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Assessment of the effect of climate change on boro rice production in Bangladesh using DSSAT model

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Abstract

Effect of climate change on yield of two varieties of boro rice has been assessed using the DSSAT modeling system. The yield of BR3 and BR14 boro varieties for the years 2008, 2030, 2050 and 2070 have been simulated for 12 locations (districts) of Bangladesh. Available data on soil and hydrologic characteristics of these locations, and typical crop management practices for boro rice were used in the simulations. The weather data required for the model (daily maximum and minimum temperatures, daily solar radiation and daily precipitation) were generated for the selected years and for the selected locations using the regional climate model PRECIS. The model predicted significant reduction in yield of both varieties of boro rice due to climate change; average yield reductions of over 20% and 50% have been predicted for both rice varieties for the years 2050 and 2070, respectively. Increases in daily maximum and minimum temperatures have been found to be primarily responsible for reduction in yield. Increases in incoming solar radiation and atmospheric carbon-di-oxide concentration have been found to increase rice yield to some extent, but their effect is not significant compared to the negative effects of temperature. Variations in rainfall pattern over the growing period have also been found to affect rice yield and water requirement. Increasing temperatures and solar radiation have been found to reduce the duration of physiological maturity of the rice varieties. Model results also suggest that in addition to reducing yield, climate change may also make rice yield more vulnerable to transplanting date. DSSAT modeling system could be a useful tool for assessing possible impacts of climate change and management practices on different varieties rice and other crops.

Keywords: Bangladesh, climate change, boro rice, rice yield, DSSAT model

1. Introduction

Agriculture is always vulnerable to unfavorable weather events and climate conditions. Despite technological advances such as improved crop varieties and irrigation systems, weather and climate are still key factors in agriculture productivity. Often the linkage between these key factors and production losses are obvious, but sometimes the linkages are less direct. The impacts of climate change on food production are global concerns, and they are very important for Bangladesh. Agriculture is the largest sector of Bangladesh's economy, which accounts for about 35% of the GDP and about 70% of the labor force. Agriculture in Bangladesh is already under pressure both from huge and increasing demands for food, and from problems of agricultural land and water resources depletion (Ahmed et al., 2000). Bangladesh needs to increase the rice yield in order to meet the growing demand for food emanating from population growth. Irrigated rice or Boro rice is a potential area for increasing rice yield, which currently accounts for about 50% of total rice production in the country (BRRI, 2006). However, climate change is a potential threat toward attaining this objective. It is therefore very important to understand the effect of climate change on rice production, especially boro production.

A number of simulation studies have been carried out to assess impacts of climate change and variability on rice productivity in Bangladesh using the CERES-Rice model (e.g., Basak et al., 2009; Mahmood et al., 2003; Mahmood, 1998; Karim et al., 1996). These studies mainly focused on the effects of higher air temperature and atmospheric CO_2 concentration on rice yield. It may be noted that 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 yield significantly. Therefore, in this study, future climate scenarios, including daily maximum and minimum temperatures, precipitation and solar radiation, for selected locations of Bangladesh have been generated and used for predicting yield of boro rice. The yield of two boro varieties (BR3 and BR14) have been simulated in the present study for the years 2008 (representing present time), 2030, 2050 and 2070, using the DSSAT modeling system. The future climate scenarios have been generated using the climate model named Providing REgional Climates for Impact Studies (PRECIS).

2. Methods

2.1 Selection of simulation locations

The yield of two boro varieties BR3 and BR14 for the years 2008, 2030, 2050 and 2070 have been simulated for 12 districts of Bangladesh, which were selected from among the major rice growing areas in different regions of Bangladesh. Among them, Rajshahi, Bogra and Dinajpur were selected from northwestern region; Mymensingh and Tangail were selected from central region; Jessore and Satkhira from southwestern region; Barisal and Madaripur from southern region; Chandpur and Comilla from southeastern region; and Sylhet district from eastern region. In addition to simulating yield for the selected years under the simulated climatic scenarios and the selected crop management conditions (described later), potential yield (i.e., yield without any water and nitrogen stresses) and vulnerability of the rice varieties under varying transplanting date were also assessed.

2.2 Crop model

The DSSAT modeling system is an advanced physiologically-based rice crop growth simulation model and has been widely applied to understanding the relationship between rice and its environment. The model estimates yield of irrigated and non-irrigated rice, determine 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 has been used for all simulations.

