Impact of Climate Change On Future Productivity And Water Use Efficiency of Wheat In Eastern India

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Abstract

High temperature and elevated CO_2 under future climate change will influence the agricultural productivity worldwide. Burgeoning population along with climate change situation is going to threaten the food security of India. According to IPCC 5th assessment report (2014), global mean surface temperature and concentration of carbon dioxide (CO_2) at the end of 21st century will increase by 4.8°C and 539 ppm respectively under Representative Concentration Pathway (RCP) 8.5 scenario. Considering the burning issue present study aims to find out the probable change in different climatic parameters under high greenhouse gas emission (RCP 8.5) scenario during 2021-2095 and their impact on wheat yield and water productivity over six locations (Jalpaiguri, Nadia, Murshidabad, Malda, Birbhum and South 24 Parganas) covering five major agro-climatic zones of West Bengal, a state of eastern India. Results showed that maximum temperature (T_{max}) and minimum temperature (T_{min}) will increase by 5.3^{o}C and 5.9^{o}C during the end of this century. The increase in annual rainfall will be maximum (22%) at Murshidabad. Wheat yield will increase by 3 to 28% across the study sites. The seasonal crop evapotranspiration value will decline by 1 to 21%. Both water- use efficiency (WUE) and transpiration -use efficiency (TUE) will increase at all the study sites.

Introduction

India is the world's second largest producer of wheat (FAOSTAT, 2017), which is one of the important cereal crops maintaining the food security of the country. Burgeoning population along with climate change situation is going to threaten the food security of India. Changes in temperature and precipitation in future may impact on water resource availability, crop water requirement and thus, affect the crop and water productivity to a greater extent (Abeysingha et al., 2016). According to IPCC 5th assessment report (2014), global mean surface temperature and concentration of carbon dioxide (CO_2) will increase by 4.8°C and 539 ppm respectively, at the end of 21st century under RCP 8.5 scenario. Indian Institute of Tropical Meteorology (IITM) ran various global and regional climate models with different emission scenarios, and indicated an increase of 3-5^{o}C temperature and 5–10% summer monsoon rainfall for Indian sub-continent (NATCOM, 2004).

Climatic parameters govern different biological and chemical processes within plant system and thus regulate crop growth and development (Porter and Gawith, 1999). Temperature, rainfall, solar radiation (SRAD) and CO_2 solely and in combination influence the crop growth and productivity to a greater extent. Both high and low temperatures reduce dry matter production and, at extremes, can drastically reduce wheat productivity (Grace, 1998). Agricultural productivity is sensitive to climate change due to direct effect of changes in temperature, precipitation, SRAD and CO_2 concentration and also due to indirect effect through changes in soil moisture, incidence of pest and diseases (Mendelsohn, 2014). Effect of climate change on crop performance varied with the climate change scenario used, cropping system, management practices and also from location to location (Islam et al., 2012; Hillel and Rosenzweig, 2011). Climate change without any adaptation measure, will negatively impact wheat production in tropical and temperate regions under 2^{o}C or more local temperature increase during late 20th century levels, although individual location may benefit (Porter et al., 2014). The overall relationship between weather and crop yield is often region specific, depending on difference in baseline climatic condition, agronomic managements and soil conditions (Porter et al., 2014). Sommer et al., (2013) predicted that climate change will benefit wheat production in Central Asia through the positive effects of temperature increase. In India, the potential yield of wheat will be reduced by 11% and 6%, under 2^{o}C increase in maximum (T_{max}) and minimum (T_{min}) temperature (Subhas and Mohan, 2012). Xio et al., (2008) predicted that climate change related warming might lead to an increase of 3% in wheat at low latitude and 4% at high latitude in China by 2030. Warmer temperatures could modify the rates of photosynthesis and respiration, thus affecting crop growth rates (Long, 1991). Increase in temperature will shorten the length of growing period, and reduce biomass accumulation and yield (Butterfield and Morison, 1992). The increase in temperature under climate change scenario is expected to increase the crop evapotranspiration (ET) rate leading to crop water stress and inhibiting yields. Therefore, understanding the impact of climate change on crop production and water resource utilisation is of prime importance for developing suitable adaptation strategies (Abeysingha et al., 2016). Elevated CO_2 (eCO_2) alone could be beneficial to most of the crop by enhancing photosynthetic rates and water use efficiency (WUE) value (Conroy et al., 1994). The effect of eCO_2 tends to be higher in C_3 plants (wheat, rice) than C_4 plants, due to high photosynthesis rate in C_3 under eCO_2 (Leakey, 2009). Since pre-industrial times, increase in atmospheric CO_2 by more than 100 ppm, has certainly increased WUE and yield of C_3 crops such as wheat and rice (McGrath and Lobell, 2011). Doubling of CO_2 concentration from 330 ppm to 660 ppm increased wheat yield by 28 percent. However, increase in ambient temperature by 1^{o}C and 2^{o}C offsets yield increase to 25 and 16 % respectively and hastened maturity by 5 and 10 days (Lal et al., 1998). Periods of abundant radiation are favourable for agricultural production (Long, 2012). Decrease in SRAD reduced the potential wheat yield by 3.1% (Subhas et al., 2012) and 9.7% (Pathak et al., 2003) in Indian condition.

The mean annual wheat yield will increase by 13.9 to15.4, 23.6 to 25.6 and 25.2 to 27.9 % during 2020s, 2050s and 2080s in Gomti river basin of India (Abeysingha et al., 2016). Mishra et al., (2013) reported a change in wheat yield − 17% to + 5.4% in lower Indo-Gangetic Plain under REMO and HadRM3 projected scenarios respectively. In contrast, according to Naresh Kumar et al., (2014), 6 to 23 and 15 to 25 % reduction in wheat yield respectively during 2050s and 2080s is expected under projected climate change scenarios in India. Thus, climate change impact will vary region to region. There is need for comprehensive? assessment of the vulnerability in agricultural productivity under future climate change at different agro-climatic regions, delineated with different soil, climate and management practices.

