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EFFECT OF ELEVATED CO_2 ON NUTRIENT DYNAMICS IN SOIL AND NUTRIENT UPTAKE BY RICE GROWN IN AN OPEN TOP CHAMBER

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ABSTRACT

The effect of an elevated carbon dioxide (eCO_2) level on nutrient concentrations in soil and rice yield was investigated in a pot experiment during August 2017 to March 2018 at the Bangabandhu Sheikh Mujibur Rahman Agricultural University, Bangladesh. The availability of nutrients in soil and nutrient concentrations in rice grown in an open top chamber (OTC) with elevated CO_2 (eCO_2) levels were determined. In this experiment, the CO_2 levels were maintained at 370 and 560 ppm and their effects were compared with those of the ambient CO_2 level (control). Inconsistent influences of eCO_2 on soil nutrient availability were observed. Compared with the control treatment, soil pH decreased by 0.15 unit (from 5.80 to 5.65), while soil organic carbon (SOC) increased by 5.48-6.94% at 560 ppm CO_2. Concentrations of N, P and K in rice grain and straw decreased with an increased CO_2 level. The microbial C content and microbial population in soil increased with increasing CO_2 concentration. The effect of eCO_2 on soil chemical and biological characteristics were found to be beneficial except the decrease in soil pH. Development of soil acidity because of eCO_2 and its amelioration should be taken into consideration in soil and crop management for rice production.

Keywords: Biomass carbon, Climate change**,** Elevated CO_2, Nutrient dynamics, Rice

INTRODUCTION

The global population is predicted to reach 9.1 billion, and food supplies need to be increased by 60-110% by 2050 (Wani and Sah, 2014) which will require crop yield improvement given the limited scope of arable land expansion, Food security is a major issue in countries with a growing population and a decreasing cultivable land area. Rice (*Oryza sativa* L.) is the most important cereal crop in the world. It has provided food for more people over a longer period of time than any other crop. For 1.3 billion people, rice provides more than half of their food requirements and for another 400 million people, rice provides 25-50% of their total food requirements (Yadav *et al.*, 2014). It is also an

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important source of calorie intake and nutrition, providing more than one-fifth of the calories consumed worldwide by humans. Rice is the staple food crop in Bangladesh where it is grown on about 75% of the agricultural land accounting for about 96% of the total cereal food supply (BBS, 2015). About 48% of the rural work force in Bangladesh is employed in rice farming, and two-thirds of the calorie supply and one half of the total protein intake of a person come from rice (Alam *et al.*, 2021).

Rice is unique because it can be grown in a wet environment, where many other crops cannot survive. Such wet environments are abundant across Asia. However, soil fertility and fertilizer management play an important role in good harvest of rice. Carbon and nutrient dynamics are vital in soil fertility and crop productivity, which vary across the crop ecosystems (Alam *et al.*, 2019a, 2019b). As the global temperature is increasing because of greenhouse gas (GHG) emissions, sustained agricultural production would be a great concern in future (Rahman, 2013). Among GHG, CO_2 is important accounting for 60% of the total greenhouse effect (Rastogi *et al.*, 2002). In the last few decades, there has been an increase in the emission of CO_2 raising the atmospheric CO_2 level from 280 ppm at beginning of the industrial revolution to 410 ppm at present (Kahn, 2009). Human activities like fossil fuel burning, indiscriminate land use and land cover, etc. are responsible for increased GHG concentrations in the atmosphere. Well-mixed GHGs such as CO_2, nitrous oxide (N_2O), methane (CH_4) and halocarbons, in addition to water-vapor and solar irradiance, contribute to global temperature rises (IPCC, 2007) causing climate changes. Global surface temperature is increasing alarmingly and it is most likely that crops could not be grown in future if such events are not abated (Risbey, 2008). Temperature rises as a result of global warming could eventually be double what has been projected by climate models, according to an international team of researchers from 17 countries. A continuous increase in atmospheric CO_2 would influence nutrients in soils and plants (Razzaque *et al.*, 2009).

Recent studies show that if temperature rises by more than another 0.5°C, the consequences will be catastrophic for millions of the poorest people around the globe because of impaired crop production. As eCO_2 causes a rise in global temperature in future, it is most likely that soil health, nutrient availability and crop production will be affected significantly. Adaptation studies are on-going globally, though not adequate in many instances. Bangladesh lags far behind in research on the impact of climate change on agriculture. Therefore, the present study was conducted to determine the effects of eCO_2 on the dynamics of nutrients in soil and rice grown in an open top chamber (OTC).

MATERIALS AND METHODS

Experimental site

The experimental site (24.09° N latitude and 90.26° E longitude with an elevation of 8.2 m from sea level), in the Madhupur Tract (AEZ 28) of Bangladesh, has a subtropical climate. The soil is an inceptisol (Shallow Red Brown Terrace Soil) belonging to the Salna series and having a pH of around 6.2 (Alam *et al*, 2019b).

Treatments and experimental setup

The experiment was carried out in an open top chamber (OTC) of the research field of Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU), Gazipur, Bangladesh during the *Boro* season (winter rice season) of 2017-2018. The treatments were: (i) control (ambient CO_2 level which varied from 380 to 385 ppm), (ii) 370 ppm CO_2 concentration and (iii) 560 ppm CO_2 concentration laid out in a randomized complete block design with eight replications. The *Boro* rice variety, BRRI dhan29, was the test crop. Soils from an adjacent field soil was collected for the experimentation, air dried, partially ground and placed in the experimental pots at the rate of 8 kg per pot. To fertilize the soil in the pot, the amounts of urea, triple super phosphate (TSP), muriate of potash (MoP), gypsum and zinc sulfate monohydrate as sources of N, P, K, S and Zn, respectively were calculated as recommended by BARC (2012) and doubled for better growth of plants in the pots. The full doses of TSP, MoP, gypsum and zinc sulfate were applied at the time of final pot preparation, whereas urea was applied in three equal splits at 20, 40 and 60 days of transplanting (DAT). Intercultural operations such as, irrigation, weeding, etc. were done as and when necessary.

Sampling and analysis

Before starting the experiment, initial soil samples were collected at a depth of 0-15 cm from the experimental field. The samples were then air dried and ground to pass through a 2 mm sieve and stored in clean plastic bags for chemical analyses. Soil samples were analyzed for pH, soil organic carbon (SOC), total nitrogen (N), available phosphorus (P), exchangeable potassium (K), calcium (Ca) and magnesium (Mg), available sulfur (S), zinc (Zn), iron (Fe) and manganese (Mn), microbial biomass C and microbial population (bacteria and Fungi) by following standard protocols (Page and Keeney, 1982). After harvesting of the crop, soil samples were also collected from each pot. The soil samples were air dried at room temperature and kept in plastic bags for chemical analyses. Grain and rice straw samples were collected at harvest, dried at room temperature and then oven dried at 75°C until constant weights were attained. The plant samples were analyzed for N, P and K following the standard protocols.

Statistical analysis

The recorded data were analyzed for variance by SPSS version 16.0. The treatment means were compared by the least significance difference (LSD) test at 5% level of probability.

RESULTS AND DISCUSSION

Effect of eCO_2 concentrations on soil chemical properties

Soil pH

Soil pH decreased with the increased CO_2 concentration (Fig. 1a). The lowest pH value (5.65) was recorded with eCO_2 at 560 ppm, while the maximum pH value (5.80) was found in with control CO_2. Carrillo *et al*. (2014) reported that eCO_2 is likely to increase CO_2 concentration in soil through the formation of H_2CO_3 and thus pH in the rhizosphere is likely to decrease. It is well known that most of the plant nutrients become available when soil pH ranges from 6.5 to 7.5. However, soil pH was not a problem for growing rice in this experiment as it was grown as a wetland crop. Soil pH generally approaches near about 7.0 upon submergence. According to Celia *et al*. (2002), the increase of CO_2 concentration influenced soil pH which consequently influenced the rate of weathering and to some extent, the availability of plant nutrients. However, studies have also shown that there was insignificant change in the pH when a high level of CO_2 was introduced to the soil system (Ravi *et al.*, 2010).

Soil organic carbon

Elevating the CO_2 level increased SOC content insignificantly (Fig. 1b). The minimum SOC (0.73%) was found in the control treatment, while with 370 ppm and 560 ppm CO_2 treatments, the increased SOC contents were 0.75% and 0.77% OC, respectively. The eCO_2 can increase SOC content mainly by augmenting the production and allocation of photosynthate to the rhizosphere and thus increasing C input into the soil. Satapathy *et al*. (2015) reported that greater biomass production with higher level of CO_2 helped in providing more crop residues and root biomass for incorporation into soil. Soil organic matter is an important parameter that governs all physical, chemical and biological activities in soils. It is the essence of soil that improves soil health, improves agricultural production and soil aggregates. Sequestration of more C in soils means reduced CO_2 levels in the atmosphere and thus minimizing global warming potential.

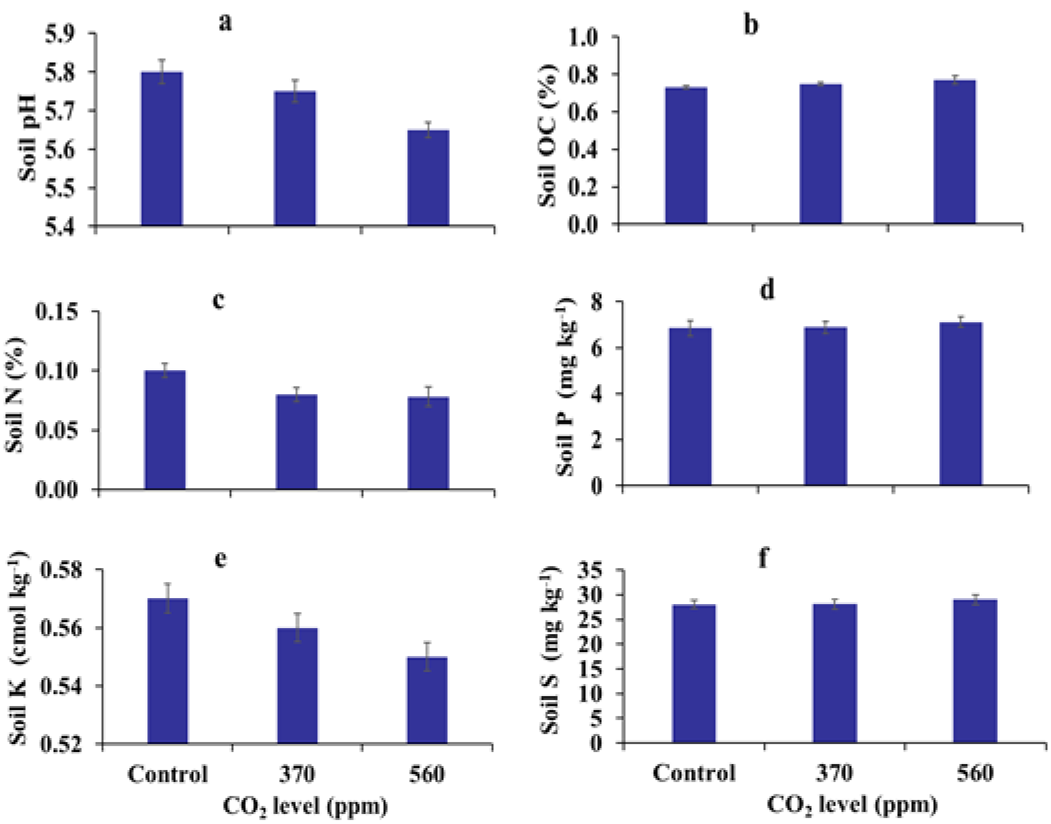

Figure 1: Bar graph representing the changes of (a) Soil pH, (b) SOC, (c) N, (d) P, (e) K and (f) S due to application different levels of CO_2; each bar is the mean and vertical line on a bar indicates the standard deviation of the mean

Total nitrogen

The level of CO_2 inside the OTC negatively impacted soil N content, which declined with increased CO_2 concentration (Fig. 1c). The highest soil N, 0.10%), was recorded with ambient CO_2, followed by 370 ppm CO_2 (0.08%) and the lowest in 560 ppm CO_2 treatment (0.078%). The eCO_2 level lowered the N content in soils because of higher uptake by rice plants. High CO_2-grown plants had increased biomass which contributed to higher nutrient uptake and obviously reduced soil N relative to ambient CO_2-grown plants. Higher grain and straw yields of rice were observed in the current study reported in the section 3.3. Reduction in N concentration commonly occurs in plants grown at elevated CO_2 and there have been various explanations such as dilution of N due to extra carbohydrates (Conroy, 1992). On the contrary, suppression of N concentration was negligible in leaf sheath despite the fact that sheath accumulates a large amount of carbohydrate at elevated CO_2 (Makino *et al*., 1997). The most plausible explanation for reduction in N concentration at elevated CO_2 is that a large amount of N is reallocated away from the photosynthetic machinery as a result of increases in photosynthetic N use efficiency (NUE) at elevated CO_2.

Available phosphorus

Available P in soil increased consistently in the eCO_2 environment compared to the ambient condition (Fig. 1d). Available P content was the highest in 560 ppm CO_2 treatment, which was 7.11 mg kg^{-1} followed by 370 ppm CO_2 (6.88 mg kg^{-1}) and the minimum value was recorded in ambient CO_2 (6.85 mg kg^{-1}). Increased CO_2 level in presence of water produces H_2CO_3 that helps in maintaining a favorable soil pH and thus greater availability of soil P for plant uptake. Generally, most of the soil P remains fixed either in alkaline or in acidic conditions. Conroy *et al*. (1990) found that when soil P availability is low, its uptake is increased by elevated CO_2. However, higher foliar P concentrations are also required to realize the maximum growth potential at elevated CO_2 levels.

Exchangeable potassium

Different levels of CO_2 concentration affected soil K content (Fig. 1e). Higher K was found in ambient CO_2 treatment, which was 0.57 cmol kg^{-1} followed by 370 ppm CO_2 (0.56 cmol kg^{-1}). The lowest value of K was observed in the 560 ppm CO_2, which was 0.55 cmol kg^{-1} at 560 pp CO_2 rate. The K content gradually decreased with the enhancement of CO_2 levels in the present investigation indicating a threat for future farming as climate change is prime concern in the upcoming days. The elevated CO_2 levels promoted increased soil organic matter, P, iron, manganese and zinc in comparison to ambient condition, while a decrease in N, K, Ca and Mg was reported by Satapathy *et al*. (2015).

Available sulphur

Due to eCO_2 in OTC, the concentration of S in the soil ranged from 28.07 to 29.0 mg kg^{-1} (Fig. 1f) although the increase was insignificant. The maximum S content was found in the 560 ppm CO_2 treated pot, which was 29.00 mg kg^{-1} followed by 370 ppm CO_2 (28.07 mg kg^{-1}) and its minimum value was recorded in ambient CO_2 (28.05 mg kg^{-1}). As the clay content of soils having variable amounts of hydrous oxides of Al and Fe, the capacity of soils fluctuates widely to adsorb sulfate. However, Fangmeier *et al*. (2002)

reported that S content in soil is nearly unaffected by the eCO_2 level. According to Shainberg *et al*. (1989) adsorption of sulfate in soil systems is favored by strongly acid conditions and the effect of eCO_2 is insignificant.

Exchangeable calcium and magnesium

Soil Ca content varied significantly with the imposed CO_2 level. Increasing CO_2 level decreased soil Ca content (Fig. 2a). The highest amount of Ca was found in control pot (8.20 cmol kg^{-1}) followed by 370 ppm CO_2 treatment (7.6 cmol kg^{-1}) and its minimum value was found 560 ppm CO_2 levels (7.5 cmol kg^{-1}). The concentration of soil Mg ranged from 2.5 to 2.60 cmol kg^{-1} (Fig. 2b). The eCO_2 level decreased soil Ca and Mg contents reported by Satapathy *et al*. (2015). Biose *et al*. (2016) also found the highest Ca content with high CO_2 zone and the lowest in soil with low CO_2 zone at 15-30 cm soil depth. Calcium and Mg are less available in acid soils because they have been leached out as observed by Miller (2016). It has been previously reported that Ca concentrations increased and Mg concentrations remains unaffected by elevated CO_2 (Conroy *et al*, 1994).

Available manganese and zinc

Soil Mn content increased slightly with the increment of CO_2 concentration (Fig. 2c). The contents of Mn were 14.2, 14.5 and 14.6 mg kg^{-1} in control, 370 and 560 ppm CO_2 treated pots, respectively. The concentration of Zn also increased with the increment of CO_2 level (Fig. 2d). Soil Zn content was comparatively higher in 560 ppm CO_2 treated pot (1.34 mg kg^{-1}) followed by 370 ppm CO_2 (1.32 mg kg^{-1}) and the least in control pot (1.26 mg kg^{-1}). The eCO_2 increased Cu, Fe, and Zn but lowered Mn concentration in grass leaves (Duval *et al.*, 2012). The effects of CO_2 enrichment on Mn and Zn concentrations are likely influence by rhizosphere conditions. Mn is redox sensitive and is reduced to more mobile forms at lower pH (Adriano, 2001).

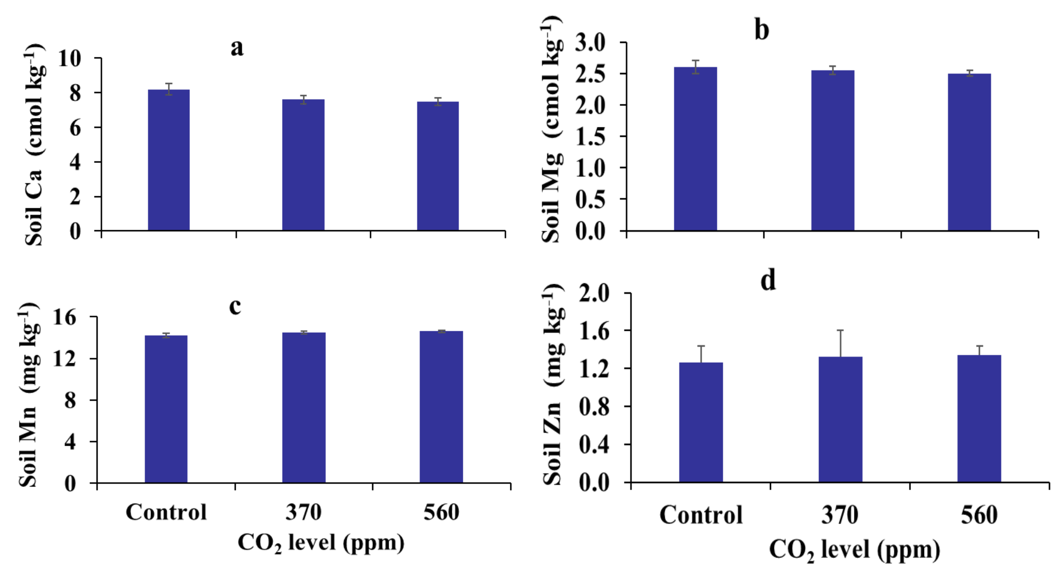

Figure 2: Bar graph representing changes in (a) Ca, (b) Mg, (c) Mn and (d) Zn in soil due to different levels of CO_2; each bar is the mean and the vertical line on a bar indicates the stand deviation of the mean

Effect of eCO_2 concentrations on soil microbial properties

Microbial carbon

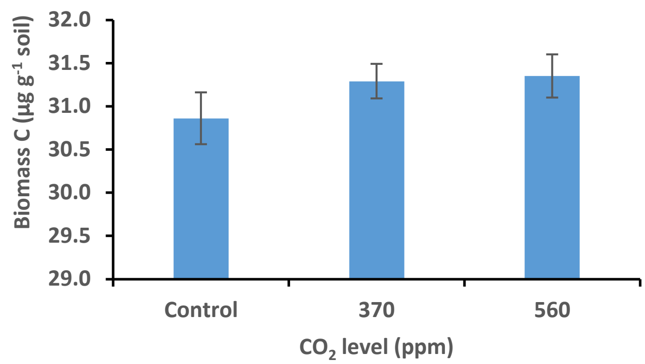

Figure 3: Bar graph representing changes in biomass C due to application of different levels of CO_2; each bar is the mean and the vertical line on a bar indicates stand deviation of the mean

The concentration of microbial C increased with the increment of CO_2 levels (Fig. 3a) in which highest amount was found with 560 ppm CO_2 treated pot (31.35 µg g^{-1} soil) followed by 370 ppm CO_2 (31.29 µg g^{-1} soil) and the control had the lowest biomass C (30.86 µg g^{-1} soil). Microbial biomass C is a reactive index of soil fertility and biotic quality (Rahman *et al.*, 2020). It plays a crucial role in biogeochemical processes and is influenced by the addition of different organic and inorganic fertilizers (Cerny *et al.*, 2008). Microbial biomass C in soil is a labile organic pool that shows a quick output and acts as a driving force of cycles of different macronutrients in crop fields. Soil microbes critically affect plant and ecosystem responses to climate change by modulating organic C decomposition and nutrient availability for plants. Experimental evidence accumulated over the last several decades has clearly shown that CO_2 enrichment in the atmosphere can significantly alter plant growth and the availability of organic C, N and cation nutrients for microbes (Cheng *et al.*, 2011).

Microbial population

Table 1: Bacterial and fungal population changes in soil at different CO_2 levels

Treatment	Bacterial population (c.f.u g^{-1} soil)	Fungal population (c.f.u g^{-1} soil)
Control	2.22×10^7	1.08×10^4
370 ppm CO_2	2.25×10^7	1.52×10^4
560 ppm CO_2	2.31×10^7	1.47×10^4
CV (%)	23.78	17.01
SE (±)	1.74	1.8

The growth of both bacteria and fungi shown an increasing trend with CO_2 increase (Table 1). However, no significant difference was observed among the treatments for microbial population. The maximum bacterial and fungal populations were recorded in 560 and 370 ppm CO_2 treated soil which were 2.31×10^7 and 1.52×10^4 c.f.u g^{-1} soil, respectively. Such variations in microbial population might have influenced organic materials breakdown. Besides, microbes constitute about one quarter of all living biomass on earth and its biomass is used as an early indicator of changing physical and chemical properties of soils. Changes in fungal and bacterial phospholipids, fatty acids and their ratios observed in a study provide new insights into how alterations in the relative availability of C and N can modulate microbial activities and their responses to elevated CO_2. Significantly higher fungi-bacteria ratios under elevated treatments than ambient CO_2 indicate that CO_2 enhancement of C inputs may still play a major role in shaping the community structure in N-rich agro-ecosystems, as shown in many forests and grasslands (Feng *et al.*, 2010). Organic matter contents, availability of water, physical and chemical properties of soil influence microbial biomass in soils (Tomich *et al.*, 2011).

Effect of eCO_2 concentrations on grain and straw yield and nutrient concentrations

Carbon dioxide concentration did not significantly affect grain and straw yields of rice (Fig. 4). However, both grain (13.15 g pot^{-1}) and straw (17.50 g pot^{-1}) yields were found to be higher at eCO_2 (560 ppm) , than that in the control treatment with values of 12.8 and 16.9 g pot^{-1}, respectively. It was reported that elevated CO_2 shows positive effect on rice grain yield (Wang *et al.*, 2020), which endorses our study. The grain and straw yield increases due to elevated CO_2 could have been due to elevated C in soil (Fig. 1b).

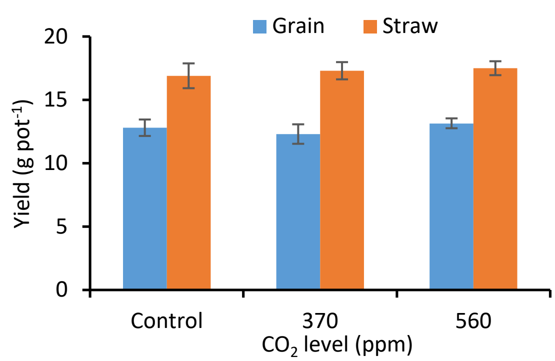

Figure 4: Grain and straw yields as affected by different levels of CO_2; each bar is the mean and the vertical line on a bar indicates the standard deviation of the mean

There was no significant effect of CO_2 levels on rice grain or straw N and K concentrations, but the P concentration varied significantly (Table 2). The highest concentration of N in grain was recorded in control treatment (1.23%) followed by 370 ppm CO_2 levels (1.18%) and 560 ppm CO_2 enrichment (1.13%). The highest concentration of P in grain was found in control treatment (0.21%), while the lowest in 560 ppm CO_2 enrichment (0.18%). The highest K concentration in grain was obtained from control treatment (0.21%) followed by 370 (0.18%) and 560 ppm CO_2 enrichments (0.16%). The highest concentration of N in rice straw was recorded in ambient CO_2 treatment 0.51% followed by 370 ppm CO_2 (0.50%) and 560 ppm CO2 (0.47%). The highest P concentration in straw was 0.09% in control treatment and the least in 560 ppm CO_2 enrichment (0.05%). The highest K concentration in rice straw was found with control treatment (1.21%) followed by 370 ppm CO_2 (1.18%) and 560 ppm CO_2 level (1.13%). The reduction in foliar N concentration at elevated CO_2 was also reported by Aben *et al*. (1999). According to Seneweera *et al*. (1994), the concentrations of P and K in all organs were lower at elevated CO_2. In contrast, P concentrations were generally lower in all organs at elevated CO_2, although P concentration was not significantly affected in the experiment when plants were grown in soil. Increases in P concentration have also been reported with rice when plants were grown at elevated CO_2 level under field conditions (Yang *et al.*, 2007).

Table 2: N, P and K concentrations in grains and straw samples grown at different levels of CO_2

Treatment	Nutrient concentration in grain (%)			Nutrient concentration in straw (%)		
	N	P	K	N	P	K
Control	1.23	0.21a	0.21	0.51	0.09a	1.21
370 ppm CO_2	1.18	0.19b	0.18	0.50	0.06b	1.18
560 ppm CO_2	1.13	0.18b	0.16	0.47	0.05b	1.13
SE (±)	0.041	0.027	0.017	0.015	0.032	0.05
CV	5.82	7.32	6.21	8.44	7.42	6.87

CONCLUSION

Elevated CO_2 levels are responsible for increased global temperature, which may greatly impact soil health, crop production and plant nutrient use efficiency. In the present experiment, elevated CO_2 appeared to increase soil acidity which may have negative consequences on soil microbial diversity and nutrient availability in the long run. As temperature is increasing along with atmospheric CO_2 levels, more trials are needed taking cropping systems into consideration to develop adaptation strategies.

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REFERENCE CROP EVAPOTRANSPIRATION VARIATION IN RELATION TO CLIMATIC VARIABLES UNDER CHANGING CLIMATIC SITUATION OF BANGLADESH

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ABSTRACT

Reference crop evapotranspiration (ET0) is a very important hydrological parameter that is affected by major climatic variables. This study was conducted in the districts of Faridpur, Jashore, Khulna and Satkhira in southwestern Bangladesh to evaluate the effect of climate change on ET0 and determining its sensitivity to certain climatic variables. Long-term weather data (1981-2017) related to minimum and maximum temperatures, humidity, wind speed and sunshine hour were used as inputs in the study. ET0 was calculated from the weather data using the Penman-Monteith method incorporated in the CROPWAT model. Annual and seasonal ET0 values were calculated from the daily ET0. Annual ET0 in the study districts varied from 1324 to 1347 mm. Seasonal ET0 variation implied that (winter rice) and transplanted *Aus* (summer rice) seasons had nearly identical ET0, despite the longer growth duration of *Boro* rice. At all four locations, both seasonal and annual ET0 showed a decreasing trend. The highest annual ET0 reduction rate was 4.78 mm year^{-1} in Satkhira and the lowest was 2.18 mm year^{-1} in Faridpur. ET0 was reduced as a result of the combined effect of increasing maximum and minimum temperatures and humidity, decreasing sunshine hours and wind speed. The sensitivity analysis indicated that ET0 was most sensitive to climatic parameters such as, ET0 maximum temperature, relative humidity and sunshine hour. ET0 was found to be relatively low in the steady areas indicating a reduced irrigation water demand under changing climatic conditions. Findings of this may be useful in devising strategies for appropriate and sustainable use of water resources for irrigation in Bangladesh.

