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TEMPORAL CHANGES OF SELECTED PHYSICO-CHEMICAL PROPERTIES OF TROPICAL PEAT UNDER MANAGED OIL PALM PLANTATION

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SUMMARY

Tropical peatland has been developed widely in Southeast Asia for agricultural plantation especially for oil palm. This is to meet the food and energy sources demand as world population is increasing over time. However, development of peatland with emphasis on monocultures has led to changes in physico-chemical properties of peat soil and less attention has been paid to the changes of peat matrix especially on nutrient cycling. Therefore, the objective of this study was to evaluate the temporal changes of physico-chemical properties of peat soil after oil palm plantation has been established over seven years and is in a more stabilised condition. The peat soil was collected from matured oil palm plot with the palms age of about 7 years old at the commencement of this study, for four consecutive years. PCA was used to generate statistical correlation among the variables and subsequently by linear regression model to observe changes to selected physico-chemical properties. The pH of peat soil decreased with temporal changes (-0.047 units year^{-1}, $p < 0.05$) and this could be due to the accumulation of organic matter or from N fertilizer input. Other properties such as nutrient level (total C, N, P, K, NH_4^+, CEC, base saturation and ash contents) also showed decreased pattern with time except for nitrate content. The negative slopes showed that fertilization is likely to be a necessity for maintaining land production capacity (Kononen *et. al*, 2015). The physical properties of peat soil particularly bulk density was observed to be constant in value with the practice of mechanical compaction before planting that leads to better water retention. The enhanced water retention with time was indicated by the positive slope of water-filled pore space (WFPS) at the rate of 1.531% year^{-1}.However, the decreasing pattern in the soil chemical properties over time can either be from palm uptake to maintain its productivity or from unidentified factors that contribute to the nutrient depletion in peat soil. Further investigation must be conducted to quantify the factors contributing to the nutrient depletion in peat soil.

Keywords: *tropical peatland, oil palm plantation, temporal changes, physicochemical properties*

INTRODUCTION

Global agriculture sector in the 21st century faces rising challenges to meet the food and fibre demands in feeding a growing population and producing more feedstocks for potentially huge bioenergy market. In Southeast Asia, tropical peatland occupies an area about 30 Mha (Miyamoto, 2013) and is one of the major potential land resources to produce foods and energy. Therefore, tropical peatland has been developed widely for agricultural purposes especially for oil palm plantation. In 2010, industrial plantations on peatlands in Malaysia and Indonesia covered around 3.1 Mha and could be doubled by 2020 (Miettinen *et al.*, 2012). This large-scale land use change has great impacts on the converted areas. One of the possible effects of conversion to oil palm plantation is the temporal changes and variation of the physico-chemical properties of peat soil.

There are many reports and scientific publications on the physico-chemical properties of converted peatland to oil palm plantation but the variation may differ from area to area as the oil palm plantation management practices are also known to be additional factors affecting changes in the physico-chemical properties over time. For instance, carbon cycling in peat is driven by four key factors; environmental condition (temperature, water table), substrate quality (recalcitrant peat), nutrients (N requirement for palm growth) and microbial community (microbe types for substrate utilization) (Savage *et.al.*, 2010). Among the four drivers listed, substrate quality is seen as the most significant and is highly dependent on vegetation type. The distribution of woody materials contributes to the variation of decomposition rate and nutrient cycling in peat soil.

Therefore, the aim of this paper is to investigate the variation of temporal changes of physico-chemical properties of peat soil from a properly-managed and stabilised oil palm plantation. The selected physical and chemical properties of peat soil were investigated and this includes bulk density, water filled-pore space, pH, carbon, nitrogen, C:N ratio,, organic matter, ammonium, nitrate, phosphorus, potassium, cation exchange capacity

(CEC) and base saturation. The environmental variables were also taken into consideration because of its influence on the physical and chemical properties of peat soil. By evaluating the properties will enable us to discern the major temporal changes in peat physico-chemical properties in an oil palm plantation.

