Original Research Article

Plant Physiological Performances, Plant Growth, Grain Yield ~~And~~ and Methane Emission ~~Of~~ of Rice (*Oryza Sativa* L.) ~~In~~ in Response ~~To~~ to Water Management ~~As~~ as Adaptation Strategy ~~For~~ for Climate Change

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ABSTRACT

Reducing water input and methane (CH$_4$) while maintaining grain yield is important for a sustainable rice production. Climate change has brought an alarming situation in the scarcity of fresh water for irrigation due to the present global water crisis, climate variability, drought, increasing demands of water from the industrial sectors and contamination of water resources. Third National Communication and Second Biennial Update Report to the United Nations Framework Convention on Climate Change (UNFCCC) reported that in 2014, rice cultivations in Malaysia produced 88.08 Gg of CH$_4$ that contributed to 20.29% of greenhouse gases (GHG) emissions from agriculture sector. Soil having high levels of organic substrates under flooding condition that creates anaerobic conditions produces CH$_4$ due to the increased activity of methanogenic bacteria. Flooding conditions create~~s~~ anaerobic conditions and high levels of organic substrates in soil which increase the activity of methanogenic bacteria that produce~~s~~ CH$_4$. This study was conducted to examine the effectiveness of different water management practices on conserving water, mitigating GHG and maintaining yields in rice production. Three water management practices are continuous flooding (T1), saturated during tillering until heading and flooding until maturity (T2) and continuous saturated condition (T3). Most of the plant physiological performance and plant growth parameters were not significantly different. The ~~Soil~~ soil moisture content of volumetric water content (57-62%) and ~~metric~~ matric water potential (0-2 kPa) of flooding and saturated conditions were not significantly different, indicated that both conditions provided adequate soil moisture content to support leaf physiological performance and plant growth. During tillering, saturated condition promoted root development and biomass, increased leaf chlorophyll content, total leaf area, specific leaf area and leaf area index. Grain yield at harvest (6.4-7.0 t/ha) ~~were~~ was not significantly different between the water management practices although saturated conditions showed an increased yield. Saturated condition reduced 38% of methane emissions throughout the growing season as compared to continuous flooding. In conclusion, rice cultivation under saturated soil condition could be an effective adaptation technique for simultaneously saving water and mitigating GHG while maintaining high rice grain yields.

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Keywords: Greenhouse gases emissions, methane, water management, net photosynthesis rate, plant growth

1. INTRODUCTION

In Malaysia, the largest freshwater withdrawal of more than 75% is for irrigation in the agriculture sector and is mainly confined to irrigated rice production (Sariam and Anuar, 2010). Rice is a heavy consumer of water but its water use efficiency is rather low. It is estimated about 3,000 litres of water is used to produce 1 kg of rice and that the water productivity index (WPI) of rice is 0.3 kg grain/m^3 water. Fresh water is becoming an increasingly scarce resource (Rijsberman, 2006), which has posed a serious threat to the productivity and sustainability of irrigated paddy systems in many countries (Peng et al., 2009). The present global water crisis, climate variability, drought, increasing demands of water from the industrial sectors and contamination of water resources made water more scarce for irrigation (Sariam and Anuar, 2010; Dawe, 2005).

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Irrigated rice is normally grown in a flooded environment during most of its growing period, thus, growing rice requires a large amount of water. Flooding conditions create anaerobic conditions and high levels of organic substrates in soil which increase the activity of methanogenic bacteria that produces CH_4 (Buendia et al., 1997). The Third National Communication and Second Biennial Update Report to the United Nations Framework Convention on Climate Change (UNFCCC) reported that in 2014, rice cultivations in Malaysia produced 88.08 Gg of methane (CH_4) that contributed to 20.29% of greenhouse gases (GHG) emissions from the agriculture sector. Paddy water management and water-saving irrigation are promising options for CH_4 mitigation (Tyagi et al., 2010). A previous study at Tanjung Karang, Selangor paddy field showed that maintaining saturated soil conditions throughout or at certain stages of rice cultivation decreased 20-40% of CH_4 emissions as compared to continuous flooding (unpublished data). This study was conducted to examine the effectiveness of different water management practices on conserving water, plant growth, plant physiological performance, mitigating GHG and maintaining yields in rice production.

