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CLIMATIC IMPACT ON WHEAT PRODUCTION IN FUTURE SCENARIO OF MYMENSINGH, BANGLADESH USING DSSAT MODEL

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ABSTRACT

Global warming is a threat to human civilization in the world as various studies emphasized the potential consequences of climate change on agriculture and food security, particularly in the developing countries. Bangladesh is at the 7th position among the countries that are highly susceptible to climate change. In this study, the effect of climate change on wheat production in Mymensingh district of Bangladesh was predicted. The MAGICC (Model for the Assessment of Greenhouse Gas Induced Climate Change) /SCENGEN (SCENario GENerator) model were used together with observed climatic data to generate Intergovernmental Panel on Climate Change (IPCC) scenario B2 and A2. The growth and the yield were simulated using CERES-Wheat model under projected changing climatic conditions in the future. Wheat yield decreased gradually in the future years compared to base period. The leaf area index (LAI) found to be influenced by climate change. A time lag of vegetal growth was observed compared to the baseline. The water use efficiency (WUE) for grain yield and biomass decreased with changing climate. The physiological maturity of wheat was accelerated due to the increase of temperature, and resulted in the decrease of growing season length. The change of temperature and precipitation also affected growing season length and water use efficiency. A potential threat to the food security was emerged as the prediction pointed toward crop yield reduction in Bangladesh alone with the state of increasing population and diminishing land resources. The outcomes of this study can be further used as a guideline to adopt mechanisms coping with changing climate to safeguard food security.

Keywords: Climate change, wheat, DSSAT, growth scenario

INTRODUCTION

Bangladesh stands 7th position among the 10 most affected countries by climate change (ANN 2020). As an agricultural country, consequences of climate change on crop production have become a matter of concern (Roudier *et al*. 2011). Bangladesh has to accommodate food for a population mass of 165.57 million with a growth rate of 1.37% per year (BBS 2019). The country is vulnerable to climatic disasters like flood, cyclones and increase in soil salinity due to rising sea level, imposing direct threat to crop production. Bangladesh relies on agriculture sector in terms of food, livelihood and economy. The country extracts 13.6% of the GDP and accommodates employment for 47.3% of total labor from agriculture. Wheat contributes in 2.5% of the country's total crop production. The northeast region of Bangladesh is primarily important for its leading roles in agricultural productions in all sector's including cereal grains, livestock and fisheries. In this region, Mymensingh earns 64.2% of its income from agriculture sharing 16.1% of the total national production of the year 2009-2010 (BBS 2011). Due to climate change, erratic behavior and distribution of rainfall and rise in temperature, the major impacts would be on agriculture. 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). Climate change will exert controls on food production, while water

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resource availability and its spatio-temporal distribution will dictate cropping system. The country needs to know, with some degree of confidence, what kind of changes in temperature, rainfall, and other climatic factors it is likely to face. This should be followed by policies for putting in place adaptation and coping up mechanisms. On-farm adjustments to climate change may require crop varieties suitable for late/early sowing, new cropping sequences, supply of seed and inputs on demand, water conservation, diversified production, etc. In water-stressed areas, adoption of irrigation, improvements in irrigation efficiency as well as soil and water conservation technologies and techniques appear to be particularly promising adaptation options in the face of climate change. Therefore, a proper crop production scenario allied with the future overall climate change scenario is needed. The objective of the study was i) to generate climate change scenarios for future years using crop (wheat) growth model (DSSAT), ii) to investigate the effect of climatic traits for wheat growth and yield in future using the simulation output 2007–2008 of wheat production year.

MATERIALS AND MEHTODS

Study area: The study site was Mymensingh district situated in the north central side of Bangladesh. The study site belongs to the agro-ecological zone (AEZ) 9, which lies at 24.45˚N latitude and 90.25˚E longitude. The elevation of the site is 18 m above the sea level.

Data collection: Data used in the present study were collected from the Department of Irrigation and Water Management (IWM), Bangladesh Agricultural University (BAU), Mymensingh. The model used in this study requires three types of data such as i) weather data; ii) soil data and iii) crop growth and management data.

