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Horizontal and vertical emissions of methane from a drained tropical peat soil cultivated with Pineapple

(*Ananas comosus* (L.) Merr.)

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Abstract

Drained tropical peat soils especially for agricultural purposes could lead to methane (CH_4) emission into the atmosphere. Methane emission from peat soils to the atmosphere depends on rates of methane production, consumption and ability of the soil and plants to transport the gas to soil's surface and also within soil particles. The objective of this study was to determine CH_4 fluxes horizontally and vertically from the floor and wall of the pit of a tropical peat soils cultivated with *Ananas comosus* (L.) Merr. and to determine the relationship between CH_4 transportation and CH_4 emission from a drained tropical peat soils. Gas samplings were conducted in the dry and wet seasons. The horizontal emission of CH_4 in the dry and wet seasons were 2.96 t CH_4 $ha^{-1}yr^{-1}$ and 4.27 t CH_4 $ha^{-1}yr^{-1}$, respectively. The vertical emission of CH_4 in the dry and wet seasons were 0.38 t CH_4 $ha^{-1}yr^{-1}$ and 0.50 t CH_4 $ha^{-1}yr^{-1}$, respectively. The total amount of the horizontal and vertical CH_4 emissions in the dry and wet seasons were 3.34 t CH_4 $ha^{-1}yr^{-1}$ and 4.47 t CH_4 $ha^{-1}yr^{-1}$, respectively. Horizontal emission of CH_4 was higher in the wet season due to increase in water table which resulted in increase of CH_4 emission. Therefore, it can be concluded that horizontal emission of CH_4 is higher than vertical emission suggesting that there is a need for direct CH_4 measurement from cultivated peat soils to ensure that CH_4 emission is neither underestimated nor overestimated.

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Introduction

Peatlands cover approximately 400 million hectares of the Earth's land surface (Maria, 2008). Peatlands occur mainly in the northern hemisphere (North America, Russia, and Europe) whereas tropical peatlands occur in the mainland of East Asia, Southeast Asia, Caribbean, Central America, South America, and Southern Africa (Maria, 2008). The current estimation of undisturbed peatland is approximately 30-40 million hectares (Maria, 2008). In Southeast Asia, peatland covers approximately 27.1 million hectares (Hooijer *et al.,* 2010) where 2.6 million hectares of the peatland occur in Malaysia (Ismail and Jamaludin, 2007). Sarawak has the largest area of peatland in Malaysia, covering approximately 1.4 million hectares, which is equivalent to 50% of the total land area (Andriesse, 1988). Globally, agriculture is considered to be responsible for approximately two-thirds of the anthropogenic sources (Melling *et al.,* 2006).

Agriculture, forestry, and peat extraction for fuel and horticultural purposes are the major causes of peatland disturbance because, as the peats get disturbed, the alteration in its hydrology results in the oxidation of peat soils. These activities alter the greenhouse gases balanced (Maria, 2008). Concern of the role of peatlands as the main carbon sequestration has been expressed because greenhouse gases (GHGs) emission contributes to global warming (Daud, 2009). Cultivation of different crops has different impact on the environment (Azqueta and Sotelsek, 2007). Currently, there is lack of information on soil CH_4 emissions horizontally and vertically from pineapple cultivation on drained tropical peatlands.

Current practices in the measurement of CH_4 emissions from peatland surface often give controversial and unsolved results in which various factors contribute to the problem. For example, CH_4 can be consumed by aerobic microbes during its transportation to the soil surface and dissolve in water, thus, transported away from peatlands. Methane fluxes are dependent on the rates of CH_4 production and consumption, so is the ability of soils and plants to transport CH_4 to the atmosphere. Methane is produced under highly reduced conditions by methanogenic bacteria (Maria, 2008). Thus, it is produced in the saturated zone of peat soil and once produced it can be transported to the atmosphere through diffusion, ebullition (bubbling) or as diffusion or mass flow through vascular plants (Maria, 2008).

