INTERNATIONAL JOURNAL OF ENVIRONMENTAL SCIENCES Volume 2, No 3, 2012

Research article **ISSN 0976 – 4402**

Impact of climate change on development phases of winter rice in Bangladesh

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doi:10.6088/ijes.00202030062

ABSTRACT

Impact of climate change on development phases of rice is one of the major concern issues due to yield reduction. In the present study, development phases of winter rice (boro rice) of BR3 and BR14 varieties for the years 2008, 2030, 2050 and 2070 have been simulated for 12 major rice growing Agro-Ecological Zones (AEZs) of Bangladesh using DSSAT model. Available data on soil and hydrologic characteristics of these locations, and typical crop management practices for boro rice were used. The weather data required for the model were generated for the selected years and for the selected locations using the regional climate model PRECIS. Compared to 2008, the model predicted average reductions in development phases in days of BR3 variety for the selected 12 locations were 1 in Emergence (E) to End Juvenile (EJ) phase, 1 in Panicle Inition (PI) to End Leaf Growth (ELG) and 1 in Grain Filling Phase (GFP) phase during 2030; 4 in E to EJ, 1 in EJ to PI, 3 in PI to ELG and 2 GFP phase for the year 2050 and 7 in E to EJ, 3 in EJ to PI, 5 in PI to ELG and 3 GFP in 2070. Similar results were also found for BR14 variety for the selected locations in Bangladesh. Therefore, developing new rice varieties with considering climatic adaptive, proper growing period should be maintained.

Keywords: Climate change, boro rice, Bangladesh, development phases, DSSAT model.

1. Introduction

Rice production is inherently sensitive due to variability of climatic parameters in Bangladesh. Temperature and rainfall are the main determinant climatic factors for maintaining the rate of rice development phase. A considerable amount of rice yield depends on its proper growth of development phase. It is necessary for rice plant to complete of its development within a process of optimum level of environmental factors such as daily maximum and minimum temperature, rainfall and solar radiation for attaining maximum yield. However, in recent decades, changing climatic parameters for example increasing maximum and minimum temperature, variations in rainfall pattern and solar radiation over the growing period of crop that shorten development stages which also one of the main causes of yield reduction of a given variety (Craufurd and Wheeler 2009). Islam (1995) studied that the higher minimum temperature during the ripening phase also affected the grain yield significantly. In Bangladesh, in many areas, early planting of short duration varieties suffered from cold temperature during boro season. Islam and Morison (1992) mentioned that boro season crops often suffered from cold at the seedling stage and sometime at reproductive phase particularly for early planting with short duration rice varieties.

Received on December 2011 Published on February 2012

Likewise temperature, changing of rainfall pattern also affects the rice crop at different times. The growth duration of rice plant is significantly affected by the variability of rainfall during early period and it is also mentioned that the variability of rainfall is associated with an untimely cessation at the reproductive or ripening stage of the rice crop, yield reduction is severe (Moomaw and Vergara 1965). Therefore, when assessing crop response to climate, an important scientific question is: how much development phases of crop will change with climate change?

According to this issue a number of simulation studies were carried out to assess the impacts of climate change and variability on rice yield in Bangladesh using the CERES-Rice model (e.g., Basak 2009; Basak et al. 2009; Mahmood et al. 2003; Mahmood 1998; Karim et al. 1996). These studies mainly focused on the effects of temperature, rainfall pattern and atmospheric CO_2 concentration on rice yield. Basak (2009) and Basak et al. (2010) reported predicted rice yield of some rice varieties may be reduced over 20% and 50% during the years of 2050 and 2070, respectively.

In this study, future climate scenarios have been generated using the climate model named Providing REgional Climates for Impact Studies (PRECIS). The weather data requirement for DSSAT (Decision Support System for Agrotechnology Transfer, version 4) model include daily maximum and minimum air temperatures, daily precipitation and daily solar radiation, all of which could affect rice development phases significantly. Therefore, future climate scenarios, including daily maximum and minimum temperatures, precipitation and solar radiation, for selected AEZs of Bangladesh have been generated. The development phases of two boro varieties (BR3 and BR14) have been simulated in the present study for the years 2008, 2030, 2050 and 2070, using the DSSAT modeling system.