Weather data: Climate or weather data such as maximum and minimum temperatures, rainfall, and daily solar radiation were collected from the weather station situated at Bangladesh Agricultural University campus, Mymensingh. Weather data were collected of 30 (thirty) years spanning from 1985 to 2014.

Soil data: The texture of the experimental soil was silt loam underlain by sandy loam. The soil data such as soil profile information, nutrient status, chemical properties, and hydraulic properties of wheat experiment was collected from previous studies (Biswas 2012) conducted at BAU, Mymensingh. The major physical and chemical properties of soil samples of wheat are given in Table 1. The organic matter content of the soil was low. The top soil was moderately acidic, but the sub-soil was neutral in reaction. The average field capacity and permanent wilting point of the soil were 39.94% and 18.70%, respectively. The average bulk density was 1.33 gm/cm^3 for the 60 cm profile.

Table 1. Physical and chemical properties of the pre-sowing soil in wheat fields

Soil Depth (cm)	Particle size distribution (%)			Bulk density (gm/cm^3)	Textural class	Field capacity (%)	Wilting point (%)	pH	Organic C (%)
	sand	silt	clay						
0–20	32.57	56.66	10.76	1.26	Silt loam	42.47	19.61	6.89	0.63
20–40	54.57	40.00	5.43	1.35	Sandy loam	38.92	18.35	7.14	0.34
40–60	67.91	26.67	5.42	1.40	Sandy loam	38.45	18.16	7.18	0.28

Crop growth and management data: Crop management data were collected from the field experiments conducted at the experimental farm of Bangladesh Agricultural University, Mymensingh, Bangladesh with single wheat cultivar (*Triticum aestivum L. cv. Shatabdi*). The major management input information of wheat cultivation is given in table 2.

Table 2. Crop management data of wheat

Planting information	Calibrated season (2007–2008)	Validated season (2008–2009)
Date of planting	12 Dec 2007	12 Dec 2008
Depth of planting (cm)	3	3
Row spacing (cm)	20	20
Plant population (per m^2)	149	149

Generation of climate change scenarios: Total seven climate scenarios were generated: a 'baseline' scenario, representing current climatic conditions, and six future scenarios of climate change. The latter were produced using output from MAGIC/SCENGEN model (Wigley 2008) for three future time periods 2025–2054 centering 2040, 2055–2084 centering 2070, and 2085–2114 centering 2100. For each time period, two emission scenarios such as A2 (A future scenario affected by strongly changed climatic condition comprising maximum, minimum temperature, rainfall and solar radiation) and B2 (A future scenario affected by mildly changed climatic condition comprising maximum, minimum temperature, rainfall and solar radiation) were simulated according the Special Report on Emission Scenarios (SRES). Observed daily mean of climatic data (maximum and minimum temperatures, rainfall and solar radiation) from 1984 to 2014, also served as baseline, were used to calculate future climatic scenarios, which were constructed together with MAGICC/SCENGEN model output by using delta change approach. The model monthly outputs were converted and used to construct daily future climatic data through the following equations:

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

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

$$2.\ T_{av(adj)}=T_{av}+adj_{tmp}$$

Where, T_{av} [$T_{dayday\ (adj)}$)] is the daily (adjusted-daily) mean temperature (ºC), and adj_{tmp} is the change in temperature (ºC). The daily solar radiation data was constructed from the daily maximum and minimum temperatures by employing modified Bristow−Campbell (B−C) model (Goodin *et al.* 1999).

Crop simulation model: The Decision Support System for Agrotechnology Transfer (DSSAT) (Jones *et al.* 2003) is a software package incorporating the effect of crop phenotype, soil, weather and crop management system on the basis of a database protocol and allows researchers to simulate experiments in computers in a moment that would take enormous time if conducted manually. DSSAT enables the user to predict the possible results from diverse managerial dimensions and strategies through separate independent programs functioning together. The inherent parts of the program include specific simulator models and databases for weather, soil, experimental condition and measurements 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 researcher to calibrate inputs for each of the programs and compare simulation results with observation, building user's confidence in models or estimate probable modification to achieve higher accuracy. 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 and CERES-Wheat modules were used to study the effect of climate change on wheat production.

