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EFFECT OF FOREST TYPE ON DECOMPOSITION RATE AND GREENHOUSE GAS FLUXES OF TROPICAL PEAT SOIL AFTER CONVERSION INTO AN OIL PALM PLANTATION

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SUMMARY

The effect of forest type on the decomposability and greenhouse gas fluxes of tropical peat soils after conversion to an oil palm plantation was evaluated through a field incubation experiment of peat soils from three representative types of primary forest in Sarawak, Malaysia, namely Mixed Peat Swamp (MPS), Alan Batu (ABt), and Alan Bunga (ABg). Carbon dioxide (CO_2) and methane (CH_4) fluxes were measured on a monthly basis for 36 months. The CO_2 and CH_4 fluxes ranged from 78–625 mg C m^{-2} h^{-1} and -67–653 μg C m^{-2} h^{-1}, respectively. Both of CO_2 and CH_4 fluxes were larger in the order ABg > ABt > MPS, which corresponded to the relative abundance of *O*-alkyl C derived mainly from polysaccharides in soil organic matter (SOM). Rate of decomposition of peat was almost constant during the 3-year period, and annual decomposition rate was estimated to be 0.033 y^{-1} for MPS, 0.048 y^{-1} for ABt. and 0.066 y^{-1} for ABg.

Keywords: *decomposition, greenhouse gas, tropical peat, vegetation*

INTRODUCTION

In Malaysia, peatland has been actively converted to agricultural land, of which 25% was oil palm plantation (Lim *et al*., 2012). The conversion of tropical peatland to an oil palm plantation may accelerate soil organic matter (SOM) decomposition (Murayama and Bakar, 1996) and promote greenhouse gas (GHG) fluxes (Jaenicke *et al*., 2008). Change in groundwater table due to drainage is considered to have a significant effect on carbon dioxide (CO_2) and methane (CH_4) fluxes (Melling *et al*., 2005; Watanabe *et al*., 2009). However, the rate of SOM decomposition may also differ depending on the composition and chemical structure of SOM. Peat in Southeast Asia generally develops to dome shape, leading to the transition of forest types from the edge to the interior (Page *et al*., 1999). It is expected that the quality and sensitivity to the environmental change vary among SOM accumulated in different types of forests. The objective of the present study was to evaluate the effect of forest type on the rate of SOM decomposition and the GHG fluxes after the conversion to an oil palm plantation, based on a field soil incubation experiment.

MATERIALS AND METHODS

Three soil samples of 20–40 cm depth were collected from Mixed Peat Swamp (MPS; 1° 25' N, 111° 07' E), Alan Batu (ABt; 1° 27' N, 111° 08' E), and Alan Bunga (ABg; 1° 27' N, 111° 09' E) zones in the Maludam National Park, Sarawak, Malaysia, in August 2012 and Dominant tree species in the MPS site included *Gonstylus bancanus, Dactylocladus stenostachys, Copaifera palutris, Shorea platycarpa, Shorea scabrida,* and *Shorea uliginosa*. Although dominant tree species in the ABg and ABts sites was same, *Shorea albida*, ABg is characterized by an even upper story with canopy at 50–60 m high while ABt site had a non-uniform forest crown. Annual mean soil temperature at 5 cm depth and annual mean groundwater table were in the ranges of 25.7°C (MPS) to 27.1°C (ABg) and -17 cm (MPS) to -7.3 cm (ABg), respectively.

The soil samples were transferred to an oil palm in Sibu, Sarawak (2° 09' N, 111° 53' E), instantaneously, and packed in the PVC pipes with a plastic net attached at the bottom after removing large roots and mixing thoroughly. Four soil-packed pipes and an empty pipe that have a flange and two lateral holes were connected as are shown in Figure 1. The pipes packed with different soil samples were installed at the same point with 1 m distance between two pipes and the distance from a nearest oil palm tree was 3–4 m. CO_2 and CH_4 fluxes as well as environmental variables, including soil temperature and moisture at 5 cm depth and groundwater table, were monitored once a month for 3 years since October 2012. The gas samples collected were brought back to the laboratory, and the concentrations of CO_2 and CH_4 were determined using gas chromatographs equipped with a

thermal conductivity detector (6890N, Agilent, Santa Clara, CA, United States) or a flame ionization detector (7890A, Agilent), respectively.

