon sagu* Rottb.) is a way of the use of tropical peatland for biological production. Records of CH_4 and CO_2 fluxes from sago palm plantation are few (Inubushi et al., 1998; Melling et al., 2005a, b), and their changes with plant growth are unknown. In the present study, we assessed the effects of a sago palm cultivation on the greenhouse gas emissions from tropical peatland by comparing CH_4 and CO_2 fluxes among sago palm soils with different number of years after transplantation and between sago palm soils and the neighboring secondary forest soils.

Materials and methods

Research site

The research was conducted at the National Timber and Forest Product sago palm plantation located in Tebing Tinggi Island, Riau Province, Indonesia (1°30'N, 103°40'E; Jong 2001). Mean annual maximum and minimum air temperatures in the 1996-2000 period, which were recorded at the nearest meteorological station, were 31.9 and 23.3°C, respectively. Annual precipitation was 1700 mm with the maximum rainfall in December (222 mm) and the minimum in July (79 mm). This plantation, which is established on deep peat (Histosols), is divided into 20 phases, and a phase is divided into 20 blocks (500 m × 1 km) surrounded by roads and facilitated with canals. Secondary forests (100 m in width) are conserved at 2-block intervals. Major plant species include *Cratoxylon arborescens, Callophyllum inophyllum, Shorea* spp., *Palaquium burckii, Eugenia* spp., *Tristania* spp., *Gonystylus bancanus,* and *Tetrameristra glabra.*

Gas samples were collected from three blocks to which sago palms had been transplanted in July 1998 (Phase 3 Block 3 (P3B3)), September 2000 (P7B4), and December 2001 (P8B19) and from their adjacent secondary forests (P3SF, P7SF, and P8SF). The sago palm density was 100 plants ha^{-1} (10 × 10 m). Chemical fertilizer was applied three times a year until 2001. The rate of application of dolomite, urea, rock phosphate, and KCl was increased with plant age from 30, 5, 5, and 5 kg ha^{-1} y^{-1} at the transplantation to 300, 60, 40, and 40 kg ha^{-1} y^{-1} for 4-year-old palm, respectively (Jong 2001). The rate of application of $CuSO_4$, $ZnSO_4$, and borate was 5, 5, and 2 kg ha^{-1} y^{-1}, respectively, irrespective of plant age.

Collection of gas samples and determinations of CH_4 and CO_2

Gas sampling was conducted 4-6 times in 2004 using the closed chamber method. An acrylic chamber (inner diameter, 15 cm; height, 10 or 15 cm) with two lateral mouths was placed on the soil at 1.5 m distance from a sago palm with the open bottom 5 cm below the soil surface. The height from the chamber top to the soil surface was recorded at four positions and averaged. After 30 min (Norman et al. 1997), the lateral mouths were closed with W-shaped rubber stoppers. From 10 to 50 min after the chamber was closed, air inside the chamber was collected three times in glass vials (20-mL) with butyl rubber stoppers through a double-ended needle. The stopper was fixed tightly using a screw cap, and the vial was evacuated using a hand-operated vacuum pump (6132-0010A, NALGENE, New York) just before gas sampling.

Proportional increases in the mixing ratio of CH_4 and CO_2 up to 40 or 60 min after closing the chamber were ascertained by collecting gas samples at 10-min intervals during a 70-min period (Fig. 1). Variations in the CH_4 and CO_2 fluxes in the daytime (9:30 − 16:40) were also measured at P3B3. This experiment was first conducted in July 2003, and no significant diurnal variation was estimated for CH_4 and CO_2. However, as the degree of experimental error was large (data not shown), a similar experiment was conducted in September 2006.