Keywords: Climatic variability, Sensitivity analysis, Rice, Reference evapotranspiration

INTRODUCTION

The hydrological cycle and crop water requirements are greatly affected by climate change. Crop evapotranspiration, one of the major components of the hydrological water balance (Shrestha, 2003), intensively alters various climatic parameters. However, evapotranspiration variability could be induced by changes in other climatic parameters. Bangladesh agriculture is facing a variety of challenges as a result of changing climate conditions, including reduced irrigation water availability in the dry season, shrinking

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cultivable lands, agricultural drought, uneven rainfall distribution, salinity intrusion into both land and river, groundwater scarcity etc. (Ahmad *et al*., 2014; Salem *et al*., 2017; Acharjee *et al*., 2017; Shahid, 2011). About 10-25% of the irrigation water demand for crop cultivation is projected to increase with various climatic scenarios in the near future (Mkhwanazi, 2006; de Silva *et al*., 2007, Roy *et al*., 2009). Excess water demand will inevitably result in water shortage for agricultural activities, impacting total crop production (Shahid and Hazarika, 2010). Irrigation demand in crop cultivation is very sensitive to changing climatic conditions because it drastically affects agricultural production (Schlenker *et al*., 2007, Lal *et al*., 1999; Andresen *et al*., 2001; Frank *et al*., 2004). The northwest region of Bangladesh is already facing a water crisis due to prolonged drought and excessive groundwater extraction for irrigation while the southern part is suffering from freshwater inaccessibility due to soil and water salinity levels exceeding safe limit (Dey *et al*., 2017; Hossain *et al*., 2019; Roy *et al*., 2014). Over the last fifty years, the drought-affected areas of Bangladesh have become hotter and drier (Dey *et al*., 2017). Climate change predictions foresee dangerously warm conditions in future, which are approaching faster than the scientists predicted, and which could soon become catastrophic for agriculture and environment in Bangladesh (Mojid *et al*., 2015).

Rice is the dominating crop in Bangladesh, and it consumes the majority of the water used in crop cultivation. Rice is grown in three seasons, namely *Aus* (summer rice), *Aman* (wet season monsoon rice) and *Boro* (winter rice). *Boro* rice contributed a maximum of 53% while transplanted *Aman* rice had a 39% share in the total rice production of Bangladesh (BBS 2019). *Boro* rice is usually fully irrigated because it receives a very small amount of rainfall (Shahid, 2011). According to an IPCC (2007) projection, temperature rise and erratic rainfall would have a significant impact on crop water requirement. Elevated temperatures can affect evapotranspiration and the growing period of rice. With rising temperature evapotranspiration demand is likely to increase, which might increase crop water demand and need for irrigation (Hossain *et al*., 2021). The rate of evapotranspiration increased as the air temperature and wind speed increased (Lutomirska and Wierzbicka 2003; Hess 1998), while net radiation and relative humidity decreased (Hidalgo *et al.*, 2005, Xu *et al*. 2006).

Mojid *et al*. (2015) found that the combined effects of increasing temperature and wind speed as well as increasing humidity and net radiation caused a reduction in evapotranspiration in the northwest region of Bangladesh. The country still lacks information on long-term evapotranspiration variability due to changing climate. Understanding the effect of climate change on evapotranspiration would lead to the appropriate and sustainable use of water resources for irrigation in Bangladesh to meet crop water demands. The current study aimed to quantify long-term annual and seasonal evapotranspiration trends as well as the effects of various climatic parameters on evapotranspiration change in the southwest region of Bangladesh. The study would provide information to overcome the knowledge gape regarding climate change impacts on reference crop evapotranspiration (ET0) and to identify climatic parameters that affect ET0.

MATERIALS AND METHODS

Study area and data collection

The study was conducted at four different locations in the southwestern part of Bangladesh, varying in soil and climate conditions. The study area included Faridpur district (23.6^{o}N latitude and 89.83^{o}E longitude) of the Dhaka division and Jashore (23.17^{o}N latitude and 89.21^{o}E longitude), Khulna (22.8^{o}N latitude and 89.21^{o}E longitude) and Satkhira (22.72^{o}N latitude and 89.07^{o}E longitude) districts of the Khulna division. The maximum annual air temperature of the study areas ranged from 30.7 to 31.8^{o}C and minimum temperature varied from 18.8 to 21.6^{o}C (Table 1). Jashore received the least amount of annual rainfall (1692 mm), while Khulna received the most (1856 mm). The study area consisted primarily of silty clay to clay loam soil suitable for crop agriculture. Rice-based cropping patterns dominated at the study locations. Historical (1981-2017) weather parameters namely, daily maximum and minimum temperatures, humidity, wind speed, bright sunshine hours (Table 1) collected from the Bangladesh Meteorological Department (BMD) were used in the climate change analysis.

Table 1: Normal climate (1981 to 2017) of the study locations

Location	Maximum temperature (^{o}C)	Minimum temperature (^{o}C)	Annual rainfall (mm)	Relative humidity (%)	Sunshine hour (hrs)
Faridpur	30.7	21.4	1840	79	6.5
Jashore	31.8	18.8	1692	73	7.0
Khulna	31.3	21.8	1856	81	6.6
Satkhira	31.4	21.6	1728	77	6.5

Calculation of reference crop evapotranspiration (ET0)

The CROPWAT 8.0 model was used to calculate ET0. This model integrated the Penman–Monteith equation (FAO, 1998) to calculate ET0 from the observed weather parameters. The equation to calculate s expressed as follows;

$$\text{ET0} = \frac{0.0408\,\Delta\,(R_n - G) + \gamma\,\frac{900}{T + 273}\,U_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34\,u_2)}$$

Where, ET0 is reference crop evapotranspiration (mm d^{-1}); Rn is net radiation at the crop surface (MJ $m^{-2}d^{-1}$); G is soil heat flux (MJ $m^{-2}d^{-1}$); T is average air temperature(°C); U_2 is wind speed measured at 2 m height (m s^{-1}); (e_s−e_a) is vapor pressure deficit (kPa); Δ is slope of the vapor pressure curve (kPa°C-1); γ is psychrometric constant (kPa $°C^{-1}$) and 900 is a conversion factor.

From the collected daily weather data, monthly average of each parameter was calculated to use as inputs in the model. The model gave monthly ET0 as an output which was then converted to annual and seasonal ET0.

Trend analysis of ET0

Historical (1981-2017) trend analysis of ET0 for annual and different rice growing seasons was made to know the changing pattern of ET0 over time. To analyze seasonal ET0 based on rice cultivation season, we considered the window, December to May as the *Boro* season. Although most of the *Boro* rice cultivars have a growth duration of 145 to 165 days (BRRI, 2020), depending on the varying sowing time, we considered a wide range (182 days) of the *Boro* period. In the same rationale, we considered the transplanted *Aus* (T. *Aus*) period to be April to August (153 days) and the transplanted *Aman* (T. *Aman*) period to be July to December (184 days). Sen's slope trend test was performed using "trend" package in R-studio software to study change in ET0. The Pearson correlation matrix was analyzed in the R-studio program to determine the relation of ET0 with the individual weather parameters.

Analysis of ET0 sensitivity to climatic variables

Sensitivity analysis of annual ET0 with the input parameters was done by varying the magnitude of climatic parameters namely temperature, wind speed, sunshine hours, and relative humidity one at a time by ±5%, ±10%, ±15% and ±20% over the base line values of climatic parameters.

RESULTS AND DISCUSSION

Seasonal variations of ET0

Annual and seasonal variations of ET0 was analyzed for all four study locations The annual ET0 varied from 1324 to 1347 mm (Fig.1), the highest value being found in Faridpur and the lowest in Satkhira. Spatial variation of seasonal ET0 showed almost similar results although Jashore showed slightly higher values in *Boro* and T. Aus seasons and Faridpur in T. Aman season. *Boro* and T. Aus seasons showed similar ET0 although the T. *Aus* season has a shorter duration (153 days) than *Boro* (182 days) and T. *Aman* (184 days) season. T. *Aman* showed the lowest ET0 among the seasons. The higher temperature, longer bright sunshine hours and greater wind speed in the T. *Aus* season increased the ET0 rate. In addition, the *Boro* season starts in winter when the ET0 rate was the lowest. On the other hand, T. *Aman* season starts in rainy season with higher humidity and cloud coverage and shorter bright sunshine hours which led to a reduced ET0 rate.

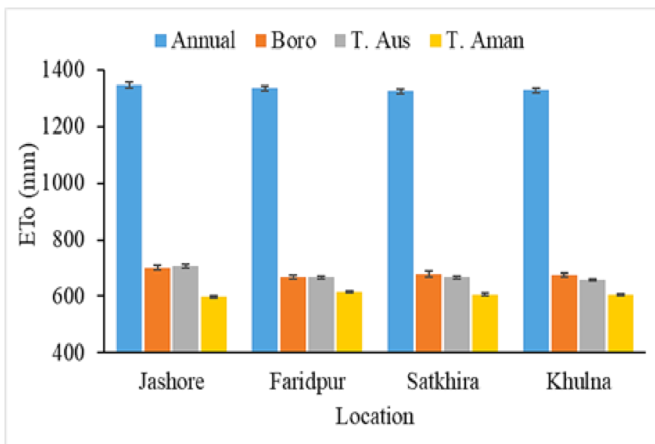

Figure 1: Seasonal and spatial variations of ET0 in Jashore, Faridpur, Satkhira and Khulna districts

Trend of ET0 and regulating factors

ET0 showed a decreasing trend over time at all four study locations of Faridpur, Jashore, Khulna and Satkhira (Fig. 2). A linear trend analysis showed that ET0 decreased at the highest rate of 4.78 mm year^{-1} in

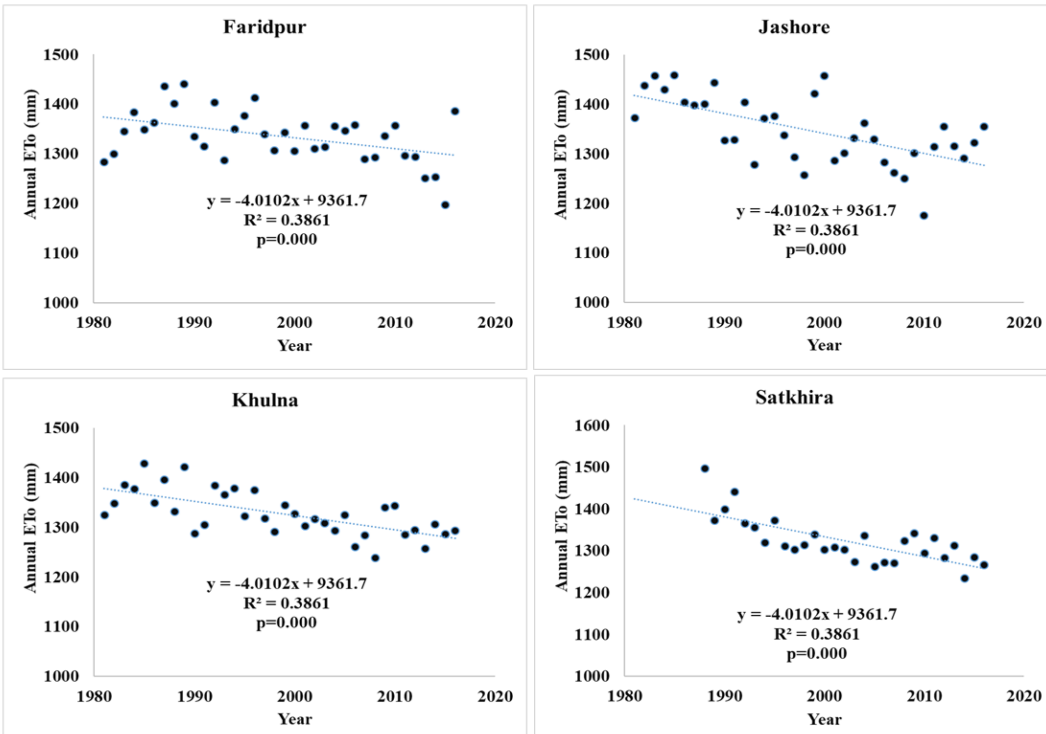

Figure 2: Annual trends of ET0 in Faridpur, Jashore, Khulna and Satkhira

Satkhira followed by 4.01 mm year^{-1} in Jashore (Table 2). The lowest decreasing rate 2.18 mm year^{-1} was found in Faridpur district. Sen's slope trend test of annual ET0 also implies the similar findings to linear trend where Satkhira showed the highest decreasing rate 4.2 mm year^{-1}. Following the same as annual trend, seasonal ET0 also showed the decreasing trend in all locations. The highest 4.7 mm year^{-1} and lowest 1.9 mm year^{-1} decreasing rate was recorded during Boro season in Satkhira and Jashore, respectively. T. Aus and T. Aman season showed comparatively less decreasing rate than Boro season. Among the locations Satkhira showed the highest decreasing rate of ET0 irrespective of seasons and highly vulnerable to climate change.

Table 2: Sen's slope analysis of ET0 (mm year^{-1}) in the study locations

Season	Jashore	Faridpur	Khulna	Satkhira
Annual	-4.0	-2.1	-2.7	-4.2
Boro	-1.9	-2.2	-2.4	-4.7
T. Aus	-1.2	-0.3	-0.5	-1.9
T. Aman	-0.3	-0.2	-0.6	-1.3

The correlation of ET0 with the climatic parameters such as maximum and minimum temperature, solar radiation, wind speed and relative humidity were analyzed and presented in heat map (Fig. 3). Except humidity, all the climatic parameters showed positive relation with ET0. At all the locations, solar radiation and maximum temperature showed the highest correlation, whereas relative humidity showed the lowest and negative correlation.

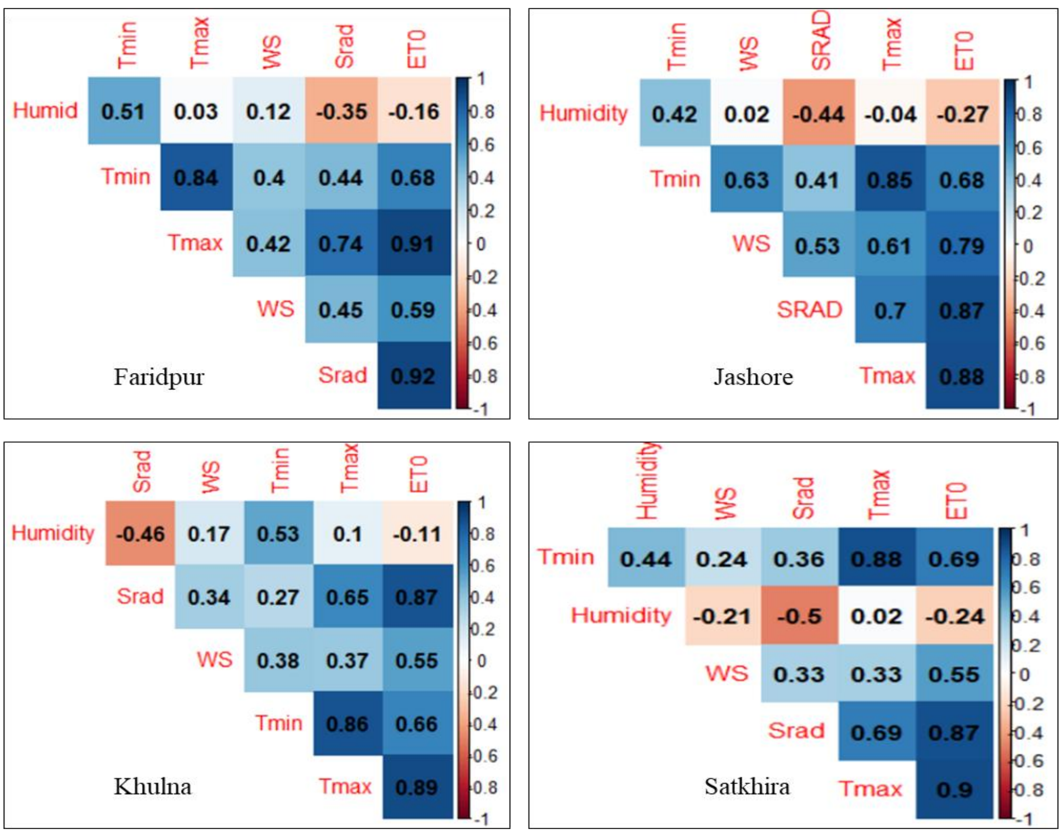

Figure 3: Correlation matrix of principal climatic variables with ET0 in Faridpur, Khulna, Jashore and Satkhira

Trend analysis of principal climatic variables was done by detecting Sen's slope and presented in Table 3. Results showed that bright sunshine hour is decreasing significantly

Table 3: Trend (Sen's slope) of major climatic parameters in Faridpur, Jashore, Khulna and Satkhira

Location	Maximum temperature	Minimum temperature	Humidity	Wind speed	Sunshine hours
Faridpur	0.003***	0.017ns	0.009ns	-0.005ns	-0.03***
Jashore	0.02*	0.005**	0.013**	-0.02ns	-0.03***
Khulna	0.025***	0.037ns	-0.02ns	-0.02ns	-0.02***
Satkhira	0.009ns	0.02***	0.2***	-0.06***	-0.03***

* 10% level of significance, **5% level of significance, ***1% level of significance, ns = not significant

over time at all four locations. Sunshine hour is decreasing at 0.03 hours annually both in Faridpur, Jashore and Satkhira and that was 0.02 hour in Khulna. Sunshine hours affect the solar radiation amount increment which acts as energy source for ET0 (Mojid *et al*, 2015). Maximum air temperature increased at a significant rate at all locations except Satkhira. Minimum temperature also showed increasing trend in all locations and the maximum rate was found 0.02^{o}C year^{-1} in Satkhira. An increase of both maximum and minimum temperature implied an increase in ET0. Humidity has negative effect on ET0. As the humidity increases, atmosphere become wetter which means the water absorption capacity in air decreases over time. Our study showed that relative humidity increased in all locations except Satkhira. Wind speed showed a downward trend in all locations, and it varied significantly at Satkhira. ET0 varied positively with wind speed. Though both maximum and minimum temperatures increased in the study areas, which had a positive effect on ET0, the sharp decline of sunshine hour, wind speed, and the upward tendency of relative humidity forced ET0 reduction.

Sensitivity of climatic variables

Fig. 4 shows the relative changes in annual ET0 with respect to positive and negative incremental change as 5%, 10%, 15%, and 20% of each major climatic parameter i.e., maximum temperature (T_{max}), minimum temperature (T_{min}), relative humidity (Humidity), wind speed (WS) and sunshine hours (SSH).

In all four locations (Faridpur, Jashore, Khulna and Satkhira), it was observed that change in T_{max} prominently influenced the annual ET0 change the most followed by SSH, Tmin and WS. However, change in humidity always inversely related to annual ET0 change. In case of 20% increase of T_{max}, annual ET0 increased by 13%, 15.7%, 13.7%, and 15.7% in Faridpur, Jashore, Khulna and Satkhira, respectively. Consequently, decrease in T_{max} by 20% diminished annual ET0 by 10.4%, 12%, 13%, and 12% in Faridpur, Jashore, Khulna and Satkhira, respectively. The change in annual ET0 varied within the small range due to both positive and negative change in T_{max} (13-16% for positive change and 10-13% for negative change) irrespective of locations. The second most important parameter that influenced annual ET0 was

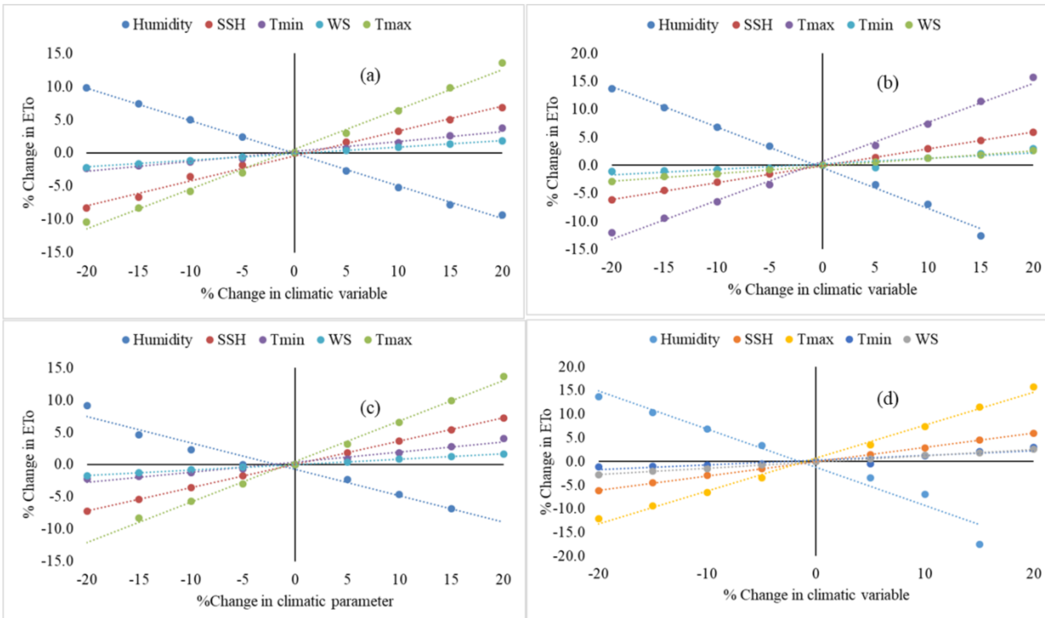

Figure 4: Sensitivity analysis of climatic parameters to ET0 at (a) Faridpur, (b) Jashore (c) Khulna and (c) Satkhira

SSH. After T_{max}, annual ET0 was affected by the change in SSH. For 20% increase in SSH, the increase in annual ET0 was 6.78%, 2.7%, 7.2% and 5.9% in Faridpur, Jashore, Khulna and Satkhira, respectively. However, for 20% decrease in SSH, annual ET0 decreased by 8.3%, 6.4%, 7.2% and 6.2% in Faridpur, Jashore, Khulna and Satkhira, respectively. For positive change in SSH, highest and lowest increment were observed in Khulna and Faridpur whereas, for negative change in SSH, highest and lowest reduction were observed in Faridpur and Satkhira. Though both positive and negative change in WS and Tmin had some effect on annual ET0 change, the changes were not considerable compared to Tmax and SSH (in between 1% and 3%) in all locations. The change in humidity, the rest of all major climatic parameters, acted differently than other parameters.

Generally, it was observed that increase in humidity percentage reduced annual ET0 and vice versa. The annual ET0 decreased by 9.7%, 17.5%, 10.1% and 12.6% in Faridpur, Jashore, Khulna and Satkhira, respectively for 20% increase in humidity. On the other hand, the annual ET0 increased by 9.83%, 13.7%, 9.1%, and 13.7% in Faridpur, Jashore, Khulna and Satkhira, respectively for 20% decrease in humidity. Goyal (2004) revealed that the annual ET0 was sensitive to temperature, wind speed, solar radiation, and humidity at arid region of Rajasthan in India. In another study, Mojid *et al*. (2015) reported that sunshine hours had the most leading role to annual ET0 change in northwest hydrological region of Bangladesh (Trans- Indo-Gangetic plain). However, our findings were similar to Patle and Singh (2015) found the similar findings of the current study that temperature was the most influential climatic parameter to annual ET0 change followed by sunshine hours, wind speed and humidity.

CONCLUSION

Annual and crop seasonal ET0 values based on historical climate data were derived for the Faridpur, Jashore, Khulna and Satkhira districts of Bangladesh using the Penman-Monteith equation. Annual ET0 varied from 1324 to 1347 mm at the study locations. There were similar seasonal ET0 for *Boro* and T. *Aus* seasons, although the duration of the T. *Aus* season is shorter (153 days) than that of either the *Boro* (182 days) season or the T. *Aman* (184 days) season. Higher temperature, longer bright sunshine hours and greater wind speed in the T. *Aus* season increased the ET0 rate.

Annual ET0 is declining linearly at all the study locations. Although both maximum and minimum temperatures showed positive relationships with increased ET0, the downward trends of sunshine hours, wind speed and upward trends of relative humidity caused ET0 reductions. Sensitivity analysis showed that maximum temperature was the dominant parameter influencing ET0 followed by relative humidity and bright sunshine hours. The irrigation demand, being directly related to ET0, tends to decrease with a decrease in ET0. The irrigation requirements for growing rice would diminish with decreasing ET0 in the study districts implying reduced irrigation demands for rice and non-rice crops in future in the present climate change scenario.

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SOIL QUALITY INDEX FOR RANGPUR AND BOGURA BASED ON PRINCIPAL COMPONENT ANALYSES

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ABSTRACT

Soil quality index (SQI) generated from principal component analysis (PCA) is a product of few selected soil properties. It warrants selection of the most appropriate properties influencing soil functions dominantly. The present study for determination of SQI was conducted in AEZ-27 (Rangpur and Bogura) having different major cropping patterns. Thirty-eight composite soil samples (from 380 sampling points) were collected from different crop fields of AEZ-27. Thirteen bio-physicochemical soil properties were analyzed. SQI was developed using weightage factors obtained from PCA following the additive index method. Soils of Rangpur and Bogura were moderately acidic to neutral, pH ranging from 5.31 to 7.57 and 4.74 to 6.85, respectively. Soil texture of Rangpur was sandy clay loam while it was clay loam in Bogura. The soil organic matter (SOM) content ranged from 0.96% to 3.04%. Total bacterial populations in the soils of AEZ-27 varied from 5.91 to 8.74 $\log_{10}$ cfu g^{-1} soil dry weight (SDW) with an average value of 6.72 $\log_{10}$ cfu g^{-1} SDW. The population densities of free-living N_2 fixing bacteria (NFB), phosphate solubilizing bacteria (PSB), rhizobia, fungi and actinomycetes were moderate to low. Soil properties explained about 74.83% of the total variation in the data set. Among the loaded soil parameters, SOM, pH, P and K were significantly ($p>0.05$) correlated with SQI. The study showed that 7% of the tested soils had a very high SQI (>0.90), 28% gave values in between 0.70 and 0.89, about 52.6% soils showed SQI values between 0.50 and 0.69 and only 10% soils had SQI<0.50. Clay loam soils had higher SQI values compared with sandy clay loam soils. In general, large variations in SQI were related with soil heterogeneity and nutrient management practices with different cropping patterns.

Keywords: Bacteria, Cropping pattern, pH, Soil texture, Soil organic matter, Nutrient

INTRODUCTION

Soil is one of the most important resources on earth and its health reflects the status of physical, chemical and biological attributes. In soil, there is continual interchange of molecules and ions between solid, liquid and gaseous phases which are mediated by physical, chemical and biological processes. It is the net result of on-going conservation and degradation processes that depend highly on the biological component of the soil

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ecosystem. The interaction between plants, soil and microorganisms is considered to be the major driver of the ecosystem functions (Suleiman *et al.*, 2013). Soil parent materials and different management practices such as cropping system, fertilizer application and agronomic management may alter physical, chemical and biological properties of soils. Soil health reflects soil quality, which can be defined as 'the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation' (Karlen *et al*., 1997). Determination of soil heath is crucial for sustaining food security as soil health greatly impacts crop production. A quantitative formula and conceptual framework were proposed to evaluate soil quality based on soil functions (Doran *et al.*, 1996; Karlen *et al.*, 1997). In general, soil quality assessment is carried out by selecting a set of soil properties which are considered as indicators of soil quality. There are several recognized methods to evaluate soil quality using index and can be classified as additive index, weighted additive, and decision support vector (Andrews *et al.*, 2002). The limitation of additive index is the selection of soil properties based on subjective opinion of experts (Basida *et al.*, 2008). Principal component analysis (PCA), a multivariate method, offers an opportunity to simplify the selection of attributes that represent better soil functionality (Gonzalez and Valenzuela, 2017). PCA reduces the dimension of large volume of data and facilitate the indicator selection by categorically grouping the soil properties into principal components.

Evaluation of soil quality for the improvement of agricultural land use is crucial. Nevertheless, during determination of nutrient requirements for crop production, soil chemical properties are mostly considered for development of fertilizer management packages, while ignoring soil biology. The incomplete information of total soil properties may impair the success of fertilizer management packages as soil biological properties are major driver of soil functions. Since SQI indicates soil physical and bio-chemical properties, consideration of all properties is needed for fertilizer recommendation, although data are not available in many cases. In the present investigation, soil biological properties along with physical and chemical properties were considered for development of SQI for AEZ-27 that might be useful for determining soil health to boost crop production.

