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Crop Modelling
ORIGINAL ARTICLE

Assessment of the effect of climate change on vegetative growth of major crops in Bangladesh using DSSAT

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A R T I C L E   I N F O

A B S T R A C T

A number of studies listed the potential consequences of climate change on crop agriculture and food security emanated from global warming, particularly in developing countries including Bangladesh. In this study, the effect of climate change on growth parameters of rice and non-rice crops was investigated. MAGICC/SCENGEN model together with observed climate data was used to generate Intergovernmental Panel on Climate Change (IPCC) scenario B2 and A2. Wheat, rice, and potato growth parameters were simulated using CERES-Wheat, CERES-Rice, and SUBSTOR-Potato models under projected change in future climatic conditions. Leaf area index (LAI), aboveground dry matter (ADM), and harvest index (HI) were found to be influenced by climate change. The effect of climate change was higher for wheat growth compared to rice and potato. The predicted change in crop growth parameters indicated the potential risk of food security in Bangladesh in the verge of increasing population and diminishing land resources. The results of this study can be used as a guideline to adopt climate change coping mechanisms to ensure future food security.

INTRODUCTION

The consequence of climate change on crop production has been a matter of concern in many developing countries including Bangladesh (Roudier et al. 2011). Bangladesh holds a population of 162 million (BBS 2016) with a growth rate of 1.37% per year (SID 2010). The economy of Bangladesh depends on agriculture, extracting 18.7% of GDP and employing 47.3% of total labor force (BBS 2013). The major crops include rice (77%) jute (4.74%), wheat (2.5%), potato (3.07%), vegetables (2.45%), and others (10.3%) (BBS 2011). Due to climate change, erratic behavior and distribution of rainfall and rise in temperature, the major impacts would be on agriculture.

Assessment reports of the Intergovernmental Panel on Climate Change (IPCC) and various other studies listed the potential consequences of climate change. According to the reports, combined with the potential increase in global temperature, rainfall has become variable and unpredictable and the occurrence and strength of climate-related extreme events such as floods, droughts, heat waves, and cyclones are anticipated to increase in the future (FAO 2007; IPCC 2007). Taking 1990 as

the base year, predictions made by IPCC show that the average global surface temperature might increase by 1 to 5°C by the year 2100 (IPCC 2001). In Bangladesh, temperature has been increasing for the last three decades, particularly during the monsoon season. The country is predicted to experience an increase in average day temperature of 1°C by 2030 and 1.4°C by 2050 (FAO 2007; IPCC 2007). Results from various other studies by simulation of models support the IPCC predictions and suggest that annual rainfall will increase in Bangladesh (Agrawala et al. 2003). However, most of the climate models estimate that precipitation will increase, but insignificantly, during the summer monsoon and decrease in the winter months of December through February.

One of the biggest concerns of climate change is the potentially disastrous consequences on crop agriculture and food security in many parts of the world, particularly in the developing countries (FAO 2007; IPCC 2007; Mertz et al. 2009; WB 2010; Roudier et al. 2011). Analyses of multiple climate change scenarios indicate that climate change will likely have a slight to

moderately negative effect on crop yields (Parry et al. 2004; Cline 2007), but crop irrigation requirements would increase (Fisher et al. 2006), as would overall water stress in many areas dependent on irrigation. Karim et al. (1999) investigated the impact of various levels of moisture stress on the rice grown in the Boro season under the baseline climate. They found that at moderate level of moisture stress of up to 30%, drop in yield was small − about 1 to 4% of the base year's yield. However, at the higher moisture stress level of 60%, yield fell by 10 to 33%. Basak et al. (2010) investigated the effect of climate change on the yield of two Boro rice varieties in 12 locations of Bangladesh. They predicted 20 and 50% yield reduction of both rice varieties for the years 2050 and 2070, respectively. Increases in daily maximum and minimum temperatures were found to be primarily responsible for the reduction in yield.

Despite the status of Bangladesh as a country that is highly susceptible to climate change, investigations on the influences of climate change on crop agriculture have been limited (Rashid and Islam 2007). A few studies investigated the effect of climate change on crop yield (Basak et al. 2010; Karim et al. 1999). Although change in temperature and precipitation has a large effect on crop's physiological processes and controls crop phenology and leaf senescence, very limited or inadequate studies explored the effect of climatic change on crop vegetative growths. Therefore, this study aimed to investigate the effect of climate change (temperature and precipitation change) on leaf area index (LAI), aboveground dry matter (ADM), and harvest index (HI) of the three major crops in Bangladesh.

METHODOLOGY

Data Collection

Data used in the present study were collected from various experiments conducted previously at Bangladesh Agricultural University (BAU) campus (24.45°N latitude and 90.25°E longitude), Mymensingh. The model (DSSAT) used in this study required three types of data, such as weather data (maximum and minimum temperatures, rainfall, solar radiation); soil data (soil profile information, nutrient status, chemical and hydraulic properties); crop growth and management data (planting, plant distribution, plant population, spacing between adjacent rows, irrigation method, amount of irrigation, fertilizer and harvesting data, previous crop information such as soil depth, cultivar coefficients, application of different management inputs, etc.). Climate data were collected from a weather station situated at Bangladesh Agricultural University campus, Mymensingh. Weather data of 30 (thirty) years spanning from 1985 to 2014 were collected.

The effect of climate change was studied for three major crops, i.e., Rice, Wheat, and Potato. These are the three major crops that supply a large part of national food production. Wheat and potato production data were collected from a study conducted in the season of 2007-2008, which investigated the interactions and effect of wastewater and fertilizer application on wheat and potato yield (Biswas 2012). In this study, only crop data irrigated with freshwater and fertilized with standard doses were used for calibration of the model. Rice production data were collected from a separate study conducted in the season of 2013, which investigated the effect of transplanting date on yield and yield attributing characters of a transplant Aman (T. Aman) variety (Reza 2014). Specific soil profile and crop information to be used as inputs for the model set up is presented in Table 1 and 2, respectively.

