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Mitigation of Greenhouse Gas Emissions Through Different Rice Cultivars During T. Aman and Boro Seasons

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ABSTRACT

To increase crop yield and improve cropping intensity, several key cropping systems have been practiced in Bangladesh. Nevertheless, greenhouse gas (GHG) emissions from various crops and agricultural fields have primarily been published on a country-by-country basis. In this study, Cool Farm Tool Version 2.0 beta-3 software was used to estimate total GHG emitted from selected rice crops and rice-based cropping patterns. Short-duration rice cultivars exhibited lower methane (CH_4) emissions and higher grain yields than long-duration rice cultivars during both the Boro and Aman rice seasons. Among rice cultivars of the T. Aman season, BRRI dhan62, BRRI dhan66, BRRI dhan71, and BRRI dhan75 were relatively more suitable to reduce about 15-25% of CH_4 emission, GHG intensity, emission factor of CH_4, and subsequent GWP (global warming potential) compared to BRRI dhan49. Short-duration Boro rice cultivars like BRRI dhan28, 58, 68,74 reduced about 8-15% of CH_4 emissions compared to long-duration rice cultivars (BRRI dhan29). Spatial variations in rice equivalent yield with a higher amount of net carbon stock were found in Rice-Potato-Rice and Rice-Mustard-Rice cropping patterns in the studied area, Kotiadi and Pakundia, Kishoreganj, Bangladesh. Rice-Mustard-Rice cropping pattern gave a higher net carbon balance and reduced half of the P, K, S, and Zn fertilizers in subsequent Boro season rice cultivation. Additional multi-location/years research trials with recommended cropping pattern and management via GHG measurement are necessary to validate and propose appropriate mitigation measures to reduce GHG emissions and reduce chemical fertilizer use in Bangladesh.

Keywords: Cropping pattern, GHG intensity, Emission factor, Methane, Global warming potential

INTRODUCTION

Bangladesh has deliberately divided into 30 agro-ecological zones (AEZs) (nearly identical ecological and soil characteristics) and 88 sub-zones for its agricultural crop production. These zones have been characterized based on physiography, soil types, nature of seasonal flooding, and agro-climatology. Although different crops are grown across the country, rice plays a dominant role in food security, and rice/rice-based cropping patterns cover almost 75% of the net cropped area (NCA) (Nasim *et al.*, 2017). Rice covers more than 80% of the land area with a steady annual production growth rate of 2.8% during 1981-2007. Recently, rice growth rate has been reported to decline due to poor crop and soil management practices by the farmers and changing climatic conditions, especially changes in rainfall patterns and increasing temperature.

Increased air temperature and associated crop yield losses have been reported in Bangladesh (Maniruzzaman *et al.*, 2018; Amin *et al.*, 2015). According to some estimates, production of wheat may drop 32% by 2050 (IPCC, 2014). If

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temperature rises by 4OC, the potential shortfall in wheat and potato production could be as high as 50% and 70%, respectively (Karim *et al.*, 1996). Temperature increases would also shorten the winter season in Bangladesh. A short winter would adversely affect the vegetative as well as reproductive growth of most of the winter crops and consequently reduce yield (Amin *et al.*, 2015). High temperature, imbalanced fertilizer application, and poor agronomic management are the most important factors for reducing yields of HYVs Aus, Aman, and Boro rice (Haque *et al.*, 2019; Maniruzzaman *et al.*, 2018; Amin *et al.*, 2015), as well as yields of non-rice crops like mustard, potato, wheat, maize, etc.

Many other agricultural management practices are involved for producing better yields, rather than imbalanced fertilization and poor agronomic management only. Researchers have discovered that the GHG emissions from rice paddy fields can be affected by the amount of nitrogenous fertilizer used (Liu *et al.*, 2009; Banger *et al.*, 2012; Pantawat Sampanpanish., 2012; Chena *et al.*, 2024; Walthall *et al.*, 2025). So, balance or rice crop manager (RCM) based fertilizations are important techniques to minimize greenhouse gas emission, better yield, and sustain soil net carbon (C) balance.

