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GREENHOUSE GAS EMISSIONS FROM SELECTED CROPPING PATTERNS AND ADAPTATION STRATEGIES IN BANGLADESH

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ABSTRACT

There are many cropping patterns existed at farmers' field in Bangladesh. Different amounts of greenhouse gas (GHG) emission takes place from different crops fields, but data are not well examined in Bangladesh. In order to estimate GHG emission from agriculture fields, Cool Farm Tool Beta-3 was used for selected cropping patterns. The non-rice based cropping patterns had lower global warming potential (GWP) than rice-rice based cropping patterns. Onion-Jute-Fallow, Jute-Rice-Fallow, Wheat-Mungbean-Rice and Maize-Fallow-Rice patterns are relatively more suitable for reducing GHG emission and subsequent GWP. There were spatial variations in CH_4 emissions and the higher amounts were found in Mymensingh and Dinajpur districts of Bangladesh. On an average, about 1.39-1.56 Tg year^{-1} CH_4 emissions took place from paddy field in Bangladesh during 2012-2015. However, Potato-Boro-T. Aman and Mustard-Boro-T. Aman cropping pattern showed highest total rice equivalent yield (REY) and low GWP than Boro-T. Aman-Fallow cropping patterns. But intermittent drainage for growing dry season irrigated rice under Potato-Boro-T. Aman and Mustard-Boro-T. Aman patterns can be adopted to reduce about 24-26% of total GHG emissions than continuous flooding and also to maintain higher crop productivity and food security in Asian countries like Bangladesh.

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INTRODUCTION

Global demands for major cereals as food, feed, and fuel are expected to increase by 70% in 2050 (Tilman *et al.*, 2011; Fedoroff *et al.*, 2010; Godfray *et al.*, 2010) including Bangladesh. Farmers are growing different type of crops in a year following variable amounts of fertilizers (Saleque *et al.*, 2004; Nayaka *et al.*, 2012) and water to meet family demand. Most of the farmers use excessive urea fertilizer (Biswas *et al.*, 2004) and try to keep paddy field continuously flooded. These practices not only increase cost of production, but also enhance GHG emission from different crop fields (Dusenbury *et al.*, 2008; Guo *et al.*, 2010; Haque *et al.*, 2013, 2015a). Annual total GHG emissions from agriculture are estimated to be 1.4–1.6 Gt CO_2-C equivalent yr^{-1}, which is about 10–12% of the human-induced warming effect (IPCC, 2014).

In general, major GHGs emitted from rice, barley, wheat and other cereal crops are CH_4, CO_2 and N_2O (Haque *et al.*, 2015b). The share of cropland N_2O emission was 25.3% of GHG emission from agriculture in 2005 and CH_4 emissions from rice cultivation was 20% (NCCC, 2012). In 1961–2010, the world average greenhouse gas intensity (GHGI) for rice decreased by 49% but it increased by 45% for wheat and maize indicating that effective mitigation strategies are needed to achieve sustainable intensification of non-rice based cropping patterns to reduce absolute emissions (Tubiello *et al.*, 2014). The adoption of more intensified cropping systems has been shown to increase crop yields with decreasing GHGI compared with abatement practices traditional cropping systems (Campbell *et al.*, 2005; Bonesmo *et al.*, 2012). In China, the GHGIs for cereal production were minimized profitably through the adoption of some improved management practices (Shang *et al*., 2011; Huang *et al*., 2013; Ma *et al*., 2013). In Asian countries like India and China were found mean CH_4 emission from rice fields 2.7 - 6.4 and 5.85-7.24 Tg $CH_4.yr^{-1}$ (Guo-ding *et al*., 2004; Adhya *et al*., 1994; Mitra, 1992, Parashar *et al*., 1997). However, there is not enough information of total CH_4 emission from total rice paddy fields in Bangladesh. These imply that climate smart agricultural practices need to be followed for estimating of CH_4 emission and reducing GHG emission from different crop fields but such type of information is lacking in Bangladesh. Moreover, total CH_4 emissions are not available at different agricultural cropping pattern in Bangladesh. So, GWP for selected major cropping patterns and total CH_4 emission from paddy fields were computed for subsequent ecosystem modification and adaptation in crop production of Bangladesh.