2.3 Selection of rice variety

The DSSAT model is variety-specific (e.g., BR3 boro) and is able to predict rice yield and rice plant response to various environmental conditions. In predicting crop growth and yield, the 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. The two boro rice varieties BR3 and BR14 have been selected in the present study because genetic coefficients for these varieties are available in the DSSAT modeling system. 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 boro rice yield in the future.

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. Input data related to 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. Required data on soil and hydrologic characteristics for the 12 selected locations (districts) were collected from Bangladesh Rice Research Institute (BRRI, Gazipur; BARC, 2005; Karim et al., 1998) and Soil Resources Development Institute (SRDI, Dhaka). As an example, the soil profile data used in the model for the North Eastern Barind Tract (i.e., Agro-Ecological Zone, AEZ-27) covering Dinajpur, Rangpur, Bogra, Gaibandha, and Joypurhat districts is presented in Table 1.

Table 1
Soil profile data for North Eastern Barind Tract (AEZ-27)

Depth Bottom Cm	Clay %	Silt %	Stones %	Organic Carbon %	pH in Water	Cation Exchange Capacity meq/100gm	Total Nitrogen %
5	19	17.5	0	0.79	5.2	5.25	0.14
15	19	17.5	0	0.79	5.2	5.25	0.14
30	19	17.5	0	0.75	5.2	5.25	0.13
45	19	17.5	0	0.63	5.2	5.25	0.11

Soil Texture: Loamy

The crop management data (i.e., agronomic data) required by the model include 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 present study are shown in Table 2; 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; 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.

Table 2
Crop management data used in the model simulations

Parameter	Input data
Planting method	Transplant
Transplanting date	1, 5, 15 and 25 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	30 kg ha^{-1}
• 38 days after transplanting	70 kg ha^{-1}
• 56 days after transplanting	30 kg ha^{-1}
Application of irrigation	855 mm in 14 applications

2.5 Weather data

In this study, 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 surroundings. 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), daily precipitation. These parameters were extracted at 12 locations mentioned in subsection 2.1.

3. Model applications and results

3.1 Impact of climate change on rice yield

Tables 3 and 4 show predicted yields of BR3 and BR14 boro rice varieties, respectively at 12 locations of Bangladesh in the years 2008, 2030, 2050 and 2070. These predictions have been made 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) and for planting date of 15 January. The Tables show significant reduction in rice yield in the future due to predicted changes in climatic condition. Compared to 2008, predicted average reductions of BR3 variety for the 12 selected locations are about 11% for the year 2030, 21% for 2050 and 54% for 2070. The corresponding reductions for BR14 variety are about 14%, 25% and 58% for the years 2030, 2050 and 2070, respectively. Some regional variation could also be observed in the predictions, with somewhat higher reductions predicted for central, southern and southwestern regions. Figure 1 shows predicted yields of BR3 and BR14 rice varieties for Barisal.

Table 3
Predicted yield of BR3 variety of boro rice (kg ha^{-1}) at 12 selected locations for the years 2008, 2030, 2050 and 2070

Station Name	Cultivar	2008	2030	2050	2070	% change in yield for 2030	% change in yield for 2050	% change in yield for 2070
Rajshahi	BR3	3063	4083	3265	1785	33.3	6.59	-41.7
Bogra	BR3	5741	5119	4070	2036	-10.8	-29.1	-64.5
Dinajpur	BR3	6848	4824	4364	2692	-29.6	-36.3	-60.7
Mymensingh	BR3	5995	5275	4455	2739	-12.0	-25.7	-54.3
Tangail	BR3	5487	5160	3874	1938	-5.95	-29.4	-64.7
Jessore	BR3	5571	4432	4583	1997	-20.4	-17.7	-64.2
Satkhira	BR3	4700	4364	3603	2066	-7.14	-23.3	-56.0
Barisal	BR3	6043	4006	3972	2091	-33.7	-34.3	-65.4
Madaripur	BR3	4582	4017	3647	2186	-12.3	-20.4	-52.3
Chandpur	BR3	5975	5455	4039	2772	-8.70	-32.4	-53.6
Comilla	BR3	6115	5987	4456	3075	-2.09	-27.1	-49.7
Sylhet	BR3	5960	5117	5750	3595	-14.1	-3.52	-39.7

