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Water table fluctuation and carbon dioxide emission from a tropical peat soil cultivated with pineapples (*Ananas comosus* L. Merr.)

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Abstract

Tropical peat land is an important buffer for climate change as it absorbs atmospheric carbon and stores large carbon reserve. Inappropriate drainage and agricultural development on peat land results in GHG emissions such as CO_2 and CH_4which could shift the peat land ecosystem from carbon sink to carbon source. The objectives of this study were to: (i) quantify CO_2 loss in a tropical soil under simulated water table fluctuation and (ii) determine the relationship between depth of water table and CO_2 loss of a tropical soil cultivated with pineapples. Soil CO_2 emission was captured using closed chamber method in field lysimeter and quantified using gas chromatography. It was carried out in July (dry month) and December 2015 (wet month). The peat soil water table fluctuation did not significantly affect emission of CO_2 in pineapple cultivation. For lower water table, 147.5 t CO_2 ha^{-1} yr^{-1} was emitted in the dry month whereas for higher water table, 19.6 t CO_2 ha^{-1} yr^{-1}. In the wet month, CO_2emission of the lower water table was 23.7 t CO_2 ha^{-1} yr^{-1}whereasfor high water tables the emission was 25.6 t CO_2 ha^{-1} yr^{-1}. Soil CO_2 emission for the lower water table was higher than that of the high water table whereas the opposite was true for the higher water table because of increase in soil temperature in the dry month. Regardless of season and depth of peat soil water table, this study will provide significant understanding of the effect of water table management on carbon loss in peat soils under pineapple cultivation.

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Introduction

Currently, tropical peat lands are being developed for agriculture. According to Melling *et al.*, (2005), peat soil reclamation for agriculture involves drainage which is characterized by lowering water table and soil compaction to aerate crop root zone. Drainage also increases peat soil bulk density, soil surface load-bearing capacity, and water-filled pore space. However, a study has shown that drainage through lowering of the water table changes peat lands from being C sink to C source because drainage generally reverses the C flux into net CO_2 emissions (Couwenberg, 2011). According to Van Huissteden *et al.* (2006), lowering peat soil water table increases peat decomposition rates due to enhanced microbial degradation of organic matter. It must be stressed that the understanding of soil C flux based on studies conducted in boreal and temperate peats is not fully applicable to tropical peat soils due to differences in environmental factors, peat soil properties, vegetation, microbial diversity and population, and management practices. On tropic peat lands, there could be other factors affecting soil CO_2 flux other than water table (Jauhiainen *et al.,* 2012).

The major greenhouse gases emitted from peat lands are CO_2, CH_4, and N_2O. Thesegases have been implicated in the global warming Chen *et al.* (2014). Thegases are emitted through aerobic and anaerobic microbial respiration, root respiration, peat oxidation, nitrification, and denitrification. Increasing water table depth increases CO_2 and CH_4 emissions (Chimner and Cooper, 2003; Berguland and Berguland, 2011). Greenhouse gas emissions are also influenced by land use type (Ismail, 2010), peat type (Kechavarzi *et al.,* 2010), temperature (Berguland *et al.,* 2010; Jauhiainen *et al.,* 2012), fertilization (Abdul *et al.,* 2005), and photosynthetic activities (Makiranta *et al.*, 2008). Samuel *et al.* (2006) and Fenner *et al.* (2007) reported that carbon also is lost as dissolved organic carbon (DOC) from peat lands through drainage water.

Research findings on GHG emissions in tropical peats are usually controversial as there is lack of standard procedures to measure GHG. Burrows *et al.* (2005) and Couwenberg (2011) suggested soil GHG emissions should measure at the soil surface using closed chamber method (Abdul *et al.*, 2005; Zulkefli *et al.*, 2010). With closed chamber method, GHG monitoring is carried out in very limited areas (few cm^2) and duration (few minutes) after which results from this method are expressed in $t ha^{-1} yr^{-1}$.Results from this method sometimes are inconsistent and sometimes controversial. To date, there is limited information on GHG emissions from peat lands cultivated with pineapples although pineapples are cultivated on tropical peat lands (Ahmed and Liza 2015; Liza and Ahmed, 2014; Ahmed *et al.,* 2013). A study conducted by Raziah and Alam (2010) suggests that the contribution of pineapples cultivation on tropical peats to GHG emissions is important as for example, 90% of pineapples are widely grown on peat soils of Malaysia.