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2. MATERIALS AND METHODS

The experiment was conducted during an off-season (June-October) of 2019 at Kg. Selarong, Alor Star Kedah, Malaysia in the Muda Irrigation Scheme (MADA). The experiment was laid out using a nested design that consists of three (3) water management practices with seven (7) replications. Three water management practices are continuous flooding, CF (T1), saturated condition after 2 weeks of transplanting until heading and flooded condition until maturity (T2) and saturated condition after 2 weeks of transplanting until maturity (T3). MARDI Siraj 297 rice variety seeds were sown ~~for~~ and after 15 days ~~before~~ the seedlings were transplanted. For the first two (2) weeks after transplanting, the standing water level was maintained at 5 cm for all treatments to control weeds. Water management treatment was started after 2 weeks of transplanting. The plants were fertilized with 120:70:80 kg/ha of N, P_2O_5 and K_2O. Pest and disease management were based on farmer's normal practices. Pesticides and weedicides were applied at -5, 5, 17, 39, 58 and 91 days after transplanting (DAT). Weather data was obtained using a weather station (WatchDog-2000). Soil moisture content ~~were~~ was determined ~~were~~ with volumetric water content~~,~~ (%) (FieldScout Spectrum TDR-150) and ~~metric~~ matric water potential~~,~~ (kPa) (~~Tensiometer, Spectrum~~ Irrometer Tensiometer 24in).

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Plant physiological performances and growth parameters analysis were determined at 4 phenological stages of tillering (23 DAT), panicle initiation, PI (50 DAT), flowering (71 DAT) and ripening stage (93 DAT). Quadrat sampling of 25 cm X 25 cm was conducted at 2 points of each replication and plants were harvested for the growth analysis. Leaf chlorophyll content was determined using 80% acetone extraction and leaf relative chlorophyll content was determined using a SPAD, portable chlorophyll meter (SPAD-502, Konica-Minolta, Japan). Leaf area index (LAI) and light-intercepted were determined using AccuPAR LP-80. Measurements of net photosynthetic rates, stomatal conductance and transpiration rate were taken using a portable photosynthesis system (LI6400XT, LICOR Inc., Nebrasca, USA). The chlorophyll fluorescence measurements were made using a portable Plant Efficiency Analyzer (PEA) (FMS 2, Hansatech Instruments Ltd, U.K.). The Fv/Fm ratio was used to determine the leaf chlorophyll fluorescence responses.

The grain yield was obtained using crop cutting test (CCT) of 1 m by 1 m of each replication (n=7) at 107 DAT. The harvested grains were dried, winnowed and weighed. The weight was then converted to per unit area crop yield based on 14% grain moisture content and presented as grain yield (t/ha). The

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~~Collection~~ collection of gas samples for methane was carried out by the closed-chamber technique using the chambers of 110cm x 35cm x 35cm (Widen and Lindroth, 2003). The ~~First~~ first sample was taken on 1 DAT and it was conducted at 2 week intervals. One fan was installed in each chamber for the homogenization of gas. Gas samples were drawn with 20 mL syringe with hypodermic needles at 0, 15, 30 and 45 minutes for methane. The samples of gases were collected and analysed using a gas chromatography (SRI 8610C). All data obtained were subjected to statistical analysis, using a one-way Analysis of Variance (ANOVA) to test the significance effect of all variables investigated. Means separation was performed using the Duncan's multiple range test (DMRT) method at 5% (P = 0.05) by the statistical package of SAS 9.3 Institute Inc. USA.

Table 1. Water management treatment for rice production.

Treatment	Water management
CF (T1)	Continuous flooding (10 - 15 cm standing water level)
S-F (T2)	Saturated from transplanting to heading and flooding (10 - 15 cm standing water level) until maturity
CS (T3)	Continuous saturated condition

