ISSN: 2634-9221
European Journal of Applied Sciences; Vol. 14 No. 01 (2026) (24-31)
https://doi.org/10.14738/aivp.1401.19791

Alternate Wetting and Drying (AWD) Increase Rice Yield, and Water-Use Efficiency while Mitigating Methane Emissions from Synchronized Rice Systems

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Abstract: A field experiment was conducted at a synchronized cropping area on a farmer's field in Nokla, Sherpur, Bangladesh using Boro rice (SL8H Super Hybrid), to identify effective water management practices for water saving, methane emission reduction, and sustainable yield. The experiment followed a Randomized Complete Block Design with two treatments and four replications. The treatments were as follows: T_1 = Irrigation with alternate wetting and drying (AWD), and T_2 = Non-AWD, which involved normal irrigation (farmer's practice) with continuous standing water in the field. The results showed that the AWD plot had a higher grain yield (6.61 t ha^{-1}) compared to the Non-AWD plot (5.83 t ha^{-1}), with a 13.4% increase in yield and a 16% reduction in irrigation water use. Moreover, cumulative methane (CH_4) emissions were higher under the Non-AWD treatment compared to the AWD treatment throughout the season. The AWD irrigation system reduced CH_4 emissions by 35%, likely due to intermittent aeration that makes the soil oxic, promoting the oxidation of CH_4 by methanotrophic microbes. This leads to a decrease in methane emissions. Thus, the implementation of alternate wetting and drying (AWD) in Boro rice cultivation proves to be an effective management strategy for reducing CH_4 production and emissions, contributing to more sustainable rice production.

Keywords: Methane emissions, AWD, Synchronized rice systems, water-use efficiency.

INTRODUCTION

Meeting the anticipated 34% increase in the world's population by 2050 will be extremely difficult for rice (Oryza sativa) production (Tilman et al., 2011). In rice-based systems, intensive production techniques have been frequently used to meet the growing demand for food. However, these practices can have a major impact on soil carbon (C) and nitrogen (N) cycling, especially methane (CH_4) emissions. These practices include altering crop establishment techniques, increasing the use of nitrogen (N) fertilizer, and using different irrigation regimes (such as continuous flooding and alternate wetting and drying, or AWD) (Feng et al., 2025; Zhang, 2025; Loaiza et al. 2024; Echegaray-Cabrera et al., 2024; Sibayan et al., 2018; Liang et al., 2017)

In rice-growing regions, synchronized cropping systems have been encouraged more and more in recent years as a way to stabilize crop production, improve agronomic management, and increase water-use efficiency. Coordinated rice planting, irrigation, and harvesting within a designated irrigation command or landscape unit, when farmers adhere to a shared cropping calendar and management schedule, is known as synchronized cropping. This coordinated strategy promotes consistent crop growth phases over wide regions, which enhances fertilizer uptake, streamlines management choices at the community or scheme level, and enables effective irrigation delivery.

Reducing pest and disease pressure is one of the main benefits of synchronized cropping. The lifecycle of many insect pests and disease organisms is disturbed when crops in a landscape grow at similar stages, which reduces the spread of these organisms between fields. Additionally, synchronized planting facilitates more effective scheduling of fertilizer inputs, pesticide application, and irrigation rotations by farmers and water management authorities. In intensively farmed rice habitats, where dispersed and disorganized management frequently results in inefficient water use and higher production costs, this collaborative action strategy is especially pertinent.

In Bangladesh, the cultivation of Boro rice, which is heavily reliant on irrigation and groundwater extraction during the dry season, is becoming more and more dependent on synchronized cropping. Coordinated water management across adjacent farms has become crucial as irrigation demand rises and groundwater supplies are under more stress. Better control over irrigation depth and frequency is made possible by synchronized cropping, which may significantly lower total water consumption without sacrificing output. However, extended anaerobic soil conditions—which are advantageous for methane-producing microbes—can also be produced by sustaining continual flooding across sizable, coordinated areas.

These anaerobic conditions have a large impact on greenhouse gas emissions, especially methane (CH_4), one of the main causes of climate change. Because there is less oxygen diffusion in the soil (Conrad, (2020), the continuous flooding that is frequently used in synchronized rice fields promotes methanogenesis. Consequently, there is a significant chance to lower methane emissions while maintaining or even raising rice yield by incorporating water-saving technologies like alternate wetting and drying (AWD) into synchronized cropping systems. In order to design climate-smart rice production techniques that balance crop yield, resource efficiency, and environmental sustainability, it is crucial to understand how AWD performs under synchronized field circumstances.

