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SOIL CARBON DIOXIDE (CO_2) EFFLUX RATE AND OIL PALM YIELD FROM DIFFERENT PEAT TYPES IN SARAWAK, MALAYSIA

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ABSTRACT

*Tropical peatlands have different characteristics as compared to temperate peatlands in terms of organic materials and topography. It is important to understand the soil characteristics for improving crop management practices. A study was conducted to investigate the effects of different types of peat on soil carbon dioxide (CO_2) emissions and oil palm yield in Sarawak. The study area was classified as Naman (Oa) and Kenyana (Oawu) series using the Malaysian Unified Classification of Organic Soils (MUCOS). Soil CO_2 efflux was determined by using a portable CO_2 analyser at monthly intervals from eight observational plots setup in each 10 ha study plot. The oil palm fresh fruit bunch (FFB) yield was recorded since the first year of harvest (*i.e.* after about 30 months field planting). Results showed that the average soil CO_2 efflux was the highest in Naman series plot (4.89±0.36 µmol CO_2 m^{-2} s^{-1}) compared to Kenyana series plot (4.44±0.37 µmol CO_2 m^{-2} s^{-1}). However, FFB yield was recorded 40% higher at Naman plot compared to Kenyana plot. Higher FFB yield in Naman plot was related to its soil consisting of sapric materials that have more nutrients available for the crop, while Kenyana plot consisted of sapric materials together with undecomposed wood that might hinder the palm growth. This study suggests that different types of peat have significant effects on oil palm yield and soil CO_2 emissions. The site-specific and peat soil management based on its characteristics is important for oil palm growth and performance especially for enhancing FFB yield and improving environmental management.*

Keywords: tropical peat, peat type, soil CO_2 efflux, FFB yield.

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INTRODUCTION

Tropical peatland is a unique ecosystem due to its characteristics that support diverse biodiversity and store large amount of carbon and natural water. It is found mostly in Southeast Asia and other countries like Africa, Central and South America (Rieley, 1996). Most tropical peats developed from organic soil materials or the remains of woody materials and form distinct dome-shaped deposits, which can sometimes be more than 10 m deep (Paramananthan, 2010). Sarawak has the largest peatlands of 1 588 142 ha from the total about 2.43 million hectares of tropical peatland in Malaysia (Wahid *et al*., 2010). Agriculture development on lowland peat is more prominent in Sarawak due to scarcity of suitable land and the need to eradicate poverty among the indigenous communities living in the swamp area. This has led to the development of peatlands for agriculture especially oil palm cultivation. However, a lack of recognition of the different types of organic soils has resulted in low crop yields and often lead to other management problems due to poor soil management (Veloo *et al*., 2015).

Previous peat classification was based on the surface vegetation of the tropical peatland forest in Sarawak (Anderson, 1958). There were six phasic peat of tropical peat forest community: Mixed peat swamp (PC1), Alan forest (PC2), Alan Bunga forest (PC3), Padang Alan forest (PC4), Padang Selunsur forest (PC5) and Padang Keruntum forest (PC6) as the centre of the peat dome based on Anderson (1958). Malaysian Unified Classification of Organic Soils (MUCOS) in Malaysian Soil Taxonomy (Paramananthan, 1998; 2010; 2012) was then developed by Paramananthan since 1984 for further efforts and improvement in classifying peat and mapping tropical peatland soil in Malaysia. This classification system considers depth, peat maturity, morphology, the presence or absence of wood, nature of wood (decomposed/ undecomposed) and underlying mineral substratum, which is more reflective of the characteristic of tropical peatland in Malaysia in complementing the international classification schemes.

Based on MUCOS, peat is defined as organic soil that consists of more than 50 cm of organic material thickness within the upper 100 cm soil layer with loss of ignition of more than 65%. It is necessary to classify the tropical peat soil by using a standard classification system in order to understand the soil for a better crop growth and performance as well as environment management. Paramananthan and Wahid (2014) had proposed the management practices needed based on soil management group, which is very useful for the successful cultivation of oil palm on peat in Malaysia.

