Climate Change

Modeling climate change impacts on Boro rice production in Bangladesh

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ABSTRACT

The study aimed at modeling of climate change impacts on boro rice production in Bangladesh under CERES-Rice model using DSSAT 4.7. Eight division of Bangladesh (Barishal, Chattogram, Dhaka, Mymensingh, Rajshahi, Khulna, Rangpur and Sylhet) and two widely cultivated variety (BRRI dhan29 and BRRI dhan58) were used as treatment of the experiment. Modeling was done by DSSAT 4.7. The estimated grain yield reduction due to temperature rise was 2.6%, 6%, and 11% for BRRI dhan29 and 8.7%, 17.2% and 26.8% for BRRI dhan58 for one °C, two °C and three °C, respectively. The highest yield reduction was observed in Dhaka, Sylhet and Chattogram whereas, the lowest was observed in Rajshahi, Rangpur and Mymensingh division. Dhaka, Sylhet and Chattogram were the most vulnerable area of rice production due to climate change. However, growing long-duration variety like BRRI dhan29 might be an option to mitigate climate change impact on these regions. The yield loss was minimized by the combined effects of higher CO2 concentration and elevated air temperature. However, elevated CO2 concentration will not be able to completely offset yield. Besides, the reduction in crop growing period due to temperature rise will cause a substantial yield reduction of current rice cultivars. Crop developers will soon face the problem of developing a new cultivar which can tolerate the effect of elevated temperature with no significant yield loss.

Keywords: Modeling, Climate Change, Impacts, Boro Rice, BRRI dhan29, BRRI dhan58, DSSAT

1. INTRODUCTION

Bangladesh is one of the top most nations vulnerable to climate change (Harmeling 2008). IPCC also recognizes Bangladesh as one of the most vulnerable countries in the world to the negative impacts of climate change. Various climate changes in Bangladesh like recurring floods, river bank erosion, drought in dry season, salinity increase due to back water effect, downing ground water level have contributed to augment the vulnerability of many regions. Nevertheless, many areas of this country remain outside the ambit of climate change-related actions (Titumir and Basak, 2012). Therefore, quick action using innovative approaches for climate change adaptation regarding crop plant is required. Rice is noticeably dominated crop by Bangladesh's agriculture. Among the rice growing seasons in Bangladesh, dry season rice (boro rice) has the maximum share (53 percent) in total rice production (Maniruzzaman et al., 2018).

Boro rice, a major crop during the dry season (January to May), is entirely dependent on irrigation. IPCC projected that Bangladesh will face an uneven rainfall distribution pattern and an increase in temperature due to climate change (Solomon, 2007). Elevated temperature will change the length of the rice growing period. High temperature will create the increased demand of evapotranspiration. Elevated temperatures will increase the need for evapotranspiration. As a result of elevated temperature, rice plant physiology will be changed and it will shorten the vegetative growth of rice. The short growth span will affect crops growth and development. However, boro rice crop are sensitive to temperature during their critical stages and increased temperature above the optimum may reduce yield drastically (Krishnan et al., 2011).

Maniruzzaman et al., (2018) noticed yield loss and reduced growth duration of irrigated rice (boro rice) in elevated air temperature over normal temperature in Bangladesh. Crop growth simulation model are the tools which may reduce the need for expensive and time-consuming field experimentations as they can be used to extrapolate the results of the research conducted in one season or one location to other seasons, locations or management (Nain and Kersebaum, 2007). It is also possible to use crop growth models to predict performance to introduce a new crop in a locality (Moorthy et al., 2003). Different crop models were used to analyze the potential effects of climate change on crop yields in various regions (Challinor et al., 2004; Watson et al., 2015; Lobell et al., 2006). Decision Support System for Agrotechnology Transfer (DSSAT) v4.7 is a windows-based programme that includes tools and utility programmes for managing soil, water resources, weather, genetic coefficients, crop and pest data.

These tools can reduce the need for expensive and time-consuming field trials and could be utilized for yield gap analyses in various crops, including rice (Pathak et al., 2004). Bangladesh has achieved a tremendous success in developing high yielding inbreed and hybrid rice varieties in recent days. Bangladesh Rice Research Institute (BRRI), Bangladesh Institute of Nuclear Agriculture (BINA), and other private organizations developed several stress-tolerant varieties for the vulnerable areas. The varieties have a variation of growth duration ranging from 140 days to 165 days (BRRI, 2022). So, a comprehensive analysis of grain yield performance is necessary to understand the impacts of elevated temperature on boro rice cultivation. The objective of the study was to assess possible change and predict boro rice yield of selected boro rice varieties due to climate change.

2. MATERIALS AND METHODS

Study area

The study area covered eight representative locations in Bangladesh (Barishal, Chattogram, Dhaka, Mymensingh, Rajshahi, Khulna, Rangpur and Sylhet).

Data collection and input parameters to model

The Bangladesh meteorological department (BMD) provided historical (1981 to 2020) daily weather data for fifteen locations, including maximum and minimum temperatures, relative humidity, wind speed, sunshine hours, and rainfall. Soil physical properties, including texture, particle size distribution (percentage of sand, silt, and clay), bulk density, and chemical properties like soil organic carbon, nitrogen, pH, etc. data from three distinct layers, 0-15 cm, 15-30 cm, and 30-60 cm, were collected from the Soil Resource Development Institute (SRDI) and used as input to the model. Decision Support System for Agrotechnology Transfer (DSSAT) v4.7 is a Windows-based programme that includes tools and utility programmes for managing soil, water resources, weather, genetic coefficients, crop, and pest data.

It allows users to input, organize, store, retrieve and analyze crop, soil and weather data and to quantify their effects on crop growth, productivity, and sustainability of agricultural production (Nain and Kersebaum, 2007). These tools can reduce the need for expensive and time-consuming field trials and could be utilized for yield gap analyses in various crops including, rice (Pathak et al., 2004). The DSSAT can be used as a decision support tool for multi-location yield trials, optimizing N fertilizer management for a targeted crop yield while minimizing nutrient losses and selecting optimum planting windows. Recently, researchers have used crop growth models to study precision agriculture within the framework of a decision support system (DSS) that automates simulations using various crop management strategies.

