INFLUENCE OF OIL PALM PLANTATION AGE AND HYDROLOGY ON DISSOLVED ORGANIC CARBON CONCENTRATION OF MALAYSIAN TROPICAL PEATLAND WATER RESOURCES

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Abstract

Due to boom recorded globally in oil palm industries, many palm oil producing countries like Malaysia and Indonesia converted the sizeable parts of their carbon-rich previously stable peat swamp forests to oil palm plantation. This conversion resulted in huge loss of the soil carbon in dissolved and gaseous forms to atmospheric body and nearby streams. This paper thus focuses on assessing the influence of oil palm plantation age and hydrological factors on dissolved organic carbon concentration in the tropical peatlands. Four different plantations were considered with different years of peat swamp forest conversion ranging from 2000, 2002, 2006 and 2010. The plantation tagged 2010 was first cleared in 1978 and hereby referred to as 2010/1978 in this study. Two tube wells were installed in each of the plantations for monitoring DOC concentration of groundwater between September 2013 and December, 2014. The results showed positive influence of heavy storm events on DOC concentrations and that the lowest DOC concentration ranging from 18.10 mg/L to 28.60mg/L was observed at 2010/1978 plantation as against the highest DOC concentration of range 169.2 mg/L to 250.50 mg/L at 2000 plantation. The results therefore justify the influence of age of plantation as 1978/2010 plantation recorded the lowest DOC concentration as against the 2000 plantation recording the highest DOC concentration. It is thus recommended that oil palm cultivation on peatlands should be avoided as this practice, if not well-managed, leads to flux and emission of stored soil carbon in both dissolved and gaseous forms to the surrounding water resources and atmospheric body.

INTRODUCTION

Malaysia is ranked as the second largest producers of palm oil globally after Indonesia. As a result of the boom recorded globally in the oil palm industries, Malaysia and Indonesia converted the sizeable parts of their carbon-rich previously stable peat swamp forests (PSFs) to oil palm plantation. This conversion resulted in a huge loss of soil carbon in dissolved and gaseous forms to atmospheric body and nearby streams. Major parts of the loss were in form of dissolved organic carbon (DOC) to the nearby streams and groundwater body (Kura et al. 2013; Adesiji et al. 2014; Prasanna et al. 2014). Starting from 1978, many of the PSFs have been converted to oil palm plantations in stages (Adesiji et al. 2014) and this has subsequently influenced the rate at which DOC is being exported and polluting to the peatland water resources (Wosten et al. 2008).

Dissolved organic carbon (DOC) has been described by Moore *et al.* (1998) as a complex collection of organic carbon molecules produced as a result of plant decay. According to van Hees *et al.* (2005), DOC has been reported to be biogeochemically important pool of total carbon which is stocked in peatlands in large quantity. With this link between plant decay and DOC production, there is therefore strong link between soil organic carbon, SOC and DOC. Thus, the amount of SOC is known to be influenced by the rate of microbial activity in the soil which enhances the plant decay and hence DOC production (Hope *et al.* 1997). Therefore, it is reasonable enough to assume that DOC is sensitive to changes in climate, most importantly temperature and rainfall patterns. DOC has also been described as an important component of soil and aquatic environment. The flux of DOC into streams lowers its DO levels which affect the quality of aquatic life (Mcmahon and Chapelle 2008) and damage the structure and functions of aquatic ecosystems by influencing water chemistry (Liu *et al*. 2014). The loss of DOC from peatland to the nearby streams is characterized by brown colour exhibited by the streams which, according to Wallage and Holden (2010), is sometimes used as surrogate measure of DOC concentration in streams. DOC is said to leach from upper organic soil layers to mineral soil layers from where it is absorbed into the receiving streams, lakes, or rivers (Schwesig *et al.* 2003).