Methane emissions from peatlands are related to water table position (Roulet *et al.*, 1992) and peat temperature (Bubier *et al.*, 1995). The three major environmental factors that control CH_4 emission rates from peatlands are water table position, temperature, and substrate properties such as pH and mineral nitrogen content (Barlett and Harriss, 1993; Moore and Dalva, 1993; Crill *et al.,* 1988). It has also been suggested that the CH_4 consumption rate depends on management factors such as drainage, compaction, and nitrogen (N) fertilization (Weitz *et al.,* 1998; Ball *et al.,* 1997; Hansen *et al.,* 1993). In the drained part of peatlands, CH_4 is easily transported through lateral inter-connected pore spaces.

The emissions of CH_4 have recently attracted considerable attention because of their contribution to the global climate change. Methane loss is also important because soil C must be stored for sustainable crop production. In spite of intensive international research efforts, the newest global CH_4 balances still have considerable uncertainties in evaluating the specific sources for enhanced CH_4 (IPCC, 1996; Mosier, 1996). Uncertainties mainly are because of the variability in soils and environmental conditions, time, and method used for measurement (Mosier, 1996; Firestone and Davidson, 1989).

Research findings on GHG emissions in tropical peatlands planted with pineapples are usually controversial due to lack of standard information (Ahmed and Liza, 2015). Besides, the contribution of pineapples cultivation to GHG emissions is important because 90% of pineapples are widely grown on peat soils of Malaysia (Raziah and Alam, 2010).

Failure to account for these GHGs losses from drained tropical peatlands could underestimate future rates of increase in atmospheric GHGs and their effects on global environmental change processes (Page *et al.,* 2007). Currently, there is limited information on soil CH_4 emissions emission from pineapple cultivation on drained peat soils. Current practices in the measurement of CH_4 emissions are only from the surface of peat soils. Research findings on CH_4 emissions in tropical peats planted with pineapples are usually controversial due to few or lack of standard information (Ahmed and Liza, 2015). Methane emissions are commonly measured using closed chamber method in a very limited area and time (Zulkefli *et al.,* 2010). 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 CH_4 emissions from peats cultivated with pineapples based on different transportation approach (horizontal and vertical emissions).

Based on the above justification, the objectives of this study were to: (i) quantify horizontal and vertical CH_4 emissions from a drained tropical peatlands cultivated with pineapple using two chamber methods and (ii) determine the relationship between CH_4 transportation and CH_4 emission from a drained tropical peatlands. In this study, we hypothesized that horizontal emission of CH_4 into the atmosphere from peat soil cultivated with pineapple will be higher than that of vertical emission. This hypothesis is based on the assumption that the mechanism of transportation of CH_4 is influenced by horizontal and vertical movements.

Materials and methods

Site Description

Methane emission from a drained tropical peatland cultivated with *Ananas comosus* (L.) Merr at Malaysia Agricultural Research and Development Institute (MARDI) Peat Research Station Saratok, Sarawak, Malaysia, was determined. Malaysia Agricultural Research and Development Institute (MARDI) Peat Research Station Saratok, Sarawak, Malaysia has a total area of 387 hectares located on a logged-over forest. The von Post Scale of Humification shows that the peat soils are sapric peat (well decomposed peat) with humification (Ahmed and Liza, 2015). The mean temperature of the peat area ranges from 22.1 to 31.7 °C with relative humidity ranging from 61 to 98% (Ahmed and Liza, 2015). The annual mean rainfall of the area is 3749 mm during the wet season. The monthly rainfall is more than 400 mm whereas during the dry season, the mean rainfall is 189 mm (Ahmed and Liza, 2015).

Greenhouse Gases Emission Measurements

Horizontal and vertical emissions of CH_4 were measured from the surface and the wall of the peat soil using different chamber methods. The horizontal emission of CH_4 from the surface of the peat soils was measured using I-shaped closed chamber method whereas the vertical emissions of CH_4 was measured using the L-closed chamber method (Ahmed and Liza, 2015). The CH_4 emission measurements were carried out at 0-5 cm and 5-10 cm peat soil depth, respectively. Measurements of the CH_4 emission were carried out in 10 m x 10 m drained peat soil plots cultivated with pineapple. Methane flux sampling was carried out for 24 hours at every 6 hours interval (between 0600 hr to 0600 hr) in July 2015 (dry season) and December 2015 (wet seasons). The five sampling periods used in this study to obtain a 24 hours CH_4 emission are listed in Table 1.

