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SEASONAL AND INTERANNUAL VARIATIONS OF DISSOLVED ORGANIC MATTER COMPOSITION IN THE GROUNDWATER OF TROPICAL PEAT UNDER OIL PALM PLANTATION MANAGEMENT

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SUMMARY

Dissolved organic matter (DOM) is the most reactive fraction of natural organic matter, of which composition reflects its source and biogeochemical processes. As such, compositional information of DOM can serve as a useful clue to better understand its surrounding environments. In this study, a long-term monitoring of DOM composition in groundwater of tropical peat (TP) under oil palm plantation (OPP) was conducted to better understand the environmental change of. Monitoring sites are located in an OPP in Sarawak, Malaysia. Twelve sampling wells were installed across the OPP and groundwater samples were collected once a month over 5 years. Dissolved organic carbon (DOC) concentrations and UV-visible spectra were measured to calculate specific UV absorption (SUVA) values (absorbance at 254 nm per unit C; a proxy for aromaticity of DOM). Fluorescence properties of DOM were measured by excitation-emission fluorescence matrices (EEMs) combined with parallel factor (PARAFAC) analysis. The average DOC concentration was approximately 48 mg C L^{-1} and increased during wet-season, while SUVA value did not change during the monitoring period. EEM was decomposed into 7 PARAFAC components with different behavior. Fluorescent component composition showed intra- and inter-annual variation. Principal component analysis of PARAFAC component compositions successfully extracted two factors responsible for the temporal changes in fluorescence compositions. One is development of reductive conditions over time, and the other is seasonal variation of the percentage of humic acid-type humic-like fluorescence associated with the seasonal variation of groundwater level.

Keywords: *dissolved organic matter composition, EEM-PARAFAC, long term monitoring, oil palm plantation, tropical peat*

INTRODUCTION

Tropical peatland area is estimated to contribute to 11% (44.1×10^4 km^2) of global peatland area, of which 56% is located in Southeast Asia (Page *et al.,* 2011). A large amount of wood peat is accumulated under tropical peat swamp forest (TPSF). Carbon stock of Tropical peat (TP) in Southeast Asia is estimated to be 68.5 PgC, and Indonesia and Malaysia account for its 65% and 10%, respectively.

Since 1960s, countries in Southeast Asia, as typified by Indonesia and Malaysia, began to develop TP to oil palm plantation (OPP) due to limited acreage of arable dry field. Once TP is developed to OPP, peat environment changes considerably, which may accelerate peat decomposition. Therefore, it is important to better understand the changes in the biogeochemical processes of peat accompanied by the changes in peat environment or land utilization to contribute to the sustainable management of tropical peat.

Dissolved organic matter (DOM) is the most reactive fraction of peat organic matter, of which composition reflects sensitively its source and biogeochemical processes. As such, compositional information of DOM can provide useful information to better understand its surrounding environments. In recent years, the analysis of optical properties as a means of characterizing DOM quality has received increasing attention. In particular, the combination of excitation emission matrix (EEM) fluorescence and parallel factor analysis (PARAFAC) modeling has enabled biogeochemists to draw out the full information contained in the fluorescence signature of DOM (e.g. Yamashita 2010).

In this study, we aim to better understand the changes in the TP environment under OPP, focusing on the quality of DOM in the groundwater. For that purpose, DOM composition in the groundwater of TP at OPP was monitored monthly for 5 years by using EEM-PARAFAC.

METHODS

Study area and water sampling

A long term monitoring of groundwater quality was conducted at Naman OPP, which is located in the southwest region of Sarawak, Malaysia (2° 9'N, 111° 53'E) (Figure 1). Sarawak belongs to tropical rainforest climate, with an average temperature of 26-35°C and annual precipitation of 2000-4000 mm with unclear wet (Nov-Feb) and dry season (Mar-Oct). The elevation of the OPP is 1-17 m asl, and the peat depth ranges from 0-16m. Oil palm trees in the study site were transplanted in 2000 at Q1-Q4, in 2001-2002 at Q5-Q8, and in 2003-2004 at Q9-Q12 (Q5 was excluded in this paper since the hydrology of Q5 was very different from other sites). a total of 12 monitoring sites Groundwater monitoring wells were established in 2008 (Figure 1). Water samples were collected at monthly interval from the wells from October 2008 to June 2013. Water samples were transported under refrigerated condition to the laboratory of water environment in Kitasato University, Japan.

