

Effect of Water Saving Irrigation Management Practices on Rice Productivity and Methane Emission from Paddy Field

Hafsa Jahan Hiya, Muhammad Aslam Ali*, Md. Abdul Baten, Sanjit Chandra Barman

Department of Environmental Science, Bangladesh Agricultural University, Mymensingh, Bangladesh Email: *aslam.envs@bau.edu.bd, *litonaslam@yahoo.com

How to cite this paper: Hiya, H. J., Ali, M. A., Baten, M. A., & Barman, S. C. (2020). Effect of Water Saving Irrigation Management Practices on Rice Productivity and Methane Emission from Paddy Field. *Journal of Geoscience and Environment Protection, 8*, 182-196.

https://doi.org/10.4236/gep.2020.89011

Received: August 31, 2020 Accepted: September 27, 2020 Published: September 30, 2020

Copyright © 2020 by author(s) and Scientific Research Publishing Inc. This work is licensed under the Creative Commons Attribution International License (CC BY 4.0).

http://creativecommons.org/licenses/by/4.0/

Abstract

Irrigation water supply is one of the vital components for sustainable rice farming, which is becoming a limiting resource in the changing climatic condition. An experiment was conducted at the research field of Bangladesh Agricultural University, Mymensingh during dry season from January-June of 2017 to investigate the suitability of Alternate Wet and Dry Irrigation (AWDI) for sustainable rice production and reducing methane emission. The modern rice variety BINA Dhan 10 was used as test crop. There were five irrigation treatments viz. T₁ (saturated condition), T₂ (continuous flooded, 5 cm standing water), T₃ (AWDI-10 cm; irrigated when water level fell 10 cm from surface), T₄ (AWDI-15 cm; irrigated when water level fell 15 cm from surface) and T₅ (AWDI-20 cm; irrigated when water level fell 20 cm from surface). Results of the field trial showed satisfactory grain yield and low seasonal methane emission along with significantly high irrigation water savings (%) in AWDI treated field plots. Among the treatments, T_3 (AWDI-10 cm) and T_4 (AWDI-15 cm) showed higher yield performance (6250 kg·ha⁻¹ and 5810 kg·ha⁻¹, respectively) with lower CH₄ emission (reduced up to 36% and 40%, respectively) compared to continuous flooded treatment (T2, CF 5 cm water). In AWDI field plots less irrigation frequency (6 - 9) was required which significantly saved the amount of irrigation water (12% - 24%). Although T₅ (AWDI-20 cm) showed the highest water savings (24%) and lowest CH₄ emission (reduced up to 50%); however the lowest grain yield (4283 kg·ha⁻¹) was found under this treatment. On the other hand, continuously irrigated (T2, 5 cm standing water) field plot showed lower yield (4783 kg·ha⁻¹) but significantly higher methane emissions compared to other treatments during rice cultivation. Water productivity index was also found higher in AWDI treated field plots compared to continuously irrigated field plot. At the

^{*}Corresponding author.

reproductive stage of rice plant well-developed aerenchyma tissue was observed in root cortex under the continuous irrigated field plot, which indicates higher diffusion pathway of methane gas from root rhizosphere to the atmosphere compared to other treatments. Therefore, alternate wet and dry irrigation water management practice may be recommended at farmers' level for sustainable rice production and reducing methane emission during dry winter Boro season which will reduce the cost of production by water saving as well as energy saving.

Keywords

Water Saving, AWDI, CH4, GWP, Rice Paddy

1. Introduction

Global agriculture in 21st century faces the tremendous challenge of providing sufficient and healthy food for growing population under increasing water scarcity, while minimizing environmental consequences. In agriculture sector, rice is a major food grain crop in the world and it will be necessary to produce about 60% more rice than currently produced to meet food demands by 2025. In Bangladesh, rice is the prime food grain crop cultivated in 77% (28.49 million hectares) of the total cropped area that covers 5th largest position of the world in respect to rice cultivation area (BBS, 2012). But rice cultivation especially in dry winter (Rabi) season requires huge amount of irrigation water, which is a great challenge due to energy crisis. From the time immemorial, rice is grown in low land areas under continuous flooding in Asian tropics and subtropics that requires between 700 and 1500 mm water per cropping season depending on soil texture (Bhuiyan, 1992) that leads to high surface runoff, seepage and percolation account for between 50% - 80% of total water input. Water availability in Bangladesh is around 90 billion cubic meters (BCM) during dry season against the demand of 147 BCM, a shortage of nearly 40%, resulting in drought situation in large parts of the country (Quassem, 2010). Boro rice in Bangladesh is fully irrigated and the Aman rice is partly irrigated. An estimated 3000 to 5000 litres of water is required to produce one kg rice (BRRI, 2016). So, Bangladesh is going to face severe water crisis within next couple of decades. In future, it will be necessary to produce more food with less water or increase the efficiency of water management. Again, flooded rice cultivation is a major anthropogenic source of methane (CH_4) which is one of the important greenhouse gases having 25 times more global warming potential than carbon dioxide (Nieder & Benbi, 2008). These flooded soils characterized by low oxygen and high organic substrates offering an ideal environment for methanogen bacteria generate anaerobic condition that favors CH₄ production as an end product from organic matter degradation (Conrad, 2002). Methane from soil is derived from C mineralization, moisture, pH, soil Eh, etc. and emitted to the atmosphere by molecular diffusion, ebullition or plant mediated transport like aerenchyma (Zheng et al., 2007). The CH_4 concentration in the atmosphere has reached 1.77 ppm by volume in 2005, which is more than double that of its preindustrial value (Solomon et al., 2007). Therefore, it is necessary to solve water scarcity and minimizing CH_4 emission from rice paddy without aggravating rice production.

