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Methane Emission Under Alternative Irrigation Regimes in Malaysian Rice Cultivation

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ABSTRACT

Rice cultivation under continuous flooding (CF) is a major anthropogenic emitter of methane gas (CH_4) due to the oxygen-deprived state of the submerged soil. The potentials of alternative irrigation regimes i.e., mid-season drainage (MD) and alternate wetting and drying (AWD) to reduce CH_4 emissions from Malaysian rice cultivation were investigated in the present study. Rice (Oryza sativa var. MR297) was transplanted into 15 tanks and randomly assigned to each of the three treatments: CF, MD and AWD in a randomized complete block design (RCBD). Emissions of CH_4 were measured weekly by collecting air samples using static chambers and analyzing the air samples for CH_4 concentration using gas chromatography (GC). The present study found that cumulative CH_4 emissions per planting cycle were 70.24, 30.75, and 15.93 g CH_4 m^{-2} from treatments CF, AWD and MD, respectively. Methane emissions of the MD and AWD treatments were 77.07% and 57.81% lower, respectively, compared to CH_4 emissions of CF. The present study indicated that AWD and MD had the potential to reduce CH_4 emission in rice cultivation.

Key words: **Methane**, **paddy rice**, **continuous flooding (CF)**, **mid-season drainage (MD)**, **alternate wetting and drying (AWD)**

INTRODUCTION

Paddy rice (*Oryza sativa*) is one of the most important crops in the world. More than half of the world's population consume rice on a daily basis, resulting in a global consumption of around 486.62 Mt between 2018 and 2019 (FAO, 2018). To meet the enormous demand for rice, there are approximately 167.25 million ha of rice paddy fields worldwide, the majority of which are in the Asia Pacific region (FAO, 2008). Malaysia's rice production in 2021 was 2,428,893 Mt from 647,859 ha of planted area, which is an increment of 3.1% compared to 2020.

Conventional rice cultivation practices involve flooding the rice fields for irrigation and to suppress weed growth. Flooded rice fields prevent oxygen from penetrating into the soil, creating an anaerobic condition in the paddy soil. This condition fosters the growth of methanogenic bacteria that produce CH_4. The longer the flooding lasts, the more methanogens accumulate, the more CH_4 are produced (WRI, 2014). Methane is a potent greenhouse gas that has a higher global warming potential (GWP) compared to carbon dioxide (CO_2), 28 to 34 times more on a weight basis (IPCC, 2013).

Alternate wetting and drying (AWD) is one of the water management techniques that can potentially reduce CH_4 emissions in paddy fields (Allen and Sander, 2019). AWD controls water usage and supplies it intermittently to paddy fields. Another water management technique that may potentially reduce CH_4 emission is mid-season drainage (MD) (Liu *et al.*, 2019). MD supplies water to crops throughout the planting except for about seven days at the end of the tillering stage. Both these irrigation practices reduce the duration of soil submergence, therefore potentially reducing CH_4 emission from rice cultivation. Despite its potentials, AWD and MD are not commonly practiced in Malaysia and its effectiveness in Malaysian rice paddy has never been studied. The present study was conducted to investigate the effectiveness of the two irrigation methods in reducing CH_4 emissions compared to the conventional continuous flooding (CF) on Malaysian rice soil planted with Malaysian rice cultivar.

MATERIALS AND METHODS

Field setup

The study was conducted at the Faculty of Agriculture, Universiti Putra Malaysia, Serdang, Selangor, Malaysia (2° 59' 05.1"N 101° 43' 59.4"E). Rice (*Oryza sativa* var. MR 297) was planted under a rain shelter where germinated seedlings were transplanted into polyethylene tanks 14 days after sowing. This variety was chosen as it has a relatively short maturity period of 110 days and was developed to resist diseases such as bacterial panicle blight. The tanks were filled with soil obtained from a paddy field in Pendang, Kedah. The soil used is of the Briah series (fine, mixed, isohyperthermic, typic endoaquepts). The soil particle size distribution was 54.20% clay, 39.14% silt, and 6.65% sand. The mean total carbon, nitrogen, and sulphur of the soil was 1.95%, 0.13%, and 0.08% respectively, while the soil pH ranged between 5.04 to 5.61.