The researcher created daily weather files and soil files in the DSSAT model. The tested two varieties were BRRI dhan29 and BRRI dhan58. The Bangladesh Rice Research Institute (BRRI) developed BRRI dhan29, a long-duration variety of the boro season, which typically takes 160 days to complete its life cycle. Whereas, the same institute also developed BRRI dhan58, a medium-duration (155 days) boro rice variety. The cultivar coefficients were collected from Maniruzzaman et al., (2017) and it was well calibrated and validated compared with nitrogen fertilizer management and multi-location (G*E) experiments in Bangladesh. For the simulation, we transplanted 25–30-day-old seedlings from 01 to 15 January at all 8 locations. BRRI recommended fertilizer doses 120 kg nitrogen per hectare, irrigation (applied 60 cm irrigation when water disappeared from the field) and other agronomic management practices were followed.

Simulation of growth duration, grain yield, and biological yield under climate change

The model simulated grain yield and agronomic parameters for eight individual study locations for the base year 2019-20 following normal condition. To do this a multi-location trial crop management files were created using the respective soil and weather file of the stations. To determine the impact of elevated air temperature, environment modification was done by adding 0.5°C, 1°C, 1.5°C, 2°C, 2.5°C, and 3°C with observed maximum and minimum temperature of 2018-2019 of each study station. The base data for CO2 in 2018 - 2019 was 413.3 ppm. Grain yield is also projected for interaction between temperature and elevated CO2 concentration by 420 ppm, 450 ppm, 480 ppm, and 510 ppm.

Yield Simulation of boro rice the Near Future and Far future

Grain yield of BRRI dhan58 and BRRI dhan29 was assessed for near future (2060) and far future (2100) projected climate conditions. The 5th phase of the coupled Model Inter-comparison Project (CMIP5) pertains to radiative concentration pathways in RCP4.5. Khan et al., (2020) projected annual maximum temperature rise by 0.4°C, 0.61°C, 0.75°C, and 0.91°C in RCP4.5 by the end of the year 2040, 2060, 2080, and 2100, respectively. However, the study estimated 0.35°C, 0.65°C, 0.78°C, and 0.96°C by the end of year 2040, 2060, 2080, and 2100, respectively. The researchers added the predicted maximum and minimum temperature rise to the base year (2018-19) temperature in the environmental modification file. Finally, simulations were done with these modifications.

Model calibration and validation

The model was calibrated and validated with known grain yield and biomass yield of time of the multi-location trial of eight locations conducted Sylhet, Rangpur, Chattogram, Dhaka, Rajshahi, Mymensingh, Khulna, and Barishal during Boro, 2018-19 and 2019-20. We compared the predicted results with the actual values to validate the model. We analyzed the model performance using normalized root mean square error (nRMSE), prediction error (Pe), the Wilmot index of agreement (d), and the coefficient of determination (R2). The equations are given below:

$$nRMSE = \frac{1}{\bar{O}}\sqrt{\frac{\sum_1^n (P_i - O_i)^2}{N}} \quad \text{(i)}$$

$$P_e = \frac{(P_i - O_i)}{O_i} \times 100 \quad \text{(ii)}$$

$$R^2 = \left[\frac{\sum(O_i-\bar{O})(P_i-\bar{P})}{\sqrt{\sum(O_i-\bar{O})^2\sum(P_i-\bar{P})^2}}\right]^2 \quad \text{(iii)}$$

$$d = 1 - \frac{\sum_{i=1}^N (P_i - O_i)^2}{\sum_{i=1}^N (|P_i-\bar{O}|+|O_i-\bar{O}|)^2} \quad \text{(iv)}$$

The coefficient of determination (R2) ranges from 0 to 1, in which values close to 1 indicate a good agreement, and values greater than 0.5 are considered acceptable in watershed simulations (Moriasi et al., 2007). In the case of nRMSE, a simulation can be regarded as excellent if nRMSE is smaller than 10%, good between 10 and 20%, fair between 20 and 30%, and poor if larger than 30% (Raes et al., 2012). The values of d range between 0 and 1, where 0 indicates no agreement and 1 indicates a perfect agreement between predicted and observed data (Willmott, 1984).

3. RESULTS AND DISCUSSION

Model calibration and validation

Simulated grain yield and biological yield of BRRI dhan29 and BRRI dhan58 from multi-location trials were well fitted with observed data (Table 1). The simulated modeled yield satisfied the statistical parameter with prediction error (2%), coefficient of determination (0.89), nRMSE (7.53%), and index of agreement (0.85) (Table 2). Similarly, predicted biological yield also satisfied observed biological yield with the statistical parameter of prediction error 5.85%, coefficient of determination 0.46, nRMSE 12.4%, and index of agreement (0.52). For both grain yield and biological yield, R^2 was above 0.5, indicating the model was a good prediction.

Table 1 Genetic coefficient of BRRI dhan29 and BRRI dhan58 for Bangladesh condition

Cultivar	P1	P2O	P2R	P5	G1	G2	G3	G4	PHINT
BRRI dhan29	950	12.8	150	550	60	0.023	1.0	1.0	83
BRRI dhan58	850	12.7	150	470	55	0.021	1.0	1.0	83

Where,

P1 = Time (expressed as growing degree days [GDD] in °C above a base temperature of 9 °C) from seedling emergence during which the rice plant is not responsive to changes in photoperiod. This period is also referred to as essential vegetative phase of the plant.

P2O = Critical photoperiod or the longest day length (in hours) at which the development occurs at a maximum rate. At values higher than P2O, the developmental rate is slowed, and hence there is a delayed growth of plants

P2R = Extent to which phasic development leading to panicle initiation is delayed (expressed as GDD in °C) for each hour increase in photoperiod above P2O.

P5 = Time (GDD in °C) from the beginning of grain filling (3 to 4 days after flowering) to physiological maturity with a base temperature of 9°C.

G1 = Potential spikelet number coefficient estimated from the number of spikelets per g of main culm dry weight (excluding leaf blades, sheaths, and spikes) at anthesis. A typical value is 55.

G2 = Single grain weight (g) under ideal growing conditions, that is, non-limiting light, water, nutrients, and absence of pests and diseases.

G3 = Tillering coefficient relative to IR64 cultivar under ideal conditions. A higher tillering cultivar would have a coefficient greater than 1.0.

G4 = Temperature tolerance coefficient. Usually, 1.0 for varieties grown in typical environments. G4 for japonica-type rice growing in a warmer environment would be 1.0 or greater. Likewise, the G4 value for indica-type rice in very cool environments or season would be less than 1.0.