3. RESULTS AND DISCUSSION

3.1 Rainfall and Water Management Control

Rice is Asia's largest water user, accounting for more than half of all irrigation water demands (Akinbile~~,~~ ~~Abd El-Lat~~ et al., 2011). In Malaysia, the estimated average water requirement for irrigated rice crops is 1,240 mm per season although most irrigated rice is supplied with much more than the field requirement because farmers maintain a continuous flooding system from crop establishment to maturity (Streck, 2005). Rice irrigation systems that use continuous flooding require a lot of water, and a larger amount of water is wasted due to evaporation, percolation, and seepage (Dong et al., 2012). Water input for rice cultivation is mainly from irrigation water and rainfall. Malaysia receives annual rainfall over 2500 mm as a result of the southwest monsoon and northeast monsoon which bring heavy rains to peninsular Malaysia. Thus, rain is the main source of water for the paddy irrigation system in Malaysia. In this experiment, total rainfall throughout the season was 500.83 mm (Fig. 1). Before planting, irrigation water was supplied to the experimental plot until saturated condition. After transplanting, the experimental plot was irrigated and the water level was maintained at 5 cm for all water management treatment for two (2) weeks. For continuous flooding (T1), the water level was maintained at 10-15 cm while for T2 and T3 depending on their saturated or flooding condition. Water from rainfall irrigated the plot at certain weeks but standing water for T2 and T3 were drained out from the plot after heavy rainfall 2 and 4 times, respectively, to maintain saturated conditions. The reduction of total water input for T2 and T3 was 180 and 410 mm throughout the season. Maintaining water at a saturated condition during the vegetative to heading stage (T2) or throughout the season (T3) reduced 15 and 33% of water input for rice cultivation, respectively.

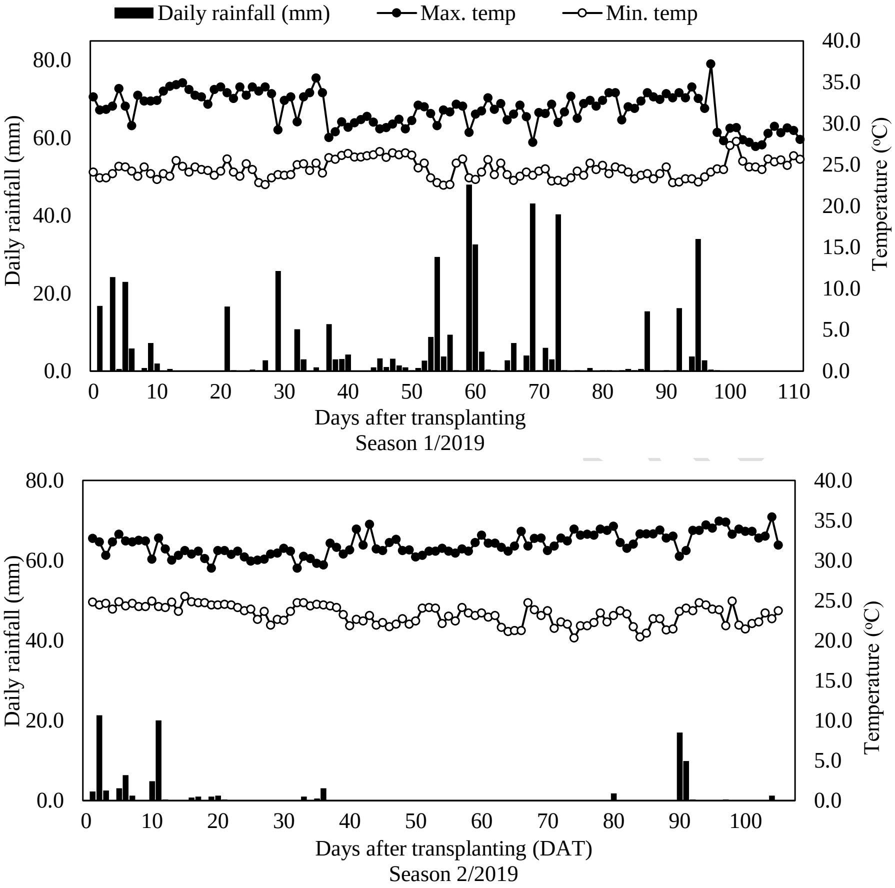

Fig. 1. Seasonal variations in daily rainfall, maximum and minimum temperature during the rice growing season 1/2019 and 2/2019.

Table 2. Total rainfall, daily maximum and minimum temperature at vegetative, reproductive and ripening phase during the rice growing season 1/2019 and 2/2019

Growing season	Total rainfall (mm)	Daily max temperate (°C)			Daily min temperate (°C)		
		Vegetative	Reproductive	Ripening	Vegetative	Reproductive	Ripening
Season 1/2019	500.8	32.8 a*	31.0 b	31.2 b	24.3 a	24.5 a	24.5 a
Season 2/2019	101.3	31.0 b	32.0 a	33.3 a	24.1 a	22.6 b	22.8 b

*Means followed by the same letter within the column are not significantly different by Fisher's Least Significant Difference (LSD) test at alpha = 0.05.

