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METHANE EMISSION FROM PADDY SOIL IN RELATION TO SOIL TEMPERATURE IN TROPICAL REGION

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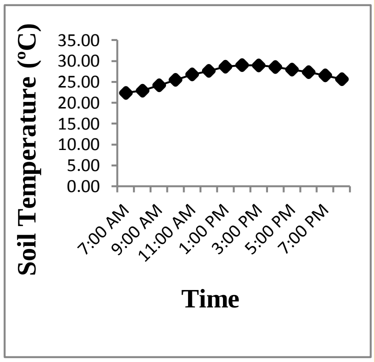
Graphical abstract



Abstract

Methane (CH_4) is 21 times more powerful as a greenhouse gas than carbon dioxide. Wetlands including flooded paddy fields are one of the major sources for this gas. Paddy fields are responsible for producing 25 to 54 Tg of CH_4 annually. Methane emission rate could be affected by several factors such as irrigation pattern, fertilizer type, soil organic matter and soil temperature. Among them, soil temperature is a determining factor which deserves to be investigated. This study performed with the aim of understanding the effect of soil temperature on the methane emission rate from paddy soil in a short period of time (hourly) and long term (during rice growing season). The results of this study suggest that soil temperature could control the amount of methane emission and there is a positive and strong correlation in both soil temperature and methane emission pattern in short period of time. However, in case of long term trend, other factors such as water management and plant age decreased this correlation from 0.768 to 0.528.

Keywords: Greenhouse gas, methane emission, soil temperature, paddy soil

1.0 INTRODUCTION

Methane (CH_4) is an effective greenhouse gas (GWP=21). It can be produced through the final step of biodegradation process of organic matter in flooded soils[1]. In fact, this greenhouse gas is a bio product of methanogenic activity in anaerobic condition of soil.

Flooded rice fields are responsible for a major amount of methane emission with production of 25 to 54 Tg CH_4 annually[2,3]. Considering growing global population, increasing the rice production is unavoidable so that it is predicted to reach 760 million tons in 2020[4,5]. As a result, methane emission from rice fields will be increased to about 145 Tg y^{-1} by 2025[6]. Under these circumstances, there is a strong demand for a sustainable rice production system toward protection of our environment. Therefore, the methane emission from rice cultivation need to be controlled by taking some strategies based on scientific findings. For this purpose, the determining factors should be known and assessed. Temperature is one of these factors.

Temperature is an influencing factor on biological process (e.g., within the soil) which controls the methane production[7]. It has been indicated that methane emission would increase from 4°C to reach a maximum at 37 °C[8]. Furthermore, in anaerobic zone of rice soils, methane formation starts at 15 to 20 °C[9]. Thus, the methane emission might be regulated by soil temperature. Therefore, the relation between soil temperature (Ts) and methane emission over short (during a day) and long term periods (during growing season of rice plant) are the main concern of this study.

2.0 EXPERIMENTAL DESIGN

2.1 Plant Material

Rice cultivar "MR219" (Oryza sativa L. ssp. indica) is being cultivated widely in Malaysia. This cultivar is producing about 80% of rice crop in Muda irrigation scheme area located at 6° 11.8' N, 100° 4.5' E[10]. Therefore, this variety was selected for cultivation. The rice seeds were grown at nursery and seedlings at the age of 25 days after planting were transplanted in paddy plots. This experiment was conducted in two cycles.

2.2 Cultivation Medium

Rice paddy Plots with 2 m length × 2 m width were selected. Soil profile, from bottom to the top, included of large gravels (below 40 cm depth); small gravels (0.5-1 cm) at depth of 30-40 cm; second layer soil (silty clay) at depth of 10-30 cm; and top soil (silty clay) at depth of 0-10 cm, respectively. The soil was from Jawa series with 51% clay and 43% silt in top 10 cm and, 53% clay and 42% silt in sub soil. In addition, the soil carbon and nitrogen content were about 6.38% and 0.62%, respectively.

2.3 Methane Emission

Static chamber method was employed for collecting methane emission from paddy soil. For this purpose, chambers (1 m height × 0.5 m diameter of basement) made of transparent Plexiglas were prepared. The bottom edges of the chambers were put in the 7 cm depth of the soil to be sealed. The methane emitted from paddy soil was collected in Tedlar® bags made of transparent 2ml film attached on the top of the chambers. Then, the methane amount was measured by a portable gas detector (Crowcon, Oxfordshire England) in three replications. Then, methane flux was calculated using the following equation (1)[11,12]:

$$Fm= \frac{\Delta X}{10^6} \times BV_{(STP)} \times 16 \times \frac{10^3}{22400} \times \frac{1}{A} \times \frac{60}{t} \qquad \text{Eq. [1]}$$

Where: Fm = CH_4 efflux in mg m^{-2} h^{-1}, Δx = change in gas concentration in ppmv from time (0 to min), BV $_{(STP)}$ = volume of the chamber (cm^3) at standard temperature and pressure, A = area of the chamber (cm^2), and t = time interval (minute).