MATERIALS AND METHODS

Collection of soil samples

Soil samples (0 to 15 cm) were collected from Mithapukur, Badarganj and Pirganj upazila of Rangpur district and Shahzahanpur upazila and Sadar of Bogura district in the year 2021 (Fig. 1). A total of 38 composite soil samples from 380 sampling points were collected from fields under different cropping patterns and analyzed for bio-physicochemical properties.

Determination of microbial population

Microbial populations were determined using spread plate count technique with specific growth media. Populations of culturable total bacteria, fungus and actinomycetes were determined in nutrient agar (NA), potato dextrose agar (PDA) and actinomycetes agar media plate, respectively. Free-living N_2 fixing bacteria, phosphate solubilizing bacteria (PSB) and rhizobium were enumerated in the N-free media, Pikovasakaya media and yeast mannitol agar (YMA) media, respectively. A series of 10-fold dilutions were prepared (up to 10^{-10} of 10 g soil) and culturable microbes were grown in respective media plates. Free-living N_2 fixing bacteria (NFB) population was determined according to Naher *et al*. (2013) and Prasad *et al*. (2001). Composition of the media was consisting (per litre) of 5 g malic acid, 0.5 g K_2HPO_4, 0.2 g $MgSO_4 \cdot 7\ H_2O$, 0.1 g NaCl, 0.02 g $CaCl_2$, 0.5% bromothymol blue in 0.2 N KOH (2 mL), 1.64% Fe-EDTA solution (4 mL) and 20 g agar.

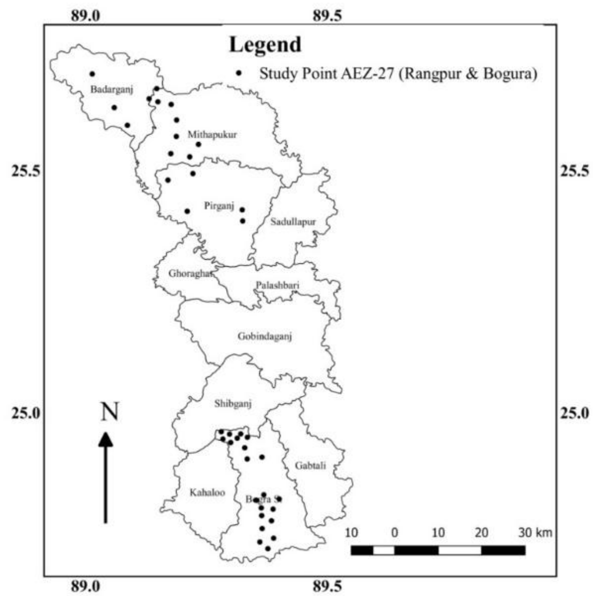

Figure 1: Location map of AEZ-27 (Rangpur and Bogura) originating from GPS coordinates

Chemical analyses of soil properties

Soil samples were air dried in shade and sieved through 2 mm mesh for chemical analyses. Soil was mixed with distilled water at 1:2.5 ratio followed by stirring with a glass rod for 5 min, which was repeated two times after 1-hour interval and then pH of the solution was determined using a portable pH meter (HANNA, Romania). The SOC and total N were determined by wet oxidation method (Walkley and Black, 1935) and Kjeldahl method (Bremner and Mulvaney, 1982), respectively. For available P determination, soil was extracted by 0.5 N sodium bicarbonate solution (pH adjusted to 8.5) and P in the extract was determined by developing blue color with ascorbic acid-ammonium molybdate vanadate complex. The colour intensity was measured colorimetrically at 710 wavelength with Jasco V630, Japan spectrophotometer (Olsen and Sommers, 1982). Exchangeable K was determined by atomic absorption spectrophometer (AAS) after extraction with 1 M $NH_4CH_3CO_2$ at pH 7 (Jones, 2001). Soil available Zn was extracted by DTPA and determine by atomic absorption spectrophotometer (AAS).

Determination of soil quality index (SQI)

All of the tested soil biochemical properties were standardized to evaluated values between 0 and 1, where 1 represented the optimum value for the indicator. After standardization, principal component analysis (PCA) was performed using SPSS version 16.0 (SPSS Inc, Chicago, IL). Components with high eigenvalues (>1.0) were considered for the SQI analyses. The correlation (Pearson's correlation) between the properties those had weight less than 0.6 were eliminated within the principal component studied. The soil quality index of different treatments was calculated using following formula of Yu *et al*, (2018);

$$\text{SQI} = \sum_{i=1}^{n} Wi \times Si$$

Where Wi is the PC weighting factor and Si is the standardized value of the selected property. We assumed that higher index scores meant better soil quality or greater performance of soil functions.

Soil quality evaluation

PCA was performed using SPSS (version 16.0) for 38 soil physical, chemical and biological properties of the soil. The objective of PCA was to reduce the dimension of data while minimizing the loss of information (Armenise *et al.*, 2013). Principal components (PC) with high eigenvalues were considered best representatives explaining the variability (Andrews *et al*, 2002). PCs with eigenvalues ≥1 (Kaiser, 1960) were selected since PC with eigenvalue >1 accounts for less variation than generated by a single variable. The retained PCs were subjected to varimax rotation to maximize the correlation between PC and the soil properties by distributing the variance (Waswa *et al.*, 2013). Under each PC, highly weighted variables were selected as soil quality indicators. Multivariate correlation coefficients were used to check for redundancy and correlation between the variables. If the variables are well correlated (r > 0.70), then variable with highest factor loading (absolute value) was retained as indicator among the well correlated variables (Andrews and Carroll, 2001).

RESULTS AND DISCUSSION

Soil biochemical properties

In Rangpur, soil of the tested area was sandy clay loam in nature with 24.58% sand, 49.28% silt, 26.19% clay. In Bogura, soil texture was clay loam with sand 42.36%, silt 26%, and clay 31.632%. The SOM ranged from 1.44% to 2.48% in Rangpur district whereas it ranged from 0.96% to 3.04% in Bogura district (Table 1). On an average the tested soils of Rangpur and Bogura contained 0.05% and 0.08% of total N (TN), respectively. Soils of Rangpur and Bogura were moderately acidic to neutral, pH ranging from 5.31 to 7.57 and 4.74 to 6.85, respectively. In average soils of Rangpur contained 18.65 mg kg^{-1} available P and 0.12 meq 100 g^{-1} exchangeable K, respectively. The mean values of available P and exchangeable K in Bogura soils were 42.34 mg kg^{-1} and 0.16 meq 100 g^{-1} soil, respectively. The content of available P and K was high as soil was fertilized and potato crop was there. The Zn and S content was also high in both the locations.

Table 1: Soil chemical properties of AEZ-27 (Rangpur and Bogura)

Location	Parameters	OM (%)	TN (%)	pH	Exch. K meq 100 g^{-1}	Avail. P mg kg^{-1}	Avail. S mg kg^{-1}	Avail. Zn mg kg^{-1}
Rangpur	Mean	1.86	0.049	6.05	0.12	18.65	12.73	2.93
	Sd	0.34	0.02	0.67	0.04	10.65	4.76	1.68
	Minimum	1.44	0.01	5.31	0.09	3.66	5.13	0.58
	Maximum	2.49	0.09	7.57	0.27	35.87	21.0	5.49
Bogura	Mean	1.87	0.08	5.93	0.16	42.34	7.99	4.97
	Sd	0.52	0.01	0.68	0.09	19.25	4.86	0.62
	Minimum	0.96	0.04	4.74	0.09	20.18	4.79	3.41
	Maximum	3.04	0.12	6.85	0.5	64.5	24.56	5.98

Sd = Standard deviation

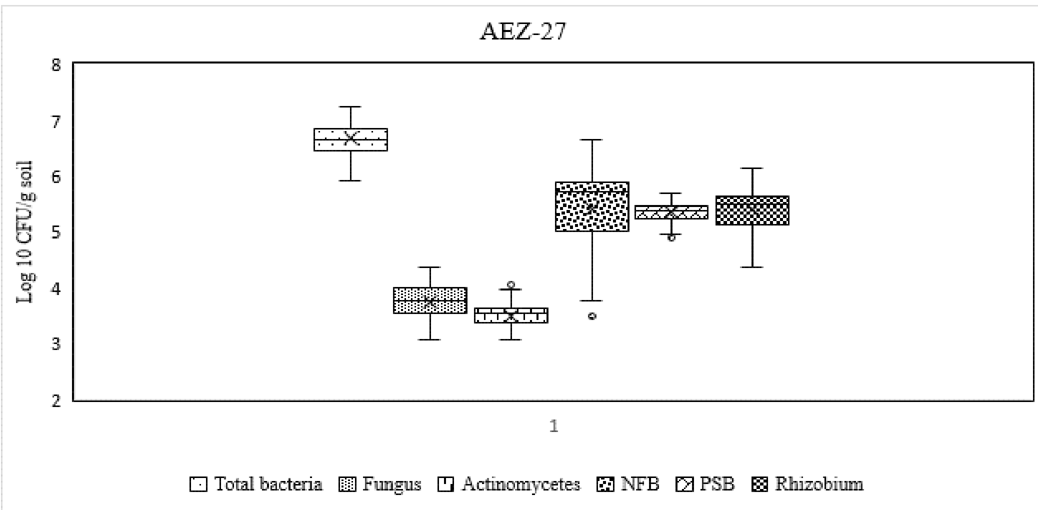

Figure 2: Soil microbial populations of AEZ-27 (Rangpur and Bogura)

In AEZ-27, total bacteria population ranged from 5.91 to 8.74 log_{10} cfu g^{-1} SDW with an average value of 6.72 log_{10} cfu g^{-1} SDW. Fungal population ranged from 3.06 to 4.37 log_{10} cfu g^{-1} SDW with 75% of the population above the median of 3.97 log_{10} cfu g^{-1} SDW. Actinomycetes population ranged from 3.06 to 4.27 log_{10} cfu g^{-1} SDW. Free living N_2 fixing and PSB populations ranged from 3.50 to 7.67 and 4.91 to 5.99 log_{10} cfu g^{-1} SDW, respectively. Average rhizobium population value was 5.38 and it ranged from 4.06 to 6.15 log_{10} cfu g^{-1} SDW (Fig. 2).

Principal component analyses

After applying the selected criteria, number of attributes that compose the minimum data set representing the greatest soil variability (initially 38) was reduced to five, the principal components that presented eigenvalues > 1.0 explained 74.83% of the total variations in the data set, (PC1 = 28.5, PC2 = 17.2, PC3 = 11.33, PC4 = 10.07 PC5 =

7.27) (Table 2). From the rotated component matrix, it was found that *Rhizobium*, available P and Zn, available S, and Actinomycetes were dominant variable in PC1. In the PC2, total N, SOM, and total bacteria were prominent variables. Exchangeable K and fungi were dominant variables in PC3. Populations of beneficial bacteria (NFB and PSB) and soil pH were dominant in PC4 and PC5, respectively (Table 2).

Table 2: Principal components, eigenvalues and component matrix variables

Properties	PC1	PC2	PC3	PC4	PC5
Eigen value	3.70	2.23	1.47	1.31	1.0
% Variance	28.51	17.2	11.33	10.07	7.72
% Cumulative variance	28.51	45.72	57.05	67.13	74.86
Weightage factor	0.107	0.128	0.130	-	-
Factor loading (Rotated component matrix)					
Total Bacteria	0.056	**0.60**	0.009	0.591	0.015
*NFB	0.480	0.007	-0.358	**0.604**	-0.072
**PSB	-0.352	0.011	0.241	**0.774**	-0.125
Fungus	-0.396	0.085	**0.716**	0.075	-0.224
Actinomycetes	**-0.656**	0.163	0.409	0.217	-0.092
Rhizobium	**0.880**	0.079	0.059	0.106	0.109
pH	-0.114	0.001	0.023	-0.096	**0.910**
Organic matter	-0.157	**0.689**	0.196	0.347	0.075
Nitrogen	0.173	**0.932**	-0.034	-0.114	-0.066
Avail. P	**0.726**	0.027	-0.115	-0.036	-0.229
Exch. K	0.183	0.042	**0.802**	0.000	0.162
Avail. Zn	**0.726**	0.017	0.243	-0.328	-0.328
Avail. S	**-0.631**	0.**611**	0.083	-0.057	-0.006

*NFB represents free living N_2 fixing bacteria, **PSB is phosphate solubilizing bacteria

Soil quality index (SQI)

The SQI was measured using weightage factor obtained from PCA. Total percentage of variance from each PC was divided by percentage of cumulative variance to derive the weightage factor (Ray *et al.*, 2014). The derived weightage factor was used with selected variables from respective PCs. The weighted variables were then summed up to derive index value for each soil. Weightage factor was assigned in such way that the total of all factors makes unity. Then the SQI for each soil was calculated as described in the additive index method. The highest SQI value was considered as 1.0 and nearest to 1 value indicates better SQI of that soil. The large variation in most of the soil properties may be attributed to a combination of intrinsic (weathering, erosion, deposition and soil forming processes) and extrinsic (management practices) factors (Rao and Wagenet, 1985). In general, it was found that higher SQI value was associated with clay loam soil compared with sandy clay loam except for soil from potato crop field. Farmers applied huge amounts of chemical fertilizers to grow potato and residual fertility influenced SQI value greatly in sandy clay loam soil (Table 3). Moreover, found the quantity and type of clay are major indicators of SQI (Vasu *et al*. 2016).

Table 3: Soil Quality index of different cropping systems in AEZ-27 (Rangpur and Bogura)

Cropping pattern	Texture	SQI
Boro-Aman-Mustard	Clay loam	0.98
Boro-Mustard-Potato	Clay loam	0.93
Boro-Aman-Mustard	Clay loam	0.92
Potato-Corn-Aman	Sandy Clay Loam	0.85
Vegetable-Aman	Clay loam	0.82
Boro-Vegetable- Corn	Clay loam	0.79
Vegetable-Aman	Clay loam	0.78
Boro-Aman- Potato	Sandy Clay Loam	0.77
Boro-Potato-Gourd-Corn	Clay loam	0.77
Vegetable-Aman	Clay loam	0.76
Boro-Aman-Potato-Corn	Sandy Clay Loam	0.76
Boro-T. Aman	Clay loam	0.74
Boro-potato-vegetable	Clay loam	0.74
Boro-potato-vegetable	Clay loam	0.71
Boro-potato-fallow	Clay loam	0.68
Boro-Aman-Fallow	Clay loam	0.68
Boro-Mustard-Potato	Clay loam	0.68
Pulses-Aroid-Potato-Sweet gourd	Clay loam	0.67
Boro-Mustard-Potato	Clay loam	0.67
Potato-Corn-Aman	Sandy Clay Loam	0.65
Boro-Fallow-Aman	Sandy Clay Loam	0.64
Boro-Fallow-Aman	Sandy Clay Loam	0.64
Vegetable-Vegetable	Clay loam	0.63
Tut tree	Clay loam	0.61
Vegetable-Aman	Clay loam	0.60
Boro-Aman-Mustard	Clay loam	0.60
Boro-Aman-Mustard	Clay loam	0.59
Boro-Jute- Fallow-Aman	Sandy Clay Loam	0.58
Boro-Fallow-Aman	Sandy Clay Loam	0.57
Potato-Corn-Aman	Sandy Clay Loam	0.57
Potato-Aman-Cucumber-Sweet gourd	Sandy Clay Loam	0.57
Potato-Corn-Aman	Sandy Clay Loam	0.56

Cropping pattern	Texture	SQI
Boro-Fallow-Aman	Sandy Clay Loam	0.54
Pulses-Aroid-Potato-Sweet gourd	Sandy Clay Loam	0.54
Boro-Corn- Fallow	Sandy Clay Loam	0.49
Boro-Aman-Potato	Sandy Clay Loam	0.48
Potato-Aus-Aman	Sandy Clay Loam	0.44
Boro-Fallow-Aman	Sandy Clay Loam	0.41

The SQI values obtained from the tested variables of AEZ-27 could be categorized into four classes (Table 4). The average values of loaded variables were highly correlated ($r^2 = 0.99$) with soil parameter and showed significant ($p < 0.05$) relationship with SOM, P, K, and pH. From the dataset we can find that SOM is considered as an important soil quality indicator (Lal, 2002). It plays major role in the rainfed production systems through nutrient supply, moisture retention and stability of soil physical properties (Bhattacharyya *et al*, 2007). We find that the highest score of SQI (>0.90) associated with high OM (2.5%), higher number of total bacteria, moderate pH value (6.12), and higher concentration of nutrients (Table 4). According to scoring of SQI (0.50-0.69), about 52.6% tested soils of different cropping pattern obtained medium fertility and 10% are low category (SQI <0.50).

Table 4: SQI classes and average values of loaded variables in AEZ-27

SQI class	TB*	NFB**	PSB***	Fungus	Actin.	Rhiz.	pH	SOM (%)	Total N (%)	Avail. P, Zn, S (mg kg^{-1})			Exch. K (meq 100 g^{-1})
	Log10 cfu g^{-1} soil									P	Zn	S	
>0.90	7.3	5.6	5.3	3.9	3.5	5.7	6.12	2.50	0.11	64.5	5.35	18.1	0.27
0.70-0.89	6.9	5.8	5.6	3.9	3.7	5.4	5.74	2.10	0.07	64.0	3.93	9.1	0.16
0.50-0.69	6.5	5.4	5.3	3.6	3.4	5.4	5.60	1.17	0.06	51.0	3.90	9.0	0.13
<0.50	6.3	5.0	5.2	3.7	3.4	4.7	5.70	1.56	0.02	22.0	2.78	11.7	0.12

*Total bacteria, **Free-living N_2 fixing bacteria, ***Phosphate solubilizing bacteria

CONCLUSION

Generally, soil quality in the study area (AEZ-27, Rangpur and Bogura districts of Bangladesh) varied from low to high. The PCA explained about 79% variations in soil properties and their interaction categorically as principal components. Study results showed that the tested soils of AEZ-27 (Rangpur and Bogura) were moderately fertile and among the soil samples 7% had a very high SQI (>90), 28% had SQI between 0.70 and 0.89 (considered as high), 52.6% within 0.50-0.69 (medium) and 10% had <0.50 indicating low soil fertility. Relatively fine textured (clay loam) soils had a higher SQI value compared with sandy clay loam soil. Among the loaded soil parameters, SOM, pH, P and K were significantly correlated with SQI. The large variations in soil quality were due to soil heterogeneity and fertilizer management practices in different cropping patterns.

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GIS-BASED *AUS-AMAN*-GROUNDNUT CROPPING PATTERN SUITABILITY ASSESSMENT IN DELDUAR UPAZILA

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ABSTRACT

Crop-land suitability analysis is a prerequisite to achieve optimum utilization of the available land resources for sustainable agricultural production. Judicious use of resources based on different aspects of land, climate and socio-economics is a must to grow suitable crops for sustainable production in a particular region. A GIS based Crop Suitability Assessment Model (CSAM) was used to assess the suitability of a rice-based groundnut cropping pattern in Delduar upazila of Tangail district. Crop suitability was determined through multi-factor analysis of land, climate and economic situation in the study area. The agro-edaphic and agro-climate suitability levels were determined separately based on the soil/land factors and climatic factors, respectively. Following this, land suitability assessment for different crops was performed through overlaying of agro-edaphic and agro-climatic suitability layers using CSAM. An *Aus-Aman*-groundnut cropping pattern was found to be very suitable for Delduar upazila based on agro-climate factors. Agro-edaphic characteristics of the study area indicate that about half of the upazila is moderately suitable for the *Aus-Aman*-groundnut cultivation, whereas about one-third area is highly suitable for the same cropping pattern. This investigation will provide spatial alternatives to the local farmers for choosing the best crops and cropping pattern. This GIS based model is user-friendly and the flexible application software will be useful for scientists, planners and decision makers.

Keywords: Agro-edaphic, Agro-climatic, GIS, Land suitability, Multi-criteria evaluation

INTRODUCTION

Globally, agriculture can potentially increase food supplies faster than the growth of population (Davidson, 1992). Yet, the capacity for available resources and technologies to meet the demands of the growing population for food and other agricultural commodities remains unused (FAO, 1993). Land is one of the most important natural resources, and maintaining its health is essential for meeting an ever increasing demand for food, fiber, fodder and fuel (Mohammad and Mohd, 2014). It is a significant resource mainly for countries where the economy is based on rural activities, such as agriculture (Agra, 2013). Therefore, maintaining the productivity of land is a determinant factor to

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obtain sustainable services and goods from land. Traditional farming practices are common where crops are usually cultivated and chemical fertilizers are applied irrespective of the existing constraints and potentials of land. Thus, land suitability evaluation is essential to guide farmers to invest on land use options that would bring the greatest social and economic benefit, and minimum environmental costs. This will help to improve crop production and allocate the land to the most suitable use (Esa and Assen, 2017).

Land suitability is a function of crop requirement and land/soil characteristics. The suitability of land is assessed considering rational cropping system, for optimizing the use of a piece of land for a specific use (Sys *et al.*, 1991). It measures how well the qualities of land unit match the requirements of a particular form of land use (FAO, 1976). Such type of suitability analysis allows identifying the main limiting factors for the agricultural production and enables decision makers to develop crop management strategies to increase the land productivity through judicious use of land and water resources (Abdullahi *et al.*, 2021). However, the suitable areas for agricultural use are determined by an evaluation of the climate, soil, and topographical environmental components and the understanding of local biophysical restraints. In this kind of situation, many variables are involved and each one should be weighted according to their relative importance on the optimal growth conditions for the crops.

Various approaches of land evaluation have been developed such as multi-criteria evaluation techniques, matrix pairwise comparison for land suitability, etc., each having a specific methodological procedure. The qualitative systems are empirical assessment systems based on the knowledge and understanding of the area. A qualitative land suitability classification procedure was adopted (Verdoodt and Ranst, 2006) to translate the large-scale bio-physical data supplied by reconnaissance soil surveys into five suitability classes within a Geographical Information System (GIS) environment. Ghaffari *et al*. (2000) used GIS to match the suitability for potatoes based on the biological requirement of the crop and the quality and characteristics of land. The methodology combined climate, land quality attributes that most influence crop suitability (long-term), and topographical data (slope and altitude). It presented a GIS-based land suitability model based on the simple limitation approach.

The relative degree of contribution of various criteria can be addressed when they are grouped into several categories and organized into many hierarchies. Agricultural land suitability involves major decisions at various levels starting from choosing a major land-use types, selection of criteria organization of the criteria, and deciding suitability limits for each class of the criteria. The relative importance of these parameters can be evaluated to determine the suitability by multi-criteria evaluation (MCE) techniques (Sarker, Gosh and Banik 2013). Diverse approaches to decision-making using relevant techniques have been adopted from time to time. In the present study, an attempt has been undertaken to use a weighted MCE and GIS in union to identify the most idealistic land evaluation for crop suitability assessment. This fusion approach of integrated MCE–GIS was adopted to overcome the shortcomings of the earlier unrealistic multi-criteria land evaluation approaches of non-spatial assessments on assumptions of spatial homogeneity. Malczewski (2006) advocated using GIS to perform spatial multi-criteria decision-making (MCDM) as it easily provides a means for developing valuation criteria based on neighbourhood analysis operations. Ceballos-Silva and Lopez-Blanco (2003) used matrix pairwise comparison for land suitability that overcomes the problem of determining weights. The MCE–GIS technique combines both traditional and modern approaches to analyze land evaluation. Spatial MCE, like MCE–GIS allows spatial reference information and analysis techniques to be combined and transformed into a decision based on the decision maker's preferences. Many GIS-based land suitability analysis approaches have been recently developed such as, Boolean overlay and modelling for land suitability analysis. However, these approaches lack a well-defined mechanism for incorporating the decision-maker's preferences into the GIS procedures (Malczewski, 2006). GIS has proved to be the best to incorporate such type of different land, crop and climate attributes that differ spatially and to identify the best suitable land use.

Integration of the GIS and MCE can help land-use planners and managers to improve decision-making processes (Malczewski, 1999). GIS enables the computation of assessment factors, while MCE aggregates them into a land suitability maps. Using GIS based multi criteria evaluation approach, many researchers evaluated land suitability for various crops e.g. rice, vegetables, sugarcane, cassava, etc. (Maddahi *et al*. 2017; Everest *et al*, 2021).

One of the most important and urgent issues in Bangladesh is to improve agricultural land management and cropping patterns to increase agricultural production with efficient use of land resources. Crop-land suitability analysis is a prerequisite to achieve optimum utilization of the available land resources for sustainable agricultural production. It is important to identify and delineate suitable areas with appropriate tools for growing particular crop(s) in order to harvest the maximum yield. Tangail is one of the most important groundnut producing districts of Bangladesh (BBS, 2020). Groundnut-based rice cropping pattern suitability maps can be important for local agriculture. Therefore, this study was undertaken to assess the suitability of Aus-Aman-groundnut cropping pattern using the GIS based CSAM, customized software for land suitability assessment.

MATERIALS AND METHODS

Study area

The Delduar upazila of Tangail district was selected for the study. It covers 184.54 sq. km, located in between 24°05' and 24°14' north latitudes and in between 89°50' and 89°59' east longitudes (Fig. 1). The upazila consists of 8 union parishads subdivided into 123 mauzas and 162 villages (BBS,

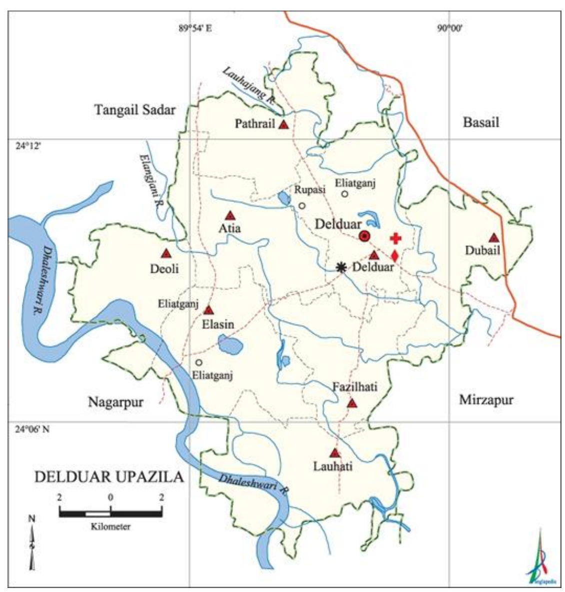

Figure 1: Study area showing soil texture (source: Banglapedia)

2014). Total cultivable land of the study area are12393 ha of which 40% is single cropped, 30% double cropped and 30% triple cropped, 75% of the land having irrigation facilities. The main crops of this upazila are paddy, jute, mustard, sugarcane, potato and wheat. The main source of income is agriculture which accounts for 47.91% of the income. The study area mainly comprises of plain agricultural land, almost flat with minor undulations. The depressions and canals are dominated by organic clay. Most depressions and canals are tectonically controlled. The average ground elevation of the study area is about 13.5m PWD. The main rivers are Dhaleshwari, Lauhajang and Elangjani. This area is flood-free which remained unaffected even by the severe floods of 1998, 2004, 2007 and 2012 (source: Banglapedia). Meteorological conditions of the area are more or less similar as in central part of the country with respect to temperature, rainfall and humidity. This area is situated in humid sub-tropical climate with large variations between summer and winter temperatures and significantly influenced by monsoons during the months of May to September when 90% of the rainfall occurs. The annual average maximum temperature is about 36^{o}C and minimum temperature is about 12.7^{o}C. Annual rainfall is about 1,469 mm.

Data used

The agro-edaphic and agro-climatic data of Land Resources Information System (LRIS) of BARC were used for land suitability assessment in order to identify and delineate suitable area for growing particular crops. Eleven agro-edaphic factors such as soil permeability, effective soil depth, available soil moisture, nutrient status, soil reaction (pH), soil salinity, soil consistency, drainage, inundation, depth of inundation, flood hazards and slope were considered for land suitability analysis. The agro-climatic factors such as length of kharif growing period, pre-kharif transition period, thermal zone and extreme temperature which influence crop growth in relation to crop phenology and photosynthesis were also considered for climatic suitability analysis of different crops.

The agro-edaphic and agro-climatic suitability of crops has been assessed separately based on each individual land and climatic factor limitations with respect to crop requirements. This assessment was done on the basis of expert judgment from the national agriculture research system (NARS) scientists and other experts who have wide knowledge and field experience in crop agriculture. Accordingly, agro-edaphic and agro-climatic suitability maps of different crops were produced. In the final stage, the agro-edaphic and agro-climatic suitability maps were overlaid to get the overall suitability maps of different crops. The agro-edaphic, agro-climatic and overall suitability was accomplished on the basis of Zijsvelt's soil-crop suitability model which was introduced in 1979 revised by Brammer in 1985 (Hussain *et al.*, 2005). The produced crop suitability maps thus show the potential areas under different class (Table 1).