Over a 100-year period, methane has a 28-fold higher potential for global warming than carbon dioxide (CO_2), making it a powerful greenhouse gas (IPCC, 2014). Due to its vast rice-growing region, Southeast Asia contributes significantly to emissions from rice fields, which are one of the main sources of anthropogenic CH_4 (Zhang et al., 2016). Numerous factors, including soil characteristics, climate, and crop management techniques like water regime, aeration, temperature, availability of readily decomposable carbon substrates, N fertilizer application, and soil pH, influence the amount of CH_4 production in soil (Zhang et al., 2016). Among these, soil water content is particularly significant because it regulates microbial activity, oxygen availability, and gas diffusion.

Continuous flooding (CF), which is a prevalent technique in many rice-growing regions, causes soils to become extremely anaerobic, which favors methanogenic bacteria and raises CH_4 emissions (Minamikawa et al., 2006). Nevertheless, there is still little data on how irrigation techniques affect soil carbon-cycling microbes in rice systems. As opposed to continuous flooding, which is still the most used irrigation method in Bangladesh, alternate wetting and drying (AWD) irrigation has been demonstrated to lower greenhouse gas emissions (Islam et al., 2024). According to earlier research, AWD can cut CH_4 emissions by as much as 40% (Li et al., 2018). However, there is currently a dearth of study on how AWD affects greenhouse gas emissions in Bangladesh.

Therefore, a clearer understanding of the effects of AWD on CH_4 emissions in Boro rice, particularly in synchronized cropping systems, is essential. It is hypothesized that the implementation of AWD will not only reduce methane emissions and environmental pollution, but also enhance water-use efficiency and maintain or improve rice yield.

MATERIALS AND METHODS

Study Site and Experimental Design

A field experiment was conducted during the Boro season of 2024 in a synchronized, farmer-managed cropping area at Nokla, Sherpur, Bangladesh, using Boro rice (SL8H Super Hybrid). The study aimed to evaluate water management practices for reducing irrigation water use, minimizing methane (CH_4) emissions, and sustaining rice yield. The experimental site is located in the Old Brahmaputra Floodplain agro-ecological zone (AEZ 9).

Soil Properties

Initial soil samples (0–15 cm depth) were collected prior to the establishment of the experiment. The soil was classified as silt loam in texture and had a pH of 6.5. Other physicochemical properties of the soil are presented in Table 1.

Table 1: Properties of initial soil and interpretation of soil test values at Farmer's field Nokla, Sherpur

Soil analysis interpretation	Texture	pH	O.C (%)	Total N (%)	P (μg g^{-1})	K (meq%)	S (μg g^{-1})
	Silt loam	6.5	1.2	0.19	12.0	0.21	39.4

O.C= Organic Carbon, meq%= milliequivalent percent, μgg^{-1}= microgram per gram

Experimental Layout and Treatments

The experiment was conducted using a Randomized Complete Block Design (RCBD) with two irrigation treatments and four replications. The treatments included: (a) alternate wetting and drying (AWD), where a 25 cm long plastic pipe perforated along the lower 15 cm was installed in each plot and irrigation was applied when the water level inside the pipe dropped to 15 cm below the soil surface, and (b) non-AWD (farmer's practice/continuous flooding), in which standing water was maintained throughout the growing period. Seedlings were raised in trays, and 25-day-old seedlings were transplanted into the field using a rice transplanter

Crop Management and Fertilizer Application

Fertilizer application was determined using recommendations from the Khamari App (digital fertilizer recommendation tool for Bangladeshi farmers) and applied at the following rates: urea @ 248 kg ha^{-1}, DAP @ 143 kg ha^{-1}, MoP @ 253 kg ha^{-1}, gypsum @ 126 kg ha^{-1}, and zinc sulfate @ 6 kg ha^{-1}. Irrigation treatments were imposed three weeks after transplanting (crop establishment stage), and the AWD treatment was maintained from the establishment period to the pre-flowering stage.

Irrigation Water Measurement

At the beginning of the experiment, pump discharge was measured using a 163-L drum and a stopwatch. During puddling and each subsequent irrigation event, the amount of water entering the plots was calculated based on the pump flow rate, the time required for irrigation, and the plot area. In addition, the cumulative volume of water supplied to each treatment plot (AWD and non-AWD) was measured using a water flow meter. The standing water depth in each plot was recorded daily throughout the cropping period.

