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C H A P T E R

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Soil Carbon and Nitrogen Dynamics in a Tropical Peatland

Q1

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s0010

INTRODUCTION

p0010 Tropical peatlands are primarily formed in coastal areas, developing behind mangroves, where sulfides and anoxia in the mud and water restrict bacterial activities, leading to a reduced decomposition of plant debris and an accumulation of organic matter as peat (Mutert et al., 1999). Tropical soil is organic soil, sometimes referred to as peat soil, which, by definition, according to Couwenberg (2009), is soil with more than 20% of organic matter. Peat soil naturally accumulates under anaerobic conditions, which favor the incomplete decomposition of organic matters to form peats (Sabihan et al., 2012). The production of peat soils is also favored by a cool, wet climate with water logged poorly drained environment, which helps preserve the plant remains and prevent them from rapid decomposition. These conditions highlighted above, though favor the formation of peat soils, but make the peat soils unsuitable for agriculture.

p0015 Among the major primary nutrients required by microorganisms present in the peat soil are carbon, nitrogen, phosphorus, and potassium (Wang and Moore, 2014). Of these, soil carbon, followed by nitrogen, has the highest percentage in composition depending on whether the soil is organic or inorganic (Hood-Nowotny et al., 2010). According to the definition of tropical peatland organic soil given earlier, the soil carbon content ranges from 40% to 65%, and it could be as low as 10%–11% in other areas if the peatlands have been in use for some time. The stored carbon is being lost due to anthropogenic and natural activities, which include deforestation,

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Munoz, 978-0-12-812128-3

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Page Number: 73 Date: 17/07/2017 Time: 11:34:37

logging activities, and bush burning, that the peatlands are being subjected to in these areas (Davies et al., 2013; Ayeni et al., 2014; Englhart et al., 2014; Crutzen and Andreae, 2016).

p0020 According to Batjes (1996), the world's soil collectively stores nearly 2200 Gt (billion tonnes) of carbon, about 80% of total C in the terrestrial biosphere. Two-thirds of this is in the form of organic matter, which is three times the amount of carbon held in the atmosphere (Lal, 2004). As a result of their high organic matter content, peatlands have large quantities of carbon and are known as carbon sinks (Ardo, 2015). Several studies have been carried out, varying from estimating the carbon stored within the peat soil (Wahyunto et al., 2004) to the factors controlling the carbon flux in the peatland (Kayranli et al., 2010). Maltby and Immirzi (1993) also concluded that peatlands can store up to 525 Gt of carbon, despite the fact that they only occupy 3% of the earth's total land area. The global tropical peat covers about 0.3 and 0.5 million km^2 (Maltby and Proctor, 1996; Lappalainen, 1996). Peat soil with a high quantity of carbon locked up in the soil is mostly found in Southeast Asia. In Malaysia, a country with the highest amount of carbon stored in the soil after Indonesia, the quantity of peat soil carbon content ranges from 44.6% to 47.8% of agricultural soil in Sarawak (Sajarwan et al., 2002; Melling et al., 2005); this was also supported by Lähteenoja et al. (2009) and Jaya (2007).

s0015 Soil Carbon and Nitrogen Loss in the Tropical Peatlands

p0025 Anthropogenic and agricultural activities in tropical peatlands in former peatland swamp forests (PSFs) that were converted for agricultural purposes have been responsible for most of the nutrient loss recorded (Kirk et al., 2015; Turetsky et al., 2015). In Southeast Asia, oil palm agriculture had been mostly practiced on mineral soils before the growth in oil palm industry was recorded. As a result of the boom recorded in the oil palm industry, there was a shift from mineral soils to organic soils as a result of inadequate management of the mineral soils for farming activities. Hence, in an effort to meet the agricultural needs of the population in the region, most of the peat swamp forests (PSFs) were converted to oil palm plantations (Tan et al., 2009). This massive conversion of PSFs, according to Koh et al. (2011) thus rendered the peatlands.