MATERIALS AND METHODS

Experimental sites

The field experiment was carried out during major cropping pattern, 2012-2015 in Pakundia, Kotiadi (24°14-19'45-46.77"N 90°40-47'37-46.84"E), Kishoreganj, Bangladesh. Soil of the selected field was silt clay loam in texture having 22.5±3.9 g kg^{-1} organic matter, 0.90 g kg^{-1} T-N, pH (1:5 with H_2O) 7.2±0.32, and available P_2O_5 85.7±3.1 mg kg^{-1}. Rest of region of Bangladesh field experiments data were collected from Hand Book of Agricultural Technology (BARC & AFACI, 2013), Proceedings Research Review and Planning Workshop of Soils Program of NARS institutes (2012-2015) and different research organization in Bangladesh. Crop area data of 2012-13 to 2014-15 were collected from Year Book of Agricultural Statistics-2012-2015. Cool Farm Tool Beta-3 (CFT) was used to determine total GHG gas emission under different cropping systems and expressed as GWP. In projects site the major cropping patterns were Mustard-Boro-T. Aman, Potato-Boro-T. Aman, Jute-T. Aman-fallow and Boro-T. Aman-Fallow. However, major cropping patterns are followed in different districts. Among them Jute-T. Aman (rainfed lowland)-Fallow, Onion-Jute-Fallow, Boro (dry season irrigated)-Fallow-T. Aman, Mustard-Boro-T. Aman, Mustard-Boro-Fallow, Wheat-T. Aus (pre-monsoon)-T. Aman, Potato-Boro-T. Aman, Maize-Fallow-T. Aman, Potato-Maize-T. Aman, Wheat-Mungbean-T. Aman and Grass pea-T. Aus-T. Aman cropping patterns were undertaken for estimation of CH_4 and GWP. Emission factors, input variables and outputs of CFT are 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	Liters 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	Liters/management practice	kg CO_2e/ha, Kg CO_2e/kg product

Experimental fertilization

Rice crop manager treatment (RCM) and comparison treatments farmer's practices were employed. Two types of rice cultivars were grown in the experimental field under fully irrigated and alternate wet and drying (AWD) conditions. The dry season (DS) rice variety, BRRI dhan 58, was transplanted in the first week of January and harvested in May. The wet season (WS) rice variety, BRRI dhan66, was transplanted in the second week of July and harvested in the fourth week of October. Two to three rice seedlings (45–50 days old in dry season and 30–35 days old in wet season) were transplanted at 20cm x 20 cm spacing. At maturity, 16 hills from each plot were harvested manually. The grain and straw were separated to evaluate yield properties. After harvest, the crop residues were incorporated into the soil.

For RCM based fertilizers, N-P-K was applied at the rates of 140-20-35 kg ha^{-1}, respectively, during dry season, and 80-25-35 kg ha^{-1}, respectively, during the wet season. Nitrogen was applied as urea in three equal splits: (1) at the final land preparation before rice transplanting, (2) the active tillering stage, and (3) one week before 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.

Rice yield

Grain and straw yields were determined at physiological maturity from 5 m^2 areas within each plot following the standard method (Saleque *et al*., 2004). 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).

Map of different regions of Bangladesh

Idrisi 3.2 system (J. Ronald Eastman, 2001) was used to make CH_4 emission maps for different regions of Bangladesh.

Correction factor determine of GHG

Using static close chamber method (Haque *et al*., 2013, 2015a,b, 2016a, b, c) and CFT (Hiller *et al*., 2011), correction factor was determined for actual GHG and GWP estimate under major cropping patterns in Bangladesh. The correction factor (CF) was 0.17.

Statistical analysis

Statistical analyses were carried out using SAS software (SAS Institute, 1995). Fisher's protected Least Significant Difference (LSD) was computed at 0.05 probability level for making treatment means comparison.