Different cropping patterns, fertilizer management, and other cultural management are the main concerns for increasing or decreasing GHG emissions and soil C balance in rice-based cropping of Bangladesh. Especially methane (CH_4) emission occurs under anaerobic conditions, while carbon dioxide (CO_2) and nitrous oxide (N_2O) are emitted under aerobic conditions (Haque *et al.*, 2023a, 2023b). Rice-Fallow-Rice cropping system with only chemical fertilizer application showed a negative carbon balance and also gave a lower yield. Therefore, it is essential to build up knowledge or awareness among the farmers, enabling them to select the most suitable cropping pattern and rice cultivars, which may reduce production cost and GHG emission while increasing productivity and maintaining net soil C balance. We hypothesized that adopting rice-based climate-smart agricultural practices in selected villages of Bangladesh may influence GHG emissions, soil net ecosystem C balance, and rice equivalent yield, which has been evaluated in the present study under different rice cultivars and the most suitable cropping patterns.

MATERIALS AND METHODS

Selection of climate-smart upazila and soil characteristics of the area

Pakundia and Kotiadi upazila of Kishoreganj district (24°14-19'45-46.77"N, 90°40-47'37-46.84"E) were selected to conduct field experiments with major cropping patterns following different agricultural managements and estimate GHG emissions and net soil C sequestration during 2015-2018. This region has a complex relief of broad and narrow ridges, inter-ridge depressions, partially filled cut-off channel, and basins. Notable variations exist among soil types, topography, hydrology, and crops grown. Crops suffer due to terminal drought and flash flood both in T. Aman and Boro seasons, especially in low-lying areas. In general, farm holding is small and marginal (0.5-0.7 ha). In selected area, the top soil (0-15cm) texture is silty clay loam with organic matter content: 22.5g kg^{-1}, pH-H2O: 7.2, total N: 0. 90 g kg^{-1}, and available P: 86.0 mg kg^{-1}.

Crop establishment, Fertilizer application, and Used crop cultivars

In 2015–2018, we carried out ten experiments at each location and year. Only rice crop manager (RCM) based fertilizers for N-P-K-S-Zn were applied at the rates of 140-20-35-6-3 kg ha^{-1}, respectively, during Boro season, and 80-25-35 kg ha^{-1}, respectively, during T. Aman season. Nitrogen was applied as urea in three equal splits: (1) at the final land preparation before rice transplanting, (2) during the active tillering stage, and (3) one week before the panicle initiation stage. The total P and K were applied as basal fertilizers before rice transplanting by using triple super phosphate and muriate of potash, respectively. In the T. Aman season, 20-25-day-old rice seedlings were transplanted at optimum planting time following proper spacing, water management, and pest control. For this season, the selected short-duration rice varieties were BRRI dhan62, BRRI dhan66, BRRI dhan70, BRRI dhan71, BRRI dhan72, BRRI dhan73, and BRRI dhan75, and the long-duration rice cultivar was BRRI dhan49. Thirty-five to forty-day-old seedlings of BRRI dhan58, BRRI dhan28, BRRI dhan68, and BRRI dhan74 were transplanted in the Boro season. Mustard (BARI Sharisha14)/Potato (Diamant) have been introduced in T. Aman-Fallow- Boro cropping pattern. T. Aman crops were established in July (2015-2017) and harvested in the last week of October (2015-2018). Mustard and potato crops were established in the first week of November (2015-2017). Mustard was harvested in the last week of February (2016-2018) and potato in the first week of February (2016- 2018). Boro rice was established after ~ 5 days of mustard and potato harvest.

Rice yield

Grain and straw yields were determined at physiological maturity from 5 m2 areas within each plot following the standard method (Haque *et al.*, 2019). Grain yield was recorded after reducing the moisture content to ca. 14% (wt wt^{-1}), and straw weights were expressed on an oven-dry basis (65°C).