PHINT = Phyllocron interval

Table 2 Statistical evaluation of observed and simulated grain yield and biological yield of BRRI dhan29 and BRRI dhan58 for genetic * environment interaction during Boro, 2018-19 for model calibration

Variety	Transplanting location	Grain yield (kg ha-1)		Biological yield (kg ha-1)	
		Simulated	Observed	Simulated	Observed
BRRI dhan29	Rajshahi	7586	8084	15638	16415
	Mymensingh	7399	7523	15547	14849
	Khulna	7229	7427	15458	14604
	Barishal	7271	6883	15743	14308
BRRI dhan58	Rajshahi	7013	7146	15445	15915
	Mymensingh	6790	6373	15184	13680
	Khulna	6795	6523	15218	13814
	Barishal	6628	6002	15113	12944
	Pe (%)	2.00		5.85	

	R2	0.89	0.46
	nRMSE (%)	7.53	12.40
	d	0.85	0.52

The values of nRMSE were below 10%, pointing out the excellent prediction of the model. The d values of 0.85 and 0.52 for grain yield and biological yield of BRRI dhan29 and BRRI dhan58 represent a perfect agreement of predicted and observed data. Model validation was also done with the observed and simulated yield and biomass data for the following year for four different locations (Sylhet, Rangpur, Khulna, and Barishal). (Table 3). All the statistical analysis between observed and model simulated data showed the perfect model validation.

Table 3 Statistical evaluation of observed and simulated grain yield and biological yield of BRRI dhan29 and BRRI dhan58 for genetic * environment interaction during Boro, 2019-20 for model calibration

Variety	**Transplanting locations**	**Grain yield (kg ha-1)**		**Biological yield (kg ha-1)**	
		Simulated	**Observed**	**Simulated**	**Observed**
BRRI dhan29	Sylhet	6634	6300	14068	14773
	Rangpur	7001	7300	14166	15257
	Chattogram	6568	7000	13993	14012
	Dhaka	7376	7100	15420	16686
BRRI dhan58	Sylhet	6047	6000	13829	13360
	Rangpur	6488	6600	14114	15937
	Chattogram	6932	6700	15017	15812
	Dhaka	6362	6400	14657	15523
	Pe (%)	1.40		5.02	
	R2	0.63		0.64	
	nRMSE (%)	5.53		9.40	
	d	0.89		0.69	

Effect of elevated temperature on boro rice

Impact of rising temperatures on grain yield

Grain yield of BRRI dhan29 (Table 3) and BRRI dhan58 (Table 4) were estimated for varying elevated temperature over base year (2018-19) in the study locations. Dhaka had the highest estimated grain yield among the study locations, but Barishal, Chattogram, and Rajshahi showed similar grain yields for the same management practices (Table 4). The lowest grain yield was found in Mymensingh. Rising temperature by 0.5 ºC decreased grain yield in six locations (Sylhet, Rangpur, Chattogram, Rajshahi, Mymensingh, and Khulna), but in other two locations (Dhaka and Barishal), grain yield will increase slightly. Yield reduction increased with the elevated temperature in all the locations.

Table 4 Yield reduction of BRRI dhan29 at an elevated temperature over the base year (2018-19) at the study locations

Locations	**Base year (2018-19) yield (kg ha-1)**	**Yield reduction (%) for rising temperature over the base year**					
		0.5ºC	**1.0ºC**	**1.5ºC**	**2.0ºC**	**2.5ºC**	**3.0ºC**
BRRI dhan29							
Sylhet	7203	1.3	2.3	5.3	8.6	13.2	19.3
Rangpur	7228	2.5	4.5	2.5	4.8	5.1	8.2
Chattogram	7389	4.1	5.9	10.7	16.8	23.5	30.5
Dhaka	7395	-1.9	0.6	3.7	7.3	14.4	19.4
Rajshahi	7378	2.9	2.6	2.8	4.5	5.2	6.4

Mymensingh	7128	1.9	1.5	2.1	2.2	5.5	9.6
Khulna	7227	2.9	3.6	4.6	4.5	8.3	11.8
Barishal	7391	-0.3	0.8	2.4	4.0	6.4	11.4
Average	7292	1.7	2.6	4.3	6.0	9.5	13.6
BRRI dhan58							
Sylhet	5994	19.6	23.8	28.1	33.6	40.1	42.7
Rangpur	6033	0.1	0.5	3.1	5.2	7.4	11.0
Chattogram	5977	7.4	12.8	21.0	29.1	34.6	39.1
Dhaka	6164	16.6	23.4	27.9	34.5	37.7	44.1
Rajshahi	6375	2.6	2.1	0.4	5.1	10.4	13.3
Mymensingh	6186	3.0	3.2	8.5	12.9	15.9	24.0
Khulna	6048	1.3	2.1	5.9	9.8	13.7	24.8
Barishal	6423	2.6	2.1	9.5	12.2	18.9	22.5
Average	6150	7.0	8.7	12.6	17.2	21.6	26.8

The maximum yield reduction was estimated for Chattogram (30.5%) followed by 19.4% and 19.3% at Dhaka and Sylhet for the mean temperature raised by three ºC. However, yield reduction didn't exceed 10% over the base year in Rangpur, Rajshahi, and Mymensingh, though the temperature raised by three ºC. This indicated that Chattogram, Sylhet, and Dhaka were the most vulnerable areas for BRRI dhan29 cultivation due to rising temperatures. On the contrary, BRRI dhan29 cultivation in Rajshahi, Rangpur, and Mymensingh exhibited less vulnerability to future climate change. BRRI dhan58 showed higher yield reduction due to temperature rise than BRRI dhan29 in all locations. Similar to BRRI dhan29, the model estimated increased yield reduction for BRRI dhan58 with the increase of mean temperature increase over the base year.

Among the tested locations, Dhaka and Sylhet showed yield reduction by >40%, Chattogram estimated 39.1%, and Mymensingh, Khulna, and Barishal projected less than 25% yield reduction for the rising temperature by three ºC. However, Rangpur and Rajshahi estimated the lowest yield reduction, less than 14%. Chowdhury and Khan, (2015) reported that a 1% increase in growing season maximum temperature and rainfall on average will reduce the yield of Boro rice by 1.68 and 0.18 t ha-1, respectively. On the other hand, a 1% increase in minimum temperature and humidity on average could raise boro rice yields by 3.50 and 5.03 t ha^{-1}, respectively.

Rising temperature effect on growth duration of boro rice

The growth duration of BRRI dhan29 and BRRI dhan58 was analyzed against rising mean temperature. Figure 1 and Figure 2 illustrate the relation between temperature rise scenarios and the growth duration of BRRI dhan29 and BRRI dhan58, respectively. The results indicated a reduction in growth duration as the temperature increased. Among the study locations, the highest observed growth duration of BRRI dhan29 was 176 days in Rangpur, followed by 165 days in Rajshahi and 162 days in Mymensingh. The minimum growth duration of the cultivar was 151 days in Dhaka. With the increment of mean temperature by 0.5ºC, the growth duration of the cultivar BRRI dhan29 reduced by 4 days in all locations except Dhaka, Rajshahi, and Barishal.