Table 4
Predicted yield of BR14 variety of boro rice (kg ha^{-1}) at 12 selected locations for the years 2008, 2030, 2050 and 2070

Station Name	Cultivar	2008	2030	2050	2070	% change in yield for 2030	% change in yield for 2050	% change in yield for 2070
Rajshahi	BR14	2334	2771	2392	1148	18.7	2.48	-50.8
Bogra	BR14	4306	3668	2637	1398	-14.8	-38.8	-67.5
Dinajpur	BR14	5047	3374	3023	1656	-33.1	-40.1	-67.2
Mymensingh	BR14	4353	3790	3186	1873	-12.9	-26.8	-57.0
Tangail	BR14	4104	3883	2565	1297	-5.38	-37.5	-68.4
Jessore	BR14	4032	3160	3153	1305	-21.6	-21.8	-67.6
Satkhira	BR14	3153	3171	2434	1377	0.57	-22.8	-56.3
Barisal	BR14	4397	2889	2705	1457	-34.3	-38.5	-66.9
Madaripur	BR14	3229	2606	2578	1491	-19.3	-20.2	-53.8
Chandpur	BR14	4389	3981	2801	1842	-9.29	-36.2	-58.0
Comilla	BR14	4678	4368	3063	1978	-6.62	-34.5	-57.7
Sylhet	BR14	4596	3764	4240	2378	-18.1	-7.74	-48.3

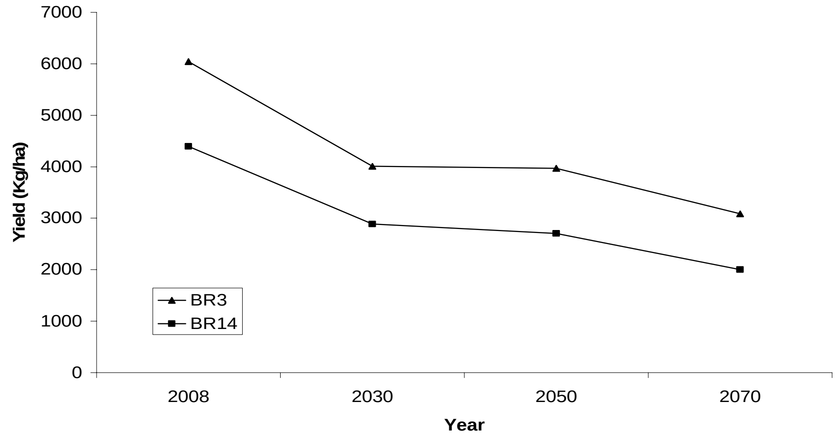

Figure 1. Predicted yield of BR3 and BR14 varieties of rice for Barisal

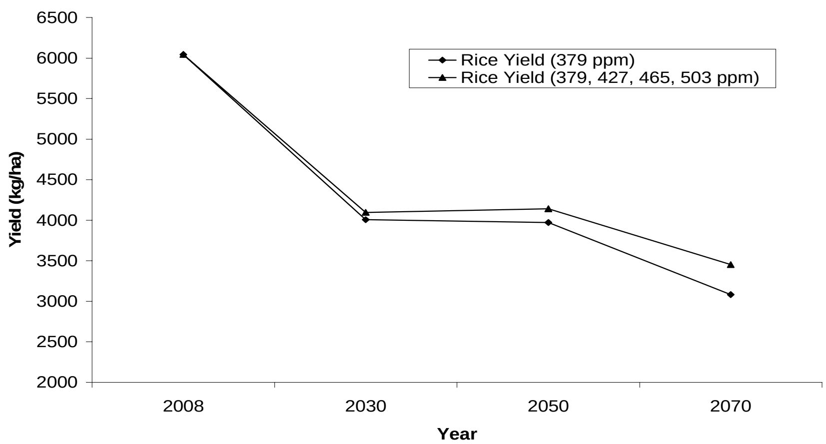

Figure 2. Predicted yield of BR3 rice in Barisal under different atmospheric CO_2 concentrations