Calibration and validation of the model: The calibration of each model was done such that the model parameters truly represented the characteristics and responses of the crops to soil and atmospheric conditions. The CERES-Wheat was calibrated using the observed data by changing one parameter at a time. The data from field experiments, conducted during 2007-2008 season, were used to calibrate CERES-Wheat models, each time, a model parameter was changed, and the model was run with the changed parameter value. The resulting model simulated LAI and yield of wheat were compared with the corresponding observed values. This process of simulation and comparison was repeated until satisfactory LAIs and yields were obtained, which were ensured by satisfactory values of the model performance indicators. The model calibration involved changing the values of the cultivar coefficients. The default and calibrated values of the cultivar coefficients for wheat is given in Table 3. After calibration, CERES-Wheat model was validated.

Table 3. Default and calibrated cultivar coefficients for CERES-Wheat model

Parameter's code	Definition (Unit)	Default value	Calibrated value	DSSAT file
P1V	Days, optimum vernalizing temperature, required for vernalization	5	6	.CUL
P1D	Photoperiod response	75	86	.CUL
P5	Grain filling (excluding lag) phase duration	450	990	.CUL
G1	Kernel number per unit canopy weight at anthesis	30	49	.CUL
G2	Standard kernel size under optimum conditions (mg)	35	80	.CUL
G3	Standard, non-stressed mature tiller wt (include grain) (g dwt)	1.0	2.0	.CUL
PHINT	Interval between successive leaf tip appearances	60	100	.CUL

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 (Anar *et al.* 2015). 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 the calibration performance evaluation of CERES-Wheat model. The deviation statistics were calculated by the following equations:

$$3.\ \text{RSME}=\sqrt{\left(\left[n^{-1}\sum_{i=1}^{n}(s_i-m_i)^2\right]\right)} \quad \text{and,}$$

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

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 same while EF < 0 indicates that simulated values (s) are fluctuated from the measured value (m). The R^2 statistic ($0 \leq R^2 \leq 1$) provides data variance in percentage accounted for by the model.

Model simulation with future climate data: The impacts of climate change on wheat production were deduced by comparing the results of model simulation under climate change projection to the baseline. The calibrated models were used to simulate growth and yield of wheat under changing future climatic conditions by selecting the generated future weather data as model weather inputs. Simulations were made to run for the baseline and three future periods of 2040, 2070 and 2100 of the projected climate change and for the two emission scenarios, B2 and A2. From the outputs of the models, yields, WUE, seasonal ET and LGS of wheat were estimated.

RESULTS AND DISCUSSION

Baseline climate: The mean monthly climatic parameters, calculated from the observed data over a period of 1985 to 2014, were illustrated in Figure 1. These values built the baseline of climate for the study. The mean monthly maximum and minimum temperatures were 31.9°C and 11.7°C, respectively. The mean annual rainfall was 2300 mm. Most of the rainfalls were concentrated in the months between April to October. The mean solar radiation ranged from 14.6 to 21.5 MJ/(m^{2}d). The monthly mean solar radiation was higher in dry periods than in rainy periods, suggesting that the solar radiation was obstructed by cloud cover before reaching the ground. The range of the monthly mean temperatures was also higher during the dry period.

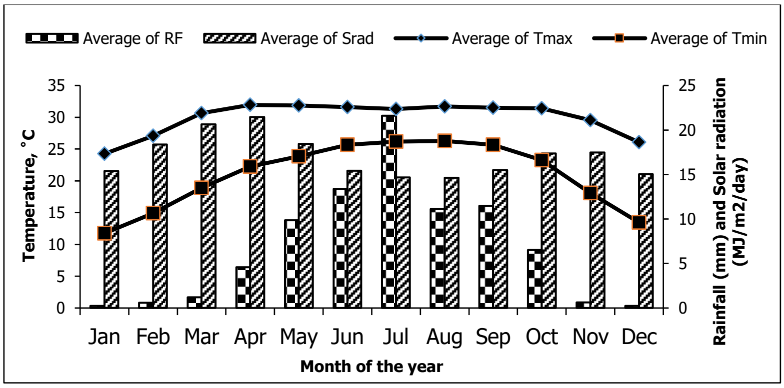

Figure 1. Mean monthly maximum and minimum temperatures, mean monthly total rainfall and mean solar radiation for the baseline period (1985-2014) in the study area.