One-degree Celsius rising temperature estimated the growth duration reduction by 6-9 days. Following the same trend, 9-11 days, 12-15 days, 14-20 days, and 17-23 days life span reduction was estimated for 1.5ºC, 2.0ºC, 2.5ºC, and 3.0ºC rising temperatures, respectively (Figure 1). BRRI dhan58 showed similar results of decreasing growth duration because of the increment of daily average temperature. Observed growth duration in the study year ranged from 142 to 166 days, of which the highest duration was observed in Rangpur and the lowest in Dhaka. Similar to BRRI dhan29, BRRI dhan58 experienced 3-5 days, 6-8 days, 9-11 days, 11-15 days, 14-19 days, 17-22 days life span reduction following 0.5ºC, 1.0ºC, 1.5ºC, 2.0ºC, 2.5ºC and 3.0ºC rising temperature, respectively. Rangpur showed the highest growth duration reduction, whereas Khulna and Barishal had the lowest (Figure 2).

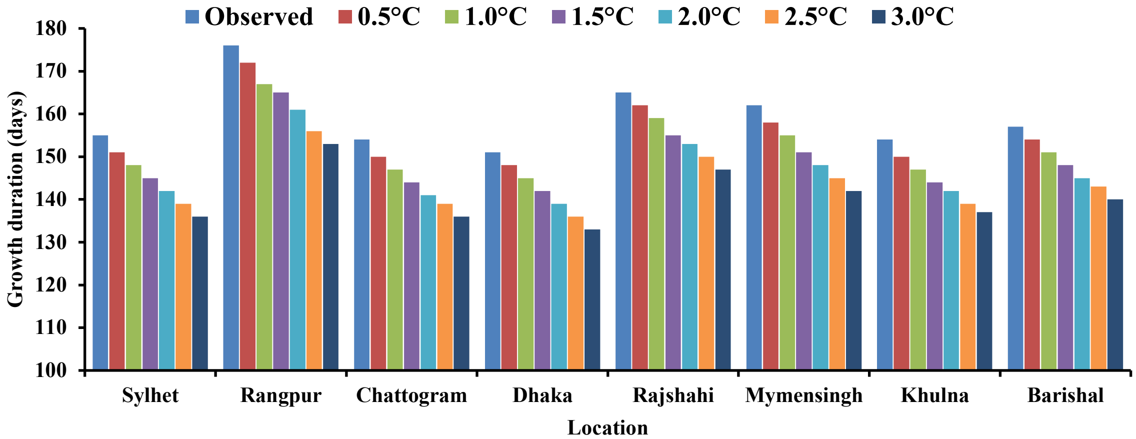

Figure 1 Growth duration of BRRI dhan29 was affected by varying degrees of temperature rise in the study location.

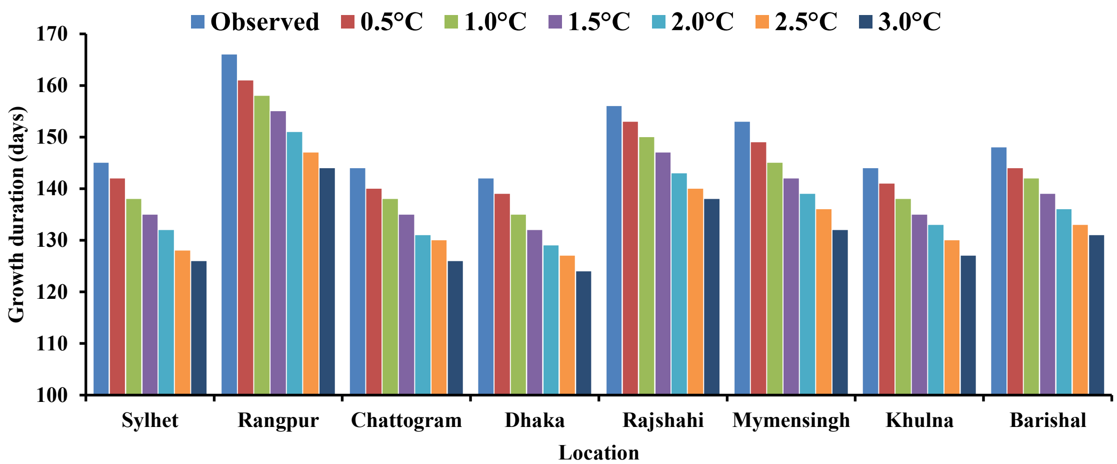

Figure 2 Growth duration of BRRI dhan29 was affected by varying degrees of temperature rise in the study location.

Relation between growth duration and grain yield

A correlation analysis was performed between grain yield and growth duration for both BRRI dhan29 and BRRI dhan58. Results showed a positive correlation between the parameters. BRRI dhan29 exhibited about 32 kg ha^{-1} yield advantages for each day growth duration increment (Figure 3). However, BRRI dhan58 estimated 60 kg ha^{-1} yield advantages for each day growth duration increment. The simulated yields demonstrate that yield increases with the increasing life duration of rice in eight divisions of Bangladesh due to climate change.

Similar results have been reported by (Soora et al., 2013; Roy and Das, 2013). Promchote et al., (2022) stated that the simulated yields are responsive to radiation and GDD. Still, the observed yields in the three years likely relate to seasonally low precipitation during the vegetative phase. Zhang et al., (2013) found that 95.0% of the data series exhibited a negative correlation between the growth duration length and temperature; this correlation was significant in 61.9% of all data series.

