International Journal of the Physical Sciences Vol. 6(23), pp. 5462-5466, 9 October, 2011
Available online at http://www.academicjournals.org/IJPS
DOI: 10.5897/IJPS11.598
ISSN 1992 - 1950 ©2011 Academic Journals

Full Length Research Paper

Effect of drainage and land clearing on selected peat soil physical properties of secondary peat swamp forest

Mohd Suffian Firdaus[1], Seca Gandaseca[1]* and Osumanu Haruna Ahmed[2]

[1]Department of Forestry Sciences, Faculty of Agriculture and Food Sciences, Universiti Putra Malaysia Bintulu Sarawak Campus, Malaysia.
[2]Department of Crop Science, Faculty of Agriculture and Food Sciences, University Putra Malaysia Bintulu Campus, Sarawak, 97008 Bintulu, Sarawak, Malaysia.

Accepted 17 August, 2011

A study was carried out to determine the effect of drainage and land clearing on selected peat soil physical properties of secondary peat swamp forest. This study was conducted in a drained secondary peat swamp forest and a cleared site of drained secondary peat swamp forest at Sibu, Sarawak, Malaysia. A 300 m^2 experimental plot was prepared at both sites. Saturated hydraulic conductivity, bearing capacity and surface soil temperature were determined *in-situ*, while fiber content, soil bulk density, gravimetric water content, volumetric water content, loss on ignition, ash content and soil total porosity were determined using standard laboratory procedures. Unpaired t-test was used to compare the variables for the two sites using statistical analysis system software. The percentage of fibre content, volumetric water content and saturated hydraulic conductivity were not significantly different between the two sites. Gravimetric water content, loss on ignition and total porosity were significantly higher in the drained secondary peat swamp forest, while ash content, bulk density, surface soil temperature and bearing capacity were significantly higher in the cleared site of drained secondary peat swamp forest. After clearing the drained secondary peat swamp forest, gravimetric water content, loss on ignition and total porosity continuously decreased while surface soil temperature increased as well as ash content, bulk density and soil bearing capacity. The changes of peat soil physical properties in the drained secondary peat swamp forest after the land clearing are the important indicators that indicate some continuous processes of peat soil degradation after the draining. However, fiber content, volumetric water content and saturated hydraulic conductivity of the drained secondary peat swamp forest were not affected by the land clearing.

Key words: Secondary peat swamp forest, drainage, land clearing, peat soil physical properties.

INTRODUCTION

Peat can be defined as organic matter derived from vegetation and having 25% or less inorganic matter on a dry mass basis (Paavilainen and Paivanen, 1995). Peat soil is composed of partly decomposed biomass and developed in depressions when the rate of biomass production from the adapted vegetation is greater than the rate of decomposition (Ywih et al., 2009).

Peat swamp forest is a waterlogged area formed when rivers drain to the area and begin to develop with peat deposits usually at least 50 cm thick and can extend up to 20 m (Firdaus et al., 2010). In Sarawak, 1.66 million hectares of the state area are covered by peat land (Huat et al., 2011) with about 1.5 million hectares of the area are peat swamp forests (Jaya, 2002). The peat swamp forests have been disturbed by logging activities and turned the virgin forests into secondary peat swamp forests (Butler, 2006).

*Corresponding author. E-mail: secags@yahoo.com. Tel: +6086855473. Fax: +6086855416.

Table 1. Mean values of selected peat soil physical properties between uncleared site (site A) and cleared site (site B) of the drained secondary peat swamp forest.

Variable	Mean	
	Site A	Site B
Fibre content (%)	34.497 ± 2.603^a	34.651 ± 5.587^a
Gravimetric water content (%)	397.623 ± 68.03^a	338.034 ± 75.182^b
Volumetric water content (%)	55.628 ± 9.639^a	53.582 ± 9.577^a
Loss on ignition (%)	96.7 ± 0.367^a	95.187 ± 1.662^b
Ash content (%)	3.3 ± 0.367^b	4.813 ± 1.662^a
Soil bulk density (g cm^{-3})	0.136 ± 0.015^b	0.17 ± 0.034^a
Total porosity (%)	89.671 ± 1.144^a	87.19 ± 2.469^b
Surface soil Temperature (ºC)	27.737 ± 0.25^b	29.807 ± 0.572^a
Saturate hydraulic conductivity (cm s^{-1})	0.034 ± 0.02^a	0.023 ± 0.014^a
Soil bearing capacity (kN m^{-2})	31.667 ± 6.604^b	53.2 ± 9.932^a