Experimental Unit Setup

Fifteen units of polyethylene tanks each measuring 40 cm × 50 cm (d × h) were used in the study. Three treatments with five replications for each treatment were assigned to the experiment. The treatments assigned were continuous flooding (CF), alternate wetting and drying (AWD) and mid-season drainage (MD). The details of each treatment is described in section 2.3. A 25 cm × 4 cm (l × d) polyvinyl chloride (PVC) pipe was installed in each tank, with 15 cm of the pipe buried in the soil to measure the soil water level. The PVC pipes were drilled with 0.5 cm diameter holes to allow water movement into and out of the pipes. A 30 cm plastic ruler was attached to the inside wall of each tank to monitor the water levels in the tanks.

Water Management Treatments

The tanks in CF treatment were flooded throughout the planting period. From the 1st to the 39th day after transplant (DAT), all experimental units were flooded up to 5 cm above the soil surface. From the 40th DAT until the 96th DAT, the tanks were flooded up to 10 cm above the soil surface. Before harvesting the grain, starting from the 97th DAT, all experimental units were not irrigated and were left to dry. Meanwhile, water management for the MD treatment was identical to CF, except from the 50th to 57th DAT, where irrigation was withheld for seven days, after which it resumed as usual. Whereas in the AWD treatment, soil was flooded during the first 20 DAT, where the water level was maintained at 5 cm above the soil. From the 21st DAT onward, AWD surface water was left to dry until the water level reached 15 cm below the soil surface. The soil was then irrigated until the water level reached 10 cm above the soil. The treatment was implemented for 75 days and stopped for two weeks during the flowering stage. After that, the irrigation resumed until the 96th DAT. Table 1 provides a brief description of the aforementioned treatments.

Table 1: Description of the irrigation treatments employed in the study

Treatment	Description
Continuous flooding (CF)	Water is maintained at 5-10 cm above soil surface at all times until harvest.
Alternate wetting-drying (AWD)	Water is allowed to dry out until soil water level reaches 15 cm below surface, after which it will be irrigated to reach soil water level of 10 cm above surface.
Mid-season drainage (MD)	Water is allowed to dry out from DAT 50 to 57. Apart from that period, water is maintained at 5-10 cm above soil surface at all times until harvest.

Static Chamber Setup

The static chamber method was used in this study to measure CH_4 emissions (Yu *et al.*, 2013). It is composed of three components; chamber head, collar, and extension. The chambers were constructed from a 6 mm thick acrylic sheet. The dimensions of the collar, chamber, and short extension were 23 × 23 × 23 cm (l × w × h), while the size of the long extension was 40 × 23 × 23 cm (l × w × h). The top of the chamber head consisted of a sampling port constructed using heparin caps from which air samples were drawn, a 120 mm battery-powered 9V fan, and a digital thermometer. The base of the chamber head was affixed with closed-cell foam, which provided an impermeable seal when placed over the collar. After transplanting the rice seedlings, the collars were inserted into the soil with 15 cm of the collar height protruding above the soil surface. The collars served as the permanent base to support the chambers, which were placed on top of the collars. Only the chamber is placed directly on top of the collar during the growth stages where the plant height is <20 cm whereas the extension will be placed between the collar and the chamber as the plant height increases. A long extension was added on the 20th to the 34th DAT, then a short extension was added on the 41st to the 110th DAT.