Crop simulation models perform well across different environmental and management conditions to understand the effect of various climatic factors on crop growth and yield by taking into account their interactions with biotic and abiotic factors. Thus, crop models are increasingly being applied in agricultural and environmental studies as complementary tools to field experiment (Matthews et al., 2013). Several studies were carried out to develop an integrated evaluation of climate variability as well as climate change on regional and global food production through dynamic modeling (Alexandrov and Hoogenboom, 2000). The Decision Support System for Agro-technology Transfer (DSSAT) was widely used for analysing yield gap, decision making and planning, framing strategic and tactical management policies and climate change studies worldwide (Arya et al., 2017; Attia et al., 2016; Kassie et al., 2016; Aggarwal et al., 2006a; Aggarwal and Mall, 2002; Pathak et al., 2003; Li et al., 2015; Timsina et al., 2008). In India, climate change impact assessments were studied to establish the necessity of crop simulation models (Das et al., 2012; Behera and Panda, 2009; Saseendran et al., 2000; Aggarwal 2003).

Increased atmospheric temperature reduces the total duration of crop by inducing early flowering and shortening the grain filling period and thus reduces yield per unit area. Positive effect of CO_2 increase will be nullified by negative response of temperature increment. Reduced transpiration, due to decrease in stomata closure under $eCO_{2,}$ increases water productivity. On the other hand increased temperature will enhance the atmospheric evaporative demand. Thus the question comes, how do different crop and weather interactions will effect on wheat yield and water productivity in future at different agro-climatic region of West Bengal? To address the above mentioned facts the study was undertaken i) to find the changing pattern of climatic variables over six selected locations of WB, India during 2021-95 and ii) to assess the impact of climate change on crop and water productivity of wheat.

Materials And Methods

2.1. Characterization of study site

West Bengal is a state situated in the eastern part of India, characterized by cool dry winter and warm-wet summers. Wheat is grown during the dry winter season. During 7th five-year plan (1985–1990), the planning commission of India divided India into fifteen agricultural zones based on agro-climatic features, soil type, climate including temperature and rainfall (Anonymous, 2017a). West Bengal comprised of Zone II (Eastern Himalyan) and Zone III (Lower Gangetic Plains) with six sub-zone namely; Hills, Terai, Old Alluvium, New Alluvium, Coastal saline and Red lateritic. The detailed agro-ecological characterizations of the sub-regions were documented by Banerjee et al., 2016. Six districts covering five agro-climatic zones were selected for this study (Fig. 1). The districts were selected based on the criteria of the maximum cultivable area of wheat under a particular agro-climatic zone. Due to non-availability of long-term weather data, we couldn’t include Hill zone in our study. The study site distributed from 22.20^{0} to 26.54^{0} N latitude and 87.68^{0} to 88.72^{0} E longitude. The annual rainfall ranged from 1370 mm at Nadia to 3383 mm at Jalpaiguri; annual rainy day ranged from 71 at Nadia to 107 at Jalpaiguri; T_{max}: 30.0 ^{O}C at Jalpaiguri to 32.3^{o}C at Murshidabad and T_{min} ranged from 19.3 ^{o}C at Jalpaiguri to 22.7 ^{o}C at South 24 Parganas. The basic physicochemical properties of the soil of the study sites are presented in Table 1.

Table 1 Basic soil (0-50 cm) information of the study sites

Location	Soil texture				pH	OC (%)	CEC (meq/100 g)	BD gcm^{-3}	Soil water (cm^{3}cm^{-3})		
	Sand (%)	Silt (%)	Clay (%)	Textural group*					Saturation	FC[a]	PWP[b]
Jalpaiguri	78.55	5.95	15.50	SL	4.6	1.56	5.0	1.56	0.41	0.27	0.11
Birbhum	43.75	28.75	27.50	CL	6.2	0.40	19.6	1.59	0.41	0.29	0.17
Malda	14.50	64.20	21.30	SiL	7.6	0.42	24.4	1.48	0.52	0.34	0.16
Murshidanad	11.16	62.74	26.10	SiL	7.6	0.45	9.2	1.47	0.45	0.34	0.16
Nadia	60.20	20.80	21.00	SCL	6.22	0.25	8.5	1.55	0.45	0.24	0.80
South 24 Parganas	15.66	40.26	44.08	SC	6.5	0.29	11.8	1.35	0.49	0.38	0.26

* SL= Sandy loam, CL = Clay loam, SiL = Silt loam, SCL = Sandy clay loam, SC = Silt clay

[a] Field Capacity, [b] Permanent wilting point

2.2. Data Acquisition

Daily weather data (1982–2012) on rainfall, T_{max} and T_{min} of the selected stations were collected from India Meteorological Department, Govt. of India. Future climatic dataset (Temperature, precipitation, and radiation) under RCP 8.5 scenario was downloaded from 'Marksim Weather Generator' (Jones and Thornton, 2013) considering suitable global circulation models (IPSLCM-5AMR, MIROC5, MIROC-ECM, MIROC-ECM-CHEM, NORESMI-M) for West Bengal condition (Yadav, 2016). RCP 8.5 scenario is the high emission scenario, representing no climate policies to change the current emission trajectory, high population, relatively slows income growth with lower rate of technology development and high energy intensity, thus corresponding to the pathway of highest greenhouse gas emission.

2.3. Data analysis

2.3.1. Climatic analysis

Daily weather data for the past 30 years (1983–2012) and future 75 years (2021–2095) were used to derive monthly, seasonal and yearly statistics for solar radiation (SRAD), rainfall, T_{max} and T_{min}. Weather cock v.3 software (Rao et al., 2014) was used to convert daily information to monthly, seasonal and yearly data.

2.3.2. Crop analysis

DSSAT v4.5 crop growth simulation model was used to simulate wheat yield under both past and future climatic conditions. The crop evapotranspiration was calculated through Ritchie (1998) water balance method in DSSAT modules.

