

Influence of Rice Establishment Methods on Water Productivity, Methane Emissions and Rice Grain Heavy Metals Content from Irrigated Rice Paddies in Bangladesh

Samina Nasrin Borna, Imran Ahammad Siddique, Abdullah Al Mahmud, Rehana Khatun, Mahmud Hossain, Shofiqul Islam, Andrew A. Meharg, and M. Rafiqul Islam

ABSTRACT

Reducing methane (CH₄) emissions and water use in irrigated rice systems while maintaining production to feed the ever-increasing population is vital in Bangladesh. Different rice establishment methods viz. alternate wetting & drying (AWD), system rice intensification (SRI) and direct wet seeded rice (DWSR), have a promising mitigation potential to reduce CH₄ emission compared to continuous flooded (CF) rice fields. A field experiment was conducted at Bangladesh Agricultural University, Mymensingh, during the Boro season in 2018 to examine whether rice establishment methods could maintain grain yield with reduced water use and CH₄ emissions. A split-plot design was employed with water management in the main plots and fertilizer management in the subplots. The yield difference was not significant ($p>0.05$) in CF, AWD, and SRI systems other than DWSR. Planting methods in combination with organic fertilizer amendment had little effect on the grain Fe, Zn, and Cd concentration but significantly affected the as concentration. AWD, SRI, and DWSR significantly reduced the total water use by 17-33% and increased water productivity by 22-35% compared to CF. SRI system performed superior ($p>0.05$) by increasing the water productivity coupled with reducing water consumption compared to CF. The impact of water management on changing climate in rice fields was compared using seasonal CH₄ emission and yield-scaled global warming potential (GWP). Total seasonal CH₄ emissions were significantly distinct ($p<0.05$) from different rice establishment methods. Seasonal CH₄ emissions from CF, AWD, SRI, and DWSR systems were 147.85, 128.11, 110.35, and 91.52 kg CH₄ ha⁻¹, respectively. Emissions were reduced by about 13-38% in contrast with continuous flooded soil. The emissions of greenhouse gases per unit grain yield (yield-scaled GWP) followed the order; CF>AWD>DWSR>SRI, while reducing yield-scaled emissions from AWD, SRI and DWSR decreased around 15-25% over that of the CF system. In conclusion, it is recommended that both SRI and AWD can mitigate CH₄ emission, powered reduce water consumption as well as grain content from irrigated rice fields without yield penalty.

Keywords: Global Warming Potential, Methane, Rice Establishment Method, System Rice Intensification, Water Management, Yield-Scaled Emissions.

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S. N. Borna

Department of Environmental Science,
Bangladesh Agricultural University,
Bangladesh.

(e-mail: nasrinborna99@gmail.com)

I. A. Siddique

Department of Soil Science, Bangladesh
Agricultural University, Bangladesh.

(e-mail: imran.siddique@bau.edu.bd)

A. Al Mahmud

Soil Scientist, Green Riyadh Project
Dorsch KSA, Riyadh, Saudi Arabia.

(e-mail: aamahmud84@hotmail.com)

R. Khatun

Department of Environmental Science,
Bangladesh Agricultural University,
Bangladesh.

(e-mail: rehana_envsc@bau.edu.bd)

M. Hossain

Department of Soil Science, Bangladesh
Agricultural University, Bangladesh.

(e-mail: mahmud.ss@bau.edu.bd)

S. Islam

Department of Soil Science, Bangladesh
Agricultural University, Bangladesh.

(e-mail: sislam_ss@bau.edu.bd)

A. A. Meharg

Institute for Global Food Security,
Queen's University, Ireland.

(e-mail: aa.meharg@qub.ac.uk)

M. R. Islam*

Department of Soil Science, Bangladesh
Agricultural University, Bangladesh.