Tropical peatlands are significant carbon sinks and store large amounts of carbon and support diverse ecosystems (Hooijer *et al*., 2006; Page *et al*., 2011). However, research that examines the rate of CO_2 flux from peatlands including oil palm plantation is relatively scarce (Page *et al*., 2011). Peat carbon emissions had been a much-debated issue once the peat is drained. The magnitude of soil CO_2 emissions from oil palm plantation on peat still remains uncertain and more studies are needed to address this issue. The study of soil CO_2 respiration from tropical peatlands is an important aspect of environmental research due to its potential impact on future climate change. One aspect is the inevitable subsidence, which occurs following drainage that is needed to provide suitable conditions for crop growth (Wősten *et al*., 1997). In addition, the decline in peat depth imposes a limit to the peat productive life (Tie, 2004). Shallow peats may eventually disappear completely, exposing the underlying mineral soil, some of which may be acid sulphate and detrimental to crop growth. Therefore, minimising drainage is the key for sustaining the productive life span of peat soils and reducing GHG emissions (Tarmizi *et al*., 2009; Hasnol *et al*., 2010; Marwanto *et al*., 2013).

Owing to several other issues of major concern regarding the use of peatland to grow oil palm, our aims were to report annual total soil CO_2 efflux (or soil respiration) and oil palm yield from oil palm plantation on a tropical peatland on different peat series (Naman and Kenyana) in Sarawak. This study is also relevant as Sarawak is the largest state in Malaysia that plant oil palm. For year 2017, out of 5.81 million hectares of oil palm planted in Malaysia, 1.56 million hectares or 26.8% is in Sarawak (Kushairi *et al*., 2018). The study provides vital information that will be useful for a better understanding of carbon emissions and oil palm yield in tropical peatlands. A better understanding of the nature and characteristics of these peatlands may help in formulating and managing oil palm plantations based on different peat types or peat series. Therefore, this information will be useful for making rational decisions concerning the future use of peatlands for agriculture in Malaysia or elsewhere. The mapping of soil classification, optimum and best management practices are important to ensure successful planting, economic yield and better environmental management of oil palm cultivation on peat.

MATERIALS AND METHODS

Site Description and Soil Classification

The study site was established at a newly planted area in an oil palm plantation located in Sibu, Sarawak. The study area was situated between latitudes 2°33.5'N and 2°34'N and longitudes 111° 58.5'E and 111° 59.3'E. The study plot consisted of 10 ha each on different peat types; Naman series (Plot 1) and Kenyana series (Plot 2) and planted with oil palm in 2010. Oil palms were planted in triangular patterns at 8.6 m distance with planting density of 154 palm ha^{-1}. Fertilisers such as urea, rock phosphate, zinc sulphate, borate, copper sulphate and muriate of potash were applied based on the general fertiliser recommendation for immature palm (Haniff *et al*., 2011). The estate has an annual rainfall between 2748-3072 mm with an occasional dry month (<100 mm). Land preparation was done according to the standard estate practices consisting of compaction, stacking of woody biomass residues between planting rows and draining the water table to 50-60 cm below the ground surface (Gurmit, 2004). The water levels were maintained at the collection drains using weirs or stop-off to regulate the peat water in the plantation.

The study area was classified as Naman (Oa) series and Kenyana (Oawu) series based on MUCOS (Paramanathan, 2011) (*Table 1*). Naman soil series is described as very deep (>300 cm) organic soil that is black in colour, non-woody and highly decomposed sapric organic soil material in the sub-surface tier (50-100 cm). It is often very poorly drained over non-sulphidic marine clay at more than 300 cm depth. The soil management group of Naman series is the Oa (organic and sapric) consisting of sapric materials, non-woody and low in fertility. Kenyana soil series is very deep (>300 cm), dark brown to black sapric organic soil materials with undecomposed wood in the upper 100 cm and often undecomposed fibric organic soil materials with some pieces of wood below 100 cm depths. The underlying material of marine clay is at over 300 cm depth and it is very poorly drained. The soil management for Kenyana series in this study was categorised as Oawu (organic, sapric and undecomposed wood) which was very deep (>300 cm) sapric material with undecomposed wood and low fertility (*Table 1*). The site was formerly Mixed Peat Swamp forest for Naman series and Alan forest for Kenyana series as recorded by Soil Division, Department of Agriculture Sarawak. The peat depth ranged from 6-8 m and classified as Anderson 3 (Records of Soil Division, Department of Agriculture Sarawak).