Water use efficiency was estimated following Arya et al., 2017(p2) as:

$WUE_{ET} = GY/ET$

The transpiration use efficiency was calculated as:

$WUE_{T} = GY/T$

Harvest Index was calculated as:

$HI = GY/CB$

Where GY is harvested grain yield (Kg ha^{-1}), CB is crop biomass (Kg ha^{-1}), ET is seasonal evapotranspiration (mm) and T is seasonal total transpiration (mm)

2.4. Input for DSSAT v 4.5 model

DSSAT v4.5 includes the cropping system model (CSM)-CERES wheat model, which was used to simulate growth and productivity of wheat (Hoogenboom et al., 2010). We selected PBW-343 wheat variety, which is most popular wheat variety in WB. The genetic coefficient of this variety (Table 2) was generated based on the research trials conducted in the research farm of Bidhan Chandra Krishi Viswavidyalaya (BCKV). The coefficient was estimated by repeated iterations until there was a close match between simulated and observed phenological parameters and yield (Thentu 2016). The optimum date of sowing of wheat in Gangetic plains of WB is considered as 15th November (Aggarwal and Kalra, 1994). In this study, the sowing date was considered as 15th November for every year in simulating wheat yield for past 30 years (1982-83 to 2011-12) and future 75 years (2020-21 to 2094-95). The soil information for the selected locations was collected from district wise soil master file of InfoCrop v2.1 model (Agarwal et al., 2006a; Kumar et al., 2014).The following recommended management practices were considered in crop management file for running the model. Nitrogen (Urea), P_2O_5 (Single super phosphate), K_2O (Muriate of potash) were applied @ 120, 60 and 40 Kg ha^{-1} respectively. Five numbers of irrigation with 50 mm depth were given each at crown root initiation (CRI), tillering, jointing, flowering, and milking stages. The real time CO_2 data collected in Mauna Loa observatory, Hawaii and expected future CO_2 concentration data under RCP 8.5 scenario (Anonymous, 2017b) were considered for simulating past and future wheat yield respectively.

Table 2 Genetic coefficient of wheat variety (PBW-343)* used in the study

Genetic coefficient	Definition	Value
PIV	Days at optimum vernalizing temperature required to complete vernalization	23
PID	Percentage reduction in development rate in a photoperiod 10 hour shorter than the threshold relative to that at the threshold	69
P5	Grain filling (excluding lag) phase duration (°C.d)	730
G1	Kernel number per unit canopy weight at anthesis (#/g)	20
G2	Standard kernel size under optimum conditions (mg)	35
G3	Standard, non-stressed dry weight (total, including grain) of a single tiller at maturity (g)	1.0
PHINT	Interval between successive leaf tip appearances (°C.d)	145

*The Genetic coefficient value has been calibrated / validated based on three years field experimentation (Thentu, 2016)

In the present study, we simulated yield and evapotranspiration (ET) considering ideal crop management practices (irrigation, fertilizer etc.) for both past and future climatic condition. We considered the past (1983 to 2012) data as baseline data. We arranged the future (2021–2095) data bases in to three time (2021-45, 2046-70 and 2071-95) periods. Comparisons of future data for all the time periods were made with the baseline data only.

Results

3.1. Weather parameters

3.1.1. Maximum Temperature

In general, all the study sites are going to face elevated T_{max}, under RCP 8.5 emission scenario during 2021-45, 2046-70 and 2071-95 time period, compared to the baseline data base (1983-12). The change of T_{max} will be a minimum of -0.2°C (2021-45) and 1.4°C (2046-70) at Malda and maximum of 2.1°C (2021-45) and 3.8°C (2046-70) at Nadia during wheat growing season (November – April). The maximum increment will be during the end of this century. The expected change in T_{max} during 2071-95 will range from 3.0°C at South 24 Parganas to 5.4°C at Nadia (Table 3). Thus, it is obvious that Nadia district is going to face highest degree of T_{max} increment during 2021-95, closely followed by Birbhum. On the other hand, Malda and South 24 Parganas will experience minimum T_{max} increment (0.4 to 3.7°C) during wheat growing period and Jalpaiguri and Murshidabad will face moderate (0.6 to 4.5 °C) T_{max} increment.

Table 3 Variation of rainy, post-rainy and annual temperature under current (observed) and future (predicted at RCP 8.5) climatic scenario for selected locations of West Bengal

Location	Maximum temperature (°C)				Minimum temperature(°C)			
	Observed	(Predicted – Observed)			Observed	(Predicted – Observed)		
	1983-12	2021-45	2046-70	2071-95	1983-12	2021-45	2046-70	2071-95
Jalpaiguri								
Nov-April	27.9	0.4	2.0	3.9	15.0	0.9	2.7	4.7
May-Oct	32.0	0.9	2.1	3.6	23.6	2.6	3.7	5.1
Annual	30.0	0.6	2.0	3.7	19.3	1.7	3.2	4.9
Malda								
Nov-April	29.9	-0.2	1.4	3.2	17.9	-2.2	-0.4	1.4
May-Oct	33.2	1.2	2.6	4.1	25.1	2.1	3.3	4.5
Annual	31.6	0.4	2.0	3.7	21.5	-0.1	1.4	2.9
Murshidabad								
Nov-April	30.7	0.6	2.3	4.2	17.5	-0.4	1.2	3.0
May-Oct	34.0	1.6	3.1	4.7	25.5	2.0	3.2	4.5
Annual	32.3	1.1	2.7	4.5	21.5	0.8	2.2	3.7
Birbhum								
Nov-April	30.0	1.4	3.0	4.9	18.3	-1.1	0.5	2.5
May-Oct	33.2	2.3	3.5	5.0	25.6	1.9	3.0	4.3
Annual	31.6	1.8	3.2	4.9	21.9	0.4	1.8	3.4
South 24 Pargana								
Nov-April	30.2	0.1	1.5	3.0	19.2	-0.4	1.0	2.4
May-Oct	33.0	1.2	2.5	3.8	26.1	1.7	2.8	3.9
Annual	31.6	0.6	2.0	3.4	22.7	0.6	1.8	3.1
Nadia								
Nov-April	30.0	2.1	3.8	5.7	16.7	0.1	1.8	3.5
May-Oct	33.7	2.0	3.5	5.0	24.0	3.5	4.6	5.9
Annual	31.9	2.0	3.6	5.3	20.4	1.8	3.2	4.7

It was found that T_{max} change during rainy season (May-October) will be higher than that of post-rainy season (November – April). The change in T_{max} will be minimum of 0.9°C (2021-45), 2.9°C (2046-70) and 3.6°C (2071-95) at Jalpaiguri and maximum of 2.3°C (2021-45), 3.5°C (2046-70), 5.0°C (2071-95) at Birbhum and Nadia.

