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Horizontal and Vertical Emissions of Carbon Dioxide and Methane from a Tropical Peat Soil Cultivated with Pineapple (*Ananas comosus* (L.) Merr.)

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Abstract

Peat soils have been developed for large scale plantations such as oil palm due to their positive contribution to Malaysia's economic growth in agriculture sector. However, these developments contribute to the emissions of greenhouse gases (GHGs) mainly carbon (CO_2) and methane (CH_4). To date, there were limited information of GHGs emissions from pineapple cultivation and also inadequate data on horizontally and vertically soil GHGs emissions in peat soil profile. Thus, this study was carried out to determine carbon CO_2 and CH_4 emissions horizontally and vertically from a drained tropical peat soils from a drained tropical peat soils cultivated with pineapple (*Ananas comosus* (L.) Merr. Horizontal and vertical movements of CO_2 and CH_4 were measured from a drained tropical peatland with *Ananas comosus* (L.) Merr. Tropical peat soils cultivated with *Ananas comosus* (L.) Merr. contributed to 79.7 % of CO_2, and 0.2 % of CH_4 based on the yearly basis regardless of the differences in diurnal transportation; horizontal and vertical emission. Soil CO_2 and CH_4 were emitted the most through horizontal transportation with 70.84 % CO_2, and 0.19 % CH_4 compared to 8.85 % CO_2, and 0.02 % CH_4 in vertical transportation. The emission of CO_2 was influenced by depth of water table and temperature. It is generally believed that lowering of peats water table leads to emission of higher CO_2 emission because this process leads to exposure of peat soils to oxidation. Seasonal variation in CH_4 flux was higher in the wet seasons due to rainfall; this might have increased the water table of the peat soil. The results suggest that CO_2 and CH_4 emissions occur both horizontally and vertically regardless of season. Therefore in order not to underestimate CO_2 and CH_4 emissions from peat soil, it is important to measure the emissions of this greenhouse gas which has been implicated in environmental pollution horizontally and vertically.

Key words: carbon dioxide, horizontal, methane, peatlands, vertical

1. Introduction

Cultivation of pineapples on peat soils is economically profitable. However, concerns have been expressed about cultivation of crops on peat soils as they are prone to emissions of harmful greenhouse gases such as carbon dioxide (CO_2) and methane (CH_4). A study on pineapple cultivation on a peat soil had revealed that CO_2 and CH_4 are emitted (Liza, 2014). Globally, agriculture contributes to 24% of the greenhouse gases emission (IPCC, 2014). Tropical peatlands with high organic matter content are naturally a conducive environment for greenhouse gas emissions especially when they are cultivated. Methane as an example, can be consumed by aerobic microbes as it moves to the soil surface.

Carbon dioxide and CH_4 are the main greenhouse gases which are emitted from pineapple cultivation on peat soils (Chen et al., 2014; Liza, 2014; Jassal et al., 2011; Florides & Christoudoulides, 2008). Peat soils contain approximately 15% to 25% of the terrestrial soil carbon and nitrogen worldwide (Bajtes, 1996). The organic carbon of peat soils undergo natural decomposition, thus causing loss of mass and release by-products such as CH_4 and CO_2 (Hadi et al., 2005). Carbon in peat soils are lost in the forms of CH_4 and CO_2. Naturally, these gases are produced under anaerobic and aerobic conditions.

Peatlands as a major carbon sequester arises because greenhouse gases (GHGs) contribute to global warming (Daud, 2009). Tropical peat soils' carbon and GHG balance is determined largely by the net balance between carbon uptake in photosynthesis and carbon release through ecosystem respiration by: (a) vegetation (autotrophic respiration resulting in CO_2 emissions from both plant foliage and root systems) and (b) organisms involved in organic matter biological decomposition. In addition, carbon is leached out from the system in drainage runoff as dissolved organic carbon (DOC) or particulate organic carbon (POC) (Moore et al., 2011).

It is important to note that: (a) carbon cycle and GHG processes are highly dynamic and vary at all spatial and temporal scales owing to regional and local variations in macro- and micro-climate and hydrology, as well as localised variations in vegetation and peat decomposition dynamics (Hooijer et al., 2011; Jauhiainen et al., 2005, 2010); and (b) in terms of emissions and global warming potential, CO_2 is the most important gas which is emitted from drained peatlands, thus, contributing 98% or more of the combined global warming potential (GWP) of CO_2 and CH_4 (Jauhiainen et al., 2011).