Soil CH_4 Horizontal Emission Measurements

The horizontal movement of CH_4 emissions from the peat soil surface was measured using the closed chamber method (Norman *et al.,* 1997; Crill, 1991). The fabricated I-shaped chamber was gently pressed vertically on the surface of the soil pit at of 3-5 cm depth. The chamber was equilibrated for 30 minutes. The 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 a 20 mL vacuum headspace vials using a disposable syringe needle. Methane concentration was measured using a Gas Chromatography (GC- Agilent 7890A) equipped with thermal conductivity detector (TCD) (Ahmed and Liza, 2015).

Soil CH_4 Vertical Emission Measurements

The vertical CH_4 movement was measured at 5 cm depth interval (0-5 cm, 5-10 cm), from the surface to 10 cm above water table (saturated zone). The L-shaped chamber was installed horizontally to the wall of the peat soil at 20 cm. The end of the chamber was covered and sealed with steel cap and parafilm, respectively. For each depth, peat soil was manually removed to a suitable working size pit. The open cylinder was left standing for approximately 30 minutes to establish an equilibrium state. Methane concentration was measured using the method described previously.

Methane flux calculation

The CH_4 results were based on the measurement of CH_4 from the five different durations using two methods (I-chamber and L-chamber) in the dry and wet seasons. The values of CH_4 emitted were averaged and converted into units of t ha^{-1} yr^{-1}. The CH_4 fluxes were then calculated using the following equation (Zulkefli *et al.,* 2010; Widen and Lindroth, 2003; IAEA, 1992):

$$Flux = \left[\frac{d\ (CH4)}{dt}\right] X\ \frac{PV}{ART'}$$

where *d(CH4)/(dt)* is the evolution rate of 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.

Measurements of Peat Soil Temperature

During CH_4 measurement, soil temperature was measured using sensors.

Statistical analysis

Analysis of variance (ANOVA) was used to detect treatment effect whereas treatments means were compared using Duncan's New Multiple Range Test (DNMRT) at $P \leq 0.05$. The relationship peat soil temperature and CH_4 emission was determined using Pearson correlation analysis. The statistical software used for this analysis was Statistical Analysis System (SAS) version 9.3.

Results and discussion

Soil CH_4 Horizontal Emission

Methane emission was significantly affected by season (Figure 1). In the dry season, the CH_4 emission was significantly lower (0.59 t ha^{-1}yr^{-1}) compared with that of the wet season (0.85 t ha^{-1}yr^{-1}) (Figure 1) due to the increase in water table which resulted in increase of CH_4 emission.

Table 1. Description of methane sampling periods with specified duration of assessment.

Methane sampling periods	Duration of assessment
Morning	6.00am to 7.00am
Afternoon	12.00pm to 1.00pm
Evening	6.00pm to 7.00pm
Midnight	12.00pm to 1.00am
Early morning	6.00am to 7.00am

The seasonal variation in CH_4 flux was higher in the wet seasons due to rainfall which might have increased the water table of the peat soil. According to Farmer *et al.,* (2011), during wet season, CH_4 is emitted in the form of bubbles which are transported by molecular diffusion through aerobic layer of the peat. S oil CH_4 emission was not significant regardless of sampling period (Figure 5). Methane emission in the morning (1.02 t ha^{-1}yr^{-1}) was the highest during the wet season followed by early morning (0.99 t ha^{-1}yr^{-1}). The lowest CH_4 emission occurred at noon (0.72 t ha^{-1}yr^{-1}).

Table 2. Day and night temperature of the experimental site (Saratok, Malaysia).

Variable	Surface		Lateral	
	Dry season	Wet season	Dry season	Wet season
	Jul-15	Dec-15	Jul-15	Dec-15
Mean day time temperature (°C)	28.7	27.3	25.5	25.3
Mean night time temperature (°C)	29.4	27.3	19.8	19.0
Mean day and night time temperature differences (°C)	0.7	0.0	5.7	6.3
Treatments	Mean soil temperature (°C)			
Morning	28.6^{b}	28.4^{b}	24.5^{b}	23.3^{b}
Noon	29.0^{b}	27.8^{bc}	25.5^{ab}	23.8^{b}
Evening	31.7^{a}	29.7^{a}	27.5^{ab}	29.5^{a}
Midnight	29.4^{b}	27.3^{c}	19.8^{c}	19.0^{c}
Early Morning	25.4^{c}	23.4^{d}	24.5^{b}	24.8^{b}

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

Table 3. Correlation between soil CH_4 emission and soil temperature.