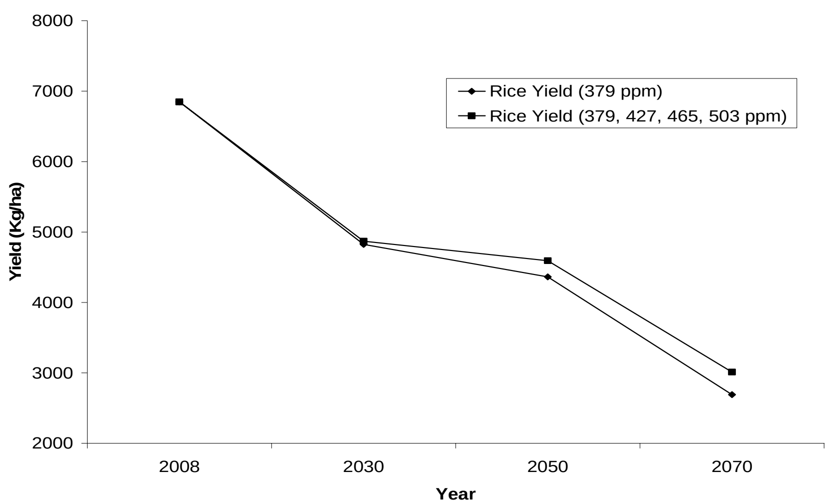

Figure 3. Predicted yield of BR3 rice in Dinajpur under different atmospheric CO_2 concentrations

Increasing atmospheric CO_2 concentration is likely to have some positive effect on rice yield. If rate of change of atmospheric CO_2 concentration from 1994 (358 ppm) to 2005 (379 ppm) (i.e., about 1.9 ppm per year) is used to set the CO_2 concentrations in the years 2030 (at 427 ppm), 2050 (at 465 ppm), and 2070 (at 503 ppm), then the model predicts slightly higher yield (compared to predicted yield at 379 ppm CO_2). These simulations (Basak, 2009) predicted average (for 12 locations) yield reductions of 8.9%, 18% and 48.7% for BR3, and 11.64%, 21.62% and 53.72% for BR14, for the years 2030, 2050 and 2070, respectively. When the CO_2 levels were increased to 427, 465 and 503 ppm in 2030, 2050 and 2070, respectively, predicted yield increased by 0.91 to 12.5% for BR3 rice and 0.09 to 13.7% for BR14 rice at different locations. Thus, increasing CO_2 concentrations are likely to offset only slightly the adverse effects of other climatic parameters on rice yield. Figures 2 and 3 show effect of increasing CO_2 on yield of BR3 rice variety at Barisal and Dinajpur, respectively.

3.2 Sensitivity of yield to climatic parameters

The climatic parameters used in the model are daily maximum temperature (T_{max}), daily minimum temperature (T_{min}), daily solar radiation (Srad) and daily precipitation (Rain). In order to assess relative importance of these parameters on predicted rice yield, sensitivity analysis was carried out by predicting BR3 rice yield for Barisal using predicted climatic parameters for the years 2008 and 2070, changing one parameter at a time; atmospheric CO_2 concentration was kept fixed at 379 ppm. As reported earlier (Table 3), predicted yield of BR3 decreased from 6043 kg ha^{-1} in 2008 to 2091 kg ha^{-1} in 2070. Table 5 shows the results of the sensitivity analysis.

Table 5
Sensitivity of BR3 yield at Barisal on climatic parameters

	T_{max}= 2008 T_{min}= 2008 Srad= 2008 Rain= 2008	T_{max}= 2070 T_{min}= 2008 Srad= 2008 Rain= 2008	T_{max}= 2008 T_{min}= 2070 Srad= 2008 Rain= 2008	T_{max}= 2008 T_{min}= 2008 Srad= 2070 Rain= 2008	T_{max}= 2008 T_{min}= 2008 Srad= 2008 Rain= 2070	T_{max}= 2070 T_{min}= 2070 Srad= 2070 Rain= 2070
Rice yield (kg ha^{-1})	6043	4160	5039	6714	4354	2091

Table 6
Sensitivity of BR14 yield at Barisal on climatic parameters

	T_{max}= 2008 T_{min}= 2008 Srad= 2008 Rain= 2008	T_{max}= 2070 T_{min}= 2008 Srad= 2008 Rain= 2008	T_{max}= 2008 T_{min}= 2070 Srad= 2008 Rain= 2008	T_{max}= 2008 T_{min}= 2008 Srad= 2070 Rain= 2008	T_{max}= 2008 T_{min}= 2008 Srad= 2008 Rain= 2070	T_{max}= 2070 T_{min}= 2070 Srad= 2070 Rain= 2070
Rice yield (kg ha^{-1})	4397	3134	3564	4950	3101	1457