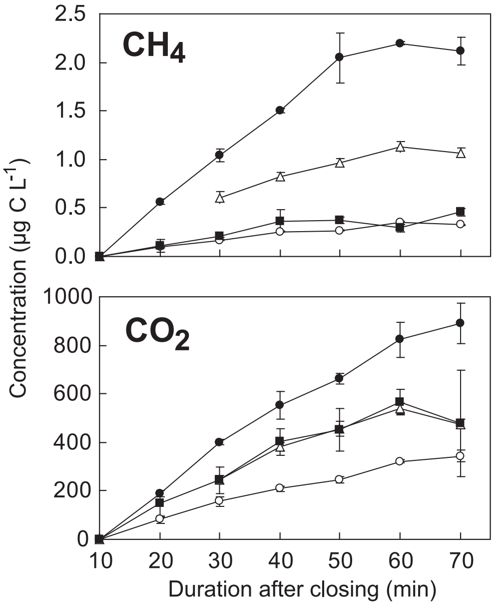

Fig. 1. Change in CH_4 and CO_2 mixing ratios with time after the chamber was closed. The first record (10 min) was regarded as 0. Different symbols indicate data from different points in P3B3. Vertical bars indicate the range of the duplicate.

The mixing ratios of CH_4 and CO_2 in gas samples were determined with a gas chromatograph equipped with flame ionization and thermal conductivity detectors (GC-9APFT, Shimadzu, Japan). The CH_4 and CO_2 fluxes were calculated on the basis of the variations in the mixing ratio of CH_4 and CO_2 in the air inside a chamber with time using linear regression. The significance of the diurnal and seasonal variations in the gas flux and that of the differences in gas emissions, sago palm growth, or soil temperature among blocks or between land use types were analyzed by one-factor or two-factor ANOVA.

Results

In Table 1, the plant height and number of leaves of sago palms are shown as mean values during the monitoring period because the temporal changes were insignificant. These two variables expressing plant growth were larger in older sago palms ($P < 0.05$).

Table 1 Plant height and number of leaves of sago palms from January to October 2004.

Block	Plant age (years old)	Plant height (m)	Number of leaves
P3B3	7	5.3±1.2[†] a	11.6±1.2 a
P7B4	5	4.0±0.8 b	10.5±1.5 b
P8B19	3	2.3±0.4 c	7.1±2.4 c

[†] Mean value±standard deviation. Values followed by different letters differ significantly ($P < 0.05$).

Figure 2 shows that the CH_4 and CO_2 fluxes from P3B3 soil did not vary significantly in the daytime from 9:40 to 16:40. Collecting gas samples manually at

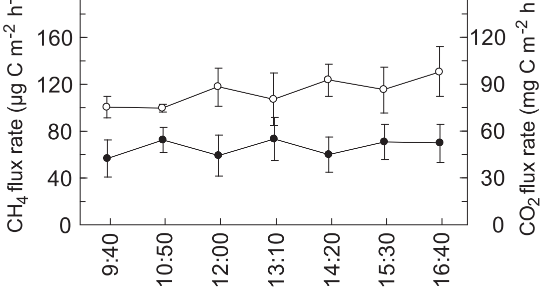

Fig. 2. Diurnal variations in CH_4 (●) and CO_2 (○) fluxes from sago palm soil (P3B3). Vertical bars indicate the standard deviation ($n = 3$).