Field Experimental Design

Eight subplots were established at each study plot for measuring soil respiration, soil temperature and soil moisture. One palm in the middle of each subplot was chosen as a reference palm in order to determine the placement of soil collars at different management zones. The soil collars for the soil CO_2 efflux measurements were located at three different management zones; inter-row, harvest-path and frond stacking area at the distances of 0.5 m, 1.75 m and 3.5 m from the trunk of reference palm for each management zone (*Figure 1*). This is shown by Y shape of measurement points in the diagram. The soil collars were made from PVC pipes with dimension of 10.5 cm diameter by 10 cm height and inserted into the soil with 8 cm below and 2 cm above the soil surface. Soil collars were installed three months prior to the initial measurement in order to avoid disturbance effects (Ventera and Baker, 2008; Grønlund *et al*., 2008; Pumpanen *et al*., 2004).

Measurement of Soil CO_2 Efflux, Soil Temperature and Soil Moisture Content

Soil CO_2 efflux rate was measured using a portable CO_2 analyser (EGM-4, PP-System, United Kingdom) based on the closed-static chamber approach (Livingston and Hutchinson, 1995). The EGM-4 consists of an infrared gas analyser (IRGA) connected to a cylindrical soil chamber SRC-1 (diameter 10 cm; height 15 cm). The rate of increase in CO_2 concentration with time within the chamber was then monitored over a 2 min enclosure period or

TABLE 1. CLASSIFICATION, SOIL CHARACTERISTIC AND ORGANIC MANAGEMENT GROUP OF STUDY SITES

Soil series/ Depth phase	Classification of the soil (Phase level)	Main characteristic/ limitation	Management practices needed	Peak yield potential ($t\ ha^{-1}\ yr^{-1}$)
Naman/ very deep (Oa)	Sapric ombrogambist, marine clayey, isohyperthermic, non-woody, autochthonous (Low ash, dysic, non-saline, sapric, drained, very deep)	• Very deep (>300 cm) • Sapric material • Non-woody to 100 cm • Poorly drained • Low fertility	• Compaction of planting rows • High planting density • Water control and management • Good fertiliser programme with Cu, B and Zn	26-28
Kenyana/ very deep (Oawu)	Sapric topogambist, marine clayey, isohyperthermic, woody-undecomposed, autochthonous (Low ash, dysic, non-saline, sapric, drained, very deep)	• Very deep (>300 cm) • Sapric material with undecomposed wood • Poorly drained • Stunted growth common after five years • Termites • Low fertility • High cost of drain construction	• Compaction of planting rows • High planting density. • Water control and management • Good fertiliser programme with Cu, B and Zn • Thinning of stunted palms	22-24

Note: Oa (organic and sapric), Oawu (organic, sapric and undecomposed wood) refers to soil management group.

Sources: Paramananthan (2012) and Paramananthan and Wahid (2014).

until an increase of 100 ppm CO_2 had been detected. Soil CO_2 efflux rate was calculated by performing linear regression on the CO_2 concentration and time. The soil CO_2 emission rates were calculated based on CO_2 efflux calculations (Marthews *et al*., 2014). The end results with a good linear fit ($R^2 \geq 0.8$ or r = 0.89) were used in the mean comparison analysis. The measurements were conducted at monthly intervals from 72 points with two replicates of measurement at each point in the study plot. The soil CO_2 efflux measurement was conducted since planting in 2010 until five years after planting. Soil temperature (STP-1 Soil Temperature Probe, PP-System, United Kingdom) and soil moisture (HydroSense CD620 and CS620, CSI, USA) were measured at 5-10 cm depth below the peat surface for each measurement point. All measurements were performed approximately from 8.00 am until noon as representative samples of the day and measurements were not taken immediately after rain to avoid effects of CO_2 diffusion caused by rain events.