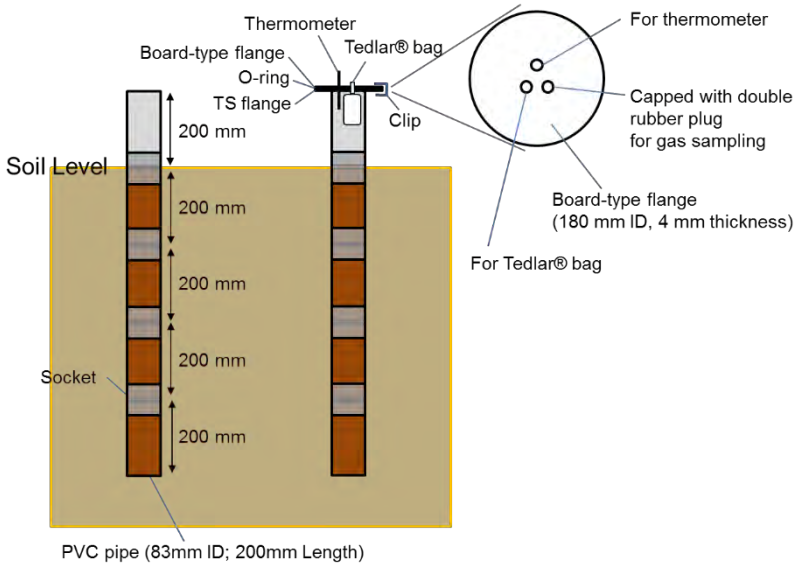

Figure 1: Design of field incubation experiment of peat soil samples collected from different types of forests.

SOM in the three soils was characterized using ^{13}C NMR spectroscopy. Ramp cross polarization (CP)/magnetic angle spinning ^{13}C NMR spectra with phase-adjusted spinning side bands (PASS) sequence (Ikeya and Watanabe, 2016) were recorded on ECA 700 spectrometer (JEOL, Tokyo, Japan) with the number of data accumulation, 2080–4160. C composition was estimated from the relative intensity of signals from major C functional groups. Soil pH, total C and total nitrogen (N) contents, and loss on ignition (LOI) were determined by using a pH meter (Metrohm 827, Metrohm, Herisau, Switzerland), NC analyzer (Sumigraph NC-22, Sumica Chemical Analysis Service, Osaka, Japan), and a thermal gravimetric analyzer (TGA 701, Leco, St. Joseph, MI, USA).

Rate constant of soil organic C (SOC) decomposition was estimated by regressing cumulative CO_2-C emissions to exponential decay model. One-way ANOVA was used to analyze the difference in the rate of SOC decomposition and GHGs fluxes among the three peat soil samples. The significance of the difference between the forest types was determined using Fisher Least Significance Difference (LSD).

RESULTS

The physico-chemical properties of the soil samples are shown in Table 1. All of the soils are very acidic with pH in the range of 3.6 to 3.7, while LOI describes the organic matter content of the soil samples in the range of 98 to 99%. Total C and total N contents were in the range of 520–535 g kg^{-1} and 13–20 g kg^{-1}, respectively. C/N ratio increase from MPS soil (27) to ABg soil (40).

Table 1 Physico-chemical properties of Maludam peat soil samples

Soil sample	pH (2:5)	LOI (%)	Total C (g kg^{-1})	Total N (g kg^{-1})	C/N ratio
MPS	3.6	98	535	20	27
ABt	3.7	99	523	16	33
ABg	3.6	99	520	13	40

Table 2 shows the C composition as was estimated from the NMR spectra. The %*O*-alkyl C was larger in the order ABg (37%), ABt (32%), and MPS (26%) and %aromatic C was also larger in the ABg soil (33%) than in the other two soils (27%). The order of %alkyl C was opposite as MPS (33%), ABt (27%), and ABg (21%), and %carboxyl C also tended to be smaller in the ABg soil (9%) compared to the other two soils (13%).