Table 1: Definition of the suitable class used in this study

Suitability class name	Characteristics
Very suitable (VS)	80% or more MAT
Suitable (S)	60 to 80% of MAT
Moderately suitable (MS)	40 to 60% of MAT
Marginally suitable (LS)	20 to 40% of MAT
Not suitable (NS)	Less than 20% of MAT

MAT = Maximum attainable yield

Most soils in Delduar upazila are loam in texture. There are also some clay, clay loam and sandy soils. Soil moisture is mainly high. Low and medium moisture holding. There are also some clay, clay loam and sandy soils. Soil moisture is mainly high. Low and medium moisture holding soils are also found in this upazila. The soils of the upazila are poorly to imperfectly drained. Besides, land elevation map and soil unit map of Soil Resources Development Institute (SRDI) and spot height, Digital Elevation Model (DEM) data were used for developing updated land type maps of Delduar upazila. Some agro-edaphic characteristics are shown in Fig. 2.

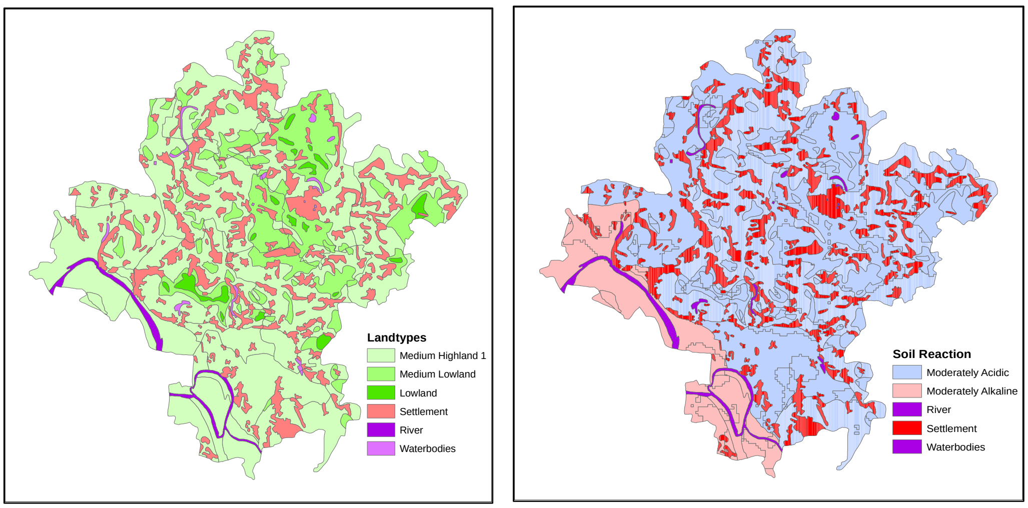

Figure 2: Agro-edaphic map of Delduar upazila

Land suitability analysis

During the suitability assessment process, suitability classification was considered as described hereafter**:** the suitability (edaphic/agro-climatic) assessment brings together all the bio-physical constraints and limitations likely to affect crops performance. The assessment takes account of all the inventoried attributes of the land (climate, inundation, soil, land form, etc.) relevant to the crop under consideration. To assess the land suitability, it is necessary to relate limitations to yields that may be anticipated if there are no further constraints for production from other factors. The yields for the five suitability classes are: very suitable, suitable, moderately suitable, marginally suitable, and not suitable

Edaphic suitability analysis

Suitability of crop depends on different physical and chemical properties of land and soil. In determining the crop suitability, nine major soil and land properties were considered. The major properties are land type, relief, water recession, drainage, soil texture, soil consistency of top soil, available moisture holding capacity, topsoil reaction and topsoil salinity. These parameters are classified according to the different levels of magnitude. Specific crop suitability was assessed by considering the degree of physical factors that limit the growth and potential yields of the crop. The physical suitability evaluation used the limiting factors method for assigning the suitability classes. Five degrees of limitation are used in this study (Table 2). The degrees of limitations (with respect to crop requirements) of each individual land factors (Table 3) for the production of crops were assessed. CSAM was developed for combined limitation ratings of each land unit (HL= high land, MHL= medium high land, MLL= medium low land, LL= low land, VLL= very low land) for a particular crop. The degree of limitations were then assigned to each land unit that counted all these factors.

Table 2: Degrees of limitations for assigning the suitability class

Limitation	Description
0	No limitation, representing the most favorable condition
1	Slight limitation
2	Moderate limitation
3	Severe limitation
4	Very severe limitation; the soil is unsuitable for the land use type

Table 3: Degree of limitations imposed for different land type for *Aus-Aman*-groundnut

Land type	Degree of limitation		
	Aus	*Aman*	Groundnut
HL	0	0	0
MHL	1	1	1
MLL	2	2	2
LL	3	3	3
VL	4	4	4

Afterwards, an overall suitability rating for each land phase was derived based on the combined limitation ratings using the set of rules.

Climate suitability analysis

Similar approach described above were followed considering length of kharif growing period, pre-kharif transition period, thermal zone and extreme temperature to carry out the task of agro-climate suitability.

Combined suitability analysis

In the final stage of land suitability assessment, the agro-edaphic and agro-climatic suitability maps were overlaid to get the overall land suitability maps of different crops. The rules were applied for combining these maps to get classification of land suitability maps as very suitable, suitable, moderately suitable, marginally suitable, and not suitable. For example, if agro-climatic suitability rating is very suitable and agro-edaphic suitability rating are very suitable, suitable, moderately suitable, marginally suitable, and not suitable, then the land suitability rating becomes very suitable, suitable, moderately suitable, marginally suitable, and not suitable, respectively. However, if agro-climatic suitability rating is not suitable and agro-edaphic suitability rating is very suitable, then the land suitability rating becomes not suitable.

Three crops namely Aus, Aman and groundnut for three consecutive cropping seasons namely Kharif-1, Kharif-2 and Rabi, respectively were selected for cropping pattern analysis. Firstly, the agro-edaphic and agro-climatic suitability of those crops were evaluated followed by combining these suitability for each crop. Secondly, suitability ratings for all crops were assessed by considering three cropping seasons. A cropping pattern database was created within each of the updated soil units or for the entire upazila.

Cropping pattern analysis

Cropping pattern analysis combines suitable crops that can be grown in a cropping year. So, GIS-based crop simulation assessment model generated cropping patterns in a mapping unit and assessed suitability of cropping pattern based on selected criteria. In this study, Aus-Aman-Groundnut cropping pattern were selected for suitability analysis.

RESULTS AND DISCUSSION

The GIS-based crop suitability assessment model performs suitability analysis of Aus-Aman-groundnut cropping pattern based on the agro-edaphic and agro-climatic parameters of the study area. Results show that land factors are more limiting than the agro-climatic factors as agro-climatically of the most parts of Bangladesh fall under very suitable to moderately suitable categories for the selected crops. Agro-climate is very suitable for Aus-Aman-groundnut cropping pattern over the Delduar upazila. Agro-edaphic characteristics of the study area indicate that about half of the upazila are moderately suitable and one-third of the upazila are suitable for the Aus-Aman-groundnut cultivation. Based on these agro-edaphic, agro-climatic and crops criteria, Aus-Aman-groundnut cropping pattern of the study area was mapped (Fig. 3).

The GIS model shows that *Aus-Aman*-groundnut is one of the best potential cropping patterns in the study area where this pattern occupied very suitable and moderately suitable areas of 5674 ha (30.75%) and 8577 ha (46.48%), respectively (Table 4).

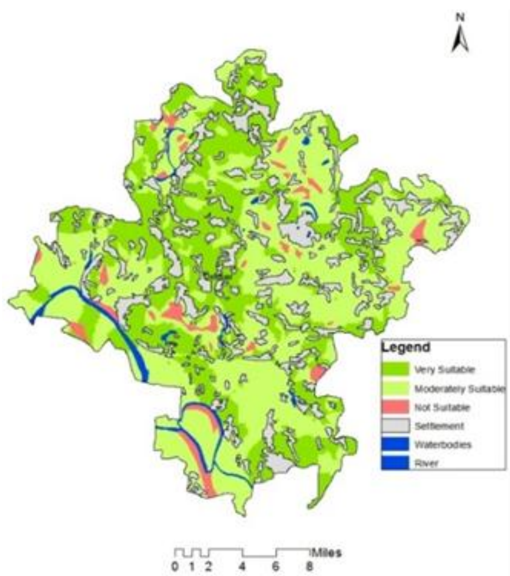

Figure 3: *Aus-Aman*-groundnut pattern suitability map of Delduar upazila

Table 4: *Aus-Aman*-groundnut suitable area in Delduar upazila

Suitability Class	*Aus-Aman*-groundnut Area (%)
Very Suitable	30.75
Moderately suitable	46.48
Not Suitable	3.28
Settlement	17.48
River	1.41
Water bodies	0.60
Total	100.00

The suitability results show that the climatic factors are very suitable for Aus-Aman-groundnut cultivation in Delduar upazila whereas soil characteristics are suitable in some areas of the upazila. The results showed that highly suitable areas (S1) were found mostly in the soil mapping unit 1, 2. These S1 areas were characterized by: inundation land type high land which is above normal flood level, soil pH 5.5 to 6.5, poorly drained soil, high soil moisture and loamy soil texture. Our investigations were acceptable in terms of the evaluation criteria set used here because, in a particular project, only a limited number of land qualities need to be selected for use in evaluation (FAO, 1993). In this investigation, the evaluation criteria were selected taking into considering the crop requirements in local conditions. In this MCE, the factors were selected based on agronomic knowledge of local experts and reviews of existing literature. Such an approach produced valuable information on the relative importance of the factors under evaluation and could be a useful model for future studies of rice and other crops. Furthermore, one of the main premises of the GIS-based land suitability analysis is that the method can help minimize and even solve conflicts among competing interests regarding land use by providing better data and information to resolve the problems. This investigation also provides general alternatives for local farmers in the area of agricultural land management of a particular crop.

CONCLUSION

In this study, we applied GIS techniques to identify suitable areas for Aus-Aman-groundnut cropping pattern in Delduar upazila of Tangail district. About one–third of the upazila is very suitable and about half of the upazila is moderately suitable for an Aus-Aman-groundnut cropping pattern. This study indicates that the application of Multi-Criteria could provide a superior database and guide map for decision makers considering crop substitution in order to achieve better agricultural production. This investigation provides information at a local level that could be used by farmers to select their cropping pattern. Additionally, this study could be useful for other investigators who could use these results for further studies. For future studies on land-crop suitability, we propose to include additional factors like irrigation facilities, disease infestation, market demand, processing, etc. which influence sustainable land use. Finally, this GIS based model is user-friendly and the flexible application software will be useful for extension experts and policy makers.

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RICE YIELD AND GREENHOUSE GAS EMISSIONS: INFLUENCE OF VERMICOMPOST APPLICATION RATE IN WETLAND CULTIVATION

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ABSTRACT

The effect of organic and inorganic fertilizers, the emission of greenhouse gases (GHG), global warming potential (GWP) and rice yield was investigated during 2019 to 2020 at Bangladesh Rice Research Institute (BRRI), Gazipur, Bangladesh. Vermicompost (VC) was applied at the rates of 0.5, 1.0, 1.5, 2.0 t ha^{-1} along with full doses of chemical fertilizers to wet season rice, and GHG emissions, GWP and rice yield were measured. Static closed chambers were used for estimating methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2) emissions from paddy fields. The emission peaks of CH_4, N_2O and CO_2 were observed at about 30-45, 21 and 42, 58 days after transplanting (DAT) rice, respectively. The total CH_4, N_2O, CO_2 fluxes, GWP, GHG intensity and GHG emission factors were lower with 0.5 t ha^{-1} VC than those with any of the other treatments. This treatment reduced the fluxes of CH_4, N_2O and CO_2 by 37-77%, 31-63% and 13-34%, respectively and decreased GWP by 35-69%. On the other hand, rice yield was the highest when 0.5 t ha^{-1} VC was applied along with chemical fertilizers. It was concluded that the use of 0.5 t ha^{-1} VC in combination with recommended chemical chemical fertilizers could be a good management option for reducing GHG emissions from wetland rice fields, suppressing GWP and increasing rice yield.

Keywords: CH_4, CO_2, Emission factor, GHG intensity, N_2O

INTRODUCTION

Rice is the staple food for more than half of the world's population and it covers about 154 million ha of agricultural land worldwide (FAO, 2012). The demand for this commodity will increase to about 650 million tons by the end of 2050 requiring enhanced production. However, long-term intensification of rice cropping has shown a declining trend in its yield (Haque *et al.*, 2019). Low soil organic carbon (SOC) and unbalanced nutrient management were the main factors for reduction in rice yield (Saleque *et al.*, 2004; Sihi *et al.*, 2017; Haque *et al.*, 2019).

In a rice–rice cropping system with no or little use of organic matter (OM), puddling damages soil structure and affects physical and hydraulic properties. . Moreover, the relatively low costs of inorganic fertilizers have enhanced their use and restrained the use

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of OM for rice cultivation. It has been found that continuous rice cropping with inorganic fertilizers has decreased SOC content. Because of deteriorated physical and hydraulic properties and low SOC, the present production potential of the rice-rice system in this region is under threat despite the increased use of inorganic fertilizers.

Soil productivity is linked with SOC and the addition of OM to paddy soils is a major remedial option to enhance and maintain soil fertility for sustained agricultural productivity. In contrast, organic amendments are also responsible for greenhouse gas (GHG) emissions from paddy soils (Kim *et al.*, 2013; Haque *et al.*, 2013, 2015a). Rice or agricultural fields are one of the most important sources for emissions of CH_4, N_2O and CO_2. CH_4 is produced under anaerobic condition (Haque *et al.*, 2013, 2015a, b). It is 28 times more potent than CO_2 in increasing the global warming potential (GWP) and the contribution of N_2O is 265 times higher than CO_2 (IPCC, 2014).

As the addition of any decomposable organic material is responsible for higher GHG emissions than the use of solely chemical fertilizers, suitable agronomic management practices can play an important role in minimizing GHG emissions as well as sustaining rice production under the changing climate (Haque *et al.*, 2017a, b, c). We hypothesized at that the use of vermicompost a suitable rate and in combination with chemical fertilizers can reduce GHG, GWP, GHG intensity and GHG emission factor. The present study was, therefore, undertaken to observe the effect of different rates of VC with chemical fertilizers on GHG, GWP, GHG intensity, GHG during wet season rice cultivation and sustaining yield of rice in Bangladesh.

MATERIALS AND METHODS

The experimental field and treatments

A field experiment was conducted at the research farm of Bangladesh Rice Research Institute (BRRI), Gazipur (23°85.9′ N and 90°82.4′ E), Bangladesh during the wet seasons of 2019 and 2020. The soil (0-15 cm depth) was clay loam having pH 7.05, organic C 12.4 g kg^{-1}, total N 1.33 g kg^{-1}, available P 1.82 mg kg^{-1} and exchangeable K 65 mg kg^{-1} soil. Vermicompost (VC) containing 50% moisture, 2.0% total N, 0.52% P, 0.42% K and 0.3% S was applied at the rates of 0.5, 1.0, 1.5, 2.0 t ha^{-1} along with full doses of recommended chemical fertilizers (RCF). The control treatment, consisted of RCF alone (no VC). The experimental plots, each measuring 4m x 4m, were laid out in a randomized block design with three replications. Twenty-five-day-old seedlings of the rice variety BRRI dhan49 were transplanted at 20- x 20-cm spacing. Transplanting was done in the last week of July and harvested the crop at maturity during 3rd week of November. Recommended rates of chemical fertilizers (N-P-K-S-Zn @ 100-10-80-5-5 kg ha^{-1}) were applied one day before rice transplanting. Rice was grown in a continuously flooded field (5-7 cm water) which was drained 21 days before harvest.

GHG collection and measurement

Static closed chambers were used to determine N_2O, CO_2 and CH_4 emissions (Haque *et al.*, 2013, 2016c, 2020, 2021a, b). Two types of chamber were used, one for the collection of CH_4 and N_2O, and the other for CO_2. Transparent glass chambers (62 cm x 62 cm and height 112 cm) were placed permanently in the plots after rice transplanting.

There were two holes at the bottom of a chamber for maintaining 5-7 cm water level above soil surface. Each chamber enclosed nine rice hills. Smaller closed chambers (20 cm x 20 cm) were placed in between rice rows for measuring CO_2 emission (Lou *et al.*, 2004; Xiao *et al.*, 2005; Iqbal *et al.*, 2008; Haque *et al.*, 2015b, 2016a, 2016b, 2017b). Each chamber was equipped with a circulating fan for gas mixing and a thermometer to record inside temperature. The chambers remained open all the time except during gas sampling.

Gas samples were collected in 50 mL air-tight syringes at 0 and 30 min after closing the chamber. Gas samples were drawn off from the chamber headspace equipped with a 3-way stop cock at 0800, 1200 and 1600 hours in a day from each treatment plot, and transferred to 20-ml air-evacuated glass vials sealed with a butyl rubber septum for analysis later on.

The gas samples were analyzed by gas chromatography (Shimadzu, GC-2014, Japan equipped with Q 80–100 mesh Porapak NQ column). N_2O, CO_2 and CH_4 emissions were quantified by flame ionization different detectors such as, ECD, TCD and FID. The colum temperatures were 100, 45 and 70°C for CH_4, CO_2 and N_2O, respectively. The injector and detector were adjusted at 60 and 100°C for CH_4, 75 and 270°C for CO_2 and 80 and 320°C for N_2O. Argon and He were used as the carrier gases and air and H_2 as the burning gases.

The CH_4 emission rates were calculated from the increase in its concentrations per unit surface area of the chamber for a specific time interval. The closed-chamber equation of Lou *et al*.(2004) was used to estimate seasonal fluxes as follows:

$$M = Q \times (W/B) \times (\Delta d/\Delta p) \times (273/T)$$

where, M is the CO_2 and CH_4 emission rate in mg m^{-2} hr^{-1}, and N_2O emission rate ug m^{-2} hr^{-1}, Q is the gas density of CH_4 , CO_2 and N_2O in mg cm^{-3}, W is the volume of chamber in m^3, B is the surface area of chamber in m^2, $\Delta d/\Delta p$ is the rate of increase of GHG concentrations in mg m^{-3} hr^{-1} and T is the absolute temperature (273 + mean temperature) in °C of the chamber.

The seasonal CO_2, CH_4, N_2O (SCCN) fluxes were computed according to Singh *et al*. (1999):

$$\text{SCCN flux} = \sum\nolimits_{f}^{e} (U_i \text{ x } V_i)$$

where, U_i is the rate of CO_2, CH_4 and N_2O flux in g m^{-2} d^{-1} during i^{th} sampling interval, V_i is the number of days in the f^{th} sampling interval, and e the number of sampling.

The relative ability of measured gases was expressed in terms of CO_2 equivalent according to Robertson *et al*. 2000, and GWP was calculated considering 28 for CH_4, and 265 for N_2O (IPCC, 2014):

$$\text{GWP } (CO_2 \text{ equivalent}) = CH_4 \times 28 + CO_2 \times 1 + N_2O \times 265.$$

Greenhouse gas emission intensity (GHGI) was calculated as follows:

$$\text{GHGI (kg } CO_2\text{eq kg}^{-1}\text{grain)} = \frac{\text{Total GWP (kg } CO_2 \text{ha}^{-1})}{\text{Grain yield (kg}^{-1})}$$

The emission factor (EF kg ha^{-1} day^{-1}) was estimated according to Haque *et al*. (2021b):

$$\mathrm{EF} = \frac{\text{Total GHG emission (kg CO}_2\text{eq ha}^{-1})}{\text{GHG measurement duration (day)}}$$

Statistical analysis

SAS package (version 9.1) was used for statistical analyses (SAS Institute, 2003). Tukey's test was used for treatment comparison and differences were considered significant at $p \leq 0.05$ level.

RESULTS AND DISCUSSIONS

Methane emission

CH_4 emission patterns significantly varied with different rates of VC application in 2019-2020 (Fig. 1). CH_4 emission rates were low at the early rice growing stage, gradually increased with the development of anaerobic conditions in the soil and progression of plant growth, and peaked at around 21-45 days after transplanting (DAT) of rice and then decreased gradually and reached almost initial levels during the grain filling stage of rice. Emission of CH_4 was the lowest from plots receiving the lowest (0.5 t ha^{-1}) dose of VC, which increased with an increase in the dose. VC at 0.5 t ha^{-1} and the only-NPKSZn treatment showed low CH_4 emission peaks throughout the study period. VC at the higher doses increased CH_4 emission by about 58-241% over that with 0.5 t ha^{-1}. For example, CH_4 emission with 0.5 t ha^{-1} VC was 71% less than that with 2.0 t ha^{-1} (Fig. 1). An optimum dose of cover crop biomass, different organic materials, water management, etc. are important techniques for reducing GHG and GWP from the field (Itoh *et al.*, 2011; Ma *et al.*, 2011; Haque *et al.*, 2015a, 2017b). There are reports that greater CH_4 emissions are related to higher doses of organic amendments than optimum rates (Haque *et al.*, 2015a, b; Hwang *et al.*, 2017).

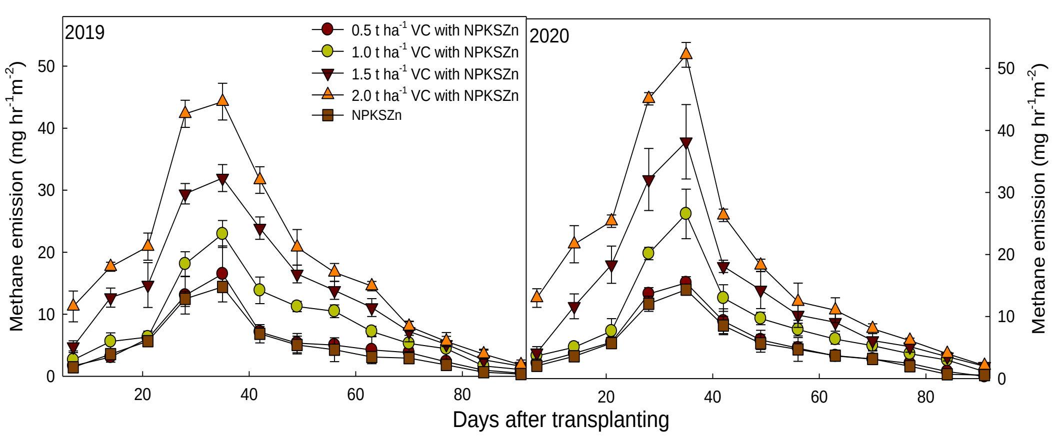

Figure 1: Methane emission from a wetland rice field as influenced by different rates of vermicompost application

Nitrous oxide emission

Increasing rate of VC application increased N_2O emission from the wetland rice field in both the years (Fig. 2). The highest peak was found at about 21 DAT and 42 DAT in both the years. The only-NPKSZn treatment gave the lowest emission N_2O emission (2.62 µg m^{-2} hr^{-1}). Win *et al*. (2021) reported statistically insignificant low N_2O emission from plots amended with cow dung. However, we found that increasing the VC rate to above 0.5 t ha^{-1} increased N_2O emission by about 20-170%. Water management is a crucial issue for microbial activities in soil, which are generally more intense under aerobic conditions than in wetland rice culture. However, in a wetland rice soil an aerated zone still exists in the interface of rice plant roots and soil and thus slight mineralization takes place accounting for the emission of N_2O.

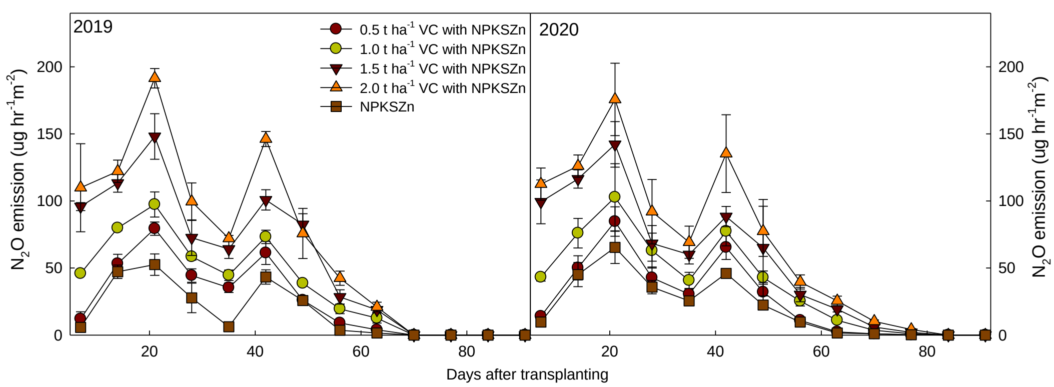

Figure 2: Nitrous oxide emission from a wetland rice field as influenced by different rates of vermicompost application

Carbon dioxide emission

Carbon dioxide emission reached its peak 56 DAT under different VC (Fig. 3). The application of 2.0 t ha^{-1} VC resulted in the highest emission of CO_2throughout the study period. About 2.42-3.65 mg m^{-2} hr^{-1} CO_2 emissions were recorded with different rates of VC treated plots, whereas NPKSZn alone gave only 1.79-1.87 mg m^{-2} hr^{-1}. Among the VC rates, soil CO_2 flux rate was the lowest with 0.5 t ha^{-1}. Higher soil respiration rates during the study period may have resulted from higher physiological activity of microorganisms (Kogel-Knabner *et al.*, 2010) because of oxygen diffusion and soil temperature and thus certain portion of the organic C was lost as CO_2. The results for low organic amendment rate are similar as CO_2 flux reports by Haque *et al.*, 2015b who found strong relationships between CO_2 flux and soil temperature and Eh (Haque *et al.*, 2013).

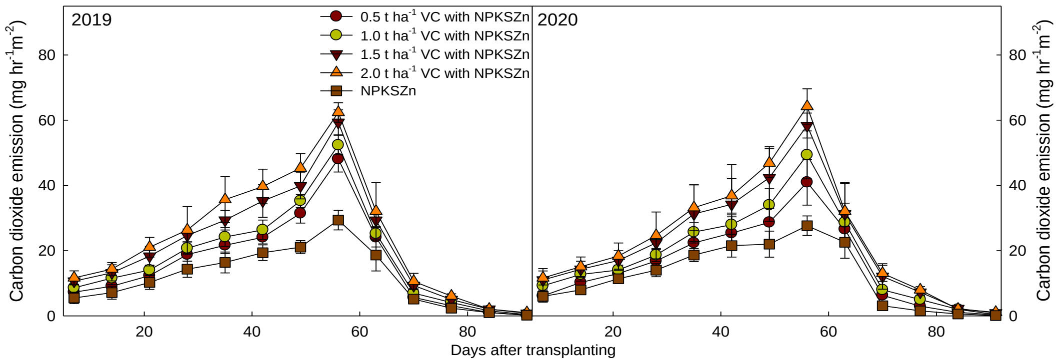

Figure 3: Carbon dioxide emission from a wetland rice field as influenced by different rates of vermicompost application

Total GHG emission

The total GHG flux (CH_4, N_2O and CO_2) increased significantly with increasing VC application rate. The lowest total flux of about 120 kg ha^{-1} was observed from plots receiving the lowest VC rate (0.5 t ha^{-1}). Higher VC rates enhanced TF to 188-407 kg ha^{-1}. The total CH_4 flux with VC at the rate of 0.5 t ha^{-1} was 37-77% less than that with the higher VC rates. . Likewise, the total N_2O flux was about 31-63% less 0.5 t ha^{-1} VC. The total CO_2 fluxes were 337-516 kg ha^{-1} under different rates of VC application whereas NPKSZn only gave the lowest total CO_2 flux of 253-264 kg ha^{-1}. Brenzinger *et al.* (2018) found reductions in CO_2, CH_4 and/or N_2O emissions with several combinations of amendments compared with unamended soils.

Global warming potential

Regardless of the VC incorporation rate, CH_4 was the most influential GHG that contributed most to total GWP. The contribution of seasonal CH_4 flux to the total GWP was 87-88% followed by that from the estimated CO_2 flux (8-9%). The N_2O flux contribution was very low (3-5%). More importantly, 0.5 t ha^{-1} VC treatment gave a relatively low GWP, 35-69% less than that with the higher rates. Brenzinger *et al.* (2018) reported reduced GWP with amended soils. Haque *et al.*, 2015a, 2020 also reported that proper doses of organic material during rice growing season could be a promising mitigation strategy that does not affect yield of rice.