Fresh Fruit Bunch Yield, Vegetative Measurement and Water Table

The fresh fruit bunch (FFB) yield was recorded to compare yield performance in tonnes (t) between different peat types since the first year of harvest in 2012 (after about 30 months field planting) until 2015. The vegetative measurement for morphological parameters such as standing biomass, trunk height and leaf area index (LAI) were based on the MPOB manual and report on oil palm measurements (Zuraidah *et al*., 2017; Corley and Breure, 1981). The vegetative measurement was conducted since 2013 until 2015. The water table depth below the peat surface was monitored using three automatic water level data loggers (Cera-Diver, Schlumberger, Canada) in each study plot as well as manual checks. The automatic water level data loggers (diver) were installed in open-ended piezometer made from perforated 10 cm diameter polyvinyl chloride (PVC) pipes. The field water table was recorded automatically at hourly intervals by divers.

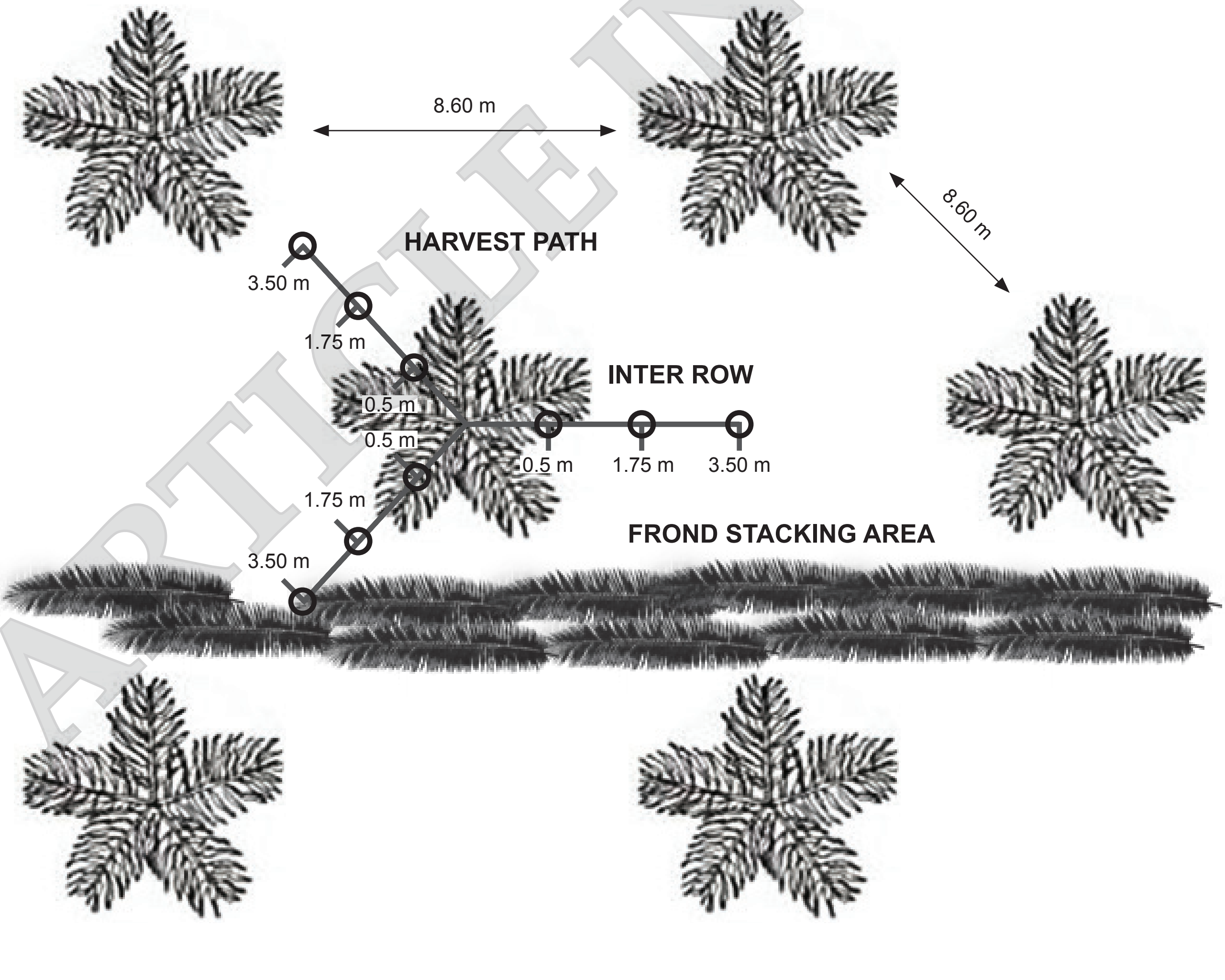

Figure 1. Location of soil carbon dioxide (CO_2) efflux sampling points at different management zones denoted by red circles.