2. Methods

2.1 Selection of Simulation Locations

Twelve Agro-Ecological Zones (AEZs) of Bangladesh were selected among the major rice growing areas in different regions of Bangladesh to predict development phases of two boro varieties BR3 and BR14 for the years 2008, 2030, 2050 and 2070. For this study, Rajshahi (AEZ-11), Bogra (AEZ-25) and Dinajpur (AEZ-27) were selected from northwestern region; Mymensingh (AEZ-9) and Tangail (AEZ-15) were selected from central region; Jessore (AEZ-14) and Satkhira (AEZ-13) from southwestern region; Barisal (AEZ-18) and Madaripur (AEZ-12) from southern region; Chandpur (AEZ-19) and Comilla (AEZ-19) from southeastern region; and Sylhet (AEZ-20) from eastern region.

2.2 Crop Model

DSSAT modeling system is an advanced physiologically-based rice crop growth simulation model and has been widely applied to understanding the relationship between rice yield, development phases and its environment (Basak 2009). The model estimates rice yield of irrigated and non-irrigated rice, determines duration of growth stages, dry matter production and partioning, root system dynamics, effect of soil water and soil nitrogen contents on photosynthesis, carbon balance and water balance. Ritchie et al. (1987) and Hoogenboom et al. (2003) have provided a detailed description of the model. In the present study, the Introductory Crop Simulation (ICSim) of DSSAT modeling system was used for all simulations for predicting development phases of the selected two varieties rice (Figure 1).