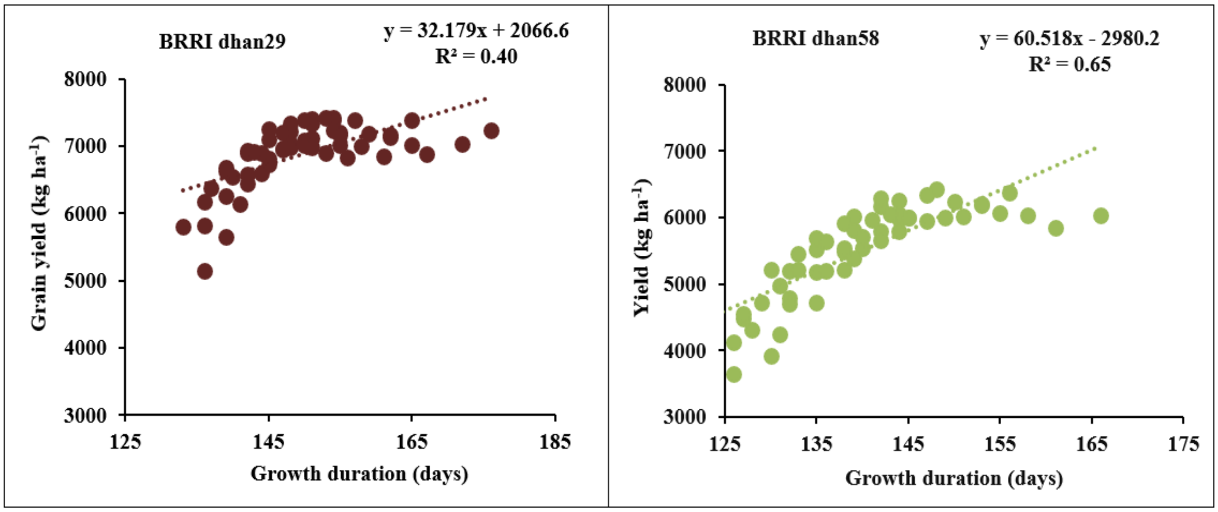

Figure 3 Relationship between growth duration and grain yield of BRRI dhan29 and BRRI dhan58

Effect of elevated temperature and CO2 concentration on boro rice

Results showed that grain yield increased with the increase in CO2 concentration for the same temperature. In Sylhet, both BRRI dhan29 and BRRI dhan58 almost compensated for yield loss due to rising temperature by 0.5 ºC with a CO2 level of 450 ppm, and after that level, the variety showed yield advantages (Figures 4 and 5). But for 1.0 ºC yield loss compensated at 510 ppm CO2 level only for BRRI dhan29. However, reduced grain yield couldn't have minimized to the present level for rising temperature over 1.0ºC. Since yield reduction was minimal due to temperature rise, increased CO2 gave yield advantages in all cases of BRRI dhan29. But BRRI dhan58 gave less yield in all CO2 concentration at a three ºC temperature rise. Rising temperature affect severely both the variety in Chattogram.

Although increased CO2 minimized the yield reduction from elevated temperature, no CO2 concentration minimized yield at any rising temperature level. Only 510 ppm CO2 level at 0.5ºC temperature rise gave a very close yield to normal conditions. In Dhaka, up to 1 ºC temperature rise condition, BRRI dhan29 compensated fully and gave yield advantages for increased CO2 level. Suppose the temperature raised by more than one ºC; no CO2 level is enough to compensate for grain yield. However, BRRI dhan58 can compensated yield at 0ºC temperature rise only. Elevated CO2 concentration in Rajshahi produced higher grain yield over present condition in all temperature rise except four ºC for BRRI dhan29 cultivation. But at 480 ppm CO2 concentration, the variety exceeded the present yield.

But BRRI dhan58 couldn't compensate yield after a 1.5 ºC temperature rise. BRRI dhan29 performed parallel in Barishal and Khulna, where elevated CO2 levels were not sufficient to compensate yield after a 1.5 ºC temperature rise. However, BRRI dhan58 in Khulna compensated yield at 480 ppm CO2 level and 1.5ºC. But no CO2 concentration showed similar yield performance of BRRI dhan58 to present conditions in Barishal. At the same time, while using ORYZA1 and INFOCROP rice simulation models at the current CO2 levels of 380 ppm, Krishnan et al., (2007) predicted average rice yield changes of -7.20 and -6.66%, respectively, for every 1.8ºC increase in temperature. Elevated temperature reduced grain yield for both the cultivar BRRI dhan29 and BRRI dhan28 in all the tested locations of Bangladesh.

Among the two inbreed varieties BRRI dhan29 experienced comparatively less yield reduction than BRRI dhan58. This may the effect of longer growth duration of the variety BRRI dhan29. BRRI dhan29 experienced average yield reduction of 2.6%, 6%, and 11% for one °C, two °C, and three °C, temperature rise respectively. However, BRRI dhan58 had higher average yield reduction of 8.7%, 17.2%, and 26.8% for one °C, two °C, and three °C elevated temperature. The maximum yield reduction was found in Dhaka, Sylhet, and Chattogram locations, whereas the minimum was found in Rajshahi, Rangpur, and Mymensingh. Hossain et al., (2021) reported that the grain yield reduction of short-duration boro variety BRRI dhan28 was projected by 0-17%, 16-35%, 31-49%, and 39-61% from the normal condition if the seasonal mean temperature was raised by one °C, two °C, three °C, and four °C, respectively.