RESULTS

Cropping System based GHG

Total CH_4 emission was about 48 kg ha^{-1} under Jute-T. Aman-Fallow, Maize-Fallow-T. Aman, Potato-Maize-T. Aman and Wheat-Mungbean-T. Aman. However, rice based cropping system like Jute-T. Aman-Fallow showed significantly lower amounts of GHG than others systems (Table 1). Rice-Rice based cropping systems showed significantly higher amounts of CH_4 emission (97-295 kg ha^{-1}), but CO_2 and N_2O emissions were not significant. Rice-Rice-Fallow cropping systems increased about 102-515% CH_4 and reduced 8-41% N_2O than Jute-T.

Table 1. Greenhouse gas emission from major cropping systems in Bangladesh

Cropping system	CO_2 (kg ha^{-1})	CH_4 (kg ha^{-1})	CH_4 (CF) (kg ha^{-1})	N_2O (kg ha^{-1})
Onion-Jute-Fallow	836.6i	0f	0f	4.3bcd
Jute-T. Aman-Fallow	668.4k	48.4e	40.17e	4.2cd
Boro (ID)-T. Aman-Fallow*	1114.2ef	196.6b	163.17b	3.9d
Boro (CFL)-T. Aman-Fallow	1141de	295.4a	245.18a	3.9d
Mustard-Boro (ID)-T. Aman	1516.1c	196.6b	163.17b	4.8abc
Mustard-Boro (CFL)-T. Aman	1543.1c	295.0a	244.85	4.8abc
Mustard-Boro-Fallow	1082.6gh	148.2c	123.0c	3.8d
Wheat-T. Aus-T. Aman	1109.1fg	96.8d	80.34d	2.5f
Potato-Boro-T. Aman	1871.3b	196.6b	163.17b	3.5de
Maize-Fallow-T. Aman	1167.5d	48.4e	40.17e	5.5a
Potato-Maize-T. Aman	1924.9a	48.4e	40.17e	5.1ab
Wheat-Mungbean-T. Aman	1080.9h	48.4e	40.17e	3.5de
Grass pea-T. Aus-T. Aman	799.2j	96.8d	80.34d	2.8ef

Small letters in a column compare means at 5% level of probability by LSD
* ID = Intermittent drainage, CFL = Continuous flooding, CF = Correction factor

Table 2. Global warming potential from selected cropping pattern under standard chemical fertilization

Cropping system	GWP (CO_2eq kg ha^{-1})	GWP (CO_2eq kg ha^{-1}) (CF)*
Onion-Jute-Fallow	2125k	2125k
Jute-T. Aman-Fallow	3129j	2923j
Boro (ID)-T. Aman-Fallow*	7191d	6355d
Boro (CFL)-T. Aman-Fallow	9688b	8432b
Mustard-Boro (ID)-T. Aman	7862c	7026c
Mustard-Boro (CFL)-T. Aman	10385a	9131a
Mustard-Boro-Fallow	6376e	5746e
Wheat-T. Aus-T. Aman	4592f	4180f
Potato-Boro-T. Aman	7811c	6975c
Maize-Fallow-T. Aman	3988h	3782h
Potato-Maize-T. Aman	4618f	4412f
Wheat-Mungbean-T. Aman	3315i	3109i
Grass pea-T. Aus-T. Aman	4055g	3643g

Small letters in a column compare means at 5% level of probability by LSD
* ID = Intermittent drainage, CFL = Continuous flooding, CF = Correcting factor

Table 3. GHG and GWP as influenced by water management

Water management	GHG (kg ha^{-1})			
	CH_4	CO_2	N_2O	GWP
Intermittent drainage	148b	543a	1.1a	4585b
Continuous flooding	247a	570a	1.1a	70821a

Small letters in a column compare means at 5% level of probability by LSD

Table 4. GHG and GWP as influenced by varietal differences

Variety (wet season)	Greenhouse gas emission (kg ha^{-1})			
	CH_4	CO_2	N_2O	GWP
HYV Rice	48.4b	406a	0.9a	1875b
Local Rice	195a	199b	0.6b	5255a