(e-mail: mrislam58@bau.edu.bd)

**Corresponding Author*

I. INTRODUCTION

Rice (*Oryza sativa*) is one of the world's most important staple food which is sown over an area of 164 million ha and accounts for 11% of the world's arable land [1]. Meanwhile, the majority of the world's rice is cultivated under continuous flooded (CF) soil conditions, which leads to the production and emissions of a major amount of anthropogenic methane (CH₄). CH₄ is a potent greenhouse gas (GHG) that has 34 times higher global warming potential (GWP) than carbon

dioxide (CO₂) over a 100- year time horizon [2]. Research outputs have underlined some effective management practices for increasing rice yields while reducing GHG emissions, including the development of new rice varieties [3]-[4], the application of manure such as cow dung [5], the selection of appropriate cultivation methods [6] and the timing of drainage [7]. Flooded soil conditions in rice fields emit about 100 kg CH₄-C ha⁻¹ season⁻¹ [8] and production of CH₄ might increase by up to 60% by 2030 from rice systems [9]. Bangladesh is the fourth largest rice-producing country

in the world [1]. Boro (dry) season rice (January/February to April/May), makes up the majority of total production in Bangladesh, covering about 4.7 million ha and producing 19.6 million MT [10] and is completely irrigated using groundwater resources. The conventional water management method leads to a high amount of surface runoff, seepage, and percolation that can account for 50-80% of the total water input [11]. As rice is a thirsty crop, it requires about 1900-5000 L of water to produce 1 kg of rough rice when grown under continuous standing water conditions [12]. Hence, water is an expensive input for rice cultivation. Rice is generally established in the field by transplanting seedlings in puddled soil. Rice scientists have been trying to find alternate options requiring less water for rice cultivation. Several studies have revealed that midseason or intermittent drainage can be a potential option to attenuate CH₄ emissions by a large margin [13]-[15]. Through drainage of wet soil, several additional benefits can also be yielded, like reduction in effective tillers, removal of toxic substances, and prevention of root rot, which ultimately lead to increased yield coupled with reduced water use [16]. From the perspective of greenhouse gas mitigation, there is a good scope to reduce methane emissions from paddy fields by applying less water to keep the soil under less reduced conditions. The need for water-saving irrigation practices such as alternate wetting and drying (AWD) proposed by International Rice Research Institute (IRRI) is increasing in Bangladesh [17]-[18] due to groundwater depletion. Various studies have also reported that AWD irrigation can save irrigation water without losses in rice grain yield [19]-[20], while reducing CH₄ emission from the rice soil [21]. The System of Rice Intensification (SRI) technique and Direct Wet Seeding of Rice (DWSR) have been shown to reduce the water requirement of crops while maintaining the same yield. SRI recommends intermittent irrigation compared to traditional continuous flooding enabling soil aeration, and root development activity [22]. Meanwhile, this could be an effective system to reduce CH₄ emissions. CH₄ emissions from rice paddies in central Thailand were diminished by 35% by drainage twice in the rice field [23]. A similar result indicates that CH₄ emission was reduced by 69.5% through prolonged midseason drainage [16]. Direct seeding rice has been introduced in Europe, Australia, and the USA, receiving much attention due to low-input demand [24]. In the DWSR systems, seeding is done in non-flooded soils, and irrigations are provided to maintain standing water conditions for about 3-4 weeks during the early reproductive phase of the crop from the panicle initiation stage to promote crop establishment [25]. DWSR may inhibit methanogenesis and reduce the seasonal

CH₄ emission during sowing by maintaining an aerobic condition. The amendment of local manures and residues is gaining popularity to improve soil fertility. Field studies revealed that early-season drainage combined with mid-season drainage lessened CH₄ emissions from residue-amended soils by 89–92% [26] and 43–67% [27]. However, very few studies have been found in Bangladesh investigating the heavy metal concentration in rice grain and the CH₄ emissions under improved drainage practices combined with organic fertilizer application. On the other hand, there are several disadvantages to using organic fertilizers, including the risk of heavy metal contamination and greater GHG emissions [28]. The redox chemistry of continuous flooded rice system favors more arsenic (As) (V)-reducing bacteria than non-flooded rice system [29] which is to be taken up by rice roots. In addition, the scenario is favored more with a relatively high dissolved organic carbon content in the flooded rice soil followed by applying organic fertilizers [30]. To our knowledge, this would be the first study to investigate the effects of rice planting methods on heavy metals content and water productivity while quantifying the GHG emissions from Bangladesh. This study aimed to quantify CH₄ emissions from different rice establishment methods through modified water management combined with inorganic and organic fertilization. It is imperative to find out alternate methods of rice establishment that require less water, have comparable yield with traditional methods of rice cultivation, and aim to elucidate the CH₄ fluxes from rice fields.

