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FULL-LENGTH RESEARCH ARTICLE

Climate Change Impacts on Yields of Phenologically Different Rice Varieties Over a Sub-Humid Climatic Environment

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Abstract The current study aims to predict the impact of climate change on rice yields for three varieties varying in duration, at representative locations falling under different agro climatic zones of Bihar, India, through crop modelling. Short (Saket-4), medium (Sita) and long duration (Radha) varieties of rice selected for the study exhibited distinct trends in terms of economic yield, but the magnitude of impact varies. Maximum effect of projected increases in temperature was on the long-duration variety and the least affected was the variety requiring lesser maturity days. Maximum reduction in yield for 2080 time period was observed for Pusa station falling in North West alluvial plains followed by locations in South Bihar alluvial plains. For 2020 and 2050 time periods, increased temperature and carbon dioxide had a positive effect on productivity of short and medium duration varieties (1–6 %),as witnessed in the simulation studies. For 2080, yield of rice declined in an increasing order from short to long duration varieties from 12 to 33 %. Average yield of all varieties showed maximum decline (34 %) for 2080 at Pusa representing zone I followed by almost 24 % decline at Sabour with the current varieties and management practices.

Keywords Climate change · Crop modelling · Rice yield · Scenarios

Introduction

Greenhouse effect and its accompanying effect (climate change) can be recognized as environmental risk [15], due to its impacts on production of food crops globally. It is expected that the increasing concentration of greenhouse gases in the atmosphere would affect the climate. Global mean surface temperature is projected to increase by 2.0–5.4 °C in 2070–2099 time period [13]. Studies on changes in climate, predicted by GCM (General Circulation Model), suggest that in addition to thermal stress due to global warming, stress on water availability in tropical Asia is likely to increase in future [12]. In India, the major part of the population is engaged in agriculture or agriculture-based enterprises, so changing climate may affect India's food security by hampering agricultural production in more than one way. Global warming and other climatic changes may have a range of impacts depending on complex interactions among managed and unmanaged ecosystems [22]. Increases in net primary productivity of crops brought about by increased CO_2 may be nullified by changes in precipitation, temperature and other meteorological variables leading to increased or decreased gross production of crops. Dynamic crop growth models are widely used to project the effects of rising atmospheric CO_2 concentration and associated climate change on crop yields. Many models are now available; which can be used for impact assessment of climate change [2]. Although these models rely sometimes on assumptions not fully tested, even then these are the best methods at present to investigate the effects of likely climate changes on agricultural production.

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Table 1 Geographical position and characteristics of agro-climatic zones of Bihar

	Zone I Pusa (Samastipur)[a]	Zone II Madhepura (Madhepura)[a]	Zone III A Patna (Patna)[a]	Zone IIIB Sabour (Bhagalpur)[a]
Latitude	25.85°N	26.11°N	25.58°N	25.33°N
Longitude	85.78°E	86.23°E	85.25°E	87.17°E
Altitude (m)	38	53.95	41	11
Soil characteristics	Heavy textured sandy loam to clay, medium acidic, flood prone, pH 6.5–8.4	Light to medium textured, sandy loam to clay loam, slightly acidic, flood prone, pH 6.5–7.8	Old alluvium sandy loam to clay, slightly alkaline patches, pH 6.8–8.0	Old alluvium sandy loam to clay, slightly alkaline patches, pH 6.8–8.0
Geographical area (lakh ha)	32.61	19.85	29.18	11.96
Irrigated area (lakh ha)	13.52	10.11	18.41	3.68
Percent gross irrigated area	45	49	81	59
Total annual rainfall (mm)	1040–1450	1200–1700	990–1240	990–1240
Average annual maximum temperature (°C)	36.6	33.8	37.1	37.1
Average annual minimum temperature (°C)	7.7	8.8	7.8	7.8