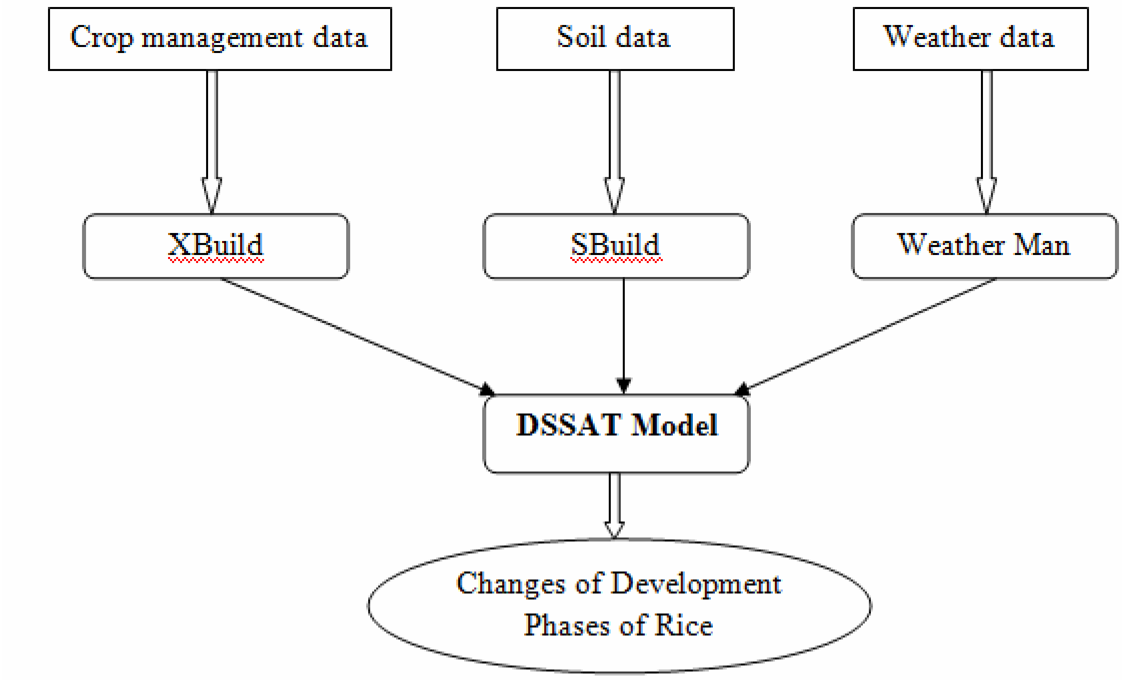

Figure 1: Flow diagram of DSSAT model

2.3 Selection of Rice Variety

In predicting crop growth (development phases), DSSAT model takes into effect of weather, crop management, genetics, and soil water, C and N. The model uses a detailed set of crop specific genetic coefficients, which allows the model to respond to diverse weather and management conditions. Therefore, in order to get reliable results from model simulations, it is necessary to have the appropriate genetic coefficients for the selected cultivars (Basak 2009). The two boro rice varieties BR3 and BR14 were selected in the present study because genetic coefficients for these varieties are available in the DSSAT modeling system (Table 1). Although these varieties are not widely used at present time, the effects of climate change and variability on these varieties provide insights into possible impact of climate change on development phases of boro rice in the future.

Table 1: Genetic coefficients for boro rice cultivars grown in Bangladesh

Rice	Cultivar	Coefficients								Source
		P1	P2R	P5	P2O	G1	G2	G3	G4	
Boro	BR3	650.0	90.0	400.0	13.0	65.0	0.025	1.0	1.0	DSSAT v4
	BR14	560.0	200.0	500.0	11.5	45.0	0.026	1.0	1.0	DSSAT v4

2.4 Soil and Crop Management Input

The model requires a quite detailed set of input data on soil and hydrologic characteristics (i.e., pedological and hydrological data), and crop management. Soil characteristics include soil texture, number of layers in soil profile, soil layer depth, pH of soil for each depth, clay, silt and sand contents, organic matter, cation exchange capacity, etc were used as a input data for this model (Basak 2009). Required data on soil and hydrologic characteristics for the selected locations (districts) were collected from Bangladesh Rice Research Institute (BRRI, Gazipur; Miah 2005; Karim et al 1988) and Soil Resources Development Institute (SRDI, Dhaka). As an example, the Old Meghna Estuarine Floodplain (i.e., Agro-Ecological Zone, AEZ-19) covering Kishoregani, Habigang, Brakmanbaria, Comilla, Chandpur, Feni, Noakhali, Laksmipur, Narsingdi, Narayanganj, Dhaka, Shariatpur, Modaripur, Gopalganj and Barisal districts is presented in Table 2.

Table 2: Soil profile data for Old Meghna Estuarine Floodplain (AEZ-19)

Depth Bottom cm	**Clay %**	**Silt %**	**Stones %**	**Organic Carbon %**	**pH in Water**	**Cation Exchange Capacity meq/100g**	**Total Nitrogen %**
5	13	38	0	1.51	5.6	11.3	0.14
15	13	38	0	1.51	5.6	11.3	0.14
30	13	38	0	1.43	5.6	11.3	0.13
45	13	38	0	1.22	5.6	11.3	0.11

Soil Texture: Silt Loam

The model required crop management data (i.e., agronomic data) which are planting date, planting density, row spacing, planting depth, irrigation amount and frequency, fertilizer application dates and amounts. The major crop management input data used in all model simulations in the current study are given in Table 3; these represent typical practices (BRRI, 2006 and Rashid, 2008) in Bangladesh. Using these inputs, the average (of 12 locations) yields of BR3 and BR14 for the year 2008, estimated by the model, were about 5500 kg ha^{-1} and 4050 kg ha^{-1}, respectively (Basak et al. 2009); these values are close to the reported yields of these varieties (BRRI 2006). These crop management inputs were subsequently used in all model simulations under the predicted weather scenarios for the years 2008, 2030, 2050 and 2070. It should be noted that the DSSAT model does not count the water required for preparation of land before transplanting (which usually varies from 200 to 300 mm, depending on soil and weather condition).