3.1.2. Minimum Temperature

During post rainy season of 2021-45, the T_{min} will decrease at Malda (-2.2^{o}C), Birbhum (-1.1^{o}C), Murshidabad (-0.4^{o}C) and South 24 Parganas (-0.4^{o}C) and increase at Jalpaiguri (0.9^{o}C) and Nadia (0.1^{o}C). The change of T_{min} will range from – 0.4^{o}C (2046-70) and 1.4^{o}C (2071-95) at Malda to 2.7^{o}C (2046-70) and 4.7^{o}C (2071-95) at Jalpaiguri (Table 3).

Like T_{max}, change in T_{min} during rainy season (May-October) will be more than post-rainy season. The change of T_{min} will range from 1.7^{o}C (2021-45), 2.8^{o}C (2046-70) and 3.9^{o}C (2071-95) at South 24 Parganas to 3.5^{o}C (2021-45), 4.6^{o}C (2046-70) and 5.9^{o}C (2071-95) at Nadia. Thus, Nadia and Jalpaiguri will face highest increase (1.7 to 4.9^{o}C) in T_{min} and the lowest will be experienced by Malda.

3.1.3. Rainfall

After cessation of monsoonal rainfall (September-October), the growing season of winter wheat extends from mid-November to end of April. The total amount of rainfall will decrease at all the study sites during post-rainy season. The reduction will be a minimum of 24 mm (2021- 45), 39 mm (2046-70) and 25 mm (2071-95) at Nadia and largest of 128 mm (2021-45), 121 mm (2046-70) and 121mm (2071-95) at Malda. On an average the decrease of post-monsoon rainfall will be 67 to 70% for Malda, 58 to 76% for Birbhum, 46 to 56% for South 24 Parganas, 31 to 50% for Murshidabad, 23 to 45 for Jalpaiguri and 18 to 28% for Nadia (Table 4).

Table 4 Variation of rainy, post-rainy and annual rainfall and solar radiation under current (observed) and future (predicted at RCP 8.5) climatic scenario for selected locations of West Bengal

Location	Rainfall (mm)				Solar Radiation (MJ m^{-2} day^{-1})			
	Observed	(Predicted – Observed)			Observed	(Predicted – Observed)		
	1983-12	2021-45	2046-70	2071-95	1983-12	2021-45	2046-70	2071-95
Jalpaiguri								
Nov-April	192.1	-86.3	-75.0	-43.8	15.8	1.7	1.8	1.6
May-Oct	3191.3	408.2	429.8	727.6	17.4	4.9	4.9	5.1
Annual	3383.4	322.0	354.8	683.8	16.4	3.6	3.6	3.6
Malda								
Nov-April	181.2	-127.7	-121.2	-121.1	15.8	2.3	2.2	2.2
May-Oct	1398.2	373.1	336.3	413.6	17.2	4.3	4.6	4.5
Annual	1579.4	245.3	215.0	292.5	16.1	3.6	3.7	3.7
Murshidabad								
Nov-April	111.0	-33.9	-53.7	-55.0	16.8	1.4	1.6	1.5
May-Oct	1384.6	245.6	361.2	387.1	17.8	3.2	3.3	3.3
Annual	1495.6	211.7	307.5	332.1	16.9	2.6	2.8	2.7
Birbhum								
Nov-April	156.8	-118.6	-98.4	-90.8	15.9	2.3	2.2	2.1
May-Oct	1494.6	110.1	198.7	275.5	16.9	3.5	3.2	2.9
Annual	1651.4	-8.5	100.3	184.6	16.1	3.2	3.0	2.8
South 24 Pargana								
Nov-April	156.6	-88.2	-72.2	-85.9	16.8	1.7	1.7	1.7
May-Oct	1688.1	-45.7	-114.7	-36.7	17.3	2.2	3.0	3.0
Annual	1844.7	-133.9	-186.9	-122.6	16.7	2.3	2.7	2.7
Nadia								
Nov-April	136.6	-24.3	-38.5	-25.1	17.1	1.5	1.5	1.3
May-Oct	1233.1	185.4	151.3	189.8	18.8	3.2	3.5	3.7
Annual	1369.7	161.1	112.7	164.7	17.7	2.6	2.7	2.7

During rainy season, all stations will experience enhanced rainfall, except South 24 Parganas. The decrease of rainfall will be 46 mm (2021-45), 115 mm (2046-70) and 37 mm (2071-95) at South 24 Parganas. Among rest five stations, the greatest increase will be 408 mm, 430 mm and 728 mm at Jalpaiguri respectively during 2021-45, 2046-70 and 2071-95. The annual rainfall of the selected stations will change by 14 to 22% (Murshidabad) 10 to 20% (Jalpaiguri), 14 to 19 % (Malda), 8 to 12% (Nadia), -1 to 11% (Birbhum) and – 7 to -10% (South 24 Parganas) during 2021 to 2095time period.

3.1.4. Solar Radiation

The solar radiation will be increasing at all the study locations during both rainy and post rainy seasons. During post-rainy season of 2021-45 the change of SRAD will range from 1.4 $MJm^{-2}day^{-1}$ at Murshidabad to 2.3 $MJm^{-2}day^{-1}$ at both Malda and Birbhum. It will be 1.5 $MJm^{-2}day^{-1}$ (2046-70) and 1.3 $MJm^{-2}day^{-1}$ (2071-95) at Nadia to 2.2 $MJm^{-2}day^{-1}$ (both 2046-70 and 2071-95) at Malda and Birbhum (Table 4).

During monsoon season, the change of SRAD will range from 2.2 $MJm^{-2}day^{-1}$ (2021-45) and 3.0 $MJm^{-2}day^{-1}$ (2046-70) at South 24 Pargana to 4.9 $MJm^{-2}day^{-1}$ (both 2021-45 and 2046-70) at Jalpaiguri. During 2071-95, the increase of SRAD will be least (2.9 MJ m^{-2} day^{-1}) at Birbhum and largest (5.1 $MJm^{-2}day^{-1}$) at Jalpaiguri.