Model calibration and validation: The prediction of wheat yield in the validation period was in closer with the observed yield (Figure 2). The simulated yield in the calibration phase was 4.12 t/ha for wheat against the observed corresponding yield of 4.11 t/ha and also good for validation. The CERES-Wheat model was calibrated well for LAI with R^2 of 0.72, RMSE of 0.28 t/ha and EF of 0.78 (Table 4) and validated also.

Table 4. Performance parameters in simulating LAI during calibration and validation of CERES-Wheat model

	Performance parameters		
	R^2	RMSE(t/ha)	EF
Calibration	0.724	0.28	0.782
Validation	0.929	0.28	0.758

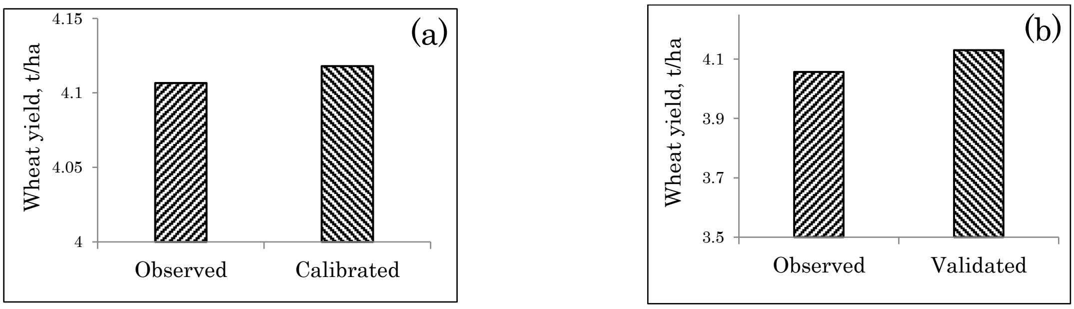

Figure 2. Calibration (a) and validation (b) for wheat yield

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Yield: The simulated wheat yield ranged from 3.69 to 2.16 t/ha in A2 scenario and 3.72 to 2.64 t/ha in B2 scenario in calibration period and also same as validation period (Table 5). The wheat yields progressively decreased with changing climate compared to baseline climate and the wheat yield decreased at a higher rate in A2 than in B2 scenario. The highest wheat yield reduction was 35.9% and 47.6% in B2 and A2 scenario, respectively, in the year 2100 during calibration and validation periods (Figure 3). Yield reduction was attributed by the change of climatic parameters in which precipitation and temperature have gone a major change in both A2 and B2 scenarios. The predicted changes in temperature and precipitation altered the crop yield by hastening plant development, altering the water and nutrient budget in the field and modifying plant stress (Long 1991 and Tubiello *et al.* 1999). The reduction in wheat yields in extreme temperature situation has been found worldwide (Lobell and Burke 2008).

Table 5. Predicted Wheat yield generated from model

Parameter		Calibrated (Year)				Validated (Year)			
		Baseline	2040	2070	2100	Baseline	2040	2070	2100
Wheat Yield, t/ha	A2	4.12	3.69	2.81	2.16	4.13	3.69	2.81	2.16
	B2	4.12	3.72	3.14	2.64	4.13	3.72	3.14	2.64