Various studies have reported the DOC loss from peatlands and have attributed this loss to various factors. According to Adesiji et al. (2014), many of the PSFs have lost their soil carbon to intensive peatland agriculture which resulted in huge loss of major nutrients stocked within the peatlands. Also peat subsidence which also as a result of peatland oxidation and irreversible drying has also been as a result of soil carbon loss due to PSFs conversion (Couwenberg, 2010). DOC loss in tropical peatland has also been attributed to some hydrological factors like rainfall and temperature. According to Hope *et al.* (1994), DOC loss from the peats is due to microbial synthesis of carbon, root exudation, leaching during rainfall events and as a result of erosion of soil organic matter. Buffam *et al.* (2001) and Inamdar *et al.* (2006) reported the occurrence of large annual DOC export during short-duration but high-intensity storm events. Michalzik, *et al.* (2001) and Neff and Asner, (2001) also reported that soil temperature, soil moisture, nitrogen (N) availability, iron, Fe, soil pH, C:N ratio and the amount of organic matter have been discovered to control the dynamics of DOC in forest soils. Peichl, *et al.* (2007); Dalva and Moore, (1991) and Kalbitz, *et al.* (2000) have also suggested soil temperature to have huge influence on the productions and concentration of DOC. According to Peichl, *et al.* (2007), the dependence of DOC concentration on soil temperature is pronounced on forest floor. Guggenberger, *et al.*

(1998) and Michalzik and Matzer, (1999) also corroborated that there is a strong correlation between soil temperature and DOC production in forest floor. Soil moisture content and DOC concentration have also been found to correlate.

Thus in this study, it is hypothesized that PSFs conversion for agricultural activities and land use change and by extension plantation age greatly influence the concentration of the DOC in peatland streams and groundwater body. In addition, it is hypothesized that hydrological factors have considerable effects on DOC concentration in peatland streams. To test these hypotheses, a periodic check on water chemistry of peatlands covering some selected sampling areas was undertaken. The check which involved some physical properties of the peatland groundwater with DOC was undertaken for the period of twenty-one 21 months covering precisely March, 2013 and December, 2014.

MATERIALS AND METHODS

Study area and site description

The study area is located in Sepang, in the state of Selangor, Malaysia within the Kuala Langat South Forest Reserve area, bounded to the West by Straits of Malacca (Figure 1), sharing the same boundary with the Malaysian Kuala Lumpur International Airport to the east between latitude 02° 43'N and longitude 101° 39'E (Figure 1). According to Cheng, (2011), Kuala Langat South peat swamp forest was first gazetted as a forest reserve in the year 1927. The study area experience tropical climate and high humidity with an annual rainfall between 2500 – 3000 mm. The average monthly air temperature ranges between 26.1°C and 27.2°C, with the highest value recorded in May each year.

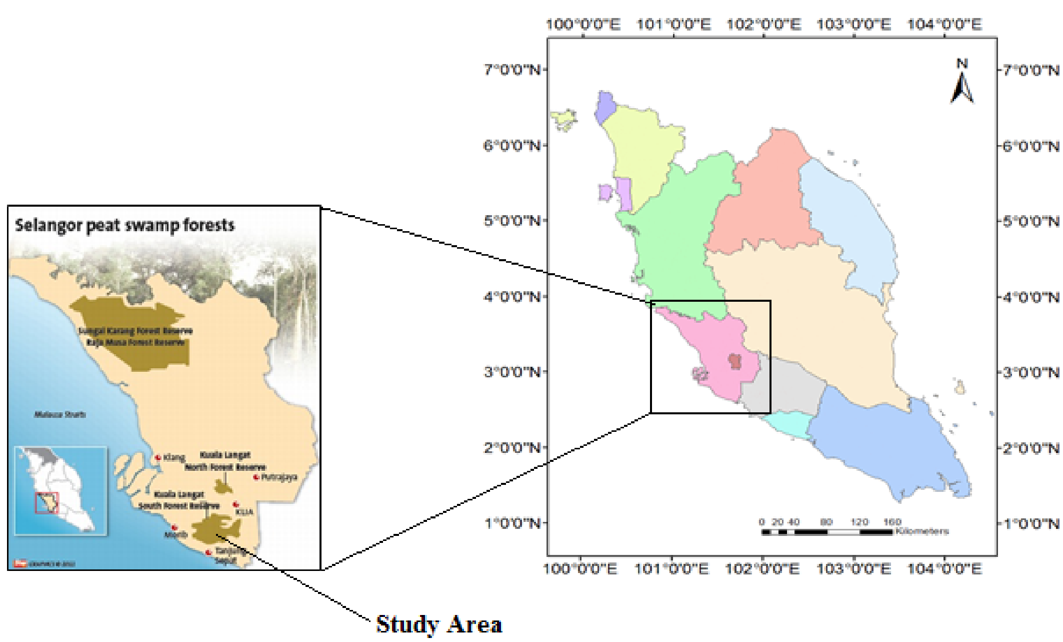

Figure 1: Location of study area

Data collection

The study ran for a period of 14 months from September, 2013 to December, 2014 with both months inclusive. The sampling was characterized by 2-monthly data collection from all the sampling points.