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

Some of the peat swamp forests in Sarawak have been logged, drained and cleared for agriculture, settlement, and other human activities although the development on peat soil is mainly restricted by many problems associated with peat's inherent properties (Jaya, 2002). Peat swamp forests in Sarawak are due to decomposition of woods, stumps and logs that have submerged. The ground water table is very high, with low bulk density of about 0.05 g cm^{-3} for fibric peat and high soil total porosity of about 80 to 90% resulting in high soil permeability. The soil organic matter content is high (96%) and low ash content (3.6%) (Hashim and Islam, 2008). The soil temperature is also low which restricts microbial activity and decomposition of organic matter (Saha, 2004). The bearing capacity of the peat soil is low and indirectly linked to the water table of the peat soil. The water content is also high ranging from 200 to 700% (Hashim and Islam, 2008) and the saturated hydraulic conductivity is generally high due to its open structure (Mohamed et al., 2002).

Draining peat swamp forests affects peat soil physical properties as hydrological characteristics of peat soil are largely related to draining and several soil physical properties such as degree of decomposition and soil bulk density (Othman et al., 2010). Once land clearing occurs, soil physical properties are the properties that are immediately affected.

Furthermore, the effects of land clearing on soil physical properties can probably lead to changes on other soil properties such as chemical, carbon storage and biological properties. Knowledge about the physical properties of peat soils affected by land clearing is necessary to develop useful resource management plans for peat land areas. The objective of this study was to determine the effect of drainage and land clearing on selected peat soil physical properties of secondary peat swamp forest.

MATERIALS AND METHODS

The study was conducted in a drained secondary peat swamp forest at Sibu, Sarawak, Malaysia. The study area has been drained in about one and a half years with some of the area been cleared shortly after the water was completely drained.

The experimental plots of the drained secondary peat swamp forest and the cleared site of drained secondary peat swamp forest were 300 m^2 each. In the two sites, thirty random data points were used to measure saturated hydraulic conductivity, soil bearing capacity and surface soil temperature. Thirty undisturbed cores and bulk samples were also collected randomly using a peat auger at 0 to 15 cm depth for laboratory analysis of bulk density, water content, fiber content, loss on ignition, ash content and total porosity.

Fibre content of the total mass of organic material was determined by wet sieving method (Jarret, 1983). The loss on ignition and ash content were determined by incineration after oven-drying at a temperature of ±800ºC (Andriesse, 1988). Soil bulk density, gravimetric water content, volumetric water content and total porosity were determined using standard procedures (Carter, 1993; Bashour and Sayegh, 2007).

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 surface temperature of the peat soil was measured by thermometric method using *in-situ* soil thermometer (Saha, 2004) and a hand operated cone penetrometer was used to determine the soil bearing capacity (Brady and Weil, 2008).

Unpaired t-test was used to compare the selected variables of both sites using statistical analysis system software.

RESULTS

The results in Table 1 show that there were no significant differences in fibre content, volumetric water content and saturated hydraulic conductivity between the drained secondary peat swamp forest and the cleared site.

Percentage gravimetric water content and % total porosity were significantly higher in the drained secondary peat swamp forest compared to the cleared site.

However, ash content, soil bulk density, surface soil temperature and bearing capacity were significantly higher in the cleared site of drained secondary peat swamp forest compared to the uncleared site.