Variable	Soil temperature	
	Dry season	Wet season
	Jul-15	Dec-15
Soil CH_4 horizontal flux	r= - 0.44	r= - 0.26
	p= 0.10	p= 0.34
	n=15	n=15
Soil CH_4 vertical flux	r= - 0.20	r= - 0.01
	p= 0.40	p= 0.98
	n=20	n=20

r- Pearson's correlation coefficient, p- probability level at 0.05.

The CH_4 emitted regardless of time of sampling was not significant (Figure 5). However, in the dry season, CH_4 emission in the early morning (0.68 t $ha^{-1}yr^{-1}$) was highest in the dry season followed by at noon (0.64 t $ha^{-1}yr^{-1}$). The lowest CH_4 emissions occurred in the morning (0.51 t $ha^{-1}yr^{-1}$).

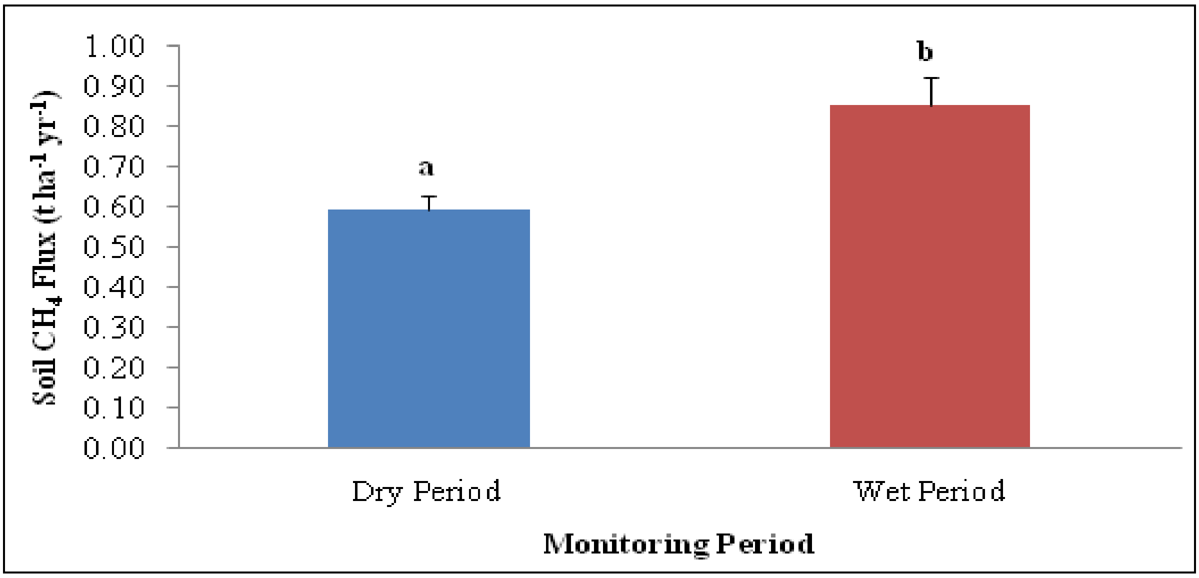

Fig. 1. Horizontal emission of methane during dry and wet seasons from a peat soil cultivated with pineapple. (Error bars represent standard error and soil mean fluxes with different letters are significantly different at $P \leq 0.05$.).

The differences in the day and night temperature of the experimental site in the dry and wet seasons (Table 2) might have also inhibited the photosynthetic activity of the *Ananas comosus* (L.) Merr. plants. Furthermore, the root respiration and decomposition of the pineapple plants might have contributed to the emission of CH_4 in the wet season (Ahmed and Liza, 2015). Methane emission did not correlate with soil temperature (Table 3) which suggests that the factor controlling CH_4 emission was related to the fluctuation of water table at the soil-water interface (Sirin and Laine, 2012).