[a] refers to name of the district

Climate change has already affected negatively India's million of rice producers [6]. Rice yield can be affected by climate change due to direct effects of temperature and carbon dioxide on crop growth and yield [7]. Rice yield during the past three decades showed negative trend may be due to gradual changes in weather conditions [1]. Simulation studies [20] showed decreasing trends of potential yields of rice and wheat in Indo-Gangetic plains of India with increasing minimum temperature and decreasing solar radiations. An increase in minimum temperature by 2 °C could decrease rice yield by about 0.75 t/ha in the high-yield areas and about 0.06 ton/hectare in the low-yield coastal regions of India [23]. Another study showed a loss of 15–17 % in grain yield of rice and wheat over India with 2 °C rise in temperature [2]. It is predicted that yield of rice would decrease by 0.6 t/ha for every 1 °C increase in temperature [22]. Studies also revealed that either daytime or night time temperature increase alone increased the damaged rice grain percentage [19]. A decrease in minimum temperature increases the crop duration and yield, and an increase in minimum temperature increases respiration leading to decline in yield [17]. Simulated potential yield of rice for combination of three temperatures and three CO_2 scenarios for the years 2020 and 2100 using weather data from seven sites in Asia was reported [14] and the effect would be a reduction in yield in high temperature scenarios and an increase in low temperature scenarios. Carbon dioxide enrichment from 330 to 660 ppm increased grain yield mainly by increasing panicles per plant [4].

A change of crop variety can mitigate the impact of climate extremes [8]. This is particularly applicable for Bihar which is a resource-poor region, where subtle changes in regional weather experienced by the crop during phenological phases remain the key determinant of agricultural production. Pre-assessment of the impact on rice which is the major crop of this region can be quite helpful in developing strategies for managing the future changes. The current study aims to project the likely impacts on three phenologically different rice varieties exposed to changing climatic scenarios in different agro climatic zones of Bihar, experiencing a sub-humid climate. The varieties are Saket-4, Sita and Radha. Assessment of impacts of changes in climate with time on the yield of above phenologically different varieties can help formulate better management options for rice in the region to enhance food production leading to food security.

Materials and Methods

Study Areas

Bihar lies in the eastern region of India extending from 24°20′10″ to 27°31′15″ N latitude and 83°19′50″ to 88°17′40″ E longitude, covering a total area of 94,163 sq.

Table 2 Genetic coefficients and variables used for simulation study

Parameters and practices used	Saket-4	Sita	Radha
Thermal Time (°C days)			
Sowing to germination	62	62	65
Germination to 50 % flowering	1250	1450	1750
50 % flowering to physiological maturity	530	570	670
Radiation use efficiency (g/MJ/day)	2.3	2.3	2.3
Specific leaf area (dm^2/mg)	0.0021	0.002	0.0017
Potential storage organ weight (mg/grain)	22.5	23.5	26.5
Date and year of sowing	21st June, 1986	30th June, 1999	12th June, 1998
	1st July, 1988	29th June, 2003	30th June, 1999
	25st June, 1989	25th June, 2005	24th June, 2002
Date and year of harvesting	15th Oct, 1986	30th Oct, 1999	5th Nov, 1998
	23rd Oct, 1988	30th Oct, 2003	10th Nov, 1999
	24th Oct, 1989	28th Oct, 2005	16th Nov, 2002

Table 3 Validation of InfoCrop model

Variety	Ist year		IInd year		IIIrd year		Coefficient of Efficiency (%)	RMSE (root mean square error, kg/ha)	MAE (mean absolute error, kg/ha)	R^2
	Observed yield(kg/ha)	simulated yield(kg/ha)	Observed yield(kg/ha)	simulated yield(kg/ha)	Observed yield(kg/ha)	simulated yield(kg/ha)				
Saket-4	3,866	3,922	4,575	4,747	3,540	3,177	71	234.15	197.00	0.97
Sita	3,015	3,106	2,663	2,561	2,966	2,970	74	78.95	65.67	0.99
Radha	3,893	3,892	3,428	3,462	3,900	3,742	82	93.31	64.33	0.87

km lying at an altitude of 52.73 m above sea level. In this study, four centers lying in different agroclimatic zones of Bihar falling under a sub-humid climatic environment were selected, on the basis of availability of data. Pusa in Samastipur district (zone I), Madhepura (zone II), Patna (zone III A) and Sabour in Bhagalpur district (zone III B) were selected to simulate the effects of climate change on rice yield. Table 1 describes geographical position and characteristics of agro-climatic zones of Bihar. In all the selected areas rice is the major crop grown [5]. In Bihar, gross cropped area (GCA) is 30.07, 20.61, 22.60, 6.21 lakh hectares for zone I, zone II, zone IIIA and IIIB, respectively. Average area under rice cultivation is 32.8 lakh hectares.

