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IS WATER TABLE THE MOST IMPORTANT FACTOR INFLUENCING SOIL C FLUX IN TROPICAL PEATLAND?

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SUMMARY

This paper aims to further investigate the role of the water table on soil carbon (C) flux in tropical peatland. Closed-chamber measurements were conducted for 12 months at an oil palm plantation, logged-over peat swamp forest and tropical peat swamp forest. The mean water table levels at these three (3) ecosystems were -67.6 cm, -14.7 cm and -3.9 cm, respectively. Mean soil CH_4 flux was lowest at the oil palm plantation (24.0 µg C m^{-2} h^{-1}), followed by logged-over peat swamp forest (577.8 µg C m^{-2} h^{-1}) and tropical peat swamp forest (1532.8 µg C m^{-2} h^{-1}). However, even though the mean water table levels in the three ecosystems differed by an average of 42.5 cm, the mean soil CO_2 fluxes were quite similar: oil palm plantation (102.5 mg C m^{-2} h^{-1}), logged-over peat swamp forest (128.1 mg C m^{-2} h^{-1}) and tropical peat swamp forest (140.5 mg C m^{-2} h^{-1}). These findings indicated that on tropical peatland soil CH_4 flux was highly influenced by water table but not soil CO_2 flux. Since the total soil CH_4 flux was much lower compared with soil CO_2 flux, it was concluded that water table was not the most important factor influencing the soil C flux in tropical peatland.

KEY WORDS: Carbon flux, CO_2, CH_4, tropical peatland, water table

INTRODUCTION

Tropical peatlands are now being developed for agriculture in the quest for economic progress. The initial phase of reclamation involves drainage by lowering the water table and compaction to aerate the crop root zone while increasing the peat soil bulk density, soil surface load-bearing capacity and water-filled pore space (Melling *et al*., 2005b; 2008a). However, it has been claimed that drainage via lowering of the water table changes peatlands from C sinks to C sources, by generally reversing the C flux into net CO_2 emissions, while CH_4 emissions decrease (Furukawa *et al*., 2005; Van Huissteden *et al*., 2006; Couwenberg, 2011). The current general consensus is that lowering the water table increases peat decomposition rates due to enhanced microbial degradation of organic matter (Van Huissteden *et al*., 2006). However, the understanding of soil C flux based on studies conducted in boreal and temperate peats is not fully applicable in the tropics due to differences in environmental factors, peat soil properties, vegetation, microbial diversity and population, and management practices. Jauhiainen *et al.* (2011) suggested that on tropical peatland, there were other underlying factors affecting soil CO_2 flux besides the water table. To date, published data on soil C flux in the tropics are still limited and vary widely, as there are many interacting regulatory factors. This paper was to determine the soil C flux from three different ecosystems on tropical peatland having different water table levels.

MATERIAL AND METHODS

Site description

Soil C flux was studied in three ecosystems: a seven (7)-year old oil palm plantation (2º11'12.0"N, 111º50'31.9"E), a logged-over peat swamp forest (1°24'1.6"N, 111°23'54.0"E) and a tropical peat swamp forest (1°27'14.8"N, 111°8'45.3"E). There were two (2) subplots for each ecosystem: the oil palm plantation (ND and NE), the logged-over peat swamp forest (CA and CB) and the tropical peat swamp forest (MB and MC).

Soil CO_2 and CH_4 fluxes measurement

Monthly measurements of soil CO_2 and CH_4 fluxes from January to December 2011 were performed using a closed-chamber method. Environmental variables such as air temperature, relative humidity and water table level were recorded simultaneously. Soil samples from the 0-50 cm depth were bulked for both physical and chemical analyses. Undisturbed core samples were also collected to determine soil bulk density and moisture content. Details of the measurements were described by Melling *et al.* (2005a; b). Soil CO_2 concentrations were determined within 4-h using a CO_2 infrared gas analyser (Fuji Electric ZFP-5). Soil CO_2 fluxes were calculated from the linear changes in the gas concentrations in the chamber headspace. Soil CH_4 concentrations were determined by a gas chromatograph equipped with a flame ionization detector (Agilent Technologies 7890A) maintained at 300ºC, using a HP-Pona column maintained at 40ºC with a He carrier gas flowing at 24 cms^{-1}. Soil CH_4 fluxes were calculated from the slope of a linear regression of the gas concentrations over time.