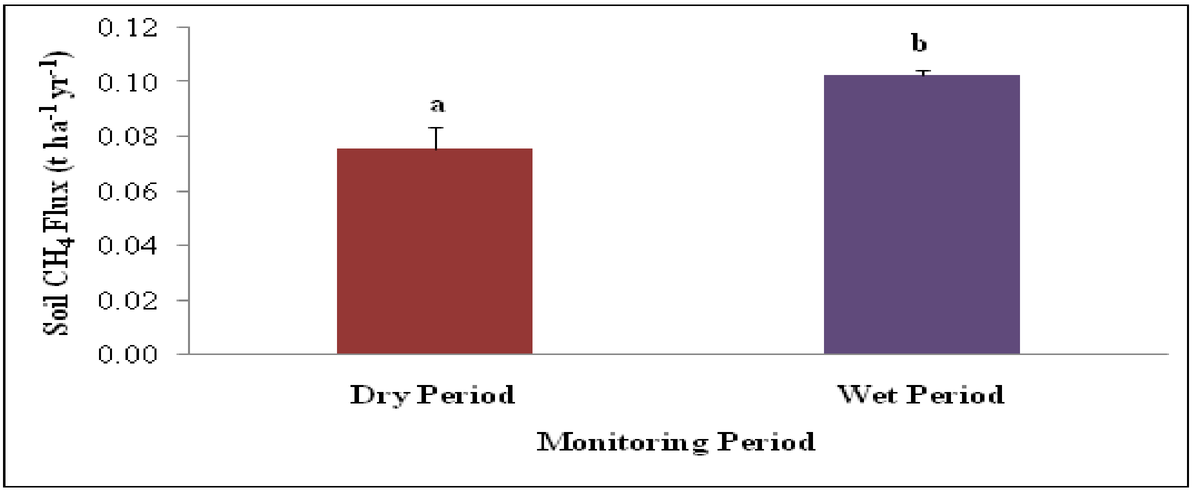

Fig. 2. Vertical emission of methane during dry and wet seasons from a peat soil cultivated with pineapple. (Error bars represent standard error and soil mean fluxes with different letters are significantly different at $P \leq 0.05$.).

Soil CH_4 Vertical Emission

In the dry and wet seasons, there was distinct seasonal variation in the vertical emission of CH_4 (Figure 2). The lowest vertical emission of CH_4 occurred in the dry season (0.08 t ha^{-1}yr^{-1}) whereas the highest CH_4 emission occurred in the wet season (0.10 t ha^{-1}yr^{-1}). Vertical emission of CH_4 was higher in the wet season due to the water table level of the peat soil. In peat soils, water table is the most important environmental variable that controls greenhouse gases flux (Moore and Dalva, 1993; Martikainen *et al.,* 1992) because the rate of CH_4 emission increases with increasing water table (IPS, 2008).

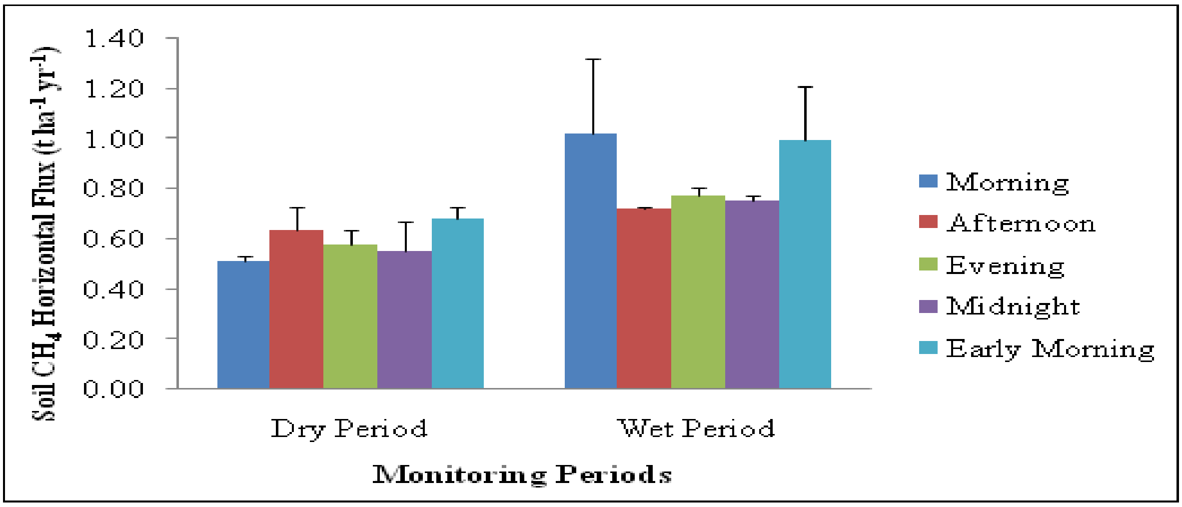

Fig. 3. Horizontal emission of methane from peat soil cultivated with pineapple at different sampling periods (dry and wet seasons). (Error bars represent standard error.).