Climate Change Scenario

The IPCC's (Intergovernmental Panel on Climate Change) Special Report on Emission Scenario (SRES) describes future scenarios predicting greenhouse gas emissions. The SRES set comprises four scenario families: A1, A2, B1 and B2 [24]. A2 scenario selected for the current study is a high emission scenario. CO_2 concentration for SRES A2 scenario increases from the current levels of 370 ppm to 414 ppm for 2020, 522 ppm for 2050 and 682 ppm for 2080. The scenario describes a very heterogeneous world and continuously increasing population. Economic development is primarily regionally oriented and lower than other storylines. General Circulation Models (GCMs) are tools designed to simulate time series of climate globally, accounting for the effect of green house gases (GHGs) in the atmosphere [21].

GCM predictions of Hadley Centre Coupled Model ver.3 (HadCM3) are incorporated individually, as per the Eqs. 1 and 2, into each year of historical weather data (1961–1990 for Pusa, Madhepura, Patna and 1972–1990 for Sabour) to generate baseline, 2020, 2050 and 2080 time periods.

$$\text{Expected changes in Temperature} = \text{Baseline temperature} + \text{Predicted change in temperature obtained from HadCM3 outputs} \quad (1)$$

$$\text{Expected changes in Precipitation} = \text{Baseline daily rainfall} \times (1 + \%\ \text{change in rainfall obtained from HadCM3 outputs}) \quad (2)$$