Currently, there is limited information on soil CO_2 and CH_4 emissions from pineapple cultivation on peat soils. According to Couwenberg (2011), CH_4 emissions from paddy ecosystem on peat soils are within uncertainty range of the Intergovernmental Panel on Climate Change (IPCC) CH_4 default emission factor. Current practices in the measurement of CO_2 and CH_4 emissions from the surface of peat soils are controversial. Moreover, the emissions of CO_2 and CH_4 have recently attracted considerable attention because of their contribution to the global climate change. The losses of these gases are also important because soil carbon must be stored for sustainable crop production. In spite of the intensive international research efforts, the newest global CO_2 and CH_4 balances still have considerable uncertainties in evaluating the specific sources for enhanced CO_2 and CH_4 (IPCC 1996; Mosier 1996). Uncertainties are because of the variability in soil, and environmental conditions, time, and method used for the measurement of CO_2 and CH_4 (Mosier 1996; Firestone & Davidson 1989).

Research findings on CO_2 and CH_4 emissions in tropical peats which are planted with pineapples are usually controversial due to few or lack of standard information (Ahmed & Liza, 2015). Greenhouse gas emissions are commonly measured using closed chamber method in a very limited area and time (Zulkefli et al., 2010; Abdul *et al.*, 2005). This leads to inconsistent and sometimes controversial issues which are related to lack of rigid information. Although pineapples are cultivated on tropical peat soils, there is little information on GHG emissions from these soils. The contribution of pineapples cultivation on tropical peat soils to GHG emissions is important. For example, 90% of pineapples are widely grown on peat soils of Malaysia (Raziah & Alam, 2010). Kuzyakov (2006) reported that it was important to partition the GHG emissions into respiration components such as microbial and root respirations before deciding on whether peat soils are net sinks or net sources of atmospheric GHG. Failure to account for these GHG losses from drained tropical peatlands could cause underestimation of future rates of increase in atmospheric greenhouse gases and their effects on global environmental change processes (Page et al., 2007).

Based on the foregoing discussion, the objective of this study was to determine the horizontal and vertical emissions of CO_2 and CH_4, from a tropical peat soil which is cultivated with pineapple (*Ananas comosus* (L.) Merr. In this study, it was hypothesized that the emissions of CO_2 and CH_4 into the atmosphere from peat soils under pineapple (*Ananas comosus* (L.) Merr cultivation are affected by horizontal and vertical transportations. This hypothesis is based on the assumption that the mechanism or mode of transportation of gases causes CO_2 and CH_4 to be lost to the environment outside or within the soil profile (horizontally and vertically). The results from this study could be used to provide ideas for the appropriate procedures for CO_2 and CH_4 emissions measurement on a cultivated peat soils. Information obtained from different emissions measurement method will also provide insights on the possible future measures to control CO_2 and CH_4 emissions from cultivated peat soils.

2. Materials and Methods

2.1 Experimental Site Description

This study was carried out at the Malaysia Agricultural Research and Development Institute (MARDI) at Saratok, Sarawak, Malaysia. MARDI, Saratok has an area of 387 hectares and located on a logged-over forest with flat topography of 5 m to 6 m above mean sea level (Ahmed & Liza, 2015). Based on von Post Scale, the peat soil is classified under H7 to H9; well decomposed sapric peat with a strong smell and thickness ranging between 0.5 m and 3.0 m (Ahmed & Liza, 2015). The mean temperature of the peat soil area ranges from 22.1 °C to 31.7 °C with a relative humidity of 61% to 98% (Ahmed & Liza, 2015). The annual mean rainfall is 3749 mm but in the wet season, the monthly rainfall is more than 400 mm whereas in the dry season it is approximately 200.7 mm (Ahmed & Liza, 2015).

2.2 Carbon Dioxide and Methane Emission Measurements

Horizontal and vertical emissions of CO_2 and CH_4 were measured from the surface and the walls of the peat soil using different chamber methods. The horizontal emissions of CO_2 and CH_4 from the surface of the peat soil were measured using I-shaped closed chamber method whereas the vertical emissions of CO_2 and CH_4 were measured using the L-closed chamber method (Ahmed & Liza, 2015). The CO_2 and CH_4 emission measurements were carried out at 0-5 cm and 5-10 cm peat soil depth, respectively. Measurements of the CO_2 and CH_4 emission were carried out in 10 m x 10 m drained peat soil plots cultivated with pineapple. Carbon dioxide, and CH_4, flux sampling was carried out for 24 hours at 6 hours interval (between 0600 hr to 0600 hr) in dry (July and August) and wet (September and December) seasons.