MATERIALS AND METHOD

Study Site

The peat soils use in this experiment was collected from oil palm plantation located in Sibu, Sarawak (N 02^o 11' E 111^o 50'). Two plots within the oil palm plantation were selected for peat soil collection. The peat soil sampling started when the oil palm age was 7 years old (matured oil palm trees) and the soil sampling was done on a monthly basis throughout the four years. The peat soil samples were collected at the depth of 0-25 cm (top soil) and 25 – 50 cm (sub soil). The samples were brought to the laboratory and immediately stored in refrigerator at 4 ^{o}C. The fresh peat soil were dried using microwave dryer to speed up the drying process as peat soils are very moist and wet.

Soil Variables

The physical properties of peat soil were determined by measuring bulk density and WFPS. Core samples were collected concurrently during peat soil collection using 100 cm^3 core-rings. The undisturbed core samples were analysed by using digital soil volume meter (DIK-1150, Daiki, Japan) and the data were used for WFPS calculation. The core samples were then analysed gravimetrically by drying the samples in 105 ^{o}C oven for 48 hours (Melling *et al.*, 2005). The pH of peat soil was extracted with distilled water with the ratio 1:2.5. The peat slurry was measured using pH meter (Metrohm 827, USA). Carbon and Nitrogen content was analysed using Trumac CN analyser (Leco, USA). The organic matter content was measured gravimetrically by heating the samples using Thermogravimetric Analyzer 701 (Leco, USA) at 800 ^{o}C for an hour. Total phosphorus and potassium were analysed by using the ashing and subsequently acid digestion method. The samples were digested by using concentrated hydrochloric acid (HCl) and determined using ICP-OES (Perkin Elmer, USA). Exchangeable cation was determined by leaching the samples in the glass column with 1.0 M ammonium acetate and the distillate was measured for its concentration using ICP-OES. Then the same samples were washed using 70% ethanol and continued with the leaching step using 0.05 M potassium sulphate for Cation Exchange Capacity (CEC) determination. CEC was done by collecting the leachate and distilled the samples using Buchii distillation unit. The distillate was then titrated using 0.1 M HCl. Base saturation was calculated based on the ratio between sums of EC and divided by CEC value. Environmental variables for relative humidity and air temperature were measured using Humidity/Temperature digital meter (Testo 632, Germany), soil moisture meter (Daiki 311E, Japan) was used for monitoring soil moisture and soil temperature was determined using soil meter probe (Hannah, Malaysia) at the depths of 5 cm and 10 cm. Water table was determined by measuring perforated pipe that has been previously installed at the experimental site.

Data Analysis

Principle Component Analysis (PCA) was used to group the physical and chemical properties and show the percentage of variation for each group. Then the data were statistically analysed for correlation among the parameter and lastly regression was decided to be used when data shows significant correlation between the parameters and time. Each parameter was determined on their linear relationship against time and significant interaction shows the temporal changing rate (slope) of physical and chemical properties of peat soil during four year measurement. We performed all analysis with SPSS software (SPSS, Version 2.1).

RESULT AND DISCUSSION

The result of the PCA for the physical, chemical and environmental variables are shown in Table 1. From the result, variance was distributed into seven components with total cumulative of 75%.

Table 1: Variance of physicochemical properties and environmental variables in oil palm plantation

Component	Eigenvalue	% of variance	cumulative %
1	4.349	21.744	21.744
2	3.827	19.134	40.878
3	1.814	9.071	49.949
4	1.552	7.758	57.707
5	1.343	6.717	64.423
6	1.121	5.603	70.026
7	1.078	5.388	75.414