p0030 The change from carbon sinks to carbon sources due to the indiscriminate deforestation and land tillage in favor of oil palm plantation. This further led to the degradation of the peat swamp forests which is as a result of massive draining of the PSFs in order to lower the peatland water table level in favor of peatland agriculture (Miettinen and Liew, 2010). Most of the nutrients like soil carbon and nitrogen were lost to the peatland streams under mobile forms, while some were lost to the atmosphere in form of nitrous oxide (N_2O) through nitrification and denitrification (Koops et al., 1991, 1997; Dinsmore et al., 2009). As a result of different land use practices on tropical peatlands, most of the forested areas were converted to agricultural land, which thus exposed the locked-up peat soil carbon and nitrogen to the atmosphere, thereby contributing to climate change (Donato et al., 2011).

p0035 The excess quantity of nitrogen in the peat soil has been traced to uncontrolled application of inorganic fertilizers, particularly nitrogen fertilizer, which has been known to increase the contents of the soil nitrates (Roth et al., 2015). The study also investigated the effects of nitrogen fertilizer application on the relationship between soil N_2O emissions and above-ground biomass yield. It was observed that a nitrogen fertilizer application significantly increased N_2O emissions, and nitrogen loss from the peatland has also been attributed to peatland

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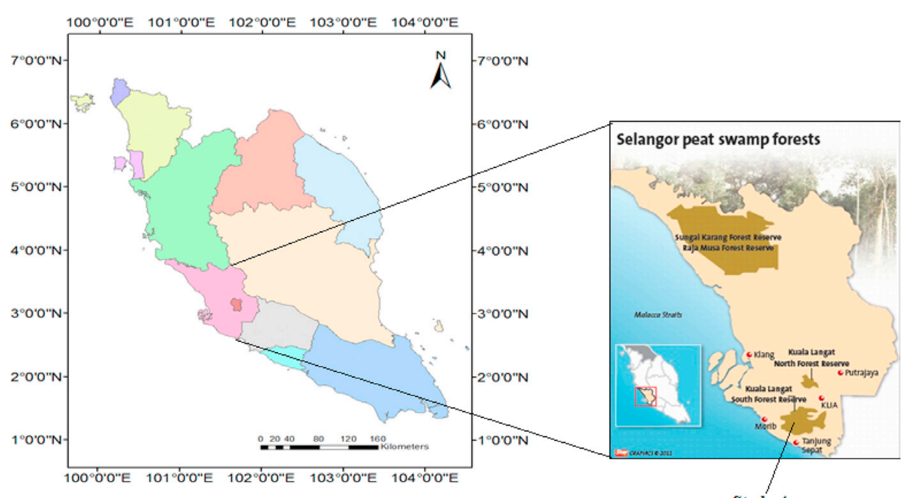
drainage. Upon draining the peat of water and fertilization of peat soil, the rate of soil carbon mineralization increases which results in a decline in the carbon/nitrogen ratio (C:N) and an increase in nitrogen availability in soil. Koops et al. (1997) reported that nitrogen is lost from peat soil in the form of nitrous oxide (N_2O) through nitrification and denitrification. The studies affirmed that N_2O produced from the peat is considered a nitrogen N loss because it is being exposed to the atmosphere as N_2O or N_2.

p0040 This chapter therefore presents the dynamics of both peat soil carbon and nitrogen in a tropical peatland during the wet and dry seasons in order to appraise the practices that influence the nutrients loss. The roles of rainfall in the nutrients dynamics are also presented in order to buttress the seasonal influence on nutrient loss. In other words, the chapter's objectives are mainly to study the dynamics of peat soil carbon and nitrogen during the two seasons considered, as well as to check the effects of peatland conversion on soil carbon and nitrogen loss.