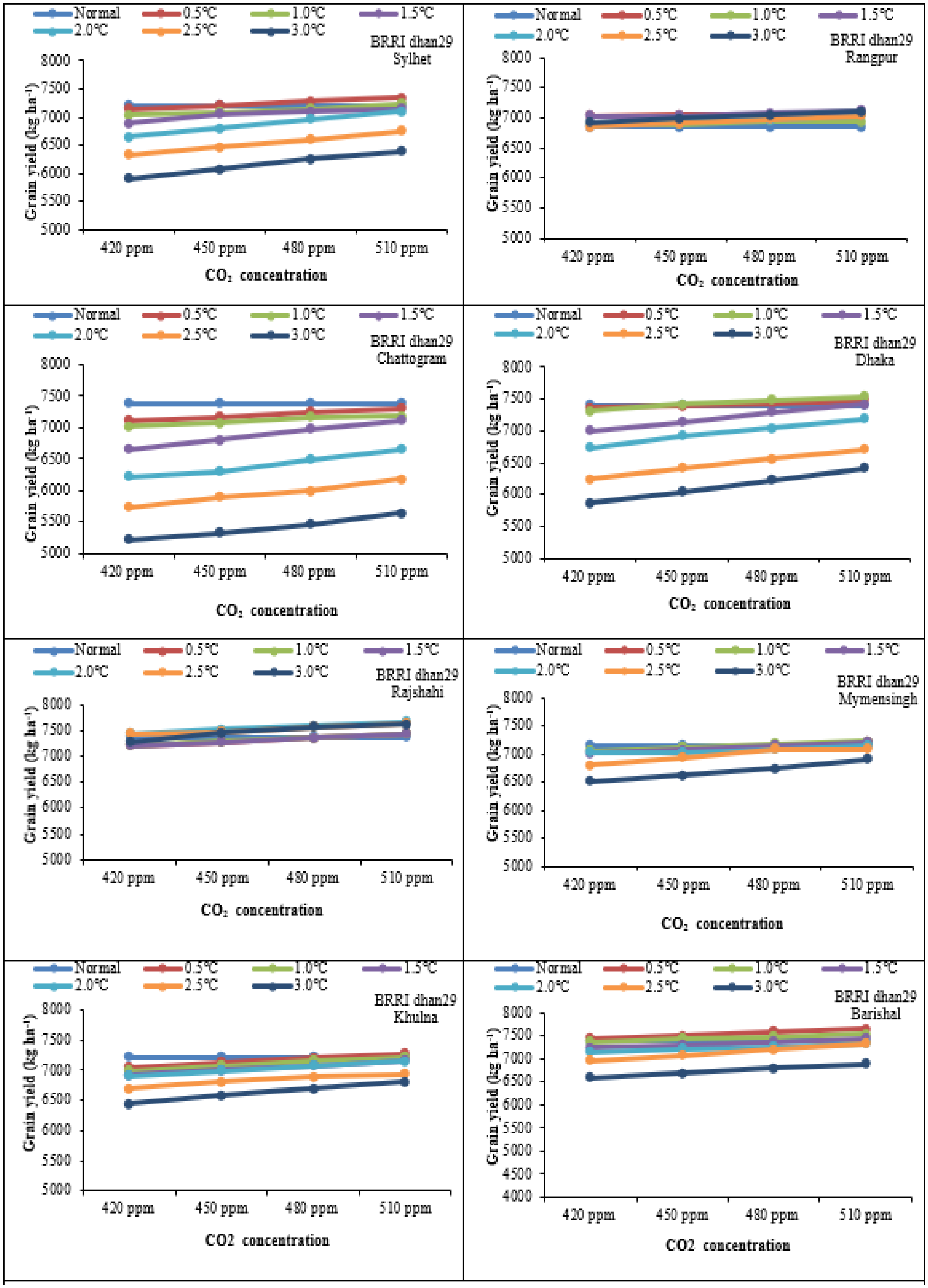

Figure 4 Grain yield of BRRI dhan29 to elevated temperature and CO2 concentration at Sylhet, Rangpur, Chattogram, Dhaka, Rajshahi, Mymensingh, Khulna, and Barishal.

Maniruzzaman et al., (2018) estimated that the average yield reduction of boro rice ranged from (13-23%) if the temperature was raised by four ºC. In another study, Rani and Maragatham, (2013) showed 13.3% and 23% grain yield reduction for 2°C and 4°C rising temperatures than ambient temperatures of dry season rice in Tamil Nadu, India. Increased mean temperature over the present condition reduced the growth duration of Boro rice. This happened due to the higher daily growing degree days (GDD) accumulation enforced earlier maturity of the crops. Guo et al., (2010) also reported that rising temperature accelerates the crop growth and development process, resulting in shortening the growth duration of irrigated rice. This study found the life span of BRRI dhan29 shortened by 6-9 days, 9-11 days, 12-15 days, 14-20 days, and 17-23 days for 1.5ºC, 2.0ºC, 2.5ºC, and 3.0ºC rising temperatures, respectively.

The growth duration reduction for BRRI dhan58 was 6-8 days, 11-15 days, and 17-22 days following one ºC, two ºC, and three ºC rising temperatures, respectively. Maniruzzaman et al., (2018) reported that if temperature rises by 4˚C, growth duration reduction would be 23–33 days over present conditions. The maximum growth duration reduction of BRRI dhan28 was 11, 18, 23, and 30 days for one °C, two °C, three °C, and four °C temperature rises, respectively, in Moulvibazar of Bangladesh (Hossain et al., 2021). The Mean surface temperature of Bangladesh is projected to rise by two ˚C to four ˚C according to Representative Concentrate Pathways (RCP) by the end of 2100 compared to the base year of 1986-2005 (IPCC, 2014).

Carbon dioxide concentration will be also increased as well (Gao et al., 2010). The current study showed that the elevated temperature decreased grain yield and growth duration of the cultivar. However, an increase CO2 concentration compensates the grain yield lost by temperature rise (Maniruzzaman et al., 2018). This study identified that yield compensation due to elevated CO2 level was higher in BRRI dhan29 than the other variety. However, Rangpur, Rajshahi, and Mymensingh showed less yield-affected area due to elevated temperature and over yield than present conditions for elevated CO2 concentration for both varieties.

Rice yield in the near and far future

Grain yield of BRRI dhan29 showed a decreasing trend in all the locations except Rangpur (Figure 6). This might be the climatic condition of Rangpur, especially at elevated temperatures. This might be due to improved rates of photosynthesis and more translocation of assimilates towards grain. In Sylhet, the model estimated almost similar grain yield up to 2060. But yield was reduced both in the years 2080 and 2100. In Rangpur, no yield reduction was estimated over the year. Gradual yield reduction was estimated for Chottogram, Rajshahi, Mymensingh, and Barishal up to 2100. Similar grain yield was found in Dhaka up to 2040, and after that gradual yield reduction occurred. For the IPCC trend of climate change, rice yield decreases from 5780.9 kg ha^{-1} to 5449.3 kg ha^{-1} and from 4588.8 kg ha^{-1} to 3993.2 kg ha^{-1} in Mymensingh and Patuakhali, respectively, and this causes the rice yield to decrease by 6% and 13% in Mymensingh and Patuakhali, respectively, for the IPCC trend.

The yield reduction of rice of 6% in Mymensingh is comparable with the yield reduction of rice of 8% in Bangladesh, as reported by (Faisal and Saila, 2004). The rice yield is predicted to vary with locations, and it ranges from 6% to 13%. Basak et al., (2010) reported that there will be a significant decrease in the yields of boro rice in Bangladesh due to climate change. But Faisal and Saila, (2004) reported that the overall impact of climate change on crop production in Bangladesh would probably be negligible in 2030. This study also agrees well with the predictions of Soora et al., (2013), who reported similar climate change impacts on rice yield. Similar to BRRI dhan29, grain yield of BRRI dhan58 was assessed for the projected temperature rise (RCP4.5) in 2040, 2060, 2080, and 2100 for the study locations and presented in (Figure 7).