II. MATERIALS AND METHODS

A. Experimental Site

The experiment was performed at the Soil Science Field Laboratory, Bangladesh Agricultural University, Mymensingh (latitude: 24°71'60" N, longitude: 90°42'58" E) during Boro season of 2018. The study area has a sub-tropical climate which is characterized by low temperature, low humidity, and light precipitation with occasional cold winds in the rabi season (16 October–15 March). The weather information regarding temperature, rainfall, relative humidity, and sunshine hours prevailed at the experimental site across the rice growing period of January to June 2018 has been presented in Fig. 1. The soil of the rice field was silt loam in texture (11.44% sand, 72.40% silt and 16.16% clay) with soil properties being 5.38 in initial pH, 0.16% in total N and 1.75% in total C. The soil contained 2.95 mg kg⁻¹ available P, 0.08 meq 100 g⁻¹ soil exchangeable K and 12.06 mg kg⁻¹ available sulfur.

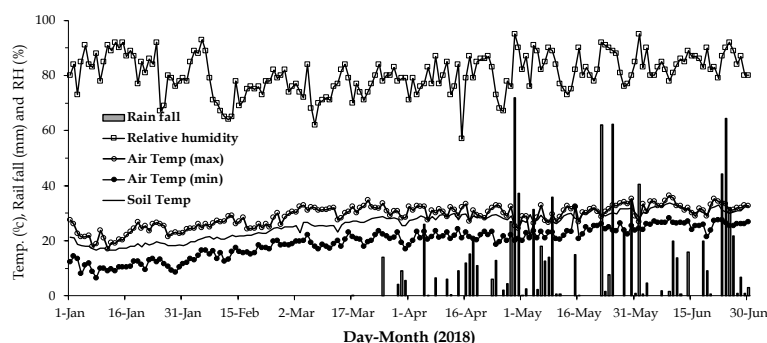


Fig. 1. Daily average of rainfall, air and soil temperatures, and relative humidity during the experiment period, January-June 2018.

B. Rice Establishment Systems and Water Regime

In this experiment, the land was prepared by four to five spading followed by laddering to prepare it for planting. Poultry manure (PM) was homogenously mixed with soil in all plots three days before transplanting. Forty-five-day-old rice seedlings with continuous flooded (CF) condition and alternate wetting & drying (AWD) condition and fourteen-days-old rice seedlings with system rice intensification (SRI) from nursery bed were transplanted to experimental plots on 29 January 2018. In the direct wet seeding of rice (DWSR) system the sprouted seeds were sown in lines on the same day. Two to three seedlings were transplanted in each hill and with 25 cm × 25 cm spacing between hills. After one week of transplanting, all plots were checked for missing hill; the missing hills were filled up with extra seedlings. The experiment was laid out in a split-plot design with triplicates using a 4×2 factorial randomized complete block design. The area of each plot was 4 m × 2 m. The first factor was rice establishment methods and the second one was fertilizer management. To check water flow, all plots were separated with a border covered with plastic film installed to a depth of 30 cm below soil surface. Under CF condition, the first level of water management, the water level kept at 3-5 cm above the soil surface, starting from transplanting until 15 days before harvest. The AWD condition is the second level of water management where the plots were continuously flooded until 14 days after transplanting (DAT) and then irrigation was stopped. When the water level reached at 15 cm soil depth as indicated by the perforated water pipe installed in the field, the plot should be immediately irrigated to a level of 5 cm above soil surface. Again, the plots were left to dry out and the process was continued until 15 days before harvesting. Under SRI system, a single seedling (14 days old) per hill was transplanted in flooded soil maintaining the water level at 3-5 cm. The flooded condition was maintained for 4 weeks after transplanting followed by intermittent wetting and drying condition. While in direct seeding of rice in wet conditions (DWSR), the pre-germinated seeds were sown along the line in the flooded soil. The plots were kept saturated for until 2 weeks before harvest then, 3-5 cm of water was maintained.