Two main types of water efficient irrigation practiced in Bangladesh are: 1) Alternate Wetting and Drying (AWD) and 2) System of Rice Intensification (SRI). AWDI developed by International Rice Research Institute, is a water saving and methane mitigation technology where rice fields are not kept continuously submerged but are allowed to dry intermittently during growing stages. But a severe AWD regime in where photosynthesis is severely inhibited and plants cannot rehydrate overnight could markedly decrease grain yield, although it reduces methane emission from paddy fields (Win et al., 2015). Again, SRI is an efficient, resource-saving and productive way to practice the use of younger rice seedlings planted singly at wider spacing, together with intermittent irrigation and organic fertilization adoption. In our country, it is difficult to follow SRI because of some limitations like organic fertilization and more laborious that sum up more cost (Uphoff & Kassam, 2009). On the contrary, alternate wetting and drying irrigation for rice has become popular in Bangladesh than SRI due to economic and environmental feasibility (Price et al., 2013). Although, few studies in Bangladesh showed the effect of AWDI on rice yield, they do not give us a clear idea to sketch out the effect of AWDI on rice yield and CH₄ emission during rice cultivation. Therefore, this research experiment was conducted to evaluate different water saving irrigation management practices in paddy field for mitigating methane emissions and sustaining rice productivity.

2. Materials and Methods

2.1. Experimental Field Preparation and Rice Cultivation

The experiment was carried out at the research field of Bangladesh Agricultural University in 2017. The soil of experimental site was well drained, loamy texture having a soil pH (6.43) with moderate organic matter (1.78), 0.17% total nitrogen, 13.9 ppm available phosphorous and 16.3 ppm available potassium. The experimental field had three side-by-side blocks for three replications and each plot (20 m²) was laid down in a randomized complete block design where block to block and plot to plot distances were 1.5 m and 1m to prevent interactions. The field was tilled with a tractor and subsequently ploughed and cross ploughed followed by laddering and cleaning. These plots were surrounded by 25 cm wide and 20 cm high levees separated by 1 m transition zones. The applied fertilizer doses were Urea 220 kg·ha⁻¹, TSP 115 kg·ha⁻¹, MoP 100 kg·ha⁻¹ and Gypsum 60 kg·ha⁻¹. Among them, nitrogenous fertilizer (urea) was applied thrice as basal dose after transplantation, whereas others were applied only once before transplanting. Rice seedlings (21 days old BINA Dhan 10) were transplanted into ex-

perimental plots at three seedlings hill⁻¹ with 25 cm \times 20 cm spacing between the rows and hills, respectively.

2.2. Placement of Perforated Pipes According to Treatments

In this study, five irrigation treatments were followed: $T_1 = Saturated$, $T_2 = Con$ $tinuous flooding (5 cm standing water), <math>T_3 = AWDI$, 5 cm irrigation applied when water level in the pipe fell 10 cm below ground level, $T_4 = AWDI$, 5 cm irrigation applied when water level in the pipe fell 15 cm below ground level and $T_5 = AWDI$, 5 cm irrigation applied when water level in the pipe fell 20 cm below ground level. Perforated PVC pipes were installed in the experimental plots 10 days after transplanting (DAT) according to treatments for measuring soil water depletion to follow AWDI techniques. The diameter of pipe was 8 cm and the lengths were 25 cm, 30 cm and 35 cm, respectively. After irrigation had been applied, water entered through perforations and water levels inside the pipe were at same level as that of outside. With the progress of time, water got depleted in AWDI plots, but a close observation revealed that there was water inside the pipe and again 5 cm irrigation was done when the depleting water table inside the pipe reached a certain level from ground soil.

2.3. Determination of Effective Rainfall, Crop Water Requirement and Water Savings

Effective rainfall was estimated by USDA Soil Conservation Method (Smith, 1992).

1)
$$P$$
 effective = $\frac{P \operatorname{total}(1.25 - 0.2 \times P \operatorname{total})}{125}$ (when, $P \operatorname{total} < 250 \operatorname{min.}$)

2) P effective = $125 + 0.1 \times P$ total (when, P total > 250 win)

where, *P* effective = effective rainfall (mm) and *P* total = total rainfall (mm).

Total rainfall data of cropping period of that year was collected from the department of Irrigation and Water Management, Bangladesh Agricultural University. Again, water requirements for rice cultivation was computed by adding applied irrigation water, effective rainfall during growing season and water for land preparation (Rashid, 1997). In the study, water saving percentage was calculated as follows:

Water Savings(%) = $\frac{\text{Water supplied in flooded plot} - \text{Water supplied in AWDI plot}}{\text{Water supplied in flooded plot}} \times 100$

Water loss was calculated based on water amount supplied in each plot.