Small letters in a column compare means at 5% level of probability by LSD

Table 5 Total methane emission (Tg year^{-1}) from paddy fields in Bangladesh during 2012-2015

Years	Methane emission (Tg year^{-1})
2012-2013	1.56
2013-2014	1.39
2014-2015	1.47

Aman-Fallow, Maize-Fallow-T. Aman, Potato-Maize-T. Aman and Wheat-Mungbean-T. Aman based systems in Bangladesh (Table 1). Carbon dioxide emission significantly increased under Potato-Maize-T. Aman cropping system but it was significantly the lowest under Jute-T. Aman-Fallow system. Non rice cropping systems showed the lowest GHG emission.

Cropping System based GWP

The GWP among different cropping systems varied significantly. Computed GWP was significantly the lowest (2125 CO_2eq kg ha^{-1}) in Onion-Jute-Fallow and the highest (9688 and 10385 CO2eq kg ha^{-1}) in Boro (CFl)-T. Aman-Fallow and Mustard-Boro (CFl)-T. Aman cropping systems (Table 2). Major cereal cropping systems viz. Jute-T. Aman-Fallow (3129 CO_2eq kg ha^{-1}), Maize-Fallow-T. Aman (3988 CO_2eq kg ha^{-1}), Potato-Maize-T. Aman (4618 CO_2eq kg ha^{-1}), Grass pea-T. Aus-T. Aman (4055 CO_2eq kg ha^{-1}), Wheat-Mungbean-T. Aman (3315 CO_2eq kg ha^{-1}) systems showed significantly the lowest GWP than other cropping systems.

Table 6. Mean yield and rice equivalent yield (REY) as influenced by different cropping patterns

Major cropping patterns	Grain Yield (t ha^{-1})			Total REY (t ha^{-1})
Jute-T.Aman-Fallow	5.50	4.10	0.00	11.71c
Boro-T.Aman-Fallow	5.69	3.70	0.00	9.39d
Mustard-Boro-T.Aman	1.90	5.33	4.36	14.60b
Potato-Boro-T.Aman	15.20	5.30	4.30	17.20a

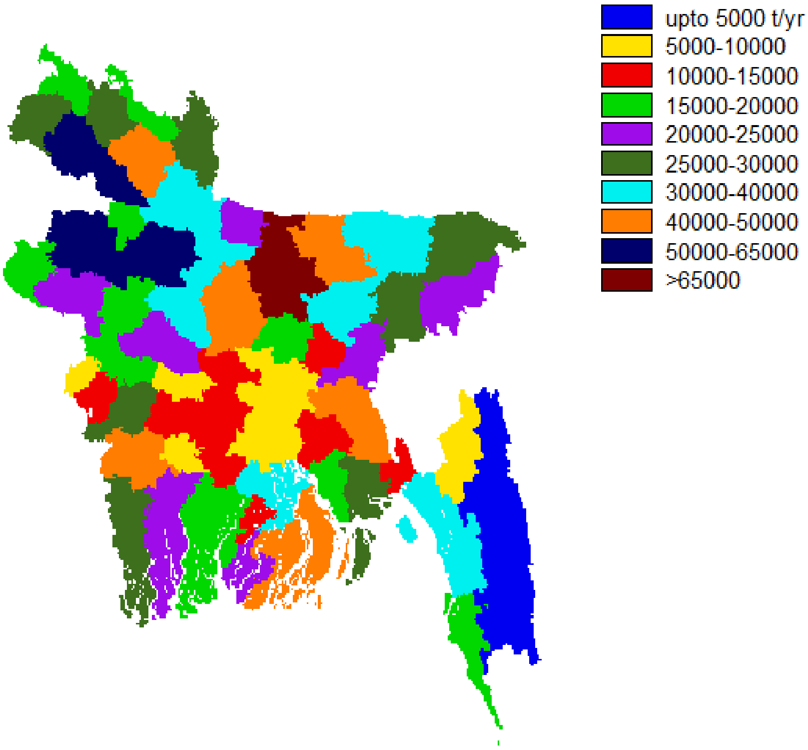

Fig. 1. Annual methane emission from paddy fields in different regions of Bangladesh