2.5 Weather data

A regional climate model named Providing Regional Climate for Impacts Studies (PRECIS) was used to generate daily weather data needed for running the DSSAT model. The special report on emission scenarios (SRES) A2 of ECHAM4 has been used as PRECIS input. In this study PRECIS runs with 50-km horizontal resolution for the present climate (2008) using baseline lateral boundary conditions (LBCs). The model domain was selected 65–103°E and 6–35°N to cover Bangladesh and its surrounding areas. In the next step, PRECIS run was completed for the year 2030, 2050 and 2070 using ECHAM 4 SRES A2 as the model input. The PRECIS outputs that were used in the DSSAT model include daily maximum temperature (T_{max}), daily minimum temperature (T_{min}), daily incoming solar radiation (Srad), and daily rainfall.

Table 3: Crop management data used in the model simulations

Parameter	**Input data**
Planting method	Transplant
Transplanting date	15 January
Planting distribution	Hill
Plant population at seedling	35 plants per m^2
Plant population at emergence	33 plants per m^2

Row spacing	20 cm
Planting depth	3 cm
Transplant age	35 days
Plant per Hill	2
Fertilizer (N) application • 18 days after transplanting • 38 days after transplanting • 56 days after transplanting	 30 kg ha^{-1} 70 kg ha^{-1} 30 kg ha^{-1}
Application of irrigation	855 mm in 14 applications

3. Model applications and results

DSSAT model has classified the development phase of rice into six phases; are Emergence (E), End Juvenile (EJ), Panicle Inition (PI), End Leaf Growth (ELG), Begin Grain Filling (BGF), and Grain Filling Phase (GFP). These phases influence the three yield components: number of panicles per unit land area, the average number of grain produced per panicle and the average weight of the individual grains. These three components determine grain yield. It should be noted that the DSSAT model counts physiological maturity from the time of “Emergence-End Juvenile” period. It takes about 10-12 days to come to this stage after transplantation. In addition, transplanting age of 35 days was considered. However, transplanting age could be up to 45 days under actual field condition. If transplanting age increases by one day, physiological maturity usually increases by 0.5 day (Biswas, 2009). These increases should be kept in mind while estimating development phases under field condition.

In this study, the six phases were separated into five distinct steps: 1st step from Emergence (E) to End Juvenile (EJ), 2nd from End Juvenile (EJ) to Panicle Inition (PI), 3rd from Panicle Inition (PI) to End Leaf Growth (ELG), 4th from End Leaf Growth (ELG) to Begin Grain Filling (BGF) and 5th from Begin Grain Filling (BGF) to Grain Filling Phase (GFP).

Tables 4 and 5 show the predicted development phases in days of BR3 and BR14 rice varieties, respectively for 12 locations of Bangladesh for the years 2008, 2030, 2050 and 2070. These predictions were made using a fixed planting date of 15 January. These predictions were conducted using a fixed concentration of atmospheric CO_2 of 379 ppm (the value reported for the year 2005 in the fourth assessment report of IPCC). The tables show significant reduction in development phases of rice in future due to predicted changes in climatic condition. Compared to 2008, predicted average reductions in development phases in days of BR3 variety for the selected 12 locations were 1 in E to EJ phase, 1 in PI to ELG and 1 in GFP phase during 2030; 4 in E to EJ, 1 in EJ to PI, 3 in PI to ELG and 2 GFP phase for the year 2050 and 7 in E to EJ, 3 in EJ to PI, 5 in PI to ELG and 3 GFP in 2070. Moreover, most significant changed of development phases were found in E-EJ and PI-ELG phases for BR3 (Figure 2).

The corresponding reductions for BR14 variety were about 1 in E to EJ, 1 in PI to ELG, 1 in ELG to BGF and 1 in GFP for 2030; 4 in E to EJ, 3 in EJ to PI, 3 in PI to ELG, 1 in ELG to BGF and 4 in GFP for 2050 and 4 in E to EJ, 7 in EJ to PI, 5 in PI to ELG, 1 in ELG to BGF and 4 in GFP for 2070. In addition, most significant changed of development phases were found in E-EJ, EJ-PI and PI-ELG phases for BR14. Some regional variation was also be observed in the predictions, with somewhat higher reductions predicted for central, southern and southwestern regions for both varieties of boro rice (Figure 3)