Greenhouse gas intensity and emission factor

Greenhouse gas intensity was 0.93-3.35 kg ha^{-1} for incorporation, which was the lowest (0.93-0.99 kg ha^{-1}) with 0.5 t ha^{-1}Increasing rate of VC incorporation above this augmented GHG intensity (1.53-3.26 kg ha^{-1}) in our study. Similarly Win *et al.* (2021) reported higher GHG intensity for cow dung treated plots compared with control and compost treated plots. However, depending on amounts of organic material incorporated, soil moisture and temperature influences not only GHG emission but also grain yield and thus GHG intensity changes. The emission factors of CH_4, N_2O and CO_2 were lower, 1.32, 0.006, 3.75 kg ha^{-1}, for the 0.5 t ha^{-1} VC treated plots than that for the other treatments. The GHG emission factors increased with increasing VC rate.

Rice yield

Addition of VC stimulated rice plant growth and increased yield (Table 1). However, rice yield gradually decreased with increasing VC rate, which was mainly attributed to increased vegetative growth stage of rice plant (Table 1). Combination of a VC rate with the full doses of chemical fertilizers was favorable for excessive unproductive tillers and greater leaf size which did not benefit rice in terms of yield. However, the 0.5 t ha^{-1} VC treated plots gave a higher grain yield. Generally, the uptake of nutrients and their utilization in plants are regulated by different mechanisms that influence crop yield (Morgan and Connolly, 2013). However, only NPKSZn fertilizers gave the lowest grain yield (4.22 t ha^{-1}). Addition of VC increased grain yield by about 12-13% over the only-NPKSZn treatment. Luo *et al*. (2018) found about 27% increase in crop yield because of organic amendment compared to mineral fertilizers alone.

Table 1: Grain and straw yields of wetland rice as influenced by different rates of VC application

Treatment	2019		2020	
	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})
0.5 t ha^{-1} VC + NPKSZn	5.06	5.22	4.93	5.57
1.0 t ha^{-1} VC + NPKSZn	4.78	5.83	4.89	5.71
1.5 t ha^{-1} VC + NPKSZn	4.77	5.90	4.88	6.13
2.0 t ha^{-1} VC + NPKSZn	4.82	5.83	4.71	6.09
NPKSZn	4.22	5.20	4.23	5.14
$LSD_{0.05}$	0.45	1.31	0.36	1.04

CONCLUSION

Increasing rate of vermicompost incorporation augmented GHG, GWP, and GHG intensity and emission factor of GHG in wetland rice cultivation. The use of 0.5 t ha^{-1} VC with full doses of chemical fertilizers reduced GHG emission, GWP, GHG intensity and GHG emission factor by about 13-77%, 35-69%, 37-71% and 13-70%, respectively. Moreover, a combination of 0.5 t ha^{-1} VC with full recommended doses of chemical fertilizers resulted in a 5% higher grain yield of rice over that obtained with chemical fertilizers alone. It is concluded that 0.5 t ha^{-1} VC with full doses of chemical fertilizers could be an important technique for reducing GHG emission, GWP, GHG intensity, emission factor of GHG and at the same time increase rice yield.

ACKNOWLEDGEMENT

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POTASSIUM-BEARING MINERALS IN SOILS OF BANGLADESH: DISTRIBUTION, RELATIONSHIPS WITH POTSSIUM AVAILABILITY AND RESPONSE OF RICE TO POTASSIUM FERTILIZER

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ABSTRACT

Potassium (K) availability to crops and their response to K fertilization depend largely on K-bearing clay minerals in soil and their interactions with other soil properties. In the present study, we used data from existing literature on K in agricultural soils of Bangladesh. The dominant group of K-bearing minerals in soils of Bangladesh is mica-smectite and mica-chlorite existing in about 40% of the cropped area of the country. The second most dominant groups are mica-vermiculite-kaolinite, kaolinite-mica, mica-kaolinite-vermiculite~suite and mica-kaolinite-vermiculite found in around 43% of the soils. Exchangeable K in soil, the most important indicator of K availability to crops, varies greatly in the country, ranging from 0.04 to 1.54 cmol kg^{-1}, the frequency of the lower values being relatively high. Potassium fixation from added fertilizer is likely to occur in soils of 47 out of 64 districts of Bangladesh. An assessment based on neural networking specified pH, organic carbon content, clay fraction, moisture at field capacity and cation exchange capacity as the most important soil properties regulating K availability to crops. Rice responded positively to applied K fertilizer when nitrogen (N) availability was not limiting. Optimization of K fertilizer rates and proper K management are imperative for sustainable crop production in the country.

Keywords: Clay, CEC, K rate, Organic matter, Rice, Soil pH

INTRODUCTION

Potassium plays an important role in crop production, but most farmers in Bangladesh tend to apply inadequate K fertilizer for crop production resulting in an undesirable depletion of this vital nutrient element from cropped soils of Bangladesh. The soils is a good source of K, but availability of the nutrient depends on its release pattern and nature of the crop (Johnston, 2003). The main K sources in soils are the minerals, added fertilizers and manures and irrigation water (Andrist-Rangel *et al.*, 2006). Not all of the fertilizer K may be available to the crop because expandable clays in soil have the potential to fix K (Chittamart *et al.*, 2010; Marchuk *et al.*, 2016). Bangladesh is a small country but the diversity of its soils is disproportionately large. This necessitates proper adjustments in K fertilizer doses for good crop harvests. Some minerals are responsible

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for K fixation under particular conditions. For example, adsorption of K can take place in the interlayers of illite, vermiculite, highly charged smectite and mixed layers depending on soil K concentrations significantly influencing K availability to crops. Feldspars and micas are the primary minerals in soil that contain most K (90-98%), but micas are resistant to weathering. On the other hand, K is relatively mobile in coarse textured soils and in soils with high an organic matter content and less mobile in fine textured soils. Moreover, the rate of reaction between the soil solution and exchangeable K phases depends largely on the type of clay minerals present (Sparks, 2001), and the method used to measure the kinetics of K exchange (Sparks, 1995; Sparks *et al.*, 1996). Kaolinite, hydrous mica, montmorillonite (smectite) and vermiculite vary significantly in selectivity for ions, ion binding affinity, and the type of ion exchange reaction. Fundamental differences in lattice structure in clay minerals mentioned above result in different kinetics of K exchange (Sparks, 2001). Weathered micas fix K^+ under both dry and moist conditions, while montmorillonite generally fixes K^+ only under dry condition. Layer silicates with high charge density fix more K^+ than those with lower charge density (Biswas, 2008). Leaching of soil solution K can govern the release of K from soil minerals but this mechanism largely depends on the soil pH, movement of K in soils, soil cation exchange capacity (CEC), liming and rate of K uptake by plants and microbes (Sparks, 2000). Soils vary in CEC and thus in retaining applied K. Leaching is also affected by the amount of clay in soils and soil organic matter. Soils having a higher CEC retain K more strongly than soils with a lower CEC (Sparks and Huang, 1985). Thus, understanding the K cycle in soil is important for sustained crop productivity (Tripler *et al.*, 2006).

The availability of K in soil and crop response to added K vary greatly depending on clay minerals. For example, the exchange kinetics of K with kaolinite and montmorillonite are more rapid than with vermiculite and micaceous minerals. The latter two minerals hinder many ion exchange reactions (Sparks, 2001). However, many factors affect K^+ fixation and release in clay minerals and soils, such as the type and quantity of clay minerals, the charge density of clays and their capacity for interlayering, soil moisture content, concentration of K^+ along with the concentrations of other competing cations, and pH of the soil solution, wetting and drying and biological activities (Sparks and Huang, 1985; Huang, 2005).

Relationships between clay mineralogy and K forms can be used in evaluating soil K fertility and K uptake by plants. Micas, vermiculite and smectite contain larger amounts of non-exchangeable K than do kaolinite and other siliceous minerals (Ghosh and Singh, 2001). Knowledge of K-bearing minerals in soil and exchangeable and non-exchangeable K may be useful in guiding K fertilizer application (Nabiollahy *et al.*, 2006). In the present investigation, we evaluated (1) the potential role of K-bearing minerals in maintaining K fertility in soils and crop productivity in different parts of Bangladesh and (2) the response of rice to K fertilization in soils varying in K availability.

MATERIALS AND METHODS

Data collection

Data on sand, silt and clay, available K and organic matter contents, pH and cation exchange capacity (CEC)of soils were collected from different annual reports and other reports of the Soil Resources Development Institute (SRDI, http://www.srdi.gov.bd/) and from online sources. Bulk density (BD), field capacity (FC), saturated hydraulic conductivity (Ks) and porosity were calculated using methods outlined by Biswas *et al*. 2019. Data on K-bearing minerals in soils were collected from the Bangladesh Agricultural Research Council (BARC, http://www.barc.gov.bd/) publications, and soil K content data were collected from existing literature. Rice yield data were collected from the Bangladesh Bureau of Statistics (BBS) and multiplied by 1.5 to derive paddy yields. Availability classes of K in soil were delineated (PDA, 2011) as shown in Table 1.

Table 1: Soil K availability classes

Range of pH	K availability status
<4.5	Highly unfavorable
4.6-5.4	Slightly unfavorable
5.5-5.8	Very slightly unfavorable
5.9-7.0	Favorable
>7.1	Highly favorable

Statistical tools

The relationships of exchangeable K with other soil parameters were established through artificial neural networking. The importance of tested soil parameters in relation to *Boro* rice (winter rice in Bangladesh) yield was assessed first and then linkages were established through artificial neural networking. Probable availability and fixation of K were projected for 64 districts considering different soil attributes such as, soil K status, soil pH and texture and distribution of K-bearing minerals.

RESULTS AND DISCUSSION

Distribution of K-bearing minerals

The most dominant group of clay minerals was found to be mica-smectite and mica-chlorite covering 20.25% and 19.89% soil areas, respectively, of the country (Fig. 1). The mica-smectite group is mostly distributed in the southwestern part of the country, while the mica-chlorite group is found mostly in the northwestern part. The second most dominant groups comprise of mica-vermiculite-kaolinite, kaolinite-mica, mica-kaolinite-vermiculite~ suite and mica-kaolinite-vermiculite occurring in around 11.71%, 10.58%, 10.65%

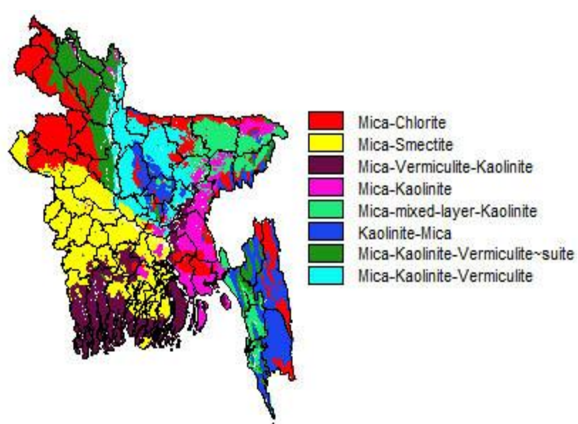

Figure 1: Distribution of K-bearing minerals in Bangladesh (adopted from http://www.barc.gov.bd/)

and 10.19% soil areas, respectively. The third group includes mica-vermiculite and mica-mixed-layer-kaolinite minerals covering about 8.18% and 8.55% soil areas, respectively. The clay mineral type along with other soil properties and soil-fertilizer-crop management plays an important role in the availability of K to crops. Soils with higher amounts of 2:1 clay mineral like micas, vermiculite and smectite contain larger amounts of non-exchangeable K than those with kaolinite and other siliceous minerals (Ghosh and Singh, 2001). Illites and vermiculites are the major sources of non-exchangeable K in soil (Moritsuka *et al.*, 2004; Britzke *et al.*, 2012). Mixed and illitic minerals bear medium levels of non-exchangeable K. Vermiculite and smectite are expandable clays (2:1) having large surface areas and high CEC which significantly influence soil fertility and crop productivity (Mandiringana *et al.*, 2005; Abe *et al.*, 2006). Plants can take up both exchangeable and non-exchangeable forms of K depending on prevailing conditions in the field (Ghosh and Singh, 2001).

Potassium-bearing minerals covering major and minor areas and K content in soils of 64 districts of Bangladesh vary greatly (Table 2). The mica-kaolinite-vermiculite~suite covers major areas in Nilphamari, Lalmonirhat, Kurigram, Gaibandha, Bogura, Sirajganj and Khagrachhari districts. mica-chlorite covers greater areas in Panchagarh, Thakurgaon, Dinajpur, Joypurhat, and Naogaon. Mica-smectite is the dominant group in Meherpur, Jhenaidah, Jashore, Magura, Pabna, Rajbari, Madaripur, Faridur, Narail, and Barishal districts. In some areas, 2-4 major K-bearing mineral groups exist. For example, mica-chlorite and mica-smectite are found in major soils of Rajshahi, and Natore districts. Mica-kaolinite-vermiculite, mica-chlorite and kaolinite-mica dominate in Mymensingh and Tangail districts. Mica-mixed layer-kaolinite is one of the major K-bearing mineral groups in Netrokona, Sylhet, Moulavibazar, Habiganj, Kishoreganj, Chattogram and Cox’s Bazar districts. The primary K source is mica and the secondary sources are illite and mixed layer phyllosylicates. Mica minerals can contain as high as 90-98% K (McAfee, 2008). Like major areas covered by different K-bearing minerals, there are also different groups of K-bearing minerals covering minor areas in different districts of Bangladesh. Such wide variations clearly indicate that appropriate K fertilizer management is highly essential for optimum crop production because the release of K from clay minerals is influenced by particle size distribution, chemical composition and weathering patterns (Huang, 2005).

Soil K status

Soil K status varies greatly in different parts of the country ranging from 0.04 to 1.54 cmol kg^{-1} (Table 2), values at the lower extremity of the scale being more prevalent than those at the higher extremity. Soil pH differentially affects K availability in different districts of Bangladesh. For example, the average soil pH in Panchagarh, Naogaon, Joypurhat, Thakurgaon, Nilphamari, Lalmonirhat, Rangpur, Gaibandha, Bogura, Sirajganj, Tangail, Dhaka, Gazipur, Narayanganj, Narsingdi, Sylhet, Munshiganj, Barguna, Cumilla, Khagrachhari, Chattogram, Cox’s Bazar, Rangamati, Moulavibazar, Habiganj, Sunamganj, Netrokona, and Bandarban is very slightly or slightly unfavorable for K availability while the low soil pH of Dinajpur district is highly unfavorable for K availability. Neutralizing soil acidity through liming would be beneficial not only for K availability but also for phosphorus (P) availability for crop production in strongly acidic soils. Application of lime can neutralize excessive hydrogen ions in the soil solution (Bolan *et al.*, 2003) and increase the availability of P, K and S (Li *et al.*, 2018). Besides, liming improves nutrient use efficiency (Fageria and Nascente, 2014) and intensifies microbial activity for nutrient transformations (Cheng *et al.*, 2013). In other districts, soil pH is mostly favorable for K availability. Due to mineral weathering and application of acid-forming chemical fertilizers, soil acidity is increasing in some parts of the country affecting K availability to crops.

Table 2: Distribution of K-bearing minerals and probable K availability in soils of different districts of Bangladesh

District	Major areas	Minor areas	Probable K availability
Panchagarh	Mica-chlorite	Mica-kaolinite-vermiculite~suite	Soil K status, 0.05-0.36 cmol kg^{-1}. Soil pH (~5.5) is very slightly unfavorable for K availability.
Nilphamari	Mica-kaolinite-vermiculite~suite	Mica-chlorite	Soil K status, 0.06-0.31 cmol kg^{-1}. Soil pH (~5.5) is very slightly unfavorable for K availability. K fixation is likely
Lalmonirhat	Mica-kaolinite-vermiculite~suite	-	Soil K status, 0.04-0.32 cmol kg^{-1}. Soil pH (~5.4) is slightly unfavorable for K availability. K fixation likely
Kurigram	Mica-kaolinite-vermiculite~suite	Mica-kaolinite-vermiculite, Mica-vermiculite	Soil K status, 0.10-0.37 cmol kg^{-1}. Soil pH (~6.0) is favorable for K availability. K fixation likely
Thakurgaon	Mica-chlorite	-	Soil K status, 06-0.46 cmol kg^{-1}. Soil pH (~5.3) is slightly unfavorable for K availability.
Dinajpur	Mica-chlorite	Mica-kaolinite-Vermiculite~suite	Soil K status, 0.18-0.31 cmol kg^{-1}. Highly unfavorable soil pH (~4.12) for K availability.
Rangpur	Mica-kaolinite-vermiculite~suite	Mica-chlorite	Soil K status, 0.07-0.38 cmol kg^{-1}. Slightly unfavorable soil pH (<6.0) for K availability. K fixation likely for added K.
Gaibandha	Mica-kaolinite-vermiculite~suite	Mica-kaolinite-vermiculite	Soil K status, 0.12-0.34 cmol kg^{-1}. Soil pH (~5.8) is very slightly unfavorable for K availability. K fixation is likely in Vermiculite rich soils.
Joypurhat	Mica-chlorite	-	Soil K status, 0.07-0.37 cmol kg^{-1}. Soil pH (~5.4) is slightly unfavorable for K availability.

District	Major areas	Minor areas	Probable K availability
Naogaon	Mica-chlorite	-	Soil K status, 0.08-0.33 cmol kg^{-1}. Soil pH (4.7) is slightly unfavorable for K availability.
Chapainawabganj	Mica-smectite	Mica-chlorite	Soil K status, 0.10-0.32 cmol kg^{-1}. Soil pH (~6.0) is favorable for K availability. K fixation is most likely
Rajshahi	Mica-chlorite, Mica-smectite	Mica-kaolinite-Vermiculite~suite	Soil K status, 0.11-0.37 cmol kg^{-1}. Soil pH (near neutral) is favorable for its availability. K fixation is likely both under dry and wet conditions. K fixation is most likely.
Bogura	Mica-chlorite, Mica-kaolinite-vermiculite~suite	Mica-kaolinite-Vermiculite	Soil K status, 0.12-0.30 cmol kg^{-1}. Soil pH (~5.4) is slightly unfavorable for K availability. K fixation is likely
Jamalpur	Mica-kaolinite-vermiculite	Kaolinite-mica	Soil K status, 0.09-0.35 cmol kg^{-1}. Soil pH (~7.1) is highly favorable for K availability. K fixation is likely
Sherpur	Mica-kaolinite-vermiculite, Mica-chlorite	Mica-kaolinite-Vermiculite~suite	Soil K status, 0.09-0.36 cmol kg^{-1}. Soil pH (~6.8) is highly favorable for K availability. K fixation is likely.
Mymensingh	Mica-kaolinite-vermiculite, Mica-chlorite, Kaolinite-mica	Mica-kaolinite	Soil K status, 0.07-0.33 cmol kg^{-1}. Soil pH (~6.0) is favorable for K availability. K fixation is likely in Vermiculite rich soils.
Natore	Mica-smectite, Mica-chlorite	Mica-kaolinite-vermiculite~suite	Soil K status, 0.11-0.37 cmol kg^{-1}. Soil pH (~6.95) is highly favorable for K availability. K fixation is most likely
Meherpur	Mica-smectite	-	Soil K status, 0.17-0.33 cmol kg^{-1}. Soil pH (~6.3) is favorable for K availability. K fixation is most likely
Kushtia	Mica-smectite	Mica-kaolinite, Mica-mixed-layer-kaolinite	Soil K status, 0.18-0.36 cmol kg^{-1}. Soil pH (~7.4) is highly favorable for K availability. K fixation is most likely in Smectite rich soils.

District	Major areas	Minor areas	Probable K availability
Chuadanga	Mica-smectite	Mica-mixed-layer-kaolinite	Soil K status, 0.12-0.32 cmol kg^{-1}. Soil pH (~7.1) is highly favorable for K availability. K fixation is most likely in Smectite rich soils.
Jhenaidah	Mica-smectite	Mica-mixed-layer-kaolinite	Soil K status, 0.19-0.36 cmol kg^{-1}. Soil pH (~7.0) is highly favorable for K availability. K fixation is most likely in Smectite rich soils.
Jashore	Mica-smectite	Mica-mixed-layer-kaolinite	Soil K status, 0.15-0.37 cmol kg^{-1}. Soil pH (~7.3) is highly favorable for K availability; but its fixation is most likely with Smectite rich soils.
Magura	Mica-smectite	-	Soil K status, 0.18-0.35 cmol kg^{-1}. Soil pH (~6.9) is highly favorable for K availability. K fixation is most likely in Smectite rich soils.
Pabna	Mica-smectite	-	Soil K status, 0.15-0.35 cmol kg^{-1}. Soil pH (~6.9) is highly favorable for K availability. K fixation is most likely in Smectite rich soils.
Sirajganj	Mica-kaolinite-vermiculite~suite, Mica-chlorite, Mica-kaolinite-vermiculite	-	Soil K status, 0.17-0.36 cmol kg^{-1}. Soil pH (~5.6) is very slightly unfavorable for K availability. K fixation is likely in Vermiculite rich soils.
Tangail	Mica-kaolinite-vermiculite, Kaolinite-mica, Mica-chlorite	-	Soil K status, 0.05-0.35 cmol kg^{-1}. Soil pH (~5.5) is very slightly unfavorable for K availability. K fixation is likely in Vermiculite rich soils.
Gazipur	Kaolinite-mica, Mica-kaolinite-vermiculite	Mica-kaolinite Mica-chlorite	Soil K status, 0.14-0.32 cmol kg^{-1}. Soil pH (~5.5) is very slightly unfavorable for K availability. K fixation is likely in Vermiculite rich soils.
Narsingdi	Mica-kaolinite-vermiculite, Kaolinite-mica		Soil K status, 0.11-0.37 cmol kg^{-1}. Soil pH (~5.6) is very slightly unfavorable for K availability. K fixation is likely in Vermiculite rich soils.

District	Major areas	Minor areas	Probable K availability
Netrokona	Mica-chlorite, Mica-kaolinite-vermiculite, Mica-mixed layer-kaolinite	Kaolinite-mica	Soil K status, 0.06-0.35 cmol kg^{-1}. Soil pH (~4.9) is slightly unfavorable for K availability. K fixation is likely.
Sunamganj	Mica-mixed layer-kaolinite, Mica-chlorite, Mica-kaolinite	Kaolinite-mica	Soil K status, 0.04-0.39 cmol kg^{-1}. Soil pH (~5.1) slightly unfavorable for K availability.
Sylhet	Mica-mixed layer-kaolinite, Mica-kaolinite	Mica-chlorite, Kaolinite-mica	Soil K status, 0.19-0.36 cmol kg^{-1}. Soil pH (~5.5) is very slightly unfavorable for K availability.
Moulavibazar	Mica-mixed layer-kaolinite, Kaolinite-mica	Mica-chlorite, Mica-kaolinite	Soil K status, 0.02-0.35 cmol kg^{-1}. Soil pH (~4.6) is slightly unfavorable for K availability.
Habiganj	Mica-kaolinite, Mica-mixed layer-kaolinite	Mica-chlorite	Soil K status, 0.23-0.40 cmol kg^{-1}. Soil pH (~5.0) is slightly unfavorable for K availability.
Kishoreganj	Mica-kaolinite-vermiculite, Mica-kaolinite, Mica-mixed-layer-kaolinite	Mica-chlorite	K status, 0.10-0.70 cmol kg^{-1}. Slightly unfavorable soil pH (~5.1) for K availability. K fixation is likely.
Dhaka	Kaolinite-mica, Mica-kaolinite-vermiculite	Mica-kaolinite	Soil K status 0.10-1.54 cmol kg^{-1}. Soil pH (~5.4) is slightly unfavorable for K availability. K fixation is likely in Vermiculite rich soils. K fixation likely
Manikganj	Mica-smectite, Mica-kaolinite-vermiculite	-	K status, 0.10-0.52 cmol kg^{-1}. Favorable soil pH (~6.0) for K availability. K fixation is most likely.
Rajbari	Mica-smectite	Mica-kaolinite-Vermiculite~suite	Soil K status, 0.17-0.37 cmol kg^{-1}. Soil pH (~6.6) is highly favorable for K availability. K fixation is likely in Smectite rich soils.
Narayanganj	Mica-kaolinite-vermiculite, Kaolinite-mica	Mica-kaolinite	Soil K status, 0.16-0.37 cmol kg^{-1}. Soil pH (~5.4) is slightly unfavorable for K availability. K fixation is likely in Vermiculite rich soils.

District	Major areas	Minor areas	Probable K availability
Brahmanbaria	Mica-kaolinite	Mica-mixed layer-kaolinite	Soil K status, 0.19-0.35 cmol kg^{-1}. Soil pH (~5.3) is slightly unfavorable for K availability.
Munshiganj	Mica-kaolinite, Mica-kaolinite-vermiculite	Mica-smectite, Mica-chlorite	Soil K status, 0.18-0.37 cmol kg^{-1}. Soil pH (~5.7) is very slightly unfavorable for K availability. K fixation is likely.
Cumilla	Mica-kaolinite, Mica-chlorite	Kaolinite-mica, Mica-smectite	Soil K status, 0.05-0.36 cmol kg^{-1}. Soil pH (~5.0) is slightly unfavorable for K availability.
Chandpur	Mica-kaolinite, Mica-chlorite	-	Soil K status, 0.18-0.29 cmol kg^{-1}. Soil pH (~6.6) is highly favorable for K availability.
Shariatpur	Mica-smectite, Mica-kaolinite		Soil K status, 0.11-0.36 cmol kg^{-1}. Soil pH (~7.3) is highly favorable for K availability. K fixation is most likely in Smectite rich soils.
Madaripur	Mica-smectite	Mica-kaolinite	Soil K status, 0.12-0.32 cmol kg^{-1}. Soil pH (~7.1) is highly favorable for K availability. K fixation is most likely in Smectite rich soils.
Faridpur	Mica-smectite	-	K status, 0.24-0.39 cmol kg^{-1}. Soil pH (>7.0) is highly favorable for K availability. K fixation is most likely in Smectite soils.
Gopalganj	Mica-vermiculite-kaolinite, Mica-smectite	Mica-chlorite	Soil K status, 0.19-0.38 cmol kg^{-1}. Soil pH (~6.5) is highly favorable for K availability. K fixation is most likely in Smectite, Vermiculite rich soils.
Narail	Mica-smectite	Mica-kaolinite	Soil K status, 0.20-0.35 cmol kg^{-1}. Soil pH (~7.6) is highly favorable for K availability. K fixation is most likely in Smectite rich soils. K fixation is most likely
Barishal	Mica-smectite	-	Soil K status, 0.11-0.24 cmol kg^{-1}. Soil pH (~7.0) is highly favorable for K availability; but its fixation is most likely in Smectite rich soils.

District	Major areas	Minor areas	Probable K availability
Satkhira	Mica-vermiculite-kaolinite,	Mica-smectite	Soil K status, 0.20-0.37 cmol kg^{-1}. Soil pH (~6.5) is highly favorable for K availability. K fixation is most likely in Smectite, Vermiculite rich soils.
Khulna	Mica-vermiculite-kaolinite	Mica-smectite	Soil K status, 0.05-0.34 cmol kg^{-1}. Soil pH (~8.0) is highly favorable for K availability; but its fixation is likely in some areas.
Bagerhat	Mica-vermiculite-kaolinite	Mica-smectite	Soil pH (~6.6) is favorable for K availability. K fixation is likely
Pirujpur	Mica-vermiculite-kaolinite	Mica-smectite	Soil K status, 0.10-0.55 cmol kg^{-1}. Soil pH (~6.2) is favorable for K availability; but K fixation is likely in Smectite and Vermiculite rich soils.
Jhalokati	Mica-smectite, Mica-vermiculite-kaolinite	-	Soil K status, 0.11-0.36 cmol kg^{-1}. Soil pH (~7.1) is highly favorable for K availability; but K fixation is most likely in Smectite rich soils.
Barguna	Mica-vermiculite-kaolinite	-	Soil K status, 0.13-0.97 cmol kg^{-1}. Soil pH (~5.7) is very slightly unfavorable for K availability. K fixation is likely
Patuakhali	Mica-smectite, Mica-vermiculite-kaolinite	-	K status, 0.20-0.45 cmol kg^{-1}. Soil pH (~6.0) is favorable for K availability. K fixation is most likely in Smectite rich soils.
Bhola	Mica-vermiculite-kaolinite	-	K status, 0.15-0.33 cmol kg^{-1}. Soil pH (~7.2) is highly favorable for K availability. K fixation is likely
Lakshmipur	Mica-kaolinite, Mica-chlorite	-	Soil pH (~6.4) is highly favorable for K availability.
Noakhali	Mica-kaolinite, Mica-chlorite	-	Soil K status, 0.11-0.58 cmol kg^{-1}. Soil pH (~6.8) is highly favorable for K availability.
Feni	Mica-kaolinite-vermiculite, Mica-kaolinite	Mica-chlorite	Soil K status, 0.20-0.30 cmol kg^{-1}. Soil pH (~6.6) is highly favorable for K availability; but its fixation is likely with vermiculite rich soils.