RESULTS

Environmental, physical and chemical characteristics

The environmental, physical and chemical characteristics of the study sites are shown in Table 1. Both air and soil temperatures at 5 cm were highest in the oil palm ecosystem, thus resulting in the lowest relative humidity due to its single canopy structure. Compared with that of forest ecosystems, soil bulk density in the oil palm ecosystem was almost double as a result of drainage, mechanical compaction and peat consolidation.

Soil CO_2 and CH_4 fluxes

As shown in Table 2, the highest mean soil CO_2 flux was recorded from the tropical peat swamp forest ecosystem (140.5 mg C m^{-2} h^{-1}), followed by the logged-over peat swamp forest ecosystem (128.1 mg C m^{-2} h^{-1}) and the oil palm ecosystem (102.5 mg C m^{-2} h^{-1}). The mean water table levels at the three ecosystems were -3.9 cm, -14.7 cm and -67.6 cm, respectively. Thus, the lowest soil CO_2 flux was recorded from the site which had the lowest water table. The differences between mean soil CO_2 fluxes from all the sites were small (ranging from 102.5 to 140.5 mg C m^{-2} h^{-1}) although a large difference of mean water table levels (ranging from -67.6 to -3.9 cm) was observed. Mean soil CH_4 flux was highest in the tropical peat

Table 1. Environmental, physical and chemical characteristics of the study sites.

Site	**Oil palm plantation**			**Logged-over peat swamp forest**			**Tropical peat swamp forest**		
	ND	**NE**	Mean	**CA**	**CB**	Mean	**MB**	**MC**	Mean
T_{air} (°C)	31.2	31.6	31.4	27.8	28.8	28.3	29.4	32.2	30.0
T_{5cm} (°C)	27.5	27.3	27.4	25.5	25.9	25.7	26.4	27.5	26.5
RH (%)	73.8	68.8	71.3	92.0	87.5	89.8	84.5	73.9	82.6
Rainfall (mm)	257.4	268.1	262.8	255.1	326.3	290.7	288.4	259.6	277.9
BD (g cm^{-3})	0.23	0.23	0.23	0.12	0.10	0.11	0.11	0.09	0.11
WFPS (%)	71.0	69.2	70.1	70.9	62.0	66.5	73.2	71.4	70.0
pH	3.4	3.4	3.4	3.5	3.5	3.5	3.6	3.5	3.5
Carbon (C) (%)	56.5	56.2	56.4	53.8	53.4	53.6	54.5	54.2	55.6
Nitrogen (N) (%)	1.8	1.8	1.8	1.8	1.9	1.9	1.8	1.7	1.7
C:N	31.1	31.1	31.1	30.3	28.2	29.3	31.5	31.7	33.7
LOI (%)	97.9	97.8	97.9	99.3	98.7	99.0	98.5	98.2	98.4
CEC (cmolkg^{-1})	34.3	33.5	33.9	35.3	32.5	33.9	30.5	30.6	33.9
BS	22.6	23.2	22.9	28.4	31.4	29.9	38.9	30.2	30.1

* T_{air}= Air temperature, T_{5cm}= Soil temperature at 5 cm, RH= Relative humidity, BD= Bulk density, WFPS= Water-filled pore space, LOI= Loss of ignition, BS= Base saturation

swamp forest ecosystem (1532.8 µg C m^{-2} h^{-1}), followed by the logged-over peat swamp forest ecosystem (577.8 µg C m^{-2} h^{-1}) and the oil palm ecosystem (24.0 µg C m^{-2} h^{-1}). Similar to soil CO_2 flux, the lowest soil CH_4 flux was also recorded from the oil palm ecosystem which had the lowest water table.

Table 2. Mean soil CO_2 and CH_4 fluxes for each study site with different water table levels.