s0020 MATERIALS AND METHODS

s0025 Study Area and Site Description

p0045 The study site is Selangor Peat Swamp Forests, located in Sepang, Selangor state, Malaysia; it is within the Kuala Langat South Forest Reserve area, bound to the west by the Straits of Malacca, which share the same boundary with Kuala Lumpur International Airports (KLIA 1 & 2) to the east between latitude 02°43′N and longitude 101°39′E (Fig. 1). The Kuala Langat South peat swamp forest was first listed as a forest reserve in 1927 with the original size of 12,141 ha with different types of big trees with its timber stock estimated at 142 m^3/ha. The encroachment in form of urbanization and development in the late 1970s started eating

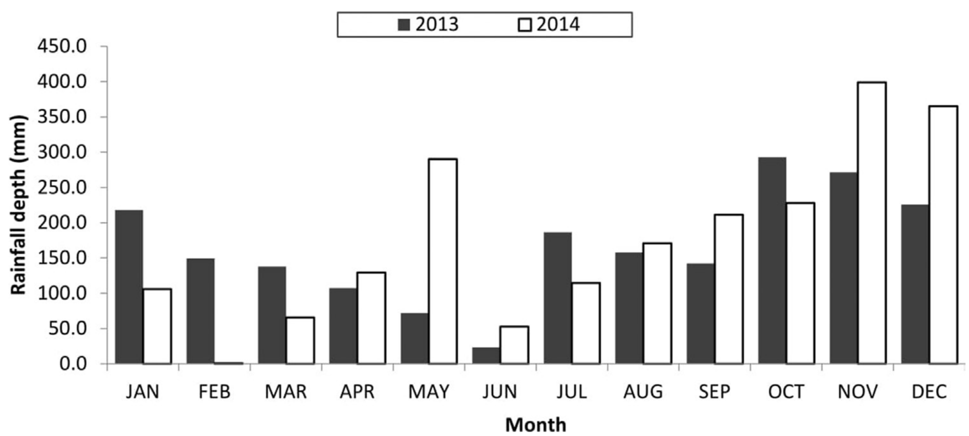


f0010 **FIG. 1** Location of the study area showing gauging station and sampling points. *Source: Cheng, L.T., 2014. Planters threaten Selangor peat swamp. Retrieved from http://www.thestar.com.my/story/?sec=lifefocus&file=%2F2011%2F2%2F1%2Flifefocus%2F7889008 (accessed 24 January, 2014).*

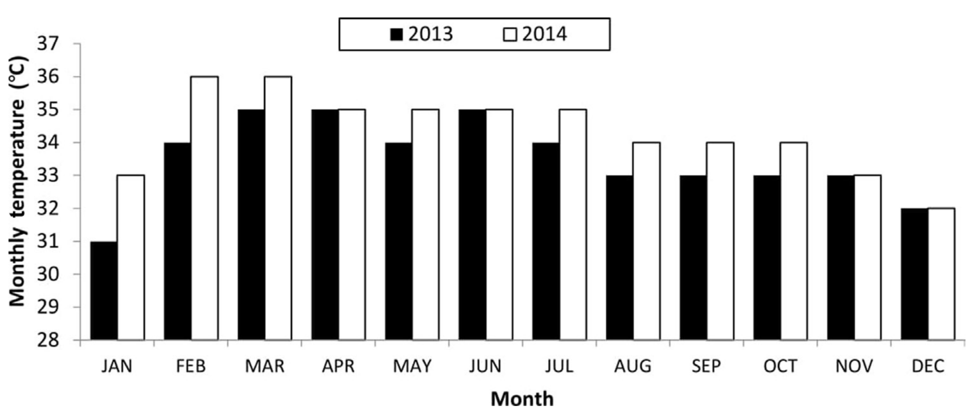
Munoz, 978-0-12-812128-3

deep into the reserve, thereby reducing it to half its size. The construction of Kuala Lumpur International Airport, which was commissioned in 1993, was part of the developments that led to the reduction in size of the reserve, apart from oil palm plantations. The growth in the oil palm industry led to the first clearing in the reserve in 1978, which was purposely to expand the oil palm industry as a result of the global oil boom during the period. Thus the first oil palm plantation was established in the reserve in 1978 with a total area of 1931 ha (19.31 km^2). This involved a lot of deforestation, site clearing, and site drainage all for the purpose of oil palm production.