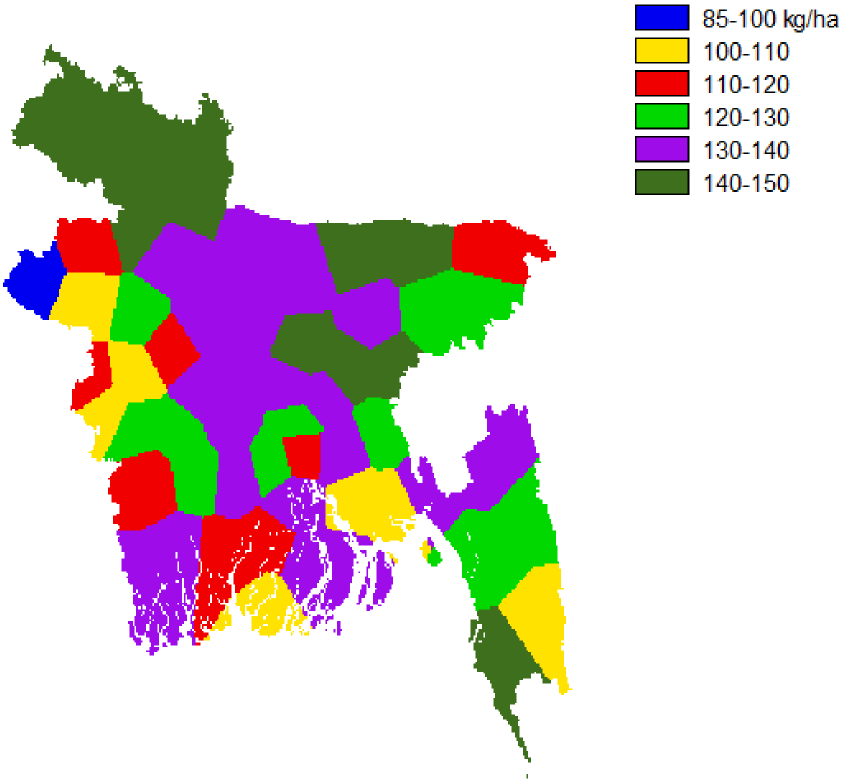

Fig.2. Methane emission rates from paddy field in different regions of Bangladesh

Crop production management and GHG emission

Water management significantly influenced GWP and CH_4 emission but not CO_2 and N_2O emissions (Table 3). About 40% CH_4 emission was reduced because of intermittent drainage. Water management also reduced about 24-26% of GWP in Boro-T. Aman-Fallow, Mustard-Boro-T. Aman patterns.

The choice of variety also influenced GHG emissions. For example, high yielding rice variety (HYV) showed significantly higher emission of CO_2 and N_2O than local rice varieties; but significantly lower amounts of CH_4 emission than local rice varieties (Table 4).

Methane emission scenario in Bangladesh

Our result indicated that Mymensingh and Dinajpur districts were the hotspot areas in Bangladesh from where significantly higher amounts of CH_4 emission took place than other districts (Fig.1). Among 64 districts, the lowest CH_4 emission was found in Ramgati and Bandarban districts. In terms of CH_4 emission rate, it varied from 89 to 148 kg ha^{-1} $year^{-1}$ depending on locations of the country and types of rice culture and variety used (Fig. 2). In total, computed CH_4 emission was about 1.39-1.56 Tg $year^{-1}$ in Bangladesh (Table 5).

Mean Grain yield and Total rice equivalent yield

Boro-T. Aman-Fallow showed significantly lowest rice equivalent yield (REY) than others cropping pattern (Table 5). However, our result also mention that Potato-Boro-T. Aman and Mustard-Boro-T. Aman were showed significant higher REY (Table 6) but total GPW was significantly lower than Boro-T. -Fallow cropping pattern (Table 2).