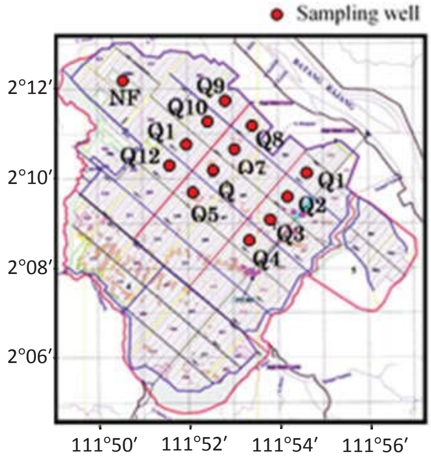

Figure 1: Map of Naman oil palm plantation and location of sampling wells. Q1 to Q12 are the monitoring wells established in OPP. NF is monitoring well established in secondary forest preserved in OPP.

Chemical Analyses

The water samples were filtered through pre-combusted at 450°C for 4h through glass fiber filters (nominal pore size 0.4μm; GB-140, ADVANTEC, JAPAN). The dissolved organic C concentrations were measured using a high-temperature catalytic oxidation (TOC-V_{CNH}, Shimadzu, Japan).

Spectroscopic analysis

The excitation-emission matrices (EEMs) of water samples were measured using a spectrofluorometer (FluoroMax-4, Horiba Scientific, Japan) equipped with a 150 W xenon lamp as the light source (Abe *et al.,* 2011). EEM was measured with an excitation wavelength from 240 to 550 nm at an increment of 5 nm and the emission signal was scanned in the range of 260 to 600 nm at an increment of 2 nm. The inner filter effect was corrected by measuring the UV-Vis absorption spectra of the sample (McKnight *et al.,* 2001; Maie *et al.,* 2006) on a UV-Vis spectrophotometer (UV-1800, Shimadzu, Japan). The obtained EEMs were further statistically analyzed using parallel factor analysis (PARAFAC) modeling with DOMFluor toolbox (Stedmon and Bro, 2008) using MATLAB software ver. 7.7 (MathWorks, Inc.) to decompose EEMs into distinct fluorescence components (Stedmon *et al.,* 2003; Stedmon and Bro, 2008). The validity of the model was confirmed based on split half analysis and Tucker's congruence coefficient (Stedmon and Bro 2008).