2.4 Cultivation System

Conventional cultivation system has been studied. For this purpose, 21–30 days old seedlings were transplanted in 3-5 seedlings per hill with 20 cm distance among them to achieve a plant density of 100 plants per m^2. Transplanting was performed on 23 March 2012 and the rice plants were harvested on 11 July 2012 at first round.

In the second round of the experiment, the growing season started on 1 October 2012 and continued to 20 January 2013. The irrigation pattern for control was conducted according to FAO (1989). Weeds were controlled manually whenever it was needed. Chemical fertilizer used was targeting N (120 kg ha^{-1}), P_2O_5 (60 kg ha^{-1}), and K_2O (40 kg ha^{-1}).

2.5 Soil Temperature

Soil temperature at a depth of 5 cm was measured by a digital thermometer in three replications. In addition, the value read by digital thermometer was controlled by a mercury thermometer. Measurements have been performed hourly and simultaneously with methane emission monitoring.

2.6 Data Analysis

This experiment was conducted in two cycles based on a completely randomized design. Data analyzes including correlation has been conducted by SPSS16.0 software. In case of significant differences, Duncan Multiple Range test (DMRT) was implemented to compare the means.

3.0 RESULTS AND DISCUSSION

The methane emission rate increased from 7:00 AM reaching a peak at 12 to 2 PM. Then, through a declining trend the methane emission reached to zero level at 8:00 PM (Figure 1). This pattern was almost in agreement with previous work[13]. Besides, changes in trend of methane emission was in harmony with the pattern of soil temperature variation (Figure 2). Maximum temperature occurred around 1:00 PM when, the methane emission got to its maximum level as well. This pattern was similar in all data sets. This consistency indicated the strong effect of soil temperature on the methane emission.

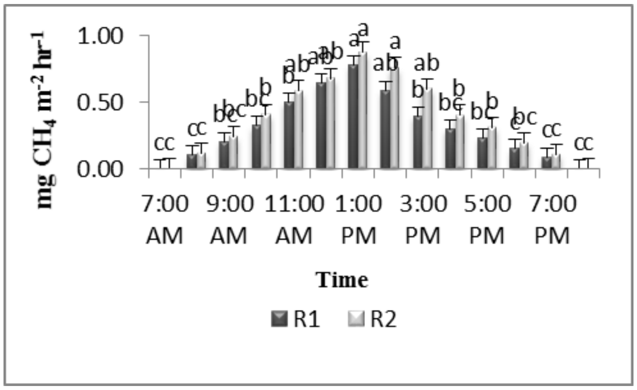


Figure 1 Hourly pattern of methane emission from 7:00 AM to 8:00 PM on 19 dates of sample gathering (first day after transplanting (DAT), 8 DAT, up to 110 DAT); R1: First round of experiment, R2: Second round of experiment

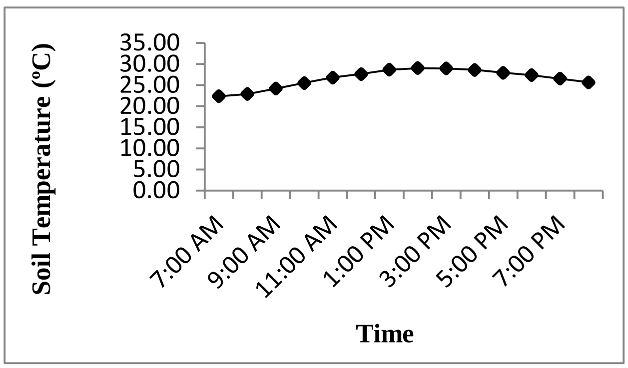


Figure 2 Hourly pattern of soil temperature from 7:00 AM to 8:00 PM on average in 19 dates of sample gathering

Maximum methane emission rate showed a strong and positive correlation with soil temperature (Table 1). The high effect of Ts on methane emission was reported in previous studies[8,14,15]. In fact, in short term, other influencing factors could be assumed constant because their alteration in such a short time (13 hours) is not significant. As a result, the potential effect of Ts was well demonstrated.

The increasing effect of temperature on biological systems considering the range of their optimum physiological temperature has been indicated by previous studies[7,15]. Thus, it could be assumed that the 'methanogens' activity could be affected by temperature in the same way[16]. Consequently, their population and activity possibly could be influenced by Ts. In this experiment, the range of soil temperature varied from 20 °C in the morning (7:00 AM) to 30 °C in the afternoon (1:00 PM). Consequently, in the morning less methane emission rate was expected to occur and, it should increase in higher temperature hours (12:00-2:00 PM). Accordingly, the hourly methane emission pattern followed the same trend.