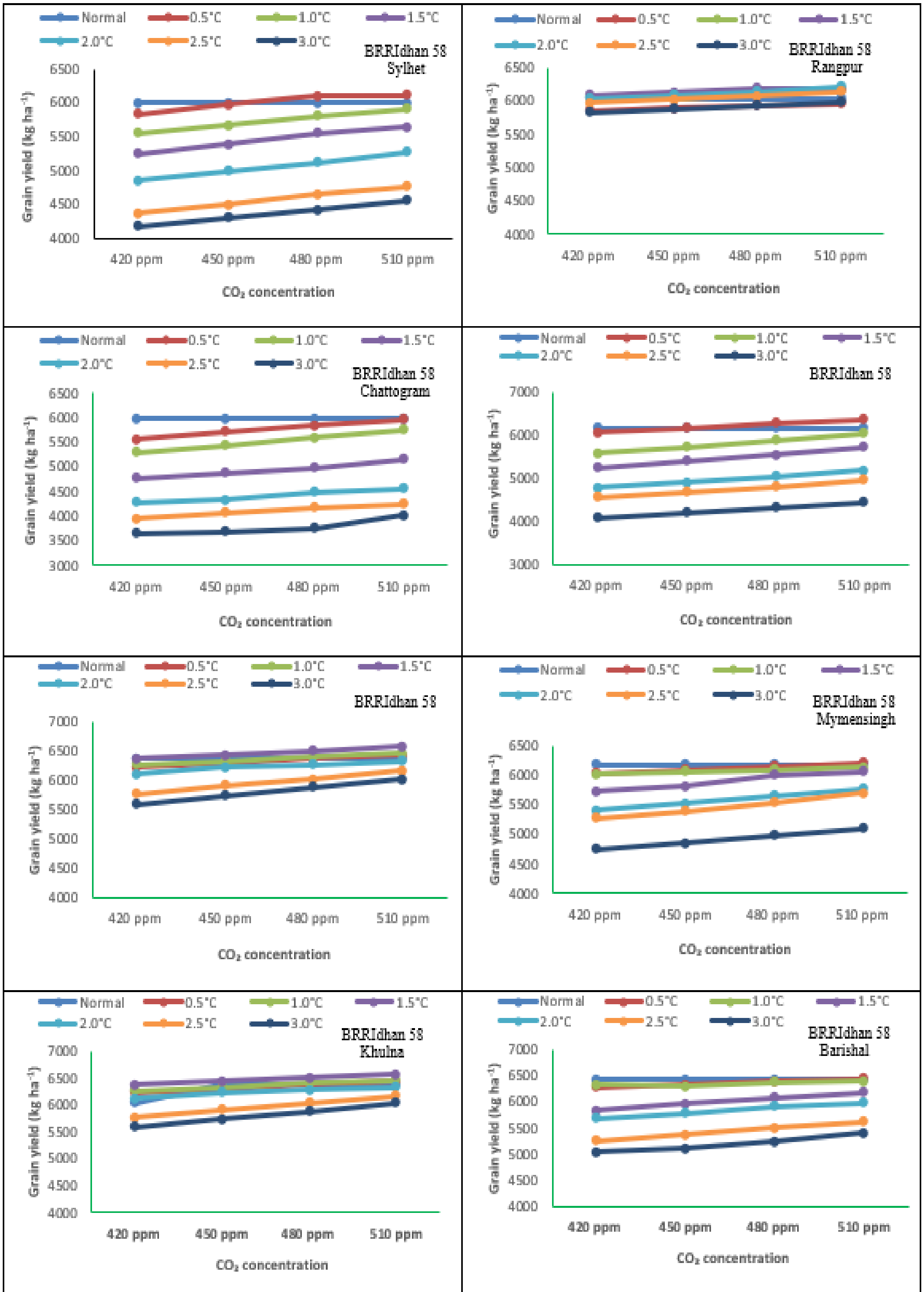

Figure 5 Grain yield of BRRI dhan58 to elevated temperature and CO2 concentration at Sylhet, Rangpur, Chattogram, Dhaka, Rajshahi, Mymensingh, Khulna, and Barishal.

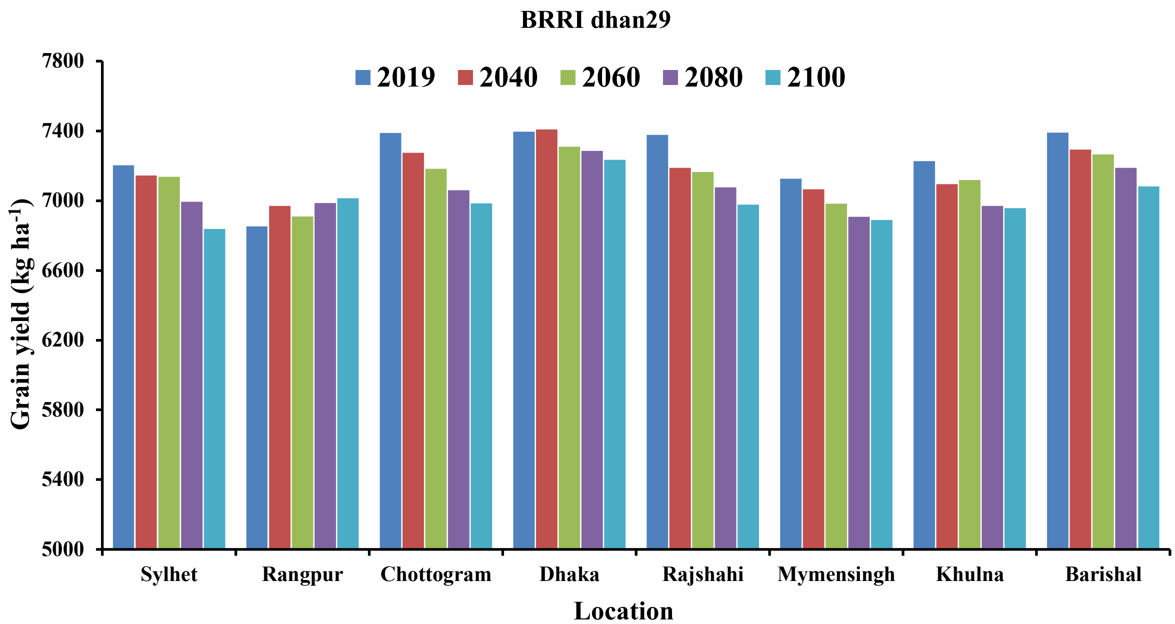

Figure 6 The yield of BRRI dhan29 under projected elevated temperature (RCP4.5) in the year 2019, 2040, 2060, 2080, and 2100 at Sylhet, Rangpur, Chottogram, Dhaka, Rajshahi, Mymensingh, Khulna, and Barishal