p0050 Fig. 2 shows the monthly rainfall pattern recorded at the gaging station 2616137 located at latitude 02°41′29.8″ N and longitude 101°40′57.5″ E. The monthly rainfall covers the study periods with lowest rainfall recorded in Feb. 2014 as 1.0 mm and highest in Nov. 2014 as 399 mm. The total annual rainfall depth for 2013 and 2014 are 1985.5 and



f0015 **FIG. 2** Monthly rainfall depth for the study period. *Source: Malaysian Department of Irrigation and Drainage, DID.*



f0020 **FIG. 3** Mean monthly temperature for years 2013 and 2014 for the study area. *Source: Malayan Meteorological Department, MMD.*

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2134.5 mm, respectively. The temperature pattern of the study area for 2013 and 2014 is as shown in Fig. 3, with the monthly mean temperature of 35°C recorded in March, April, and June 2013 (dry season) and the lowest in December 32°C (wet season). In 2014, during the dry season, the highest monthly mean temperature of 36°C was recorded in February and March (35.6°C), and the lowest was recorded in November (wet season) at 33°C. Thus 2014 was considered wetter but hotter than 2013.

s0030 ## Soil Sampling and Analysis

p0055 The sampling locations in the study area were chosen to evenly represent the entire study area. Soil sampling was done in both dry and wet seasons and were collected at three different depths of 0.5, 1.5, and 2.5 m in three replicates during both the dry/wet sampling periods. The dry season sampling covered March through May 2014 while the wet season sampling covered October to December of the same year. All of the 150 soil samples were collected during the two seasons from the study site with a basin area of 1931 ha. A CNS-2000 automated elemental analyzer (LECO Corporation, St Joseph, Michigan, USA) was used to determine the carbon and nitrogen content of the soil samples. In the laboratory, 2 g of air-dried soil samples that passed through a 2 mm sieve were placed in the plastic containers, covered well, and then transferred to the flash combustion, carbon, nitrogen, and sulfur analyzer, the LECO Analyzer. The results came out in triplicates, and the average results are as shown in Table 1. The pH values of the samples were determined on a 1:2 (v/v) soil-water mixture: 10 mL of distilled water were added to 5 g of oven-dried soil samples that passed through a 2 mm sieve. The mixture was stirred intermittently with a glass rod for 30 min. The pH was then measured and recorded using a Beckman pH meter. Soil moisture content was carried out using the dry weight basis as reported in Zaccone et al. (2014). The statistical analysis of the parameters using a correlation matrix and an analysis of variance (ANOVA) was used to check the correlation among the soil properties in both dry and wet seasons. The Pearson correlation analysis and ANOVA were performed using IBM SPSS statistics 21 (Tables 2 and 3).

t0010 **TABLE 1** Physicochemical Properties of Peat Soil With Means and Standard Error (SE) of Means for Both Dry and Wet Sampling Periods

Season	Depth (m)	pH	Moisture Content %	Carbon %	Nitrogen %	Carbon/ Nitrogen
Dry	0.5	3.38 ± 0.03	336.21 ± 24.19	43.30 ± 2.44	1.20 ± 0.07	36.08 ± 0.01
	1.5	3.46 ± 0.02	356.03 ± 28.61	27.73 ± 2.43	0.72 ± 0.13	38.35 ± 0.23
	2.5	3.55 ± 0.01	342.03 ± 8.66	16.16 ± 2.33	0.32 ± 0.04	50.49 ± 0.21
Wet	0.5	3.13 ± 0.03	264.15 ± 11.19	47.29 ± 3.55	1.34 ± 0.06	35.29 ± 1.23
	1.5	3.25 ± 0.02	513.15 ± 23.19	47.10 ± 3.59	1.37 ± 0.07	34.38 ± 2.13
	2.5	3.35 ± 0.04	656.92 ± 97.22	12.11 ± 0.16	1.15 ± 0.41	10.53 ± 0.21