Table 5 shows that T_{max} has the most significant negative impact on rice yield, followed by Rainfall, and T_{min}; predicted solar radiation on the other hand has some positive effect on yield. Analysis of predicted temperatures (see Fig. 4) shows that average T_{max} during January-May (i.e., rice growing season) for 2008 and 2070 are 30.73 and 35.11 ºC, respectively; this significant increase in T_{max} resulted in reduction of yield of BR3 rice by about 31%. Average T_{min} during this period for 2008 and 2070 were 21.52 ºC and 25.22 ºC, and the increase in T_{min} caused a reduction of 17% in the predicted yield. Average solar radiation in 2008 and 2070 are 15.37 and 16.71 MJ/m^2/day, respectively and this increase in solar radiation actually increases the predicted yield by about 11%. It should be noted that the predicted increase in yield for Rajshahi for 2030 and 2050 (see Table 3) could also be explained by the variation in predicted temperatures at this location (Basak, 2009). Like BR3, similar yield reductions were also predicted for BR14 rice (see Table 6).

Tables 5 and 6 show significant negative effect of rainfall on BR3 and BR14 rice yields. Since a fixed irrigation schedule (855 mm in 14 applications) was used in all model simulations, change in rainfall would affect predicted yield by changing availability of water. Analysis of predicted rainfall data (see Fig. 4) shows total rainfall (during January to May) of 144.6 mm and 356.1 mm for 2008 and 2070, respectively. So, total water available from rainfall was higher in 2070. However, a closer look shows that in 2008, significant rainfall (96.3 mm) is predicted during January to March, which represent the vegetative phase and a part of reproductive phase of rice plant and during which water requirement is the highest. In 2070 only 21.6 mm rainfall is predicted for this critical growth phase; on the other hand relatively high rainfall of 334.5 mm is predicted for April-May, when water requirement is not significant. This variation in rainfall pattern is responsible for the predicted reduction in rice yield in 2070. However, in theory, this reduction in yield may be avoided by applying additional irrigation during the early stages of growth. Sensitivity analysis was also carried out for Dinajpur, Mymensingh, Jessore and Comilla (Basak, 2009). These analyses yielded similar results, demonstrating significant negative impact of increasing T_{max} and T_{min} on rice yield. Depending on rainfall pattern, the effects of rainfall on rice yield at these locations were different (Basak, 2009). Similar results were also found for other four locations in Bangladesh (Dinajpur, Mymensingh, Jessore and Comilla) but the percentages of changing rice yields were various due to location variations of those climatic factors (Basak et al., 2009).

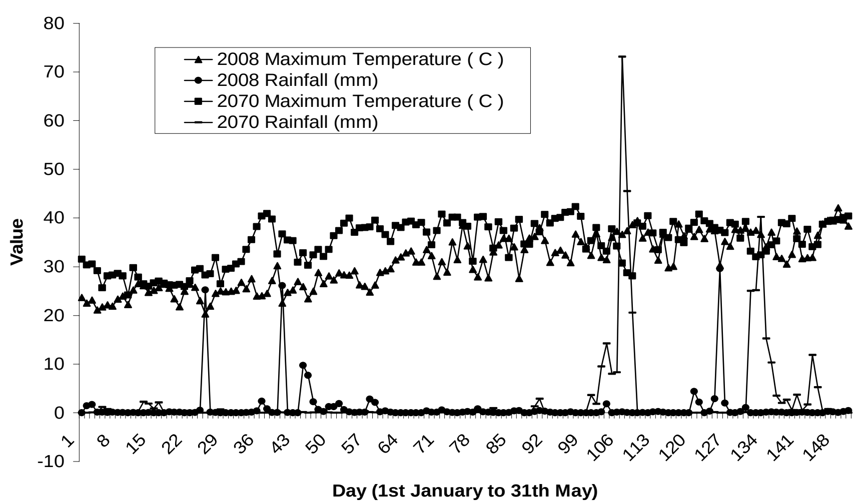

Figure 4. Variation of T_{max} and Rainfall during January-May in 2008 and 2070.