DISCUSSION

In Bangladesh, very suitable (VS), suitable (S) and moderately suitable (MS) areas for T. Aus (Pre-monsoon), T. Aman (Monsoon) and Boro (Dry season irrigated rice) rice covers about 2.01, 2.01 and 2.43 million ha (Mha) of cultivable land, respectively (Hossain *et al*., 2012). In future, such suitable areas will be affected because of climate change impacts, especially with Boro rice. Boro rice based cropping patterns gave higher GWP than T. Aus and T. Aman rice based cropping patterns because of variations in growth duration, yield, fertilizer and water management than other rice varieties. Since Boro rice is mostly grown under continuous flooded water (CSW) condition with greater amounts of fertilizers, GHG emission was higher. Haque *et al*., (2016b, c) also reported that fertilizer and irrigated water increases total GHG emission and subsequent GWP. Jute-Rice-Fallow (3129 CO_2eq kg ha^{-1}), Wheat-Mungbean-Rice (3315 CO_2eq kg ha^{-1}), Maize-Fallow-Rice (3988 CO_2eq kg ha^{-1}), Wheat-Rice-Rice (4592 CO_2eq kg ha^{-1}) and Potato-Maize-Rice (4618 CO_2eq kg ha^{-1}) patterns had relatively lower GHG emission indicating that adoption of these patterns could be one of the options for mitigation of GHG emission in Bangladesh. Although higher GWP (8432-9131 CO_2eq kg ha^{-1}) was estimated with Boro-T. Aman-Fallow and Mustard-Boro (CFL)-T. Aman patterns, the GWP could be reduced by 24-26% if intermittent drainage practice is followed having higher total rice equivalent yield (Table 2) 42-46% reduction in methane emission per hectare was reported by Wang *et al*., 2014; Haque *et al*., 2016b, 2017. Moreover, integrated soil-crop-water management practices are advocated to improve yield and to alleviate environmental impacts, specifically reducing GHG emission by 17-40% from agriculture (Fan *et al*., 2011; Zhang *et al*., 2012).

Amongst different cereal crops grown worldwide, rice emits the highest GHG, especially when grown under irrigated conditions. We also found that CH_4 emission varies across different regions of the country because of rice culture types, varieties and water management conditions (Table 1 and 3). In low lying areas of Bangladesh, local deep water Aman rice cultivars are gown primarily under flooded conditions that favors greater CH_4 emission from paddy fields. Similar findings were reported by Gupta *et al*., 2009 and Alberto *et al*., 2014. We have found higher CH_4 emission in Bangladesh than India (Alberto *et al*., 2014 and Xu *et al*., 2013) might be because of variations in soil organic carbon contents and water management options. Mymensingh and Dinajpur districts were the CH_4 hotspots due to more areas with rice-rice based patterns than other districts of Bangladesh (Fig. 1 and 2). Since population in Bangladesh will be 215.4 million in 2050 requiring 44.6 MT of clean rice (Kabir *et al*., 2015), like Potato-Boro-T. Aman and Mustard-Boro-T. Aman cropping pattern cropping pattern will play a dominant role for food security in Bangladesh in future. Adaptation measures such as Potato-Boro-T. Aman and Mustard-Boro-T. Aman cropping pattern, alternate wetting and drying, balanced fertilization, short duration rice varieties, etc will be needed to reduce CH_4 emission as well as met up of food demand in Bangladesh.

Conclusion

There were spatial variations in the GHG emissions over Bangladesh, primarily because of cropping pattern differences along with inputs and/or management options for growing different crops. Jute-Rice-Fallow and Wheat-Mungbean-Rice cropping patterns are suitable to reduce GHG emission and subsequent GWP than other patterns. Best resource management practices that not only improve crop yields but also reduces GHG emission should be adopted globally. The options needed to mitigate GHG emission for various agro-ecological zones of Bangladesh are to be delineated.

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