2.4. Gas Sampling, Analysis and Estimation of CH₄ Emission

A closed-chamber method (Ali et al., 2008) was used to estimate CH_4 emission during rice cultivation. Gas samples were collected by 50 ml gas-tight syringes at 0, 15 and 30 minutes after chamber placement over flooded plots at different rice growth stages to get average CH_4 emissions. The dimension of closed chamber

was 62 cm × 62 cm × 112 cm. Samples were analyzed to determine CH_4 concentration by gas chromatograph (Shimadzu, GC 2014, Japan) with a Flame Ionization Detector. The temperatures of column, injector and detector were adjusted at 100°C, 200°C and 200°C, respectively. A closed-chamber equation (Rolston, 1986) was used to estimate methane fluxes for every treatment.

$$F = \rho \times V / A \times \Delta c / \Delta t \times 273 / T$$

where, $F(\text{Flux}) = \text{CH}_4$ emission rate (mg CH₄ m⁻²·hr⁻¹), ρ = gas density (0.714 mg·cm⁻³), V = volume of chamber ($A \times h$; m³), A = surface area of chamber (length × width; m²), h = height of the chamber (m), $\Delta c/\Delta t$ = rate of increase of CH₄gas concentration (mg·m⁻³·hr⁻¹), T (absolute temperature) = 273 + mean temperature (°C).

Total methane flux for the entire cropping period was computed by the formula (Singh et al., 1999):

Total CH₄ flux =
$$\sum_{i=1}^{n} (R_i \times D_i)$$
,

where, R_i = rate of methane flux (g·m⁻²·d⁻¹) in the *i*th sampling interval, and n = number of sampling intervals.

2.5. Estimation GWP of CH₄

To estimate the GWP, CO_2 is typically taken as the reference gas, and an increase or reduction in emission of CH_4 is converted into " CO_2 -equivalents" by means of their GWPs. In this study, we used the IPCC factors to calculate the combined GWP for 100 years (GWP = $25 \times CH_4$, kg CO_2 -equivalents ha⁻¹) from CH_4 under various agricultural irrigation practices. In addition, the greenhouse gas intensity (GHGI) was calculated by dividing GWP by grain yield for rice (Mosier et al., 2006).

2.6. Explorations of Rice Plant Growth and Yield

Rice plant growth parameters like plant height, root length were investigated during different growing period. Again, 4 - 5 cm long root samples collected at reproductive stage were conserved in proper tagged glass tubes (with FA solutions) for free hand sectioning to show anatomical view whether aerenchyma developed or not under a scanning electron microscope. Yield components such as panicle number per hill and grain numbers per panicle were determined at harvesting stage. When 95% grains became yellow, harvesting was done. After harvesting, crops were separately collected, bundled and tagged for threshing. Finally, the grains were sun dried up to14% moisture content, then weighed as $kg\cdotha^{-1}$.

2.7. Estimation of Water Productivity Index

Water productivity index is the ratio of crop yield (kg/ha) per unit water (m^3/ha) supplied (Jaafar et al., 2000) and calculated as follows:

Water productivity index $(kg/m^3) = \frac{\text{Grain Yield}(kg/ha)}{\text{Total water supplied}(m^3/ha)}$

2.8. Investigation of Soil Properties

Soil redox potential (Eh) were measured during rice cultivation at certain time intervals by glass electrode Eh meter. At harvesting stage, soil bulk density (BD) was analyzed using cores (volume 100 cm³, inner diameter 5 cm), filled with fresh moisture soils. The collected core samples were oven dried at 105°C for 24 h and then measured the weight of dried core samples. Soil porosity was calculated using BD and particle density (PD, 2.89 Mg·m⁻³) according to the equation:

$$porosity(\%) = (1 - BD/PD) \times 100$$

At harvesting stage, chemical properties of the collected soil samples were analyzed for organic carbon by wet oxidation method (Walkley & Black, 1965), organic matter content by multiplying the percent organic carbon with Van Bemmlen factor of 1.73, total nitrogen by Micro-kjeldhal method (Page et al., 1982), available phosphorus by Olsen method (Olsen et al., 1954), exchangeable potassium by Flame photometer (Brown & Lilleland, 1946).

2.9. Statistical Analysis

The compiled and tabulated data of rice growth, yield, soil properties and CH_4 emission were statistically analyzed by Analysis of Variance (ANOVA) to examine whether treatment effects were significant or not. The mean differences among treatments were compared by Duncan's Multiple Range Test. The computer software MSTAT-C was used for statistical analysis.