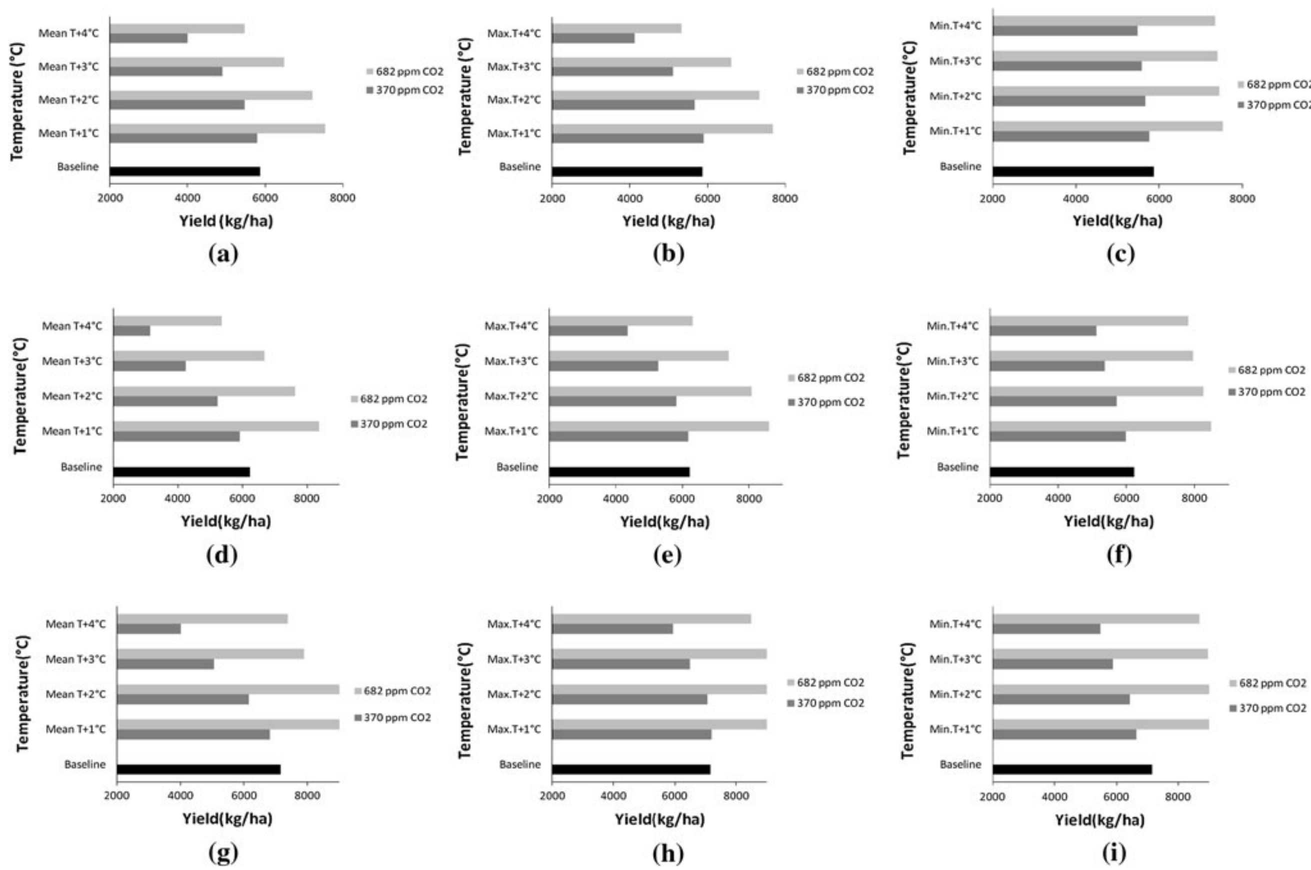


Fig. 1 Change in potential grain yields with changes in temperature in Saket-4 (**a–c**), Sita (**d–f**) and Radha (**g–i**) varieties

$$E = 1.0 - \left(\frac{\sum_{t=1}^{N} (O_t - P_t)^2}{\sum_{t=1}^{N} (O_t - \overline{O})^2} \right) \quad (3)$$

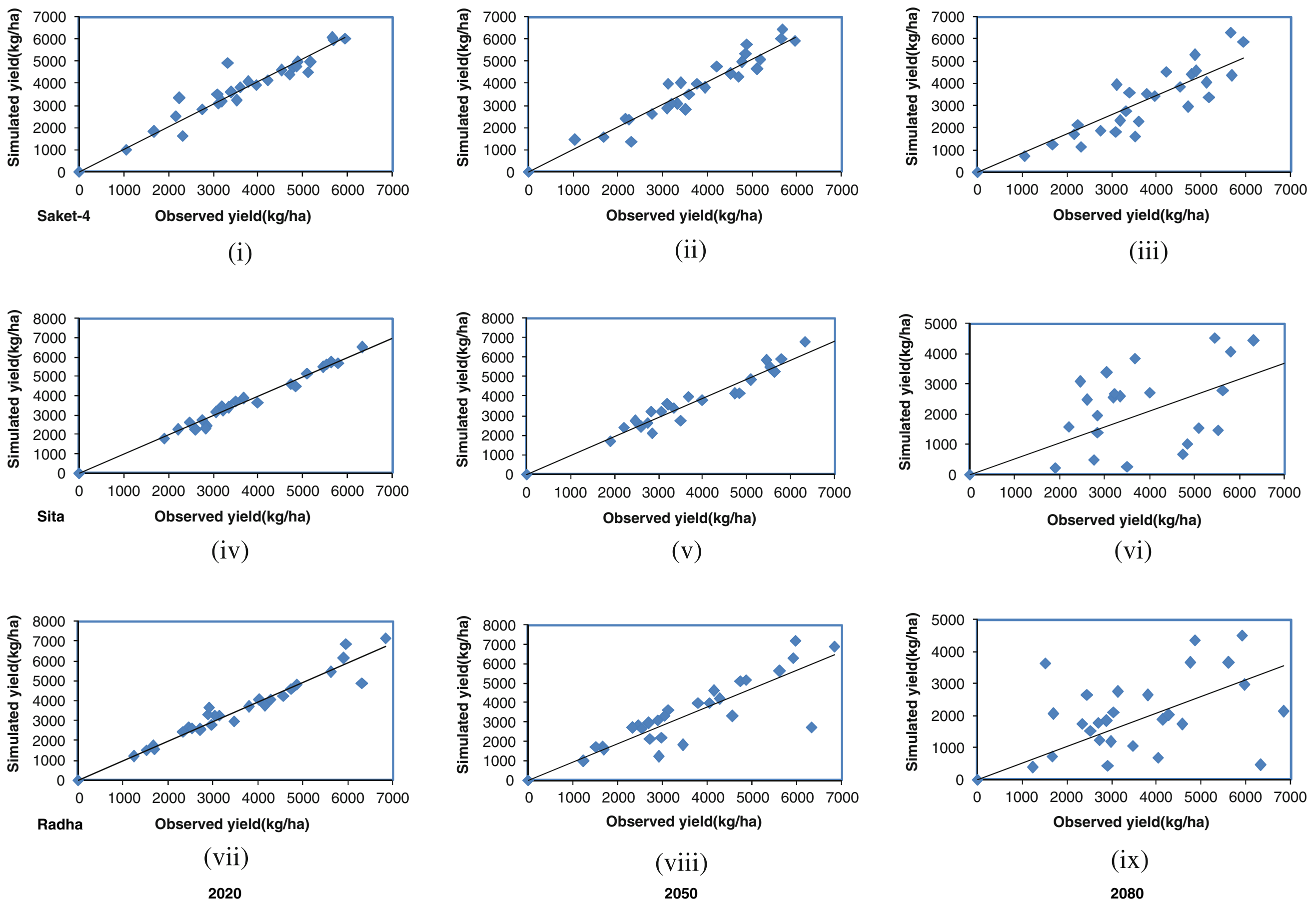
Where O is observed and P is yield predicted by the model and N is the number of observations.