Table 2: C composition of Maludam peat soil samples

Soil sample	%alkyl C (0–45 ppm)	%*O*-alkyl C (45–110 ppm)	%aromatic C (110–160 ppm)	%carboxyl C (160–190 ppm)	%ketone C (190–220 ppm)
MPS	33	26	27	13	1
ABt	27	32	27	13	2
ABg	21	37	33	9	1

The monthly CO_2 flux ranged from 95 to 480, 78 to 592, and 138 to 625 mg C m^{-2} h^{-1}, for the MPS, ABt, and ABg soils, respectively. The total CO_2 emission during the 3-year period was larger ($P < 0.05$) in the order ABg, ABt, and MPS (Figure 2). CO_2 flux the ABt and ABg soils was correlated negatively with groundwater table (-99.0–16.2 cm), while none of the three soil showed significant correlations between CO_2 flux and soil moisture content (54%–85%) or soil temperature. The monthly CH_4 flux ranged from -67 to 402, -60 to 607, and -20 to 653 µg C m^{-2} h^{-1}, for the MPS, ABt, and ABg soils, respectively. The total CH_4 emission during the 3-year period was also larger ($P < 0.05$) in the order ABg, ABt, and MPS (Figure 2). A positive correlation was observed between CH_4 flux and groundwater table in all three soils type ($r = 0.37$-0.44; $P < 0.05$). The rate constant of SOM decomposition was estimated to be 0.033 y^{-1}, 0.048 y^{-1} and 0.066 y^{-1} for the ABg, ABt, and MPS soils, respectively.

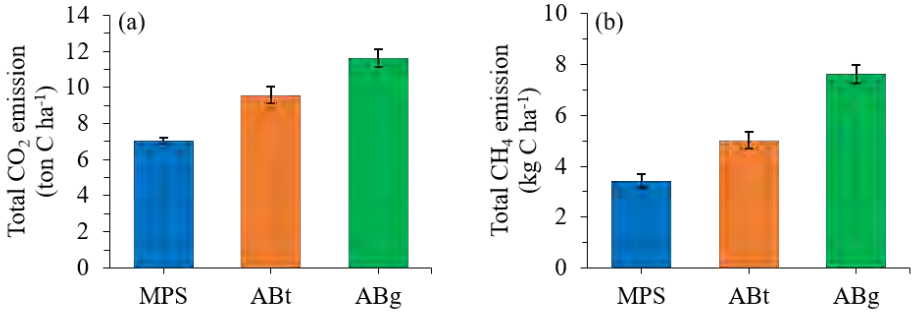

Figure 2: Total emissions of CO_2 (a) and CH_4 (b) for 3 years from peat soils developed under different types of forests.

DISCUSSION

The variation of CO_2 and CH_4 fluxes from the three peat soils suggested the difference in SOM stability under the environmental conditions in the oil palm plantation, i.e. higher temperature and lower groundwater level compared to those in natural forests. However, temperature change may be a minor or insignificant factor in tropical peatland, because the increase in soil temperature was the largest for the MPS soil that emitted the smallest amount of CO_2 and CH_4. No correlation between GHG fluxes and soil temperature supported it. Numerous studies have reported the relationship of lower groundwater table and higher CO_2 flux in temperate peatland (e.g., Dinsmore *et al*., 2009; Berglund and Berglund, 2011). Similar trend has also been observed in tropical peatland (Furukawa *et al*., 2005; Melling *et al*., 2013). There are spatial variations in groundwater level in the Maludam National Park and it is higher in the order ABg > ABt > MPS. The change in groundwater level after installation in the oil palm plantation was more drastic in the same order, which is a possible cause of the difference in CO_2 emission among the three soils.

Another possible cause is the difference in the composition of SOM. CO_2 emission was larger in a soil that contains a larger amount of *O*-alkyl C, which is derived mainly from polysaccharides such as cellulose and hemicellulose. Greater decomposability of *O*-alkyl C than alkyl C in peat SOM has been recognized (e.g., Purwanto *et al*., 2008; Leifeld *et al*., 2012). While the seasonal variation in CH_4 flux shows a not so tight relationship with that in groundwater table, total CH_4 emission from the three Maludam soils was higher in the same order as total CO_2 emission (Figure 2). The amount of labile SOM determines the rates of development of reducing conditions after water saturation and supply of substrates for methanogenesis. Thus, the decomposability of peat SOM could also be the major factor of CH_4 flux in the oil palm plantation.

CONCLUSION

The conversion of the tropical peat forest to oil palm plantation can cause the annual SOC loss of 3–6%. Variations in the rate of SOM decomposition and GHG fluxes among the three soils from the different types of forests were confirmed, which was possibly due to the variations in the extent of groundwater level change and the composition/structure of SOM, in particular the relative abundance of polysaccharides. As the independency of SOM quality from the groundwater level is still unknown, direct effect of tree species on the composition/structure of tropical peat SOM should be examined.

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