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Comparison of Methane Emission from Conventional and Modified Paddy Cultivation in Malaysia

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Abstract

Methane (CH_4) is a potent greenhouse gas (Global Warming Potential = 25). Flooded rice fields are main sources for methane. Finding solutions to suppress the methane emission seems necessary toward a sustainable rice production. This study’s aim is to assess the methane emission from some modified rice cultivation systems in Malaysia. Three cultivation methods including, two modified cultivation systems (MC) and conventional method (C) were studied. Consequently, the maximum methane emission was significantly lower in MCs (3.15 and 3.29 mg CH_4 m^{-2} d^{-1}) compared to C (8.91 mg CH_4 m^{-2} d^{-1}). Irrigation pattern and plant density were the key factors.

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Keywords: Greenhouse gas; Methane; Rice; Cultivation system; Modified cultivation system; Sustainable production

1. Introduction

Methane (CH_4) is a well-known potent greenhouse gas with a global warming potential of 25 over 100 years period (IPCC, 2007). One of the main sources for this gas in agricultural sector is the flooded rice cultivation system (Das and Adhya, 2014). In fact, anaerobic condition in the soil is the prerequisite for biological methane production (Feng et al., 2012). Flooding continuously in conventional rice cultivation system stimulates the biological process of methane production by inducing the anaerobic condition in the soil (Mitra et al., 2012). The demand for rice as a

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staple food is growing with an increasing world population. It has been anticipated that rice production will be increased as much as 250 mt yr^{-1} in 2020 (Das et al., 2011; Kim et al., 2012; Hou et al., 2013). Accordingly, it has been stated that rice production should be 50% increased until 2025 to meet the demand (Singh et al., 2013). Subsequently, CH_4 emissions will be increased to about 150 mt yr^{-1} in 2025 (Dubey, 2005; Hou et al., 2013). In such situation, finding a capable solution to suppress the methane emission seems necessary for achieving a sustainable rice production.

Modifying the current cultivation system might be a way to decrease the methane emission from rice fields. In this regard, system of rice intensification has been introduced since 1980 (MC1) (Tsujimoto et al., 2009). This cultivation system differs from conventional method in some aspects. For example, irrigation is performed by alternate wetting and drying the soil which causes aeration in soil periodically. Furthermore, weeding is done manually that can supply air into the soil. Plantation of a single plant in each point influences the amount of methane emission by providing fewer conduits for methane transferring from the soil into the atmosphere. In fact, the aerenchyma texture of rice plants is a transferring passage for this gas (Neue et al., 1996; Dobermann, 2004; Barison and Uphoff, 2011; Krupnik et al., 2012).

Another cultivation system (MC2) has been introduced by changing the cultivation pattern of system of rice intensification. In this cultivation system 3 seedlings should be planted per hill with a separation distance of 7 cm and 40×45cm regular distances between hills. This leads to a higher plant density in MC2 (24 plants per m^2) comparing to original one (MC1) with 18 plants per m^2. However, it's still less than the plant density in conventional method (75-125 plant per m^2) (Zheng et al., 2004). Therefore, this study aimed to assess the methane emission from some modified rice cultivation systems in Malaysia and consequently indicating the less methane emitting cultivation system for a sustainable rice production.

2. Materials and methods

2.1. Experimental design

MR 219 (Oryza sativa L. ssp. indica) is a Malaysian-Indica rice cultivar produced by the Malaysian Agricultural Research and Development Institute (MARDI) in 2001 (Fasahat et al., 2012). "MR219" as a high yielding variety with 105 to 111 days maturation period was selected to be sown. This study was conducted in experimental plots located in University of Putra, Malaysia (2.9° N, 101.7° E). Plots with the dimension of 1 m length × 1 m width were prepared. The soil was silty clay, from Jawa series with 51% clay and 43% silt and the soil carbon and nitrogen content were about 6.38% and 0.62%, respectively.

Three cultivation methods including, two modified cultivation systems (MC1 and MC2) and conventional method (C) were studied. In C seedlings were transplanted at age of 21–30 day-old. In this cultivation system 5 seedlings per hill were cultivated with 20 cm interval distance so that a plant density of 125 plants per m^2 was obtained. On the other hand, in MCs, the seedlings were transplanted at 12-day old with a plant density of 18 plants per m^2 in MC1 and 24 plants per m^2 MC2. The irrigation pattern for C and MCs are shown in Table1.

Standing water level was controlled by a water level adjustment system. The standing water depth could be adjusted at 0 and 2 cm levels for MCs and at 0, 5 and 10 cm depths for C (Table 1). The drainage was controlled by piping system and a reservoir.

This experiment was based on a completely randomized design. Data collection for each parameter has been performed in triplicate. Analyzing data was done by SPSS 16.0 software, and for constructing the graphs Microsoft Excel software has been used.

Table 1. Irrigation pattern applied to each cultivation system during the rice growth season.