Methane Emissions Measurement

Air samples were collected weekly throughout the study between 0900 and 1000. Once the static chamber was placed on the top of the collar, the fan on the chamber was switched on to homogenize the air in the chamber headspace. Air samples from each experimental unit were collected at 10-minute intervals for 30 minutes and transferred to evacuated 12 ml borosilicate vials with rubber septum (Labco Exetainer®, Labco Ltd., Lampeter, UK). Collected air samples were analysed using gas chromatography (GC) (HP6890N Network Gas Chromatograph, Agilent Technologies, CA, USA). Soil CH_4 fluxes (F_{cham}) expressed in units of µmol m^{-2} s^{-1} were calculated using the following equations (Hutchinson and Livingston, 1993):

$$F_{cham} = \frac{\partial C}{\partial t} \times \frac{Vc}{A} \times \frac{M}{Vm}$$

Where $\partial C/\partial t$ is the rate of change of mixing ratio of the gas of interest (nmol mol^{-1}), V_c (m^3) is the chamber headspace volume, A (m^2) is the area covered by the chamber, M (g mol^{-1}) is the molecular mass of CH_4 and V_m (m^3 mol^{-1}) is the molecular volume at chamber temperature and barometric pressure calculated from the ideal gas law.

RESULTS AND DISCUSSION

Figure 1 shows the recorded daily water depth fluctuations in CF, MD, and AWD throughout the planting period. CF was continuously flooded from the first DAT until the 98th DAT. The range of water loss from the CF tank was around 3.5-4.5 cm during the vegetative phase, 2-9 cm during the reproductive phase, and 5.5-9.4 cm during the ripening phase. MD was flooded throughout the planting period until the 98th DAT but withheld irrigating from the 50th to the 56th DAT. The range of water loss from the MD tank was around 2.8-4.8 cm during the vegetative phase, 3.9-9 cm during the reproductive phase, and 2-9.5 cm during the ripening phase. Treatment AWD commenced on the 21st DAT until the 98th DAT, where tanks are left irrigated until the water depth reaches 15 cm below the soil surface, after which they were irrigated again until 10 cm above the soil surface. On average, it took around three to five days for the water depth to reduce from 10 cm above the soil surface to 15 cm below the soil surface.

Figure 1: Water depth above and below the soil surface of CF, MD, and AWD.

Figure 2 shows the mean weekly CH_4 fluxes measured from all experimental units. Significant differences existed between treatments from the third to the sixth week of air sampling. There were no significant differences in CH_4 flux rates between treatments on weeks one, seven, and eight of air sampling. CF showed significantly higher CH_4 fluxes in weeks three to six, with mean flux rates ranging from 0.003 to 1.476 µmol m^{-2} s^{-1}.

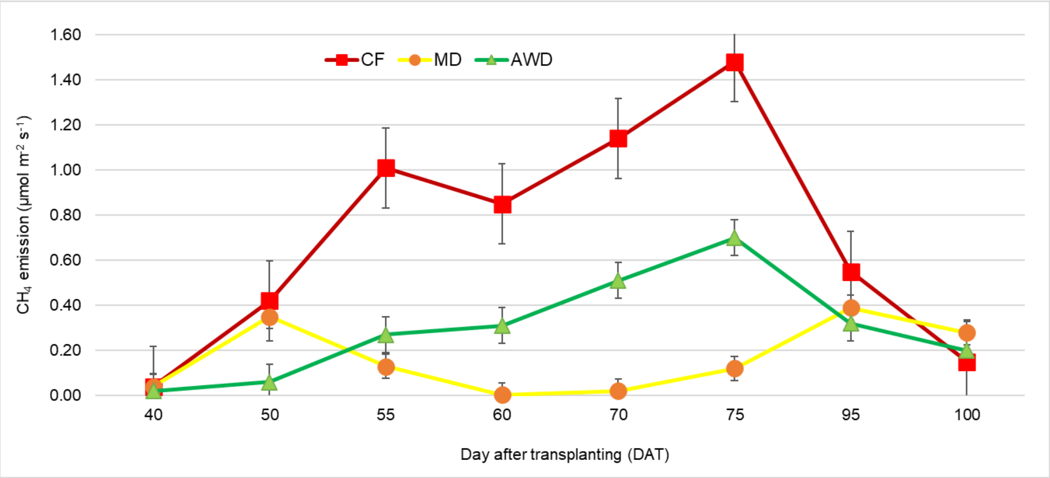

Figure 2: Mean weekly soil CH_4 fluxes measured from the CF, MD and AWD treatments. Means with different letters within each sampling date are significantly different at $P<0.05$