3.2 Soil Moisture Content

Soil moisture in paddy fields represents plant water availability and is necessary for irrigation scheduling, water resource allocation, management, and planning (Arif, Mizoguchi, Mizoguchi and Doi, 2012). The pattern of evapotranspiration, runoff, and deep percolation in paddy fields is affected by soil moisture variations (Kim, Jang, Im and Park, 2009). The soil moisture content of all water management treatments was not significantly different at tillering, flowering, and ripening stages. The saturated conditions contained the same amount of moisture as compared to flooding conditions (Table 3), thus providing adequate moisture to support plant physiological performances and growth of rice. Rice irrigation systems that are constantly flooded demand a lot of water. Soil organic matter management, such as the addition of appropriate organic amendments, may improve ~~in~~ the retention of soil moisture in water-stressed situations (Haque et al., 2021).

Table 3. Soil moisture content as affected by water management treatment

Plant stage	Treatment	Volumetric water content (%)	Water potential (kPa)
Tillering	T1	62.66 a	1.25 a
	T2	62.77 a	1.75 a
	T3	60.08 a	1.33 a
Flowering	T1	56.07 a	0.00 a
	T2	62.23 a	0.00 a
	T3	57.42 a	0.00 a
Ripening	T1	60.10 a	1.75 a
	T2	62.38 a	0.00 a
	T3	60.52 a	1.75 a

3.3 Leaf physiological responses

The study on leaf photosynthesis rate, stomatal conductance and transpiration rate are essential for the basic understanding of leaf physiology and plant productivity (Schaper and Chacko, 1993). Most of the leaf physiological performances were not significantly different between all water management (Table 4). Volumetric water content (57-62%) and metric water potential (0-2 kPa) of flooding and saturated soil conditions were not significantly different, indicated that both soil conditions provided adequate soil moisture content to support leaf physiological activities of photosynthesis, stomatal conductance and transpiration. Chlorophyll fluorescence (Fv/Fm ratio) between different water management also showed no significant difference at all plant stages. Chlorophyll fluorescence provides detailed information on the saturation characteristics of electron transport, as well as the overall photosynthetic performance of a plant (Ralph and Gademan, 2005). In this study, Fv/Fm ratios of flooding and saturated soil conditions of all water management were mostly between 0.75-0.79 (except for tillering stage) and high Fv/Fm indicated that plants were at higher plant photosynthetic performance and not under stress factors such as drought or limited water condition.

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High soil moisture content of saturated conditions provided adequate moisture for leaf physiological activities similar to flooding conditions. ~~Net~~ The net photosynthetic rate of saturated conditions showed slight reduction during the ripening stage~~,~~ however, the stomatal conductance and leaf transpiration rate were significantly higher compared to flooding conditions. Stomatal conductance is measured to determine the degree of stomatal opening and it can be used to indicate the plant water stress (Giménez et al., 2013). The increase of leaf transpiration rate in the saturated condition is ~~in~~ parallel to the stomatal conductance due to the stomatal opening and indicates there was no water stress condition occurred (Pallardy, 2008). The reduction of net photosynthetic rate was probably due to uneven leveling, especially at the saturated treatment that caused certain areas to be slightly drier than other areas. This condition was observed with the development of narrow cracks (less than 2 cm) at a small area of saturated treatment. However, this condition only affected the soil surface during certain days of the growing season and did not have significant effect on plants as high soil moisture content was recorded at a deeper level of soil.

Table 4. Leaf physiological responses and chlorophyll fluorescence (Fv/Fm ratio) as affected by water management treatment

Growth stage	Treatment	Net photosynthetic rate (A) (µmol/m2/s)	Stomatal conductance (gs) mol/m2/s	Leaf transpiration rate (E) mmol/m2/s	Chlorophyll fluorescence (Fv/Fm ratio)
Tillering	T1	19.62 a	1.56 a	7.19 a	0.58 a
	T2	21.57 a	1.72 a	7.73 a	0.59 a
	T3	20.02 a	1.61 a	7.53 a	0.61 a
Panicle Initiation (PI)	T1	20.97 a	2.34 a	7.90 a	0.79 a
	T2	19.39 a	1.79 b	7.66 a	0.78 a
	T3	21.00 a	1.68 b	7.31 a	0.77 a
Flowering	T1	21.18 a	1.83 a	5.19 a	0.79 a
	T2	21.20 a	1.52 ab	4.72 ab	0.79 a
	T3	22.83 a	1.14 b	4.22 b	0.77 a
Ripening	T1	22.48 a	1.45 b	5.19 b	0.75 a
	T2	19.02 b	2.75 a	6.08 a	0.77 a
	T3	18.38 b	2.57 a	6.05 a	0.71 a