Table 4: Development phases in days of BR3 boro rice

Location/ Year	**2008**					**2030**					**2050**					**2070**				
	1st	**2nd**	**3rd**	**4th**	**5th**	**1st**	**2nd**	**3rd**	**4th**	**5th**	**1st**	**2nd**	**3rd**	**4th**	**5th**	**1st**	**2nd**	**3rd**	**4th**	**5th**
Northw																				
Rajshahi	2	9	3	8	1	2	1	3	8	1	2	1	3	8	1	1	1	3	8	1
Bogra	2	1	3	8	1	2	1	3	8	1	2	1	3	7	1	2	8	3	9	1
Dinajpur	2	1	3	9	2	2	1	3	9	1	2	1	3	7	1	2	8	3	8	1
Central																				
Mymens	2	1	3	9	1	2	1	3	8	2	2	1	3	8	1	2	8	3	9	1
Tangail	2	1	3	8	1	2	1	3	8	1	2	1	3	7	1	2	8	3	9	1
Southw																				
Jessore	2	1	3	8	1	2	1	3	8	1	2	9	3	8	1	1	7	3	8	1
Satkhira	2	1	3	8	1	2	1	3	8	1	1	9	3	8	1	1	7	3	7	1
Souther																				
Barisal	2	1	3	8	1	2	1	3	9	1	2	9	3	9	1	1	7	3	8	1
Madarip	2	1	3	8	1	2	1	3	8	1	2	1	3	8	1	1	8	3	8	1
Southea																				
Chandp	2	1	3	8	1	2	1	3	9	1	2	1	3	8	1	1	8	3	8	1
Comilla	2	9	3	9	1	2	1	3	9	1	2	1	3	8	1	2	8	3	7	1
Eastern																				
Sylhet	2	1	4	9	2	3	1	4	1	2	2	9	3	9	2	2	1	3	8	1

(1st step: E to EJ; 2nd step: EJ to PI; 3rd step: PI to ELG; 4th step: ELG to BGF and 5th step: BGF to GFP)

Table 5: Development phases in days of BR14 boro rice

Location/ Year	**2008**					**2030**					**2050**					**2070**				
	1st	**2nd**	**3rd**	**4th**	**5th**	**1st**	**2nd**	**3rd**	**4th**	**5th**	**1st**	**2nd**	**3rd**	**4th**	**5th**	**1st**	**2nd**	**3rd**	**4th**	**5th**
Northw																				
Rajshahi	1	1	3	8	1	1	2	3	8	1	1	1	3	8	1	2	8	3	8	1
Bogra	1	1	3	8	2	1	2	3	8	2	1	1	3	8	1	1	1	3	8	1
Dinajpur	1	1	3	9	2	1	2	3	9	2	1	1	3	8	1	1	1	3	8	1
Central																				
Mymens	2	2	3	8	2	2	2	3	8	2	1	1	3	8	2	1	1	3	8	2
Tangail	1	1	3	8	2	1	1	3	7	2	1	1	3	8	1	1	1	3	9	1
Southw																				
Jessore	1	1	3	8	2	1	1	3	8	1	1	1	3	8	1	1	1	3	8	1
Satkhira	1	1	3	8	2	1	1	3	8	1	1	1	3	9	1	1	1	3	7	1
Souther																				
Barisal	1	1	3	9	2	1	1	3	9	2	1	1	3	9	1	1	1	3	8	1
Madarip	1	1	3	8	2	1	1	3	8	2	1	1	3	8	2	1	1	3	8	1
Southea																				
Chandp	1	1	3	9	2	1	1	3	9	2	1	1	3	8	2	1	1	3	7	1
Comilla	1	1	3	1	2	1	1	3	9	2	1	1	3	8	2	1	1	3	8	1
Eastern																				
Sylhet	2	2	3	1	2	2	2	4	1	2	1	1	3	9	2	1	1	3	8	2

(1st step: E to EJ; 2nd step: EJ to PI; 3rd step: PI to ELG; 4th step: ELG to BGF and 5th step: BGF to GFP)