The first principal component (PC1) accounted for 21.7% of the total variance, and was highly correlated with the WFPS, soil moisture and NO_3^- content as shown in Table 2 ($r > 0.6$) , characterizing the distribution of air and water in peat soil influence the availability of NO_3^- content. PC2 accounted for 19.1% of the total variance with strong correlation with peat soil pH, organic matter and base saturation ($r > 0.6$), characterizing the distribution of mineral and organic matter which influence pH value of peat soil. PC3 accounted for 9.1% of total variance correlated with NH_4^+ content, air temperature and relative humidity ($r > 0.6$), characterizing that mineralization was affected by air temperature and relative humidity of the surrounding environment. PC4, PC5, PC6 and PC7 show no differences in their total variance with 7.8%, 6.7%, 5.6% and 5.4% respectively ($r > 0.6$), characterizing nutrient contents and bulk density of peat soil. The bulk density was categorized solely in PC7 showing that the compaction and water management in the oil palm plantation supported nutrient availability for the palms. The experiment area also does not display fluctuation in bulk density and this shows that the area is stabilised over time with proper management. Table 2 shows the correlation matrix of physico-chemical and environment variables.

Table 2: Correlation matrix of the PCA for the physicochemical and environmental variables

Variables	PC1	PC2	PC3	PC4	PC5	PC6	PC7
$NO3^-$	**-0.770**	0.612	0.328	0.060	-0.141	0.132	-0.095
WFPS	**0.904**	-0.223	-0.320	0.084	0.080	0.084	0.195
Soil Moisture	**0.744**	0.063	-0.005	-0.095	-0.119	-0.003	0.093
pH	0.245	**0.702**	-0.274	-0.101	0.166	-0.439	0.196
Organic Matter	0.373	**-0.750**	0.320	-0.273	-0.108	-0.144	-0.025
Base Saturation	-0.190	**0.822**	-0.083	0.214	0.078	-0.343	0.145
NH_4^+	0.064	0.474	**0.664**	0.438	-0.394	-0.266	-0.126
Relative Humidity	0.543	-0.287	**0.742**	0.386	-0.119	0.104	-0.147
Air Temperature	-0.817	0.282	**-0.834**	-0.377	0.222	0.003	0.248
Total Nitrogen	0.193	-0.483	0.119	**0.866**	-0.079	-0.077	0.009
CN Ratio	-0.050	0.649	0.244	**-0.868**	0.476	-0.084	0.074
Total Carbon	0.297	0.031	0.640	-0.052	**0.865**	-0.296	0.014
Total Phosphorus	-0.122	0.470	0.358	-0.198	**0.656**	0.196	-0.253
CEC	0.068	0.465	0.23	-0.114	-0.075	**0.642**	0.207
Total Potassium	-0.093	0.307	0.268	0.187	0.066	**0.782**	0.555
Bulk Density	-0.055	0.098	-0.513	0.059	0.382	0.197	**0.836**

The temporal changes of physico-chemical properties of peat soil were determined by linear regression model. The interaction between physico-chemical properties against time were shown in Table 3 below. The homogeneity test of regression slopes showed 13 parameters with significant difference against time while 2 parameters were not significant.

Table 3: Comparison of the significant, non-significant changing rates and other related parameters derived from the linear regression model

Variables	Changes Rate	Mean	Standard Deviation	F Value	Significance
	Slope				$P < 0.05$
Significant homogeneous slopes					
pH (Unit $Year^{-1}$)	-0.047	3.430	0.129	19.063	0.000
NH_4^+ (mg kg^{-1} $year^{-1}$)	-11.081	54.671	29.091	21.089	0.000
Total Nitrogen (g kg^{-1} $Year^{-1}$)	-0.057	18.680	0.119	38.219	0.000
Total Carbon (g kg^{-1} $Year^{-1}$)	-0.562	550.230	2.310	7.602	0.007
CN Ratio (g kg^{-1} $Year^{-1}$)	0.605	29.49	2.579	7.012	0.009
Organic Matter (% $Year^{-1}$)	0.169	97.608	0.508	15.330	0.000
Cation Exchange Capacity (cmol kg^{-1} $Year^{-1}$)	-2.018	32.27	5.036	23.897	0.000
Base Saturation (cmol kg^{-1} $Year^{-1}$)	-1.157	8.187	2.927	23.108	0.000
Total Phosphorus (mg kg^{-1} $year^{-1}$)	-130.208	332.578	259.021	44.073	0.000
Total Potassium (mg kg-1 $Year^{-1}$)	-78.142	293.19	281.049	10.172	0.002
WFPS (% $Year^{-1}$)	1.531	78.709	6.121	8.069	0.006
Non-Significant homogenous slopes					
$NO3^-$ (mg.kg^{-1} $year^{-1}$)	0.707	86.443	64.878	0.014	0.906
Bulk Density (g.cm^{-3} $Year^{-1}$)	0.001	0.228	0.016	0.191	0.663