Table 1. Physical and chemical properties of the pre-sowing soil at different layers in wheat, potato, and rice experimental field (Biswas 2012; Reza 2014)

Crop	Soil depth (cm)	Particle size distribution (%)			Bulk density (gm/cm^3)	pH (extract)	Organic Carbon %	Total nitrogen (%)	Available phosphorus (mg/kg)	Exchangeable potassium Cmol/kg
		sand	silt	clay						
Wheat and Potato	0-20	32.6	56.7	10.8	1.3	6.9	0.63	0.06	4.01	0.1
	20-40	54.6	40.0	5.4	1.4	7.1	0.34	0.03	2.24	0.1
	40-60	67.9	26.7	5.4	1.4	7.2	0.28	0.02	1.92	0.1
Rice	5	10	60	30	1.4	5.8	1.42	0.11	–	–
	15	10	60	30	1.4	5.8	1.42	0.11	–	–
	20	10	60	30	1.4	5.8	1.42	0.11	–	–

Table 2. Cropping information of wheat, potato, and rice (Biswas 2012; Reza 2014)

Crop Information		Wheat	Potato	Rice
Planting	Date	12/12/07	11/12/07	19/08/13
	Depth, cm	3	5	3
	Row spacing, cm	20	60	15
	Plant population/m^2	149	8	158
Irrigation (mm)	1st	31/12/07 (32.5)	01/01/08 (35)	19/10/13(60)
	2nd	26/01/08 (42.5)	21/01/08 (45)	03/11/13(60)
	3rd	28/02/08 (50)	10/02/08 (50)	-
Fertilizer (kg/ha)	N	120	160	126
	P	32	44	24
	K	62	132	52
Harvest	Maturity stage	31/03/08	3/03/08	23/12/13

Generation of Climate Change Scenarios

One 'baseline' scenario, representing the current climatic conditions and two climate change scenarios at three future periods were constructed. The latter were produced using output from MAGIC/SCENGEN model (Fordham et al. 2011) for three future time periods of 2025—2054 centering 2040, 2055—2084 centering 2070, and 2085—2114 centering 2100. For each time period, two emission scenarios such as A2 (high) and B2 (medium) were simulated according the Special Report on Emission Scenarios (SRES) (Nakicenovic and Swart 2000).

Observed daily mean of climatic data (maximum and minimum temperatures, rainfall, and solar radiation) from 1984 to 2014, also served as baseline, was used to calculate future climatic scenarios; which were constructed together with MAGICC/SCENGEN model output by using delta change approach.

MAGICC is a combination of models of coupled gas-cycle and climate and ice-melt and can be used to estimate the mean global temperature and effects of sea level rise under different emission of GHGs and aerosol scenarios. SCENGEN (SCEnario GENarator) comes as embedded in MAGICC and is used to generate a range of geographically explicit climate change projections by using combination results of MAGICC together with GCM, coupled Atmospheric-Ocean General Circulation Models (AOGCM), and observed data. In combination with the observed data, SCENGEN can generate climate scenarios for any regions and for any time period in the 21st century. SCENGEN uses observed data from 1961−1990 from every regions of the world and constitutes as baseline data. The output of SCENGEN model is obtained in 2.5×2.5 degree latitude/longitude grids resolution.

The model monthly outputs were converted and used to construct daily future climatic data through the following equations:

$$R_{day(adj)} = R_{day}\left(1 + \frac{adj_{pcp}}{100}\right) \qquad (1)$$

where, R_{day} [$R_{day\ (adj)}$] is the rainfall (adjusted-rainfall) amount falling in the study area on a given day and adj_{pcp} is the percentage change in rainfall.

$$T_{day(adj)} = T_{day} + adj_{tmp} \qquad (2)$$

where, T_{day} [$T_{day\ (adj)}$] is the daily (adjusted-daily) mean temperature (°C), and adj_{tmp} is the change in temperature (°C).

Daily solar radiation was constructed from daily maximum and minimum temperatures by modified B-C model as described by Goodin et al. (1999). Simulations were performed for baseline and three future periods of 2040s, 2070s, and 2100s for two scenarios of A2 and B2.

Crop Simulation Model

The Decision Support System for Agrotechnology Transfer (DSSAT) is a software package which incorporates the effect of crop phenotype, soil, weather, and crop management system on the basis of a database protocol and allows researchers to simulate experiments of various scenarios. DSSAT enables the user to predict the possible results from diverse managerial dimensions and strategies through separate independent programs functioning together (Jones et al. 2003). The inherent parts of the program include specific simulator models and databases for weather, soil, experimental conditions, and genotype information. The crop model simulates crop yield, growth, and development based on some characteristics of the simulated crops: phenology, photoperiod, biomass accumulation as well as partitioning among its roots, stems, and leaves, as defined by cultivar-specific genetic coefficients. The software enables researchers to calibrate inputs parameters for each of the programs and compare simulation results with observations. Risk assessment associated with different crop production strategies through its multi-year simulation is another feature of DSSAT. Moreover, it allows changing weather variables without modifying original weather data outfitting for climate change impact studies through its built-in functions. Among the suits of the Cropping System Model (CSM) in DSSAT, CERES-Wheat, CERES-Rice and SUBSTOR-Potato modules were used to study the effect of climate change on respective crops. The reasons for selecting DSSAT model for this study were its ability to accurately simulate crop phenology and biomass accumulation and partitioning technique, being suitable for climate change studies.