Draining of tropical peat land commonly results in loss of soil carbon reserve. The decomposition of organic materials and microbial activities could release CO_2, CH_4, organic acids, and organic particulates. The rate of carbon loss is expected to be affected by the much talked about climate change, particularly from the increased intensity of dry and wet periods. The resultant extreme water table fluctuation may affect the amount and nature of aerobic and anaerobic peat material, which subsequently affect the decomposition of peat material and microbial activity, as well as crop performances.

In this study, it was hypothesized that peat soil water table fluctuation will affect the emissions of GHG in pineapple cultivation. Thus, the study was carried out to: (i) quantify CO_2 emission in a tropical soil under simulated water table fluctuation and (ii) determine the relationship between depth of water table and CO_2 emission of a tropical soil cultivated with pineapples.

Materials and methods

Site Description

A field study was carried out at the Malaysian Agricultural Research and Development Institute (MARDI), Sessang, Sarawak, Malaysia.

The experimental site has a total area of 387 ha located on a logged-over forest with a flat topography of 5 to 6 m above mean sea level. Based on the Von Post scale of H7 to H9, the peat soil is classified as well decomposed dark brown to dark coloured sapric peat with a strong smell with a thickness of 0.5 to 3.0 m. The average temperature of the area ranges from 22.1 to 31.7°C. The relative humidity of the area ranges from 61 to 98% humidity. The experimental site has annual mean rainfall of 3749 mm. From November to January (wet month), the monthly rainfall is more than 400 mm, but in July (dry month), the rainfall is 189 mm (Ahmed and Liza, 2014). The total area of the peat soil cultivated with *Moris* pineapple was 0.21 hectares. Weed sprouting on the soil surface was controlled manually when necessary.

Description of the Lysimeters Set up

Ten cylindrical field lysimeters made from ahigh density polyethylene (HDPE) measuring 0.56 m in diameter and 0.97 m in height were set up to simulate the natural condition of drained tropical peats. The size of the lysimeters used in this study was designed to ensure satisfactory growth and development of the pineapple plants. The lysimeters were equipped with water spillage opening which was attached to clear tubes mounted on the outside of the vessel to regulate and monitor water level. Each lysimeter was filled with peat soil to 0.90 m depth. Water loss from the soil was replenished by showering each lysimeter with rainwater. The amount of the rainwater added was based on the volume of the fabricated lysimeter and the mean annual rainfall at Saratok, Sarawak, Malaysia. The lysimeters with the peat soil was left in the open for five months (January to June 2015) to ensure that the peat soil had settled before the study was started.

Soil CO_2 Emission Measurements

Carbon dioxide emissions from the lysimeters were measured using the closed chamber method (IAEA, 1992). The peat soil CO_2 emissions were quantified using gas chromatography (Agilent 7890A) equipped with thermal conductivity detector (TCD). On the peat soil surface, the chambers were placed vertically.

Carbon dioxide emission measurements were carried out in early morning I (6:00 a.m. to 6:35 a.m.), afternoon (12:00 noon to 12:35 noon), evening (6:00 p.m. to 6:35 a.m.), midnight (12:00 a.m. to 12:35 a.m.), and early morning II (6:00 a.m. to 6:35 a.m.). These measurements represented the total monthly CO_2 losses through the peat soil surface. The values obtained were averaged and converted into units of t $ha^{-1}yr^{-1}$. The CO_2 flux was calculated from the increase in the chamber concentration over time using the chamber volume and peat soil area covered. The equation used to calculate CO_2 flux is present as (IAEA, 1992):

$$\text{Flux} = [d(CO_2)/dt] \times PV/ART$$

Where $d(CO_2)/(dt)$ is the evolution rate of CO_2 within the chamber headspace at a given time after putting the chamber into the soil, P is the atmospheric pressure, V is the volume headspace gas within the chamber, A is the area of the soil closed by the chamber, R is the gas constant, and T is the air temperature.

The CO_2 flux was measured in the early morning I (6:00 a.m. to 6:35 a.m.), afternoon (12:00 noon to 12:35 noon), evening (6:00 p.m. to 6:35 a.m.), midnight (12:00 a.m. to 12:35 a.m.), and early morning II (6:00 a.m. to 6:35 a.m.) to obtain a 24 hour CO_2 emission. The CO_2flux measurements were carried out in July 2015 and December 2015 to represent dry and wet seasons.

Measurement of environmental data

Soil temperature was measured at the same time of sampling CO_2 using digital thermometer.