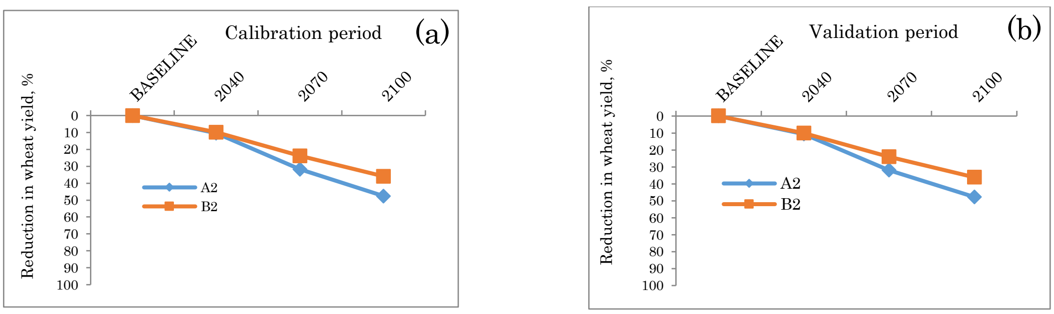


Figure 3. Simulated yield reduction (%) of wheat at baseline and in prediction (calibration (a), validation (b)) years under projected climate change scenarios

Water use efficiency: The simulated biomass water use efficiency increased in the year 2040 under projected climate change compared to baseline and decreased thereafter (Figure 4). The reduction of water use efficiency of wheat observed in the present study which is in parallel with the previous study, who observed that water use efficiency depended on water balance component and thus varied with location and time slice (Jalota *et al.* 2014).

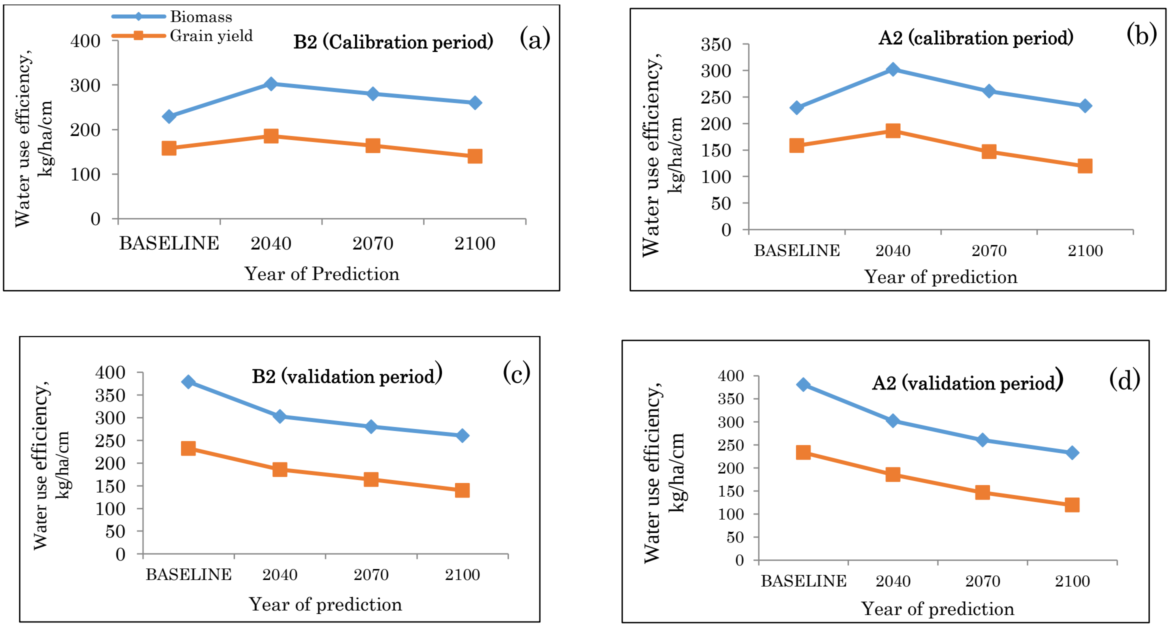
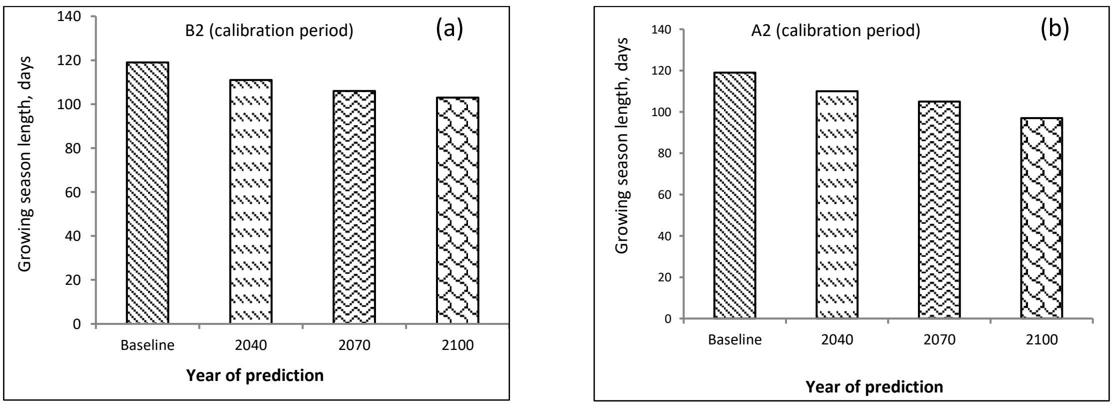