From the collected weather, soil and crop phenology and management data, five input files were created to run the model. The input files were: weather file (FILE.WTH), soil files (FILES), crop management file (FILEX), experimental data file (FILEA), and genetic coefficient file (FILEC)

Model calibration

Precalibrated models (Banu 2016) were used in this study. CERES-Wheat *(Shatabdi)*, CERES-Rice *(BRRI dhan11, T. Aman),* and SUBSTOR-Potato *(Red Lasoda)* were calibrated using observed data by changing one-parameter-at-a-time. Data from the field experiments conducted in 2007-2008 season was used to calibrate the CERES-Wheat and SUBSTOR-Potato models, while for CERES-Rice, data collected in 2013 season were used for calibration. For each change of a parameter, the model was run with the changed value. The resulting model simulated values of LAI and yield were compared with the observed value. This process was repeated until satisfactory results were obtained as indicated by different model performance indicators. During the calibration, plant population, row spacing, planting date, planting method, etc. were slightly changed. In this study, default cultivar coefficients were used, and calibration also involved changing the values of cultivar coefficients. The details of the calibration are found elsewhere (Banu 2016).

Model Performance Evaluation

Before applying the models for simulation with future climatic data, the model calibration performances were evaluated to see the predictability of the model. The two deviation statistics, i.e., root mean square error (RMSE) and Forecasting Efficiency (EF), and one test statistic, coefficient of determination (R^2), were calculated for evaluating calibration performance of the CERES-Wheat, SUBSTOR-Potato, and CERES-Rice models. The deviation statistics were calculated by the following equations:

$$RMSE = \sqrt{\left(\left[n^{-1}\sum_{i=1}^{n}(s_i - m_i)^2\right]\right)} \qquad (3)$$

$$EF = \frac{\sum_{i=1}^{n}(m_i - \bar{m})^2 - \sum_{i=1}^{n}(s_i - m_i)^2}{\sum_{i=1}^{n}(m_i - \bar{m})^2} \qquad (4)$$

where, s_i refers to model simulated value of a parameter; m_i is measured value, n refers to the number of data points used; and $\bar{m}$ is the mean value of the measured data. The RMSE measures the average of difference between simulated and measured values in same unit. In case of model efficiency, $EF = 1$ indicates absolute correspondence between simulated and measured data (such as, $s = m$), which means simulated and observed data are the same while $EF < 0$ indicates that simulated values (s) are fluctuated from the measured value (m). The R^2 statistic ($0 \leq R^2 \leq 1$) explains variances of data in percentage accounted for by the model.

Model simulation with future climate data

The calibrated models were used to simulate crop growth in future climatic conditions by selecting the generated future weather data as model weather inputs. The other model input parameters were kept unchanged as were in the calibrated values. From the model output, leaf area index, aboveground dry matter, and harvest index were calculated.

RESULTS AND DISCUSSION

Climate change scenarios

In baseline climate, the mean monthly maximum and minimum temperatures, mean precipitation, and mean solar radiation were 31.9°C, 11.7°C, 21.6 cm and 21.5 MJm^{-2}d^{-1} (data not shown), respectively, which corresponded to the month of April, January, July, and April. The majority of rainfall concentrated in the

month of April to October. The monthly mean of solar radiation was higher in dry periods of low rainfall and lower in rainy periods, suggesting that the cloud cover obstructed solar radiation reaching ground. The range of monthly mean temperature was also higher during dry period.

B2 scenario showed that temperature gradually increased with time, and the highest increase was observed for the year 2100 (Figure 1a). The colder months during winter went on larger changes than the warmer months of the year, with the highest increment was for the month of January in 2100. The magnitude of change among the months became larger as time elapsed from the baseline to the future years of projected climate change. The amount of precipitation varied considerably in different months of the year from the baseline (Figure 1b). However, percent change in precipitation was higher at dryer months as observed in the baseline climate. The highest increase in precipitation was in the month of December in 2100 with a magnitude of 42.2%. Precipitation decreased during April to June, the highest decrease of 12.5% was observed in the month of April in 2100.

In A2 scenario, the magnitude of change of temperature increased as the time elapsed from the baseline to the future years of prediction (Figure 1c). The change of temperature in 2040 was almost similar in both A2 and B2 scenarios. However, the predicted temperature change was higher in 2070 and 2100 under A2 climate change scenario compared to B2 (Figure 1d). The highest increase in temperature due to climate change was 3.29 and 5.32°C in 2070 and 2100, respectively, in the month of January. Similar to B2 climate change scenario, the variation of temperature change among the months was higher in the future years of prediction. Like temperature, change in precipitation was also higher in A2 compared to B2 climate change scenario. Precipitation varied considerably from the baseline in different months of the future years, and the highest change occurred in the year 2100. The highest increase of precipitation was 62.2% in the month of December in 2100, while the highest decrease of precipitation was observed in the month of April of the same year and was 18.4%. Similar trend of change in temperature and precipitation was observed in both the A2 and B2 scenarios but with different magnitudes.

