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Full Length Research Paper

Comparison of selected physical properties of deep peat within different ages of oil palm plantation

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The environment of young and mature oil palm plantation were found to be different due to the size of the oil palms and the depth of water tables applied. The environments in both sites have probably influenced the changes of peat soil physical properties towards the peat land degradation. A study was carried out to compare selected physical properties of deep peat between two different ages of oil palm plantation to determine the changes that occurred after the oil palm plantation has been established. This study was conducted by comparing selected peat soil physical properties of 2 and 10 years old oil palm plantations developed on 3 m depth of peat land which was classified as deep peat. A 300 m^2 experimental plot was designed in both sites. Comparison analysis showed that fiber content, loss on ignition, total porosity, liquid limit, surface soil temperature and bearing capacity were found greater in young oil palm plantation (YOPP) but volumetric water content, bulk density and ash content were found greater in mature oil palm plantation (MOPP). Meanwhile, gravimetric water content, specific gravity and saturated hydraulic conductivity were found statistically similar between the both sites. The soil compaction and the reduction of organic matter content increased the bulk density and reduced the total porosity. Surface soil temperature and bearing capacity were decreased due to the closed condition and high water table, respectively in MOPP, whereas the change in saturated hydraulic conductivity was hardly determined due to the presence of partially decomposed residues in the peat soil of YOPP.

Key words: Deep peat soil physical properties, young and mature oil palm plantation.

INTRODUCTION

Peat is an organic soil formed largely from inhibited decomposition of various plant materials in submerged environment (Spedding, 1988). In the study area, the peat is classified as deep peat due to the peat depth of 3 m (Abdullah et al., 2007). Generally, deep peat has lower fertility and poor anchorage compare to shallow peat due to the lower bulk density and nutrient content. Unlike the deep peat, shallow peat which is less than 2 m depth contains greater amount of mineral matter and better anchorage (Andriesse, 1988).

The major constraints of peat land for oil palm plantation development includes drainage requirement, shallow water table hazard, low soil bearing capacity, low soil fertility and root anchorage problems of top-heavy perennial crops such as oil palm (Jaya, 2002). Even though the peat land is less suitable for oil palm

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cultivation compared to mineral soil, the development is still continued since the shortage of the suitable land to fulfil the increasing demand of crude palm oil. The constraints become more substantial on deep peat as oil palm plantation development on deep peat requires additional works including deep drainage, additional soil compaction and application of mineral fertilizers (Mutert et al., 1999).

Degree of decomposition seems to be a key property of peat soil (Rezanezhad et al., 2010) even though it is not clearly defined and is difficult to quantify. Removal of trees for logging operation possibly increases soil surface temperature once the peat swamp forest has been logged, thereby aerobic decomposition increased and consequently accelerating organic matter decomposition (Satrio et al., 2009). Further development on peat land such as for agricultural and residential inevitably involve drainage and land clearing which will continue to increase peat soil decomposition rate and the degree of decomposition.

The development of peat land into oil palm plantation causes major changes on peat soil physical properties. Drainage, land clearing, fertilizing and cultivating are the most common and important processes that are involved in the development which inevitably affect the peat soil physical properties. Drainage will increase the decomposition rate of peat which can cause reduction of fiber content and increase of bulk density (Othman et al., 2010). Previous study has reported that drainage has increased peat soil bulk density and volumetric water content but gravimetric water content was found not affected (Anshari et al., 2010).

Land clearing by heavy machinery causes soil compaction that generally increases bulk density and bearing capacity as well as reduces total porosity and saturated hydraulic conductivity (Murtedza et al., 2002). Land clearing also reduces inputs of organic content due to removal of plant biomass (Eneji et al., 2003) and rapid microbial decomposition induced by higher surface soil temperature which also will reduce the loss on ignition and increase mineral content due to rapid microbial mineralization activity (Brady and Weil, 2008). After the area has been converted into oil palm plantation, biomass production and organic matter accumulation in the peat soil were fairly stopped due to removal of vegetation during land clearing, in the meantime, the oxidation and decomposition processes continued. Certainly, biomasses produced by oil palms were used to restore organic matter in the peat soil. However, biomass production was slower compared to decomposition rate of organic matter which leads to prolonged reduction of organic matter content in the peat soil (Germer and Sauerborn, 2008).

