Characteristics of natural tropical peatland and their influence on C flux in Loagan Bunut National Park, Sarawak, Malaysia

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Summary

Tropical peat swamp forest (PSF), being a unique dual ecosystem, i.e. tropical rainforest and tropical peatland, is highly influenced by the characteristics and nature of the latter. For tropical peatland, vegetation is both a biotic and parent material in the peat-forming factors. Elemental composition of peat soil differs from that of geological materials in its striking enrichment of carbon and nitrogen compounds relative to most rocks. The organic compounds of the plants are the ultimate sources of the large amount of C and N sequestered in the natural peatland. Thus different forest types that live on the tropical peatland influence the peat properties and are themselves influenced by the peat properties. Tropical peatland has been variously claimed to be both a carbon sink and source to the atmosphere and may contribute to global warming. These bipolar roles of tropical peatland are probably the result of site-specific composition of vegetation, the chemical properties of the peat and environmental factors, above and below ground. However, the quantification of the effects of these factors on carbon fluxes and the dominant conditions that cause it to switch from a carbon sink to a source are still uncertain.

Key index words: tropical peatland, biosequence, carbon fluxes

Introduction

Tropical peat swamp forest (PSF), being a unique dual ecosystem (i.e. tropical rainforest and tropical peatland) is highly influenced by the characteristics and nature of the latter. Based on Jenny's (1941) equation of five soil-forming factors i.e. S = f(C, R, B, P, T), the biotic (B) component is the most multifaceted, and can be grouped into vegetation, micro-organisms, animals and human activities. Vegetation is considered to be the most important facet of the biotic factor.

This idea led many researchers to characterise tropical peatland in terms of the influence of biota using biosequence studies. These studies involve examining a series of soil profiles across which the biotic soil-forming factor varies, while other soil-forming factors remain relatively constant. Within the context of a biosequence, the effect of the changing biotic factor upon any soil property can be assessed quantitatively. For tropical peatland, vegetation is both a biotic component and a parent material for forming the soil. Elemental composition of peat soil differs from that of mineral soils in its striking enrichment of carbon and nitrogen compounds. The organic compounds of the plants are the ultimate sources of the large amounts of C and N sequestered in natural peatland. Different forest types observed on tropical peatlands such as those in Sarawak, Malaysia, both influence the peat properties and are themselves influenced by the peat properties.

Tropical peatland has been variously claimed to be both a carbon sink and a source to the atmosphere, and hence may contribute to global warming. These bipolar roles of tropical peatland are probably due to its site-specific composition of vegetation, the chemical properties of the peat substrate and the environmental factors, below and above ground. However, the quantification of the effects of these factors on carbon fluxes and the dominant conditions that cause peat to switch from being a carbon sink to a source are still uncertain.

The objective of this paper is to describe the characteristics of the tropical peatland Loagan Bunut National Park in relation to the forest types and their influence on carbon flux.

Materials and methods

Study sites

Soil carbon fluxes from tropical peatland were investigated for three different forest types: the mixed peat swamp forest, Alan forest and Padang Alan forest at the Loagan Bunut National Park, Miri, Sarawak, Malaysia (Melling *et al.,* 2006). The three studied sites were all located along a transverse line across the peat basin.

Flux measurements

Flux measurements were made at each forest type over a year from April 2006 to March 2007. Four sample plots were selected for each site. For details on the closed chamber method, see Melling *et al.* (2005a, 2005b). During the gas flux measurements, all the environmental parameters such as air temperature, soil temperature at 5 cm and 10 cm, relative humidity and water table depth were recorded simultaneously.

Undisturbed soil core samples (100 cm^3) for determining both the soil bulk density and water-filled pore space were also taken. The latter property was later measured in the laboratory using a soil volume analyzer (Model DIK-1110, Daiki Rika Kogyo Co., Ltd). The contents of the cores were transferred to a weighed beaker and oven dried at 105°C for 48 hours, cooled in a desiccator and weighed to determine their bulk density.

Soil samples at 0-25 cm using a peat auger were taken from each chamber site after each flux measurement. The soils were sampled from April 2006 to March 2007. The samples were bulked and air-dried, ground and sieved with a 2 mm sieve. A sub-sample from the homogenized sample was used for chemical analysis.

Gas concentration analysis

Soil CO_2 gas concentrations were determined in the laboratory within 4 h of collection using a CO_2 infrared gas analyzer (Fuji Electric, ZFP-5). The gas analyzer was calibrated using standard calibration gas mixtures of 0 and 1887 ppm CO_2 in N_2. The gas fluxes were calculated from the linear changes in the gas concentrations in the chamber headspace.