(a) B2 scenario

(b) A2 scenario

(c) B2 scenario
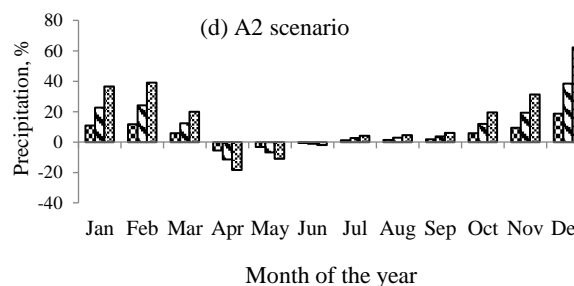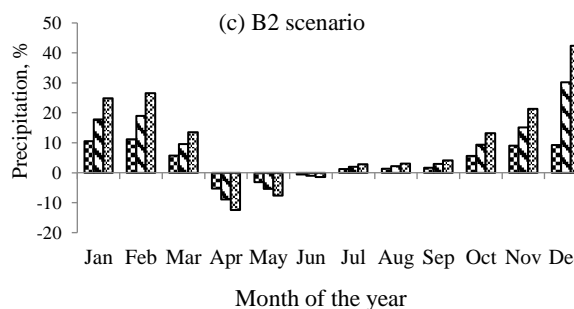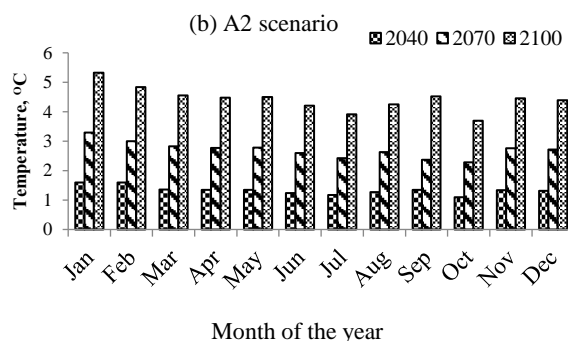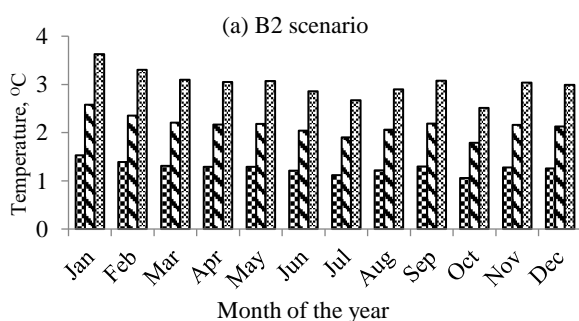
(d) A2 scenario

Figure 1. Increase or decrease of mean monthly temperature (a,b) and precipitation (c,d) from baseline in 2040, 2070, and 2100 in different climate change scenarios

Model Calibration

Calibration of CERES-Wheat, SUBSTOR-Potato, and CERES-Rice models was performed taking simulated and measured data of LAI of the crops. During calibration, over or under prediction of LAI was observed for values that fell either in the lower or higher range. However, overall model performance for LAI prediction was satisfactory as indicated by the coefficient of determination and deviation statistics (Table 3). The model prediction in SUBSTOR-Potato was higher than the observed in most of the cases. The calibrated model showed slight scatter of data points of LAI about 1:1 line indicating a strong correlation between simulated and observed LAIs. Model calibration for yield resulted in close agreement between simulated and observed values and described in detail elsewhere (Banu 2016).

Table 3. Coefficient of determination (R2), root mean square error (RMSE) and model efficiency (EF) for the observed and simulated LAIs during calibration for wheat, rice, and potato

| Variable	Wheat			Potato			Rice		
	R^2	RMSE	EF	R^2	RMSE	EF	R^2	RMSE	EF
LAI	0.72	0.28	0.78	0.71	0.29	0.45	0.87	0.83	0.74

Impact of climate change on wheat, potato, and rice growth parameters

Leaf area index

Wheat

Figure 2 shows the simulated LAI at baseline and in 2040, 2070, and 2100 under projected climate change of both B2 and A2 scenarios. Comparing the figures suggests similar trends of LAI for both scenarios, except lower peaks in A2 scenario than that in B2 scenario. The lower peak in A2 could be due to the effects of increased temperature and precipitation than in B2 resulting from climate change. Leaf area index is an important parameter for measuring growth and vigor of plant and it affects radiation uptake, precipitation interception, energy conversion, momentum, and gas exchange (Monteith and Unsworth 1990). Light interception influences photosysthesis thereby determines growth and productivity of crops (Ewert 2004). The lower LAIs of wheat at different changing climatic scenarios suggest a decreased assimilation rate and could be the likely cause of yield reduction.
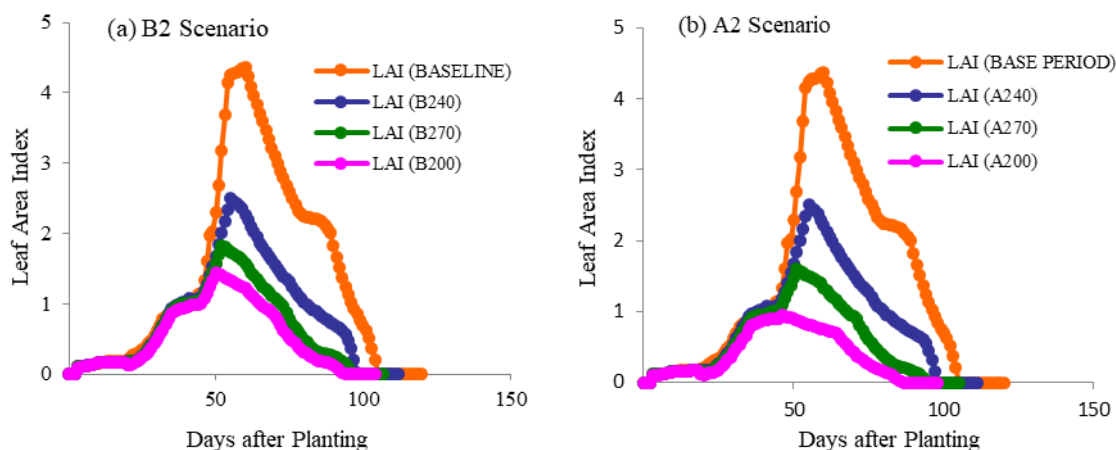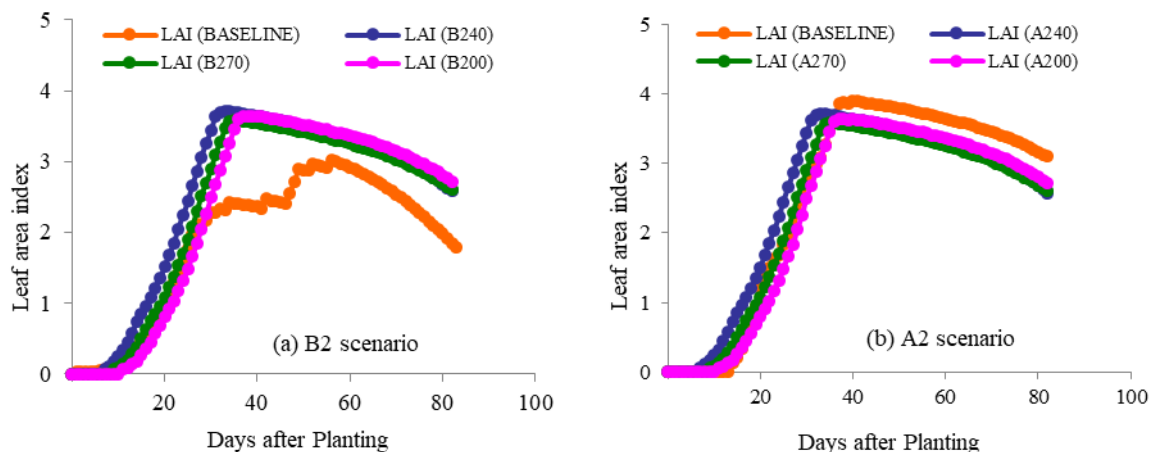