Fertilization is purposely applied to increase the availability of essential nutrients for palm growth such as nitrogen, phosphorus and potassium as well as other palm nutrients (Mutert et al., 1999). It may provide a good condition for palm growth but not for peat soil, where the increase of mineral matter in the soil will increase the bulk density and specific gravity of the peat soil as well as decrease soil porosity and saturated hydraulic conductivity (Bell, 2000).

The environment of young and mature oil palm plantation are normally different due to the size of the oil palms and depth of water tables applied. In the mature oil palm plantation, the height of oil palm is about 10 m with bigger crown and longer frond. The surface soil temperature is between 25.9 to 27.8°C with water saturation due to high water table (35 to 45 cm depth). In the young oil palm plantation, oil palms are approximately 2.5 m high with the surface of peat soil mostly exposed to the sun heat due to the short frond length and the soil temperature is between 27.2 to 28.6°C with the water table approximately 1 m depth.

The different environment in both sites can influence the changes of peat soil physical properties. Therefore, the objective of this study was to compare selected soil physical properties of 2 and 10 years old of oil palm plantations on a deep peat soil to find out the continuation effect on peat soil physical properties after oil palm plantation has been established.

MATERIALS AND METHODS

The study was conducted in an oil palm plantation with 2 and 10 year old oil palm in Igan, Sarawak, Malaysia. The coordinate of the study area is approximately between 111°35′-111°47′ E and 2°19′-2°24′ N (Figure 1). The study area was a peat swamp forest area that lies on deep peat soil but has been converted into oil palm plantation.

Thirty undisturbed cores and bulk samples were collected randomly using a peat auger at 0-15 cm depth for laboratory analysis of bulk density, water content, fiber content, loss on ignition and ash content, specific gravity, total porosity and liquid limit.

Fiber content of the total mass of organic material was determined by the wet sieving method (Jarret, 1983). A 150 g of fresh peat soil was shaken with the mixture of 200 ml distilled water and 30 ml of 5% sodium hexametaphosphate for 24 h. The sample was then washed through 125 µm sieve and the percentage of oven-dried fibers retained on the sieve were used to classify the decomposition status according to the classification of peat soil according to the fiber content.

Loss on ignition and ash content were determined by incineration after oven-drying at a temperature of ±800°C (Andriesse, 1988). A 5 g of oven-dried sample (oven at 60°C for 24 h) was weighed into porcelain dish, placed in a furnace and heated at 300°C for 1 h before the temperature has been increased to 550°C and left for 8 h. The weight loss represent as loss on ignition while the remaining weight represent as ash content.

Soil bulk density, gravimetric water content, volumetric water content and total porosity were determined using standard procedures (Carter, 1993; Bashour and Sayegh, 2007). The weight of soil core was determined after drying in an oven at 105°C to a constant weight to bulk density determination. The weight loss after drying was represented as gravimetric water content and the value

Figure 1. The study area.

was then converted to a volumetric basis by multiplying with the bulk density.

The volumetric flask method was used to determine the specific gravity of the peat soil (GLOBE, 2002). A 25 g of air dried and sieved peat soil was placed in the weighed flask. 50 ml of distilled water was added before the peat soil-water mixture was gently boiled on a hot plate for 10 m to remove air bubbles. Then, the flask was removed from the heat to be cooled and left for 24 h before it was filled by distilled water until the 250 ml meniscus line and re-weighed.

Total porosity was determined using the value of bulk density and specific gravity of the peat soil by following the equation (Carter, 1993):

Total porosity (%) = (1 – bulk density/specific gravity) x 100

Soil liquid limit was determined using Casagrande's apparatus (Saha, 2004). The cup of the apparatus was filled with peat soils of varying water content and a groove of 12 mm wide was made in the middle of each of the peat soil. Then, the cup was raised and lowered continuously until the two sides of the peat soil of the groove touches each other and the number of blow required for this was recorded. A graph between water content and corresponding number of blow for touching the two sides of the peat soils were plotted. From the graph, the liquid limit was interpolated as the water content at which the number of blow for touching the two sides of the peat soil of the groove is 25.