C. Fertilization

Recommended doses of nutrients viz. N (125 kg/ha), P (25 kg/ha), K (85 kg/ha) S (20 kg/ha) and Zn (3 kg/ha), were applied as urea, triple super phosphate, muriate of potash gypsum and zinc oxide respectively for all plots. In all the field experiments, triple super phosphate, muriate of potash, gypsum and zinc oxide were applied during final land preparation. Urea was applied in three equal splits at 11, 36 and 55 DAT.

D. Water Input and Water Productivity

During the season, irrigation water usage was measured by multiplying the flow rate in the pipe by the time of irrigation to the plot. Water productivity was calculated as the grain yield per unit of total water input including irrigation and rainfall. Water input was calculated as the sum of irrigation and rainfall [31].

E. Gas Sampling, Analysis and Calculation

A closed chamber technique was used to quantify the emissions of methane following standard guidelines [32]. A closed chamber consisting of a chamber top and chamber base was installed permanently in the field after the transplanting of rice during the growing period. The acrylic glass was used to prepare a chamber top (0.60 m × 0.40 m × 1.3 m, length, width, and height), while a separate chamber base (0.6 m × 0.4 m × 0.3, length, width and height) was prepared using the same glass. The chambers are equipped with a circulating fan for the homogenization of gas mixture and a thermometer to monitor the temperature inside the chamber during the sampling time. The air gas samples were collected from chambers using 50 ml air-tight syringes at 0, 15- and 30-min intervals after chamber placement. CH₄ concentrations in the collected air samples were measured by gas chromatography (Shimadzu, GC-2015, Japan) packed with a Porapak NQ column (Q 80–100 mesh) and equipped with a flame ionization detector (FID). The temperatures of the column, injector, and detector were adjusted at 100 °C, 200 °C, and 200 °C, respectively. Gas samples were always carried out during mid-morning at 09:00-11:00 [33]. Collected gas samples were then transferred to 10-mL air-evacuated vial for analysis. The hourly fluxes of CH₄ (mg CH₄ m⁻² h⁻¹) was calculated using (1).

$$\text{Flux}_{\text{CH}_4} = \frac{\Delta C}{\Delta t} \times \frac{V}{A} \times \rho \times \frac{273}{273+T} \quad (1)$$

where $\Delta C/\Delta t$ is the concentration change over time (ppm-CH₄ h⁻¹); V is chamber volume (m³); A is chamber area (footprint; m²); ρ is gas density (0.717 kg m⁻³ for CH₄ at 0 °C); and T is the mean air temperature inside the chamber (°C).

Trapezoidal integration method (i.e., linear interpolation and numerical integration between sampling times) was used for calculating cumulative gas emissions [32]. To calculate CO₂-equivalent for CH₄ from rice growing season, global warming potential (GWP) is measured by multiplying 34 [2] and yield-scaled GWP is calculated in relation to per kg grain yield [34].

F. Chemical Analysis

The rice grains were dehusked mechanically. The grains were ground using a mill ball into fine powder. The samples were digested with Aristar grade HNO₃-H₂O₂ and analyzed for different trace elements and heavy metals using ICP-MS. The reliability of the procedure for the estimation of all elements was assessed by analyzing the Certified Reference Material (CRM) GBW(E) 080684.

G. Statistical analysis

Plant parameters (yield and yield components) and plant analysis data was statistical analyzed through computer based statistical program Statistical Tool for Agricultural Research (STAR 2.0.1, International Rice Research Institute, Philippines). Significant effects of the treatments were determined by analysis of variance (ANOVA) and the treatment means were compared at 5% level of significance by Duncan's Multiple Range Test (DMRT).

III. RESULTS

A. Grain Yield, Yield Components and Water Use

The grain yield was found highest in the alternate wetting and drying system, while the grain yields of system rice intensification were comparable to those in a continuous flooded system (Fig. 2a). In the direct wet-seeded rice system, the grain yield ($3989.5 \text{ kg ha}^{-1}$) was significantly less than the continuous flooded system ($4902.9 \text{ kg ha}^{-1}$). Alternate wetting & drying and system rice intensification systems achieved higher grain yields of 5041.3 and $4844.9 \text{ kg ha}^{-1}$ respectively. But there is no significant difference of grain yield among CF, AWD, and SRI (Fig 2a). Plant height ranged from 79.7 cm in the DWSR planting method to 93.2 cm in SRI method (Table I).