During 2021-95, the highest increase (2.87 to 3.7 MJ m^{-2} day^{-1}) of SRAD will be noticed at Malda, Jalpaiguri and Birbhum. It will be in moderate level (2.3 to 2.8 MJ m^{-2} day^{-1}) at Murshidabad, South 24 Parganas and Nadia district.

3.2 Plant Parameters

3.2.1. Phenology

Warming advances phenological period and thus reduces total crop duration. As compared to 1983–2012 period, the length of total crop duration will be shortened by 18 days during 2021–2095 for Jalpaiguri district (Table 5). The main reduction was found in the length of pre-anthesis periods (eg. Sowing to anthesis) by 13, 12, 13 days and grain filling periods by 5, 6, 5 days respectively during 2021-45, 2046-70 and 2071-95 periods. In Nadia district, the total crop duration will decrease by 9 days in which 6–7 days reduction in pre-anthesis stage and no significant change in grain filling stage (2 to 3 days) will occur. There will be no significant difference in total duration (3 to 4 days), pre-anthesis (1 to 3 days), grain filling (1 to 2 days) periods between past and future climate scenario at Murshidabad, Birbhum, and South 24 Parganas. Malda will likely to experience negligible extended pre-anthesis period (2 days) and total crop duration (1 to 2 days) during 2021-95 compared to 1983-12 period.

Table 5 Variation of phenology and crop growth parameters under current (observed) and future (predicted at RCP 8.5) climatic scenario for selected locations of West Bengal

Location	Current	Future (RCP 8.5)		
	1983-12	2021-45	2046-70	2071-95
Jalpaiguri				
Anthesis (DAS*)	104	91	92	91
Grain filling duration (days)	41	36	35	36
Total duration (days)	145	127	127	127
Maximum LAI	2.8	2.5	2.5	2.5
Biomass (Kg ha^{-1})	10390	10664	10860	11092
Harvest Index	0.41	0.41	0.42	0.43
Malda				
Anthesis (DAS)	95	97	97	97
Grain filling duration (days)	37	36	36	37
Total duration (days)	132	133	133	134
Maximum LAI	2.8	2.6	2.6	2.6
Biomass (Kg ha^{-1})	9695	9239	9452	9787
Harvest Index	0.42	0.46	0.47	0.48
Murshidabad				
Anthesis (DAS)	94	91	92	91
Grain filling duration (days)	37	36	35	36
Total duration (days)	131	127	127	127
Maximum LAI	2.6	2.4	2.4	2.5
Biomass (Kg ha^{-1})	6250	6254	6547	7169
Harvest Index	0.5	0.55	0.56	0.56
Birbhum				
Anthesis (DAS)	94	93	93	93
Grain filling duration (days)	37	35	35	35
Total duration (days)	131	128	128	128
Maximum LAI	2.6	2.3	2.3	2.3
Biomass (Kg ha^{-1})	6346	6552	6954	7523
Harvest Index	0.51	0.54	0.54	0.55
South 24 Parganas				
Anthesis (DAS)	91	89	89	89
Grain filling duration (days)	36	36	36	35
Total duration (days)	127	125	125	124
Maximum LAI	2.7	2.6	2.6	2.6
	8332	8324	8797	9485

Biomass (Kg ha^{-1})				
Harvest Index	0.47	0.5	0.49	0.48
Nadia				
Anthesis (DAS)	98	91	92	91
Grain filling duration (days)	38	36	35	36
Total duration (days)	136	127	127	127
Maximum LAI	2.6	1.8	1.8	1.9
Biomass (Kg ha^{-1})	7391	7975	8133	8634
Harvest Index	0.47	0.43	0.45	0.45

*DAS= Days after sowing

3.2.2. Biomass

The total above ground biomass will increase at all the stations except Malda, where reduction will be 5% and 3% during 2021-45 and 2046-70 respectively (Table 5). The increase will be 3–7% (Jalpaiguri), 0–14 % (South 24 Parganas), 0–15 % (Murshidabad), 8–17% (Nadia) and 3–19 % (Birbhum) during 2021-95.

3.2.3. Leaf area index

Reduction of leaf area index (LAI) was found for all the study sites under future climatic scenario during 2021-45 (Table 5). The decrease will be marginal at all the stations except Nadia. The average reduction of LAI will be 4 % (South 24 Parganas), 4 to 8 % (Murshidabad), 7 % (Malda), 11% (Jalpaiguri), 12 % (Birbhum) and 27 to 31% (Nadia) during 2021-95 compared to 1983-12 period.

3.2.4. Harvest Index

The harvest index (HI) will increase marginally at all the stations except Nadia, where the HI will decrease by 4–9 % during 2021-95 compared to 1983–2012 (Table 5). The increase in HI will be from 3 to 7% at Jalpaiguri, 0 to 14 % at South 24 Parganas, 10 to 14 % at Malda, 0 to 15 % at Murshidabad, 8 to 17% at Nadia and 3 to 19 % at Birbhum during 2021-95 compared to 1983-12 period.

3.2.5. Yield

Figure 2 illustrated the wheat yield, simulated by CERES model, under future climate change (RCP 8.5) scenario (2021–2095) and baseline period (1983–2012). It was observed that long-term (2021-45, 2046-70, 2071-95) average yield increased continuously for all the study sites. The maximum yield increase will be 9.9 % (2021-45), 18.1 % (2046-70) and 28.4% (2071-95) at Murshidabad. The yield increment will range from 9.1 to 26.5% at Birbhum, 5.5 to 16.7 % at South 24 Parganas, 5.1 to 16.2 % at Malda, 2.7 to 12.6 % at Jalpaiguri during 2021-95. In Nadia district, negligible depression (-0.1 %) in wheat yield will be expected during 2021-45, followed by 5.1 and 11.3 % increase during 2046-70 and 2071-95 respectively compared to the base line yield of 3425 Kg ha^{-1}.