Comp. by: Bibin Stage: Revises1 Chapter No.: 6 Title Name: Munoz
Page Number: 77 Date: 17/07/2017 Time: 11:34:37

t0015 **TABLE 2** Correlation Matrix and ANOVA of the Physiochemical Properties of Peat Soil—Dry Season

		Carbon	Nitrogen	C/N	pH	Mois Cont	Depth
Carbon	Pearson correlation	1	0.517[a]	0.206[b]	0.16	0.235[b]	−0.575[a]
	Sig. (2-tailed)		0	0.04	0.12	0.021	0.000
Nitrogen	Pearson correlation	0.517[a]	1	−0.667[a]	0.128	0.597[a]	−0.191
	Sig. (2-tailed)	0.000		0.000	0.215	0.000	0.062
C/N	Pearson correlation	0.206[b]	−0.667[a]	1	0.139	−0.399[a]	−0.102
	Sig. (2-tailed)	0.04	0		0.177	0.000	0.324
pH	Pearson correlation	0.16	0.128	0.139	1	−0.054	0.271[a]
	Sig. (2-tailed)	0.12	0.215	0.177		0.6	0.008
Moisture content	Pearson correlation	0.235[b]	0.597[a]	−0.399[a]	−0.054	1	0.014
	Sig. (2-tailed)	0.021	0	0	0.6		0.894
Depth	Pearson correlation	−0.575[a]	−0.191	−0.102	0.271[a]	0.014	1
	Sig. (2-tailed)	0.000	0.062	0.324	0.008	0.894	

[a]*Correlation is significant at* $P < 0.01$ *level (2-tailed).*
[b]*Correlation is significant at* $P < 0.05$ *level (2-tailed).*

t0020 **TABLE 3** Correlation Matrix and ANOVA of the Physiochemical Properties of Peat Soil—Wet Season

		Depth	Nitrogen	Carbon	C/N	pH	Moisture Content
Depth	Pearson correlation	1	0.786	−0.603	0.258	0.5	0.579
	Sig. (2-tailed)		0.424	0.588	0.153	0.667	0.607
Nitrogen	Pearson correlation	0.786	1	0.019	−0.704[a]	−0.142	−0.596[a]
	Sig. (2-tailed)	0.424		0.988	0.000	0.909	0.000
Carbon	Pearson correlation	−0.603	0.019	1	0.468[a]	−0.992	−0.097
	Sig. (2-tailed)	0.588	0.988		0.007	0.079	0.596
C/N	Pearson correlation	0.258	−0.704[a]	0.468[a]	1	−0.463[a]	0.500[a]
	Sig. (2-tailed)	0.153	0.000	0.007		0.008	0.004
pH	Pearson correlation	0.5	−0.142	−0.992	−0.463[a]	1	−0.417
	Sig. (2-tailed)	0.667	0.909	0.079	0.008		0.726
Moisture Content	Pearson correlation	0.579	0.959	0.302	0.500[a]	−0.417	1
	Sig. (2-tailed)	0.607	0.183	0.805	0.004	0.726	

[a]*Correlation is significant at* $P < 0.01$ *level (2-tailed).*

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s0035

RESULTS

p0060 The results of the analysis conducted on soil samples collected during both dry and wet sampling periods are as shown in Table 1. The table presented the means of the physicochemical properties of peat soil, which include soil carbon, soil nitrogen, a carbon-nitrogen ratio, soil moisture content, and soil pH at three different depths.

p0065 From Table 1, more soil carbon was observed at the peat surface than at the other depths. More carbon was also recorded during the wet period than the dry period. The lowest soil carbon quantity was observed at a 2.5 m depth in both the dry and wet seasons. Soil carbon and nitrogen were significantly correlated in the dry season at $P < 0.01$ as shown in Table 2 compared to a nonsignificant correlation that existed between them during the wet season. There was positive significant difference between soil nitrogen and soil carbon at $P < 0.01$. Nitrogen, however, did not show any significant correlation with soil pH and depth.