3.3 *Effect of climate change on physiological maturity*

Model results also showed significant effect of climate change on physiological maturity of rice. The duration of physiological maturity has been predicted to decrease significantly due to changes in climatic scenario (see Tables 7 and 8). For example, predicted physiological maturity (in days) of BR3 rice varieties varied from 93 (in Satkhira) to 114 (in Sylhet) in 2008; while the corresponding values are 77 and 90 in 2070. For BR14, it varied from 92 (in Rajshahi) to 121 (in Sylhet) in 2008; while the corresponding values are 86 and 95 in 2070. Some regional variation could be observed in the predictions (Basak, 2009). 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 physiological maturity under field condition. Changes in temperatures and solar radiation are important factors affecting physiological maturity of rice. Planting date was also found to affect physiological maturity; delayed planting was found to reduce physiological maturity significantly (Basak, 2009). Figure 5 shows predicted physiological maturity in days for BR3 for different regions of Bangladesh.

Table 7
Predicted physiological maturity (days) of BR3 for different locations.

Location	2008	2030	2050	2070
Rajshahi	88	95	84	83
Bogra	100	100	89	83
Dinajpur	105	99	89	82
Mymensingh	106	105	96	86
Tangail	99	98	87	84
Jessore	96	91	84	80
Satkhira	93	89	82	77
Barisal	99	94	87	80
Madaripur	96	94	86	80
Chandpur	99	97	87	81
Comilla	102	100	92	82
Sylhet	114	114	104	90

Table 8
Predicted physiological maturity (days) of BR14 for different locations.

Location	2008	2030	2050	2070
Rajshahi	92	99	88	86
Bogra	105	105	90	87
Dinajpur	110	104	93	85
Mymensingh	112	111	101	90
Tangail	104	104	90	87
Jessore	101	96	87	83
Satkhira	97	94	86	81
Barisal	105	99	91	84
Madaripur	101	98	91	85
Chandpur	105	102	92	84
Comilla	109	105	96	85
Sylhet	121	121	110	95

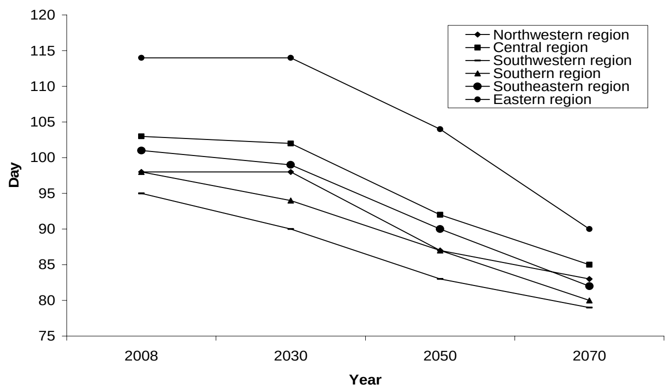

Figure 5. Region-wise prediction of physiological maturity (in days) of BR3 rice

3.4 *Effect of planting date on rice yield*

The effect of planting date on rice yield was assessed by setting the planting date on 1, 5, 15 and 25 January and simulating yield for each case. Table 9 and 10 show predicted yield of BR3 and BR14 for different planting dates for the 12 selected locations. In general, the predictions indicate significant reduction in rice yield for delayed planting, especially beyond 15 January. The effect appears to be more pronounced for the years 2050 and 2070. Also the predicted yields appear to show more pronounced effect of planting data for locations in northwestern and central regions. For example, for planting dates of 15 and 25 January, the average reductions in BR3 yield (compared to yield for planting date of 1 January) for the three locations in northwestern region are 23% and 40%, respectively for the year 2050; and 35% and 41%, respectively for the year 2070; the corresponding yield reductions for BR14 are 28% and 41%, respectively for the year 2050; and 29% and 37%, respectively for the year 2070. It may be noted that Mahmood et al. (2003) reported significant reduction in yield of aman (wet season rice) as planting is delayed beyond 1 June. Thus, the climate change could not only cause significant reduction in boro rice yield, but could also make yield more sensitive to planting time.