**Means followed by the same letter within the column and growth stages are not significantly different by DMRT at P≤0.05.*

3.4 Plant growth parameter and leaf chlorophyll content

In the growing season of 1/2019, the effect of three water management practices on all plant growth parameters were not significant (Table 5). Saturated condition promoted root development of rice, probably increased nutrient absorption by root therefore increasing leaf chlorophyll content and growth parameters. The System of Rice Intensification study also reported similar findings where root length ~~of~~ in saturated condition was higher compared to continuous flooding (Arif et al., 2019). During ripening stage, leaf area index ~~using~~ and light intercepted using AccuPAR LP-80 of saturated treatment showed slight reduction, indicated that certain degree of leaf rolling may occur. However, the total leaf area, specific leaf area, leaf area ratio and actual leaf area index of saturated condition were not reduced as compared to flooding condition. In conclusion, plant growth parameters and relative chlorophyll content of rice ~~of~~ under flooding and saturated conditions ~~were~~ mostly showed no significant difference during tillering, panicle initiation, flowering and ripening stages. These results showed that saturated soil condition did not negatively affect the plant growth of rice as compared to flooded conditions, and even at certain stage increased plant growth of rice. Volumetric water content and metric water potential of flooding and saturated conditions were not significantly different, indicated that saturated soil conditions provided adequate soil moisture content for the plant growth similar to flooded condition. Although there was no observable standing water in the field, rice can take up adequate water from the subsurface soil around the root zone (Lempayan et al., 2015).

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Table 5. Plant growth parameters of rice as affected by different water management treatment of growing season 1/2019 and 2/2019

	Stages	Treatment	Plant height (cm)	Tiller number (No m^{-2})	Leaf number (No m^{-2})	Total leaf area (cm m^{-2})	Leaf area index	Leaf dry weight (g m^{-2})	Total leaf chlorophyll content (mg cm^{-2})	Aboveground dry weight (g m^{-2})	Crop growth rate (g m^{-2} d^{-1})
Season 1/2019	Tillering	CF	69.14 a	656.86 a	2363.43 a	46427.54 a	4.69 a	246.43 a	10.14 a	1074.76 a	21.07 a
		S-F	73.00 a	572.00 a	2099.43 a	43648.41 a	4.41 a	253.53 a	9.96 a	927.14 a	18.18 a
		CS	64.50 a	594.00 a	1958.00 a	36114.58 a	3.65 a	199.61 a	9.00 a	922.53 a	18.09 a
	Heading	CF	93.57 a	575.14 a	2360.29 a	61693.31 a	6.23 a	315.20 a	9.76 a	1189.82 a	18.30 a
		S-F	93.14 a	540.57 a	2115.14 a	53517.95 a	5.41 a	316.61 a	8.58 a	1301.27 a	20.02 a
		CS	93.29 a	474.57 a	2005.18 a	47548.23 a	4.80 a	286.44 a	8.50 a	1482.11 a	22.80 a
	Maturity	CF	109.14 a	521.71 a	1543.04 a	37847.67 a	3.82 a	235.93 a	5.52 a	1947.44 a	20.72 a
		S-F	111.00 a	622.29 a	1646.86 a	38121.13 a	3.85 a	228.55 a	6.01 a	2221.78 a	23.64 a
		CS	106.00 a	524.86 a	1684.57 a	41399.98 a	4.18 a	239.74 a	6.13 a	1956.87 a	20.82 a
Season 2/2019	Tillering	CF	65.00 a	704.00 a	1936.00 ab	31115.75 a	3.14 a	157.99 ab	9.40 a	630.27 a	5.95 a
		S-F	64.50 a	737.00 a	1800.86 b	27824.22 a	2.81 a	138.25 b	9.05 a	534.10 a	5.04 a
		CS	66.67 a	730.00 a	2407.43 a	34706.18 a	3.51 a	188.57 a	8.31 a	720.19 a	6.79 a
	Heading	CF	78.67 a	561.00 a	2162.29 b	42454.03 b	4.29 b	281.85 a	6.99 a	1850.14 a	17.45 a
		S-F	78.83 a	638.00 a	2838.00 a	59202.74 a	5.98 a	262.03 a	7.15 a	1540.63 a	14.53 a
		CS	76.83 a	553.67 a	2841.14 a	48248.33 ab	4.87 ab	309.73 a	6.75 a	2012.84 a	18.99 a
	Maturity	CF	88.67 a	469.33 a	2495.40 a	32122.92 a	3.24 a	260.92 a	3.62 a	3345.60 a	31.56 a
		S-F	84.67 a	561.00 a	2379.14 a	30375.41 a	3.07 a	242.47 a	4.24 a	2789.10 a	26.31 a
		CS	88.33 a	520.67 a	1876.29 a	25409.72 a	2.57 a	234.01 a	1.98 b	2896.45 a	27.33 a