2.3 Horizontal Carbon Dioxide and Methane Emission Measurements

The horizontal emissions of CO_2, and CH_4 were measured using the closed chamber method (Norman et al., 1997 and Crill, 1991). The fabricated I-shaped chamber was pressed vertically on the surface of the soil pit to a depth of 3 cm to 5 cm (Figure 1). The chamber was equilibrated for 30 minutes. Headspace samples of 20 mL were extracted from the chamber at minute 1, minute 2, minute 3, minute 4, minute 5, and minute 6 using a 50 mL syringe. The extracted gas was then transferred to 20 mL vacuum headspace vial using a disposable syringe needle. Carbon dioxide and CH_4 concentrations were measured using a Gas Chromatography (GC – Agilent 7890A) equipped with thermal conductivity detector (TCD) (Ahmed & Liza, 2015).

Figure 1. Fabricated I-shaped chamber pressed vertically on the surface of the peat soil pit to a depth of 3-5 cm

2.4 Vertical Carbon Dioxide and Methane Emission Measurements

The vertical emissions of CO2 and CH4 were measured at the walls of the soil pit (10 cm depth interval), starting from the soil's surface to 10 cm above the water table (saturated zone). The L-shaped chamber was installed horizontally to the walls of the soil pit to a distance of 20 cm (Figure 2). For each depth, peat soil was manually scrapped to a suitable working size. The open cylinder was equilibrated for approximately 30 minutes. Headspace sample of 20 mL was extracted from the chamber at minute 1, minute 2, minute 3, minute 4, minute 5, and minute 6 using a 50 mL syringe. The extracted gas was transferred to 20 mL vacuum headspace vial using a disposable syringe needle. Carbon dioxide and CH4 concentrations were measured using Gas Chromatography (GC – Agilent 7890A) equipped with thermal conductivity detector (TCD) (Ahmed & Liza, 2015).

Figure 2. Fabricated L-shaped chamber installed horizontally to the wall of the peat soil pit to a distance of 20 cm

2.5 Carbon Dioxide and Methane Fluxes Calculation

The gas flux results were based on the measured CO_2 and CH_4 from the three replications using different methods (I-chamber and L-chamber) in the dry and wet seasons. The values were averaged and converted to t ha^{-1} yr^{-1}. The CO_2 and CH_4 fluxes were then calculated using the following equation (Zulkefli et al., 2010; Widen & Lindroth, 2003; IAEA, 1992):

$$Flux = [(CO_2/CH_4)\ dt]\ X\ PVART'$$

where $d(CO_2/CH_4)/(dt)$ is the evolution rate of CO_2/CH_4 within the chamber headspace at a given time after which the chamber were placed into the soil, P is the atmospheric pressure, V is the volume headspace gas within the chamber, A is the area of soil enclosed by the chamber, R is the gas constant, and T is the air temperature.

2.6 Measurements of Peat Soil Temperature

During gas flux measurement, soil temperature was measured using a portable weather station (WatchDog 2900) installed at the study site.

2.7 Statistical analysis

Analysis of variance (ANOVA) was used to detect treatment effects whereas treatments means were compared using Tukey's Studentized Range (HSD) Test at $p \leq 0.05$. The relationship between peat soil temperature and gas flux emission was determined using Pearson correlation analysis. The statistical software used for this analysis was Statistical Analysis System (SAS) version 9.3.