The development of plant height, panicle length and filled grains per panicle in SRI system were significantly superior to all other planting methods. The plant heights in other establishment methods were statistically identical. Effective tiller showed the highest tiller number of 414.0 m^{-2} by DWSR which was statistically similar to that with SRI. All these superior yield properties of SRI system eventually led to the highest grain yield.

The amount of irrigation water and rainfall included to the total water input to rice growing season during 2018. The total amount of water use was significantly greater in CF with least in DWSR (Fig 2b). The average water uses in CF and AWD were 11016 and $9159 \text{ m}^3 \text{ ha}^{-1}$, respectively, while in SRI and DWSR were 8084 and $7377 \text{ m}^3 \text{ ha}^{-1}$ respectively. The total water consumption was significantly cut down by using AWD (by 17 %), SRI (by 27 %) and DWSR (by 33 %) compared to CF (Fig. 2b). In the present study, water productivities in the AWD, SRI and DWSR systems were significantly higher than that of the CF system. Water productivity in AWD, SRI and DWSR were 24, 35 and 22 %, respectively higher than CF (Fig. 2c).

B. Micronutrient and Heavy Metal Concentration in Rice Grain

Different rice establishment methods had little effect on the concentration of iron (Fe), manganese (Mn), and Zinc (Zn) in rice grains (Table II). Iron concentration in grains ranged from 26.3 mg kg^{-1} in the AWD water management to 31.2 mg kg^{-1} in the DWSR planting method. Manganese concentration was lower in the AWD system (26.4 mg kg^{-1}) than in the CSW (30.4 mg kg^{-1}). The Mn concentrations in rice grains of SRI (31.2 mg kg^{-1}) and DWSR (31.3 mg kg^{-1}) planting methods were almost equal. The concentration of Zn

ranged from 12.4 mg kg^{-1} in AWD to 15.3 mg kg^{-1} in CSW practice.

Zinc concentration in grains obtained with SRI and DWSR methods was very close. Arsenic concentration showed a marked variation between CSW (0.202 mg kg^{-1}) and other planting methods ($0.155\text{-}0.163 \text{ mg kg}^{-1}$). Organic fertilizer application also showed some increase in grain As concentration compared to without fertilizer application. The interaction effect of the planting method and fertilizer application significantly affected As concentration in grains (Table II). Organic fertilizer application combined with CSW irrigation had the highest grain As concentration (0.229 mg kg^{-1}), while the lowest As was observed in AWD irrigation combined with organic fertilizer application (0.125 mg kg^{-1}). Cadmium concentration in rice grain was quite low and varied a little among the treatment combinations ($0.018\text{-}0.024 \text{ mg kg}^{-1}$)

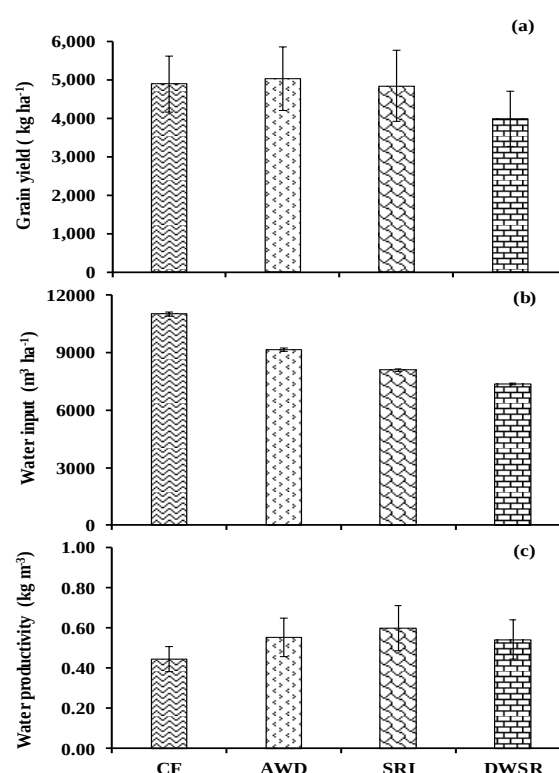


Fig. 2. Grain yield; a) water input (irrigation + rainfall); b) and water productivity; c) under Continuous Flooded (CF), Alternate Wetting & Drying (AWD), System Rice Intensification (SRI) and Direct Wet Seeded Rice (DWSR) establishment methods during Boro season in 2018. Black lines in the bars represent the standard deviation. Different lowercase letters are significantly different at $p < 0.05$.