Statistical analysis

Treatment effects were tested using analysis of variance (ANOVA) and means of the treatments were compared using Duncan's New Multiple Range Test at $P \leq 0.05$. The relationship between soil temperature and CO_2emission was determined using Pearson correlation analysis. The statistical software used for this analysis was the Statistical Analysis System (SAS) Version 9.3.

Results and discussion

In the dry (July) and wet (December) months, lysimeters were used to simulate CO_2 emission for low (0.9 m from soil surface) and high (0 m from soil surface) water table.

Table 1. Correlation between soil temperature and soil CO_2 emission for different water table during dry and wet months.

Variable	Soil temperature (°C)			
Soil CO_2 flux	Dry month (July 2015)		Wet month (December 2015)	
	Low water table	High water table	Low water table	High water table
	r =0.17	r =-0.16	r = 0.26	r =-0.05
	p =0.53	p =0.56	p =0.34	p =0.86

r - Pearson's correlation coefficient, p – probability level at 0.05 (n =15).

Table 2. Soil temperature (°C) during CO_2 measurement at different times of the day (dry and wet months).

Time	Dry month (July 2015)		Wet month (December 2015)	
	Low water table	High water table	Low water table	High water table
Early morning I (6:00 a.m. to 6:35 a.m.)	24.0^{a}	25.0^{a}	32.5^{a}	32.3^{a}
Afternoon (12:00 noon to 12:35 noon)	36.7^{b}	36.0^{b}	28.8^{b}	31.3^{b}
Evening (6:00 p.m. to 6:35 p.m.)	36.7^{b}	36.0^{b}	25.3^{c}	25.7^{c}
Midnight (12:00 a.m. to 12:35 a.m.)	27.3^{c}	25.0^{a}	27.3^{d}	25.0^{cd}
Early morning II (6:00 a.m. to 6:35 a.m.)	24.3^{a}	30.0^{c}	25.0^{c}	24.3^{d}

Mean values with different letters within the same column are significantly different at $P \leq 0.05$.

The greenhouse gas measurements were carried out in the early morning I(6:00 a.m. to 6:35 a.m.), afternoon (12:00 noon to 12:35 noon), evening (6:00 p.m. to 6:35 p.m.), midnight (12:00 a.m. to 12:35 a.m.) and early morning II (6:00 a.m. to 6:35 a.m.) to obtain a 24 hour CO_2 emission. In the dry month, CO_2 emission was higher (147.5 t $CO_2 ha^{-1}$ yr^{-1}) in the low water table compared with that of the high water table (19.6t CO_2 ha^{-1} yr^{-1}) (Fig. 1).

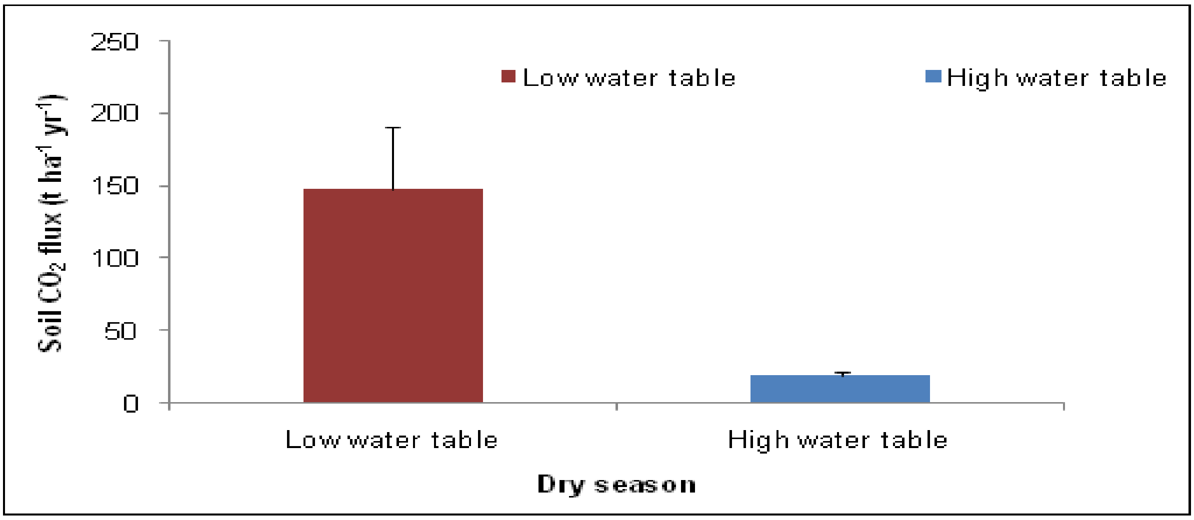

Fig. 1. Carbon dioxide emissions from a tropical peat of different water table in July (dry month) cultivated with pineapple. (Error bars represent standard error).