District	Major areas	Minor areas	Probable K availability
Khagrachhari	Kaolinite-mica, Mica-kaolinite-Vermiculite~suite, Mica-chlorite		Soil K status, 0.13-0.33 cmol kg^{-1}. Soil pH (~5.6) is very slightly unfavorable for K availability. K fixation is likely in Vermiculite rich soils.
Rangamati	Kaolinite-mica, Mica-chlorite	Mica-kaolinite-vermiculite	Soil K status, 0.10-0.77 cmol kg^{-1}. Soil pH (~5.4) is slightly unfavorable for K availability. K fixation is likely
Chattogram	Kaolinite-mica, Mica-mixed layer-kaolinite	-	Soil K status, 0.05-0.43 cmol kg^{-1}. Soil pH (~5.3) is slightly unfavorable for K availability.
Bandarban	Kaolinite-mica, Mica-chlorite	-	Soil K status, 0.13-0.71 cmol kg^{-1}. Soil pH (~5.5) is very slightly unfavorable for K availability.
Cox's Bazar	Kaolinite-mica, Mica-mixed layer-kaolinite	Mica-Kaolinite-Vermiculite	Soil K status, 0.05-0.42 cmol kg^{-1}. Soil pH (~5.3) slightly unfavorable for K availability.

Coarse textured soils having a low pH require special care in K fertilizer management for growing crops. . Potassium fixation is most likely in certain soils of Chapai Nawabganj, Rajshahi, Natore, Meherpur, Kushtia, Chuadanga, Jhenaidah, Jashore, Magura, Pabna, Manikganj, Shariatpur, Madaripur, Faridpur, Gopalganj, Narail, Barishal, Satkhira, Jhalokati, and Patuakhali districts because of variations in K-bearing minerals (Table 2). In calcareous soils with a high clay content and a relatively high CEC, K fixation may be high (Ghiri and Abtahi, 2012). However, reversible K release and fixation may be possible in soils containing abundant easily weatherable minerals (Simonsson *et al.*, 2009). Application of K fertilizer on vermiculite and illite soils needs special attention in terms of K use efficiency.

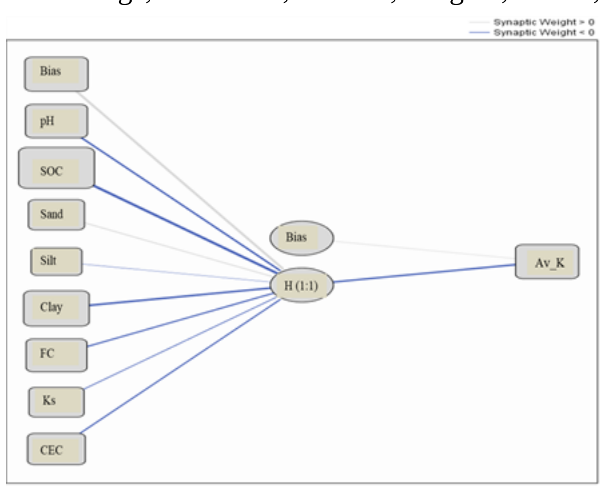

Figure 2: Relationships of different soil parameters with K availability

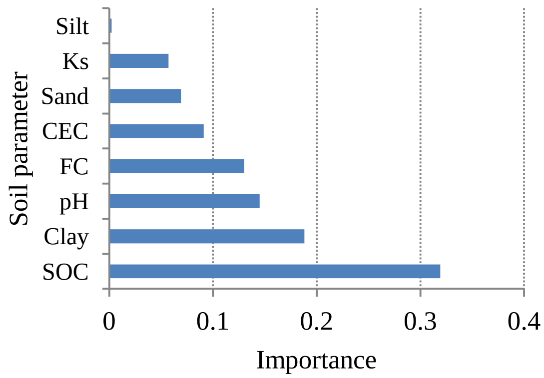

Figure 3: Importance of soil parameters in K availability

Among the soil parameters, pH, soil organic carbon (SOC), clay fraction, moisture level field capacity and CEC were found to be important in (relative error, 0.80) K availability (Fig. 2), with SOC (normalized importance, 100%) and clay fraction (normalized importance, 59.1%) being the dominant components (Fig. 3). However, there is a hidden layer (1:1) that influenced (-0.421) the output layer, i.e, K availability in the relationships. Kozak *et al.* (2005) found a strong relationship of K availability with soil pH. Wang and Huang (2001) reported that K availability was affected by soil organic matter content. Clay mineralogy played an important role in availability of K. Raheb and Heidari (2012) found significant correlations between exchangeable K, clay content and CEC. As the ambient temperature is rising because of climate change, soil mineralization will be faster in future (Hossain *et al.*, 2017; Naher *et al.*, 2019) and changes in particle size distribution, mineralogy and mass loss will occur (Zihms *et al.*, 2013) which might affect soil K fertility.

Response of rice to K fertilizer

Grain yield of rice increased greatly with increasing K doses at Gazipur (Fig. 4) in both wet and dry seasons. However, such a K response may not be obtained if N deficiency exists (BRRI, 2017). In many parts of the country, K deficiency is widespread and farmers generally apply lower amounts of K fertilizer than urea indicating (Biswas *et al.*, 2004, 2017) that crop yield can be improved with higher K rates. Islam and Muttaleb (2016) obtained higher grain yield of rice with higher K fertilizer rates. A neural networking analysis (relative error, 0.969) showed that *Boro* rice yield also depended on other soil

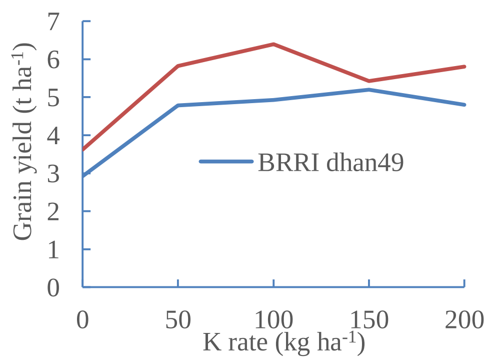

Figure 4: Grain yield of rice as influenced by K rate, Gazipur (Source: BRRI, 2017)

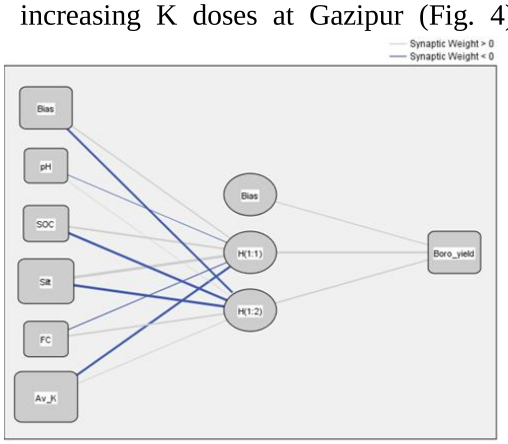

Figure 5: *Boro* rice yield in relation to selected soil parameters

parameters like SOC, pH, field capacity (FC) and silt content along with hidden layers (Fig. 5). In terms of importance, soil available K (weight, 0.511 and normalized importance, 100%) and silt fraction (weight 0.332 and normalized importance, 65%) were dominant components for influencing *Boro* rice yield. Some other factors (hidden layers 1:1 and 1:2) also influenced (weight as 0.240 and 0.143, respectively) *Boro* grain yield.

CONCLUSION

Mica-smectite and mica-chlorite are the most dominant K-bearing minerals covering 20.25% and 19.89% soil areas, respectively, in Bangladesh. Mica-smectite are mostly found in the southwestern and mica-chlorite in the northwestern part of the country. The mica-vermiculite-kaolinite, kaolinite-mica, mica-kaolinite-vermiculite~suite and mica-kaolinite-vermiculite groups are the second most important K-bearing minerals in about 11.71%, 10.58%, 10.65% and 10.19% soil areas, respectively. The third group includes mica-vermiculite and mica-mixed-layer-kaolinite minerals covering about 16% areas of the country. The characteristics of these minerals and other soil properties dictate K availability in soil. The K status varies greatly in different parts of the country.

Special care is needed for growing crops on coarse textured soils having low SOC. Moreover, K fixation is most likely in certain soils of Chapainawabganj, Rajshahi, Natore, Meherpur, Kushtia, Chuadanga, Jhenaidah, Jashore, Magura, Pabna, Manikganj, Shariatpur, Madaripur, Faridpur, Gopalganj, Narail, Barishal, Satkhira, Jhalokati, and Patuakhali districts. Potassium fertilizer recommendations should take into account K-bearing minerals along with crop requirements. Although rice yield was found to increase with increasing K fertilizer rate, the benefit of K fertilization may not be achieved if N is limiting. Finally, we advocate massive efforts for developing soil health cards for farmers to improve soil and crop productivity.

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GREENHOUSE GAS EMISSION AND CARBON SEQUESTRATION DURING WHEAT CULTIVATION IN BANGLADESH

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ABSTRACT

In view of the importance of greenhouse gas (GHG) emissions from crop fields and carbon dioxide (CO_2) sequestration in cropping systems, this study was undertaken to assess the total amounts of GHG emission and net carbon sequestration during the cultivation of wheat, the second most important cereal. Primary and secondary data were used to estimate GHG emission from wheat fields and net CO_2 sequestration in the wheat growing season. GHG emission during wheat cultivation was 3043.43 kg CO_2 eq. ha^{-1} considering direct and indirect emissions. The irrigation regime and fertilizer management were the major regulators contributing 35.39% and 23.42%, respectively to total GHG emission. The estimated net CO_2 sequestration was 2109.42 kg ha^{-1}. The GHG emission rates varied spatially across Bangladesh, the highest emissions being from the northwestern region of the country. The estimated CO_2 sequestration in Bangladesh during 1971-72 to 2019-20 was 0.26-1.72 million tons $year^{-1}$. Given that wheat has the ability to sequester CO_2 from the atmosphere, we advocate expanding the wheat cropping area in Bangladesh as a climate smart option to face the challenges of climate change.

Keywords: Carbon sequestration, Greenhouse gas emission, Wheat

INTRODUCTION

Crop production is associated with greenhouse gas emissions as well as CO_2 fixation. Both direct and indirect GHG emissions from agricultural enterprises play an important role in global warming which in turn aggravates climate change. Greenhouse gas emissions are increasing globally and at present the GHG rate is about 50 billion tons per year in which the contribution of agriculture is about 18.4% (Ritchie and Roser, 2020). Gases that are mostly emitted from agriculture are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) with global warming potentials (GWP) of 1, 28, and 265, respectively (IPCC, 2014). Wheat is one of the most important cereal crops in the world,

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which is grown on 215 million ha of land globally and is consumed by 2.5 billion people in 89 countries (wheat.org, 2021).

GHG emissions have been increasing over the years mostly because of the large scale combustion of fossil fuels and industrial non-combustion processes (Oliver and Peters, 2020). Increasing amounts of GHG emissions from agricultural enterprises are also on the increase due to intensification of the production systems essential for the existence of mankind. The harmful emissions cannot be prevented but can be minimized in different ways like adoption of improved production packages, development of resource efficient crop varieties, etc. Among different GHGs contributing to the global warming potential (GWP), CH_4 is important as large amounts of CH_4 emission take place from rice fields. From upland crop fields, N_2O and CO_2 the major GHGs emitted as major gas. Moreover, there are indirect emissions from agricultural operations and inputs used for crop production. However, carbon fixation also takes place during photosynthesis.

Wheat is the second most important cereal crop in Bangladesh. This crop is grown in the winter season mostly in a rice-wheat rotation. Wheat crop covered quite a large area, 332274 ha, in 2019-2020 (BBS, 2020). It is necessary to assess the total amounts of GHG emission and net carbon sequestration (as CO_2 fixation) during wheat cultivation in Bangladesh to address future challenges from climate change.

The carbon balance in nature largely depends on gross primary productivity (GPP) and net ecosystem productivity (NEP). On the other hand, GPP and NEP are affected by biotic factors in different seasons (Järveoja *et al.*, 2018; Fu *et al.*, 2019). Abiotic factors, especially temperature, moisture availability and crop management also influence GPP by modulating phenological and/or physiological processes (Wang *et al.*, 2019; Xu *et al.*, 2019; Caparros-Santiago *et al.*, 2021). Moreover, length of growing season favorably enhances GPP (Richardson *et al.*, 2013; Piao *et al.*, 2019) and thus, the net ecosystem carbon balance. In the present investigation, we estimated total GHG emission and CO_2 fixation during wheat cultivation in Bangladesh over the years.

MATERIALS AND METHODS

Data collection and calculations

Data on area coverage of wheat during 1980 to 2020 were collected from various publications of the Bangladesh Bureau of Statistics (BBS). Wheat grain yield data were collected from existing literature (http://www.bari.gov.bd/; Kabir *et al.*, 2009; Mahmud *et al.*, 2016) and straw yield was derived as per the following formula:

$WSY = \frac{Grain\ yield}{0.70}$, where WSY is the wheat straw yield in t ha^{-1}

Different mathematical models were used for calculating GHG emissions and net CO_2 fixation described below:

Net ecosystem C balance (NECB) in kg CO_2 eq. ha^{-1} was calculated according to Ma *et al.*, (2013); Zhang *et al*. (2014) and Haque *et al*. (2021) and net primary productivity (NPP) according to Smith *et al*. (2010):

$$NECB = NPP - R_{ecosystem\ respiration} - Harvest - CH_4 + Manure/Fertilizer$$

$$NPP = NPP_{grain} + NPP_{straw} + NPP_{root} + NPP_{litter} + NPP_{rhizodeposit}$$

Net CO_2 sequestration (NCS) in kg CO_2 ha^{-1} was calculated as follows:

NCS = NECB – N_2O emission (kg CO_2 eq. ha^{-1}) – IDE (kg CO_2 eq. ha^{-1})

where harvest includes grain and straw, CH_4 is the amount of methane as kg CO_2 eq. ha^{-1}, and IDE is the indirect emission (kg CO_2 eq. ha^{-1}) in relation to crop production as shown in Table 1. Methane emission was measured based on static closed chamber techniques (Haque *et al.*, 2017, 2018, Haque and Biswas, 2021). Inputs use related GHG emissions are shown in Table 1. About 30-62% healthy persons emit CH_4 (Sahakian *et al.*, 2010). We took the mid-point of 45% of the labor forces to estimate CH_4 emission in 8 working hours.

The root biomass of wheat was determined according to Huang *et al*. (2007) as follows:

Wheat root biomass (kg ha^{-1}) = (Above ground biomass, kg ha^{-1}) x 0.11

Litter weight (kg ha^{-1}) was estimated according to Kimura *et al*. (2004) by taking 5% of aboveground and root biomass.

Rhizodeposits for wheat were estimated by taking 18% of total biomass (Gregory, 2006).

Statistical tools

Descriptive statistics were used to show the variations in GHG emission and net CO_2 fixation in relation to wheat cultivation. Quantum Geographic Information System (QGIS) version 2.18 was used for showing spatial distribution of total GHG emission and net CO_2 fixation in different districts of Bangladesh.

Table 1: GHG emission patterns during wheat cultivation in Bangladesh

Item	Emission (kg ha^{-1})	Comments
Land preparation	153.57	Land preparation is mostly mechanized (Hossen *et al.*, 2020). About 80% land is prepared by power tiller, 20% by tractor. Human gut emission was 1.12 kg CO_2 eq. man-day^{-1} (https://badgut.org). Diesel burning emission-3.56 kg CO_2 eq. L^{-1} (Flessa *et al.*, 2002). Diesel burning values as per IPCC, 2006
Sowing	1.12	About 45% labor emit CH_4 at 1.12 kg CO_2 $capita^{-1}$ man-day^{-1} (Adapted from https://badgut.org)
Harvesting	15.88	Harvesting is mostly done manually and required about 30 man-day^{-1}. About 2% areas are harvested by combine harvester and reaper (Farhad, 2020). We assume that combine harvester was mostly used and fuel requirement was 17.65 L ha^{-1} (Hasan *et al*., 2019).
Threshing	119.86	About 80% threshing was done by machine (Hossain, 2017). Open drum (60.3%) - 5 L. Close drum (30%) - 25.4 L, manual (10%)
Weeding 2x	4.03	Generally, 6-10 labors ha^{-1} are used for weeding (BBS, 2010). We have considered 8 labors ha^{-1} for weeding. Taking 45% of labor forces emit GHG at 1.12 kg CO_2 eq. day^{-1}

Item	Emission (kg ha^{-1})	Comments
Fertilizers	712.66	One fifth urea is generally imported. For imported and manufactured urea, the GHG was 0.93 and 4 kg CO_2 eq. kg^{-1} respectively (Gathorne-Hardy *et al.*, 2013; FAO, 2017) and 1.29 kg CO_2 eq. kg^{-1} for TSP and 1.47 kg CO_2 eq. kg^{-1} for MoP (FAO, 2017)
Irrigation	1076.93	Average water requirement for wheat cultivation was 665 mm ha^{-1} (Mustafa *et al.*, 2017). In wheat field, minimum or no irrigation is provided. Depending on soil type and water availability it could be 242-295 mm water requirement for successful wheat cultivation (Mustafa *et al.*, 2017). We have taken average values of 9 observations
Steel embedded emission for thresher	3.375	2.7 kg CO_2 eq. kg^{-1} steel (Gathorne-Hardy *et al.*, 2013). In 5 years, life spans for open drum and close drum thresher are 300 and 600 ha, respectively.
Seed (120 kg ha^{-1})	134.4	Seed rate under 1-2 irrigations and CO_2 eq. emission was 1.12 kg ha^{-1} (van Hung *et al.*, 2020)
Total indirect	**2221.83**	
Field emission		Static close chamber technique was used (Haque *et al.*, 2017, 2019; Haque and Biswas, 2021)
CH_4 (8 kg ha^{-1})	224.00	
CO_2	487.64	
N_2O (0.415 kg ha^{-1})	109.96	
Total field scale	**821.60**	
Grand total	**3043.43**	
Net CO_2 fixation (kg ha^{-1})	**2109.42**	

RESULTS AND DISCUSSION

Total GHG emission owing to wheat cultivation was 3043.43 kg CO_2 eq. ha^{-1} in which 2221.83 kg CO_2 eq. ha^{-1} was related to inputs and 821.60 kg CO_2 eq. ha^{-1} was direct emission (Table 1). Among the inputs, irrigation contribute most (35.39%) to GHG emission followed by fertilizers (23.42%). Field scale measurements of GHG accounted for 26.99%) (Fig. 1). Even when both direct and indirect emissions were considered, the net CO_2 fixation amounted to 2109.42 kg ha^{-1} (Table 1).

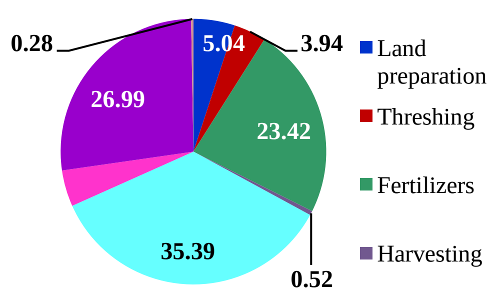

Figure 1: Contributions (%) of different components to GHG emissions during wheat cultivation in Bangladesh

There were great variations in total GHG emission in different districts of Bangladesh, ranging from 2.0 to >100000 tons CO_2 eq. (Fig. 2). The highest amounts of GHG emission were observed in major wheat growing areas (north and northwest regions. Likewise, total net CO_2 fixation varied across production regions and ranged from 2.0 to >60000 tons in different districts of Bangladesh (Fig. 2). Like total GHG emission, net CO_2 fixation/sequestration was also higher in major wheat growing areas, as stated earlier, in Bangladesh.

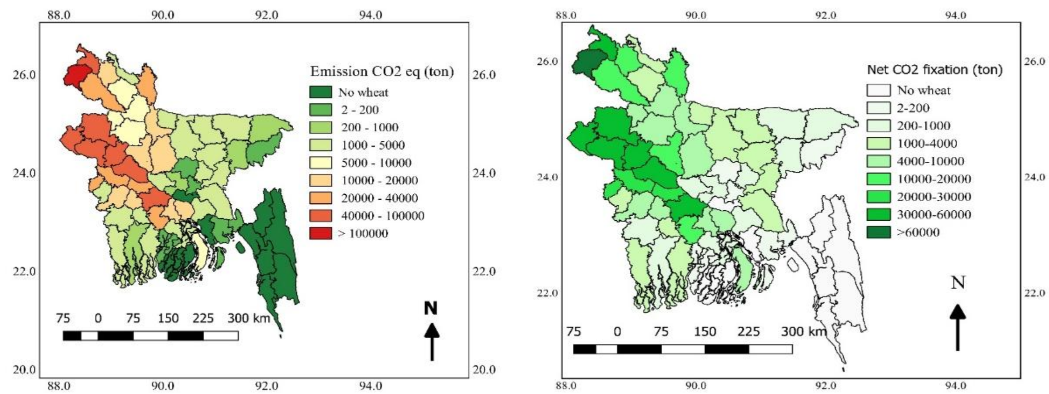

Figure 2: Total GHG emission (left) and net CO_2 sequestration (right) during wheat cultivation in different districts of Bangladesh

Since there was net positive carbon balance during wheat cultivation, we estimated total net CO_2 fixation/ sequestration in Bangladesh during 1971-72 to 2019-20 (Fig. 3). CO_2 sequestration varied from 0.26 to 1.72 million tons year^{-1}.

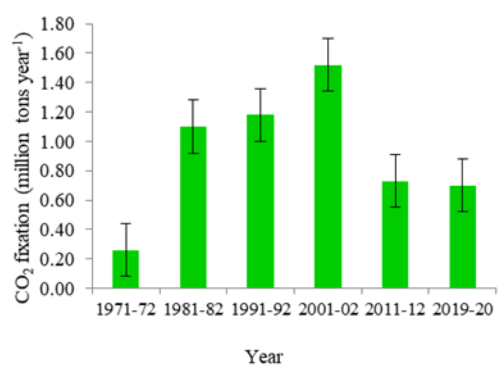

Figure 3: Estimated net fixation of CO_2 during wheat cultivation in Bangladesh (line bars indicates standard error)

The lowest CO_2 sequestration was in 1971-72 which gradually increased up to 2001-02 and then declined during 2011-2020. These fluctuations in total GHG emission were related with variable area coverage by wheat crop. The other factors could be disparities in sowing time and crop husbandry. As area coverage by the wheat crop changed during 1971-72 to 2019-20, so did estimated CO_2 sequestration vary did during the same period.

The total amounts of GHG emission, as estimated in the present investigation, from unit wheat area considering field scale measurements and inputs use was similar to the findings of Huang *et al*. (2017). They found 2978 kg CO_2 eq. ha^{-1}. However, Zhang *et al*. (2017) reported 5455 kg C eq. ha^{-1} (about 20002 kg CO_2 eq. ha^{-1}) much higher than our finding. Based on lifecycle assessment, GHG emission could be 524-3197 CO_2 eq. ha^{-1} during wheat cultivation (O'Donnell, 2008; Brook *et al.*, 2012). Such high variations are related to soil-fertilizer nutrient sources and ecological variations. The limitations of estimating GHG based on life cycle assessment are the inadequacy of data. Country specific data are unavailable in many cases. In such cases, we utilized judgement of experts and our own experiences. So, more emphasis needs to be given to data generation for precise estimation of GHG emission and CO_2 sequestration in relation to wheat cultivation in Bangladesh.

Although wheat is grown under upland conditions, small amounts of CH_4 emission was recoded because of irrigation water application (Table 1). However, in many cases wheat is grown on residual moisture after rice cultivation and thus there would be about 1077 kg CO_2 eq. ha^{-1} reduction in GHG emissions. We speculate that under such situations, CO_2 sequestration could be higher which needs to be investigated. About 0.24 million ha is covered by the rice-wheat cropping system in Bangladesh (Nasim *et al.*, 2017). Location-specific data from these areas need to be collected on input uses and field scale GHG emissions for the evaluation of total GHG emission and net CO_2 sequestration during wheat cultivation. The contribution of fertilizers to total GHG emission is quite high indicating that fertilizer management needs to be optimized. Improvement in fertilizer use efficiency and recycling of decomposable agricultural residues can play an important role in this regard. Use of urea super granules, as we observed in some of our other experiments, can minimize N_2O emission and thus the total emission could be cut down. At the present moment with limited data, CO_2 sequestration during wheat cultivation was calculated as about 2109 kg ha^{-1}. O'Donnell (2008) also reported 517-8538 kg ha^{-1} CO_2 sequestration that depended on grain yield. Our findings clearly indicate that wheat cultivation favors CO_2 fixation/sequestration from the atmosphere. Like many other wheat growing countries around the globe, wheat cultivation in Bangladesh is also favoring CO_2 sequestration from the ecosystem. Increasing the area under wheat as a sole crop or as a component crop of the rice-wheat system can be a good climate smart strategy for crop agriculture in Bangladesh. Besides, improvement in optimal irrigation and proper fertilizer management can act as synergistically in minimizing GHG emissions from crop fields of Bangladesh.

CONCLUSION

We estimated GHG emission and net CO_2 sequestration in wheat cropping systems of Bangladesh during the past fifty years using relevant data from various sources. Using the lifecycle assessment technique, GHG emission from wheat fields was estimated as 3043.43 kg CO_2 eq. ha^{-1} and net CO_2 sequestration as 2109.42 kg ha^{-1}. Considering direct and indirect GHG emissions, irrigation water management was found to contribute most to GHG emission, followed by fertilizer management. There were spatiotemporal variations in GHG emission and CO_2 sequestration. The estimated CO_2 sequestration was 0.26-1.72 million tons $year^{-1}$ during 1971-72 to 2019-20. The cultivation of wheat in Bangladesh utilizes both labor and mechanized forces for different operations which account for the variations in GHG emission across the wheat growing areas of the country. Judicious and rational use of resources keeping in mind the implications for climate change is necessary not only to improve grain yield, but also to augment CO_2 sequestration in the wheat cropping system of Bangladesh.

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CLIMATIC VULNERABILITY: THE FUTURE OF WET SEASON RICE CULTIVATION IN BANGLADESH

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ABSTRACT

Rice production is largely affected by atmospheric temperature and carbon dioxide (CO_2) concentration along with the management practices adopted. The probable relationships of rice of the wet season rice varieties, BRRI dhan49 and BRRI dhan76, with increased temperatures and CO_2 concentrations were investigated for futuristic crop management in six regions of Bangladesh using the CERES-Rice model (DSSATv4.6). Genotypic coefficients of the tested rice varieties were generated by the DSSAT model. Increments of 1, 2 and 3^{o}C for the maximum and minimum temperatures and CO_2 concentrations of 380 (ambient), 450, 550 and 670 ppm were considered for this simulation study. Rice grain yield varied from 3.37 to 4.94 t ha^{-1} under normal weather and ambient CO_2 concentration. Simulations indicated rice yield declines by 10% or more in four districts of Bangladesh if temperature rises by 1°C above the normal level, in 39 districts if it rises by 2°C and in 54 districts if it rises by 3°C. Conversely, an elevated CO_2 concentration would compensated for the rice grain loss at all the test locations. Projections indicated that only in a few cases yield reductions might occur by 5-30% depending on location, magnitude of temperature rise and atmospheric CO_2 concentration. This study predicts fragility of the transplanted *Aman* rice (wet season monsoon rice) growing environment in the future climate change scenario central and southern regions of Bangladesh. Development of heat tolerant rice varieties along with climate smart fertilizer and water management practices, necessary shifts in sowing and transplanting dates and rejuvenation of soil health would be needed to mitigate the adverse impacts of climate on transplanted *Aman* rice production.