CH_4 concentration was determined by a gas chromatograph equipped with a flame ionization detector (HP 6890N; Hewlett Packard, Palo Alto, CA) maintained at 250° C, using a 2 m long Porapak N column (80/100 mesh Hewlett Packard) maintained at 50°C with a N carrier gas flowing at 40 ms^{-1}. CH_4 fluxes were calculated from the linear increase or decrease in the gas concentration in the chamber with time, using a linear regression equation.

Results and discussion

Characteristics of the Loagan Bunut Peat Swamp

The mixed peat swamp forest is generally less woody than the other types and its peat is the most decomposed. Thus the bulk density of the peat is generally the highest. This forest type is generally found at lower elevations that receive water from a larger area upslope.

The Alan forest has the woodiest peat and is generally found in more stressful locations of the peat swamp. This may have led to a physiological adaptation of the trees whereby they have a bigger buttress and are almost invariably hollow, with a very dense shell of timber remaining. Owing to the harsher environment, the roots of the Alan Batu forest type are also more extensive. This extensive root system creates a vacant layer in the peat profile of about 20 – 30 cm within the top 100 cm of peat (Yonebayashi and Lim, 1995).

The Padang Alan forest is a dense pole-like forest. It is generally found on the bog plain of the peat dome, i.e. on flatter topography. The peat here is not woody but is very fibrous. It is generally the most undecomposed peat, and hence very raw. This may be due to the restricted lateral water movement with the surface peat soil probably being more anaerobic. Thus, the peat here is the most porous.

Environmental characteristics

Environmental characteristics of the study sites are shown in Table 1. Mixed peat swamp forest had the lowest mean air temperature of 26.7°C while those of Alan and Padang Alan were 27.5°C and 27.2°C respectively. Monthly soil temperatures at 5 cm for the three sites were almost constant and had a similar pattern. From these data, it is observed that the Alan Forest generally had slightly higher temperatures compared to the other study sites with the mixed peat swamp having the lowest. The differences were, however, very small.

The study sites had a very high annual rainfall of about 3000 mm. The mixed peat swamp forest had the highest rainfall which appeared to decrease towards the centre of the peat basin.

Monthly variations in water table depth across the three forest types did not tally with the monthly rainfall. Generally, the mixed peat swamp forest being next to the

Table 1. Environmental characteristics of the study sites

Forest Type	Mixed peat swamp	Alan	Padang Alan
Peat depth (cm)	950	935	750
Air temperature (°C)	26.7	27.5	27.2
Soil temperature at 5 cm (°C)	25.5	25.8	25.6
Annual rainfall (mm)	3385.6	3115.3	2807.7
Water table (cm)	5.1	17.5	20.7
Water filled pore space, WFPS (%)	90.3	63.0	62.2
Relative humidity (%)	95.4	93.9	94.9

Table 2. Physical and chemical characteristics of the peat

Forest Type	Mixed peat swamp	Alan	Padang Alan
Bulk density (g/cm^3)	0.16	0.12	0.13
Soil pH	3.37	3.40	3.33
Pyrophosphate solubility index (PSI)	18.04	11.11	11.64
Loss on ignition (%)	96.45	97.32	96.52
Total C (%)	57.47	56.42	55.48
Total N (%)	1.94	1.90	1.83
C:N ratio	29.70	29.65	30.27
CEC ($cmol_c\ kg^{-1}$)	37.95	34.36	36.03
Base saturation (BS)	13.72	13.76	7.92

Loagan Bunut lake had a higher water table. This may be due to the back flow effect from both the Tinjar River and the Teru River towards the Loagan Bunut Lake. This phenomenon also resulted in the mixed peat swamp having a higher water table for a longer period and even being flooded in the months between October and December 2006.

As expected the water-filled pore space was highest in the mixed peat swamp forest and lower in the Alan and Padang Alan forests which is again influenced by their high water table. Similarly, the relative humidities were all above 90%, which is generally typical of a tropical forest. Mixed peat swamp forest had the highest relative humidity of 95.4% which may again be due to the high water table, high water-filled pore space and a greater canopy cover. Thus all these factors may have favoured a lower air temperature for this forest type.