Saturated hydraulic conductivity was measured in the field using Model 2800K1 Guelph Permeameter based on the constant head well permeameter method (Quinton et al., 2008). The equipment was placed in the hole with the depth of approximately 15 to 30 cm. The water from the equipment flowed into the hole and penetrated the peat soil. The flow of water from the equipment into the peat soil was measured in unit of cm s^{-1} until it reached a constant value.

The surface temperature of the peat soil was measured by thermometric method using in-situ soil thermometer (Saha, 2004). The thermometer probe with the length of 10 cm was directly inserted into the surface peat soil for 2 to 3 min before the reading was recorded.

A hand operated cone penetrometer was used to determine the soil bearing capacity (Brady and Weil, 2008). The penetrometer was pressed into the soil manually and the force required to drive the probe approximately 1 m through the peat soil was recorded in order to determine the bearing capacity. Unit cone tip (q_c) resistance was obtained from the test by following equation:

q_c= Required force to penetrate cone/ Base area of the cone

Bearing capacity of the peat soil was then determined by the following equation:

Bearing capacity (K Pa) = K_b x q_c

Where, K_b = bearing capacity factor for peat soil (0.10)

Random sampling and data collection were done in two experimental plots of 2 year and 10 year old of oil palm plantation with the size of 300 m^2 each. Analysis results of the selected variables of both sites were compared by Independent t-test using Statistical Analysis System Software (9.2) to determine the changes of the variables after the oil palm plantation has been established.

RESULTS

Results in Table 1 showed that some of the variables are statistically different between young and mature oil palm plantations which indicate that the development has changed some of the physical properties of deep peat soil. The mean comparison of the variables showed that fiber content, loss on ignition, total porosity, liquid limit, surface soil temperature and bearing capacity were found significantly higher in the young oil palm plantation. Whereas, volumetric water content, ash content and bulk

Table 1. Annual fertilizer nutrient application for oil palm established on tropical peat soil.

Phase	Kg/ha/year						
	N	P_2O_5	K_2O	MgO	CaO	B_2O_3	$CuSO_4$
Young	50-100	65-80	140-260	-	140-230	6-12	1-2
Mature	120-160	50-70	550-700	0-10	300-400	13-18	3-5

Source: Ng et al. (1990).

Table 2. Mean values of selected deep peat physical properties between young oil palm plantation (YOPP) and mature oil palm plantation (MOPP).

Variables	Mean	
	YOPP	MOPP
Fiber content (%)	33.774[a]	24.97[b]
Gravimetric water content (%)	281.21[a]	275.94[a]
Volumetric water content (%)	49.7[b]	68.983[a]
Loss on ignition (%)	96.23[a]	94.235[b]
Ash content (%)	3.77[b]	5.765[a]
Bulk density (g cm^{-3})	0.182[b]	0.273[a]
Specific gravity (g cm^{-3})	1.317[a]	1.319[a]
Total porosity (%)	86.167[a]	79.324[b]
Liquid limit (%)	203.845[a]	164.21[b]
Surface soil temperature (°C)	27.821[a]	26.442[b]
Saturated hydraulic conductivity (cm s^{-1})	0.024[a]	0.016[a]
Bearing capacity (k Pa)	44.5[a]	31.5[b]

Note: Means with the same letter for each variable are not significantly different at $p \leq 0.05$ using independent t-test.

density were found significantly higher in the mature oil palm plantation (Table 2). Both sites also were statistically similar on gravimetric water content, specific gravity and saturated hydraulic which indicate that the variables were not affected by the development.

DISCUSSION

The decomposition rate of peat soil in the peat swamp forest slightly increased after the logging activity (Satrio et al., 2009). The increase continued after the area had been converted into oil palm plantation. The development in the peat swamp forest involved drainage which has affected the oxidation and microbial decomposition and increased the decomposition rate of peat soils.