The higher CO_2 emission from the low water table was because of the availability of substrates as energy source for microbial metabolism (Kerchavarzi *et al.*, 2010; Kuzyakov, 2006). The CO_2 emission in the wet month was higher in the lysimeter with high water table (25.6t CO_2 ha^{-1} yr^{-1}) compared with that of the low water table (23.7t CO_2 ha^{-1} yr^{-1})(Fig. 2). The higher CO_2 emission from the high water table in the wet month was because of oxidation of the peat soil as CO_2 emission relates to heterotrophic respiration from microbial activities (Jauhiainen *et al.*, 2012; Kuzyakov, 2006).

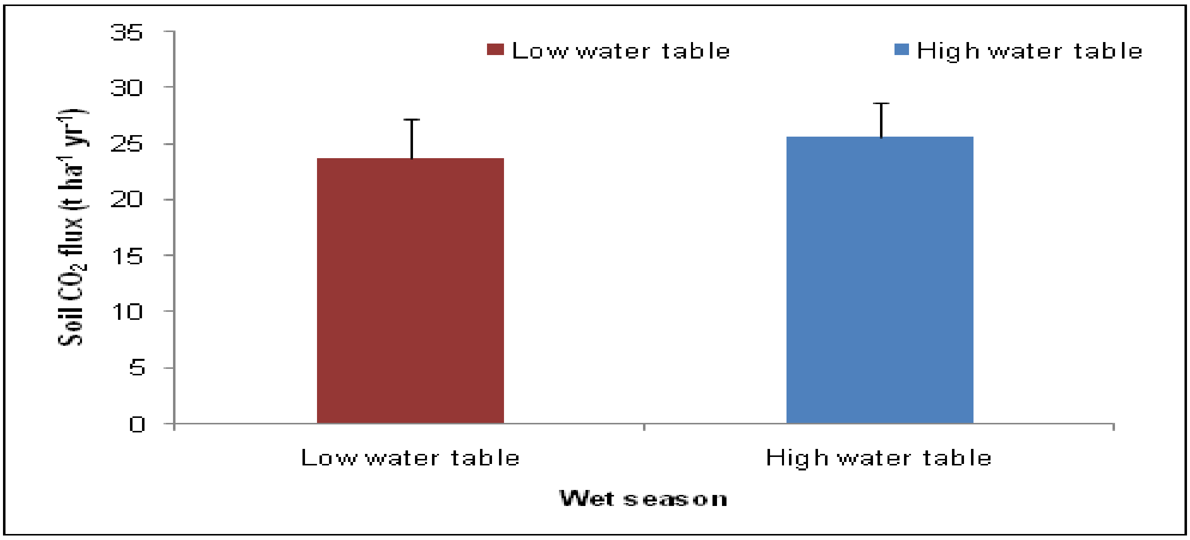

Fig. 2. Carbon dioxide emission at different water table in December (wet month) cultivated with pineapple. (Error bars represent standard error).

In the dry month, the soil temperature at low and high water tables was highest in the afternoon and evening because of microbial activities in the soil (Petterson, 2014). At low water table (wet month), soil temperature was highest in early morning I followed by afternoon, midnight, evening, and early morning II. Moreover, high water table showed that the soil temperature decreased from early morning I to early morning II.