p0070 There was no correlation between the soil moisture content and soil depth during the dry season compared to a moderate significant correlation observed between the moisture content and soil depth during the wet season. The highest soil moisture content of 356.03% on average was recorded at a 1.5 m depth during the dry season compared to 656.92% on average recorded at 2.5 m depth during the wet season. The lowest in both cases were recorded at the peat surface (0.5 m). During the dry season, soil moisture content positively correlated with both soil carbon and nitrogen at $P < 0.05$ and $P < 0.01$, but negatively correlated with the C/N ratio at $P < 0.05$. There was no correlation between the soil moisture and other parameters during the wet period. A positive correlation was observed between the soil moisture content and soil nitrogen during the dry period at $P < 0.01$ as against the negative correlation observed during the wet season also at $P < 0.01$. This shows that more soil nitrogen is lost with increased soil moisture during the wet season (Murdiyarso et al., 2010).

p0075 The soil pH was observed to increase towards alkalinity with soil depth during both the dry and wet period. But in both cases, the peat soil pH during the wet period was observed to be more acidic than that of dry period. During the wet season, there was no significant correlation between the soil pH and the soil nitrogen and carbon. Soil pH showed no significant correlation with the soil depth during the wet season. During the dry season, soil pH had a significant correlation with the soil depth at a 0.01 level (2-tailed). As it was observed during the wet season, there was no significant relationship between the soil pH and nitrogen and soil carbon, and there was none during the dry period as well. The C/N ratio during the wet sampling period positively correlated with soil carbon and moisture content, but negatively correlated with soil nitrogen and soil pH.

p0080 The results showed that there are significant differences between all the parameters both during the dry and wet seasons ($P < 0.01$ and 0.05) (Tables 2 and 3). There is both a positive and significant correlation between soil carbon and soil moisture in both the dry and wet periods ($P < 0.05$). This is against the negative but significant correlation recorded between soil nitrogen and soil moisture during the wet period. There was, however, a positive, significant correlation between nitrogen and soil moisture during the dry period ($P < 0.01$).

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Page Number: 79 Date: 17/07/2017 Time: 11:34:37

s0040 DISCUSSION

p0085 The increase in soil carbon content observed during the wet sampling period compared to the dry sampling period could be attributed to rainfall events (Satrio et al., 2009; Zhang et al., 2010). This increase is therefore attributed to the effects of rainfall on both plants productivity inputs and soil respiration losses (Zhang et al., 2010). The negative, weak, and moderate correlations of soil carbon with depth during both the dry and wet sampling periods could be attributed to the deposition of biomass and carbon fixation in the plantation biomass at the surface, which is consistent with Fierer et al. (2003), Eilers et al. (2012), Sabihan et al. (2012), and Germer and Sauerborn (2008). The difference in soil carbon content along the soil depth could be as a result of fundamental differences in the activities of soil microbes between the soil surface and deep layers (Blume et al., 2002). The lowest values of soil carbon recorded at 2.5 m in both seasons could also be attributed to the mixing of peat soil with the mineral soil and the fact that the peat is shallow. This is referred to as carbon mineralization, where peat soils rich in carbon are mixed with mineral soil and loses its carbon contents. The increase in the rate of soil carbon mineralization, which is as a result of draining the peat of water, liming, and fertilizing of peat soil, results in a decline in the carbon/nitrogen ratio, (C/N) and an increase in the nitrogen availability in soil (Smith et al., 2016; Hyvonen et al., 2013). The C/N ratio increase relative to depth during the dry season could be attributed to the carbon mineralization that could result in the production of CH_4 and CO_2, especially in a warmer temperature of above 22°C (Inglett et al., 2012; Kim et al., 2015).