Crop Model

In this study InfoCrop model developed at IARI, Pusa [3] was used. 'Infocrop is a decision support system (DSS), based on a generic crop model developed to provide a platform for scientists. The model in this DSS is designed to simulate the effects of weather, soils, agronomic management (including planting, nitrogen, residues and irrigation) and major pests on crop growth and yield. It is user friendly, targeted to increase applications of crop models in research and development and has simple and easily available input requirements. The inputs required by the model include soil data (soil type, pH, organic matter, bulk density, etc.), crop management data (sowing date, sowing depth, transplanting date, irrigation, fertilizer, etc.), daily weather data (maximum temperature, minimum temperature, rainfall, solar radiation, vapour pressure) and variety-specific genetic coefficient data (Table 2).

Table 4 Simulated economic yield (kg/ha) of rice varieties for different time periods

	Baseline (1961–1990)	2020	2050	2080
Pusa				
Radha	3,644	3,625	3,472	2,066
Sita	4,005	3,972	3,930	2,239
Saket-4	3,796	3,909	3,869	3,221
Madhepura				
Radha	4,005	3,972	3,930	2,239
Sita	3,796	3,909	3,869	3,221
Saket-4	4,005	3,972	3,930	2,239
Patna				
Radha	3,655	3,712	3,736	2,643
Sita	2,957	3,011	3,127	2,246
Saket-4	3,190	3,243	3,378	3,004
Sabour				
Radha	3,172	2,957	2,820	1,921
Sita	3,059	3,111	3,252	2,957
Saket-4	2,042	2,107	1,811	1,414



(a) Pusa

Fig. 2 **a–d** 1:1 Line graph for observed and simulated grain yield at **a** Pusa, **b** Madhepura, **c** Patna and **d** Sabour

Crop Model Calibration

Crop-specific generic variables characterize the difference in performance among varieties. Short, medium and long duration varieties differ primarily in days to flowering and maturity; short, medium and long duration varieties require nearly 110, 125 and 145 days, respectively, to mature. Radha yields ~5–6 t/ha, Sita (4–5 t/ha) and Saket-4 (3.5–4 t/ha) under optimum growing conditions. Medium and long duration varieties require 4–6 irrigations, while Saket-4 is primarily rainfed, requiring less irrigation as compared with Radha and Sita if grown under irrigated conditions.