DISCUSSION

Waterlogged conditions of peat swamp forests prevent rapid microbial decomposition of organic material (Yule and Gomez, 2009). The rate of microbial decomposition is generally described by means of fiber content in the peat soil (Paavilainen and Paivanen, 1995). The fibre content (Table 1) indicates that the peat soil is not well decomposed and is classified as intermediate in degree of decomposition (Firdaus et al., 2010). Draining of secondary peat swamp forests leads to aerobic (oxygen-rich) conditions which encourages microbial activities to oxidize and reduce the organic matter in the peat soil (Othman et al., 2010). Even though there is no data on fibre content before the draining, it is believed that draining enhanced decomposition and caused reduction of fibre content in the two sites (Germer and Sauerborn, 2008)

The non significant difference in fibre content between the drained secondary peat swamp forest and the cleared site indicates that land clearing did not affect the rate of decomposition. Supposedly, fibre content in the cleared site of the drained secondary peat swamp forest was expected to be lower than the uncleared site as a result of high decomposition rate due to absence of forest trees, high temperature and dry soil (Nuri et al., 2011). However, the rate of decomposition may have been reduced because of poor aeration in the peat soil caused by soil compaction during land clearing.

Generally, draining reduces soil gravimetric water content (Mc Lay et al., 1992). Previous studies have shown that peat soil can contain as high as 700% of water (Hashim and Islam, 2008). This indicates that the percentage soil gravimetric water content at the two sites may have been decreased after the draining.

The cleared site of the drained secondary peat swamp forest showed lower percentage of soil gravimetric water content due to water evaporation from the surface and lower soil organic matter content (Firdaus et al., 2010). Removal of vegetation and soil compaction due to land clearing increase surface runoff and reduces water retention (Moduying et al., 2000). In addition, direct heat from sunlight may be partly responsible for the reduction of the gravimetric water content in the surface soil. The closed condition and high humidity as well as higher percentage of soil organic matter in the drained secondary peat swamp forest (Firdaus et al., 2010) enabled more water retention.

Water content on volumetric basis showed no significant difference between the two sites. Previous studies reported that drainage increased volumetric water content in peat soil and continued to increase after logging and cultivation (Anshari et al., 2010). However, the volumetric water content appeared to increase as the degree of decomposition increased (Andriesse, 1988). Based on the results of fibre content, degree of decomposition seemed to be the same between the two sites which could be the reason for no significant difference in volumetric water content for the drained secondary peat swamp forest and the cleared site.

The loss on ignition can represent the amount of organic matter content in the peat soil (Anshari et al., 2010). The loss on ignition of peat soil in peat swamp forest decreased due to logging operations (Satrio et al., 2009), but it increased with time post logging. After draining the secondary peat swamp forest, the loss on ignition reduced because of increase of decomposition rate. The draining improves soil aeration and reduces the loss on ignition by encouraging microbial decomposition of soil organic matter (Firdaus et al., 2010). Vegetation also usually influences soil organic matter content (Brady and Weil, 2008). The greater biomass productivity engendered by high humidity in the drained secondary peat swamp forest led to greater addition to the pool of soil organic matter and thereby increased the loss on ignition.

Ash content can represent the amount of mineral matter in the peat soil (Andriesse, 1988). High percentage of the loss on ignition indicates low ash content in peat swamp forest (Satrio et al., 2009). Ash content in peat soil can be as low as 2% or may be as high as 50% (Bell, 2007). The lower ash content in the drained secondary peat swamp forest was due to the significantly higher percentage of the loss on ignition. The higher rate of decomposition in the cleared site of the drained secondary peat swamp forest encouraged mineralization of organic nitrogen in the soil organic matter and thereby increased the ash content (Brady and Weil, 2008).

Logging operation increased soil bulk density in the peat swamp forest (Satrio et al., 2009) but decreased with time after logging due to greater reproduction of organic matter than the rate of decomposition in the secondary peat swamp forest. However, draining in the secondary peat swamp forest increased the soil bulk density due to increase in decomposition rate (Rattan, 2005). It has been reported that peat soil material which is classified intermediate in degree of decomposition is commonly characterised with bulk densities ranging between of 0.07 and 0.18 g cm^{-3} (Andriesse, 1988). The 0.15 g cm^{-3} bulk density of the peat swamp forest before disturbance (Satrio et al., 2009) indicates that the soil material was intermediate in degree of decomposition even after draining and land clearing. Land clearing inevitably increased the soil bulk density due to usage of heavy machinery and this might have caused soil compaction. Furthermore, the reduction of soil organic matter at the cleared site of the drained secondary peat swamp forest also contributed to the increase in soil bulk density (Brady and Weil, 2008).