Collection of soil samples and analysis

Soil samples were collected from the surface layer (0-15 cm) before the start of the experiment and at the end of three years of experimentation. Collected soil samples were then air-dried, ground and sieved by 2mm sieve, as well as analysed for organic C content (Walkley and Black, 1934; Allison, 1965), pH-H_2O (1:2.5), total N (Yoshida *et al.*, 1976), available P (Olsen *et al.* 1982) and exchangeable K by ammonium acetate extraction method (Page *et al.*, 1982). Soil bulk density was determined by the core sampler method (Haque *et al.*, 2015; Black and Hartge,1986).

Estimation of Greenhouse gas emissions

Cool Farm Tool Beta-3 (CFT) was used to determine total GHG emission under different cropping systems and expressed as GWP (Haque *et al.*, 2017). In study sites, the major cropping patterns were T. Aman-Mustard-Boro, T. Aman-Potato-Boro, T. Aman-Fallow-Boro, and Jute-T. Aman-Fallow. Input variables and outputs of CFT were as follows:

Emission factor	Input variables	CFC output
Fertilizer-induced N_2O	Fertilizer types/application rate ha^{-1}/ management practices ha^{-1}	kg CO_2e/ha, kg CO_2e/kg product
Fertilizer production	Fertilizer type/ application rate, production technology	kg CO_2e/ha, kg CO_2e/kg product
Pesticide production	Number of applications	kg CO_2e/ha, kg CO_2e/kg product
Diesel use	Litres used	kg CO_2e/ha, kg CO_2e/kg product
Electricity use	Kwh	Kg CO_2e/ha, kg CO_2e/kg product
Crop residue management	kg/management practice	kg CO_2e/ha, kg CO_2e/kg product
Water management	Litres/management practice	kg CO_2e/ha, Kg CO_2e/kg product

Net soil carbon sequestration

Total soil organic carbon sequestration (TSOC) was determined as follows:

TSOC sequestration = OC*soil depth*bulk density……….. (i)

Statistical analysis

Statistical analyses were performed using the SAS package, version 9.1 (SAS Institute, 2003). A two-way ANOVA was carried out to compare the crops and cropping pattern means. Tukey's test was used for mean comparison, and differences were considered significant at p≤ 0.05.

RESULTS AND DISCUSSION

Variation of estimated GHG emission across rice cultivars

In the T Aman season, short-duration rice cultivars (100-135 days) BRRI dhan62, BRRI dhan66, BRRI dhan71, BRRI dhan72, and BRRI dhan75 significantly lowered (ranged from 98 to 124 kg CH_4 ha^{-1}) seasonal CH_4 emission compared to long-duration rice cultivar BRRI dhan49 (140-145 days) with 130 kg CH_4 ha^{-1} (Table 1). Across short-duration rice cultivars, BRRI dhan62 showed the significantly lowest total CH_4 flux (Table 1). Total CH_4 flux ranged from 98-124 kg ha^{-1} among short-duration rice cultivars. BRRI dhan62 and BRRI dhan75 reduced about 15-25% total CH_4 flux than BRRI dhan49. During Boro season, the long-duration rice cultivar BRRI dhan29 emitted about 156 kg ha^{-1} total CH_4 flux. About 133-143 kg ha^{-1} total CH_4 was emitted across short-duration rice cultivars. Short-duration rice varieties reduced about 8-15% seasonal CH_4 emission compared to long-duration rice cultivars. Among short-duration cultivars, BRRI dhan74 produced the lowest total CH_4 flux (133 kg ha^{-1} $season^{-1}$). Long-duration rice cultivars increased about 9-18% CH_4 emission due to their longer life cycle and field duration, which were the main sources of producing more CH_4 and increased net emission. Previous findings mentioned that different life cycles of rice cultivars are the main factor in increasing or decreasing GHG emissions (Haque *et al.*, 2017; Ding *et al.*, 2022; Zhang *et al.*, 2024). In both seasons, total N_2O emission was significantly lower in all short-duration rice varieties than that in long-duration rice cultivars BRRI dhan49 and BRRI dhan29, while this was the case for Boro season CO_2 emission only (Table 1).

Table 1. Long and short-duration rice cultivars with respective estimated greenhouse gas emissions during T. Aman and Boro season.