Figure 2. Simulated LAI at baseline and in the year of 2040, 2070, and 2100 under projected climate change for B2 and A2 scenarios

Potato

Figure 3 shows the simulated leaf area index at the baseline and the future periods under projected climate change in both scenarios. It is seen from the figure that the simulated LAIs for future periods under predicted climate change are almost identical. However, a difference was observed between A2 and B2 at baseline scenario. Increased interception of light accelerates growth of crops, which also increases LAI. When crops develop rapidly, its LAI reaches maximum before the start of reproductive stage. In potato, for both scenarios, different rates of LAI production were observed before LAI reached maximum. However, the rate of LAI production was similar for all future years of climatic change.
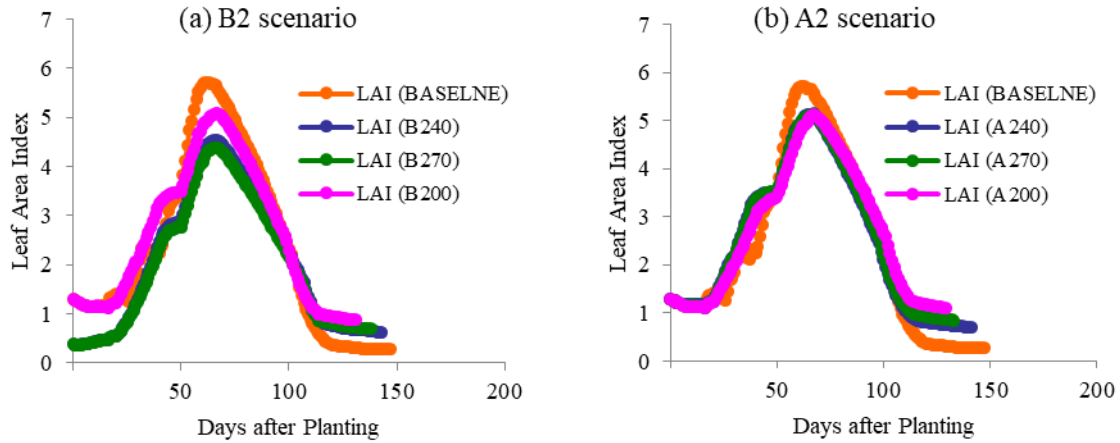

Figure 3. Simulated leaf area index of potato at baseline and in the year of 2040, 2070, and 2100 under projected climate change for B2 and A2 scenarios

Rice

Figures 4 (a) and (b) show the simulated leaf area index, LAI, of rice at the baseline climate and in the future years under projected climate change for both B2 and A2 scenarios. As seen from the figures, trend of LAI was similar in A2 scenario with a higher peak at baseline. However, at B2 scenario, peak decreased with elapsing time. As a general rule, maximum LAI is achieved just prior to flowering in cereal crops, and as indicated in both scenarios the crop phenology did not shift appreciably due to change in climatic condition. The simulated LAIs of potato at B2 scenario during different future climate change periods were higher than the baseline was probably due to the occurrence of optimum temperature for potato growth.
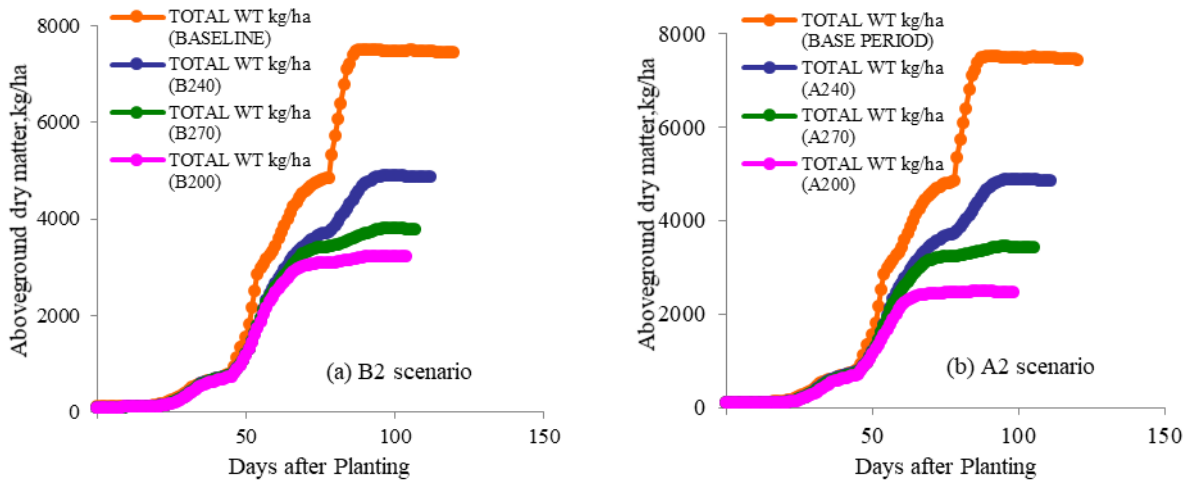
Figure 4. Simulated LAI of rice at baseline and in the year of 2040, 2070, and 2100 under projected climate change for B2 and A2 scenarios