3. Results and Discussion

3.1 Horizontal Carbon Dioxide Emission

Carbon dioxide emission decreased from the early morning I to afternoon after which it increased at midnight and early morning II (Figure 3). The lower CO_2 emission was due to the decrease in soil temperature and this caused a decrease in the oxidation of the peat soil. On the other hand, the increase in CO_2 emission was the results of increase in soil temperature (25 ℃ to 30 ℃) as increase in soil temperature favours microbial activities within the soil profile. Studies have shown that CO_2 emissions from peat soils relate to soil temperature, as increase in soil temperature increases production of CO_2 through decomposition of organic materials (Jauhiainen et al., 2012; Berglund et al., 2010; Kechavarzi et al., 2010; Zulkefli et al., 2010). Furthermore, the increase in CO_2 emission might be due to heterotrophic and autothrophic processes in the rhizosphere (Mäkiranta et al., 2008; Kuzyakov, 2006). However, the lowest CO_2 emission occurs in the evening when peat soil temperature above optimal temperature (>30 ℃) inhibits microbial respiration due to the inactivation of biological oxidation system (Zulkefli *et al.*, 2010, Pietikäinen et al., 2005, Petterson, 2004).

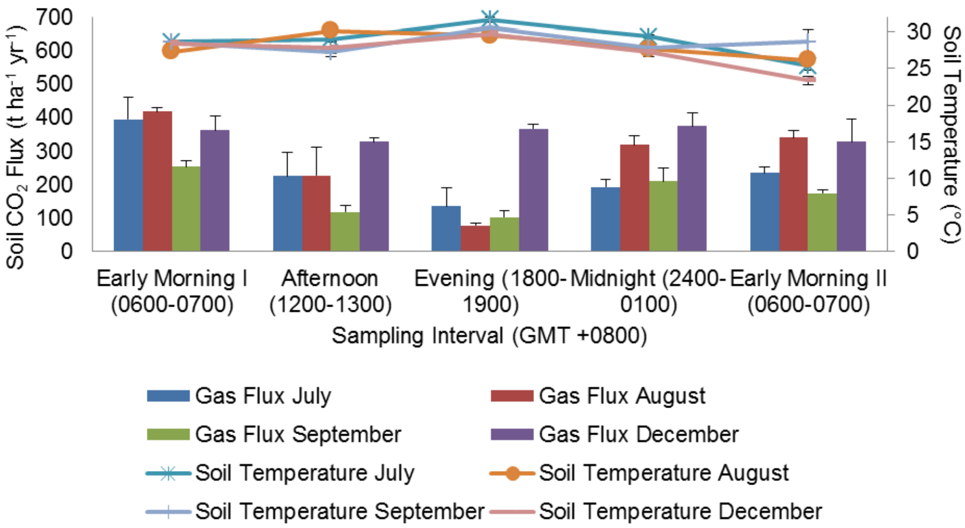

Figure 3. Horizontal emissions of CO_2 at different sampling interval and different monitoring period from a tropical peat soil cultivated with pineapple (Error bars represent standard error)

3.2 Vertical Carbon Dioxide Emission

In July 2015 and December 2015, the CO_2 emission increased from early morning I to evening and thereafter it decreased in the evening till early morning II (Figure 4). The decrease in CO_2 was due to heterotrophic respiration was affected by increase in soil temperature (Zulkefli et al., 2010). In September 2015, the decrease in CO_2 emission from early morning I to midnight was due to moderate temperature fluctuation from early morning I to midnight (Figure 4). The increase in CO_2 emission in the early morning II is related to respiration of the roots of the pineapple plants at 5 months old (Liza, 2014). Furthermore, the increase in CO_2 emission in the early morning II might be due to heterotropic respiration in the rhizosphere (Mäkiranta et al., 2008; Kuzyakov, 2006). In August 2015, the CO_2 emission decreased from early morning I to afternoon after which it gradually increased in the evening before decreasing at midnight and early morning II (Figure 4) due to soil temperature fluctuations which commonly influence CO_2 emission.