Site selection

The study area was divided into four plots according to the years the PSFs were converted to oil palm plantations. The years of conversion are; 2000, 2002, 2006 and 2010/1978. 2010/1978 represents the first ever conversion of PSFs in 1978 which was later re-cultivated in 2010. The plots were further divided into 10 different sampling points; 2000-A1, 2000-A2, 2000-B1, 2000-B2, 2002-1, 2002-2, 2006-1, 2006-2, 2010-A1, and 2010-A2 which were chosen to fully cover the entire study area.

Water samples collection

Groundwater and surface water samples were both collected for analysis. Two observation wells were installed in each of all the study areas for groundwater sampling (Red circles in Figure 2). For groundwater sampling, water samples were collected from the observation wells in all the sampling points for analysis. Groundwater samples were collected with the aid of improvised bailers before being stored in well-labeled containers and kept in the ice packs and transported to laboratory for analysis. The groundwater *in-situ* data such as dissolved oxygen, DO, temperature, turbidity, groundwater pH, and hydraulic conductivity were analyzed directly in the tube wells by gently raising and lowering an *YSI* multi-probe (556 MPS, YSI Incorporated, Yellow Springs, Ohio) into the tube wells.

For surface water sampling, samples were collected from the site drains that were located adjacent to the study plots that majorly drain the peatlands for the purpose of controlling the peatland water table (Yellow circles in Figure 2). Similar to the groundwater sample collection, surface water samples were collected with the aid of bailers. The *in-situ* data as analyzed in the groundwater were also analyzed and the remaining samples stored in well-labeled containers, kept in the ice packs before transporting them to laboratory for further analysis.

Both the groundwater and surface water collected samples were filtered in the laboratory using 0.45 µm Whatman filter paper and stored at $4^{o}C$ until the analysis which was shortly after. Both samples were analyzed for DOC using S::CAN spectrolyser (Avagyan et al. 2014). A S::CAN Spectrolyser measures optical spectra from 200 to 750 nm directly in liquid media. A S::CAN Spectrolyser was rinsed with distilled water before and after each measurement was taken. The readings were displayed on the PC that was connected with spectrolyser.

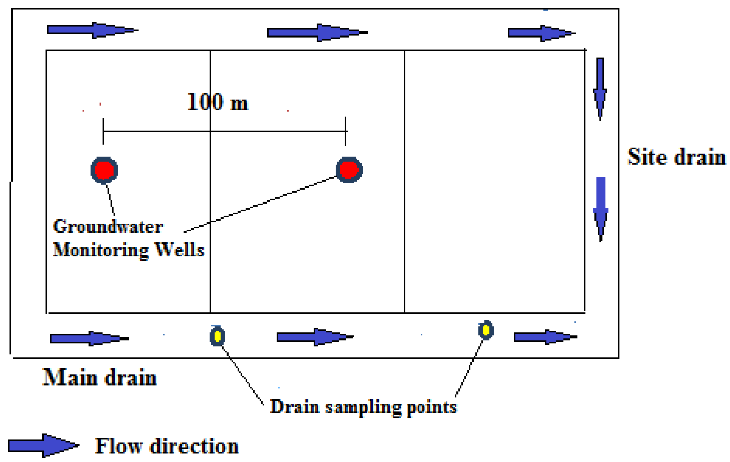

Figure 2. A typical study plot in a peatland. 2 Tube Wells in each Block and 2 Samplings at Ditch as Represented.

RESULTS

Statistical analysis

The statistical analysis gave a negative and weak correlation between DOC concentration and age of plantation. This means the oldest plantation recorded the lowest DOC concentration, though with weak correlation. DOC showed positive and strong correlation with rainfall in 80 % of the sampling points with negative but strong correlations with soil temperature (Kalbitz, *et al.* 2000). DOC also exhibited positive and significant correlation with groundwater depth.