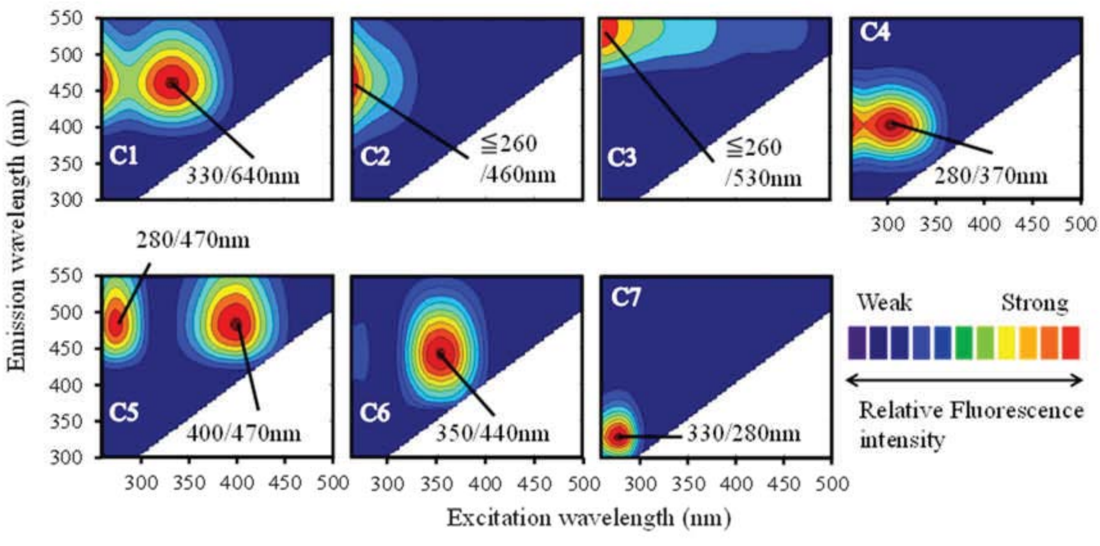

Figure 2: Contour graph of 7 fluorescence components decomposed by PARAFAC analysis. C1, C2, & C6, terrestrial fulvic acid-type humic like peak; C3, terrestrial humic acid-type humic like peak; C4, Microbial fulvic acid-type humic like peak; C5, Ubiquitous fulvic-type humic like peak; C7, protein-like peak.

RESULTS AND DISCUSSION

Average DOC concentration was 48±8 mgC $L^{-1}$and showed seasonal variation. DOC generally increased during wet season (Nov. – Feb) when groundwater level became high. Specific UV absorbance (SUVA) value, which is a proxy for aromaticity of DOM, did not change appreciably during the monitoring period.
DOM in the groundwater of OPP contained different amount of these 7 PARAFAC components (Figure 2). To extract factors which induce variations in the PARAFAC component composition, principal component analysis (PCA) was conducted.. The PC1 scores increased from Oct. 2008 to Aug. 2010 and generally continued to be flat without seasonal variation (Figure 3). Factor loading plots (Figure 4) indicated that the increase of PC1 score was associated with either the increase of C1, C4, and C7, or the decrease of C2 and C6. When groundwater was incubated with nutrients (N & P) under anoxic conditions, %C1 increased. However, when groundwater was oxidized with laccase, %C2 and %C6 increased. Therefore, the variation in PC1 score can be attributed to the lowering of redox potential from Oct. 2008 to Aug. 2010, which may be caused by the increase of microbial activity in groundwater due to long term fertilizer application. The PC2 score showed seasonal cycle, which generally increased during wet season and decreased toward the end of dry season. Variations in the PC2 score shows the changes in the relative proportion of humic-like (C3) and fulvic-like humic substances (C4) (Figure 4). The reason of this variation may be explained as follows. Water soluble organic matter (WSOM), which is rich in humic acid-like fluorescence, is formed in peat at above groundwater level during dry season. The WSOM is dissolved into groundwater in wet season when groundwater level rises. During dry season, DOM, rich in humic acid-like fluorescence, runs off and decreases its contribution.

CONCLUSION

Quality of DOM provides useful information on peat environment and formation process of DOM. Microbial activity in groundwater might increase under oil palm plantation, leading to the development of reductive conditions of groundwater. DOM composition in groundwater changes seasonally, which might indicate that the fluctuation of groundwater level accelerates runoff of peat organic matter from OPP in dissolved form.