TABLE I: RICE GROWTH AND YIELD PROPERTIES UNDER CONTINUOUS FLOODED (CF), ALTERNATE WETTING & DRYING (AWD), SYSTEM RICE INTENSIFICATION (SRI) AND DIRECT WET SEEDED RICE (DWSR) ESTABLISHMENT METHODS DURING BORO SEASON IN 2018

Establishment methods	Plant height (cm)	Effective tiller m^{-2}	Panicle length (cm)	Filled grains panicle ⁻¹	1000 seed weight (g)
CF	81.6b	317.3b	18.6b	77.2b	20.8a
AWD	83.6b	333.7b	18.6b	78.7b	19.8bc
SRI	93.2a	413.3a	19.6a	84.6a	19.4c
DWSR	79.7b	414.0a	15.8c	45.9c	20.4ab
CV (%)	4.27	3.58	2.49	5.77	3.36
p-value	0.0001	0.0001	0.0001	0.0001	0.0180

Within a column, means followed by same lowercase letters are not significantly different at $p < 0.05$.

TABLE II: MICRONUTRIENTS AND HEAVY METALS CONTENTS IN RICE GRAIN UNDER CONTINUOUS FLOODED (CF), ALTERNATE WETTING & DRYING (AWD), SYSTEM RICE INTENSIFICATION (SRI) AND DIRECT WET SEEDED RICE (DWSR) ESTABLISHMENT METHODS AND FERTILIZER MANAGEMENT ALONG WITH THEIR INTERACTIONS DURING BORO SEASON IN 2018

Establishment methods	Fe (mg kg ⁻¹)	Mn (mg kg ⁻¹)	Zn (mg kg ⁻¹)	As (mg kg ⁻¹)	Cd (mg kg ⁻¹)
CF	30.3	30.4	15.3	0.202	0.023
AWD	26.3	26.4	12.4	0.155	0.021
SRI	31.1	31.2	14.8	0.163	0.021
DWSR	31.2	31.3	14.9	0.163	0.023
CV (%)	16.8	16.8	15.3	16.5	11.6
<i>p</i> -value	0.332	0.334	0.138	0.055	0.296
Fertilizer management					
Without fertilizer	31.0	31.1	14.4	0.160	0.023
With fertilizer	29.6	29.7	14.4	0.174	0.022
CV (%)	15.58	15.66	11.72	12.62	11.61
<i>p</i> -value	0.304	0.304	0.839	0.134	0.352
Interaction variables					
CF+ Without fertilizer	33.2	33.3	15.4	0.175bc	0.023
AWD+ Without fertilizer	28.0	28.1	13.1	0.186ab	0.023
SRI+ Without fertilizer	29.9	30.0	14.2	0.143bc	0.020
DWSR + Without fertilizer	33.0	33.1	15.1	0.137bc	0.024
CF + Fertilizer	27.4	27.5	15.2	0.229a	0.022
AWD+ Fertilizer	24.7	24.7	11.6	0.125c	0.018
SRI + Fertilizer	32.4	32.5	15.4	0.183ab	0.023
DWSR +Fertilizer	29.3	29.4	14.8	0.189ab	0.022
CV (%)	16.83	16.86	15.36	16.52	11.66
<i>p</i> -value	0.534	0.533	0.783	0.011	0.133

Within a column, means followed by the same letters are not significantly different at $p < 0.05$.