DOC concentration in groundwater

In all the ten sampling points, study plots 2010 (2010-A1 and 2010-A2) recorded the lowest DOC concentration ranging from 18.10 mg/L to 28.60mg/L compared to other plots, especially 2000-A1 and 2000-A2, followed by 2006-A1 and 2006-A2. Figure 3 shows the seasonal pattern of DOC concentration in all the sampling points covering the study period September, 2013 to December, 2014. Sampling point 2000-B1 recorded the highest DOC value of 250.50 mg/L in June, 2014 as against the lowest, 157.70 mg/L at the same sampling point. From the figure, the lowest DOC concentration recorded was in May 2014 at 2010-A1 sampling point (2010/1978 plantation) which coincidentally recorded the lowest groundwater table depth of 90.8 cm though with considerable rainfall depth of 119 mm. The DOC concentration could be described as seasonal as observed in the figure. The highest DOC concentrations in 2013 were observed in September at 2000-B1 sampling point which marked the end of Southwest Monsoon as 230.93 mg/L. Though the DOC concentration further decreased from 230.93 mg/L in September, 2013 at point 2000-B1 to 186.10 mg/L in December, 2013, the DOC concentration continued to increase in almost all other sampling points except at points 2006-A2, and 2010-A2. The lowest DOC concentration was recorded in May, 2014 as 1.60 mg/L in 2010 plot as against the highest, 28.60 mg/L recorded in the same plot during the same period. There was a continuous rise in DOC concentration in all the sampling points until October 2014 when the average monthly rainfall reached its peak. The highest DOC concentration recorded was 250.50 mg/L at 2000-B1 sampling point followed by the lowest, 14.9 mg/L at 2010-A2.

DOC concentration in surface water

The highest DOC concentrations in surface water was recorded in 2000 study plots and ranged from 128.8 mg/L in June 2014 to 155.7 mg/L in December 2014. The lowest was observed in the oldest plantation (1978/2010 plantation) and ranged from 2.9 mg/L in May 2014 to 10.0 mg/L in August same year Influence of hydrology (rainfall, temperature and evaporation) on the DOC concentration from the peatland into the streams was also observed as periods of lower storm events recorded low DOC concentrations.