*Means followed by the same letter within column of each season are not significantly different by DMRT test at alpha = 0.05.

3.5 Grain yield and Yield Parameters

The grain yield of rice under different water management treatments was between 6.44-6.96 t/ha and showed no significant difference between treatments (Table 6). Although 7.5% increase ~~of~~ in grain yield ~~of~~ under saturated condition was not significant as compared to flooding condition, but the increase was probably due to saturated condition that promoted leaf development and plant growth during tillering stage. These results showed that conserving water by maintaining soil water condition at saturation did not cause any reduction in grain yield. Water management at saturated soil condition was shown to sustain similar moisture content in soil thus supporting leaf physiological and plant growth performances that resulted in maintaining high grain yield of rice. Maintaining soil at saturated condition also could be an effective technique to conserve water, reducing CH_4 emission while preventing reduction of grain yield, which in contrast with ~~other~~ another adaptation strategy such as Alternate Wetting and Drying (AWD) technique that was reported to cause reduction in grain yield (Sariam and Anuar, 2010; Xu et al., 2015). Others also reported that continuous submergence is not essential for obtaining high rice yields (Suryavanshi et al., 2013; Sato and Uphoff, 2007; Guerra et al., 1998).

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Table 6. Yield component and grain yield of rice as affected by different water management treatment of growing season 1/2019 and 2/2019

Growing season	Treatment	Tiller number/m^2	Panicle number/m^2	Filled grains (%)	1000-grain weight (g)	Grain yield (kg ha^{-1})
Season 1/2019	CF	594.00 a	534.60 a	92.38 a	26.33 a	6440.30 a
	S-F	548.43 a	515.43 a	91.62 a	26.63 a	6888.08 a
	CS	521.40 a	464.20 a	90.97 a	26.01 a	6959.45 a
Season 2/2019	CF	425.66 a	413.78 a	93.28 a	26.16 a	5742.43 a
	S-F	422.12 a	415.82 a	93.36 a	25.93 a	5944.62 a
	CS	443.68 a	429.18 a	94.86 a	26.49 a	6122.81 a

*Means followed by the same letter within column of each season are not significantly different by DMRT test at alpha = 0.05.

3.6 Methane emission

The dynamics of temporal methane flux from rice grown under different water management practices was analysed by measuring methane at 2 week intervals after transplanting (Fig. 2 and Table 7). The methane fluctuated between 24.93 mg/m^2/day and 206.01 mg/m^2/day. Methane fluxes increased to a high level at maximum tillering, especially for continuous flooding treatment. The methane emissions were decreased during the plant maturity stage. Cumulative methane flux was the highest in continuous flooding with 14,925.70 mg/m^2/season. Cumulative methane flux for saturated at vegetative stage (T2) and saturated condition (T3) were 9,055.49 mg/m^2/season and 9,295.44 mg/m^2/season, with a reduction of 39.33% and 37.72%, respectively. The ~~Emission~~ emission factor of methane for continuous flooding in this study was 1.41 kg/ha/day and was slightly higher than 1.3 kg/ha/day reported by the Intergovernmental Panel on Climate Change IPCC, 2006. The ~~S~~saturated condition of T2 and T3 reduced emission factor of methane by 36.9% and 37.6%, respectively. Pardis and Hasfalina (2014) indicated modified rice cultivation systems by applying alternate wetting (2 cm standing water level) and drying (0 cm standing water level) techniques of 6 days interval after 12 DAT until maturity stage resulted significant reduction in methane emission (60% - 64% reduction) and significantly higher grain filling of 1000 grain weight (g) of MR219 rice cultivar compared to continuous flooding.