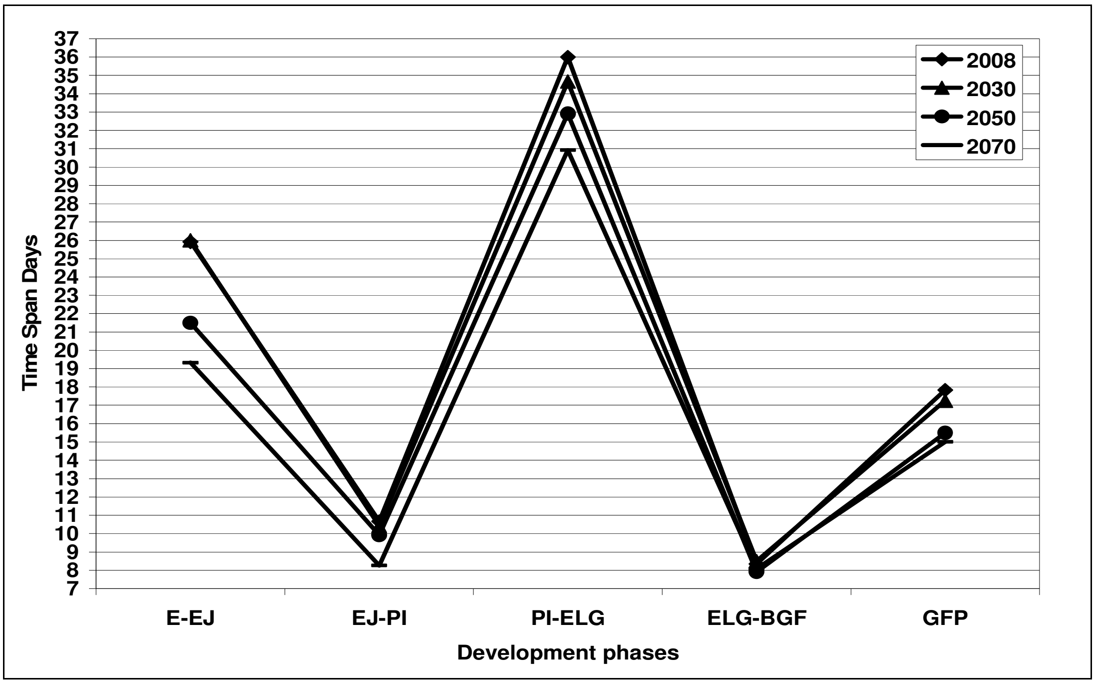

Figure 2: Development phases in days (average) of BR3 boro rice

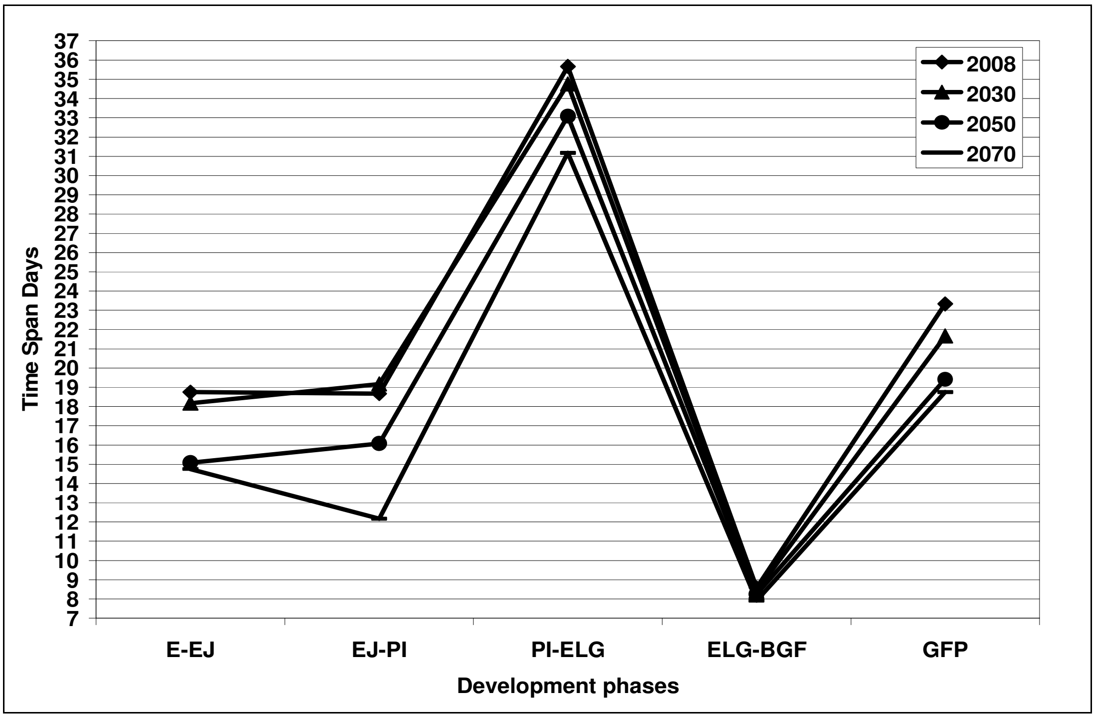

Figure 3: Development phases in days (average) of BR14 boro rice

Tables 6 and 7 show the predicted maximum and minimum temperature, rainfall and solar radiation for the years 2008, 2030, 2050 and 2070. Compared to 2008, maximum temperature increased from 24.7 to 27.5^{0}C (increased 2.8^{0}C) in E-EJ phase, 25.8 to 37.7^{0}C (increased 11.9^{0}C) in EJ-PI phase, 31.1 to 37.5^{0}C (increased 6.4^{0}C) in PI-ELG, 35.2 to 39.8^{0}C (increased 4.6^{0}C) in ELG-BGF and 36.5 to 38.6^{0}C (increased 2.1^{0}C) in GFP during 2070. Minimum temperature also increased from 14.3 to 19.1^{0}C (increased 4.8^{0}C) in E-EJ phase, 17.3 to 18.8^{0}C (increased 1.5^{0}C) in EJ-PI phase, 21.9 to 23.6^{0}C (increased 1.7^{0}C) in PI-ELG, 25.8 to 26.6^{0}C (increased 0.8^{0}C) in ELG-BGF and 26.5 to 27.8^{0}C (increased 1.3^{0}C) in GFP. Likewise, maximum and minimum temperature, rainfall pattern and solar radiation also changed for the specific growth phases which caused a significant reduction of development phases in 2070 at Madaripur (AEZ-12). The reduction of development phases in days during 2070 compared to 2008 were 6 in E-EG, 3 in EJ-PI, 5 in PI-ELG and 2 in GFP for BR3 in 2070 for Madaripur.