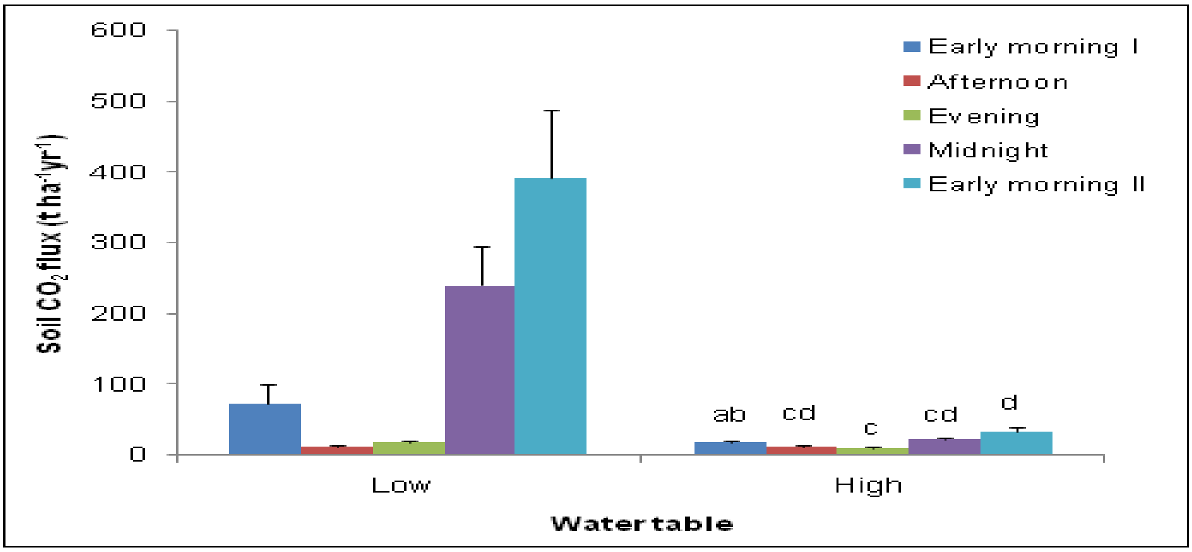

Fig. 3. Carbon dioxide emissions from a tropical peat soil at different times sampling and water table in July (dry month) cultivated with pineapple. (Error bars represent standard error and soil mean fluxes with different letters are significantly different at $P \leq 0.05$).

Temperature affects CO_2 emission from peat decomposition. Activation of microbial activities was due to increase in peat soil oxidation. A study conducted by Zulkefli *et al.* (2010) and Petterson (2004) showed that higher soil temperature favours microbial activity however, above optimal temperature (> 30°C) may inhibit microbial respiration as inactivation of biological oxidation system.

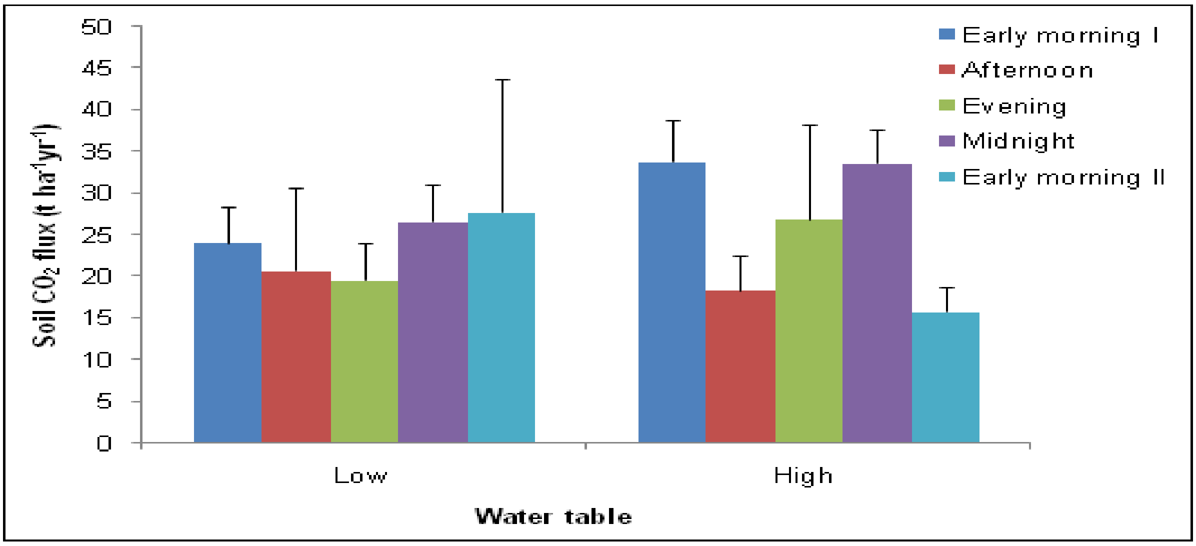

Fig. 4. Carbon dioxide emissions from lysimeter with a tropical peat soil at different times of the day and water table in December (wet month) cultivated with pineapple. (Error bars represent standard).

Conclusion

Peat soil water table fluctuation does not significantly affect the emission of CO_2 in pineapple cultivation on the tropical peat soil. Soil CO_2 emission under low water table in July (dry month) was higher than that of high water table (during wet month). This study will provide significant understanding on the effect of water table fluctuation and carbon loss in peat land ecosystem. This is essential because there are limited studies on the relationship between depth of water table and carbon losses through CO_2 from tropical peat soils cultivated with pineapples.

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