3. Results

3.1. Effect of Irrigation Managements on CH₄ Emission during Rice Growing Season

The different irrigation managements significantly influenced on CH_4 emission from paddy field at all stages of growing season (**Figure 1**). Although, CH_4 emission rate showed increasing trend from the very beginning of growing stage, suddenly fluctuated at active tillering stage (42 DAT), then gradually increased onwards and sharply increased from panicle initiation stage (56 DAT), peaked at flowering stage (84 DAT) and finally dropped at grain maturation stage (91 - 105 DAT) for all irrigation systems. In study, the highest CH_4 peak was detected in continuous flooded plots and the lowest emission was in AWDI plots. Among AWDI plots, T_3 (10 cm) showed comparatively higher CH_4 flux than T_4 (15 cm) and T_5 (20 cm). Different considerable factors influencing CH_4 emission are given below:

A negative correlation was observed between soil Eh and CH_4 emission rate. It was found that soil redox potential significantly decreased by advancement of growth stage and AWDI treatments showed less soil Eh reduction than other



Figure 1. Changes in CH₄ emission rate and soil redox status (Eh) under different irrigation treatments.

treatments which might be due to having capability of AWDI to improve the soil Eh of rice paddy soils. In study, CH_4 emission was increased significantly with the development of soil reductive condition (Figure 1). When water supply was stopped before harvesting (after 84 DAT), the oxidation process was more for available oxygen that increased Eh values. The maximum and sharply decreased soil Eh value after tillering stage (42 DAT) from continuous flooded and saturated plots could be related to the development of anaerobic conditions. The intense reductive condition, e.g. soil Eh value -120 to -220 was noticed during reproductive stage which caused significant amount of CH_4 emissions. AWDI significantly improved the soil redox potential status which ultimately decreased CH_4 emissions during the entire rice growing period.

The highest CH_4 emission rate was found in continuous flooded plots where aerenchyma tissue was well developed, probably due to waterlogging conditions (**Figure 1**). The most interesting phenomenon in this study is aerenchyma development in rice root during reproductive stage that was significantly influenced by different irrigation managements. The deficiency of oxygen mainly triggers root aerenchyma development which facilitates gas diffusion between roots and aerial environment. In study, AWDI plots showed less remarkable aerenchyma for more availability of oxygen as like as CH_4 emission influenced by different irrigation managements (**Figure 2**). Again, the formation and more intensity of aerenchyma development in continuous flooded and saturated plots might have accelerated the gas exchange rate between the rhizospheric soil environment and the atmosphere.

The decomposition rate of soil organic matter was more under irrigated field most probably due to the presence of available water. In study, the decomposition rate was more in continuous flooded plots that showed the highest CH_4 emission among all treatments. AWDI plots showed more soil organic carbon due to less decomposition that might be for less water requirements (**Figure 3**). After heading stage, CH_4 flux was decreased constantly due to lack of CH_4 producing conditions caused by the end of irrigation and plant senescence, when labile organic C are no longer released due to the lack of water for decomposition.



Figure 2. Development of aerenchyma tissue in rice root cortex at reproductive stage under different irrigation treatments. (a) Saturated conditions; (b) Continuous flooded; (c) AWDI, 10 cm; (d) AWDI, 15 cm; (e) AWDI, 20 cm.



Figure 3. Changes in soil organic carbon with plant growth stages under different irrigation water management practices.

3.2. Effect of Irrigation Managements on Rice Grain Yield and Water Productivity

During first 2 weeks after transplantation, 5 cm standing water was maintained in all plots to avoid weed infestation. Water required for crop establishment was 62.6 cm and for land preparation was 45 cm. Then, plots were irrigated according to treatments. Effective rainfall was 21.7 cm. In study, the maximum 13 irrigations required for continuous flooded plots followed by saturated plots (10 irrigations) in where AWDI treatments T_3 (10 cm), T_4 (15 cm) and T_5 (20 cm) received 8, 7 and 6 irrigations, respectively. The required water volume were 19,430 m³·ha⁻¹, 17,930 m³·ha⁻¹, 16,930 m³·ha⁻¹, 16,430 m³·ha⁻¹ and 15,930 m³·ha⁻¹ for continuous flooded, saturated plot, AWDI-10 cm, AWDI-15 cm, AWDI-20 cm, respectively. Finally, it was found that AWDI-20 cm could save highest amount (18%) of irrigation water followed by AWDI-15 cm (16%) and AWDI-10 cm (13%) in where saturated plot could save only 8% irrigation water compared to continuous flooded plot.

The grain yield of rice was significantly increased by AWDIs. In present study, AWDI-10 cm gave the highest grain yield ($6250 \text{ kg}\cdot\text{ha}^{-1}$) followed by AWDI-15 cm ($5810 \text{ kg}\cdot\text{ha}^{-1}$) but the lowest yield ($4283 \text{ kg}\cdot\text{ha}^{-1}$) was found in AWDI-20 cm due to more water stress. Again, continuous flooded plots gave 5783 kg $\cdot\text{ha}^{-1}$ grain yield most probably for more waterlogged conditions throughout the growing season. Table 1 also shows the highest water productivity index ($0.369 \text{ kg}\cdot\text{m}^{-3}$) was obtained in AWDI-10 cm followed by AWDI-15 cm ($0.354 \text{ kg}\cdot\text{m}^{-3}$), saturated plots ($0.299 \text{ kg}\cdot\text{m}^{-3}$), continuous flooded plots ($0.298 \text{ kg}\cdot\text{m}^{-3}$) and AWDI-20 cm ($0.269 \text{ kg}\cdot\text{m}^{-3}$).