Aboveground dry matter

Wheat

Figure 5 shows the simulation results of ADM for the baseline and three projected climate change periods. Like LAI, ADM production decreased with elapsing time from the baseline. The highest ADM production was observed in baseline, and it decreased progressively with time when temperature increased gradually. The reduction of ADM production was also higher in A2 than in B2 scenario, suggesting the higher influence of temperature in reducing ADM production due to climate change.
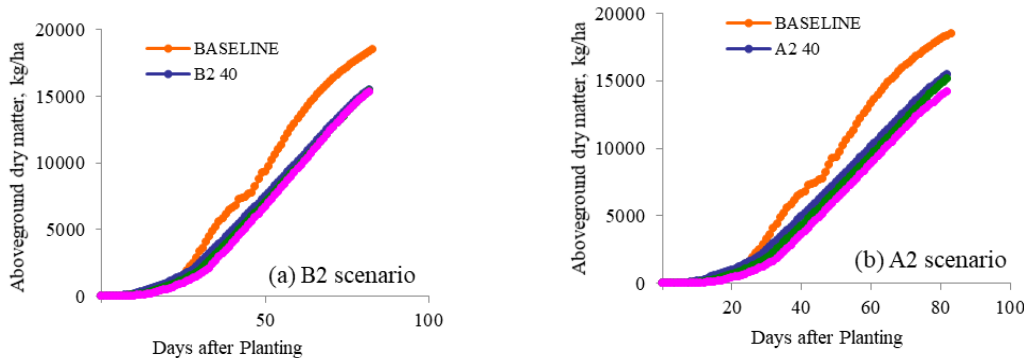

Figure 5. Simulated ADM of wheat at baseline and in the year of 2040, 2070, and 2100 under projected climate change for B2 and A2 scenarios

Potato

Like LAI, aboveground dry matter, ADM, produced of potato, simulated in different years under projected climate change, was almost similar as shown in Figure 6. However, the simulated ADM was higher in baseline as compared to other years under projected climate change in both scenarios. For A2 scenario, simulated ADM decreased gradually, but at a slower rate, with time (Figure 6b).
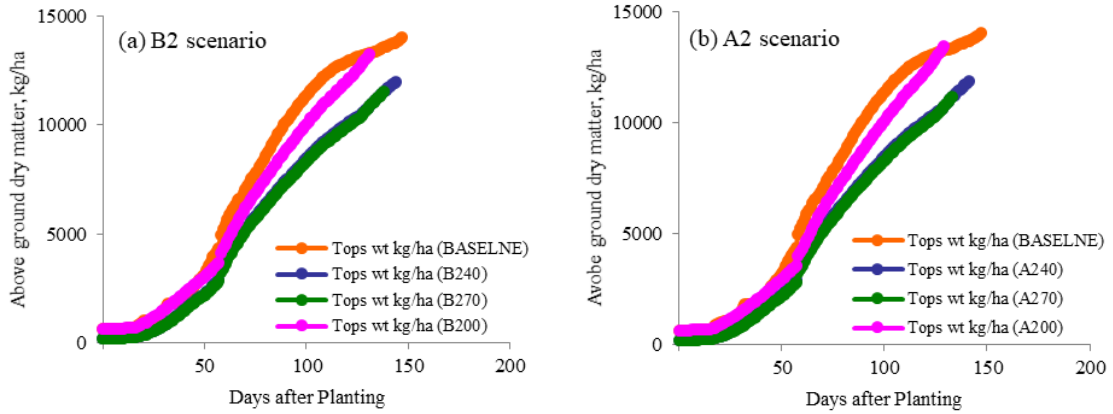

Figure 6. Simulated aboveground dry matter of potato at baseline and in the year of 2040, 2070, and 2100 under projected climate change for B2 and A2 scenarios

Rice

Figures 7 (a) and (b) show the simulated aboveground dry matter, ADM, at baseline and in the future years under projected climate change. The trend of simulated dry matter production was similar in both A2 and B2 scenarios. The highest ADM was observed in the baseline, it decreased thereafter and increased in the end of 2100. It should be noted that shifting of time of ADM production was not observed in either any scenario or year.

Radiation conversion to dry matter is affected by temperature and increasing above an optimum temperature range may decrease dry matter production (Porter and Semenov 2005). Wheat dry matter production was more sensitive to change in temperature and precipitation and decreased gradually with time. However, for potato and rice, decrease of dry matter production was not gradual, suggesting that their development was not largely affected by further increase of temperature above the optimum.
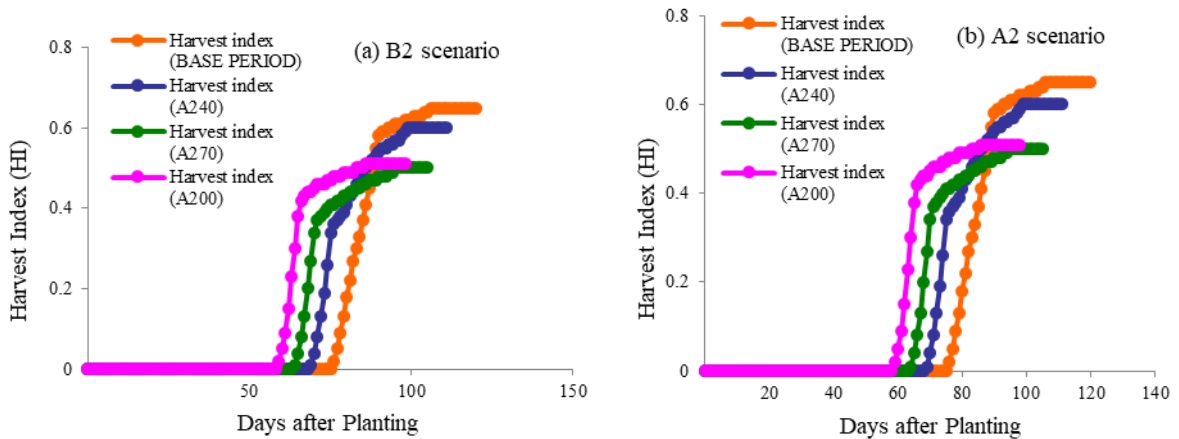