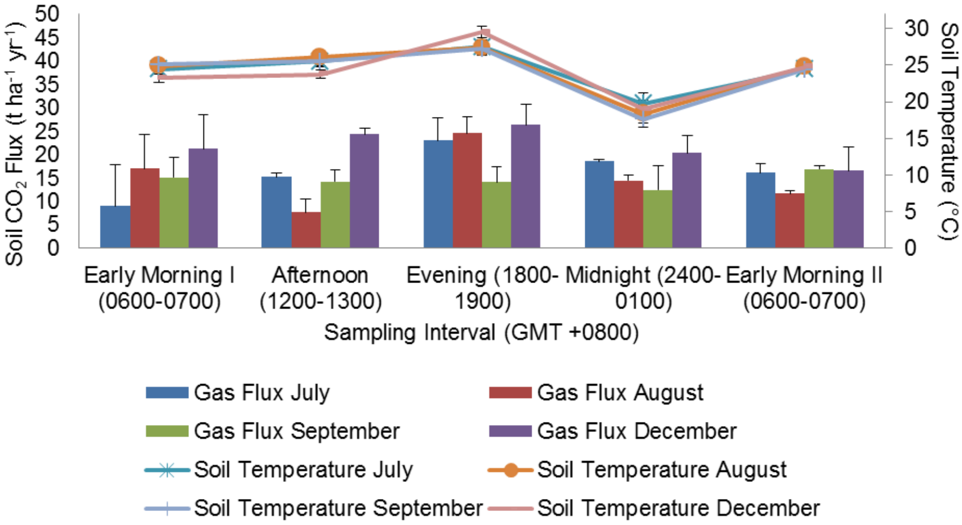

Figure 4. Vertical emissions of CO_2 at different sampling interval and different monitoring period from a tropical peat soil cultivated with pineapple (Error bars represent standard error)

3.3 Summary for Carbon Dioxide Emission

Between July 2015 and December 2015, there were significant differences in the horizontal emission of CO_2 (Figure 5). The highest CO_2 emission occurred in December 2015 because of high soil moisture. According to Jauhiainen et al., (2012), in the presence of oxygen, soil moisture above water table affects CO_2 emission (Liza, 2014). In August 2015, CO_2 emission correlated negatively with soil temperature (Table 1), suggesting that soil temperature causes increases CO_2 emission. This relationship is in agreement with the observation in Figure 3 where soil CO_2 emission increased with decreasing temperature from midnight to early morning. However, from July 2015 to December 2015, CO_2 emission did not correlated with soil temperature due to temperature fluctuation across monitoring periods.

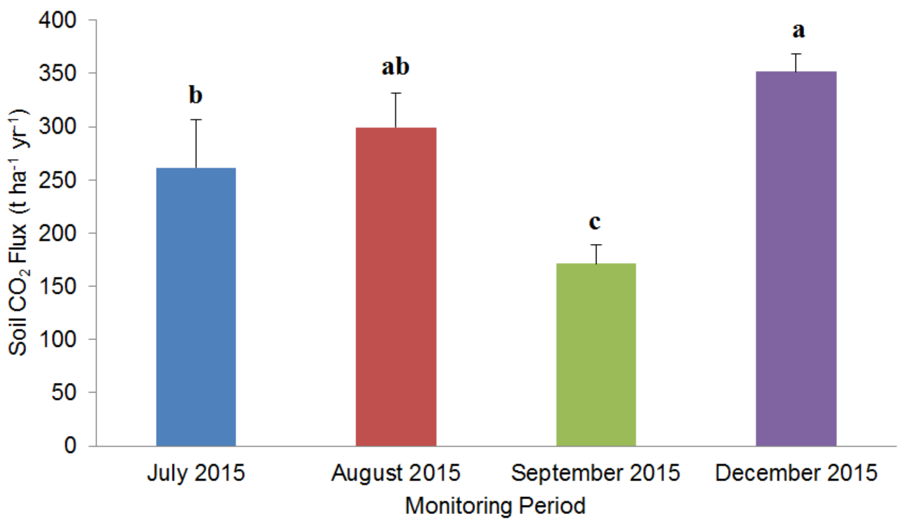

Figure 5. Horizontal emission of carbon dioxide at different monitoring period from a tropical peat soil cultivated with pineapple (Error bars represent standard error and soil mean fluxes with different letters are significantly different at $p \leq 0.05$)

Table 1. Correlation between horizontal soil carbon dioxide emission and soil temperature of a tropical peat soil

	Soil Temperature			
Month/ Variable	July 2015	August 2015	September 2015	December 2015
Soil CO_2 emission	-0.13^{ns}	0.62**	0.05^{ns}	0.48^{ns}

** $p \leq 0.05$

Between August 2015 and December 2015, there were significant differences in vertical CO_2 emission (Figure 6). The highest CO_2 emission occurred in December 2015 due to high soil moisture (Jauhiainen et al., 2012). From July 2015 to December 2015, there was no correlation between soil CO_2 emission and soil temperature (Table 2). These results were consistent with the no significant differences in CO_2 emission regardless of time as reported in Figure 6.