Statistical Analysis

Statistical analysis was performed using IBM SPSS Statistics 20. The distribution of the variables was tested using the Shapiro-Wilk test. The independent samples *t* test was used to compare means between the study plots for each variable such as soil CO_2 efflux, field water table, soil moisture, soil temperature and FFB yield. Statistical significance was set at probability level of 0.05. Results were presented as mean with standard error of mean for each variable in their respective unit except for rainfall data (total).

RESULTS AND DISCUSSION

The annual mean total soil CO_2 efflux for six years (2010-2015) of measurements was analysed using independent *t* test. Soil CO_2 efflux was higher at the Naman plot at 4.89±0.36 µmol CO_2 m^{-2} s^{-1} (67.85 mg ha^{-1} yr^{-1}) than the Kenyana plot at 4.44±0.37 µmol CO_2 m^{-2} s^{-1} (61.61 mg ha^{-1} yr^{-1}) as shown in *Table 3*. There was a significant difference in soil CO_2 efflux between the plots at *p*-value < 0.001. The soil CO_2 efflux rates in this study were within the range of soil CO_2 emission reported by other studies of oil palm plantations on tropical peat swamp forest using the closed chamber technique (Ishikura *et al.*, 2018; Hergoualc'h *et al*., 2017; Husnain *et al*., 2014; Wigena *et al*., 2014; Marwanto and Agus, 2014; Dariah *et al*., 2013; Comeau *et al.*, 2013; IPB, 2011). Previous studies reported the total soil respiration of oil palm plantation on peat ranged between 38 mg ha^{-1} yr^{-1} (Ishikura *et al.*, 2018) to 104 mg ha^{-1} yr^{-1} (Comeau *et al*., 2013). Studies reported by some researchers (Melling *et al*., 2004; 2005; 2007; IPB, 2011) showed results of soil CO_2 emission measured at oil palm sites (4-5 years after planting) ranging from 56.5-85 mg ha^{-1} yr^{-1}. Results of soil CO_2 efflux from this study were comparable with a soil CO_2 flux measurement using the closed-chamber method with IRGA (LICOR 820) conducted by Dariah *et al*. (2013) on 6-year-old oil palm plantation located at Jambi, Indonesia with the magnitude of 67.36 mg ha^{-1} yr^{-1} after one month of fertilisation. The average total soil respiration reported in their study ranged from 48.16-99.27 mg ha^{-1} yr^{-1} over a period of seven months of measurement. Husnain *et al*. (2014) and Wigena *et al*. (2014) also reported on the rate of soil CO_2 efflux measured using closed-chamber method with IRGA (LICOR 820) on 4-year-old oil palm on peat with 66.00±25 and 66.17±25.54 mg ha^{-1} yr^{-1}, respectively. Both studies were conducted between 6-13 months of measurement at the plantations in Riau and Jambi, Indonesia. Study conducted by Hergoualc'h *et al*. (2017) on 6-year old and 1-year old oil palm planted on peat in central Kalimantan, Indonesia showed soil CO_2 efflux measured using the closed-chamber method (EGM-4) for about 13 months at 50.65±0.30 mg ha^{-1} yr^{-1} and 43±0.30 mg ha^{-1} yr^{-1}, respectively.

Meaningful comparison is hard to achieve due to the method used, sampling frequency and the length of the soil CO_2 efflux measurement period that differ between studies. For example, the measurements for this study were taken from the first year until five years after planting at a newly cleared logged-over peat swamp forest. Other studies mostly reported for one year or less than one year of measurement in immature or matured oil palm plantations.