3.3. Effect of Irrigation Managements on Seasonal CH₄ Flux, GWP and GHGI

The total GWP of CH_4 significantly decreased with AWDI treatments as compared to continuous flooded plots. The total and highest GWP from the continuous

Irrigation system	Grain yield (kg∙ha ⁻¹)	Water productivity (kg·m ⁻³)	Water Savings (%)	CH4 flux (kg·ha ⁻¹ season ⁻¹)	GWP^a (Mg CO ₂ ha ⁻¹)	GHGI [♭]
Saturated	5365 c	0.299 b	8 d	152.91 b	3.82 b	0.712 b
Continuous flooded (Control)	5783 b	0.298 b	-	206.43 a	5.16 a	0.892 a
AWDI (10 cm)	6250 a	0.369 a	12 c	130.41 c	3.26 c	0.522 d
AWDI (15 cm)	5810 b	0.354 a	16 b	121.93 d	3.05 d	0.525 d
AWDI (20 cm)	4283 d	0.269 c	24 a	101.72 e	2.54 e	0.593 c
Level of significance	*	*	**	*	*	*
CV (%)	0.51	2.31	8.97	0.87	2.56	0.58
LSD	52.95	0.01	1.85	2.32	0.17	0.06

Table 1. Rice grain yield, water productivity, water saving percentage, seasonal CH_4 flux, GWPs and GHGI under different irrigation system.

In a column, figures having similar letter(s) or no letters do not differ significantly whereas figures with dissimilar letter(s) differ significantly as per DMRT. ** = Significant at 1% level of probability and * = Significant at 5% level of probability. ^aGWPof CH₄ were calculated by multiplying 25 times on seasonal CH₄ fluxes; The IPCC GWP factors (mass basis, kg CO₂-equivalent ha⁻¹) for CH₄ is 25 in the time horizon of 100 years (Froster et al., 2007); ^bGHGI (kg CO₂-equivalent kg⁻¹ grain yield) was calculated by dividing GWPs of CH₄ emissions by rice yield.

irrigated plot was 5.16 Mg CO₂ ha⁻¹ followed by saturated plots (3.82 Mg CO₂ ha⁻¹). Conversely, under AWDI treatments the lowest GWP from the AWDI-20 cm was 2.54 Mg CO₂ ha⁻¹ followed by AWDI-15 cm (3.05 Mg CO₂ ha⁻¹) and AWDI-10 cm (3.26 Mg CO₂ ha⁻¹). In general, intermittent irrigation system (AWDI) significantly reduced the total GWPs (**Table 1**), even though continuous flooded and saturated plots showed two-fold higher GWPs. The GHGI also decreased remarkably with AWDI treatments compared to other treatments. As a result, AWDI-20 cm reduced highest percentage (50%) of CH₄ emission rate but gave lower yield due to more water stress compared to continuous flooded plots. AWDI-15 cm could reduce 40% CH₄ emission with satisfactory yield although AWDI-10 cm reduced only 36% CH₄ emission with the highest grain yield production.

3.4. Effect of Irrigation Managements on Nutrient Status Prior to Rice Harvesting Stage

In study, **Table 2** shows that the intermittent AWDI system increased soil porosity, the content of soil organic matter compared to continuous irrigated control plots in where total N content, available P and K content showed non-significant variation under different irrigation treatments. AWDI did not affect the soil nutrient status in addition, increased organic carbon as like as soil organic matter status. Soil organic matter significantly varied from 2.10% to 1.90% in where the highest % OM was found in AWDI-15 cm and the lowest was in continuous flooded plots.

Irrigation System	Soil porosity	Soil pH	Soil Eh	Organic matter (%)	Total N (%)	Available <i>P</i> (ppm)	K (meq/100g)
Saturated	0.54	6.7	-57.71	1.97	0.12	13.92	0.12
Continuous flooded	0.52	6.8	-66.6	1.74	0.10	12.56	0.12
AWDI (10 cm)	0.57	6.6	-43.5	2.07	0.14	14.17	0.13
AWDI (15 cm)	0.57	6.62	-31.6	2.10	0.13	13.66	0.12
AWDI (20 cm)	0.59	6.52	-27.32	1.99	0.12	13.24	0.11
Level of significance	*	NS	**	*	*	*	NS
CV (%)	2.18	3.53	21.77	8.87	22.22	6.43	15.21
LSD	0.59	0.22	3.8	0.13	0.02	1.04	0.02

Table 2. Chemical properties of soil prior to rice harvesting stage.

** = Significant at 1% level of probability; * = Significant at 5% level of probability and NS = Not significant.

3.5. Correlations Correlation of CH₄ Emissions with Other Parameters

There were negative correlations between total seasonal CH_4 flux with grain yield, water productivity index, soil Eh, organic matter, total N, available *P* and K content except no. of irrigation, total volume of water supplied for rice grain production, soil porosity and soil pH under continuous irrigated treatment (**Table 3**). On the other hand, CH_4 flux showed a strong positive correlation with no. of irrigations, total volume of water supplied for paddy field, grain yield, water productivity index, the availability of soil organic matter, soil pH, total N, available *P* and K content, while there were only negative correlation with soil Eh and soil porosity under AWDI systems.