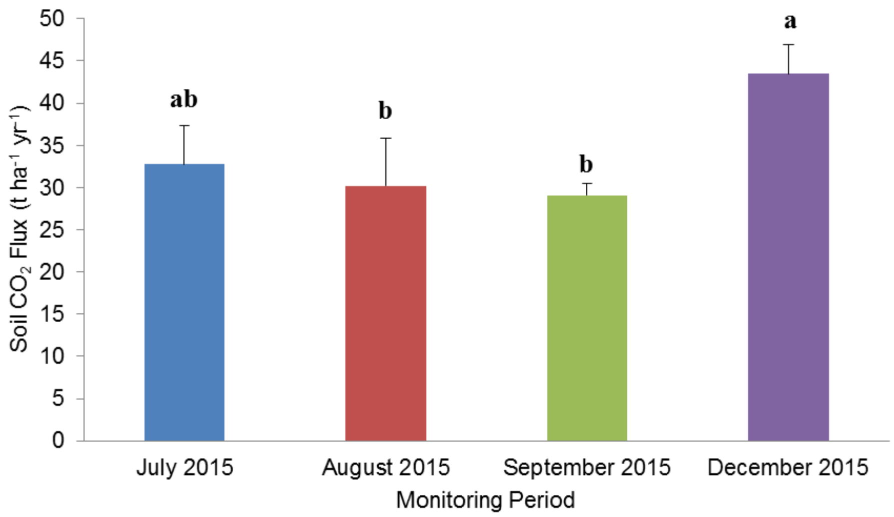

Figure 6. Vertical emission of carbon dioxide at different monitoring period from a tropical peat soil cultivated with pineapple (Error bars represent standard error and soil mean fluxes with different letters are significantly different at $p \leq 0.05$)

Table 2. Correlation between vertical soil CO_2 emission and soil temperature of a tropical peat soil

	Soil Temperature			
Month/ Variable	July 2015	August 2015	September 2015	December 2015
Soil CO_2 emission	-0.02^{ns}	0.05^{ns}	-0.29^{ns}	0.14^{ns}

3.4 Horizontal Methane Emission

Methane emissions increased in July 2015, August 2015, and September 2015 from early morning I to evening and afterwards, it decreased moderately from evening to early morning II whereas in December 2015, CH_4 emissions decreased from early morning I to afternoon after which it increased from evening to early morning II (Figure 7). The increase in CH_4 emissions might be due to favorable environment and soil temperature. Additionally, the increase in CH_4 emissions is related to transportation of CH_4 whereby CH_4 might have been transported in bubbles through diffusion (Farmer et al., 2011). However, the decrease in CH_4 emissions relates to methanogenic bacteria whose activities affect CH_4 emissions. Conversion of CH_4 to CO_2 by methanotrophs at the peat aerobic zone could also be one of the reasons for the reduction in CH_4 productions (Liza, 2014).

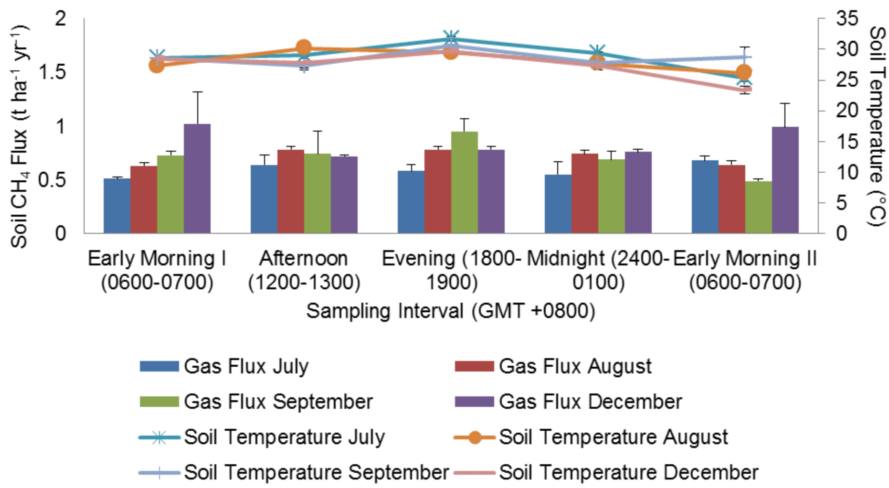

Figure 7. Horizontal emissions of CH_4 at different sampling interval and different monitoring period from a tropical peat soil cultivated with pineapple (Error bars represent standard error)

3.5 Vertical Methane Emission

There were no significant differences in CH_4 emissions across sampling intervals (Figure 8). This trend relates to availability of nitrate (electron acceptors) which inhibits production of CH_4 (Sirin & Laine, 2012; Jassal et al., 2011). Availability of nitrate was due to nitrogen fertilizer application (Liza, 2014). The CH_4 emissions were statistically similar irrespective of sampling interval and month of sampling because of the oxidation of CH_4 by methanotrophs to CO_2 (Parmentier et al., 2009).