Soil bulk density and soil organic matter content influence peat soil total porosity (Brady and Weil, 2008). The logging might have reduced the percentage soil total porosity due to increase of soil bulk density and reduction of organic matter (Satrio et al., 2009). However, the waterlogged conditions allowed re-accumulation of organic matter to improve soil aggregation and thereby increased the soil total porosity in the secondary peat swamp forest.

After draining, the increase of soil bulk density might have reduced the soil total porosity in the drained secondary peat swamp forest. However, results show that % soil total porosity (Table 1) ranged from 80 to 90% for undisturbed peat swamp forest. Nevertheless, land clearing reduced the soil total porosity as a result of increase in soil bulk density due to the use of heavy machinery.

Moreover, land clearing reduces soil organic matter content and contributes to the reduction of soil total porosity (Saha, 2004).

The surface temperature of the drained secondary peat swamp forest might have decreased after draining because of reduction in the peat water content and changes in peat structure as well as vegetation (Byrne and Farrel, 2005).

However, after the drained secondary peat swamp forest had been cleared, the surface temperature increased. Direct sunlight exposure might have caused an increase in the surface temperature of the peat soil after land clearing (Eelaart, 2010).

Bearing capacity of peat soil is affected by the water table and the presence of woody debris in the soil (Kazemian et al., 2011). Draining secondary peat swamp forest reduces the water table which causes the quantity of water stored in the peat soil to reduce and an increase in soil bearing capacity (Paavilainen and Paivanen, 1995). After land clearing, the peat soil was compacted through heavy machinery use which leads to an increase in soil bearing capacity (Mohamed et al., 2002).

The saturated hydraulic conductivity of undisturbed peat swamp forest can range from 4×10^{-2} to 9×10^{-8} cm s^{-1} (Paavilainen and Paivanen, 1995). Previous studies showed that draining in peat swamp forest can reduce saturated hydraulic conductivity (Gandaseca et al., 2009). However, the results in Table 1 show that the saturated hydraulic conductivity of drained secondary peat swamp forest and the cleared site were not significantly different and the values were similar to the range of values for undisturbed peat swamp forest. Saturated hydraulic conductivity of the study area was not affected by the draining and land clearing which could be due to generally higher saturated hydraulic conductivity of the woody peat of the study area (Paavilainen and Paivanen, 1995).

Conclusion

Conversion of peat swamp forest to secondary peat swamp forest through logging operations changed the loss on ignition and bulk density of the peat soil. Draining reduced gravimetric water content, loss on ignition, total porosity and surface soil temperature but increased ash content, soil bulk density, soil bearing capacity and saturated hydraulic conductivity of peat soil in the drained secondary peat swamp forest. Land clearing reduced gravimetric water content, loss on ignition and total porosity, but it increased ash content, soil bulk density, surface soil temperature and soil bearing capacity of peat soil. However, fibre content, volumetric water content and saturated hydraulic conductivity were not affected by the land clearing.

The changes of peat soil physical properties in the drained secondary peat swamp forest due to the land clearing are the important indicators that indicate some continuous processes of peat soil degradation after the draining. The impact of peat land development towards peat soil degradation should be fully considered. Therefore, peat land development should be based on a clear management policy to minimize the impact and sustain the peat resources as much as possible.

ACKNOWLEDGEMENTS

Funding for this research was provided by the Ministry of Higher Education Malaysia. The authors also thank Forest Department of Sarawak, Sarawak Forestry Corporation and New Time Resources Sdn. Bhd. for their cooperation during the research.

REFERENCES

Andriesse JP (1988). Nature and Management of Tropical Peat Soils. 1st ed. FAO, Rome.

Anshari GZ, Afifudin M, Nuriman M, Gusmayanti E, Arianie L, Susana R, Nusantara RW, Sugardjito J, Rafiastanto A (2010). Drainage and land use impacts on changes in selected peat properties and peat degradation in West Kalimantan Province, Indonesia. Biogeosciences, 7: 3403-3419.

Bashour II, Sayegh AH (2007). Methods of Analysis for Soils of Arid and Semi-Arid Regions. 1st ed. FAO, USA.

Bell FG (2007). Engineering Geology. 2nd ed. Butterworth-Heinemann, USA.

Brady NC, Weil RR (2008). The Nature and Properties of Soils. 14th ed. Prentice Hall, USA.