Table 9
Predicted yield of BR3 (kg ha^{-1}) for different planting dates

Location	2008				2030				2050				2070			
	1st	5th	15th	25th	1st	5th	15th	25th	1st	5th	15th	25th	1st	5th	15th	25th
Rajshahi	4310	4847	3063	2020	5305	6056	4083	2907	4498	4216	3265	2417	2589	2035	1785	1662
Bogra	6439	6063	5741	4538	6205	5969	5119	4162	5435	4352	4070	2781	3492	2684	2036	1961
Dinajpur	6071	5186	6848	5357	6419	7063	4824	4586	5338	5085	4364	3913	3929	3401	2692	2290
Mymensingh	5599	5808	5995	5595	5985	5977	5275	3652	4634	5181	4455	4944	4550	4235	2739	2856
Tangail	6141	6039	5487	4733	6419	5963	5160	3998	5425	4192	3874	3269	3444	2662	1938	1763
Jessore	5235	4929	5571	4851	4956	4808	4432	4187	4785	4313	4583	3342	2794	2602	1997	1857
Satkhira	5092	4660	4700	3803	4865	5630	4364	3608	4377	4001	3603	3481	2955	2621	2066	1966
Barisal	5850	4603	6043	4618	4301	5686	4006	3798	4924	4250	3972	4246	3941	3732	2091	2021
Madaripur	4630	3389	4582	4205	4121	5174	4017	3070	4039	4193	3647	3812	3450	3499	2186	2238
Chandpur	6417	6025	5975	5462	4475	5949	5455	3993	5130	4685	4039	4422	3999	4123	2772	2629
Comilla	7034	6400	6115	5623	6646	6788	5987	4110	5095	4871	4456	4401	4130	4248	3075	2798
Sylhet	5797	5559	5960	5299	5398	5425	5117	4309	6007	5511	5750	5032	4885	4546	3595	4756

Table 10
Predicted yield of BR14 (kg ha^{-1}) for different planting dates

Location	2008				2030				2050				2070			
	1st	5th	15th	25th	1st	5th	15th	25th	1st	5th	15th	25th	1st	5th	15th	25th
Rajshahi	2744	3362	2334	1125	3726	4225	2771	1673	3269	2810	2392	1750	1724	1651	1148	1076
Bogra	4794	4093	4306	3534	4523	4324	3668	3195	3968	2879	2637	2135	2050	1907	1398	1223
Dinajpur	4614	3452	5047	4045	4677	4927	3374	3461	3977	3354	3023	2715	2130	2136	1656	1417
Mymensingh	4171	4264	4353	4263	4326	4340	3790	2919	3435	3503	3186	3628	2770	2749	1873	1923
Tangail	4195	3971	4104	3388	4607	4413	3883	3043	3913	2741	2565	2171	2088	1703	1297	1182
Jessore	3783	3247	4032	3690	3420	3395	3160	3060	3033	2855	3153	2413	1853	1720	1305	1297
Satkhira	3527	3055	3153	2967	3323	4277	3171	2597	2855	2763	2434	2406	1924	1606	1377	1309
Barisal	4382	3127	4397	4031	2963	4001	2889	3029	3510	2800	2705	2798	2481	2546	1457	1374
Madaripur	3372	2323	3229	3088	2858	3614	2606	2383	2745	2869	2578	2762	2274	2357	1491	1534
Chandpur	4664	3902	4389	4243	3158	4243	3981	3171	3644	2862	2801	3163	2461	2675	1842	1770
Comilla	4964	3884	4678	4507	4887	4916	4368	3293	3639	3345	3063	3187	2598	2790	1978	1827
Sylhet	4252	4257	4596	4000	4394	4131	3764	3281	4493	3793	4240	3813	3255	2875	2378	3470

Table 11
Predicted water requirement (mm) of BR3 for different locations

Location	2008	2030	2050	2070
Rajshahi	795.4	852.8	795.4	783.4
Bogra	862.4	800.6	841.6	792.8
Dinajpur	787.6	752	831.6	797
Mymensingh	651.8	549.2	703.2	687.8
Tangail	844	761.6	771.6	770.8
Jessore	841.8	755.6	840.4	778.2
Satkhira	779	742.6	760.2	733.2
Barisal	729.6	611.4	689.4	673
Madaripur	742.2	667.8	721.8	673.4
Chandpur	712.4	650.2	702.8	703
Comilla	700.4	656.4	723.8	726.2
Sylhet	535.2	439.4	558.4	592.8