	Duration (DAT[b])	Standing water level (cm)
C[a] (Brouwer, 1989)		
	1-15	10
	16-45	5
	46-87	10
	88-111	Drained
MCs[c]		
	7-12, 19-24, 41-47, 52-56, 61-64, 69-71, 75-77, 83-87[d]	2
	88-111	Drained

[a]C: Conventional method
[b]DAT: Day after transplanting
[c]MCs: MC1= Original system of rice intensification, MC2= Modified system of rice intensification
[d]At not-listed DATs the soil was dried for MCs

2.2. Methane emission measurement

For collecting the emitted methane, static chamber method was employed. Chambers with diameters of 1 m height × 0.5 m diameter of basement, made of transparent Plexiglass were utilized. Regarding sealing the edge of chambers, the bottom edge of chambers was pushed into 7 cm soil depth of the soil. The methane gas was collected by Tedlar® bags made of transparent 2ml. film attached on the top of the chambers. A portable gas detector (Crowcon, Oxfordshire England) was used to read the amount of methane in the Tedlar bags (Fig. 1). Then, methane flux was calculated using following equation (Eq. 1) (Tyagi et al. 2010).

$$Fm = \frac{\Delta X}{10^6} \times BV_{(STP)} \times 16 \times \frac{10^3}{22400} \times \frac{1}{A} \times \frac{60}{t} \quad (1)$$

Where:

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

Daily methane emission was measured during the rice growing season in triplicate and it has been reported in 7 days intervals. The seasonal methane emission was calculated by summation of the daily methane emission of all 110 days of rice growing period. Moreover, for calculating the total methane flux following equation (Eq. 2) was applied (Ali et al., 2008).

$$\text{The total } CH_4 \text{ flux} = \sum i^n (R_i \times D_i) \quad (2)$$

where,

R_i= the rate of CH4 flux (g m^{-2} d^{-1}) in the ith sampling interval, D_i = the number of days in the i^{th} sampling interval, and n is the number of sampling intervals.

2.3. Yield calculation

Harvest was performed at physiological maturity stage of rice plants. At this time, almost 95% of grains were turned to yellow and the grain moisture content of grains was 25%. The grains of all panicles in each experimental plot were oven-dried at 70 °C until the grain moisture content of 14% was obtained. The yield per plot was applied for estimation of the yield per hectare with consideration of 10% grain loss (Eq. 3). 1000 grain weight was obtained by the mean of 3 samples of 1000 of completely filled grains.

$$GY_{ha} = \frac{G_t}{T_a} \times 10000\ m^2 - \ 10\%\ loss \tag{3}$$

where,

$G_{t=}$ grain yield per plot (at grain moisture content of 14%) (t), $T_{a=}$ plot area ($1m^2$), $GY_{ha\ =}$ estimated grain yield per hectare (t)

Fig. 1. A static chamber with a gas bag at 71 days after transplanting in MC1, also, some equipment relating to water level adjustment system has been shown in the picture (e.g. Adjustment valves in the front of the experimental plot (a) and the reservoir at the back (b))

3. Results and discussion

In all treatments, methane emission initiated with a short time delay after flooding the soil. Both MCs showed same pattern of methane emission through the rice growing season but different from C. This pattern was mostly in harmony with the irrigation pattern. In fact, irrigation could affect methane emission pattern indirectly by influencing the availability of organic maters and thus, influencing the microbial process of methane production in the soil (Fig. 2). The maximum methane emissions in MCs have been observed at panicle initiation stage which coincides with 71 DAT, with a significantly lower amount (3.29 mg CH_4 m^{-2} d^{-1}) in comparison with C (8.91 mg CH_4 m^{-2} d^{-1}). It seems that this increase was in consequence of decomposition of root exudates and rice plants' litters (Gogoi et al., 2008). On the other hand, two peaks were recorded in C. the first peak at 46 DAT and the second one at 68 DAT. The first peak was dominantly resulted by decomposition of soil organic matters which provide carbon source for methanogenic activity. However, at the second peak the carbon source for methanogens were available from the plant related organic matters entering into the soil from rice roots (Khosa et al., 2011). Therefore, more carbon source was available for methanogenic activity at 68 DAT and thus, resulted in a higher methane emission than 46 DAT (Neue et al., 1996; Gogoi et al., 2008). After drying the soil near the end of growing season (88 DAT) the methane emission lessened with a steep decline so that at harvest time we could not observe any methane emission.

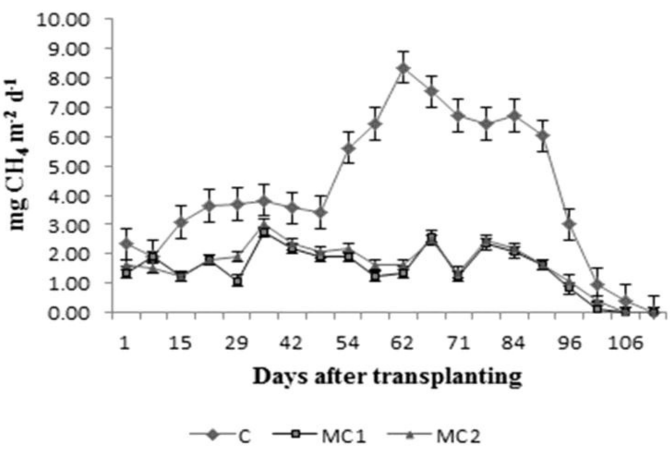

Fig. 2. Daily methane emission from cultivation systems during growth season. C: Conventional method, MC1: Original system of rice intensification, MC2: Modified system of rice intensification.