Our results indicated the mean annual total soil CO_2 efflux rates were decreasing over years (*Table 2*). Higher soil CO_2 efflux rate was recorded in the first year of measurement due to early disturbance of peatland. The microbial community changes and organic matter decomposition immediately following conversion possibly led to high soil temperature and subsequently increased in soil CO_2 emissions. However, soil CO_2 efflux decreased after four to five years after planting and expected to be lower when the palm and peat reach maturity. This might be due to decline in soil organic matter quality and nutrients which may decrease substrate-driven rates of CO_2 production from peat decomposition over time (Swails *et al*., 2017).

In addition, the palm canopy provided shade as they grow and resulted in low soil temperature, which contributed to lower soil CO_2 emissions. Jauhiainen *et al*. (2014) reported 90% of shaded area of agriculture land on tropical peatland resulted in a 33% lower CO_2 emission average on the unfertilised plots and a 66% lower emission average on the fertilised plots. As the palms matured, the soil temperature dropped, leading to lower CO_2 emission over time (*Figure 2*). The best management practices such as maintaining water table at 35-45 cm below the peat surface in oil palm plantation might contribute to reduced soil CO_2 emissions by minimising the peat oxidation layer and mineralisation rates (Tarmizi *et al*., 2009; Hasnol *et al*., 2011). In this study, the water table fluctuated between 30-43 cm (*Table 2*) below the peat surface which was regulated by weirs installed at collection drains and influenced by wet and dry seasons.

Field observation at the study sites showed that oil palm growth at Naman plot was healthier with larger canopies compared to Kenyana plot which showed poor growth. This was supported by the higher average standing biomass (*Table 3*) recorded in Naman plot (91.85±1.57 kg $palm^{-1}$) compared to Kenyana plot (83.34±2.02 kg $palm^{-1}$) and other morphological parameters such as trunk height; Naman plot (84.28±2.51 cm), Kenyana plot (70.26±2.08 cm) and LAI; Naman plot (3.23±0.06) and Kenyana plot (2.73±0.06). Hardon *et al*. (1969) reported a positive correlation was found between the leaf area and yield of different palms within the same family. High biomass might contribute to higher soil CO_2 efflux due to soil respiration by roots and microbes utilising the roots exudates in the rhizosphere (Lohila *et al*., 2003, Hirano *et al*., 2007). This suggests that more oil palm roots density was found in Naman plot than Kenyana plot which contributed to autotrophic respiration. Plant growth stage affects the root respiration that has a significant contribution to total soil respiration (Dariah *et al*., 2013). Research conducted by Khalid *et al*. (1999) and Henson and Chai (1997) have shown that high root density was found closer to the oil palm trunk and thus resulted in higher total soil respiration than further away from palm trunks (Swails *et al*., 2018; Manning *et al*., 2017; Comeau *et al*., 2016; Dariah *et al*., 2014). Other parameters measured such as the average field water table at Naman plot was -34.52±1.81 cm and Kenyana plot at -35.49±2.17 cm below the peat surface. Soil temperature and moisture content were 27.57±0.04°C (Naman plot), 27.68±0.04°C (Kenyana plot) and 43.77±0.75% (Naman plot) and 45.11±0.75% (Kenyana plot), respectively.

The highest average FFB production was recorded in the research Naman plot (14.15±1.52 t ha^{-1} yr^{-1}) and Kenyana plot (8.43±0.98 t ha^{-1} yr^{-1}) for the first four years of harvest (*Table 3*). There was a significant different of FFB between the plots at *p*-value <0.05. The lower FFB yield recorded from both peat types (Naman; 9.68 t ha^{-1} yr^{-1} and Kenyana; 6.04 t ha^{-1} yr^{-1}) were recorded in the early 2012 since it was the first year of harvesting for this research plot and have declined slightly in 2014 (*Figure 3*) and this could be due to the dry spell. A study reported by Melling *et al*. (2007) on FFB yield planted for the first and second year of harvest on Mixed peat swamp ex-forest were 6.64 t ha^{-1} yr^{-1} and 9.88 t ha^{-1} yr^{-1} respectively. The FFB yield for oil palm planted on Alan ex-forest area was 2.12 t ha^{-1} yr^{-1} and 2.37 t ha^{-1} yr^{-1} for the first and second year of harvest. Gurmit, 2004 also reported FFB