3.3. Crop water use

3.3.1. Evapotranspiration

During 1983-12, the highest actual ET (404 mm) was under Jalpaiguri, closely followed by Malda (374 mm). South 24 Parganas (334 mm) and Nadia (324 mm) had moderate ET values and lowest ET values were at Birbhum (249 mm) and Murshidabad (249 mm). Under climate change scenario, simulated actual ET value for wheat-growing season of 2021-95, will decrease at all the study sites except Murshidabad (Table 6). The maximum reduction in ET will be 44, 53 and 68 mm respectively during 2021-45, 2046-70 and 2071-95 at Nadia. The decline will range from 16 to 48 mm at Jalpaiguri, 3 to 27 mm at Malda, 18 to 21 mm at South 24 Parganas and 13 to 15 mm at Birbhum during 2021-95 compared to 1983-12 period. In Murshidabad district, negligible increase (3 to 9 mm) in ET will be expected during 2021-95 compared to the base line ET.

Table 6 Variation of crop evapotranspiration, water use efficiency (WUE_{ET}) and transpiration use efficiency (WUE_T) of wheat under current (observed) and future (predicted at RCP 8.5) climatic scenario for selected locations of West Bengal

Location	Current	Future (RCP 8.5)		
	1983-12	2021-45	2046-70	2071-95
Jalpaiguri				
Evapotranspiration (ET), mm	404.0	387.9	375.8	356.2
WUE_{ET} (Kg m^{-3})	10.4	11.2	12.0	13.3
WUE_T (Kg m^{-3})	14.8	15.2	16.6	19.0
Malda				
Evapotranspiration (ET), mm	374.4	371.8	365.3	347.1
WUE_{ET} (Kg m^{-3})	10.7	11.4	12.2	13.5
WUE_T (Kg m^{-3})	14.7	14.7	16.0	18.1
Murshidabad				
Evapotranspiration (ET), mm	248.5	253.0	251.3	257.9
WUE_{ET} (Kg m^{-3})	12.6	13.6	14.7	15.6
WUE_T (Kg m^{-3})	19.7	21.1	23.3	25.4
Birbhum				
Evapotranspiration (ET), mm	248.6	233.8	232.6	235.2
WUE_{ET} (Kg m^{-3})	13.0	15.1	16.0	17.4
WUE_T (Kg m^{-3})	19.9	22.1	23.6	25.8
South 24 Pargana				
Evapotranspiration (ET), mm	333.5	315.8	314.8	312.3
WUE_{ET} (Kg m^{-3})	11.7	13.1	13.8	14.6
WUE_T (Kg m^{-3})	16.5	17.6	18.6	20.1
Nadia				
Evapotranspiration (ET), mm	324.4	280.0	271.1	256.4
WUE_{ET} (Kg m^{-3})	10.6	12.2	13.3	14.9
WUE_T (Kg m^{-3})	13.3	14.7	16.4	19.0

3.3.2. Water use efficiency

The WUE_{ET} value will be increasing at all the study sites during 2021-95, compared to respective baseline values (Table 6). The increase will range from 15 to 41% (Nadia), 16 to 34 % (Birbhum), 8 to 28% (Jalpaiguri), 7 to 26 % (Malda), 12 to 25 % (South 24 Parganas) and 8 to 24% (Murshidabad) during 2021–2095 compared to 1983–2012 period.

3.3.3. Transpiration use efficiency

Like WUE_{ET}, the WUE_T value also will be increasing at all the study sites under climate change scenario. The increase will range from 11 to 43% (Nadia), 11 to 30 % (Birbhum), 7 to 29% (Murshidabad), 3 to 28% (Jalpaiguri), 0 to 23 % (Malda), and 7 to 22 % (South 24 Parganas) during 2021-95 compared to 1983-12 period (Table 6).

Discussion

4.1. Phenology and crop growth parameters

Jalota and Vashist (2016) found that duration of wheat will be shortened by 9–13, 17–21 and 23–29 days during 2020, 2050 and 2080 respectively. Warming led earlier anthesis (Tian et al., 2014) and hastened maturity by 5, 10 and 12 days under elevated CO_2 with 1°C, 2°C and 3°C temperature increase respectively (Lal et al., 1998). We also found 1 to 7 days shortening of pre-anthesis period and thus reduction of 2 to 18 days for crop maturity. The maximum reduction in crop duration at Jalpaiguri and Nadia might be attributed due to increase in mean temperature (T_{mean}) by 2.4 and 2.8 °C during 2021-95 periods. Comparatively lower degree of change (0.5 to 1.9 °C) in T_{mean} in other study locations might be responsible for insignificant change in crop phenological stages. Increase in pre-anthesis period and total duration at Malda might be due to temperature decrease during 2021-70 periods.

In our study crop biomass across all the study locations will be changed to the tune of -5 to + 19 % during 2021–2095 compared to 1983–2012 periods. Warming-led positive effect on wheat leaves (higher chlorophyll content) may increase wheat biomass under un-limited soil moisture condition (Bonnett and InColl, 1992) for all the study sites. Increase in photosynthesis rate under eCO_2 is also responsible for more biomass accumulation in plants (De Souza, 2008). Increase in atmospheric CO_2 concentration from 360 to 550 ppm and 380 to 684 ppm under well irrigated condition increased wheat biomass respectively by 11% in USA (Kassie et al., 2016) and (6 to 13%) in UK (Wheeler et al., 1996). In our study we also found that, during 2021-95 the expected increase (62 to 385 ppm) of CO_2 concentration under RCP 8.5 scenario will impose positive influence (1 to 19 %) on crop biomass across the study sites.

When the crop exposed to > 34°C temperature, wheat yield decreased up to 50% due to increase in leaf senescence (Asseng et al., 2011). An increase in temperature by 6°C reduced yield by 17% (Kassie et al., 2016). Lal et al., (1998) observed that 4°C increases in temperature could lead 54% reduction in wheat yield if other environmental conditions remain unchanged. However, warming led earlier anthesis by 10 days could advance the post anthesis period to a lower temperature condition compared to normal condition, which results better grain filling and thus enhances grain weight (Tian et al., 2014). Under sufficient soil moisture condition wheat productivity increased in China (Fang et al., 2013; Hou et al., 2012) and India (Abeysingha et al., 2016) even though there was 1.6 to 2.0°C temperature increment. The decrease in rainfall and increase in temperature during wheat growing season (November to April) will not influence wheat yield negatively. The expected increase in solar radiation might help in producing more grain yield by increasing the photosynthesis process.

