Faculty of Resource Science and Technology

Characterization of the Humification Degree of Peat Soils under Cultivation of Sago and Oil Palm Plantations

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Characterizations of the Humification Degree of Peat Soils under Cultivation of Sago and Oil Palm Plantations

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DECLARATION

I declare the work in this thesis was carried out in accordance with the regulations of Universiti Malaysia Sarawak. It is original and is the result of my work, unless otherwise indicated or acknowledged as reference work. The thesis has not been accepted for any degree and is not concurrently submitted in candidature for any other degree.

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ABSTRACT

Sago palm (*Metroxylon sagu*) and oil palm (*Elaeis guineensis*) is a tropical crop that can adapt the acidic condition of peat soil, which is cultivated at large scale in Sarawak (Malaysia). The question is whether this large-scale development on peat soil are sustainable because of the challenges in their production yield. The production of sago palm and oil palm on deep peat are inconsistent, and not all the tree is able to grow to maturity and produce a yield. Besides, the production yield of the oil palm and sago palm at the mineral soil is greater than the one been cultivated on deep peat soil. For this reason, it is hypothesis that the extent of humification may have been the root cause to the slower and poorer performance of oil palm and sago palm on deep peat. This study is set out to investigate humification degree of peat soil under oil palm and sago palm plantations to provide a deeper insight. The soil samples were collected from the sago palm and oil palm estate. The physical and chemical soil characterisation were conducted between the sample's origin and depth. Meanwhile, the carbon dioxide measurement was only conducted on the surface soil in oil palm estate and forest. The result indicated the peat soil in sago palm and oil palm had the most nutrient at the surface soil while, the degree of humification decreased with increasing depth. The trunk performance at trunking plot might be due to higher conductivity (460.00 μScm^{-1}) ($p<0.05$) and lower C/N ratio (47.27%) ($p> 0.05$) compared to the non-trunking plot at the surface soil, while the FTIR shown the uncultivated peat was humified than cultivated peat because the latter was continuously replenished with new plant matter. On the basis of FTIR spectroscopy, no significant difference was found between cultivated peat sampled adjacent to trunking hand non-trunking palms. On the other hand, the UV-Vis and FTIR data suggested lower humification degree in the underlying peat which may have led to inconsistent growth. Meanwhile, the oil palm result shown the forest was more humified than the oil palm estate with significantly higher in conductivity (451.87 μScm^{-1}) ($p<0.05$). The leaching of K (0.21-0.50 $cmolc.kg^{-1}$) and Ca (0.55-1.119 $cmolc.kg^{-1}$) ($p<0.05$) at the oil palm estate indicated the estate has lower nutrient, the lower C/N (21.43%) ($p>0.05$) in forest revealed a higher degree of humification, the higher N-enrich litter falls led to higher nitrogen fixation in the forest. Besides, the FTIR spectra suggested the forest is more humified than the oil palm estate and the forest is significantly has lower carbon dioxide flux (1.04 kg CO_2 m^{-2} yr^{-1}) than oil palm estate (1.16 kg CO_2 m^{-2} yr^{-1}). However, the Pearson correlation shown a weak liner regression between the degree of humification and carbon dioxide flux, R^2=0.1516 in oil palm and R^2= 0.0005 for forest. The correlation coefficient (r) for oil palm and forest is 0.389 and 0.023 ($p>0.05$). The carbon dioxide was not influence by the degree of humification nevertheless the higher air (27.2-33.3 °C) and soil temperature (27.0-28.4 °C) ($p<0.05$) at oil palm estate might be the factor for the higher carbon dioxide flux.

Keywords: Decomposition**,** carbon dioxide flux, soil degradation, histosol, soil fertility, productivity yield, Sarawak.