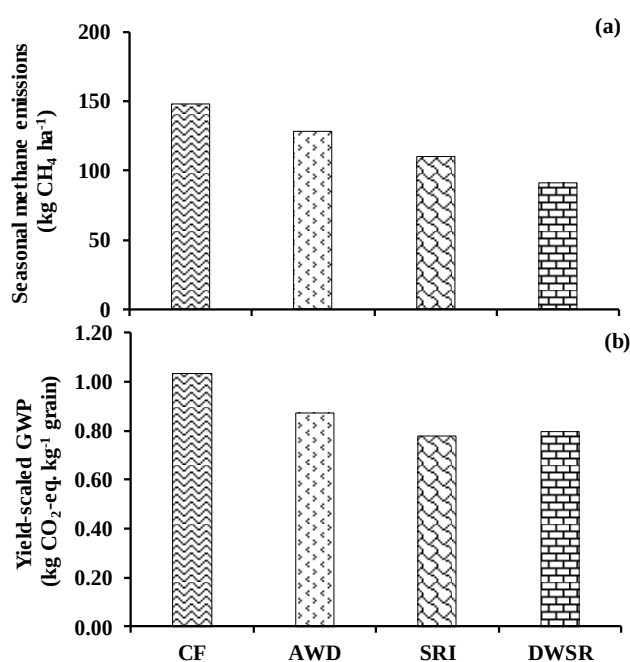


Fig. 3. Seasonal methane emissions (a) and yield-scaled Global Warming Potential (GWP) (b) under Continuous Flooded (CF), Alternate Wetting & Drying (AWD), System Rice Intensification (SRI) and Direct Wet Seeded Rice (DWSR) establishment methods during Boro season in 2018.

C. Seasonal CH₄ Emissions and Yield Scaled GWP

The seasonal total CH₄ emissions was significantly distinct ($p < 0.05$) from different rice establishment methods (Fig. 3a). Compared with AWD, SRI and DWSR, the amount of CH₄ emissions was higher in CF system. Seasonal CH₄ emissions from CF, AWD, SRI and DWSR systems were 147.85, 128.11, 110.35 and 91.52 kg CH₄ ha⁻¹, respectively. Due to establishment systems, the emissions were curtailed about 13~38 % in contrast with continuous flooded soil. Therefore, the total CH₄ emissions reduced by almost 13, 25 and 38% under AWD, SRI and DWSR treatment compared with CF.

The yield scaled GWP was significantly affected by establishment methods (Fig. 3b). Under the continuous flooded method, yield-scaled emissions were highest (1.03 kg CO₂-eq. kg⁻¹ grain), whereas the system rice intensification method significantly decreased yield-scaled emissions (0.79 kg CO₂-eq. kg⁻¹ grain). Both AWD and DWSR were statistically identical in yield-scaled emissions. Due to water management in different establishment systems, the yield-scaled emissions from AWD, SRI and DWSR decreased around 15-25% over that of CF system.

IV. DISCUSSIONS

This study is the first to compare the effect of different rice establishment methods over CF in terms of yield, heavy metal contamination, water consumption and reducing the methane emissions in Bangladesh. Over 75% of world paddy rice cultivation requires a waterlogged condition [35] which eventually a major source of CH₄ emission from soil. In contrast, alternate irrigations systems limit the water layer to the soil surface, initially to save the water as well to mitigate CH₄ emission [36].

A. Effect of Establishment Methods on Rice Yield and Water Use

Rice yields were not affected for the establishment methods (Fig. 2b). Rice yield for the tested cultivar was ranged from 3989 kg ha⁻¹ in DWSR to 5041 kg ha⁻¹ in AWD.

We found no significant yield variation of AWD and SRI comparing to CF. Result is consistent with the previous records [18], [21]. Rice Yield was positively affected by alternate soil drying process in different systems except DWSR which enhance root growth, grain filling and carbon remobilization from vegetative tissues to grain [37]. Although the grain yield in DWSR was significantly less than other three systems (CF, AWD and SRI), water consumption was much to produce grain yield, which considerably

increased the water productivity than flooded system [38]. Also, the AWD and SRI systems achieved higher grain yield while saving water consumption respectively 17 and 27 % [39]-[40], confirmed that water productivity was significantly higher compared with conventional continuous flooded system [41]-[42]. Without loss of yield and yield components' maintaining highest water productivity SRI has an edge over other water saving techniques.

B. Effect of Establishment Methods on Micronutrients and Heavy Metal Content of Rice Grain

The different planting methods of BRRI dhan28 had insignificant effects on concentrations of Fe, Mn, and Zn in rice grains. The practice of AWD reduced the concentrations of Fe, Mn and Zn in grains compared to those with CSW water management. The Fe, Zn and Mn in grains grown by DWSR and SRI methods. The grain-As concentration was higher when rice was grown under transplanting method with CSW than in other planting methods. The grain-Cd concentration remained unaffected due to different planting methods of BRRI dhan28. AWD decreased grain concentration of Fe and As, while it increased the grain concentration of Mn and Cd [43]. These results indicate that plants grown under safe AWD conditions at this site have an increased grain mass compared to plants grown under CF, and this may be partly due to a high number of productive tillers. They also stated that AWD decreases the concentration of As in the grains in this site, but elevates the Cd concentration.