Thermal time is the actual time taken by the crop to attain specific stages in its life cycle [18]. Initial values of genetic coefficients were first supplied from the experimental data to run the model according to cultivar characteristics and most matching values of duration and grain yield were worked out. A correct estimation of grain yield was taken into account for validation of crop model. The accuracy of the model was evaluated by calculating the coefficient of efficiency (Eq. 3) based on the model adopted [10]. Simulation studies were performed considering present varieties and management practices.

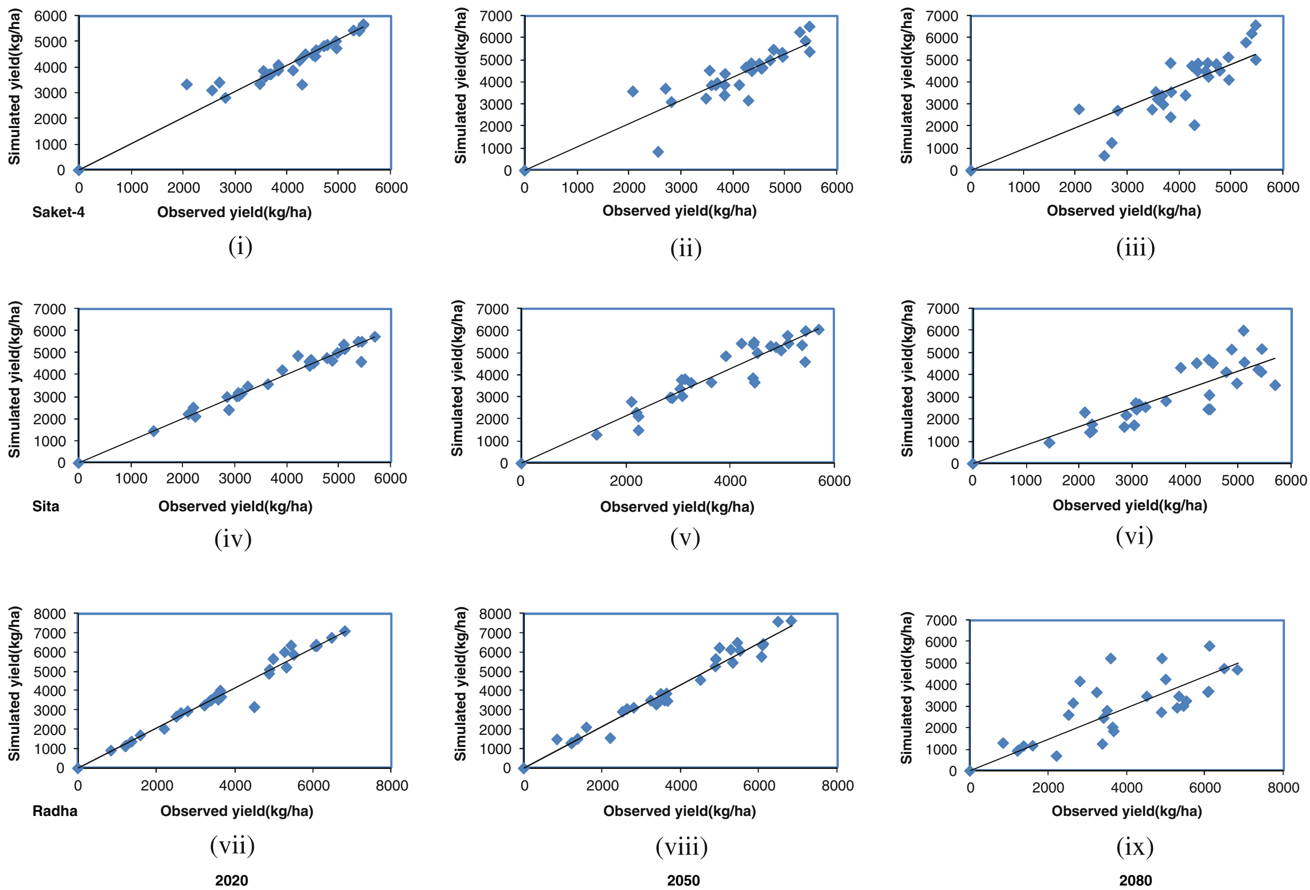
Results and Discussion

Crop Model Validation

A comparison between observed and simulated yield and their statistics are presented in Table 3 and on this basis the crop yield for future scenarios was generated. Validation and testing of model for the three varieties of rice gave coefficient of efficiency ranging between 70 and 80 %. In general, it can be said that the model effectively simulates grain yield except for unusually high- or low-yield experiments may be due to pest damage or some weather extremes experienced during critical stages.