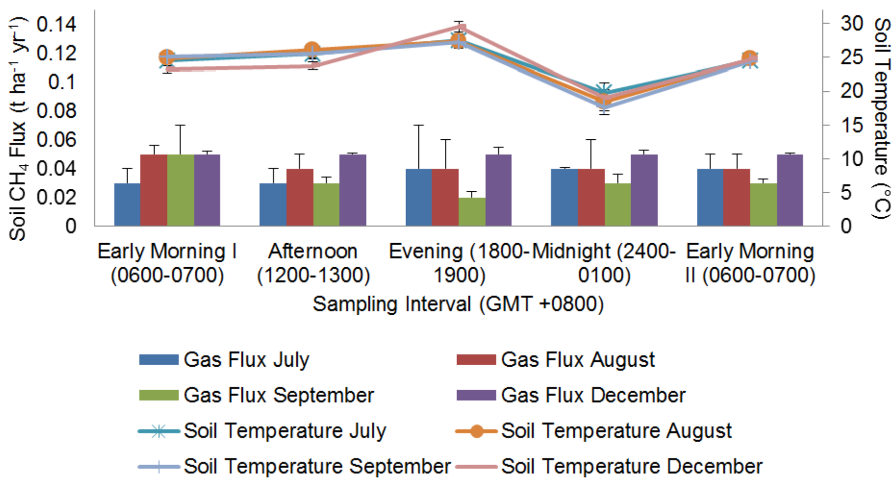

Figure 8. Vertical emissions of CH_4 at different sampling interval and different monitoring period from a tropical peat soil cultivated with pineapple (Error bars represent standard error)

3.6 Summary for Methane Emission

From July 2015 to December 2015, there were significant differences in CH_4 emission (Figure 9). The highest CH_4 emission occurred in December 2015 due to high rainfall (697 mm). This resulted in anaerobic and water logged condition such that it favored emission of CH_4. This water logged condition restricted diffusion of atmospheric oxygen and microbial decomposition of organic materials (Chimner & Cooper, 2003). However, anaerobic degradation of carbon to methanogens-CH_4 was possible (Parmentier et al., 2009). From July 2015 to December 2015, there was no correlation between soil CH_4 emission and soil temperature (Table 3), suggesting that the factor controlling CH_4 emission is related to the fluctuation of water table at the soil-water interface (Sirin & Laine, 2012).

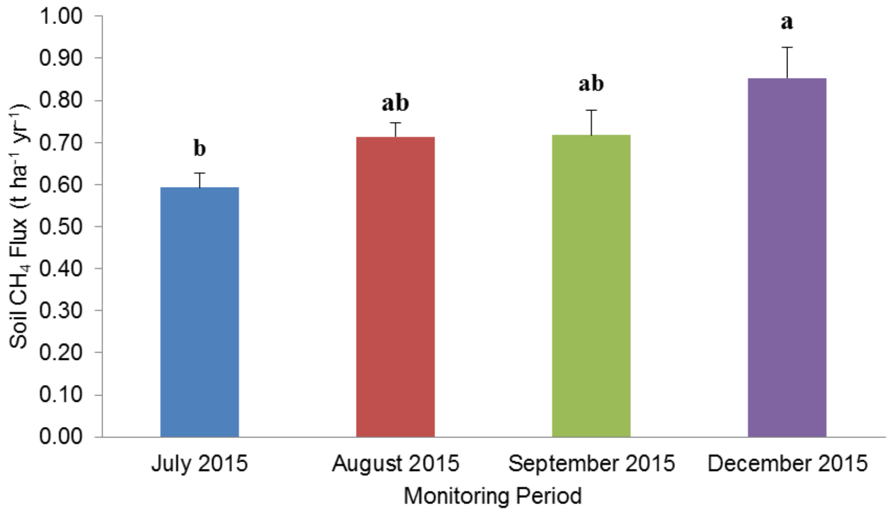

Figure 9. Horizontal emission of methane at different monitoring period from a tropical peat soil cultivated with pineapple (Error bars represent standard error and soil mean fluxes with different letters are significantly different at $p \leq 0.05$)