Klasifikasi Darjah Humifikasi Tanah Gambut di bawah Penanaman Sagu dan Ladang Kelapa Sawit

ABSTRAK

Pokok sagu atau rumbia (Metroxylon sagu) *dan pokok kelapa sawit* (Elaeis guineensis) *adalah tanaman tropika yang boleh beradaptasi pada keadaan tanah gambut yang berasid, di mana ia ditanam secara berskala besar di Sarawak (Malaysia). Persoalannya, adakah penanaman secara berskala besar di tanah gambut ini mampan kerana cabarannya dalam pengeluaran hasil tanaman. Pengeluaran hasil pokok sagu dan kelapa sawit ditanah gambut dalam adalah tidak konsisten, dan tidak semua anak pokok tumbuh hingga matang dan mengeluarkan hasil. Sementara itu, hasil pengeluaran kelapa sawit dan pokok sagu di tanah mineral jauh lebih tinggi berbanding pada tanaman yang ditanam di tanah gambut dalam. Oleh kerana itu, ia dihipotesiskan bahawa darjah humifikasi tanah gambut dalam mungkin merupakan punca utama kepada prestasi kelapa sawit dan pokok sagu yang perlahan dan sedikit di tanah gambut dalam. Kajian ini bertujuan untuk mengkaji tahap humifikasi pada tanah gambut dalam di ladang kelapa sawit dan pokok sagu. Sampel diambil daripada ladang pokok sagu dan kelapa sawit. Sifat fizikal dan kimia tanah dikaji diantara tempat asal sample diambil dan kedalaman sampel. Manakala, pengiraan pelepasan karbon dioksida hanya dikaji di atas permukaan tanah di ladang kelapa sawit dan hutan simpanan. Hasil kajian menujukan bahawa permukaan tanah di tanah gambut pada pokok sagu dan kelapa sawit mengandungi nutrien yang lebih banyak dan tahap humifikasinya menurun dengan peningkatan kedalaman tanah. Prestasi pembesaran batang pokok sagu yang lebih baik pada plot trunking mungkin disebabkan oleh kekonduksian elektrik (460.00 µScm*$^{-1}$*) ($p<0.05$) yang lebih tinggi dan nisbah C/N yang lebih rendah(47.27%) ($p> 0.05$ pada permukaan tanah berbanding plot bukan trunking, manakala FTIR menunjukkan tanah gambut yang tidak ditanam mempunyai humifikasi yang lebih tinggi berbanding tanah* *gambut yang ditanam kerana tanahnya yang sentiasa dijatuhi dengan daun palma yang baru. Namun, data spektroskopi FTIR menunjukkan tidak terdapat perbezaan yang signifikan diantara bukan trunking dan trunking. Sebaliknya, data UV-Vis dan FTIR menunjukkan darjah humifikasi yang lebih rendah di bawah permukaan tanah gambut menyebabkan pertumbuhan pokok yang tidak konsisten. Hasil kajian pada ladang kelapa sawit menunjukkan tahap humifikasi di hutan adalah lebih tinggi berbanding ladang kelapa sawit dengan kekonduksian elektrik yang lebih tinggi (451.87 µScm*$^{-1}$*) (*$p<0.05$*). Sementara itu, pelepasan K (0.21-0.50 cmolc.kg*$^{-1}$*) dan Ca (0.55-1.119 cmolc.kg*$^{-1}$*) (*$p<0.05$*) di estet kelapa sawit menunjukkan ladang mempunyai nutrien yang lebih rendah dan C/N yang lebih rendah (21.43%) (*$p>0.05$*) pada hutan menunjukkan tahap humifikasi yang tinggi. Kandungan serap N di dedaun pokok menyebabkan penebalan nitrogen di dalam hutan. Selain itu, spektrum FTIR juga menunjukkan hutan mempunyai darjah humifikasi yang tinggi berbanding ladang kelapa sawit dan hutan secara signifikannya mempunyai fluks karbon dioksida yang lebih rendah (1.04 kg* CO_2 m^{-2} yr^{-1}*) berbanding ladang kelapa sawit (1.16 kg* CO_2 m^{-2} yr^{-1}*). Korelasi Pearson menunjukkan regresi liner yang lemah di antara darjah humifikasi dan fluks karbon dioksida,* $R^2 = 0.1516$ *untuk kelapa sawit dan* $R^2 = 0.0005$ *pada hutan. Koefisien korelasi (r) untuk ladang kelapa sawit dan hutan adalah 0.389 dan 0.023 (*$p> 0.05$*). Ini kerana, karbon dioksida tidak dipengaruhi oleh darjah humifikasi tetapi suhu udara (27.2-33.3 °C) dan tanah (27.0-28.4 °C) (*$p<0.05$*) merupakan faktor fluks karbon dioksida yang lebih tinggi pada ladang kelapa sawit.*