Similar to BR3, it was also found that climatic parameters had also negative impacts on development phases of BR14 variety. Compared to 2008, maximum temperature increased from 24.4 to 26.7^{0}C (increased 2.3^{0}C) in E-EJ phase, 25.8 to 34.6^{0}C (increased 8.8^{0}C) in EJ-PI phase, 31.3 to 37.5^{0}C (increased 6.2^{0}C) in PI-ELG, 34.9 to 39.8^{0}C (increased 4.9^{0}C) in ELG-BGF and 37.0 to 39.6^{0}C (increased 2.6^{0}C) in GFP during 2070. Minimum temperature also increased from 13.4 to 19.4^{0}C (increased 6.0^{0}C) in E-EJ phase, 17.5 to 18.6^{0}C (increased 1.1^{0}C) in EJ-PI phase, 21.9 to 23.9^{0}C (increased 2.0^{0}C) in PI-ELG, 25.7 to 26.6^{0}C (increased 0.9^{0}C) in ELG-BGF and 26.8 to 27.7^{0}C (increased 0.9^{0}C) in GFP. Likewise, maximum and minimum temperature, rainfall pattern and solar radiation also changed for the specific growth phases in 2070 at Madaripur. These reductions of development phases in days in 2070, compared to 2008 were 5 in E-EG, 5 in EJ-PI, 5 in PI-ELG and 1 in GFP for BR14 during 2070. Similar results were also found for other locations in Bangladesh but the reduction of development phases were different due to location variations of those climatic factors and soil properties.