Variety	T. Aman season GHG emission (kg ha^{-1})			Variety	Boro season GHG emission (kg ha^{-1})		
	CH_4	N_2O	CO_2		CH_4	N_2O	CO_2
BRRI dhan49	130.0a	0.8a	300.9a	BRRI dhan28	143.0b	1.3a	493.8b
BRRI dhan62	97.5c	0.7a	285.1a	BRRI dhan29	156.0a	1.4a	521.7a
BRRI dhan66	114.4b	0.7a	285.1a	BRRI dhan58	141.7bc	1.30a	490.1b
BRRI dhan70	123.5ab	0.7a	285.1a	BRRI dhan68	135.2bc	1.30a	490.1b
BRRI dhan71	117.0ab	0.7a	285.1a	BRRI dhan74	132.6c	1.30a	490.1b
BRRI dhan72	123.5ab	0.7a	285.1a				
BRRI dhan75	110.5bc	0.7a	300.9a				

Here, GCV = Genotypic co-efficient of variation, PCV = phenotypic Co-efficient of variation, GA = genetic advance, = GA (%) = Genetic Advance as percent of mean, DFF = Days to 50% flowering, DM = Days to maturity, PH = Plant height (cm), FLL = Flag leaf length (cm), ETH = Number of effective tillers $hill^{-1}$, PL= Panicle length (cm), NGP= Number of grains $panicle^{-1}$, SF= Spikelet fertility, TGW= Thousand grains weight (g) and YH= Yield $hill^{-1}$(g).

Grain yield of different rice cultivars in Boro and T. Aman seasons

In the T. Aman season, BRRI dhan49 gave a lower yield than other varieties tested (BRRI dhan70, BRRI dhan71, BRRI dhan72, and BRRI dhan75). Among introduced varieties, BRRI dhan71 and BRRI dhan75 gave higher yield than the old variety BRRI dhan49 (Fig. 1). In the Boro season, BRRI dhan58 and BRRI dhan74 gave higher yield compared to BRRI dhan28.

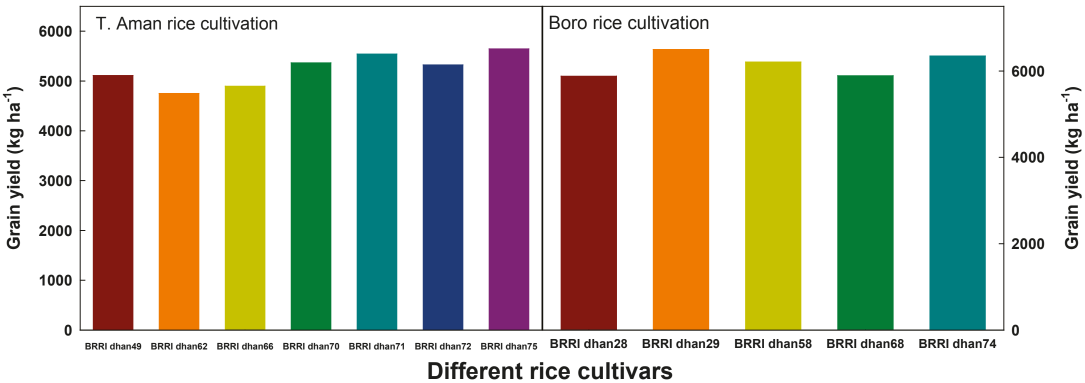

Fig.1. Grain yields of different rice cultivars during T. Aman and Boro rice season

GWP, GHG intensity, and emission factor of different rice cultivars in T. Aman and Boro seasons