Figure 4. Simulated water use efficiency (WUE) of wheat at baseline and in prediction years (calibration (a,b) and validation (c,d)) under projected climate change scenarios

Likely, changes in temperature and precipitation due to climate change were in appropriate proportions that resulted in higher water efficiency in the year 2040. Temperature mediated increase of water use efficiency for wheat (Guo *et al.* 2010) in a similar climate change study in China.

Growing season length (GSL): Growing season length for wheat decreased gradually from the baseline to the future periods projected climate change for both A2 and B2 scenarios. Growing season length ranged from 118 days in baseline climate and 102 days in A2 scenario and 103 days in B2 scenario observed in the year 2100 during calibration and validation periods (Figure 5). Changes in temperatures and solar radiation are important parameters affecting physiological maturity of any crop that might have accelerated development and thereby reducing growing season length (Tao *et al.* 2006). Planting date has also an effect on physiological maturity of crop; delayed planting may reduce physiological maturity or growing season length (Basak 2009). However, accelerated development due to increased temperature may reduce growing season length in which there might not have enough time for filling grains that may result in reduced yield (Menzel 2003).



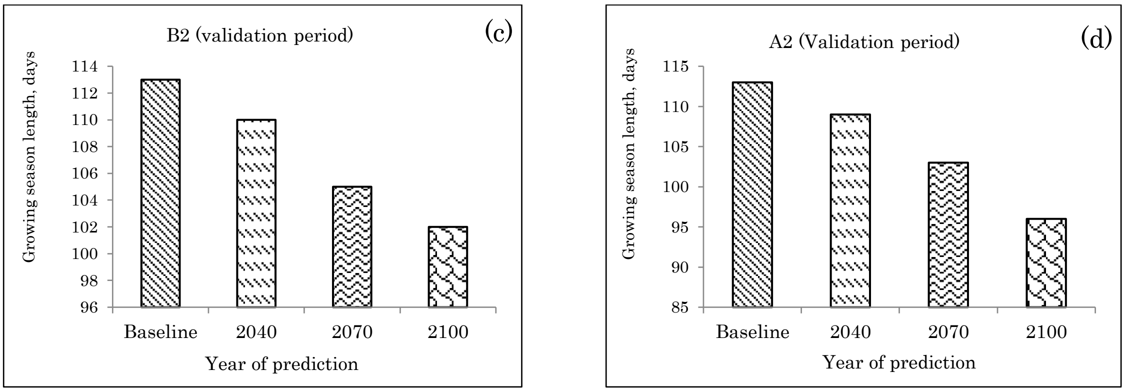


Figure 5. Simulated growing season length of wheat at baseline and in prediction years (calibration (a,b) and validation (c,d)) under projected climate change scenarios

Seasonal Evapotranspiration: In wheat, simulated evapotranspiration shows gradual linear decrease from baseline to the future periods under projected climate change. Highest evapotranspiration was found 254.2 mm and 255.5 mm in A2 and B2 scenarios respectively in 2040 year during calibration and lowest evapotranspiration was found 211.1 mm and 224.5 mm respectively in 2100 year (Figure 6). Amount of evapotranspiration depends on climatic and non-climatic variables such as precipitation, temperature, sunshine, wind speed, soil porosity, slope, crop variety, etc. (Basak *et al.* 2010).