Kata kunci: *Penguraian, karbon dioksida fluks, degradasi tanah, histosol, kesuburan tanah, hasil pengeluaran, Sarawak.*

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LIST OF ABBREVIATIONS

ATR	Attenuated Total Reflectance
ANOVA	Analysis of Variance
C	Carbon
Ca	Calcium
CEC	Cation exchange capacity
C-H	Carbon hydrogen bond
cm	Centimeter
Cmolc Kg^{-1}	Centimoles per kg
CO_2	Carbon dioxide gas
C-O	Carbon oxygen bond
C=O	Carbonyl group
COOH	Carboxylic acid
C/N	Carbon over Nitrogen ratio
DOA	Department of Agriculture
Df	Degree of freedom
EGM	Environmental gas monitor
FA	Fulvic acid
FAO	Food and Agriculture Organization of United Nations
FTIR	Fourier-transform infra-red
g/cc	Gram per cubic
g	Gram
Gt	Gigatonnes
HA	Humic acid

Ha	Hectare
HCl	Hydrochloric acid
h	Hour
H^+	Hydrogen ion
HS	Humic substances
K	Potassium
Kg	Kilogram
M	Meter
Mg	Magnesium
Mm	Millimeter
Mha	Milionhectra
µm	Micrometer
µs	Microsiemens
Mmhos	Millimhos
N	Nitrogen
Na	Sodium
NaCl	Sodium chloride
NH_4^+	ammonium
NaOH	Sodium hydroxide
$Na_4P_2O_7$	Tetrasodium pyrophosphate
$C_2H_7NO_2$	Ammonium acetate
O	Oxygen
OH	Hydroxyl group
PVC	Polyvinyl chloride
SD	Standard deviation

T-C	Total carbon
T-N	Total nitrogen
UV-Vis	Ultra-violet visible spectrophotometry

CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

2.1 Introduction

Peat is soil consists of partially decomposed biomass that develops in wet coastal areas where the rate of biomass production is greater than the rate of decomposition. This is due to the presence of a consistently high-water table that prevents aerobic decomposition of plant debris (Laiho, 2006). Typically, peat soil contains 65% of organic matter within at least 50 cm depth (Melling et al., 2007). Tropical lowland peat is acidic with pH 3-4 and ash content less than 2%. Tropical peat soil is commonly classified into hydric tropohemists, dysic, isohyperthermic although troposaprists and tropofibrists can also be found (Paramananthan, 2014). It is generally heterogeneous as it contains admixtures of fine and fibrous materials as well as woody fragments which develop through time from the residues of trees and shrubs that occupy the forest floor of the swamp (Melling et al., 2007).

The peat in Sarawak occurs in large basin and in small interior valleys that is developed in comparatively recent time (Zulkifley et al., 2014). The large basin swamps are generally dome-shaped. The organic soil deposits occupying the central portion of the dome is generally known as ‘ombrogenous peat’. It comprises mainly of disaggregated tree trunks, branches, leaves, roots and fruits (Murtedza et al., 2002). The peatland represents an important long-term sink of atmospheric C (450 Gigatonne (Gt) of Carbon (C)) that constitutes of brown to black organic materials, forming under waterlogged condition from the partial decomposition of plant litter (Yu, 2011).