Sensitivity Analysis

One widely accepted approach to analyse possible effects of different climatic parameters on crop growth and yield is



(b) Madhepura

Fig. 2 continued

by specifying the incremental changes in climatic parameters and applying these changes uniformly to baseline/normal climate [11]. Sensitivity analysis was thus performed for all the three varieties revealing the effects of projected changes of maximum and minimum temperature in various combinations at current and projected levels of CO_2 on potential yield. Maximum, minimum and both maximum and minimum temperatures were increased from 1 to 4 °C at 370 ppm of CO_2 (current level) for the baseline period (1961–1990) and in the next cycle, model was run by increasing the CO_2 level to 682 ppm along with the changes in temperature as before. Further, the maximum, minimum and daily mean temperature was increased gradually from 1 to 4 °C, as incremental variable scenarios have the capacity of capturing a wide range of possible changes in the future.

The results of this analysis showed interactive effects of increasing temperature and CO_2 concentration under no stress (unlimited water and nutrients) conditions. The yield of Saket-4, Sita and Radha varieties decreased from the current levels on increasing the mean, maximum and minimum temperature at 370 ppm of CO_2 while, an increase in yield was observed with the same increase in temperature combined with 682 ppm CO_2 (Fig. 1).

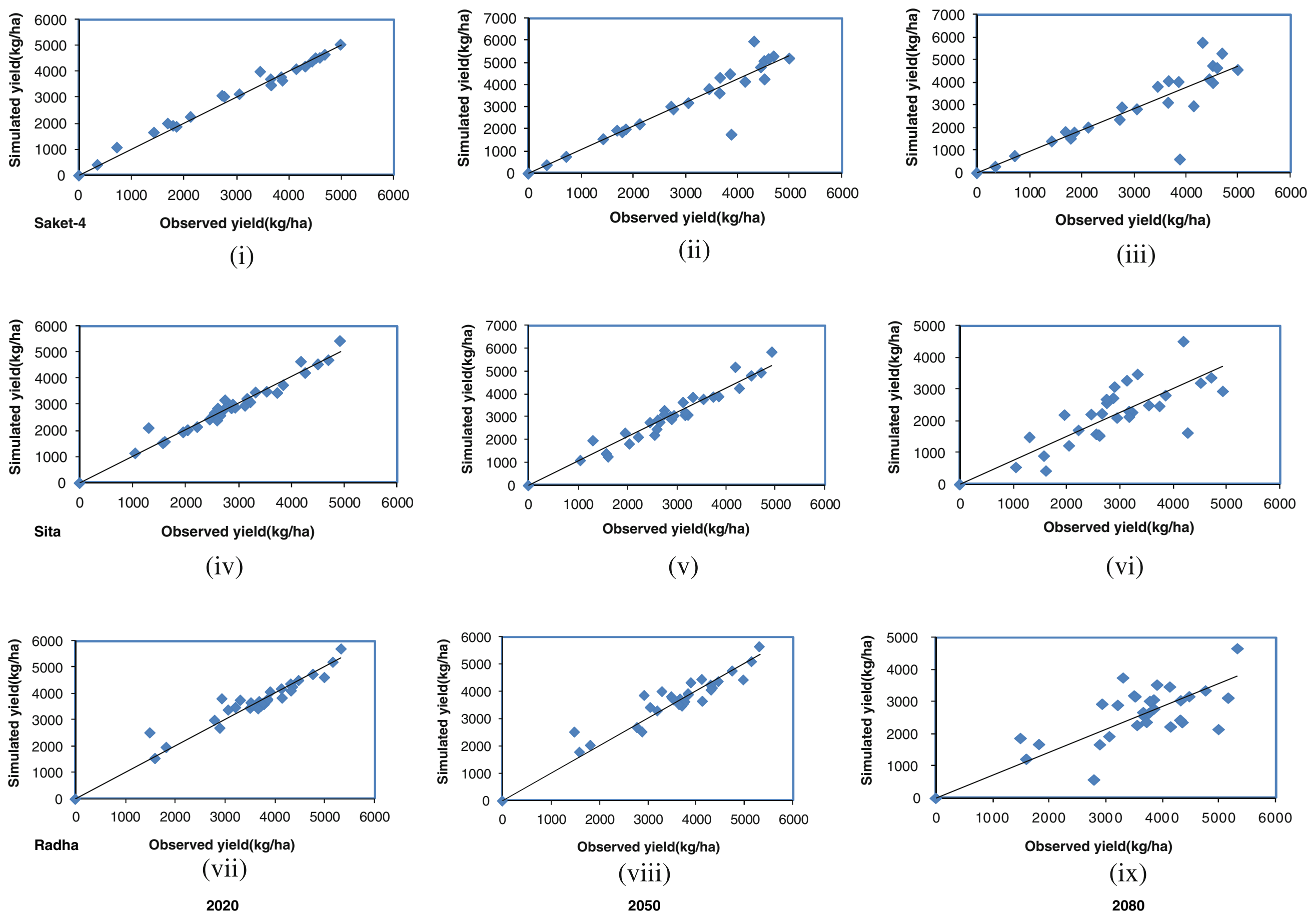
This result is in agreement with that of the earlier study [11] where effect of temperature on growth and yield of cereal crops was counter-balanced by favourable effect of increasing CO_2 levels up to some particular combination of CO_2 and temperature.