Chamber Installation and Methane Gas Sampling

The base of the gas sampling chambers was installed 1–2 days before the first sampling and inserted into the soil to a depth of 8–10 cm to prevent gas exchange between the inside and outside of the chamber (**Fig.1**). Soda glass chambers (40 cm × 40 cm × 50 cm) with stainless steel collars were placed over six rice hills per plot. The collars were inserted 10 cm into the soil and fitted with neoprene seals to ensure an airtight closure. Sampling was conducted from the transplanting date until harvest. Gas samples (16 ml) were collected three times on each sampling day at 0, 30, and 60 minutes after chamber closure between 10:00 a.m. and 1:00 p.m. Additionally, samples were collected at 0, 3, 5, 7, 10, and 14 days following each split application of urea, as described by Das et al. (2022) and Jahangir et al. (2021). Urea was applied by broadcasting within the pre-installed chamber bases to capture emissions immediately after fertilization.

Fig.1: CH_4 gas collection under AWD and Non-AWD irrigation system in farmer's field, Nokla.

Methane (CH_4) concentrations were measured using a gas chromatograph (GC-2010; Shimadzu Co., Kyoto, Japan). Samples were withdrawn from the chamber headspace using a 20-ml polypropylene syringe with a 25-gauge Luer-lock needle and injected into pre-evacuated 12-ml vials (Labco Wycom Ltd.) to create over-pressure. Methane emission rates were calculated from the slope of the linear regression between CH_4 concentration and chamber closure time (Gaihre et al.,2013).

Methane (CH_4) flux was calculated using the following equation (Gaihre et al., 2013):

$$\mathrm{CH_4\ emission\ rate\ (mg\ m^{-2}d^{-1})} = \frac{\mathrm{Slope\ (ppm\ min^{-1})} \times \mathrm{Vc} \times \mathrm{MW} \times 60 \times 24}{22.4 \times (\frac{273 + \mathrm{T}}{273}) \times \mathrm{Ac} \times 1000}$$

Here, Vc is the volume of the gas chamber in liters (L), MWis the molecular weight of the respective gas, 60 is min h^{-1}, 24 is h d^{-1}, 22.4 is the volume of 1 mol of gas in L at standard temperature and pressure, 273 is the standard temperature in °K, T is the temperature inside the chamber in °C, Ac is the area of the chamber in m^2, and 1000 is μg mg^{-1}.

Data Collection

Data were collected throughout the experiment to evaluate water use, methane emissions, and rice productivity. The volume of irrigation water applied to each plot was measured using calibrated flow meters for both AWD and non-AWD treatments, while daily standing water depth was monitored using a ruler or gauge. Methane (CH_4) flux was measured at regular intervals using the closed-chamber technique and analyzed by gas chromatography. At maturity, grain yield and key yield-contributing traits; including panicle number, grains per panicle, 1000-grain weight, and dry grain yield were recorded.

RESULTS AND DISCUSSION

Effects of AWD on Rice Yield, Irrigation Water Requirements, Water Savings and Water Foot-print (WF)

The higher grain yield was observed in AWD plot (6.61 t ha^1) compared to the Non-AWD plot (5.83 t ha^1) (**Table 2.1**). Overall, yield was increased in the AWD plot by 13.4%, and Irrigation water saved by 15.9%. The earlier researchers also supported these results (Islam et al. 2020). To produce 1 kg of rice, 1173 litter and 1569 litter of water were needed respectively, for T_1 (AWD) and T_2 (Non-AWD) treatments. The increase in yield under AWD may be due to increased tiller per hill, increased microbial activity due to oxidation facility, and increased rate of decomposition of organic matter. The harvesting time under AWD was 4-6 days earlier than that of non-AWD.