p0090 Nitrogen loss in the peat soil is in the form of nitrous oxide (N_2O) through the processes of nitrification and denitrification (Koops et al., 1991, 1997), and it is known to be higher in the peat soil than in the mineral soil, according to Hyvonen et al. (2013). A reduction in the quantities of soil nitrogen with depth in the form of nitrates could be the result of applied pesticides and fertilizers, which are dissolved and leached to the deep surface of the peat to join the groundwater, thereby polluting it. Permeable sediments of peat soil have contributed to the movement of nitrates through the soil to the groundwater, which lowers its quantities with depth. This movement is greatly influenced by the long history of intensive farming (Burow et al., 2008).

p0095 The higher soil moisture content recorded during the wet season in comparison to the dry season was attributed to storm events during the wet sampling period, which have higher impacts at the soil surface than beneath it. The higher soil moisture content recorded at both 1.5 and 2.5 m depths could therefore be attributed to the samples collected close to the water table, especially for the samples collected during the dry period. However, during the wet period, there is a statistically significant difference between the soil moisture and soil depth. This indicated that with increasing soil depth, the soil moisture tends to increase, which could be attributed to more soil moisture moving downwards or infiltrating into the subsoil surface due to low bulk density of the peat soil made possible by intensive peat cultivation (Rieley et al., 2008). The loss of nitrogen observed during the wet season was attributed to high soil moisture content, which was consistent with Murdiyarso et al. (2010) which reported maximum emission of nitrogen (though denitrification) from the peatland at field capacity. This means the more moisture was contained in the soil, the more soil nitrogen was emitted from the peat surface.

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s0045
CONCLUSION

p0100 The dynamics of soil carbon and nitrogen, with some physical properties of tropical peatland soils during both the dry and wet seasons, have been studied. Soil carbon and nitrogen were observed to have higher values during the wet season in all depths considered. The microbial activities at the peat surface were observed to play major roles in carbon stocks, hence the higher values of C recorded at the soil surface. Rainfall was also observed to play a major role in carbon stocks, as more soil carbon were deposited at the peat surface during the wet season than during the dry season. However, a reduction in soil carbon content during the dry season suggests that a large quantity of soil carbon is being lost due to peat oxidation, making the peatlands a carbon source rather than a sink of carbon. The same is applied to soil nitrogen, as a greater nitrogen deposition was observed at the peat surface during the wet period. Hence, the loss of soil carbon and nitrogen stored in the peat soil to the atmosphere in gaseous form contributed to greenhouse effects. Therefore this means that to sustain a tropical peatland, best management practices should be adhered to, thereby reducing the negative effects of climate change.

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Non-Print Items

Abstract

The conversion of peat swamp forest to oil palm cultivation has resulted in the loss of stored nutrients in the peat soil, especially to the atmosphere. Soil carbon and nitrogen are the two major nutrients that are found in large quantities in the peat soil. Therefore this chapter studies the dynamics of these two primary nutrients within the peatland and how their losses are influenced by seasonal changes. Detailed samplings were carried out in wet and dry periods, with samples collected at three different depths during the dry and wet seasons. The flash combustion method using the LECO analyzer was part of the analysis of carbon and nitrogen. The results of the analyses of the soil carbon obtained in triplicates showed that the soil carbon at the peat surface is higher than that below the surface. The soil carbon recorded at the surface (0.5 m) during the wet season was 47.29%, which is higher than that recorded at the surface during the dry period. 1.34% of the soil nitrogen was observed at the surface during the wet period compared to 1.2% recorded during the dry spell. Rainfall was considered to be the main driver of both soil carbon and nitrogen in the tropical peatland, coupled with the fact that more nutrients were observed at the soil surface due to microbial activities at the surface. Hence, sustaining tropical peatlands would mean that practices that encourage nutrient loss from the peatlands to be controlled and well managed so as not to aggravate the climate change process that is associated with the nutrients' loss to the atmosphere.

Keywords: Soil carbon, Soil nitrogen, Peat swamp forests, Tropical peatland, Climate change

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