CF and AWD had the highest CH_4 flux between weeks and within treatments on week six, with mean rates of 1.48 µmol m^{-2} and 0.70 µmol m^{-2} s^{-1}, respectively. For MD, however, the highest between weeks and within treatment mean CH_4 flux was recorded on week two with a mean flux rate of 0.35 µmol m^{-2} s^{-1}. Overall, the CH_4 flux rates in CF showed increasing trends for rice growth, which was low during the vegetative stage and peaked at the end of the reproductive stage, then declined after the flowering stage. When the mean weekly fluxes were interpolated and extrapolated to account for daily fluxes, the present study observed a reduction of between 57.81% to 77.07% from AWD and MD, respectively, when compared to CH_4 emissions from CF. The cumulative CH_4 fluxes for the growing season were 70.24, 30.75, and 15.93 g CH_4 m^{-2} for CF, AWD, and MD, respectively.

The constant submerged soil under CF conditions emitted high CH_4 emissions compared to MD and AWD, especially peaking on the 75th DAT during the flooded flowering stage due to the full development of the aerenchyma system. For MD treatment, the drying period from the 50th to the 56th DAT reduced CH_4 emission from the 50th day to the 70th day. The CH_4 emission increased after the 70th until the 95th DAT due to the re-irrigation process. While a series of wet and dry cycles under AWD emitted intermediate methane emission, they are still lower when compared to CF. Emissions from AWD peaked at 75th DAT due to flooding during the flowering stage.

Methane emission trends from CF and AWD coincide with the different stages of rice growth. The high fluxes observed during the flowering stage were similar to other studies (Ma et al., 2010; Gaihre *et al*., 2011). Such observation is potentially due to the well-developed aerenchyma tissue during the flowering stage, which is responsible for plant-mediated CH_4 transport (Adhya *et al*., 1994). This is supported by Yao et al. (2000), who stated that CH_4 conductance is positively correlated with plant size, especially with the root volume at the reproduction stage.

Low methane emissions during the vegetative phase may be due to the low root volume and incomplete aerenchyma system. Chandrasekaran *et al*. (2022) found that rice emitted high methane emissions during the reproductive stage and was lower during the vegetative and maturity phases. A study by Gaihre *et al*. (2011) also found that CH_4 emission increased with increasing rice growth and peaks during the flowering stage, and is reduced toward maturity.

According to Zhan *et al*. (2010), CH_4 emission decreases during the maturity stage due to decreasing dissolved organic carbon (DOC) and root exudates that reduce the transport capacity of the aerenchyma tissues. Besides, the population of methanogens also plays an important role, which is less populated during the vegetative stage compared to the reproductive stage, where they have abundantly established. In essence, alternate wetting-drying (AWD) and mid-season drainage (MD) irrigation techniques demonstrated that the two strategies have the potential to minimise CH_4 emissions from Malaysian rice cultivation.

CONCLUSION

The alternative irrigation regimes, i.e., alternate wetting and drying (AWD) and mid-season drainage (MD), have shown a 57.81% to 77.07% reduction of CH_4 emissions compared to continuous flooding (CF). Findings of the present study had demonstrated that alternative irrigation could reduce CH_4 emission from Malaysian rice cultivation. However, implementing alternative irrigation regimes in Malaysia requires more concentrated effort and participation from all stakeholders (i.e., rice farmers, researchers and extension officers, and the government). Further research, especially implementation of the alternative irrigation regimes on commercial rice fields, is required to observe whether the present study's findings can be replicated. Advocation and education to farmers by extension officers are also important as changes to the farmers' long-held conventional rice cultivating method are challenging to implement. Finally, the government must have a clear policy on implementing the use of alternative irrigation regimes in rice cultivation in Malaysia if it is serious about ensuring that the country's greenhouse gas reduction target is achieved while still being able to produce rice.

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