Overall, GWP and emission factor of CH_4 in T. Aman season strikingly lowered compared to Boro season rice (Table 2). In the T. Aman season, GWP in short duration rice cultivars was significantly reduced than long long-duration rice variety BRRI dhan49. In this season, also BRRI dhan62 and BRRI dhan75 reduced GWP by 5-23% to that of BRRI dhan70, BRRI dhan71, and BRRI dhan72. Across short-duration rice cultivars, the GHG intensity in BRRI dhan75 was significantly lower than that in BRRI dhan66, BRRI dhan70, and BRRI dhan72. In Boro season, GWP in all short-duration rice cultivars was significantly lower than that in long-duration rice cultivar, BRRI dhan29 (Table 2). Among short-duration cultivars, BRRI dhan74 would be a good fit for the environment because the GHG intensity and emission factor of CH_4 in this variety were significantly lower than those in another popular short-duration variety BRRI dhan28. BRRI dhan74 produced more root and above-ground biomass than other varieties, which might have a positive effect on reducing overall GWP. Previous researchers found that some rice cultivars provide more rice root volume, length, radial oxygen loss, exudates, and biomass that might influence reduced CH_4 emission (Qi *et al.*, 2024; Qian *et al.*, 2023; Ding *et al.*, 2022; Girkin *et al.*, 2018; Girkin *et al.,* 2020; Girkin & Cooper., 2022).

Table 2. Global warming potential, GHG intensity, and emission factor of CH4 in long and short-duration rice cultivars during T. Aman and Boro season.

Variety	T. Aman season GHG emission (kg ha^{-1}) GWP	GHG intensity	Emission factor of CH_4	Variety	Boro season GHG emission (kg ha^{-1}) GWP	GHG intensity	Emission factor of CH_4
BRRI dhan49	4153	0.81	1.18	BRRI dhan28	4842	0.82	1.30
BRRI dhan62	3201	0.67	0.98	BRRI dhan29	5261	0.81	
BRRI dhan66	3674	0.75	1.14	BRRI dhan58	4802	0.77	1.28
BRRI dhan70	3929	0.73	1.17	BRRI dhan68	4620	0.78	1.22
BRRI dhan71	3747	0.68	1.17	BRRI dhan74	4547	0.72	1.21
BRRI dhan72	3929	0.74	1.17				
BRRI dhan75	3580	0.63	1.13				
$LSD_{0.05}$	289	0.09	0.08		312	0.08	0.07

Grain yield and GHG emission in different cropping patterns at Pakundia and Kotiadi Upazila

Researchers' management involving climate-smart practices, i.e., introducing Mustard or Potato during the fallow period in double rice cropping, provided almost double annual crop yields compared to the existing Rice-Fallow-Rice cropping pattern. This was also possible via the introduction of short duration improved rice varieties like BRRI dhan62, BRRI dhan66, BRRI dhan71 and BRRI dhan75 which allowed an additional crop instead of leaving the field fallow. In addition, climate-smart or best management practices were followed. The attained rice equivalent yields (REY) ranged from 15-29 t ha^{-1} in Rice-Mustard-Rice and Rice-Potato-Rice cropping patterns, whereas the harvested REY in Rice-Fallow-Rice cropping pattern was only about 11-12 t ha^{-1} (Table 3). Although REY increased due to the inclusion of Mustard and Potato during the fallow period in the studied farmers' fields, T. Aman-Potato-Boro- cropping pattern provided almost twice the REY than T. Aman-Mustard-Boro-Also, T. Aman- Mustard-Boro- T. Aman cropping pattern showed higher REY despite some increase in total GHG emission (707-818 kg ha^{-1}) compared to T. Aman-Fallow-Boro cropping system.

Table 3. Crop yield, rice equivalent yield and GHG intensity of different cropping pattern at Pakundia and Kotiadi Upazila.

Location	Cropping pattern	Grain yield (kg ha^{-1})			REY	Total GHG (kg ha^{-1})
		T. Aman	Mustard/Potato	Boro		
Pakundia	T. Aman-Mustard-Boro	4.76b	2.01b	5.66b	15.44b	5438b
	T. Aman-Potato-Boro	4.75b	33.0a	5.80b	28.35a	6129a
	T. Aman-Fallow-Boro	5.11a	-	6.20a	11.31c	4620c
Kotiadi	T. Aman-Mustard-Boro	4.80b	1.97b	5.60b	15.33b	5224b
	T. Aman-Potato-Boro	4.90b	34.5a	5.45b	28.96a	5932a
	T. Aman-Fallow-Boro	5.56a	-	6.30a	11.86c	4517c