Site		**Water table** *(cm)*	**CO_2 flux (mg C m^{-2} h^{-1})**	**CH_4 flux (µg C m^{-2} h^{-1})**
Oil palm plantation	ND	- 65.7	108.6	27.4
	NE	- 69.6	96.3	20.6
	Mean	- 67.6	102.5	24.0
Logged-over	CA	- 16.7	148.6	329.9
peat swamp forest	CB	- 12.6	107.6	825.6
	Mean	- 14.7	128.1	577.8
Tropical peat swamp	MB	- 4.8	134.4	1282.1
forest	MC	- 3.0	146.5	1783.4
	Mean	- 3.9	140.5	1532.8

DISCUSSION

In this study, it was observed that the soil CO_2 flux showed a decreasing rather than increasing trend with lower water table. Melling *et al.* (2005b), Berglund and Berglund (2011) and Muhr *et al*. (2011) also demonstrated similar results. These results suggested that increased emission of soil CO_2 as a result of lowering the water table in peat soils by drainage did not occur in all environments (Smith *et al*., 2003; Melling *et al*., 2005b).

As observed earlier by Melling *et al.* (2005b), the oil palm ecosystem had a lower soil CO_2 flux compared to the forest ecosystems. The lowest mean soil CO_2 flux (102.5 mg C m^{-2} h^{-1} at the oil palm ecosystem) might be attributable to the high soil bulk density (0.23 g cm^{-3}) in this ecosystem, as a result of compaction and post drainage subsidence due to further consolidation. Adachi *et al*. (2006) found that a higher bulk density increased the WFPS resulting in reduced soil gas diffusiveness and underground biotic activity. Thus, the soil CO_2 flux decreased beyond the effects of a lower water table achieved by drainage alone.

Even though the annual rainfall at the oil palm ecosystem was the lowest (262.8 mm) among the three ecosystems, the peat soil of this ecosystem had the highest WFPS (70.1%) indicating a high water holding capacity due to the higher peat bulk density. Since air-filled pore space is the inverse of moisture content, oxidation of organic matter decreased because of lower oxygen (O_2) availability in the peat soil pore space (Jauhiainen *et al.*, 2011). The seasonal fluctuations in soil temperature were relatively small; hence higher moisture content has a greater impact on soil respiration rates (Van Huissteden *et al*., 2006).

Mean soil CO_2 flux was highest in the tropical peat swamp forest ecosystem (140.5 mg C m^{-2} h^{-1}) even though the mean water table level was highest (-3.9 cm). The above-ground and living root biomass of this ecosystem and the logged-over peat swamp forest ecosystem were greater than that of the oil palm ecosystem. Thus, the biomass might contribute to higher soil CO_2 flux due to soil respiration by both roots and microbes utilising the root exudates in the rhizosphere (Lohila *et al*., 2003), irrespective of water table as also noted by Hirano *et al*. (2007). The thicker decomposing litter layer of labile C on the forest floor also contributed to its higher soil CO_2 flux.

The highest mean soil CH_4 flux was recorded at the highest water table in the tropical peat swamp forest ecosystem (1532.8 µg C m^{-2} h^{-1}) whereas the converse was found from the oil palm ecosystem (20.6 µg C m^{-2} h^{-1}), which had the lowest water table. The peat swamp forest ecosystem was mainly dominated by large Alan trees (*Shorea albida*) (Anderson, 1972). The heavily buttressed trees in this forest type and its low bulk density (0.11 g cm^{-3}) peat soil might also contribute to higher soil CH_4 flux (Melling *et al.*, 2008b). The lower soil CH_4 flux in the oil palm ecosystem was due to the lowering of the water table, which increased O_2 availability for the oxidation of CH_4 by methanotrophs and decreased CH_4 production (Couwenberg, 2011).

This finding further supported the results of Moore and Knowles (1989) which showed that water table was the major control on soil CH_4 flux. In this study, the soil CH_4 flux was predominantly influenced by water table but not soil CO_2 flux. Since the total soil CH_4 flux was much lower compared with soil CO_2 flux, it was concluded that water table was not the most important factor influencing the soil C flux in tropical peatland.

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