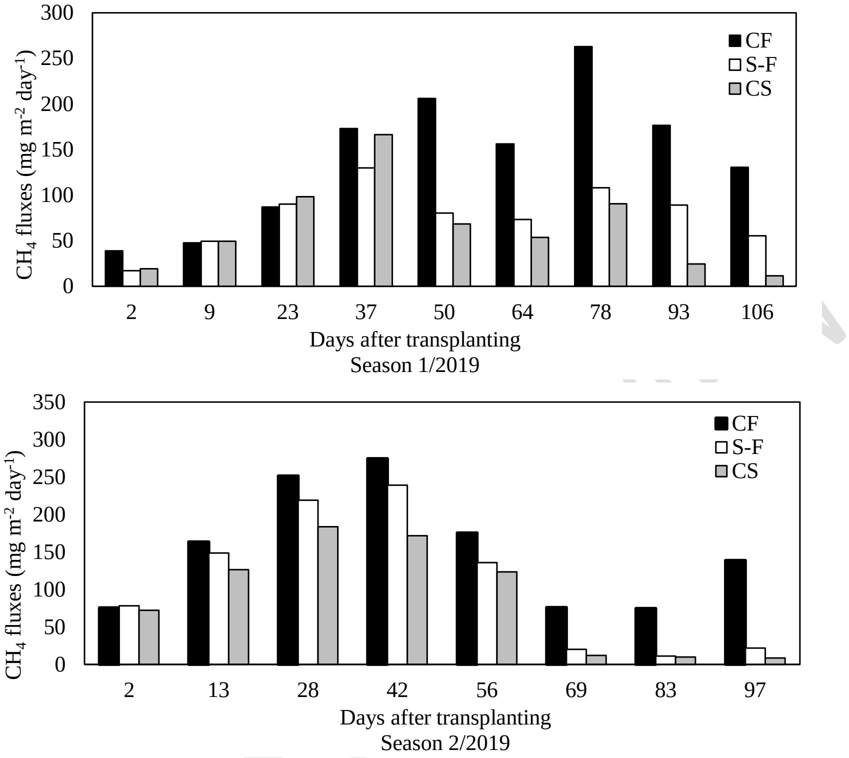

Fig. 2. The CH_4 emissions under different water management treatments, i.e., continuous flooding (CF), saturated and flooded condition (S-F) and continuous saturated condition (CS), during the rice growing seasons 1/2019 and 2/2019.

Table 7. The CH_4 emission from rice field under different water management treatments, i.e., continuous flooding (CF), saturated and flooded condition (S-F) and continuous saturated condition (CS), during seasons 1/2019 and 2/2019 in Alor Setar, Kedah, Malaysia

Growing season	Treatment	Average fluxes of CH_4 emissions (mg m^{-2} day^{-1})	Total amount of CH_4 emissions (kg ha^{-1} season^{-1})	Emissions factor (kg ha^{-1} day^{-1})
Season 1/2019	CF	142.04 a*	163.85 a	1.48 a
	S-F	77.06 b	89.12 b	0.80 b
	CS	64.70 b	74.54 b	0.67 b
Season 2/2019	CF	153.80 a	168.47 a	1.57 a
	S-F	109.31 b	118.52 b	1.11 b
	CS	88.46 b	95.47 b	0.89 b

*Means followed by the same letter within column of each season are not significantly different by DMRT test at alpha = 0.05.

4. CONCLUSION

Plant physiological performance and growth parameters of rice were mostly not significantly different between all water management practices at all plant stages. At early growth, saturated conditions promote root development that induces leaf chlorophyll content and plant growth. Saturated conditions at the vegetative stage and throughout the growing period produced high grain yield similar to flooding conditions. These results indicated that flooding conditions were not essential for rice plants at the reproductive stage or throughout the growing period for the plant‘s optimal physiological, growth performance and grain yield. Water management ~~of~~ under saturated soil condition was shown to sustain similar moisture content in soil thus supporting leaf physiological and plant growth performances that resulted in high grain yield of rice production. Incidents of weeds, pests and diseases are very low with good agronomic management that includes periodic application of pesticides and weedicides. In conclusion, rice cultivation by maintaining soil ~~at~~ in saturated conditions could be an effective adaptation technique for simultaneously saving water and mitigating GHG while maintaining high grain yields of rice.

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