Figure 7. Simulated ADM of wheat at baseline and in the year of 2040, 2070, and 2100 under projected climate change for B2 and A2 scenarios
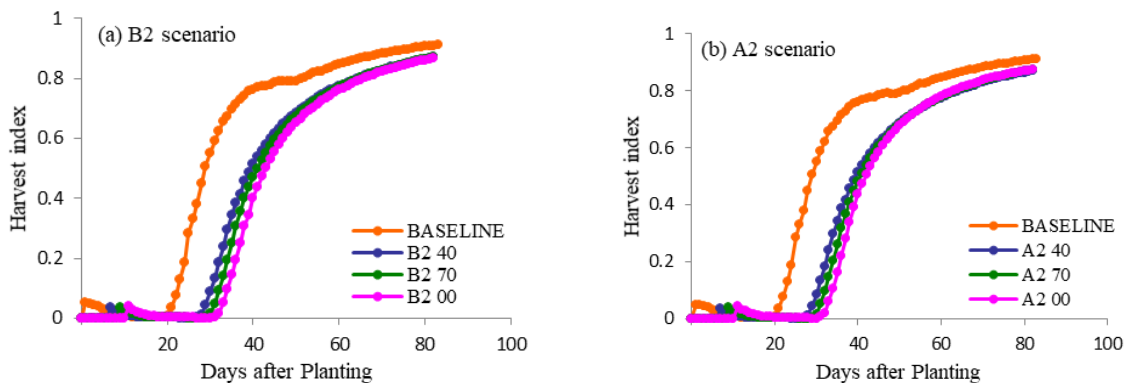
Harvest index

Wheat

Figure 8 shows the harvest index (HI) of wheat at A2 and B2 scenarios for different future years under climate change. It is evident from the figures that the grain production decreased with increasing temperature and precipitation resulting from climate change, which resulted in lower values of HI. The variation of HI in A2 and B2 scenarios likely depended on climatic parameters, cropping pattern, and cultivar coefficients.

Figure 8. Simulated harvest index (HI) of wheat at baseline and in the year of 2040, 2070, and 2100 under projected climate change for B2 and A2 scenarios

Figure 9. Simulated harvest index of potato at baseline and in the year of 2040, 2070, and 2100 under projected climate change for B2 and A2 scenarios

Potato

Simulated harvest index of potato did not change substantially during the years under projected climate change in both scenarios as shown in Figure 9. However, a difference in time lag between baseline and future years of projected climate was observed in both B2 and A2 scenarios. As seen in both Figures 9 (a) and (b)**,** the simulated harvest index at baseline and future years under projected climate change approached unity asymptotically after an initial time lag at the starting of the growing season.

Rice

Figure 10 shows the simulated harvest index, HI, of rice in both B2 and A2 scenarios. Harvest index in A2 scenario was the highest at baseline and then decreased gradually. In B2 scenario, the highest harvest index was found in 2040, and the lowest was observed in 2100. However, an early start of increasing harvest index was observed in future years under projected climate change in B2 scenario compared to baseline (Figure 10a).

Dry matter partioning to grain is affected by temperatures at anthesis and developmental stages (Porter and Semenov 2005) and with moisture stress (Ong 1984) both of which decrease the grain yield and resulting decrease in harvet index. Like LAI and ADM, harvest index for wheat was also largely affected by changes in temperature and precipitation. This change in HI was not gradual for potato after a certain value. However, for rice, HI decreased with time except in B2 scenario in 2040 in which HI was higher than the baseline.
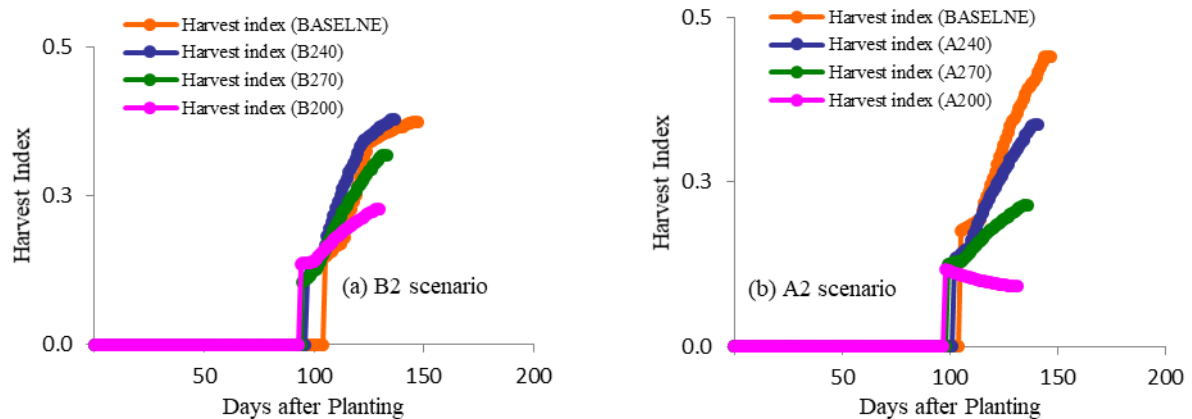
Figure 10. Simulated harvest index (HI) at baseline and in the year of 2040, 2070, and 2100 under projected climate change for B2 and A2 scenarios

CONCLUSION

Temperature and precipitation were observed to undergo changes in the predicted future climate scenarios. Temperature increased progressively from the baseline to the year of 2100, and the increase was higher for A2 than B2 scenarios. Precipitation found increasing except in the months of April, May, and June. The increase of precipitation was gradual from October to February but was the highest in December, in both scenarios. Simulation of growth of major crops in future changing climatic conditions revealed a major change in growth parameters of crops. Leaf area index, aboveground dry matter, and harvest index were found to be influenced by climate change. However, the effect was higher for wheat compared to rice and potato. Predicted change in crop growth parameters likely reduces yield and suggests potential risk of food security in Bangladesh in the verge of increasing population and diminishing land resources. The results of this study can be used as a guideline to adopt climate change coping mechanisms to ensure future food security.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this paper.