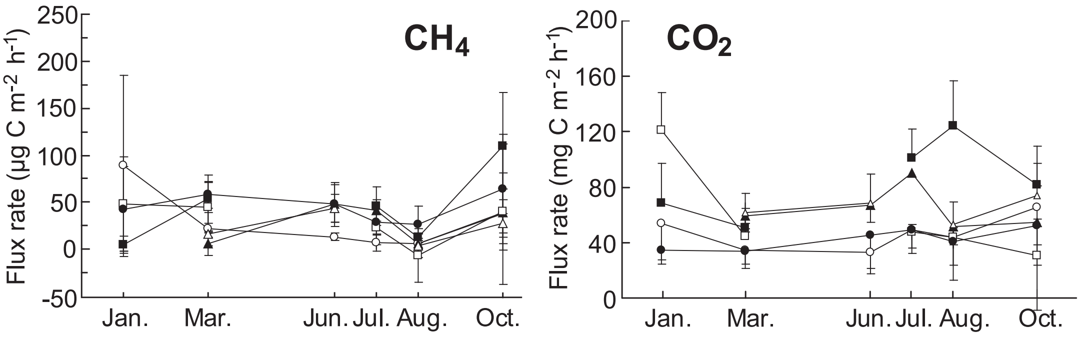

Fig. 3. Seasonal variations in CH_4 and CO_2 fluxes from sago palm soils with different plant ages and the adjacent secondary forest soils in 2004. Closed symbols, sago palm soil; open symbols, secondary forest soil. ●○, Phase 3 (transplantation in 1998); ▲△, Phase 7 (transplantation in 2000); ■□, Phase 8 (transplantation in 2001). Vertical bars indicate the standard deviation ($n = 3$).

remote places simultaneously is difficult. Our results indicate that CH_4 or CO_2 flux recorded at different times on the same day can be compared directly.

Figure 3 shows the seasonal variations in the CH_4 and CO_2 fluxes from sago palm soils and secondary forest soils. The mean values and ranges of CH_4 and CO_2 fluxes are presented in Table 2. The CH_4 flux from three forest soils did not differ significantly from each other. The seasonal pattern in the CH_4 flux varied from site to site. Through the monitoring period, the CH_4 emissions from P3B3 and P8B19 soils were larger ($P < 0.05$) than those from P7B4 and P7BF soils.

Table 2 Methane and CO_2 fluxes from sago palm soils and secondary forest soils.

Land use	Block	CH_4 (μg m^{-2} h^{-1})		CO_2 (mg m^{-2} h^{-1})	
Sago palm	P3B3	43±32	(7-131)†	43±21	(13-75)
	P7B4	25±25	(-9-67)	52±21	(15-87)
	P8B19	44±48	(-5-167)	88±34	(39-144)
Secondary forest	P3SF	30±52	(-3-121)	44±19	(23-82)
	P7SF	23±18	(-10-55)	64±18	(37-88)
	P8SF	30±36	(-37-92)	55±37	(0-145)

† Mean±standard deviation with range in parentheses.

The CO_2 emissions were largest in P8B19 ($P < 0.05$), followed by P7SF. No significant differences in CO_2 emission were observed between P3B3 and P3SF, between P7B4 and P7SF, and between P3B3 and P7B4. The largest CO_2 flux was recorded in January at P8SF but larger in October at P3SF. At the other sites, the seasonal variation in CO_2 flux was not significant.

The mean soil temperatures at 5-cm depth during gas sampling are presented in Fig. 4. The soil temperature showed a small seasonal variation, <1.5°C (P7SF) to <3.5°C (P8B19), and was higher ($P < 0.05$) in the sago palm block than in secondary forest in each phase. The soil temperature at P3B3 was also higher than that at P7B4 but did not differ from that at P8B19.

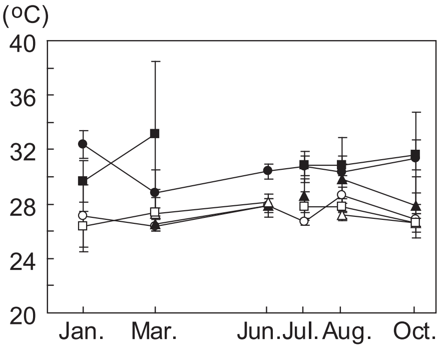

Fig. 4. Mean soil temperature at 5-cm depth during gas sampling. Closed symbols, sago palm soil; open symbols, secondary forest soil. ●○, Phase 3; ▲△, Phase 7; ■□, Phase 8. Vertical bars indicate the standard deviation ($n = 3$).