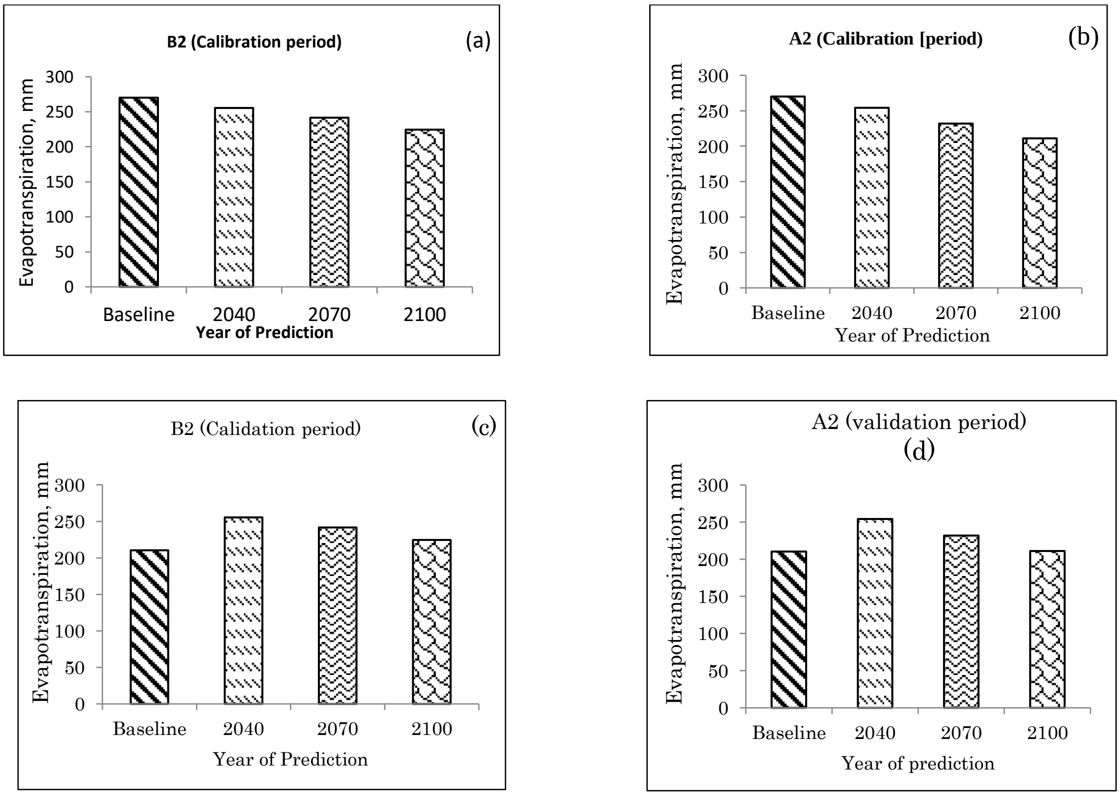


Figure 6. Simulated evapotranspiration of wheat at the baseline and in prediction years (calibration (a,b) and validation (c,d)) under projected climate change scenarios

CONCLUSION

The temperature and precipitation were observed to undergo changes in the predicted future climatic scenarios. Temperature increased progressively from the baseline to the year 2100 and the increase was higher for A2 than B2 scenarios. Precipitation would also increase, except in the months of April to June; the increase would be higher during October to February than in the other months. Change in climatic scenarios in future periods influenced strongly on wheat production. Simulation of growth and yield of wheat in future changing climatic conditions revealed a major change in yield and other growth parameters. By changing climatic condition in the year 2040, 2070 and 2100, the yield of wheat would decrease by 10.5%, 31.8% and 47.6% in A2 scenario and 9.8%, 23.8% and 36% in B2 scenario. Since the results of this DSSAT based study point towards a prediction of reduction in the yield of wheat, further studies can be conducted using other crop models and in other study locations.

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