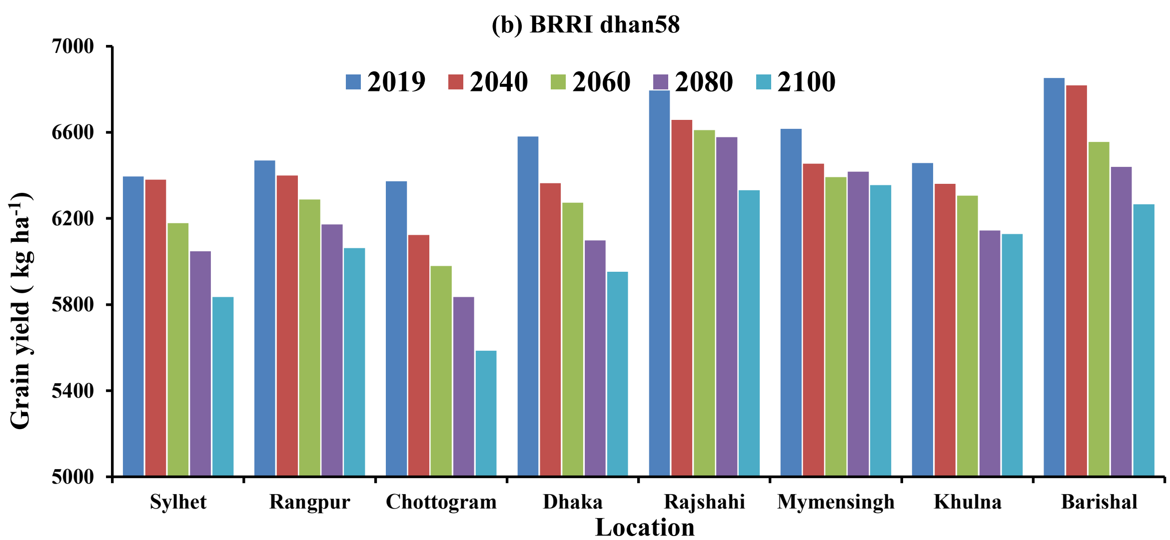

Figure 7 The yield of BRRI dhan58 under projected elevated temperature (RCP4.5) in the year 2019, 2040, 2060, 2080, and 2100 at Sylhet, Rangpur, Chottogram, Dhaka, Rajshahi, Mymensingh, Khulna, and Barishal

Grain yield showed a decreasing trend in all the places over time. In Sylhet, the model estimated almost similar grain yield up to 2040. But yield was reduced both in the year 2040, 2080, and 2100. Gradual yield reduction was estimated for Rangpur, Chottogram, Dhaka, Rajshahi, Khulna, and Barishal. BRRI dhan58 estimated almost similar grain yield up to 2080 however, yield reduction occurred in 2100. In Mymensingh, grain yield reduction was minimal among the locations. BRRI, (2012) reported that BRRI dhan28 declines at the rate of 30.5 kg ha^{-1} whereas BRRI dhan29 declines at 36.7 kg ha^{-1} for each day delay in sowing after 15 November. Biswas et al., (2011) also reported that both growth duration and grain yield of rice reduce depending on planting time. Our results based on model predictions are thus similar to those obtained from the field experiments.

Climate change alone would lead to a 3.5-23.2% and a 5.8-27.2% reduction in rice yields for the 2020s and 2040s, respectively, with the most significant decreases in Cambodia. This arises mainly from Cambodia has tropical climates with a warmer and drier baseline climate Redfern et al., (2012), so any further warming and, or drought will pose a more significant threat to rice production. Easterling et al., (2007) reported that the current temperature is already close to or above optimum for maximum crop yields in this region. About 52% of the reductions in yields are triggered by an increase in temperature. Further warming would impose a dramatic negative impact on crop yield. The results seem consistent with the idea that the warming trend would lead to a reduction in the rice yield, although the magnitude differs between countries (Li et al., 2015; Makowski et al., 2015). These findings coincided with the present findings of all studied location of except Rangpur region.

4. SUMMARY AND CONCLUSION

Elevated air temperature influenced both the grain yield and life span of irrigated boro crops, but rising temperature shortened the crop growth duration and reduced the grain yield. On the contrary, elevated atmospheric CO2 concentration increased the rice yield by increasing photosynthesis. According to this study, the elevated temperature had less of an impact on BRRI dhan29 than BRRI dhan58 among the two tested varieties. The estimated grain yield reduction due to temperature rise was 2.6%, 6%, and 11% for BRRI dhan29 and 8.7%, 17.2% and 26.8% for BRRI dhan58 for BRRI dhan58 for one °C, two °C, and three °C, respectively. Dhaka, Sylhet, and Chattogram locations saw the greatest yield reduction, while Rajshahi, Rangpur, and Mymensingh experienced the least.

Thus, Dhaka, Sylhet, and Chattogram were the most vulnerable areas of rice production due to climate change. However, cultivating long-duration varieties like BRRI dhan29 could be an option to mitigate climate change's impact on these areas. The combined effect of elevated air temperature and increased CO2 concentration minimized the yield loss. However, the elevated CO2 concentration will not be able to compensate yield fully. Besides, the reduction in crop growing period due to temperature rise will cause a substantial yield reduction of current rice cultivars. It would be a near-future challenge for a crop developer to introduce a new type of cultivar that can tolerate the effect of elevated temperature with no significant yield loss. From the above findings, the following conclusion was drawn.

- The estimated grain yield reduction due to temperature rise was 2.6 %, 6 %, and 11 % for BRRI dhan29 and 8.7 %, 17.2 %, and 26.8 % for BRRI dhan58 for one °C, two °C, and three °C, respectively.
- The maximum yield reduction was found in Dhaka, Sylhet, and Chattogram locations whereas, the minimum was found in Rajshahi, Rangpur, and Mymensingh. Thus, Dhaka, Sylhet, and Chattogram are the most vulnerable area of rice production due to climate change.
- The combined effect of the elevated air temperature and increased CO2 concentration minimized the yield loss. However, elevated CO2 concentration will not be able to compensate yield fully.

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Authors' contributions

Dr. Md Abu Zafur Al-Munsur, was Conceptualization of research; Designing of the experiments; Execution of field experiments and data collection, analysis of data and interpretation Preparation of the manuscript.

Dr. Mirza Hasanuzzaman and Dr. Parimal Kanti Biswas and Dr. Md. Ismail Hossain were help Conceptualization of research, Designing of the experiments, Contribution of experimental materials, and editing of the manuscript. (Member Supervisory committee).

Dr. Md Shahidul Islam giving the overall instruction, reading and approved the final manuscript (Chairman Supervisory committee).

Ethical approval

The ethical guidelines for plants & plant materials are followed in the study.

Informed consent

Not applicable.

Conflicts of interests

The authors declare that there are no conflicts of interests.

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Data and materials availability

All data associated with this study are present in the paper.

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