ACKNOWLEDGEMENTS

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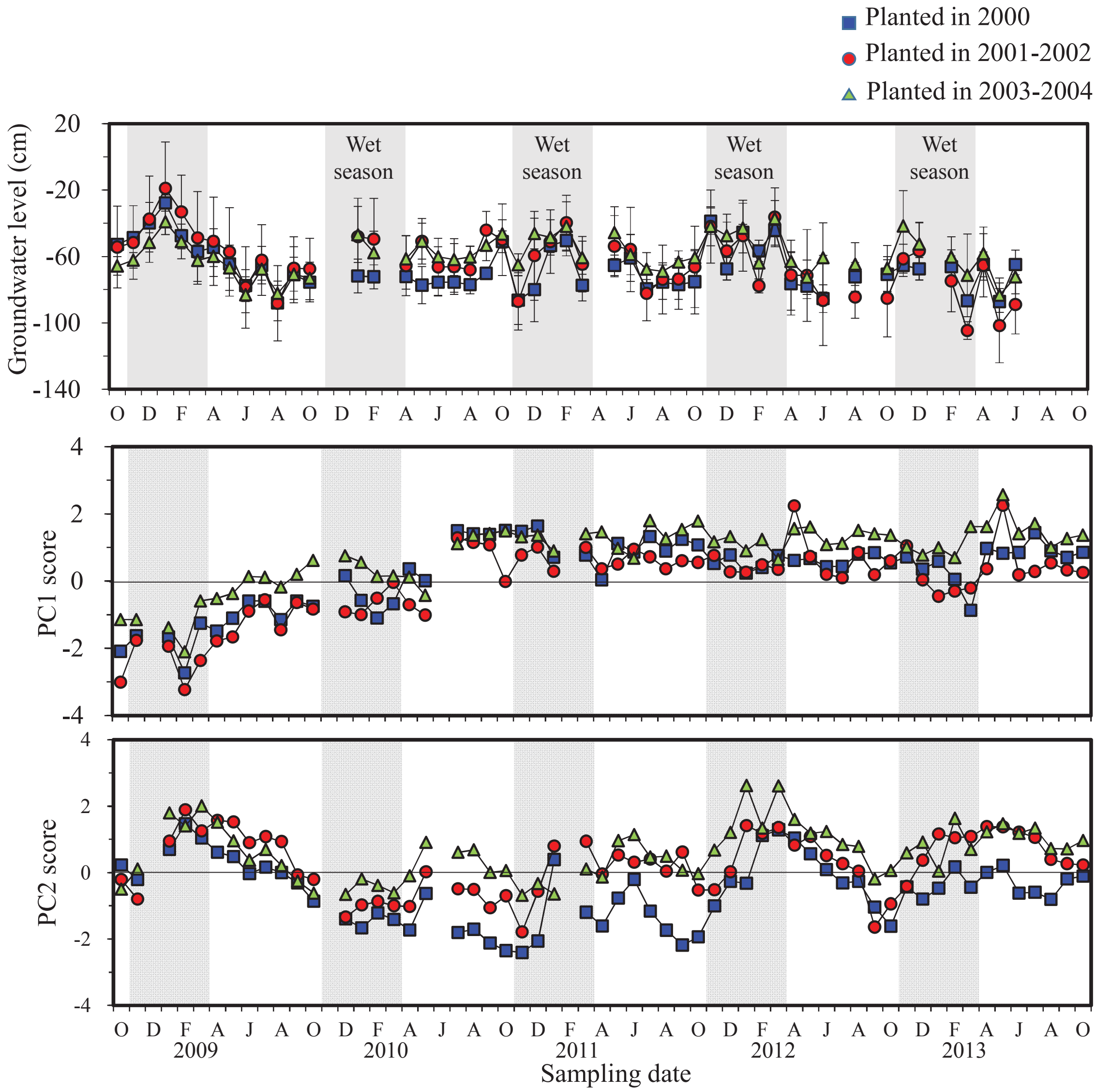

Figure 3: Temporal variations of groundwater level (upper panel), and PC1 (upper panel) and PC2 (lower panel) score plots.

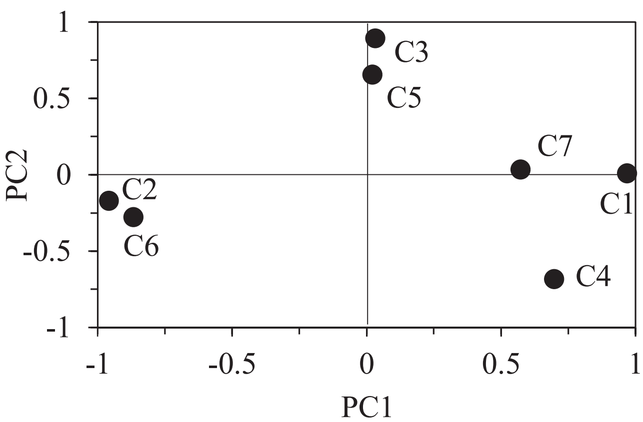

Figure 4: Factor loading plot.