TABLE 2. AVERAGE SOIL CARBON DIOXIDE (CO_2) EFFLUX WITH STANDARD ERROR OF MEAN, FRESH FRUIT BUNCH (FFB) YIELD WATER TABLE AT DIFFERENT PLOT AND TOTAL ANNUAL RAINFALL (2010-2015); P1 IS PLOT 1 WHILE P2 IS PLOT 2

Parameter	Year					
	2010	2011	2012	2013	2014	2015
Soil CO_2 efflux (μmol m^{-2} s^{-1})						
Naman (P1)	6.09±0.20	4.32±0.20	4.84±0.12	5.53±0.10	4.97±0.10	3.59±0.13
Kenyana (P2)	5.90±0.20	4.20±0.19	4.26±0.12	5.07±0.11	3.79±0.09	3.39±0.14
FFB yield (t ha^{-1} yr^{-1})						
Naman (P1)	-	-	9.68±1.57	16.30±1.86	15.79 ± 2.51	14.83±1.02
Kenyana (P2)	-	-	6.71±0.98	8.21±0.88	7.58±0.89	11.23±0.77
Water table (cm)						
Naman (P1)	-	-30.67±0.56	-36.68±0.50	-35.06±0.33	-39.85±0.52	-30.34±0.53
Kenyana (P2)	-	-42.62±0.70	-33.12±0.50	-32.34±0.34	-38.33±0.41	-31.05±0.55
Annual rainfall (mm)	3 071.64	2 959.21	2 984.82	2 777.28	2 748.28	2 37.51

Note: The data represents the mean ± standard error of mean except for annual rainfall data (total).

TABLE 3. AVERAGE SOIL CARBON DIOXIDE (CO_2) EMISSION, FFB YIELD, SOIL AND MORPHOLOGICAL PARAMETERS

Item	Naman series	Kenyana series
Total soil CO_2 efflux (μmol m^{-2} s^{-1})	4.89±0.36^a	4.44±0.37^b
Field water table (cm)	-34.52±1.81^a	-35.49±2.17^b
Soil moisture content (%)	43.77±0.75^a	45.11±0.75^b
Soil temperature (°C)	27.57±0.04^a	27.68±0.04^b
Fresh fruit bunch (FFB) (t ha^{-1} yr^{-1})	14.15±1.52^a	8.43±0.98^b
Standing biomass (kg $palm^{-1}$)	91.85±1.57^a	83.34±2.02^b
Trunk height (cm)	84.28±2.51^a	70.26±2.08^b
Leaf area index (LAI)	3.23±0.06^a	2.73±0.06^b

Note: The data represents the mean±standard error of mean. Plots with significantly different (p<0.05) parameters have been denoted by suffix a and b.

yield of the early oil palm plantings on deep peat in United Plantation Berhad was around 11.4-12.8 t ha^{-1} for the fifth to sixth year after planting. The reduction in average FFB yield might be associated with the decreasing inorganic nutrient in peat surface especially phosphorus, calcium and iron towards the centre of the peat dome (Anderson, 1958; Muller, 1972). It was also stated that higher FFB yield was recorded from oil palm planted on Mixed peat swamp ex-forest than Alan ex-forest (Melling *et al*., 2007). Veloo *et al*. (2015) also reported that Naman series with sapric materials gave significantly better yields ranging from 19.48-22.92 t ha^{-1} for matured palms. Different types of peat have a significant effect on oil palm yield ranging from 9.47-22.9 t ha^{-1} (Veloo *et al*., 2015).

The higher soil CO_2 efflux rate might be attributed to low soil moisture and water table during the dry season (March until September) recorded in this study. There were significant differences (p<0.05) in soil CO_2 efflux rate, field water table, soil moisture and FFB yield between the study plots. Results showed that different types of peat have significant effects on soil CO_2 emissions and oil palm yield. Annual variation of soil CO_2 efflux rates and FFB yield could be attributed to various factors such as seasonal variation, soil heterogeneity and plantation management. Therefore, further research needs to be explored to find the relationship of related variables that contribute to soil CO_2 emissions and oil palm yield from peatland.