In the wet season, higher CH_4 emission occurred because of favourable condition essential for methanogenesis as methanogenesis increases oxidation of CH_4 (Melling *et al.,* 2005). The CH_4 emission is also related to the microbial population and the availability of adequate substrate for microbial metabolism, but not for plant root activities (Kechavarzi *et al.,* 2010; Kuzyakov, 2006). According to Melling *et al.* (2005), a thick aerobic layer with higher temperature increases CH_4 oxidation thus, resulting in higher CH_4 uptake as shown in CH_4 emission during the wet season (Figure 3). The CH_4 emissions were statistically similar across all the five sampling periods however, there was higher CH_4 emission in the early morning (2.73 t $ha^{-1}yr^{-1}$) during wet season followed by at noon (2.59 t $ha^{-1}yr^{-1}$) and morning (2.06 t $ha^{-1}yr^{-1}$) in that order. The CH_4 emitted regardless of time of sampling was not significantly different (Figure 4).

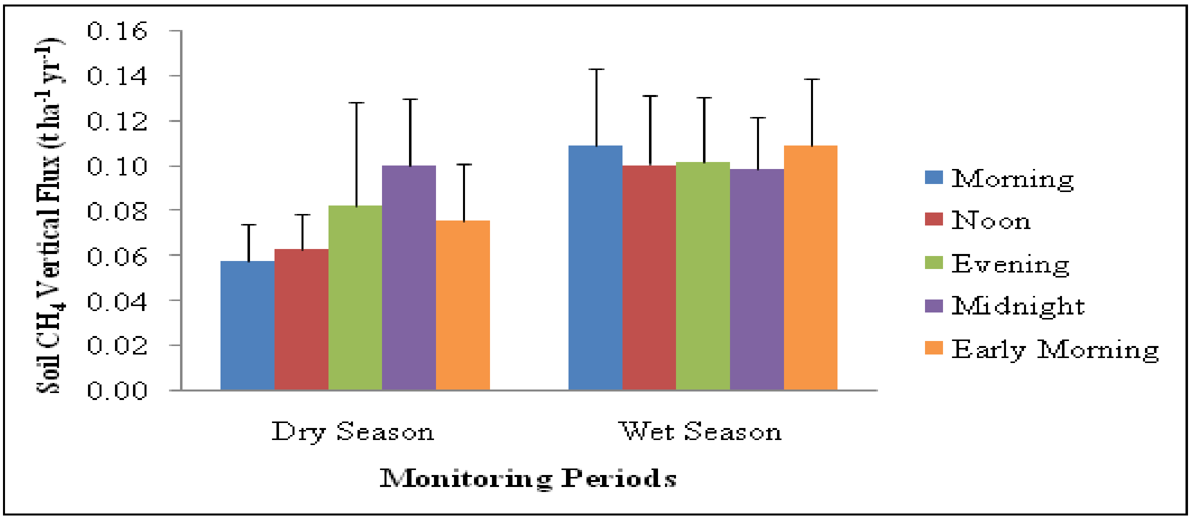

Fig. 4. Vertical emission of methane from peat soil cultivated with pineapple at different sampling periods (dry and wet seasons). (Error bars represent standard error.).

Irrespective of season, there was no correlation between vertical emission of CH_4 and soil temperature in the dry season for vertical emission (Table 3). These results suggest that CH_4 emission from the tropical peat cultivated with pineapple is not affected by soil temperature (Table 3).

Conclusion

In pineapple cultivation tropical peat soils, horizontal emission of CH_4 is higher than vertical emission. However, to avoid underestimation of CH_4 emission from pineapples cultivation on tropical peats, both horizontal and vertical emissions of this gas must be considered regardless of season.

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