Table 3. Correlation between horizontal soil CH_4 emission and soil temperature of a tropical peat soil

	Soil Temperature			
Month/ Variable	July 2015	August 2015	September 2015	December 2015
Soil CH_4 emission	-0.44^{ns}	0.28^{ns}	0.15^{ns}	-0.26^{ns}

Between August 2015 and December 2015, there were significant differences in vertical CH_4 emission (Figure 10). The highest CH_4 emission in December 2015 was due to high soil moisture in the top soil above the water table which affects CH_4 emission through oxygen availability (Jauhiainen et al., 2012). From July 2015 to December 2015, there was no correlation between soil CH_4 emission and soil temperature and this suggests that CH_4 emission from the tropical peat under pineapple cultivation is not affected by soil temperature.

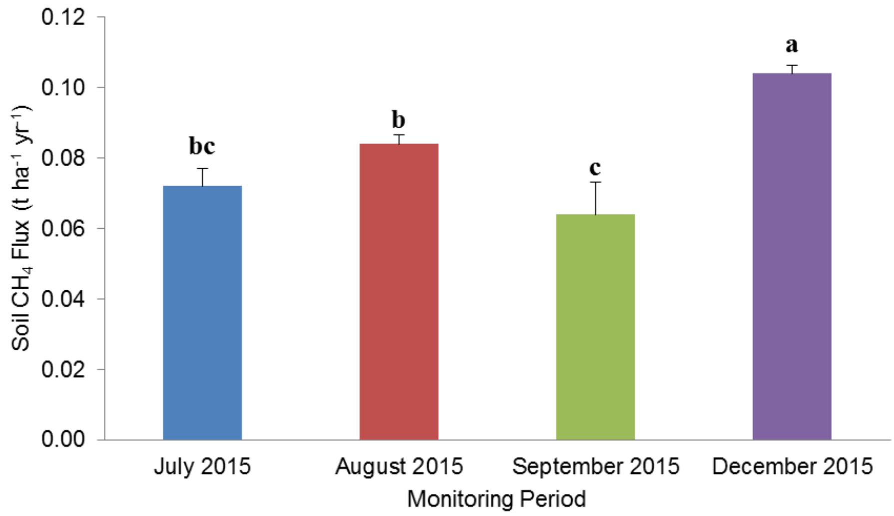

Figure 10. Vertical emission of methane at different monitoring period from a tropical peat soil cultivated with pineapple (Error bars represent standard error and soil mean fluxes with different letters are significantly different at $p \leq 0.05$)

Table 4. Correlation between horizontal methane emission and soil temperature of a tropical peat soil

	Soil Temperature			
Month/ Variable	July 2015	August 2015	September 2015	December 2015
Soil CH_4 emission	0.19^{ns}	0.27^{ns}	0.22^{ns}	0.01^{ns}

4. Conclusion

The horizontal soil CO_2 emission was higher in the dry season than in the wet season due to the high carbon content of the peat soil. The vertical soil CO_2 emission was higher in the wet season than in the dry season due to higher rainfall during the wet season.

The horizontal soil CH_4 emission was higher than in the wet season due to the increase in water table which resulted in increase of CH_4 emission. The vertical soil CH_4 emission was higher in the wet season than in the dry season because of favourable condition essential for methanogenesis as methanogenesis increases oxidation of CH_4.

Soil CO_2 emission was higher compared with CH_4 regardless of the differences in diurnal transportation and mode of transportation (horizontal or vertical transportation of CO_2 and CH_4). With respect to the nature of transportation, horizontal transportation contributed 70.84% of CO_2 and 0.19% CH_4 emissions whereas vertical transportation contributed 8.85% of CO_2, and 0.02% CH_4 emissions. Therefore, it can be concluded that CO_2 and CH_4 emissions occur horizontally and vertically regardless of season and time of the day. In order not to underestimate CO_2 and CH_4 emissions from peat soils, it is important to measure the emissions of these greenhouse gases horizontally and vertically.

Acknowledgements

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