Table 6: Climatic parameters in different development phases of BR3 boro rice at Madaripur

Location/ Year	2008					2030					2050					2070				
	1st	2nd	3rd	4th	5th	1st	2nd	3rd	4th	5th	1st	2nd	3rd	4th	5th	1st	2nd	3rd	4th	5th
Madar																				
Mx.	2	2	3	3	3	2	2	3	3	3	2	3	3	3	3	2	3	3	3	3
Mi.	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2
Rainfal	3	5	1	1.	2.	3	2.	2	1	1.	0.	1.	2	8.	2	4	0.	1.	0.	9.
Srad	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.	1	1	2	1

(Mx. Temp: Maximum Temperature; Mi. Temp: Minimum Temperature; Srad: Solar radiation) (1st step: E to EJ; 2nd step: EJ to PI; 3rd step: PI to ELG; 4th step: ELG to BGF and 5th step: BGF to GFP)

Table 7: Climatic parameters in different development phases of BR14 boro rice at Madaripur

Location/ Year	2008					2030					2050					2070				
	1st	2nd	3rd	4th	5th	1st	2nd	3rd	4th	5th	1st	2nd	3rd	4th	5th	1st	2nd	3rd	4th	5th
Madar																				
Mx.	2	2	3	3	3	2	2	3	3	3	2	3	3	3	3	2	3	3	3	3
Mi.	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2	1	1	2	2	2
Rainfal	2	5	1	1.	3.	1	2	2	1	4	0.	2.	2	8.	3	9.	1.	1.	0.	9.
Srad	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	8.	1	1	2	2

(Mx. Temp: Maximum Temperature; Mi. Temp: Minimum Temperature; Srad: Solar radiation) (1st step: E to EJ; 2nd step: EJ to PI; 3rd step: PI to ELG; 4th step: ELG to BGF and 5th step: BGF to GFP)

4. Conclusion

Even though BR3 and BR14 rice varieties are not widely used currently, the model simulations carried out in this study provide useful insight into the possible effects of climate change on development phases of boro rice. The growth of development phases and yield of rice are directly related to the rate of photosynthesis and phenology and their response to temperature, solar radiation and rainfall. Increased temperatures during the growing season cause grain sterility as well as reduce rice yield significantly. Very high temperatures, sometimes exceeding 35^0C, have been predicted, especially for the years 2050 and 2070, due to climate change. Although there are significant uncertainties in the predicted climate parameters, the crop model simulation results suggest that if climate change causes significant increase in temperatures, this may in turn cause significant reduction in development phases which is one of the main causes of yield reduction. The model simulations also suggest that changes in rainfall and solar radiation pattern may also adversely affect on development phases of rice growth. In order to assess the effect of climate change on the rice varieties currently being grown in Bangladesh, it is necessary to find out their genetic coefficients through carefully controlled experiments. It is also necessary to develop high temperature-resistant rice varieties and modify management practices to offset the adverse effects of climate change with considering proper growing period. Modeling tools, such as the DSSAT modeling system, could be very useful in assessing possible impacts of climate change and management practices on yield and development phases of rice. The predicted values of temperature and rainfall used in the present study are not calibrated on daily scale. Uncertainty in assessing possible impacts of climate change may also be reduced using high resolution climate model outputs with ensembles and calibrated outputs.

Acknowledgments

The Author acknowledge the British Council and Professor Dr. Jobair Bin Alam and M. Ashraf Ali of the Department of Civil Engineering, BUET for providing fund this study under the Higher Education Linkage Project titled Impact of Climate Change and Adaptation Strategy. The Author would like to thank Dr. Nazrul Islam of SAARC Meteorological Research Center and Dr. Jiban Krishna Biswas, Dr. Abdur Rashid and Md. Abdus Salam of Bangladesh Rice Research Institute (BRRI), Gazipur and Dr. Selvaraju Ramasamy of FAO, Rome, Italy for their kind support throughout the study.

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