On the other hand, high photosynthesis rate under eCO_2 increase wheat yield. Simulation through CERES model showed 12.5 and 28 % yield increment respectively under eCO_2 of 550 and 720 ppm, compared to 360 ppm (Kassie et al., 2016). Rao and Sinha (1994) illustrated that CO_2 enrichment compensated yield decrease partially under climate change scenario at New Delhi, India. Increase partitioning of dry matter to grain under eCO2 (Wheeler et al., 1996) resulted in higher grain yield of wheat during 2021-95 at all the study sites. Crop growth and simulated yields are less sensitive to LAI > 3 as higher LAI contribute marginally to radiation interception. Reduction of LAI below 2 under climate change scenario at Nadia may be one of the reasons for having negative yield during 2021-45. Subsequent yield increment by 173 and 386 $Kgha^{-1}$ during 2046-70 and 2071-95, may be due to positive affect of CO_2 enhancement of 193 ppm and 385 ppm during 2046-70 and 2071-95 respectively.

As eCO_2 didn't affect duration of grain filling, the higher rate of increase (18%) in HI at eCO_2 compared to normal CO_2 (Wheeler et al., 1996) resulted in higher HI values (3 to 19%) at all the study sites under future climate change (RCP 8.5) scenario. Greater relative yield increment, compare to biomass increase, resulted such higher HI values under future climate change.

4.2. Crop evapotranspiration and water use efficiency

Crop evapotranspiration is regulated by many factors e.g. atmospheric evaporative demand, soil moisture status, crop duration and transpiring surface area etc. The atmospheric evaporative demand increases with increase in ambient temperature. Mishra et al., (2013) has observed that according to HadRM3 global circulation model prediction, as 1^{o}C decrease in T_{max} will reduce the ET rate by 3.5 and 6% respectively at Allahabad and Udham Singh Nagar, India during 2011-40 time periods. On the other hand doubling of CO_2 concentration caused 40% decrease in stomatal apertures, which reduced transpiration of wheat crop by 23–46 % (Morison, 1987) in USA and 11% (Lal et al., 1998 p9) in India. Transpiration, which is more influenced by higher CO_2 concentration, contributes more to ET during most part of crop growth period and thus, lower ET is expected under eCO2 (Bencze et al., 2014). We observed 1 to 21 % decrease in crop ET, which might be for shortening of duration and reduction of transpiration due to eCO_2 under future climate change.

Reduced transpiration due to reduction in stomatal conductance under eCO2 could result in higher WUE (Lal et al., 1998; Morison, 1987; Bencze et al., 2014) and transpiration use efficiency (Asseng et al., 2004). As eCO2 decreased transpiration in C_3 plants, this reduction in evaporation combine with the increased photosynthesis can contribute to higher WUE (Prior et al., 2011). Doubling of CO_2 concentration may reduce crop transpiration by 40% due to changes in stomatal conductance resulting higher water use efficiency (Morison, 1987).

Conclusions

In this study,we investigated variability and change of seasonal and yearly rainfall, T_{max} and T_{min} of six representative stations covering five agro-climatic zone of WB. DSSAT v4.5 model was used to simulate yield considering past and future climatic data of high emission scenario (RCP 8.5). The main conclusions are summarized as below:

1. Throughout the state the increase in annual T_{max} will range from 3.7^{o}C to 5.3^{o}C at the end of this century. Both Nadia and Birbhum will experience highest increase in T_{max} during both rainy and post-rainy season.

2. The annual T_{min} will decrease during 2021-45 at all the study sites, except Nadia and Jalpaiguri, followed by gradual increase thereafter. At the end of this century the expected increase in annual T_{min} will range from 2.9^{o}C to 4.7^{o}C across the entire study sites.

3. The annual rainfall will increase (7 to 22%) at all the study sites except South 24 Parganas (-7%).

4. Wheat yield under future climate scenario will increase (3 to 28%) across the study sites.

5. Crop evapotranspiration value will decline (1 to 21%).

6. Water -use efficiency will increase by 7 to 41% and transpiration -use efficiency will increase by 3 to 43% across the study sites.

7. For simulating future yield, the recommended irrigation practice has been followed for all the study sites to ensure no water-deficit stress during crop growing period. Result shows that the crop evapotranspiration will decrease and subsequently the water use efficiency and transpiration use efficiency will increase in future climate condition. Thus, further research is needed to improve the irrigation management strategies under future climatic scenarios for judicious use of scarce water resource.

Declarations

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D. Code availability

Not applicable

E. Authors' contributions

1. A Mukherjee: Conceptualization, Methodology, Data collection and compilation, Data analysis Data curation, Writing- Original draft preparation.

2. AKS Huda: Supervision and Writing- Correction

3. S Saha: Writing, Reviewing and Editing.

All authors read and approved the final manuscript.

F. Ethics approval

This work has no research with biological applications, in which case ethical approval does not apply

G. Consent to participate

This research has not involved any human or animal participants; it was entirely performed with computational modelling. All authors have reviewed the manuscript and consent to publication.