4. Discussion

In study, Alternate Wetting and Drying Irrigation (AWDI) significantly decreased the seasonal CH_4 emissions during rice cultivation. The lower CH_4 emission from AWDI plots was due to increased aeration, stabilization of soil organic carbon, improved soil redox potential status. Among AWDI treatments, T_3 (10 cm) reduced 36% CH_4 flux followed by T_4 -15 cm (40%) and T_5 -20 cm (50%). This result revealed that AWDI treatments are the most effective options for reducing CH_4 emission during Boro rice cultivation, which was consistent with the findings of Jain et al. (2013). This result might be also due to highly promoting soil reduced condition that was influenced by different irrigation treatments (Supparattanapan et al., 2009). Ali et al. (2013) also reported that intermittent irrigations significantly reduced total seasonal CH_4 emissions by 27% compared to conventional (124 kg CH_4/ha) irrigated rice paddy field.

The increased Eh values might have suppressed the methanogens' activities that were responsible for CH_4 emission from rice field, while stimulated the methanotrophs activities, and eventually decreased methane emission rate during rice cultivation (Ali, 2008). On the other hand, the highest CH_4 emission rate

Damanastana	Correlation coefficient (r)					
Parameters	Saturated + Continuous	AWDIs				
Grain yield	-0.547	0.585				
Water productivity	-0.754	0.444				
Soil pH	0.309	0.009				
Soil Eh	-0.918	-0.794				
Soil porosity	-0.712	-0.782				
Organic matter	-0.772	0.309				
Total N	-0.997	0.292				
Available P	-0.385	0.062				
K	-0.883	0.311				

Fab	le 3.	Correl	lation o	of CH₄	emissions	with se	lected	plant	parameters	and soil	l pro	perties.
------------	-------	--------	----------	--------	-----------	---------	--------	-------	------------	----------	-------	----------

was found in continuous flooded plots due to more conductivity of CH_4 gas through aerenchyma channel, more decomposable organic carbon and highly soil reduced status under waterlogged condition. Tarlera et al. (2016) also observed more CH_4 emission rate in the treatment of continuous flooding than AWDI treatment. In the present study, although saturated plots showed low CH_4 emission than continuous irrigated control plots but always gave high rate of CH_4 emission than AWDI treatments.

The seasonal CH_4 emissions gave more or less similar pattern in both cultivation systems, i.e. CH_4 flux was higher during reproductive stage of rice growth in all treatments due to the development of root aerenchyma (Kludge et al., 1993), and decomposition of soil organic materials (Dubey, 2005). The sudden and sharp fall in CH_4 emission rates at grain maturation stage in all might be due to the aging of rice plant, the end of irrigation and plant senescence, when labile organic C are no longer released by organic matter decomposition due to lack of available water that was also supported by Cai et al. (1997). Finally, AWDI treatments significantly could mitigate the rate of CH_4 emission upto 50% (20 cm), 40% (15 cm) and 36% (10 cm) from that of continuous flooding in a cropping season which was supported by Win et al. (2015) and Itoh et al. (2011).

In our experiment, AWDI-20 cm saved upto 18% irrigation water with the lowest CH_4 emission rate compared to continuous flooded treatment but gave lower yield due to more water stress. But AWDI—10 cm and 15 cm saved upto 13% and 16% irrigation water, respectively with minimum rate of CH_4 emission compared to continuous flooded treatment as supported by Chapagain and Yamaji (2010). Yang et al. (2016) also reported that moderate AWDI—in which photosynthesis was not severely inhibited and plants could rehydrate overnight, during soil drying period or when water table was maintained at 10 to 15 cm below soil surface, could increase not only WUE but also grain yield.

AWDI treatments stimulated the more rice yield, which were negatively interlinked with total seasonal CH₄ flux in where more root depth was found most probably for the more soil porosity that supported more tillers and ultimately more yield of rice. This might be due to more depth of rice root support more nutrient uptake from different soil nutrient layer. Rice grain yield was increased by 11%, only in AWDI (10 cm) in where AWDI (15 cm) gave more or less similar grain yield over the control irrigated plots in our experiment. Conversely, rice grain yield was negatively correlated with seasonal CH₄ flux, which was supported by Denier van Der Gon et al. (2002). Among the all treatments, AWDI (10 cm) and AWDI (15 cm) are economically feasible and effective for mitigating seasonal CH₄ flux and increasing rice productivity over the conventional flooded rice cultivation.

5. Conclusion

This field experiment confirmed that AWDI is a promising method which provides duel benefits of water saving and optimum rice productivity with low CH₄ emission compared to conventional flood irrigation during dry season Boro rice cultivation. Conclusively, suitable alternate wet and dry irrigation water management practices (Irrigate when water level falls below 10 - 15 cm from surface) could be implemented in farmers' field based on site specific agro-ecological zone for significant water savings, reducing methane emission and sustaining rice productivity. Further field trials in different agro-ecological zones may provide wider adaptability and farmers' acceptability.