Grain yield of Boro rice influenced by reduced rate of chemical fertilizers in Rice-Mustard-Rice cropping system

Applying full doses of chemical fertilizers for mustard and then half doses of phosphorus (P), potassium (K), sulfur (S), and zinc (Zn) for the subsequent Boro rice can maintain rice grain yield primarily due to the remaining residual effect of these nutrients applied to mustard. In both locations, there was no significant difference in grain yield of Boro rice cultivated with a full dose of PKSZn and a half dose of PKSZn after growing mustard crops, except for Pakundia in 2016-2017 (Table 4). This indicated that a significant portion of these nutrients remains in the soil in a form available to the next crop. Another important nutrient sources come from the decomposition of mustard residues, which further releases nutrients back into the soil, creating a slow-release nutrient source. This approach improves the nutrient use efficiency of the entire cropping system, reducing fertilizer costs and environmental impact without sacrificing yield. This strategy is most effective for reduction of chemical fertilizers during Boro rice cultivation under Rice-Mustard-Rice cropping system.

Table 4. Grain yield of Boro rice cultivating with reduced rates of chemical PKSZn fertilizers at Pakundia and Kotiadi Upazila, Kishoreganj.

Fertilizer management	2015-2016		2016-2017	
	Location			
	Pakundia	Kotiadi	Pakundia	Kotiadi
	Grain yield		Grain yield	
NPKSZn@140-20-60-6-3kg ha^{-1}	5.90	5.72	6.10	5.80
50% reduce rate of PKSZn with full urea-N	5.60	5.63	5.75	5.65
$LSD_{0.05}$	0.32	0.21	0.20	0.19

Net soil C stock under different major cropping systems

Rice-Jute-Fallow cropping pattern increased about 7-20% net soil C stock compared to Rice-Mustard-Rice and Rice-Potato-Rice cropping systems at both locations (Table 5). Rice-Fallow-Rice cropping system significantly lowered net C stock due to fallow period CO_2-C loss. However, when farmers add another crop, like potato or mustard, into the Rice-Fallow-Rice cycle, the soil absorbed more C due to the addition of root biomass, litter, rhizodeposition, and leaf. Therefore, Rice-Mustard-Rice, Rice-Potato-Rice, and Rice-Jute-Fallow cropping patterns supplied more soil organic C (Table 5), which can help to bind soil particles together, form aggregates, and improve water infiltration, aeration, and overall soil structure. All these make the soil more resilient to erosion and compaction, hence facilitate proper root growth as well as increased net soil C budget. Similar results were also reported by Haque *et al.* (2015, 2019, 2020) and Kumar *et al.* (2021).

Table 5. Soil net C stock influenced by different cropping patterns at Pakundia and Kotiadi, Kishoreganj.

Pattern	Pakundia			Kotiadi		
	BD	Net C stock (kg ha^{-1})	Net C balance (kg ha^{-1})	BD	Net C stock (kg ha^{-1})	Net C balance (kg ha^{-1})
Rice-Mustard-Rice	1.35b	2471a	581a	1.34bc	2472b	596b
Rice-Potato-Rice	1.38ab	2381b	491b	1.36b	2407c	531c
Rice-Jute-Fallow	1.32c	2495a	605a	1.32d	2515a	638a
Rice-Fallow-Rice	1.39a	2189c	299c	1.38a	2215d	338d
Initial	1.40a	1890d	-	1.39a	1877e	-

CONCLUSION

Irrespective of seasons, short-duration rice cultivars reduced about 8-25% CH4 emission compared to long-duration rice cultivars. Spatial variations of rice equivalent yield and net soil C balance were ensured due to the adoption of the most suitable cropping systems with appropriate inputs and management practices. Jute-Rice-Fallow, Rice-Mustard-Rice and Rice-Potato-Rice cropping systems are suitable for increasing net C stock and yield than the Rice-Fallow-Rice cropping pattern. In sum, understanding and implementing cropping patterns that promote a positive C balance are essential strategies for improving soil health, ensuring long-term agricultural productivity and contributing to environmental sustainability.

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