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Figures

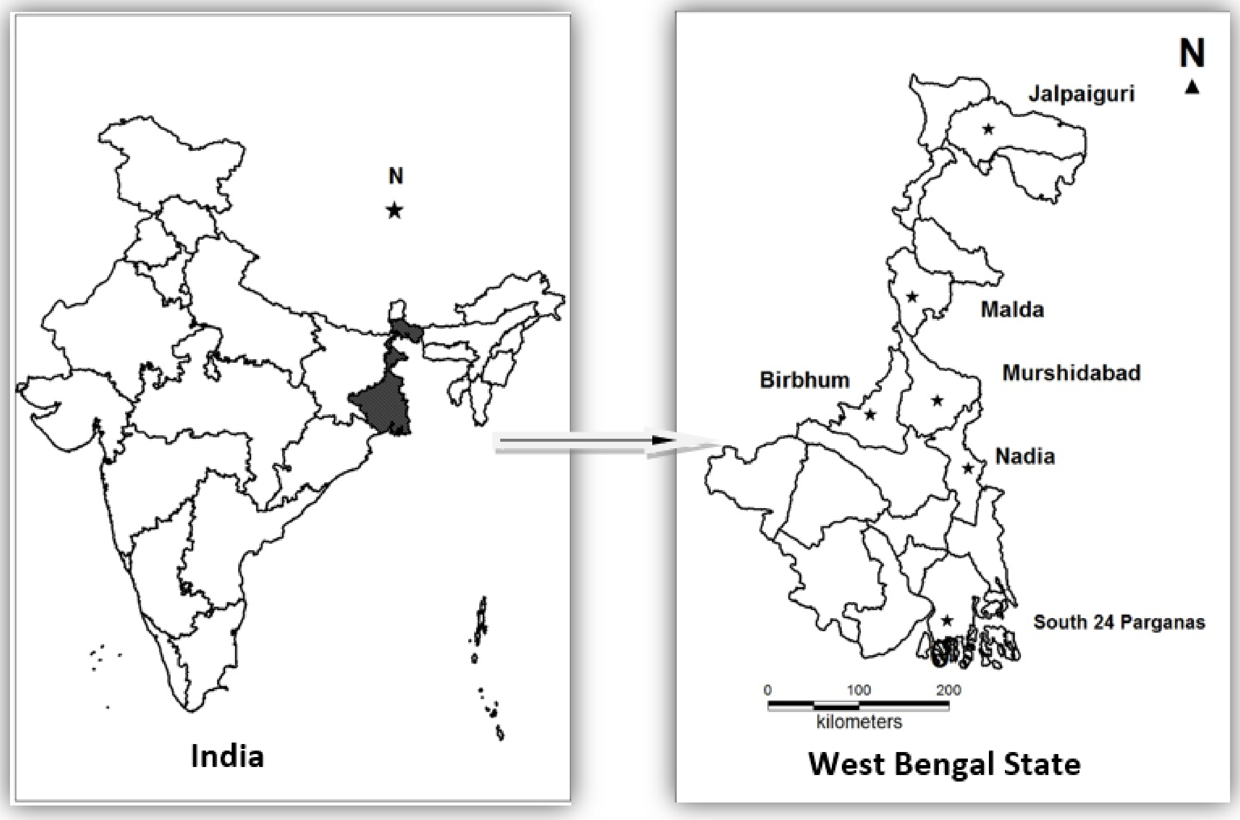

Figure 1

Map of the study sites

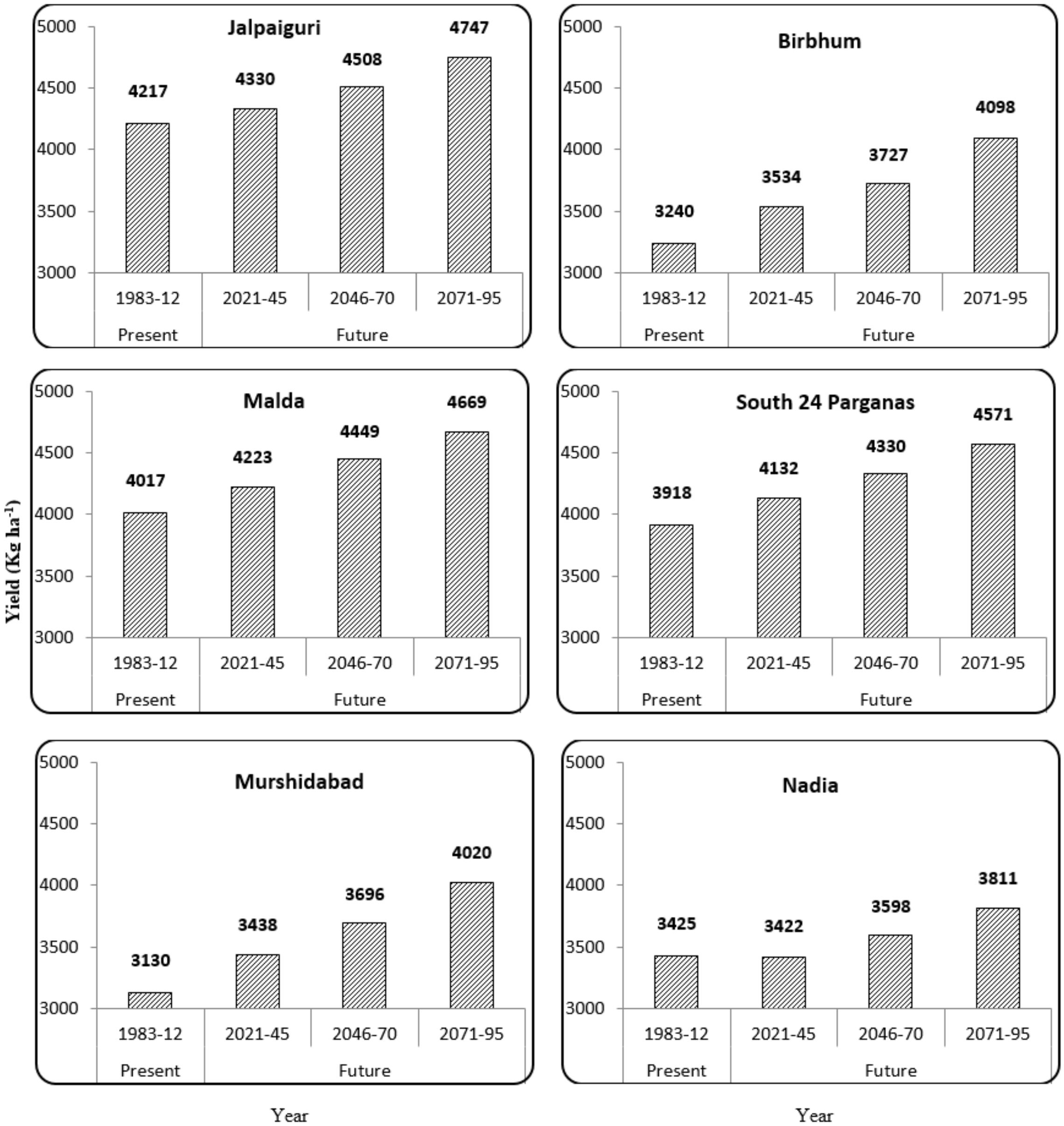

Figure 2

Variation of wheat yield under present (observed) and future (predicted at RCP 8.5) climatic scenario for selected locations of West Bengal