Keywords: Atmospheric CO_2, Regional variability, Temperature, Yield compensation

INTRODUCTION

Bangladesh is a south Asian deltaic country with population density with a population of about 160 million (UN, 2015) and having a population density which is one of the highest in the world. Almost all arable land of the country is under cultivation, but arable land is decreasing due to increasing demands for residential and industrial uses (Hasan *et al.*, 2013). Bangladesh now enjoys near rice food self-sufficiency (MoEF, 2005; DoE, 2007;

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Huq and Rabbani, 2011). The global mean surface temperature for 2081–2100 relative to 1986–2005 is projected to increase by 0.3°C to 4.8°C (IPCC, 2013). Such changes will also occur in Bangladesh where average day temperature increase is likely to be 2.0°C to 4.0°C by 2100 (IPCC, 2013).

In the last 150 years, atmospheric CO_2 concentration has increased from 280 ppm to 385 ppm in 2008 (http://www.esrl.noaa.gov/gmd/ccgg/trends/) due to large scale fossil fuel burning, cement production, and modified land use patterns (IPCC, 1996; Fan *et al*., 2007). At the current rate of atmospheric CO_2 increase, it will be double before 2100 causing dramatically affecting on global and regional scale climate. The effect of temperature rise is already visible. For example, rainfall has become increasingly variable and has demonstrated an uneven distribution. This erratic pattern produces extreme events, such as floods and drought, which have shown noticeable adverse effects on rice yield (UNDP, 2008; GoB and UNDP, 2009). As a result, rice production is likely to decline by 8–17% by 2050 (BBS, 2015; IPCC, 2007).

Crop agriculture in Bangladesh is dominated by rice monoculture-- a synonym of food security in Bangladesh. Almost 80% of the total cropped area is under rice in different seasons, which accounts for more than 90% of total grain production (BBS, 2016; Asaduzzaman, 2010). Among the rice growing seasons, wet season rice (monsoon rainfed rice) contributed about 38.6% of the total rice production from about 48.8% of rice area in Bangladesh (BBS, 2016). So, there is a crucial need to assess effects of climate change on rice productivity and economic growth of Bangladesh.

Some studies have recently investigated the economic effects of climate change on agricultural production in developing countries (Gbetibouo and Hassan, 2005; Kurukulasuriya and Ajwad, 2007; Haim *et al*., 2008; Daressa and Hasan, 2009; Moula, 2009; Wang *et al*., 2009). Although these studies showed susceptibility of crop agriculture to climate change, limited information about Bangladesh is available. Some reports on the influence of climate change by considering cyclones, storm surges, coastal erosion and brackish water effects and reported large land losses in eastern part of Bangladesh because of beach erosion (Mahmood, 1998; Paul, 1998; Ali, 1999; Rahman, 2000; Rashid and Islam, 2007). Rashid and Islam (2007) identified droughts, floods, soil salinity and cyclones as the major extreme climate events that have affected agricultural production adversely.

The CERES-Rice model and the DSSAT model were used to study the influence of higher air temperature and higher atmospheric CO_2 concentration on rice yield (Karim *et al*., 1996; Mahmood *et al*., 2004; Basak *et al*., 2010) with outdated rice varieties that are not available in the fields nowadays. The objective of this study was to assess the impact of climate change on wet season rice production in terms of temperature rises and CO_2 concentrations along with regional vulnerabilities in Bangladesh for futuristic adoption indication in agriculture.

MATERIALS AND METHODS

Site characterization

The selected study locations across the country of Bangladesh are diverse in soil and weather conditions. They were located in Gazipur ($23^o45'$ N latitude, $90^o22'$ E longitude, 8.4 m above mean sea level [AMSL]), Rangpur (24°41' N latitude, 89°16' E longitude, 33.04 m AMSL), Rajshahi (24°22' N latitude, 88°22' E longitude, 17.24 m AMSL), Barisal (22°41' N latitude, 90°21' E longitude, 2.54 m AMSL), Cumilla (23°28' N latitude, 91°09' E longitude, 6.54 m AMSL) and Habiganj (24°25' N latitude, 91°25' E longitude, 22.54 m AMSL) districts of Bangladesh.

Model inputs parameters

Selected input data used for CERES-Rice model are shown in Table 1.

Weather data

Weather data of the study regions were collected from the Bangladesh Meteorological Department (BMD) for the period of 1981–2017. Base year daily average (normalized weather data to minimize unusual phenomenon) of maximum and minimum temperatures, rainfall and sunshine hours were calculated and a weather file for DSSAT format created. As transplanted *Aman* (*T. Aman*) rice is grown from June to December, the seasonal model simulation was run in SIMMETEO mode for 30 years to capture temperature and CO_2 effects on yield and growth duration of selected varieties.

Soil parameters

Location-wise soil parameters used in DSSATv4.6 model were thickness of three layers, layer-wise sand, clay, bulk density, soil organic carbon and soil hydraulic characters. Soil pH, EC and slope also are required as inputs for different locations are shown in Table 2. The terms ‘lower limit’ and ‘drained upper limit’ correspond to the permanent wilting point and field capacity, respectively (Ritchie, 1991).

Table 1: Selected input data requirements for the CERES-Rice model

Agronomic data	Pedological-hydrological data	Daily weather data
Sowing and transplanting date	Soil classification	Maximum and minimum air temperature
Row spacing: seeding depth	Texture	Precipitation
Number of plants hill^{-1}	Number of layers in soil profile	Solar radiation
Number of plants m^{-2}	Slope	
Age of seedling (day)	Permeability	
Base temperature to estimate phenological stages	Drainage	
Station information:	Soil layer depth	
Latitude	Soil horizon	
Longitude	Clay, silt, and sand content	
	Bulk density	
	Saturated hydraulic conductivity for each soil layer,	
	Total nitrogen for each layer	
	Soil pH for each layer	
	Root quantity for each layer	

Table 2: Physical and chemical properties of soils for the selected locations

Attribute	Gazipur			Rangpur			Rajshahi			Barishal			Cumilla			Habiganj		
Soil depth (cm)	20	40	60	20	40	60	20	40	60	20	40	60	20	40	60	20	40	60
WP (vol, frac.)	0.29	0.29	0.28	0.09	0.08	0.06	0.23	0.17	0.15	0.24	0.24	0.22	0.26	0.25	0.24	0.26	0.25	0.24
FC (vol, frac.)	0.45	0.43	0.40	0.28	0.22	0.26	0.41	0.35	0.35	0.44	0.44	0.44	0.41	0.39	0.38	0.41	0.39	0.39
Porosity (vol, frac.)	0.50	0.50	0.49	0.48	0.46	0.40	0.48	0.49	0.44	0.49	0.48	0.48	0.46	0.47	0.47	0.46	0.47	0.47
Ks (cm/hr)	0.32	0.35	0.32	1.10	0.89	0.81	0.15	0.48	0.48	0.15	0.14	0.14	0.17	0.19	0.19	0.29	0.21	0.19
BD (g/cc)	1.35	1.34	1.35	1.39	1.41	1.52	1.29	1.42	1.42	1.26	1.30	1.31	1.36	1.35	1.35	1.34	1.35	1.35
OC (%)	0.72	0.60	0.38	0.45	0.37	0.20	1.18	1.10	0.90	0.90	0.70	0.40	0.54	0.31	0.29	0.74	0.31	0.21
Clay (%)	48.0	48.0	47.0	17.0	8.0	5.0	60.0	35.0	37.0	34.0	36.0	34.0	46.0	44.0	42.0	45.0	44.0	42.0
Silt (%)	47.0	46.0	47.0	51.0	37.0	15.0	27.0	30.0	30.0	59.0	58.0	56.0	42.0	41.0	40.0	43.0	41.0	40.0
Total N (%)	0.07	0.06	0.04	0.04	0.03	0.02	0.15	0.12	0.10	0.09	0.07	0.04	0.05	0.03	0.03	0.07	0.03	0.02
pH	6.4	6.3	6.2	5.5	5.9	6.1	5.6	6.0	6.2	7.5	7.0	6.8	6.7	7.0	7.3	6.6	7.0	7.2

* WP- Wilting point, FC- field capacity, Ks- Saturated hydraulic conductivity, BD- Bulk density, OC- Organic carbon

Crop parameters

BRRI dhan49 and BRRI dhan76 were used depending upon the suitability of that locations for grain yield and growth duration under varying levels of increased temperatures and CO_2 concentrations. The performance of BRRI dhan49 was tested against 01 July sowing, the optimum sowing date for *T. Aman* rice cultivation at all locations except southern tidal affected areas, where BRRI dhan76 was tested against 20 July sowing, the optimum sowing date of late planted locations to cope with tidal inundation. In sowing date experiment, seeds were sown on 01 June to 15 August at 7 days interval to find out the optimum sowing date and to overcome the climatic effects on *T. Aman* rice cropping. The genetic coefficients were determined based on experiments conducted at BRRI regionals stations and head office by repeated iterations until a close match between simulated and observed phenology and yield was obtained. The data of field experiments were used for calibration and validation and calculating the coefficients that are shown in Table 3. There was a good agreement between simulated and observed phonological development and grain yield. The performance of the model has been well validated in Bangladesh (Maniruzzaman *et al*., 2017).

Yield simulations

Potential yield is defined as the maximum yield of a variety restricted only by season-specific weather variabilities. This assumes that other inputs (nutrient, water, etc.) are non-limiting and cultural practices are optimal. Thus, the potential yield of a crop depends on the temporal variation in CO_2 level in the atmosphere, solar radiation, maximum and minimum temperatures during the crop growing season and physiological characteristics of the variety. Mechanistic crop growth models are routinely used to estimate potential yield and assess the effects of climate change (Kropff *et al*., 1997; Aggarwal *et al*., 2000).

To simulate potential rice yield, CERES-Rice v4.6 was used. This mechanistic model simulates crop growth and development processes, net photosynthesis based on radiation use efficiency, leaf area index, extinction coefficient and light absorption by the canopy

(Mall and Aggarwal, 2002). The model can also simulate the effect of CO_2 on photosynthesis and water use based on stomatal conductivity (Jones *et al*., 1994).

Table 3: Genetic coefficients of rice varieties used in DSSAT model

Genetic coefficient parameters	Values	
	BRRI dhan49	BRRI dhan76
Juvenile phase coefficient (P1), GDD[a]	760	950
Photoperiodism coefficient (P2R), GDD h^{-1}	170	180
Grain filling duration coefficient (P5), GDD	500	450
Critical photoperiod (P20), h	10.3	12.5
Spikelet number coefficient (G1)	43.5	60
Single grain weight (G2), g	0.022	0.025
Tillering coefficient (G3)	1.0	1.0
Temperature tolerance coefficient (G4)	1.0	1.0

[a] GDD, growing degree days (^{o}C)

Selection of scenarios for model applications

The rise in temperature is likely to be 2-4^{o}C by 2100 in South Asia including Bangladesh (IPCC, 2013). So, the CERES-Rice model was applied for normal (no temperature rise) and 1, 2, and 3^{o}C rise over normal weather conditions. *T. Aman* rice is normally grown as rain fed crop that exposed to hot and wet conditions during initial growth stages and a little cooler environment at flowering to harvesting stages. This crop is generally grown under different hazards like droughts, floods and cyclones based on locations. Any further changes in temperature and CO_2 levels, such natural hazards will be increased in future. According to CMIP5 and Earth System Model, predicted CO_2 concentrations will be reaching 421 to 936 ppm by the year 2100 based on different RCPs (IPCC, 2013). So, we have selected three CO_2 levels of 450 ppm, 550 ppm and 650 ppm and compared with ambient CO_2 concentration (380 ppm).

RESULTS AND DISCUSSION

Weather data

Long-term (1981-2017) monthly mean weather data showed that mean maximum wet seasonal temperature varied from 22.6 to 36.1^{o}C for all the study regions. The lowest mean maximum temperature was found in January in Dinajpur and the highest mean maximum temperature in April in Rajshahi (Fig. 1). Long-term mean minimum temperature varied from 10.5 to 26.0^{o}C. The lowest minimum and the highest minimum temperatures were recorded in Dinajpur during January and July, respectively (Fig. 1). Among the study regions, Sylhet, Mymensingh and Cumilla experienced comparatively less variability in temperature than in other regions. On the contrary, Khulna, Rajshahi and, Dhaka exposed to higher temperature.

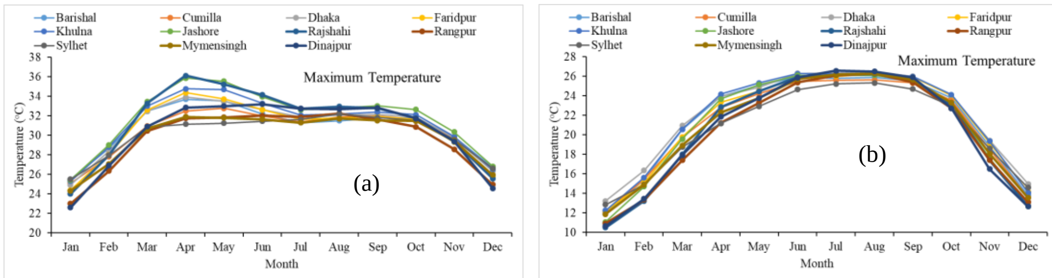

Figure 1: Saptio-temporal distribution of (a) maximum and (b) minimum temperatures in various regions of Bangladesh.

Monthly distribution of rainfall showed that December to March received comparatively less rainfall (Fig. 2). Considerable amount of rainfall starts in April and reached the peak in July. In all the locations, huge amounts of rainfall occurred in May to September. Spatial variation showed that Habiganj received the highest (2353 mm) annual rainfall whereas, Rajshahi received the lowest rainfall (1452 mm). Moreover, seasonal rainfall distribution pattern showed that monsoon had the highest amount of rainfall in each location. The highest 73% and the lowest 58% monsoon rainfall occurred in Rajshahi and Habiganj, respectively.

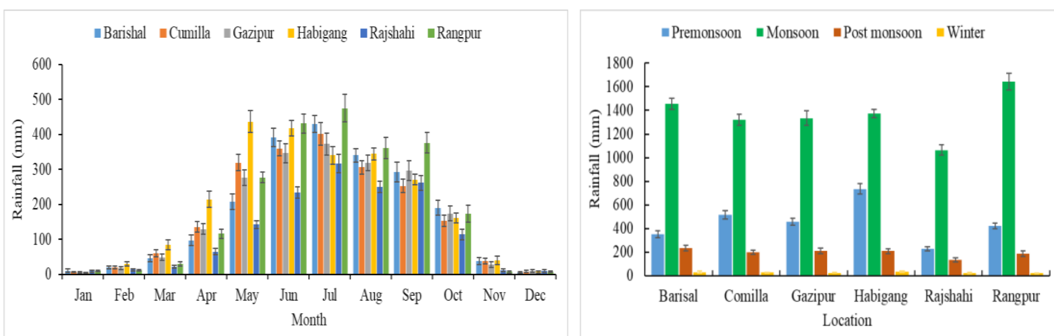

Figure 2: Distribution of monthly (left) and seasonal (rightrainfall in major study locations of Bangladesh

Grain yield

Grain yield of tested rice varieties varied among regions mainly due to weather variability and soil properties. In general, the highest potential grain yield was found in Rajshahi and the lowest in Barishal regions irrespective of varieties (Fig. 3). Normal grain yield varied from 3.84 to 4.94 and 3.37 to 4.59 t ha^{-1} for BRRI dhan49 and BRRI dhan76, respectively based on long-term (1981-2017) weather parameters (Fig. 1). These variations were related to weather parameters and soil properties. Pathak (2003) reported 7.7-10.7 t ha^{-1} yield of wet season rice in Indo-Gangetic Plains (IGP). Aggarwal *et al*. (2000) reported about 10 t ha^{-1} rice yields in Punjub and Haryana. Mohandas *et al*. (1995)

also reported 10.5 t ha^{-1} potential yield in Kapurthala district, Punjab but 7.1 t ha^{-1} in Cuttack, Orissa. These clearly indicate that grain yield of rice varies across locations.

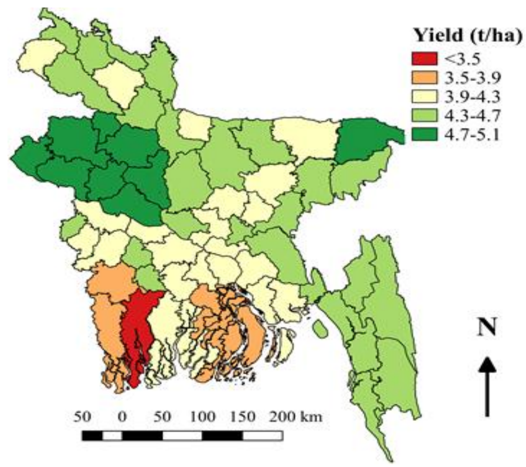

Figure 3: Variation of rice grain yield under normalized weather condition in different locations of Bangladesh

Effect of temperature on *T. Aman* rice yield

Projections indicated severe yield declines of rice if temperature were to rise. We found up to 5% yield reduction in the north-west, south-west and south-central parts of the country because of a temperature rise by 1^{o}C (Fig. 4). The south-east part of the country showed about 5-8% yield reduction. More than 10% yield reduction was projected in smaller parts (four districts) of the south-east and north-central regions of Bangladesh under similar conditions. A 2^{o}C temperature rise would expand the vulnerable area. More than 15% yield reduction was estimated in 27 out of 64 districts in Bangladesh. The south-

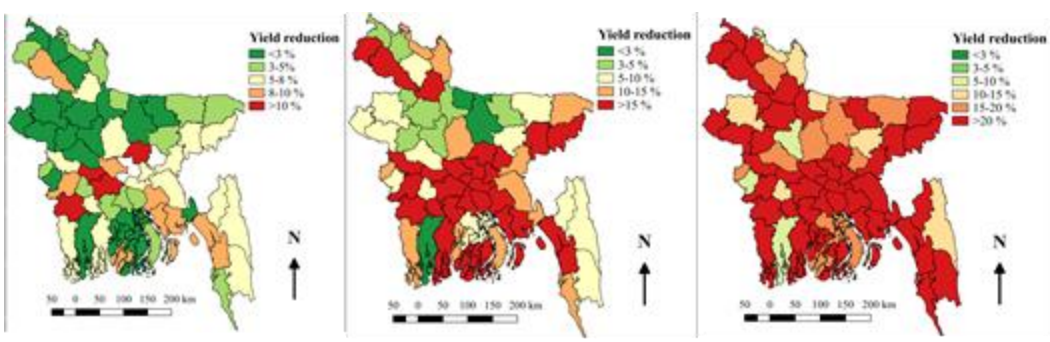

Figure 4: Rice grain yield reductions because of 1^{o}C (left), 2^{o}C (center) and 3^{o}C (right) temperature rises over normalized weather data

west, north-central and south-central regions showed more vulnerability in terms of rice grain yield reduction at an elevated temperature. Moreover, in 12 districts, the estimated yield reductions were 10-15 % based on only a 2^{o}C rise in temperature. The magnitude of rice yield reduction would be relatively low (>5%) in a 2^{o}C temperature rise condition in only 11 districts in the north-west and north-central regions of Bangladesh. In a further temperature increase (3^{o}C rise) scenario, all the districts of Bangladesh would become highly vulnerable in terms of rice yield loss. With a 3^{o}C rise, rice grain yield loss may be as high as > 20% in 37 districts and 10-20% in another 17 districts. In a temperature rise situation, unfortunately there would be no place remaining in Bangladesh where a rice yield loss by at least 5% would not occur. Mahmood (1998) reported 9.7-22.7% yield reductions at Mymensingh and 7.3-17.0% at Barishal with BR3 due to temperature rise. Hossain *et al*. (2021) estimated grain yield reductions by 0–17%, 16–35%, 31–49%, and 39–61% from the normal weather condition if the seasonal mean temperature increased by 1°C, 2°C, 3°C, and 4°C, respectively in the *Boro* (winter rice) season.

Effect of CO_2 concentration on T. Aman rice yield

Rice grain yield responses to various CO_2 levels at a 1^oC temperature rise situation were analyzed (Fig. 5). The projected maximum grain yield reduction by 10-15% at a 1^oC temperature rise and 380 ppm was noted in four districts. However, for 23 out of 64 a 5-10% yield reduction was projected because of temperature rise, while an elevated CO_2 level minimized the yield losses. An increase in the CO_2 concentration to 450 ppm would neutralize the effect of a temperature rise in reducing rice grain yield, at all the study locations. A yield reduction of more than 10% was projected for only two locations, and for 17 locations the projected yield loss was 5-10%. No rice grain yield reduction was predicted for 17 districts at a CO_2 level of 550 ppm and for 33 districts at a CO_2 level of

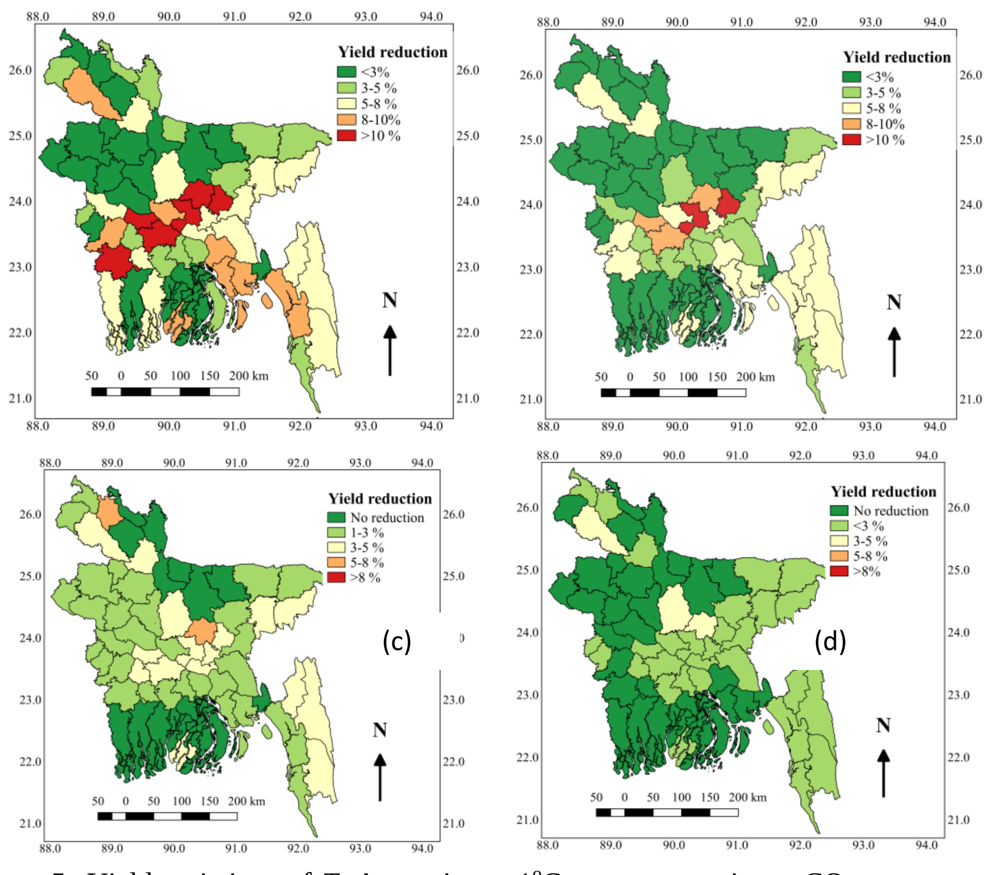

Figure 5: Yield variations of *T. Aman* rice at 1^oC temperature rise at CO_2 concentration of (a) 380 ppm, (b) 450 ppm, (c) 550 ppm and (d) 650 ppm.

650 ppm. (Krishnan, 2007) predicted rice grain yield reductions of 7.20 and 6.66% at 380 ppm CO_2 level using the ORYZA1 and INFOCROP rice models, respectively with a 1°C increase in temperature. Increasing the CO_2 concentration up to 700 ppm, however, indicated rice grain yield increases by 30.73% and 56.37% by the ORYZA1 and INFOCROP crop models, respectively. In a scenario with a 4°C temperature rise above the ambient level, ORYZA1 predicted yield reductions of 7.63, 9.38 and 15.86%, respectively, based on the General Fluid Dynamics Laboratory (GFDL) Model, Goddard Institute of Space Studies (GISS) model and the United Kingdom Meteorological Office (UKMO) model, while INFOCROP predicted reductions of 9.02, 11.30 and 21.35%, respectively. In our study, the predicted magnitude of yield loss was lower, however. Our predictions were similar as those of IPCC (2007) and BBS (2005) who estimated 8-17% decline in rice production by 2050 in the south Asian region.

An increase in the concentration of CO_2 in the air is generally likely to increase crop yield due to a stimulated photosynthetic process and improved water use efficiency. In general, the effect of increased temperature would be negative because of heightened respiration and shortened vegetative and grain filling periods (Horie *et al*., 1995). Although major rice models indicated about 5% yield reduction for every degree rise in the mean temperature, (Matthews *et al*., 1995). Dias *et al*. (2016) estimated 25-35% yield reductions in Sri Lanka using DSSAT. Basak *et al*. (2010) reported 20% and 50% yield reductions by 2050 and 2070, respectively in the *Boro* season with BR3 and BR14 rice varieties. These rather alarming predictions of grain yield losses as a consequence of future climate change could be attribute to unusual responses of the varieties studied to changes in the climatic parameters or to the use of inappropriate genetic coefficients in the model.

CONCLUSION

This study was conducted to determine the effect of increased daily maximum and minimum temperatures and elevated CO_2 levels on grain yield of *T. Aman* rice (wet season rice) in Bangladesh using the CERES-Rice model. Long-term normalized weather data were used to predict the effects of temperature rises of 0, 1, 2 and 3°C above the ambient level and CO_2 concentrations in air at the ambient level, i.e., 380 ppm and elevated levels of 450, 550 and 650 ppm on the grain yield of *T. Aman* (wet season rice) in Bangladesh. *T. Aman* rice grain yield varied from 3.37 to 4.94 t ha^{-1} in normal weather conditions. Grain yield reductions by 10% or more from that obtained under normal weather were predicted for 4, 39 and 54 districts if the temperature were to rise by 1, 2 and 3°C rise in temperature, respectively. However, an elevated CO_2 concentration would neutralize the adverse effect of a temperature rise on rice grain yield. In a 1°C temperature rise and 450 ppm CO_2 scenario, a rice yield loss of >10% would occur in only two districts and 5-10% yield loss would occur in 17 districts. However, no yield reduction was predicted for 16 districts at a CO_2 level of 550 ppm for 32 districts at even a higher CO_2 level of 650 ppm. Projections indicated the development of a fragile environment in the future for *T. Aman* rice in the southwestern, south-central and southeastern regions of Bangladesh. In general, the magnitude of grain yield loss and compensation with elevated CO_2 were estimated to be lower in the currently warmer regions and higher in the cooler regions. In the projected climate change scenario, the maximum temperature at the flowering stage of rice might cross the critical limit which could result in a significant yield loss. Climate smart strategies like proper adjustments of the sowing and transplanting dates, development of stress tolerant varieties and suitable soil-crop-water management practices need to be developed to face future climate change adversities in agriculture.

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NUTRIENT UPTAKE BY *BORO* RICE IN RESPONSE TO FERTILIZERS APPLICATION IN *HAOR* AREAS OF SUNAMGANJ

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ABSTRACT

A field experiment was conducted during November 2018 to April 2019 in a farmers' field of Noagaon village of the South Sunamganj upazila of Sunamganj district to study nutrient uptake by different varieties of *Boro* rice in response to fertilizer application in *Haor* area. Three rice varieties viz., BRRI dhan28, BRRI dhan29 and BRRI dhan58 and two fertilizer levels viz., N-P-K-S-Zn at the rates of 138-22-63-13-1 kg ha^{-1}, based on the national fertilizer recommendation guide (FRG), and the local farmers' practice (FP), N-P-K at the rates of 57-12-12 kg ha^{-1}, were tested in this experiment. The experiment was laid out in a randomized complete block design (RCBD) with three replications. Nutrient concentrations in the rice plant and nutrient uptake varied significantly with both rice variety and fertilizer level. The highest amounts of N (102.96 kg ha^{-1}), P (12.94 kg ha^{-1}), K (103.45 kg ha^{-1}), S (5.26 kg ha^{-1}) and Zn (0.51 kg ha^{-1}) were taken up by BRRI dhan29 and BRRI dhan28 absorbed the lowest amounts of N (83.95 kg ha^{-1}) and P (10.26 kg ha^{-1}). Besides, the lowest K (88.60 kg ha^{-1}) and S (4.10 kg ha^{-1}) uptake was observed for BRRI dhan58 whereas BRRI dhan28 showed the lowest Zn (0.45 kg ha^{-1}) uptake. In case of the rate of fertilizer application, higher amounts of N (124.80 kg ha^{-1}), P (14.67 kg ha^{-1}), K (105.54 kg ha^{-1}), S (5.81 kg ha^{-1}), and Zn (0.63 kg ha^{-1}) were taken up from FRG plots than those from the FP plots indicating a better plant nutrition with more balance fertilization with FRG than with FP. Evaluation of apparent nutrient balances in the post-harvest soil indicated positive results for all nutrients (N, P, S, Zn) except K with recommended doses of fertilizers.