References

Agrawala S, Ota T, Ahmed AU, Smith, J, Aalst M. 2003. Development and Climate Change in Bangladesh: Focus on Coastal Flooding and the Sundarbans, OECD, Paris.

Banu S. 2016. Assessment of potential impacts of climate change on major crops at mymensingh, Bangladesh using DSSAT model. Unpublished MS thesis submitted to the Department of Irrigation and Water Management, Bangladesh Agricultural University, Mymensingh-2202, Bangladesh.

Basak JK, Ali MA, Islam MN, Rashid MA. 2010. Assessment of the effect of climate change on boro rice production in Bangladesh using DSSAT model. J. Civ. Eng, 38, 95-108.

BBS (Bangladesh Bureau of Statistics). 2016. Yearbook of Agricultural Statistics of Bangladesh. Statistics Division, Ministry of Planning, Government of the People's Republic of Bangladesh.

BBS (Bangladesh Bureau of Statistics). 2013. Yearbook of Agricultural Statistics of Bangladesh. Statistics Division, Ministry of Planning, Government of the People's Republic of Bangladesh.

BBS (Bangladesh Bureau of Statistics). 2011. Yearbook of Agricultural Statistics of Bangladesh. Statistics Division, Ministry of Planning, Government of the People's Republic of Bangladesh.

Biswas SK. 2012. Effects of irrigation with municipal wastewater on wheat and potato cultivation. PhD dissertation submitted to Dept. of Irrigation and Water Management, Bangladesh Agricultural University, Mymensingh 2202.

Cline W. 2007. Global Warming and Agriculture: Impact Estimates by Country. Washington, DC: Cent. Global Dev.

Ewert F. 2004. Modelling plant responses to elevated CO2: how important is leaf area index? Annals of botany, 93(6), 619-627.

FAO (Food and Agriculture Organization). 2007. Adaptation to Climate Change in Agriculture, Forestry and Fisheries: Perspective, Framework and Priorities. Rome, Italy.

Fisher G, FN Tubiello, H van Velthuizen, D Wiberg. 2006. Climate change impacts on irrigation water requirements: effects of mitigation. 1990/2080. Tech. Forecast. Soc. Change vol. 74, pp 1083–107.

Fordham DA, Wigley TML, Watts MJ, Brook BW. 2011. Strengthening forecasts of climate change impacts with multi-model ensemble averaged projections using MAGICC/ SCENGEN 5.3. – Ecography 35: 4–8 (version 5.3).

Goodin DG, Hutchinson MS, Vanderlip RL, Knapp MC. 1999. Estimating solar irradiance for crop modeling using daily air temperature data. Agronomy Journal, 91(5),845–851.

IPCC (Intergovernmental Panel on Climate Change). 2007. Summary for Policymakers. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC (Intergovernmental Panel on Climate Change). 2001. Climate Change 2001: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, U.K.

Jones JW, Hoogenboom G, Porter CH, Boote KJ, Batchelor WD, Hunt LA, Ritchie J T. 2003. The DSSAT cropping system model. European journal of agronomy, 18(3), 235-265.

Karim Z, Hussain SG, Ahmed AU. 1999. Climate change vulnerability of crop agriculture. In Vulnerability and adaptation to climate change for Bangladesh (pp. 39-54). Springer Netherlands.

Mertz O, Halsnaes K, Olesen JE, Rasmussen K. 2009. Adaptation to climate change in developing countries. Environmental management, 43(5), 743-752.

Monteith JL, MH Unsworth. 1990. Principles of environmental physics. Edward Arnold, London, 291 pp.

Nakicenovic N, Swart R. 2000. Special report on emissions scenarios (SRES). Intergovernmental Panel on Climate Change (IPCC), pp. 599.

Ong C K. 1984. The influence of temperature and water deficits on the partitioning of dry matter in groundnut (Arachis hypogaea L.). J. Exp. Bot. 35, 746-755.

Parry ML, Rosenzweig C, Iglesias A, Livermore M, Fischer G. 2004. Effects of climate change on global food production under SRES emissions and socio-economic scenarios. Glob. Environ. Change 14 (1), 53–67.

Porter J R, Semenov M A. 2005. Crop responses to climatic variation. Philosophical Transactions of the Royal Society of London B: Biological Sciences, 360(1463), 2021-2035.

Rashid MH, MS Islam. 2007. Adaptation to climate change for sustainable development of Bangladesh agriculture. Bangladesh Country Paper, APCAEM, reference evapotranspiration in the Yangtze River basin. Theo. Appl. Climatol., vol. 90(1–2), pp. 13–23.

Reza SN. 2014. Growth, yield and grain dimensions of T. Aman rice varieties as influenced by date of transplanting. Unpublished MS thesis submitted to the Department of Agronomy, Bangladesh Agricultural University, Mymensingh-2202.

Roudier P, Sultan B, Quirion P, Berg A. 2011. The impact of future climate change on West African crop yields: What does the recent literature say? Global Environmental Change, 21(3), 1073-1083.

SID (Statistics and Informatics Division). 2010. Ministry of Planning, Government of the People's Republic of Bangladesh, Dhaka.

WB (World Bank). 2010. World Development Report. The World Bank, Washington, DC.