Butler RA (2006). A place out of time: Tropical rainforests and the perils they face. Mongabay.com. http://rainforests.mongabay.com/0305.htm.

Byrne KA, Farrel EP (2005). The effect of afforestation on soil carbon dioxide emissions in blanket peatland in Ireland Forestry. Forestry, 78(3): 217-227.

Carter MR (1993). Soil Sampling and Methods of Analysis. 1st ed. Lewis Publishing, England.

Eelaart AVD (2010). Swamp development in Indonesia. http://www.eelaart.com/index.htm.

Firdaus MS, Gandaseca S, Ahmed OH, Majid NMA (2010). Effect of converting secondary tropical peat swamp forest into oil palm plantation on selected peat soil physical properties. Am. J. Environ. Sci., 6: 402-405.

Gandaseca S, Sabang J, Ahmed OH, Majid NMA (2009). Vegetation assessment of peat swamp forest using remote sensing. Am. J. Agric. Biol. Sci., 4: 167-172.

Germer J, Sauerborn J (2008). Estimation of the impact of oil palm plantation establishment on greenhouse gas balance. Springer Netherlands, 10: 697-716.

Hashim R, Islam MS (2008). A model study to determine engineering properties of peat soil and effect on strength after stabilisation. Euro. J. Sci. Res., 22(2): 205-215.

Huat BBK, Kazemian S, Prasad A, Barghchi M (2011). State of an art review of peat: General perspective. Int. J. Phys. Sci., 6(8): 1988-1996.

Jarret PM (1983). Testing of Peats and Organic Soil-STP 820. 1st ed. ASTM International, USA.

Jaya J (2002). Sarawak: Peat agricultural use. MARDI, Malaysia. http://www.strapeat.alterra.nl/.../15%20Sarawak%20peat%20agricultural%20use.pdf

Kazemian S, Huat BBK, Prasad A, Barghchi M (2011). A state of art review of peat: Geotechnical engineering perspective. Int. J. Phys. Sci., 6(8): 1974-1981.

Moduying V, Yangkat Y, Laugesen CH, Greer T (2000). Environment Impact Assessment (EIA) Guidelines Oil Palm Plantation Development. State Environmental Conservation Department (ECD) Sabah, Malaysia.

Mc Lay CDA, Allbrook RF, Thompson K (1992). Effect of development and cultivation on physical properties of peat soils in New Zealand. Geoderma, 54: 23-37.

Mohamed M, Padmanabhan E, and Mei BLH (2002). The peat soils of Sarawak. STRAPEAT. http://www.strapeat.alterra.nl/download/12%20peat%20soils%20of%20Sarawak.pdf.

Nuri ASM, Gandaseca S, Ahmed OH, Majid NMA (2011). Effect of tropical peat swamp forest clearing on soil carbon storage. Am. J. Agric. Biol. Sci., 6: 80-83.

Othman H, Mohammed AT, Harun MH, Darus FM, Mos H (2010). Best Management Practices for Oil Palm Planting on Peat: Optimum Groundwater Table. MPOB Information Series.

Paavilainen E, Paivanen J (1995). Peatland Forestry: Ecology and Principles. 1st ed. Springer-Verlag, Berlin.

Quinton WL, Hayashi M, Carey SK (2008). Peat hydraulic conductivity in cold regions and its relation to pore size and geometry. Hydrol. Process, 22: 2829 2837.

Rattan L (2005). Encyclopedia of Soil Science. 1st ed. CRC Press,n USA.

Saha, AK (2004). Text book of soil physics. 1st ed. Kalyani Publisher, India.

Satrio AE, Gandaseca S, Ahmed OH, Majid NMA (2009). Effect of logging operation on soil carbon storage of a tropical peat swamp forest. Am. J. Environ. Sci., 5: 748-752.

Yule CM, Gomez LN (2009). Leaf litter decomposition in a tropical peat swamp forest in peninsular Malaysia. Wetlands Ecol. Manage., 17: 231-241.

Ywih CH, Ahmed OH, Majid NMA, Jalloh MB (2009). Effect of converting secondary forest on tropical peat soil to oil palm plantation on carbon storage. Am. J. Agric. Biol. Sci., 4: 123-130.