Acknowledgements

The authors are highly grateful to the National Science and Technology, Ministry of Science and Technology, 2015-2016, Government of the People's Republic of Bangladesh for financial support after this research.

Conflicts of Interest

There is no conflict of interest for this research publication.

References

- Ali, M. A. (2008). Effect of Soil Amendments Having Electron Acceptors for Mitigating Methane Emission during Rice (Oryza sativa) Cultivation. Ph.D. Thesis, Jinju: Division of Applied Life Science, Gyeongsang National University.
- Ali, M. A., Haque, M. A., & Kim, P. J. (2013). Mitigating Global Warming Potentials of Methane and Nitrous Oxide from Rice Farming in Bangladesh. AMBIO, 42, 357-368. https://doi.org/10.1007/s13280-012-0349-3
- Ali, M. A., Oh, J. H., & Kim, P. J. (2008). Evaluation of Silicate Iron Slag Amendment on Reducing Methane Emission from Flood Water Rice Farming. *Journal of Agriculture, Ecosystem and Environment, 128*, 21-26. <u>https://doi.org/10.1016/j.agee.2008.04.014</u>
- Bangladesh Rice Research Institute (BRRI) (2016). Alternate Wetting and Drying (AWD) Method. Bangladesh Rice Knowledge Bank (BRKB).
- BBS (Bangladesh Bureau of Statistics) (2012). *Statistical Year Book of Bangladesh 2012: Bangladesh Bureau of Statistics*. Dhaka: Stat. Div., Min. Plan. Govt. People's Repub.

- Bhuiyan, S. I. (1992). Water Management in Relation to Crop Production: Case Study on Rice. *Outlook on Agriculture, 21,* 293-299. https://doi.org/10.1177/003072709202100408
- Brown, J. D., & Lilleland (1946). Rapid Determination of Potassium and Sodium in Plant Material and Soil Extracts by Flame Photometry. *Proceeding of the American Society of Horticultural Sciences, 48,* 341-346.
- Cai, Z., Xing, G., Yan, X., Xu, H., Tsuruta, H., Yagi, K., & Minami, K. (1997). Methane and Nitrous Oxide Emissions from Paddy Fields as Affected by Nitrogen Fertilizers and Water Management. *Journal of Plant Soil, 196*, 7-14. https://doi.org/10.1023/A:1004263405020
- Chapagain, T., & Yamaji, E. (2010). The Effects of Irrigation Method, Age of Seedling and Spacing on Crop Performance, Productivity and Water-Wise Rice Production in Japan. *Paddy and Water Environment, 8*, 81-90. https://doi.org/10.1007/s10333-009-0187-5
- Conrad, R. (2002). Control of Microbial Methane Production in Wetland Rice Fields. *Nutrient Cycling in Agro-Ecosystems, 64,* 59-69. https://doi.org/10.1023/A:1021178713988
- Denier van Der Gon, H. A. C., Kropff, M. J., van Breemen, N., Wassmann, R., Lantin, R. S., Aduna, E., & Corton, T. M. (2002). Optimizing Grain Yields Reduces CH₄ Emissions from Rice Paddy Fields. *Proceedings of the National Academy of Sciences of the United States of America, 99*, 12021-12024. https://doi.org/10.1073/pnas.192276599
- Dubey, S. K. (2005). Microbial Ecology of Methane Emission in Rice Agro-Ecosystem: A Review. *Applied Ecology and Environmental Research, 3*, 1-27. https://doi.org/10.15666/aeer/0302_001027
- Itoh, M., Sudo, S., Mori, S., Saito, H., Yoshida, T., Shiratori, Y., Suga, S., Yoshikawa, N., Suzue, Y., Mizukami, H., Mochida, T., & Yagi, K. (2011). Mitigation of Methane Emissions from Paddy Fields by Prolonging Midseason Drainage. *Agricultural and Ecosystems Environment*, 141, 359-372. https://doi.org/10.1016/j.agee.2011.03.019
- Jaafar, M. N., Saad, P., & Vel Arjunan, S. N. (2000). A Computational Model for Water Use Efficiency in Rice Production. *Jurnal Teknologi Maklumat, 12,* 1-13.
- Jain, N., Dubey, R., Dubey, D. S., Singh, J., Khanna, M., Pathak, H., & Bhatia, A. (2013). Mitigation of Greenhouse Gas Emission with System of Rice Intensification in the Indo-Gangetic Plains. *Paddy and Water Environment*, *12*, 355-363. https://doi.org/10.1007/s10333-013-0390-2
- Kludge, H. K., Delaune, R. D., & Patrick Jr., W. H. (1993). Aerenchyma Formation and Methane and Oxygen Exchange in Rice. *Soil Science Society of America Journal*, *57*, 386-391. https://doi.org/10.2136/sssaj1993.03615995005700020017x
- Mosier, A. R., Halvorson, A. D., Reule, C. A., & Liu, X. J. (2006). Net Global Warming Potential and Greenhouse Gas Intensity in Irrigated Cropping Systems in Northeastern Colorado. *Journal of Environmental Quality*, 35, 1584-1598. https://doi.org/10.2134/jeq2005.0232
- Nieder, R., & Benbi, D. K. (2008). Bidirectional Biosphere-Atmosphere Interactions. In *Carbon and Nitrogen in the Terrestrial Environment* (pp. 235-305). Berlin: Springer Science + Business Media B.V. https://doi.org/10.1007/978-1-4020-8433-1_8
- Olsen, S. R., Cole, C. U., Watanable, F. S., & Deun, L. A. (1954). *Estimation of Available P in Soil Extraction with Sodium Bicarbonate* (p. 929). U.S. Dept. of Agric. Cir.
- Page, A. L., Miller, R. H., & Keeney, D. R. (1982). *Methods of Soil Analysis, Part 2* (2nd ed.). Madison WI: American Society of Agronomy.
- Price, A. H., Norton, G. J., Salt, D. E., Ebenhoeh, O., Meharg, A. A., Meharg, C., Islam, M.