Table 2.1: Summary results showing yield (t ha^{-1}), Irrigation water requirement, IWR (cm); Irrigation water saving (%) and Water Footprint, WF (L kg^{-1})

Treatment	Yield (t ha^{-1})	IWR (cm)	Yield increased (%)	IW saving (%)	WF (L kg^{-1})
AWD	6.61	76.5	13.4	15.9	1173
Non-AWD	5.83	91.0	-	-	1569

Effects of AWD on Methene Gas Emissions

The dynamics of CH_4 emissions measured from the two irrigation systems are presented in **Fig.2.1**. Magnitudes and patterns of CH4 emissions varied with irrigation regimes. Over the rice-growing season, daily CH_4 emission rates ranged from 9 to 275 mg m−2 d^{-1} under AWD irrigation and from 42 to 409 mg m^{-2} d^{-1} under Non-AWD condition (data were not shown). Across the year, cumulative CH_4 emissions were higher under the Non-AWD irrigation compared to those recorded at the AWD irrigation. AWD irrigation reduced CH_4 emissions by 34.7% compared to the Non-AWD irrigation system (**Fig.2.1**).The cumulative emissions from this study ranged from 131.48 to 201.35 kg ha^{-1} $season^{-1}$ (Fig.2.1). Similarly, the emission ranged from 99 to 313 kg ha^{-1} $season^{-1}$ in Bangladesh (Islam et.al 2020), which is comparable to our results.

AWD reduced emission factor of CH_4 by 34.7% compared to the Non-AWD irrigation system (**Fig.2.2**). Similar findings were also reported in previous studies (Ku et al., 2017; Islam et al., 2018; Li et al., 2018; Zhang, 2025).

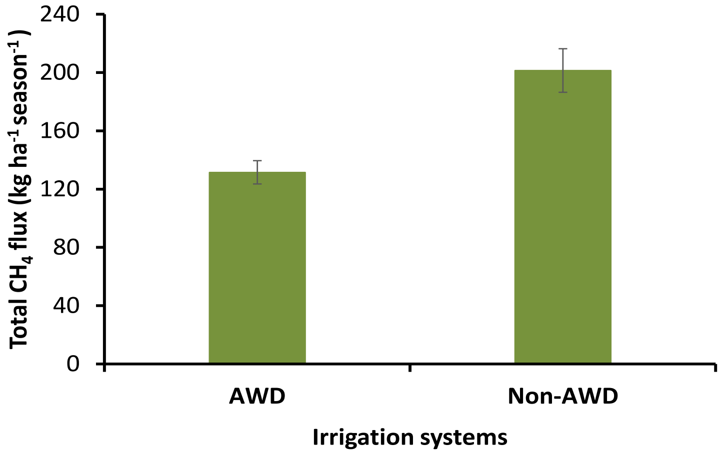

Fig 2.1: Total CH_4 flux during Boro rice cultivation under AWD and Non-AWD

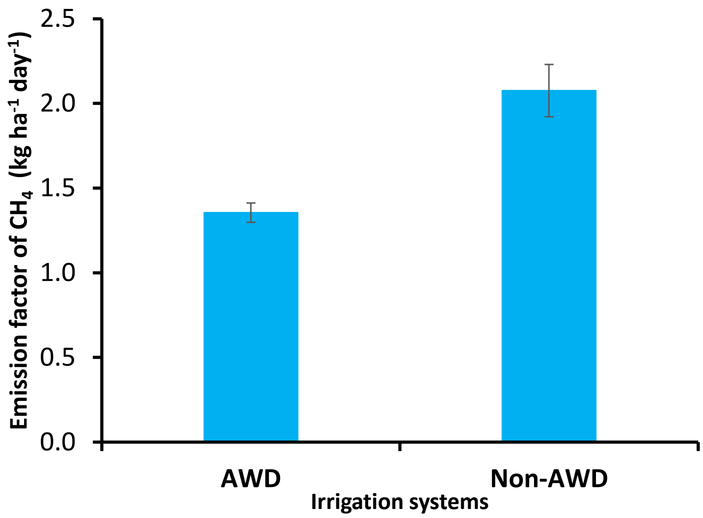

Fig 2.2: CH_4 emission factor with water management

CONCLUSION

From the present study it is revealed that, overall:

- AWD method saved water by 15.9%, and rice yield increased by 13.4%, compared to the Non-AWD irrigation method.
- AWD irrigation decreased CH_4 emission by 34.7%,

Therefore, the alternate wetting and drying (AWD) implementation on the Boro rice provides a promising management strategy to effectively decrease CH_4 production and emissions from rice field, which will contribute to sustainable rice production.

ACKNOWLEDGEMENT

The authors acknowledge the guidance and financial support of Bangladesh Agricultural Research Council (BARC), and acknowledge the cooperation from BINA substation Nalitabari, Sherpur. The authors also thank to the Bangladesh Rice Research Institute (BRRI) for their assistance in conducting the greenhouse gas analyses.

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