Furthermore, methane emission was decreased by 64.15% and 60.07% from MC1 and MC2 respectively in comparison with C (Table 2). Water management seems to be the most determining factor in this regard (Khosa et al., 2011). In the other words, irrigation pattern in MCs aerated the soil in intervals and thus, affected the activity of methanogens. As methanogens are anaerobic unicellular organisms (Garcia, 1990) they are more active under flooding condition rather than dry condition (Watanabe et al., 2009) therefore, draining the soil in MCs decline the methane emission (Neue et al., 1996; Tyagi et al., 2010; Khosa et al., 2011; Zhang et al., 2011). Accordingly, MCs had a regulating effect on seasonal methane emission (SME) compared to C (Fig. 3) while, there was an insignificantly higher SME in MC2 compared to MC1 due to more plant density in MC2.

Remarkably, MCs produced significantly more yield in comparison to C significantly. In fact, higher plant density (125 plants per m^2) in C caused intense competition between plants and thus, it resulted in a lower yield in C due to less grain weight (Fig. 4). Regarding higher yield of MC2, it seems due to higher plant density in MC2 (24 plants per m^2) rather than MC1 (18 plants per m^2). The competition between plants in MC2 was not as much as effective to influence the yield negatively because of its special sowing pattern with 7 cm distance between each planting point.

Grain filling was done more vigorously in MCs so that the 1000 grain weight was higher in MCs compared with C (Fig. 4). This result was in harmony with the previous report (Zhang et al., 2010) in which more effective grain filling in inferior spikelets were achieved by the same irrigation pattern as MCs. Similarly, in previous works MC1 resulted in a higher grain yield in comparison with conventional method (Sinha and Talati, 2007; Glover, 2011).

Table 2. Comparison of methane emission reduction and increasing in the yield between modified cultivation systems and conventional method.

	C[a]	MC1[b]	MC2[c]
Total CH_4 flux (g CH_4 m^{-2})	31.47	10.09	11.93
Reduction in methane emission (%)	-	64.15	60.07
Yield (ton ha^{-1})	6.80	7.00	7.01
Increase in the yield (%)	-	2.9	3.09

[a]C: Conventional method
[b]MC1: Original system of rice intensification
[c]MC2: Modified system of rice intensification

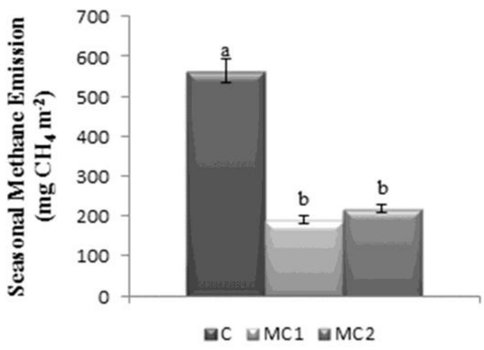

Fig. 3. The seasonal methane emission from all treatments (mg CH_4 m^{-2})

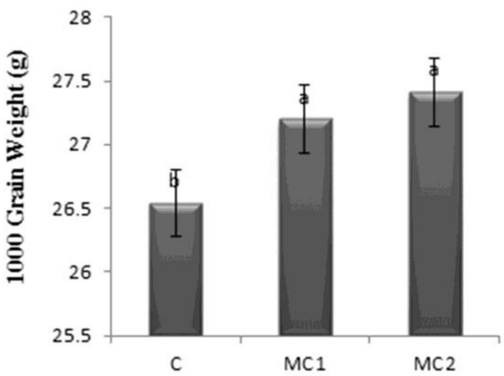

Fig. 4. Comparison of 1000 grain weight (g) between treatments

4. Conclusions

Generally, every modification in current cultivation systems towards aerating the soil can suppress the methane production and emission from paddy fields. Soil aerating in MCs was done mostly by alternate draining the soil in 3-6 days intervals and also with weeding manually. However, avoiding water stress in rice plants was of crucial importance in obtaining an acceptable yield. As a result, MCs decreased the SME to even less than half comparing to C. This way, MCs demonstrated a potential towards being lower methane emitting cultivation systems. Another noteworthy result was obtaining higher grain yield from MCs rather than C. In addition, with a change in sowing pattern in MC2 a slight higher grain yield was gained. Water management (including irrigation pattern and standing water level) was the main influencing factor which provided these positive results in MCs. It influenced the amount of methane emission through affecting two microbial communities involved in methane cycle in the soil, methanogens and methanotrophs. In conclusion, MCs can provide a sustainable rice production system considering both global warming issue and more rice demand in future resulted from fast growing world population.

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