Peat swamp forest plays a crucial role in maintaining the regional ecosystem balance and to support social and economic system. Hydrological functions are especially important at the local scale. Peat acts as a sponge that absorbs water during wet periods and releases it slowly during dry periods. Thus, peatland plays a role in preventing loss of life, controlling flood and maintaining minimal flows in rivers over dry season to support irrigation works and to prevent saline intrusion (United Nations Development Programme, 2006). However, due to increasing population and the need to eliminate rural deficiency, vast area of peatland, particularly in Indonesia and Malaysia, have been logged and cleared for pulp, sago and oil palm plantation over the last twenty years (Paramananthan, 2014).

Sarawak has the largest reserve of peatland in Malaysia, there are about 1.6 million hectare (ha) of peatland in Sarawak (Naim et al., 2016). This accounts for 66% of the peatland in Malaysia. Most of the peatland in Sarawak has been cleared for agriculture development of which 27.5% is used for oil palm (*Elaeis guineensis*) (Wong, 2016) and 7.6% for sago palm (*Metroxylon Sagu*) (Yamamoto et al., 2003). Sago and oil palm are two crops that can thrive in the harsh swampy environment; they have been exploited as valuable sources for economies in Sarawak to support the demands in market (Jamaludin, 2002).

The next question to consider is whether this large-scale development on peat soil is sustainable. As reported in the literature, one of the challenges of oil palm and sago palm plantation is their production yield on deep peat soil. Generally, these palms grow slower compare to those planted on mineral soil and shallow peat soil (Veloo et al., 2015b). In the experience of sago plantation where the trunk is harvested as the end product, the palms cannot produce a trunk even after 10 years of cultivation (Sim et al., 2005). According to Yamamoto et al. (2014), the time taken for harvesting was longer in the sago palms cultivated on deep peat soils compare to those cultivated on mineral soil. Jong et al., (2006) compare the growth performance of sago palm cultivated on deep and shallow peat. It was reported that only 20% of sago palm produce trunk in deep peat while on the shallow peat they grew better with more than 80% trunking in 5-6 years and reaching maturity in ten years.

As reported by Kakuda et al. (2000), the poor growth of sago palms cultivated on deep peat is associated with the lower mineralization of nitrogen per unit volume. The insufficient nutrient in the deep peat is the cause to the slower and poorer growth (Sim et al., 2005). Likewise, the yield potential of oil palm planted on peatland has also been a divisive subject. The low yield of fresh fruit bunch in deep peat soil is found to associate with the presence of undecomposed wood in the peat profile which contributes to poor rooting and nutrient uptake, causing pre-mature dehydration of the fronds (Veelo et al., 2015b).

Commonly, the poor growth performance of sago palm and oil palm on deep peat were associated with the soil characteristics. According to Melling (2000), the degree of humification is a very important factor to consider when developing peat for agriculture as it has profound effects on the bulk density, moisture holding capacity and nutrient availability. During the decomposition process, a stabilized organic material consisting of hydrophobic and hydrophilic functional groups, referred to as humic materials, is formed (Semenov et al., 2013). The humified materials serve to agglutinate soil (Totsche et al., 2018), improving aeration and water retention capacity which ultimately lead to increased crop production (Piccolo, 2002). A more humified soil is often characterized by higher nitrogen (N) content which is indicated with a lower C/N ratio (Xu & Saiers, 2010). Venegas-Gonzàlez et al. (2013) further states that the growth of blackberry in compost with increased degree of humification has resulted in enhanced nutrient uptake. For these reasons, it is hypothesized that the extent of humification may have been the root cause to the slower and poorer performance of oil palm and sago palm on deep peat.

Although Veloo et al. (2015b) has identified humification degree as the cause to the poor growth performance of oil palm, the study thorough profile of humification degree at both sago and oil palm plantation is still limited. The inconsistent growth of sago palm on deep peat is yet to be explained and the humification profile across oil palm plantation has not been studied. Hence, this study is set out to investigate humification degree of peat soil under oil palm and sago palm plantations to provide a deeper insight.

2.2 Objectives

The specific objectives of the study are to characterise the humification degree of peat soil under:

i. sago plantation against the uncultivated peat;

ii. oil palm plantation against the forest peat.