Table 12
Predicted water requirement (mm) of BR14 for different locations

Location	2008	2030	2050	2070
Rajshahi	834.8	879.8	837.8	748.4
Bogra	935.8	855	845	770.2
Dinajpur	842.2	807	892.2	784.8
Mymensingh	683.4	589.6	771.2	677.2
Tangail	903	845	807.6	752.4
Jessore	888.8	814.4	868.6	775.2
Satkhira	840.8	806.8	790.6	735
Barisal	788.8	640.6	714.4	696.2
Madaripur	770.8	681.6	755.6	702.2
Chandpur	772.8	694	742	702.8
Comilla	774.8	691.8	740.2	724.6
Sylhet	569.6	460	580.2	613.2

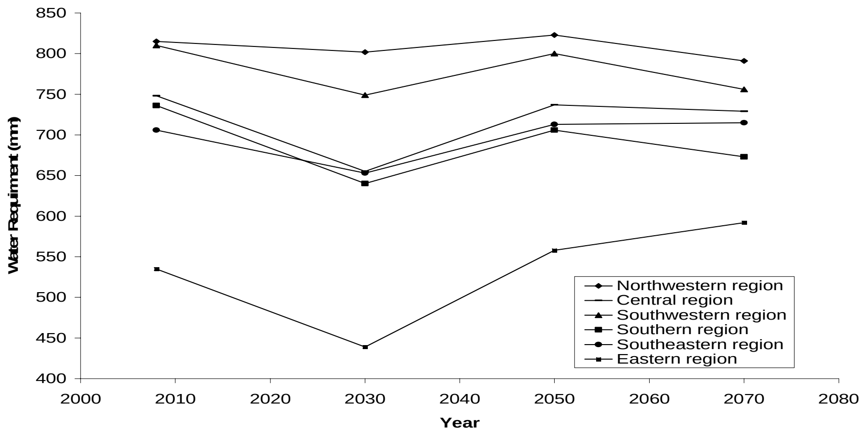

Figure 6. Region-wise prediction of water requirement (mm) of BR3 rice

3.5 Effect of climate change on irrigation water requirement

Tables 11 and 12 show predicted irrigation water requirement for BR3 and BR14 rice varieties, respectively, for the selected locations. Figure 6 shows variation of average water requirement for BR3 rice variety for different regions. 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). In general, the model predicted slightly decreasing water requirement in the future, especially for the central, southwestern and southern regions (compared to 2008). Higher water requirements are predicted in northwestern region which is a drought prone region, relatively lower water requirements are predicted in eastern region where more rainfall occurs. Planting date also affects water requirement significantly according to model results. Model results show that water requirement is comparatively higher if boro rice is planted earlier, i.e.., 1 or 5 January, compared to plantation on 15 or 25 January) (Basak , 2009). The amount of water available for plant growth is affected by a combination of climatic and non-climatic variables such as precipitation, temperature, sunshine, wind speed as well as soil porosity, slope, etc. Climatic factors and duration of physiological maturity have significant roles on water requirement for plant. While higher evapotranspiration increases water requirement, shorter physiological maturity decreases water requirement. Higher temperature and higher solar radiation lead to higher evapotranspiration but shorten the period of physiological maturity. Predicted shorter physiological maturity in is one of the main reasons for lower water requirement in some of the future years, especialy in 2070.

4. Conclusions

Although currently the BR3 and BR14 rice varieties are not widely used, the model simulations carried out in this study provide useful insight into the possible effects of climate change on boro rice yield. The growth and yield of crops are directly related to the rate of photosynthesis and phenology and their response to temperature, solar radiation and rainfall. Optimum temperatures for maximum photosynthesis range from 25 to 30 ºC for rice under the climatic conditions of Bangladesh. Increased temperatures during the growing season cause grain sterility. Very high temperatures, sometimes exceeding 35°C, 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 rice yield. Sensitivity analysis indicates that crop model is sensitive to CO_2 levels and solar radiation. Although higher CO_2 levels and solar radiation in the future would balance the detrimental effects of increased temperatures to some extent, these would not be able to offset the adverse effect of temperature. The model simulations also suggest that changes in rainfall patter may also adversely affect rice yield. Simulation results also suggest that planting dates could significantly affect rice yield, and this effect could become more pronounced in the future. In order to assess the effect of climate change on the rice varieties currently being grown in Bangladesh, it is necessary to determine 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. Modeling tools, such as the DSSAT modeling system, could be very useful in assessing possible impacts of climate change and management practices on rice yield. 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.

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