In terms of long term study, the highest soil temperature was observed from 58 days after transplanting (DAT) to 89 DAT at first round (reproductive development stage) and between 29 and 65 DAT (from active vegetative to panicle initiation stage) at second round of the experiment (Figure 3). In addition, daily methane emission (Figure 4) was positively and significantly correlated to Ts. Therefore, soil temperature was an efficient factor on enhancing methane emission during this period. Nevertheless, stronger short term correlation (hourly pattern) was observed compared to long term (Table 1). This could be better explained by substantial time in the rice growing season in which other influencing factors were altered and moderated the Ts effect. For instance, coincide with high methane emission, root exudates and litters of rice plant form an effective carbon source for methanogens[17,18,19]. Subsequently, a multiple increasing effect (e.g., the effects of soil organic matters availability and higher standing water depth) along with higher soil temperature might be mostly responsible for higher methane emission during reproductive stage[20,21,22,23].

Table 1 Correlation between methane emission and soil temperature (°C).

Methane emission	Correlation (Temperature)
Methane emission (mg CH_4 m^{-2} hr^{-1}) at maximum emission	0.768**
Methane emission rate in average (mg CH_4 m^{-2} hr^{-1})	0.656*
Daily methane emission (mg CH_4 m^{-2} d^{-1}) at R1	0.528*
Daily methane emission (mg CH_4 m^{-2} d^{-1}) at R2	0.509*

*Correlation is significant at the 0.05 level
**Correlation is significant at the 0.01 level
R1: First round of experiment, R2: Second round of experiment

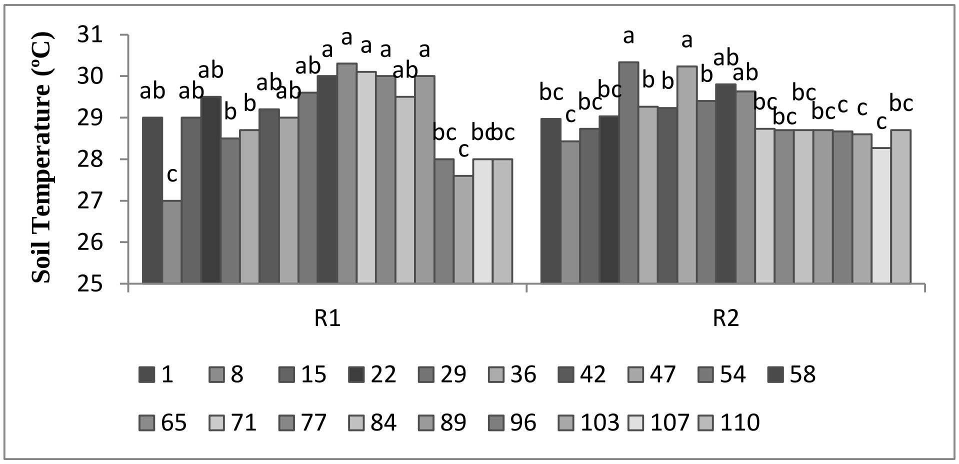


Figure 3 Soil temperature at 5 cm depth in 19 dates of data gathering (first day after transplanting (1 DAT), 8 DAT up to 110 DAT); R1: First round of experiment, R2: Second round of experiment

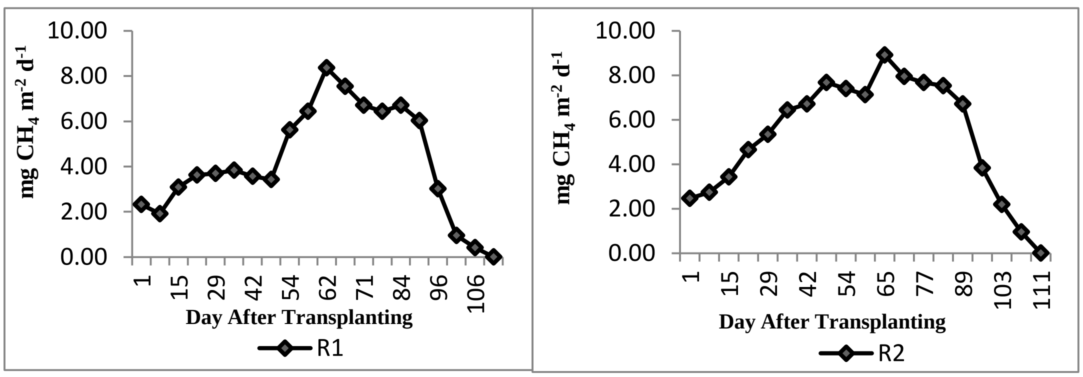


Figure 4 Daily methane emissions during rice growth season); R1: First round of experiment, R2: Second round of experiment

4.0 CONCLUSION

The pattern of methane emission seems to be significantly regulated by soil temperature (especially in short term period). However, the pattern of methane emission in long term advocates the involvement of factors other than temperature (irrigation pattern, applied fertilizers, soil properties, and rice biological activities). Since, anoxic area of the soil is the main habitat of methanogens, the effect of soil temperature in this soil depth (> 10 cm) is suggested to be a subject of further research in future. The methanogens populations and their activities in respective depths also need to be studied. This possible evaluation could help to derive a more accurate perception of soil temperature effect on methane production in tropical paddy soils.

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