R., Sarma, R. N., Dasgupta, T., Ismail, A. M., Mcnally, K. L., Zhang, H., Dodd, I. C., & Davies, W. J. (2013). Alternate Wetting and Drying Irrigation for Rice in Bangladesh: Is It Sustainable and Has Plant Breeding Something to Offer? *Food and Energy Security*, *2*, 120-129. <u>https://doi.org/10.1002/fes3.29</u>

Quassem, M. A. (2010). The Daily Star. 22 August, Newspaper, Bangladesh.

- Rashid, M. H. (1997). *Manual on Irrigation and Soil-Water Engineering*. Joydebpur: Irrigation and Water Management Division, Bangladesh Agricultural Research Institute.
- Rolston, D. E. (1986). Gas Flux. In A. Klute (Ed.), *Methods of Soil Analysis* (Part 1, 2nd ed., pp. 1103-1119). Agron. Monogr. 9, Madison, WI: Soil Sci. Soc. America and America Soc. Agron. <u>https://doi.org/10.2136/sssabookser5.1.2ed.c47</u>
- Singh, S., Singh, J. S., & Kashyap, A. K. (1999). Methane Flux from Irrigated Rice Fields in Relation to Crop Growth and N-Fertilization. *Soil Biology and Biochemistry, 31*, 1219-1228. https://doi.org/10.1016/S0038-0717(99)00027-9
- Smith, M. (1992). CROPWAT-A Computer Programme. Irrigation Planning and Management. FAO Irrigation and Drainage Paper 46. Rome.
- Solomon, S., Qin, D., Manning, M., Alley, R. B., Berntsen, T., Bindoff, N. L., Chen, Z., Chidthaisong, R., Tignor, M. L., & Miller, H. (2007). The Physical Science Basis. In Contribution of Working Group I to the Fourth Assessment Report of Intergovernmental Panel on Climate Change (pp. 20-91). New York, Cambridge: Cambridge University Press.
- Supparattanapan, S., Saenjan, Cecile, Q., Maeght, J. L., & Olivier, G. (2009). Salinity and Organic Amendment Effects on Methane Emission from a Rain-Fed Saline Paddy Field. *Soil Science and Plant Nutrition*, 55, 142-149. https://doi.org/10.1111/j.1747-0765.2008.00330.x
- Tarlera, S., Capurro, M. C., Irisarri, P., Scavino, A. F., Canton, G., & Roel, A. (2016). Yield-Scaled Global Warming Potential of Two Irrigation Management Systems in a Highly Productive Rice System. *Scientia Agricola (Piracicaba, Braz.), 73*, 43-50. <u>https://doi.org/10.1590/0103-9016-2015-0050</u>
- Uphoff, N., & Kassam, A. (2009). A Case Study: The System of Rice Intensification, Agricultural Technologies for Developing Countries. Annex 3, Science and Technology Options Assessment (STOA), European Parliament.
- Walkley, & Black, C. A. (1965). An Examination of Digtiareff Method for Determining Soil Organic Matter and Proposed Modification for the Chronic Acid Titration Method. *Soil Science*, *37*, 29-38. <u>https://doi.org/10.1097/00010694-193401000-00003</u>
- Win, K. T., Nonaka, R., Win, A. T., Sasada, Y., Toyota, K., & Motobayashi, T. (2015). Effects of Water Saving Irrigation and Rice Variety on Greenhouse Gas Emissions and Water Use Efficiency in a Paddy Field Fertilized with Anaerobically Digested Pig Slurry. *Paddy and Water Environment*, 13, 51-60. https://doi.org/10.1007/s10333-013-0406-y
- Yang, J., Zhou, Q., & Zhang, J. (2016). Moderate Wetting and Drying Increases Rice Yield and Reduces Water Use, Grain Arsenic Level and Methane Emission. *The Crop Journal, 5*, 151-158. <u>https://doi.org/10.1016/j.cj.2016.06.002</u>
- Zheng, X. H., Zou, J. W., Huang, Y., & Wang, Y. S. (2007). Quantifying Direct CH₄ Emissions in Paddy Fields during Rice Growing Season in Mainland China: Dependence on Water Regime. *Atmospheric Environment*, *41*, 8030-8042. https://doi.org/10.1016/j.atmosenv.2007.06.049