Keywords: Apparent nutrient balance, Balanced fertilizer, *Haor*, Nutrient uptake, Rice, Variety

INTRODUCTION

Agriculture is a very important sector contributing to food security and the economy of Bangladesh. Rice (*Oryza sativa* L.) is the main crop in terms of area, production and contribution to the national economic development of Bangladesh. The total rice growing area in the year 2019-20 was 11.42 million ha and the estimated total rice production was about 36.60 million metric tons (BBS, 2020). *Boro* rice (winter dry season rice) is the most important crop accounting for about 55 % of the total rice output of Bangladesh. In

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2019-20, *Boro* rice covered 4.8 million ha and produced 19.64 million metric tons (BBS, 2020). In *Haor* areas, making up a specialized wetland ecosystem, crop agriculture are chiefly dominated by *Boro* rice monoculture. Almost 80 % of this area is covered by *Boro* rice (Huda, 2004). Farmers of the *Haor* areas commonly grow local *Boro* (0.47 %), HYV *Boro* (82.43 %) and hybrid (17.10 %) especially BRRI dhan28, BRRI dhan29 (Master Plan, 2012). In Bangladesh, nutrient deficiency in soils is intensifying (Shahane *et al.* 2018) one of the reasons for this being unbalanced fertilizer use. A number of surveys revealed that the farmers of *Haor* areas apply unbalanced fertilizers in *Boro* rice cultivation (Ali, 2016; Aziz, 2020; Saha, 2020). Unbalanced fertilizer use may affect inherent soil fertility causing 'soil mining' as against 'soil binding' that could result from balanced fertilization (BARC, 2018). Soil binding leads to sustainable increase in crop production for meeting future challenges. Application of balanced fertilization is the key to enhancement of nutrient use efficiency of the applied plant nutrients for maintaining soil productivity. The present experiment was carried out with a view to observing the response of different varieties of *Boro* rice to fertilizer application in terms of nutrient uptake in H*aor* area of Bangladesh.

MATERIALS AND METHODS

The experiment was carried out during the 2018-19 *Boro* season (November 2018 to April 2019) in a farmer's field of the *Dekar Haor* area of South Sunamganj upazila of the Sunamganj district of Bangladesh. Agro-ecologically, the experimental site belongs to the Sylhet Basin (AEZ-21). The treatments in the two-factor experiment consisted of three *Boro* rice varieties viz., V_1 = BRRI dhan28, V_2 = BRRI dhan29 and V_3= BRRI dhan58; and two fertilizer levels viz. F_1 = N-P-K-S-Zn at the rates of 138-22-63-13-1 kg ha^{-1}, (FRG-2012) and F_2 = the local farmers' practice (FP), N-P-K at the rates of 57-12-12 kg ha^{-1}. The experiment was laid out in a randomized complete block design (RCBD) with three replications. The size of the unit plot was 5 m × 4 m i.e. 20 m^2. Seeds were sown in the seedbed on 25 November, 2018. Seedlings were transplanted in the main field on 1 January, 2019 with a row to row and hill to hill 25 cm × 15 cm spacing. Urea, TSP, MoP, gypsum and $ZnSO_4$ were used as N, P, K, S and Zn sources, respectively. All fertilizers except urea were applied as basal dose. Urea was top dressed in three equal splits at 15, 30 and 45 days after transplanting. Timely irrigation, weeding and pesticide application were done. Grain and straw yields were recorded on a whole plot basis. Nutrient concentrations in grain and straw were estimated by analyzing grain and straw samples following standard methodologies (Table 1). Nutrient uptake by the crop (grain + straw) was calculated from nutrient concentrations and crop yields using the following formula-

Nutrient uptake by grain = nutrient concentration in grain×yield (kg ha^{-1})/100. Nutrient uptake from straw was also calculated by the same formula. Apparent nutrient balance of soil was calculated as the difference of the amount of nutrients added through fertilizers and the total nutrient uptake by the above ground rice crops biomass.

Table 1: Methods used for chemical analysis of grain and straw

Parameters	Analytical methods
Total N	Total N content of grain and straw was determined by micro-Kjeldahl method (Bremner and Mulvaney, 1982). Sample was digested with conc. H_2SO_4 in presence of catalyst mixture (K_2SO_4:$CuSO_4.5H_2O$: Se=10:1:0.1). Nitrogen in the digest was estimated by distilling the digest with 10N NaOH followed by titration of the distillate trapped into H_3BO_3 indicator solution with 0.01N H_2SO_4.
Available P	The sample was digested with di-acid mixture (HNO_3-$HClO_4$) (Fang, 1991) and this digest was used to determine P, K, S and Zn contents. The concentration of P in the digest was determined colorimetrically using molybdovanadate solution yellow colour method (Yoshida *et al*. 1976).
Exchangeable K	The concentration of K in the digest was determined directly by flame photometer (Yoshida *et al*. 1976).
Available S	The S concentration in the digest was determined by developing turbid using $BaCl_2$ (Chapman and Pratt, 1964)
Total Zn	The concentration of Zn in the acid digest was determined directly by atomic absorption spectrophotometer (Yoshida *et al.* 1976).

The data were analyzed by using R package software and means were adjudged by DMRT (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Nitrogen content and uptake in grain and straw

Variety, fertilizer, and interaction of variety and fertilizer influenced N concentration in rice grain and straw and total N uptake significantly (Table 2). The highest grain (0.894%) and straw (0.438%) N concentrations were recorded in BRRI dhan58 whereas BRRI dhan28 had the lowest N concentrations in grain (0.821%) and straw (0.377%). Higher N concentrations in grain (0.992 %) and straw (0.473%) were as found to be due to the application of recommended fertilizers while lower N concentrations in grain (0.511%) and straw (0.301%) were the result of unbalanced fertilizer application in FP. In case of variety×fertilizer interaction, the highest N concentrations in grain (1.072%) and straw (0.540%) were found in BRRI dhan58 with balanced fertilizers (FRG) while the lowest N concentrations in grain (0.501%) and straw (0.262%) were recorded in BRRI dhan29 with FP.

Table 2: Single and interaction effect of varieties and fertilizers on N content and uptake by *Boro* rice

Treatment	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	N concentration (%)		N uptake (kg ha^{-1})		Total N uptake (kg ha^{-1})
			Grain	Straw	Grain	Straw	
Variety							
V_1	6.08 b	8.53 a	0.821c	0.377 c	51.80 b	32.15 b	83.95 b
V_2	7.66 a	9.23 a	0.839bc	0.396 b	64.26 a	38.70 a	102.96 a
V_3	6.37 ab	7.25 b	0.894a	0.438 a	56.94 ab	31.76 b	88.70 b
Level of significance	*	*	**	**	**	**	**
Fertilizer							
F_1	7.18	9.02 a	0.992 a	0.473 a	71.22 a	42.66 a	113.88 a
F_2	6.23	7.67 b	0.511b	0.301b	31.83 b	23.08 b	54.91b
Level of significance	NS	**	**	**	**	**	**
Variety × Fertilizer							
$V_1 F_1$	6.58	10.06 a	0.985b	0.463b	64.81 b	46.57 a	111.38 b
$V_1 F_2$	5.59	7.01 b	0.567c	0.300c	31.69 d	21.03 c	52.72 d
$V_2 F_1$	8.17	9.84 a	0.993b	0.470b	81.12 a	46.24 a	127.36 a
$V_2 F_2$	7.14	8.62 ab	0.501d	0.262d	35.77 c	22.58 c	58.35c
$V_3 F_1$	6.77	7.15 b	1.072a	0.540a	72.57 ab	38.61 b	111.18 b
$V_3 F_2$	5.97	7.37 b	0.510d	0.297c	30.45 d	21.88 c	52.33 d
Level of significance	NS	*	**	*	*	*	*
CV (%)	17.65	10.85	2.72	5.19	13.40	14.02	9.86

** = significant at 1 % level of probability, * = significant at 5 % level of probability, NS = Not significant, V_1 = BRRI dhan28, V_2 = BRRI dhan29, V_3 = BRRI dhan58, $F_1 = N_{138}P_{22}K_{63}S_{13}Zn_1$ kg ha^{-1} (FRG - 2012), $F_2 = N_{57}P_{12}K_{12}$ kg ha^{-1}(FP), CV (%) = Coefficient of variation (%)

BRRI dhan29 had the highest N uptake in grain (64.26 kg ha^{-1}) and straw (38.70 kg ha^{-1}). The lowest N uptake in grain (51.80 kg ha^{-1}) was recorded for BRRI dhan28 while BRRI dhan58 had the lowest N uptake in straw (29.59 kg ha^{-1}) which was statistically similar to BRRI dhan28. Nitrogen uptake in grain (71.22 kg ha^{-1}) and straw (42.66 kg ha^{-1}) was higher with balanced fertilizers (FRG) whereas lower N uptake in grain (31.83 kg ha^{-1}) and straw (23.08 kg ha^{-1}) was found with unbalanced fertilization (FP). In case of interaction, the highest N uptake in grain (81.12 kg ha^{-1}) was found in BRRI dhan29 while BRRI dhan28 showed the highest N uptake in straw (46.57 kg ha^{-1}) with balanced fertilizers. BRRI dhan28 showed the lowest N uptake in grain (30.45 kg ha^{-1}) while the lowest N uptake in straw (21.03 kg ha^{-1}) was found in BRRI dhan29 with farmers' practiced fertilizers. The highest total N uptake (102.96 kg ha^{-1}) was recorded in BRRI dhan29 while BRRI dhan28 showed the lowest total N uptake (83.95 kg ha^{-1}) which was statistically similar to BRRI dhan58. Balanced fertilization (FRG) resulted in higher total N uptake (113.88 kg ha^{-1}) whereas lower total N uptake (54.91 kg ha^{-1}) was found with FP.

Variety x fertilizer interaction showed the highest total N uptake (127.36 kg ha^{-1}) in BRRI dhan29 with balanced fertilizers (V_2F_1) while the lowest total N uptake (52.33 kg ha^{-1}) was found in BRRI dhan58 with FP (V_3F_2). The experimental results indicated that the content and uptake of N were increased due to the application of balanced fertilizers. Improvement in N uptake with increased N level was reported by Sandhu and Mahal (2014).

Phosphorus content and uptake in grain and straw

Differences in variety caused significant variation on P concentration and P uptake in rice grain and straw and total P uptake (Table 3). The highest P concentrations in grain (0.121%) and straw (0.050%) were recorded for BRRI dhan58 whereas BRRI dhan28 showed the lowest P concentrations in grain (0.110%) and straw (0.042%). BRRI dhan29 showed the highest P uptake in grain (8.88 kg ha^{-1}) and straw (4.06 kg ha^{-1}) while the lowest P uptake in grain and straw was recorded 6.68 kg ha^{-1} and 3.58 kg ha^{-1}, respectively in BRRI dhan28. The highest total P uptake (12.94 kg ha^{-1}) was recorded in BRRI dhan29 whereas BRRI dhan28 showed the lowest total P uptake (10.26 kg ha^{-1}).

Significant variations in P concentration, P uptake in rice grain and straw and total P uptake were observed due to fertilizer packages. The P concentrations in grain (0.113%) and straw (0.054%) were found higher due to the application balanced fertilizers while lower P concentration in grain and straw was recorded 0.072% and 0.029%, respectively with farmers' practiced fertilizers. Similar trend was also observed for P uptake in rice grain and straw and total P uptake.

Interaction of variety and fertilizer did not affect P concentration and P uptake significantly in rice grain and straw except total P uptake. The highest total P uptake (16.59 kg ha^{-1}) was observed in BRRI dhan29 with application of recommended fertilizers (V_2F_1). The lowest total P uptake (5.66 kg ha^{-1}) was found in BRRI dhan28 with farmers' practiced fertilizers (V_1F_2). Nair and Rajasree (2004) reported that higher contents of P in grains and straw could be obtained with higher levels P_2O_5 treatment. Sahar and Burbey (2003) observed that increasing the rates of P significantly increased the grain number $panicle^{-1}$. Sharma and Prasad (2003) concluded that application of TSP had significant effects on grain and straw P uptake in rice. Brasil *et al.* (2002) also reported that higher level of P_2O_5 showed the higher grain and straw P uptake. Similar results also found by Kumar *et al.* (2004).

Table 3: Single and interaction effects of varieties and fertilizers on P content of and uptake by *Boro* rice

Treatment	P concentration (%)		P uptake ($kg\ ha^{-1}$)		Total P uptake ($kg\ ha^{-1}$)
	Grain	Straw	Grain	Straw	
Variety					
V_1	0.110c	0.042b	6.68c	3.58b	10.26c
V_2	0.116b	0.044b	8.88a	4.06a	12.94a
V_3	0.121a	0.050a	7.70ab	3.63b	11.33b
Level of significance	**	**	**	*	**
Fertilizer					
F_1	0.113a	0.054a	8.11a	4.87a	12.98a
F_2	0.072b	0.029b	4.48b	2.22b	6.7b
Level of significance	**	**	**	**	**
Variety × Fertilizer					
$V_1 F_1$	0.123	0.060	8.09	6.03	14.12b
$V_1 F_3$	0.070	0.025	3.91	1.75	5.66d
$V_2 F_1$	0.133	0.058	10.89	5.70	16.59a
$V_2 F_3$	0.070	0.030	4.99	2.58	7.59c
$V_3 F_1$	0.143	0.061	9.68	4.36	14.04b
$V_3 F_3$	0.083	0.029	4.95	2.13	7.09c
Level of significance	NS	NS	NS	NS	*
CV (%)	9.72	14.89	15.93	23.78	12.75

** = significant at 1 % level of probability, * = significant at 5 % level of probability, NS = Not significant, V_1 = BRRI dhan28, V_2 = BRRI dhan29, V_3 = BRRI dhan58, $F_1 = N_{138}P_{22}K_{63}S_{13}Zn_1 kg\ ha^{-1}$ (FRG - 2012), $F_2 = N_{57}P_{12}K_{12}\ kg\ ha^{-1}$(FP), CV (%) = Coefficient of variation (%)

Potassium content and uptake in grain and straw

Variety and fertilizer packages showed significant variations in K concentration, K uptake in rice grain and straw and total K uptake (Table 4). BRRI dhan58 showed the highest K concentration in grain (0.205%) and straw (0.181%) while BRRI dhan28 showed the lowest K concentration in grain (0.181%) and straw (0.946%). Balanced fertilizers gave higher K concentration in grain (0.186 %) and straw (1.022 %) whereas lower K concentration in grain and straw was found due to the application of farmers' practiced fertilizers. BRRI dhan29 showed the highest K uptake in grain (14.477 kg ha^{-1}) and straw (88.977 kg ha^{-1}) while BRRI dhan28 showed the lowest K uptake in grain (11.00 kg ha^{-1}) and straw (80.693 kg ha^{-1}).

Table 4: Single and interaction effects of varieties and fertilizers on K content and uptake by *Boro* rice

Treatment	K concentration (%)		K uptake (kg ha^{-1})		Total K uptake (kg ha^{-1})
	Grain	Straw	Grain	Straw	
Variety					
V_1	0.181c	0.946c	11.00c	80.69a	91.69b
V_2	0.189b	0.964bc	14.47a	88.97a	103.45a
V_3	0.205a	1.042a	13.06b	75.54b	88.60b
Level of significance	**	**	**	**	**
Fertilizer					
F_1	0.186a	1.022a	13.35a	92.18a	105.54a
F_2	0.176b	0.871b	10.96b	66.80b	77.77b
Level of significance	**	**	**	**	**
Variety × Fertilizer					
$V_1 F_1$	0.178	0.985	11.71	99.09	110.80
$V_1 F_2$	0.169	0.820	9.44	57.48	66.93
$V_2 F_1$	0.182	0.987	14.87	97.12	111.99
$V_2 F_2$	0.172	0.845	12.28	72.84	85.12
$V_3 F_1$	0.202	1.074	13.67	76.79	90.47
$V_3 F_3$	0.179	0.945	10.69	69.64	80.33
Level of significance	NS	NS	NS	NS	NS
CV (%)	10.69	3.47	17.80	15.54	14.32

** = significant at 1 % level of probability, * = significant at 5 % level of probability, NS = Not significant, V_1 = BRRI dhan28, V_2 = BRRI dhan29, V_3 = BRRI dhan58, F_1 = $N_{138}P_{22}K_{63}S_{13}Zn_1$kg ha^{-1} (FRG - 2012), F_2 =$N_{57}P_{12}K_{12}$ kg ha^{-1}(FP), CV (%) = Coefficient of variation (%)

Higher K uptake in grain (13.35 kg ha^{-1}) and straw (92.18 kg ha^{-1}) was found with balanced fertilizers while lower K uptake in grain and straw was observed due to the application of farmers' practiced fertilizers.

BRRI dhan29 showed the highest total K uptake (103.455 kg ha^{-1}). The lowest total K uptake (88.603 kg ha^{-1}) was found in BRRI dhan58 which was statistically identical to BRRI dhan28. BARC recommended fertilizers gave higher total K uptake (105.539 kg ha^{-1}) while lower total K uptake (77.77 kg ha^{-1}) was found with FP. Insignificant variations were found due to interaction effect on K concentration, K uptake in rice grain and straw and total K uptake. Bachkaiya *et al.* (2007) reported that the highest dose of K fertilizer gave the highest mean K contents in the grain and straw and in total K uptake. Rahman *et al.* (2004) found that increasing potassium level promoted K uptake in rice grains and straw. Panaullah *et al.* (2006) reported that the majority of K uptake was in straw compared to grain.

Sulphur content and uptake in grain and straw

Variety showed insignificant variations in S concentration, S uptake in rice grain and straw and total S uptake (Table 5). Fertilizers packages exerted significant effect on S concentration and S uptake in rice grain and straw. The S concentration in grain (0.032%) and straw (0.039%) was recorded higher due to the applications of $N_{138}P_{22}K_{63}S_{13}Zn_1$kg ha^{-1} (FGR, 2012) fertilizers. Lower S concentration in grain (0.021%) and straw (0.022%) was found with FP. Similar trend was also observed for S uptake in rice grain and straw and total S uptake.

Table 5. Single and interaction effect of varieties and fertilizers on S content and uptake by *Boro* rice

Treatment	S concentration (%)		S uptake (kg ha^{-1})		Total S uptake (kg ha^{-1})
	Grain	Straw	Grain	Straw	
Variety					
V_1	0.031	0.035	1.88	2.98	4.87
V_2	0.029	0.033	2.22	3.04	5.26
V_3	0.028	0.032	1.78	2.32	4.10
Level of significance	NS	NS	NS	NS	NS
Fertilizer					
F_1	0.040a	0.047a	2.87a	4.24a	7.11a
F_2	0.021b	0.022b	1.30b	1.68b	2.99b
Level of significance	**	**	**	**	**
Variety × Fertilizer					
V_1 F_1	0.037	0.047	2.43	4.72	7.16
V_1 F_2	0.017	0.020	0.95	1.40	2.35
V_2 F_1	0.037	0.033	3.02	3.24	6.27
V_2 F_2	0.020	0.023	1.42	1.98	3.41
V_3 F_1	0.039	0.036	2.78	2.57	5.35
V_3 F_2	0.023	0.027	1.37	1.98	3.36
Level of significance	NS	NS	NS	NS	NS
CV (%)	25.82	33.77	25.40	31.83	18.59

** = significant at 1 % level of probability, * = significant at 5 % level of probability, NS = Not significant, V_1 = BRRI dhan28, V_2 = BRRI dhan29, V_3 = BRRI dhan58, F_1 = $N_{138}P_{22}K_{63}S_{13}Zn_1$kg ha^{-1} (FRG - 2012), F_2 =$N_{57}P_{12}K_{12}$ kg ha^{-1}(FP), CV (%) = Coefficient of variation (%)

There were no significant interaction effect of varieties and fertilizers on S concentration, S uptake in rice grain and straw and total S uptake. Ali *et al*. (2004) reported that S content and uptake increased with the increased rates of S fertilizers (applied alone or in combination).

Zinc content and uptake in grain and straw

Variety showed significant variations in Zn concentration in rice grain and straw and Zn uptake in rice grain (Table 6). BRRI dhan58 showed the highest Zn concentration in grain (18.42 ppm) and straw (47.08 ppm) whereas the lowest Zn concentration in grain (16.32 ppm) and straw (41.17 ppm) was observed in BRRI dhan28. The highest Zn uptake in grain (0.13 kg ha^{-1}) was observed in BRRI dhan29 while BRRI dhan28 showed the lowest grain Zn uptake (0.10 kg ha^{-1}).

Table 6. Single and interaction effect of varieties and fertilizers on Zn content and uptake by *Boro* rice

Treatment	Zn concentration (ppm)		Zn uptake (kg ha^{-1})		Total Zn uptake (kg ha^{-1})
	Grain	Straw	Grain	Straw	
Variety					
V_1	16.32b	41.17b	0.10c	0.35	0.45
V_2	16.79b	41.33b	0.13a	0.38	0.51
V_3	18.42a	47.08a	0.12b	0.34	0.46
Level of significance	**	**	**	NS	NS
Fertilizer					
F_1	22.08a	52.25a	0.16a	0.47a	0.63a
F_2	14.33b	35.83b	0.09b	0.28b	0.36b
Level of significance	**	**	**	**	**
Variety × Fertilizer					
$V_1 F_1$	20.33	49.33	0.13	0.50	0.63
$V_1 F_2$	13.67	34.00	0.08	0.24	0.31
$V_2 F_1$	21.33	49.67	0.17	0.49	0.66
$V_2 F_2$	14.00	33.33	0.10	0.29	0.39
$V_3 F_1$	25.00	58.00	0.17	0.41	0.58
$V_3 F_2$	15.00	39.33	0.09	0.29	0.38
Level of significance	NS	NS	NS	NS	NS
CV (%)	10.55	6.04	16.80	17.21	14.53

** = significant at 1 % level of probability, * = significant at 5 % level of probability, NS = Not significant, V_1 = BRRI dhan28, V_2 = BRRI dhan29, V_3 = BRRI dhan58, F_1 = $N_{138}P_{22}K_{63}S_{13}Zn_1$kg ha^{-1} (FRG - 2012), F_2 =$N_{57}P_{12}K_{12}$ kg ha^{-1}(FP), CV (%) = Coefficient of variation (%)

Fertilizers packages exerted significant effect on Zn concentration, Zn uptake in rice grain and straw and total Zn uptake. The Zn concentration in grain (22.08 ppm) and straw (14.33 ppm) was recorded higher with balanced fertilizers while lower Zn concentration in grain (52.25 ppm) and straw (35.83 ppm) was found with FP. Similar trend was also observed for Zn uptake in rice grain and straw and total Zn uptake. Khan *et al.* (2007) found that paddy yield was significantly influenced by Zn levels (ranged from 3.9 to 5.9 t ha^{-1}).Ram *et al.* (2012) found that Zn content in grain was 155.55 ppm and 171.95 ppm for two rice varieties NDR-359 and HUBR 2-1, respectively.

Apparent nutrient balance

Fertilizer packages showed positive apparent N balance (Table 7). Uptake of N in the rice crop was lower than addition of N except the interaction of V_2F_2. Positive apparent P balance was found for fertilizer as well as interaction of variety and fertilizer. In case of interactions, the P range was 4.41 to 8.36 kg ha^{-1}. Both fertilizers packages and interaction of variety and fertilizer exerted negative apparent K balance. In case of interactions, the K range was -73.12 to -26.97 kg ha^{-1}. The apparent balance for S and Zn were found positive due to the application of balanced fertilizers while negative apparent S (-2.99 kg ha^{-1}) and Zn (-0.36 kg ha^{-1}) balance was found with unbalanced fertilization (FP) where S and Zn fertilizers were not applied.

Table 7. Apparent nutrient balance of soil as affected by different fertilizers doses, and interactions of variety and fertilizers

Treatment	Total nutrient added (kg ha^{-1})					Total nutrient uptake (kg ha^{-1})					Nutrient balance (kg ha^{-1})				
	N	P	K	S	Zn	N	P	K	S	Zn	N	P	K	S	Zn
Fertilizers															
F1	138	22.4	63.5	13.5	1.3	113.88a	12.98a	105.54a	7.11a	0.63a	24.12	9.42	-42.15	6.39	0.67
F2	57	12	12	-	-	54.91b	6.70 b	77.77b	2.99b	0.36b	2.09	5.3	-65.7	-2.99	-0.36
Level of significance	NA	NA	NA	NA	NA	**	**	**	**	**	NA	NA	NA	NA	NA
Variety × Fertilizer (V × F)															
$V_1 F_1$	138	22.4	63.5	13.5	1.3	111.38	14.12b	110.80	7.16	0.63	26.62	8.28	-47.3	6.34	0.67
$V_1 F_2$	57	12	12	-	-	52.72	5.66d	66.93	2.35	0.31	4.28	6.34	-54.93	-2.35	-0.31
$V_2 F_1$	138	22.4	63.5	13.5	1.3	127.36	16.59b	111.99	6.27	0.66	10.64	5.81	-48.49	7.23	0.64
$V_2 F_2$	57	12	12	-	-	58.35	7.59cd	85.12	3.41	0.39	-1.35	4.41	-73.12	-3.41	-0.39
$V_3 F_1$	138	22.4	63.5	13.5	1.3	111.18	14.04a	90.47	5.35	0.58	26.82	8.36	-26.97	8.15	0.72
$V_3 F_2$	57	12	12	-	-	52.33	7.09c	80.33	3.36	0.38	4.67	4.91	-68.33	-3.36	-0.38
Level of significance	NA	NA	NA	NA	NA	NS	*	NS	NS	NS	-	-	-	-	-
CV (%)	-	-	-	-	-	9.86	12.75	14.32	18.59	14.53	-	-	-	-	-

** = significant at 1 % level of probability, * = significant at 5 % level of probability, NS = Not significant, NA = not analyzed; V_1 = BRRI dhan28, V_2 = BRRI dhan29, V_3 = BRRI dhan58, $F_1 = N_{138}P_{22}K_{63}S_{13}Zn_1$ kg ha^{-1} (FRG- 2012), $F_2 = N_{57}P_{12}K_{12}$ kg ha^{-1}(FP), CV (%) = Coefficient of variation (%)

Interaction of variety and fertilizer also showed positive apparent N balance except the interaction of V_2F_2 (-1.35 kg ha^{-1}). Uptake of N in the rice crop was lower than addition of N except the interaction of V_2F_2. Positive apparent P balance was found for fertilizer as well as interaction of variety and fertilizer. In case of interactions, the P range was 4.41 - 8.36 kg ha^{-1}. Both fertilizers packages and interaction of variety and fertilizer exerted negative apparent K balance. In case of interactions, the K range was -73.12 to -26.97 kg ha^{-1}. The apparent balance for S and Zn was found positive due to the applications of balanced fertilizers while negative apparent S (-2.99 kg ha^{-1}) and Zn (-0.36 kg ha^{-1}) balance was found with farmers' practiced fertilizers when S and Zn fertilizers were not applied.

CONCLUSION

Boro rice was found to absorb relatively high amounts of nutrients from soil in Haor areas when balanced soil fertilization was done according to the national fertilizer guidelines compared with local farmers' practices of fertilization which was largely unbalanced. The application of recommended fertilizers is expected to increase nutrient concentrations in crops, boost yield and maintain a good soil environment for sustainable crop production in the future.

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Author Contributions

A statement outlining the authors' individual contributions to the paper (e.g. conceptualization, experiment designing and methodology, investigation, data analysis, supervision, writing/editing, etc.) should be submitted.

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