The linear regression slopes showed an increase or decrease of physicochemical properties value with time. The pH shows a negative slope with the rate of -0.047 units $year^{-1}$. It shows that the hydrogen ions, H^+ or cation contributed by organic acid are increasing or possible depletion of anion in peat soil. One of the possible factors that cause soil acidification is accumulation of organic matter (Ritchie and Dolling, 1985) faster than decomposition rate of peat soil. Based on the temporal changes of organic matter, the result shows increasing rates of organic matter in peat soil with 0.169 %. $year^{-1}$. However, the accumulation of organic matter is not the only mechanism that can lead to soil acidification in cultivated soils (Ritchie and Dolling, 1985). Ammonium-based fertilizers are one of the factors in lowering of the pH of soil when it is leached rather than taken up by plants. Based on the results above, nitrate content does not give significant temporal changes but the slopes show positive slope which means the tendency for nitrate to accumulate in peat soil after nitrification process. Hydrogen ions can be released and neutralised or possibility to have extra charge of hydrogen ions which lead to lower pH during nitrification process.

Ammonium, NH_4^+ marked temporal decrease; -11.081 mg.kg^{-1}. $year^{-1}$ in peat soil and this could be due to slow mineralization rate, faster nitrification of NH_4^+ ion in peat soil or taken up by plant as a as a nutrient source. Total nitrogen and carbon also show the temporal decrease with at the rate of -0.057 g kg^{-1} $year^{-1}$ and -0.562 g kg^{-1} $year^{-1}$ respectively. However the CN ratio marked positive temporal rates with 0.605 g kg^{-1} $year^{-1}$. This explained the accumulation of nitrogen in soil, which is higher than carbon or it could be contributed by nitrogen fertilization to the soils. The cation exchange capacity and base saturation was observed to have temporal changes in decreasing manner. Other nutrients that show the same pattern is phosphorus and potassium. The depletion of nutrients could be due to the increase in uptake of the oil palm trees for their growth. Therefore fertilization of cultivated area must be done in order to supply sufficient nutrients to the crops.

The physical properties of WFPS were observed to have temporal increase with 1.531% $year^{-1}$ while the bulk density was statistically not significant in their temporal changes but the rate shows an increasing pattern. This is because the experiment sites in the plantation area were very consistent in their compaction that leads to increase of WFPS. This can also be caused by mineralization of organic matter into small particles and reduce porosity of air percentage in the peat soil. The physical properties showed that oil palm plantation was properly managed.

CONCLUSION

The physico-chemical results observed do not show erratic changes in their properties because the oil palm plantation has been properly managed and stabilised over time. However, certain chemical properties such as total phosphorus and potassium show a very large variation and fluctuation which could be affected by surface soil which is generally believed to be the most active layer in terms of fertility-related parameters (Wang *et. al*., 2013). The depletion of nutrients in oil palm plantation need to be further investigated to minimise the losses. With the improvement in physical properties such as compaction level with consistent bulk density result, reduce air porosity and increase water capillary-rise, these will enhance the efficiency of nutrient uptake by crops for their growth. Therefore, it is very important to continuously manage oil palm plantation sustainably in peat area.

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