The physical and chemical characteristics of the peat for the three forest types are shown in Table 2. Peat depths were all >2.5m, which is classed as being deep. Peat thickness was least at the Padang Alan forest (750 cm) and greatest (950 cm) at the mixed peat swamp forest. Bulk density of peat is closely related to many physical parameters such as the degree of humification, total pore space, water content and wood content. The peat bulk density (BD) values are very essential for calculation of volumetric nutrient concentrations, as the values of total carbon and nitrogen are based on weight and not volume. The peat is very acidic with a pH of less than 4. Mixed peat swamp had the highest pyrophosphate solubility index value (18.04) and this also means that the peat was more humified. A loss on ignition of more than 95% shows that the mineral contents of the samples are exceptionally low. The low mineral content indicates that the peat is of an ombrogenous type, that it only receives its nutrient influx from rain.

Cumulative flux

The peat soil at all three forest sites emitted CO_2, CH_4 and N_2O. Cumulative CO_2 flux of the soils in the three forest types did not show any significant difference (Fig. 1). The annual CO_2 production from the soil was highest in the Alan forest at 1216 g C m^{-2} yr^{-1} followed by Padang Alan at 1134 g C m^{-2} yr^{-1} and Mixed Peat Swamp at 1049 g C m^{-2} yr^{-1}. The annual soil CO_2 fluxes were similar to those observed by other researchers on tropical ecosystems (Inubushi *et al.*, 2003; Melling *et al.*, 2005a).

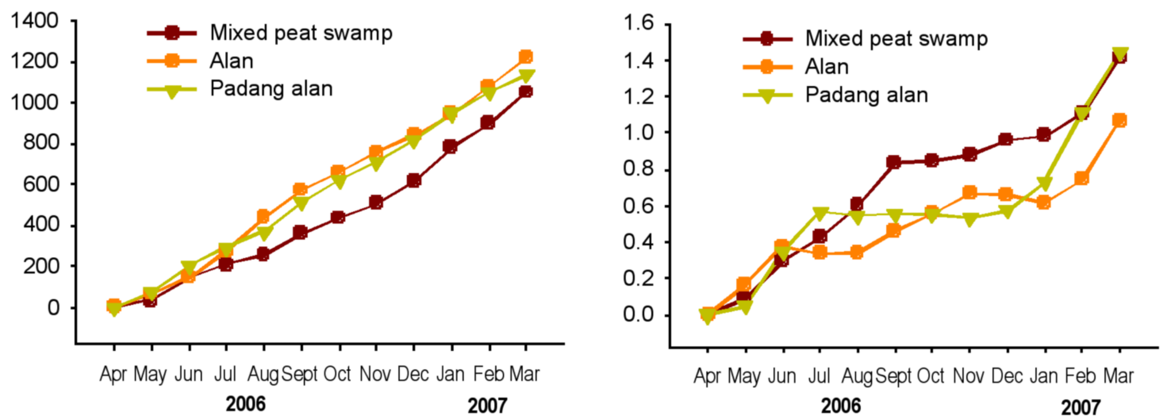

Figure 1. Cumulative soil CO_2 and CH_4 fluxes of Mixed Peat Swamp, Alan and Padang Alan forest.

On an annual basis, all the forests were a CH_4 source, with Padang Alan having the highest cumulative value of 1.44 g C m^{-2} yr^{-1} while those of mixed peat swamp and Alan forest were 1.41g C m^{-2} yr^{-1} and 1.07 g C m^{-2} yr^{-1}, respectively.

By using the tree regression analysis (for details on tree regression methods, see Melling *et al.,* 2005a), soil CO_2 fluxes in mixed peat swamp and Alan forest were mostly influenced by soil temperature albeit at different depth. This might be attributed to the denser canopies in mixed peat swamp forest which shaded the peat soils resulting in lower soil temperature fluctuation at lower depth. The results showed that higher soil temperature would increase the soil CO_2 emissions. In Padang Alan forest, the soil CO_2 fluxes were mainly controlled by the soil bulk density where higher values, which indicated wetter condition, resulted in lower gas fluxes. This might be attributed to the poorer gas diffusion under wet conditions.

The soil CH_4 emissions in mixed peat swamp and Padang Alan forest were mainly influenced by relative humidity. Their low relative humidity led to the high CH_4 emission. This effect might be attributed to the more rapid gas exchange between the peat soils and the atmosphere.

In Alan forest, the controlling factor for CH_4 fluxes was bulk density. This might be attributed to the unique soil biophysical properties under Alan forest which has large roots that cause voids or hydric layers in the peat. These voids lower the bulk density and would be filled with water particularly during the wet season, resulting in the production of CH_4 that would be released in subsequent months.

Conclusions

This study has shown that tropical peatland emits the major greenhouse gases CO_2 and CH_4 and that the amount of soil CO_2 emitted was similar to that produced by a tropical forest on mineral soils. To fully understand the ecosystem carbon balances, a tower study using the Eddy Covariance method will be needed.

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