Significant lower fiber content in the mature oil palm plantation compared to the young oil palm plantation indicates higher degree of decomposition of peat soil. In the young oil palm plantation, decomposition of peat soil continued after the oil palms had been planted and the decomposition accelerated due to drier and higher temperature of the peat soil surface (Nuri et al., 2011). The continuous decomposition process resulted in a higher degree of decomposition of peat soil in the mature oil palm plantation. In addition, application of mineral fertilizers in the mature oil palm plantation may have contributed to increase the decomposition rate of the peat soil (Sullivan, 2004).

Gravimetric water content between the young and mature oil palm plantation does not show significant difference. The different conditions might have contributed to the similar gravimetric water contents between the two sites. However, comparison of volumetric water content has shown that the variable was higher in the mature oil palm plantation consistent with the higher degree of decomposition of peat soil and lower organic matter content (Andriesse, 1988).

Higher loss on ignition in the young oil palm plantation indicates the higher organic matter content compared to the mature oil palm plantation. In the mature oil palm plantation, the increase rate of fertilizer application with growth of oil palm increased mineral content in the peat soil thus contributed in improvement of aggregation and aeration of the peat soil (Sullivan, 2004) which have increased the decomposition rate and reduced loss on ignition. Moreover, the increase of decomposition rate during the early years of oil palm planting has resulted to lower loss on ignition when the oil palms become mature. In addition, higher biomass production of oil palm in mature oil palm plantation did not contribute much to restore the organic matter in peat soil. The biomass production and the organic matter accumulation rates are slower compared to the decomposition rate of organic matter and this causes a continuous reduction of organic matter content in the peat soil (Germer and Sauerborn, 2008).

Continuous decomposition of peat soil has reduced loss on ignition but in the same time increased ash content in the mature oil palm plantation through continuous mineralization process. In addition, higher rate of mineral fertilizer application during the mature growth phase of oil palms also contributed to increase ash content (Paavilainen and Paivanen, 1995).

Bulk density of peat soil is influenced by the degree of decomposition (Andriesse, 1988). Higher degree of decomposition of peat soil in the mature oil palm plantation indicates lower organic matter content and the soil particles were less likely to be aggregated and bulk density was commonly higher (Brady and Weil, 2008). The higher bulk density also indicates that the peat soil was compact with less total pore spaces hence reduced the soil total porosity (Brady and Weil, 2008). Because of the canopy created by the older oil palm plantation, soil surface temperature was lower in mature oil palm plantation compared to the young oil palm plantation.

Liquid limit of peat soil was found higher in the young oil palm plantation compared to the mature oil palm plantation. Lower degree of decomposition as well as higher loss on ignition and lower ash content in the young oil palm plantation have contributed to the higher value of peat soil liquid limit of the site (Bell, 2000).

Degree of decomposition is an important factor influencing saturated hydraulic conductivity of peat soil. Increase of degree of decomposition has increased the bulk density and reduced the total porosity of peat soil and this indirectly reduced saturated hydraulic conductivity (Bell, 2000). Obviously, saturated hydraulic conductivity of young and mature oil palm plantation were statistically similar even though the two sites showed significant difference in degree of decomposition of peat soil. The presence of partially decomposed residues in the young oil palm plantation influenced the measured values of saturated hydraulic conductivity. Therefore, no significant difference of the variable was found between the two sites.

Bearing capacity is primarily influenced by water content in peat soil (Paavilainen and Paivanen, 1995). High water table in the mature oil palm plantation caused the subsoil to be fairly saturated with water. This saturation decreased the bearing capacity in the mature oil palm plantation and became lower compare to the young oil palm plantation.

Conclusion

Peat soil decomposition was continued after the oil palm plantation has been established. The decomposition process was enhanced by lower water table and higher mineral content in young oil palm plantation. Increased degree of decomposition of peat soil with higher fertilization rate in the mature oil palm plantation caused continuous increase of bulk density and ash content and continuous reduction of fiber content, loss on ignition, total porosity and liquid limit. However, high water table in the mature oil palm plantation has reduced the bearing capacity and restored the water content in the peat soil.

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