Discussion

The CH_4 emissions from three sago palm blocks did not differ from those from the respective adjacent forests. Inubushi et al. (1998) also reported no significant difference in CH_4 emissions between a sago palm plantation and a secondary forest in Sarawak, 1.38 ± 0.82 versus 1.10 ± 0.61 mg m^{-2} h^{-1}. Although CH_4 emissions in Inubushi et al. (1998) were much greater than ours, no information to discuss about this difference, such as field management and environmental conditions, are available. In Melling et al. (2005b), CH$_4$ emissions from a sago palm plantation in Sarawak (22.06 ± 5.68 μg m^{-2} h^{-1}) were similar to ours but larger than those from a forest and an oil palm plantation in their research area (-3.58 to 2.27μg m^{-2} h^{-1} on average). They attributed this difference to a higher groundwater table, higher soil temperature, and lower soil C/N ratio in the sago palm plantation. Although the data set is incomplete, the groundwater table in Tebing Tinggi (Fig. 5) may not have been appreciably different between the sago palm block and the adjacent forest. Furthermore, the groundwater pH and soil bulk density did not differ significantly between P3B3, P7B4, or P8B19 and their respective adjacent secondary forests (H. Ando, personal communication). Although the soil temperature was higher in sago palm soils than in forest soils (Fig. 4), the difference in soil temperature did not reflect the CH$_4$ flux.

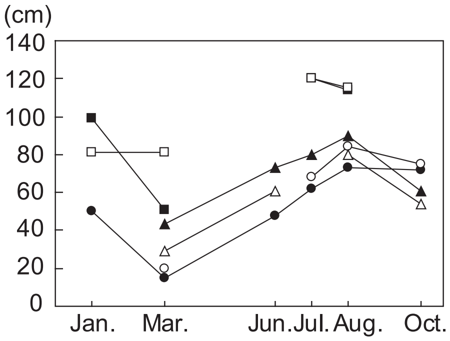

Fig. 5. Seasonal variation in groundwater table. Closed symbols, sago palm cultivation block; open symbols, secondary forest. ●○, Phase 3; ▲△, Phase 7; ■□, Phase 8.

Melling et al. (2005a) observed larger CO$_2$ emissions from a peat swamp forest (100 − 533 mg C m^{-2} h^{-1}) than from a sago palm plantation (46 − 335 mg C m^{-2} h^{-1}) in Sarawak. The small CO$_2$ emissions from Tebing Tinggi forest soils were likely responsible for the lack of a similar tendency in the present study. As the secondary forests in Tebing Tinggi started to develop ca 35 years ago, the size of the plant biomass and productivity as a source of readily decomposable organic C might have remained small (Melling et al. 2005a). According to Furukawa et al. (2005) and Haji et al. (2005), the CO$_2$ emissions from Malaysian and Indonesian peat soils used as an upland crop field were 99 − 396 mg C m^{-2} h^{-1}. The CO$_2$ emissions from the Tebing Tinggi sago palm soils were much smaller than those reported values. Furthermore, the CO$_2$ flux was smaller in blocks with older palms (Fig. 3). The loss of easily decomposable soil organic matter accumulated before drainage or supplied from forest clearing may, with time, have a greater impact on CO$_2$ emissions than sago palm growth. A similar trend was observed in afforested boreal agricultural soils in Finland (Maljanen et al. 2001).

In Maljanen et al. (2001), CH$_4$ emissions as well as CO$_2$ emissions were smaller in older afforested soils. However, in the present study, the CH$_4$ emissions from P3B3 and P8B19 soils were larger than those from P7B4 soil. Thus, the duration of sago palm cultivation and the difference in plant biomass were not major factors in the difference in CH$_4$ emissions. The lower soil temperature at P7B4 than at P3B3 and P8B19 could be a cause. However, seasonal variations in CH$_4$ flux (Fig. 3) did not correspond to those in soil temperature (Fig. 4) and groundwater table (Fig. 5). No synchronicity between them was observed for a mire area in the U.K. (Hutchin et al. 1996). The time lag from CH$_4$ production to CH$_4$ release (Martikainen et al. 1995) can mask the correlations between the CH$_4$ flux and those environmental factors, although whether or not the same reason can be applied to the present case is unknown. Since the groundwater table has been found to affect sago palm growth (Jong et al. 2006), further investigation on the relationship between groundwater table and greenhouse gas fluxes from sago palm plantation may be useful for suggesting the groundwater management that lead to better sago palm growth with a smaller contribution to the global warming.

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