2.3 Distribution of peat soil in Malaysia

Malaysia has approximately 2.6 million hectare (Mha) of peatland, of which 1.6 Mha are found in Sarawak (Wong, 2016). They represent 66% of the total peatland in Malaysia. Figure 1.1 illustrates the distribution of peatland in Malaysia and Table 1.1 summaries the area of peatland according to states. In Sarawak, peat occurs mainly between the lower stretches of the main river courses (basin peat) and in poorly drained interior valleys (valley peats). They are mainly found in Kuching, Samarahan, Sri Aman, Sibu, Sarikei, Bintulu, Miri and Limbang (Zainorabidin & Wijeyesekera, 2007).

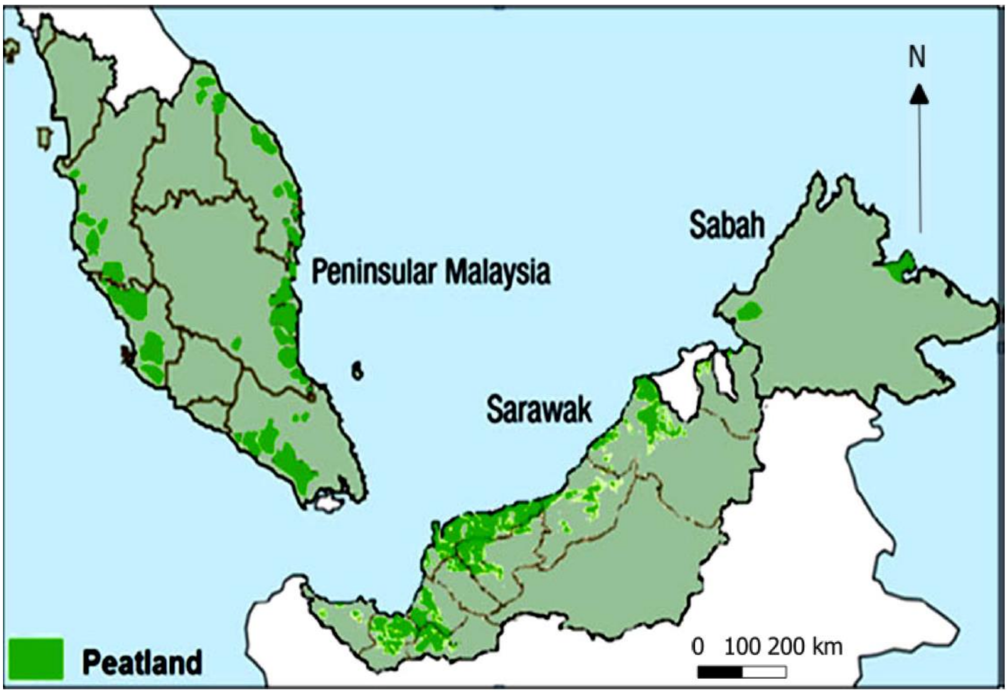

Figure 1.1: Distribution of lowland peatlands in Malaysia (DOA Malaysia, 2002).

Table 1.1: The area of peatland in Malaysia according to states (Zainorabidin & Wijeyesekera, 2007).

State	Area (ha)
Sarawak	1,657,600
Johor	228,960
Pahang	219,561
Selangor	194,300
Perak	107,500
Terengganu	81,245
Sabah	86,000
Kelantan	7,400
Negeri Sembilan	6,300
Total	**2,588,866**

2.4 Formation of tropical peat

Peat is formed under the conditions of constant water logging with abundant organic matter fed from the vegetation of mangroves, grasses, and swampy forest. The saturated and anaerobic conditions greatly reduce the rate of decomposition (Gao et al., 2016). Figure 1.2 shows the formation processes of peat. The large basin swamps in dome shape with organic soil deposited in the central portion is generally known as 'ombrogenous peat'. It is typically found near the river or coastal area. The surrounding fringes of the peat dome is predominated by 'topogenous peat' which comprises mainly of slight to moderately decomposed plant matter and fine clastic sediments (Murtedza et al., 2002).