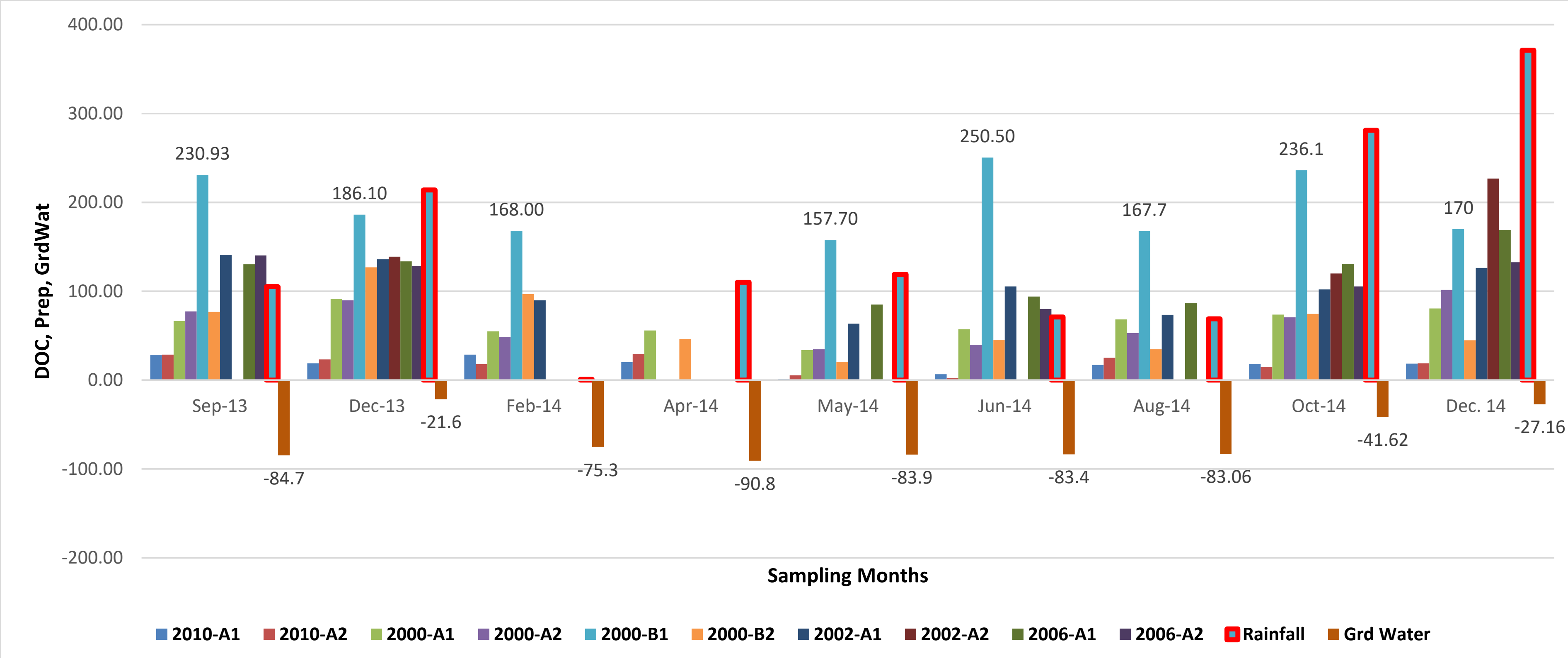

Figure 3. Periodic Groundwater DOC Concentration With Rainfall, Temperature, Evaporation and Groundwater Table Depths for the Study Area Covering the Study Period

Figure 4 reveals the influence of one of the variables over the other, as the peatland experienced rise in groundwater levels with increased rainfall depth as seen in December, 2013. Reverse was the case in April-May due to a prolonged period of no remarkable rainfall between January to April, 2014. The groundwater level reached its lowest level in April (90.8 cm) and as a result, this greatly affected the DOC concentration.

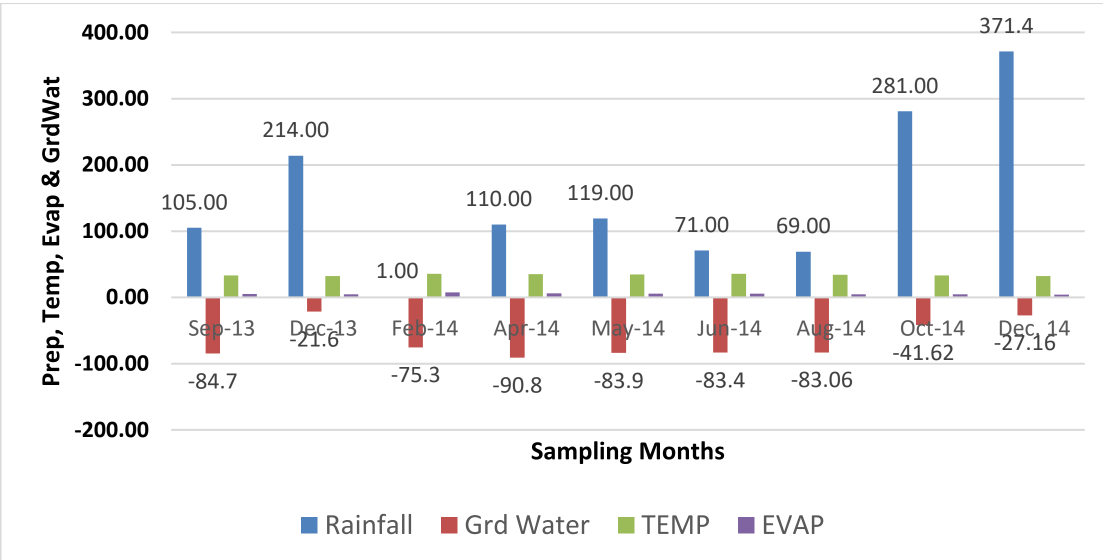

Figure 4. Relationship Between Rainfall, Temperature, Evaporation and Groundwater Levels in the Study Area

DISCUSSION

It has been observed that age of plantation played major role in DOC concentrations. Plot 2010 is the oldest oil palm plantation in the study area having been converted from peatland forests to oil palm plantation for the first time in 1978 before the re-cultivation in the year 2013. It recorded the lowest DOC concentrations in groundwater body. This justifies the effects of peatland farming on tropical peatlands which contributes to soil carbon loss as reported by Hirano et al. 2012, Gandois et al. 2013 and Dowrick et al. 2015)