C. Effect of Establishment Methods on Methane Emissions and Yield Scaled GWP

Rice establishment methods through water management are known to play a promising role in reducing CH₄ emissions from rice systems [44]. Over the rice growing season this study indicated that CH₄ emissions were significantly lower under AWD, SRI and DWSR than CF rice establishment practices (Fig. 3). To our knowledge, this is the first case in Bangladesh where different water saving establishment systems were directly compared with conventional continuous flooded rice system. Flooded soil in rice systems creates an anaerobic condition which is conducive for CH₄ emission [9]. Any reduction in the flooded water would allow effective mitigation of CH₄ emission to different levels depending on the chosen establishment methods. In the present study, water saving techniques was directly reduced the emissions. Although the soil redox potential was not recorded in this study, it was assumed that soils were aerobic in condition under non-flooded condition. Under AWD condition, it is confirmed that CH₄ emissions from rice field can be reduced with deploying single or multiple aeration which is consistent with previous result [45]. Though the extent of reducing methane under AWD in current study is less than the result stated by several reports [46]-[47], because of no yield penalty there may be still possibility to prolong the soil drying period in order to further reduction of CH₄ emissions. While SRI method maintaining a saturated condition in the rice growing season curtailed the CH₄ emissions. The finding of CH₄ emission from SRI method is in line with field study [21]. The reduction in the current study is relatively low compared to other field studies [16], [48]. Although a good drainage system was established in

experiment, due to high precipitation and unpredictable rainfall patterns strongly affected the CH₄ production, which could explain the lower CH₄ emission reduction from SRI treated plots. Also increasing the mid-season drainage could be potential option to increase the magnitude of reducing CH₄ emissions [23]. In our study, seasonal CH₄ emissions was significantly declined under direct wet seeded rice compared to that of continuous flooded system which was consistent with previous study [49]. The decrease of CH₄ emission trend in DWSR might be explained by the development of shallower root systems [50], which allows the oxidation of CH₄ to CO₂ eventually leads to reducing CH₄ emissions [51]. Yield-scaled GWP links GHG emissions directly to agricultural production [52]. As the results shown that grain yields were not significantly affected by AWD and SRI systems, the yield scaled GWP was lower than CF, namely by 15 % in AWD and 25 % in SRI treatment. However, due to high plant density favorable for crop diseases and weed infestation in DWSR contributed to the yield gap among all systems. Meanwhile, the lowest seasonal emissions significantly lowered the yield scaled GWP. Limiting the flooding condition of soil through mid-season drainage could bring the oxic condition in soil which effectively elucidates the CH₄ emissions. Moreover, the presence of organic substrate as labile organic carbon may serve as an electron donor for methanogens. Deploying the water management systems could potentially affect the degradation of organic substrate. These results indicate that the rice establishment methods in irrigated rice systems in Bangladesh could be an effective soil management strategy to reduce the impact of GHG emissions without changing rice productivity. Incorporation of mid-season drainage, while increasing the number of drainage cycles and extent of drainage period could be strategy to reduce CH₄ emissions from irrigated rice systems.

V. CONCLUSION

The present study concluded that the rice plant established by the SRI method assessed significantly in agronomic performance compared to all other planting methods. In contrast, the grain yield obtained in AWD water management was the highest, statistically identical to the SRI method. Due to establishment systems, the emissions were curtailed by about 13~38 %, in contrast with CSW. In general, the methane emissions followed the order CSW>AWD>SRI>DWSR. Due to water management in different establishment systems, the yield-scaled emissions from AWD, SRI, and DWSR decreased by around 15-25% over that of the CSW system. It suggested that the AWD and SRI treatments can potentially reduce CH₄ emissions, water use, grain As content, and increase grain yield.

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CONFLICT OF INTEREST

Authors declare that they do not have any conflict of interest.

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