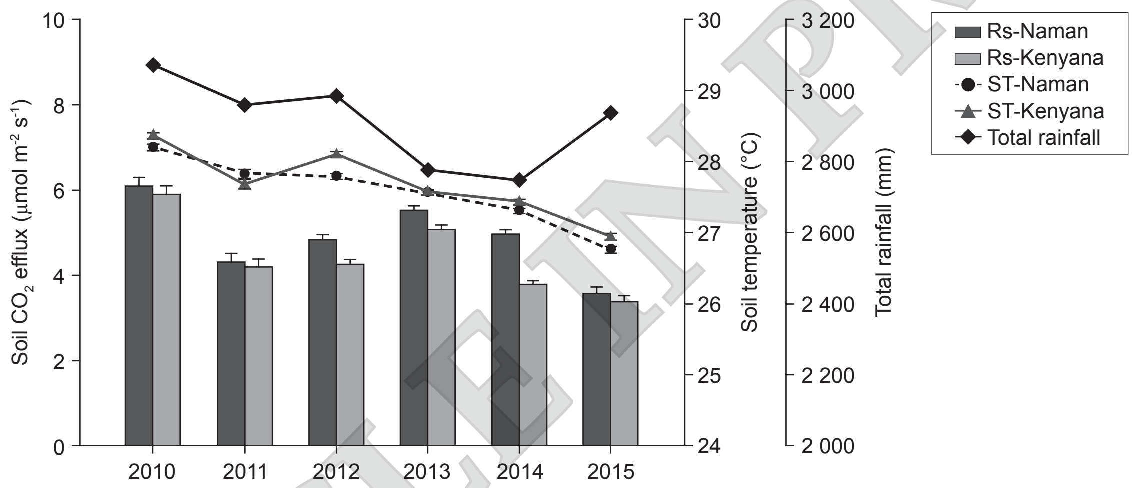

Figure 2. Average total soil respiration (Rs) rate and soil temperature (ST) with standard error of mean at different peat types and total rainfall.

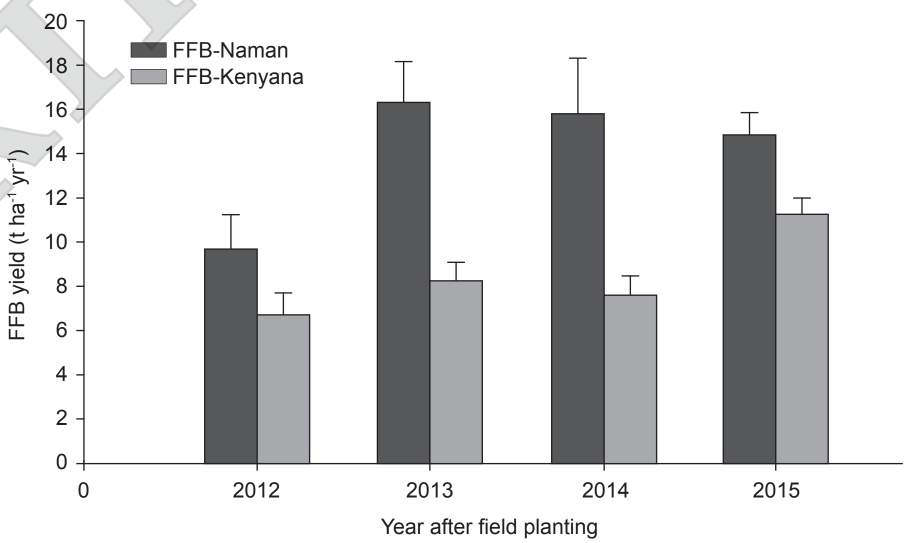

Figure 3. Average fresh fruit bunch (FFB) at different peat types.

CONCLUSION

There were significant differences in soil CO_2 efflux rate, field water table, soil moisture and FFB yield between the study plots. The average soil CO_2 efflux was highest in plot from Naman series compared to plot from Kenyana series. The highest FFB yield was recorded in plot from Naman compared to plot from Kenyana due to different characteristics of both peat soil series. Variation of CO_2 emission rates and FFB yield could be attributed by plantation management practices, interannual variation (wet and dry seasons throughout the year) and soil heterogeneity due to different peat types and properties in the study plots.

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