DOC concentrations in the peatland streams and groundwater in the study area also followed seasonal pattern and are attributed to the hydrological factors like storm events, surface temperature, evaporation pattern, and most importantly, the groundwater table depth which is a function of precipitation. From the statistical analysis, out of 10 sampling points considered, DOC and rainfall were only positively correlated at 2 sampling points namely; 2006-A1 and 2000-A2. Thus the seasonal variation of DOC concentration is consistent with rainfall distribution pattern during the two prominent seasons (Southwest Monsoon and Northeast

Monsoon) in Malaysia. DOC showed positive correlation with groundwater depth in four sampling points, namely 2006-A1, 2010-A1, 2000-A2 and 2000-A1 (Worrall *et al.* 2007; Armstrong *et al.* 2010). Though there is correlation between the DOC and groundwater in the remaining plots but the correlation between them was weak in such plots. DOC was also negatively and strongly correlated with surface temperature in most of the sampling plots like 2006-A1, 2000-A2, 2000-A2 and 2010-A1 (Raymond and Saiers 2010; Clark *et al.* 2009) and though very weak, but still correlated in the remaining plots of 2010-A2, 2000-B2, 2002-A1, and 2000-B1. In all the sampling plots, there was no correlation between the DOC concentration and evaporation.

From these statements, there are two different factors that control the DOC concentration: age of plantation and hydrology. In peat soils, the results of the DOC concentration supported the claims according to Moore *et al.* (2008) and Caverly *et al.* (2013) which suggested that the DOC concentration depend on factors such as hydrological elements which include temperature and storm events coupled with properties of peat soil and types of available vegetation in the region. The results also satisfied the claim by Dillon *et al.* (2005) which reported that the dynamics of DOC within the soil and its hydrologic transportation is greatly influenced by the storm events. However, the observation in February, 2014 in most of the sampling points suggested that surface temperature also influenced the production of DOC. February, 2014 witnessed remarkable low rainfall depth (1.0 mm), highest temperature, (36 ^{o}C), and the highest evaporation (7.4 mm/day) and as a result of extreme drought, peat fires were reported in the sampling areas.

The influence of groundwater levels was also of great significance as observed in May-June, 2014. There was a decline in DOC concentration between January to May 2014, which was attributed to the lowering of groundwater levels from 21cm (from peat surface) in January to 90.8 cm in April, 2014 as a result of decrease in rainfall depth. In other words, the DOC concentrations were highest when the groundwater levels were far below the peat surface. This could be further explained by relating the DOC concentration with soil moisture content which is controlled by the groundwater levels (Beldring *et al.* 1999; Swenson *et al.* 2008; Rosenbaum *et al.* 2012). Therefore the increase in DOC concentrations during the Northeast Monsoon period could be due to increased microbial activity within the biomass which was further enhanced by the increase in moisture content of the soil (Manzoni *et al* 2012; Myer *et al.* 2012; Kwon *et al.* 2013)

Regarding the DOC concentrations in surface water, DOC concentrations increased during the storm events as a result of increased runoff which aided the influx of DOC from forest floors to peatland streams (Raymond and Saiers, 2010; Matsunaga *et al.* 2014). December 2013 recorded the highest DOC concentration which was consistent with rainfall depth recorded during the period. The low DOC concentration observed in February, 2014 in all the streams sampled could be attributed to drought experienced as a result of low rainfall, high surface temperature and high evaporation which could result to a decrease in microbial activity within the soil channels.

CONCLUSIONS

Land use changes have been observed to influence the rate of DOC concentrations in peatland water resources. This was concluded as older plantations recorded the lowest DOC concentrations compared to the recently converted PSFs. Hydrological factors like precipitation, evaporation and temperature coupled with soil properties like moisture content which determines the depth to groundwater table have also been observed to increase the rate of DOC concentration in the peatlands. The seasonal variation in the concentration of DOC was observed and the concentration were higher during Northeast Monsoon periods (November to March) which was characterized by heavy rainfall and subsequent increased microbial activities within the peat soils than that observed during the period of Southwest Monsoon (May to September). The observed results thus tend to support the hypothesis that the PSFs conversion and land use change greatly influence the concentration of the DOC in peatland streams and groundwater body. It was also concluded that DOC concentration follow a seasonal pattern and is dependent of storm events, surface temperature and groundwater depth. It is thus recommended that best management practices (BMPs) should be extended to oil palm cultivation on peatlands in order to avoid emission and influx of stored soil carbon in both dissolved and gaseous forms to the surrounding water resources and atmospheric body.

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