Impact of Climate Change at Different Locations

With the current varieties, cultivation and management practices, the impacts of climate change on grain yield of three varieties of rice were explored at the selected centres (Table 4). Grain yield of baseline was compared with different time scales, i.e. 2020, 2050 and 2080 and is presented in 1:1 line graph of observed and predicted yield in different locations and varieties of rice (Fig. 2a–d).

Zone 1 (Pusa)

In case of Saket-4, an increase in yield up to 3 % was observed for 2020 time period from baseline and thereafter



(c) Patna

Fig. 2 continued

yield decreased by 1 % for 2050. In 2080 time period, yield declined to 15 % from baseline yield. Sita variety exhibited decrease in yield right from 2020 (1 %), 2050 (2 %) and a major decline of 44 % for 2080. For Radha, grain yield decreased to the tune of 1, 5 and 43 % for 2020, 2050 and 2080, respectively.

Zone II (Madhepura)

All varieties showed yield increase up to 2050 time period and decrease under 2080 from baseline yield. For Saket-4 an increase of 3 % in 2020 and 6 % in 2050 was observed, whereas for Sita and Radha varieties an increase of 1 and 3 % in 2020 and 7 and 8 % in 2050 was observed, respectively. For 2080 time period, reduction in yield to the tune of 24, 17 and 5 % was observed for Radha, Sita and Saket-4, respectively.

Zone III A (Patna)

A similar pattern in change of yield for different varieties of rice is projected for Patna as in case of Madhepura. For both short and medium duration varieties of rice an increase of 6 % in yield was observed up to 2050, whereas for long duration variety only 2 % increase in yield up to 2050 was recorded. The yield of all the selected varieties decreased for 2080 scenario to the extent of 28 % (Radha), 24 % (Sita) and 6 % (Saket-4).

Zone III B (Sabour)

Maximum decline of 31 % from baseline for 2080 period was observed for Saket-4. Yields of Saket-4 and Radha decreased by 11 % for 2050 time period, and both Saket-4 and Sita showed yield increase of 3 and 2 %, respectively, for 2020 period. Sita, however, behaved differently from Saket-4 and Radha varieties by showing an increase in yield till 2050 up to 6 %, which then decreased to 3 % for 2080 scenario.

Station and Variety Wise Average Yield

Overall analysis of yield data for three varieties and four stations taken for study showed an increase in rice yield till

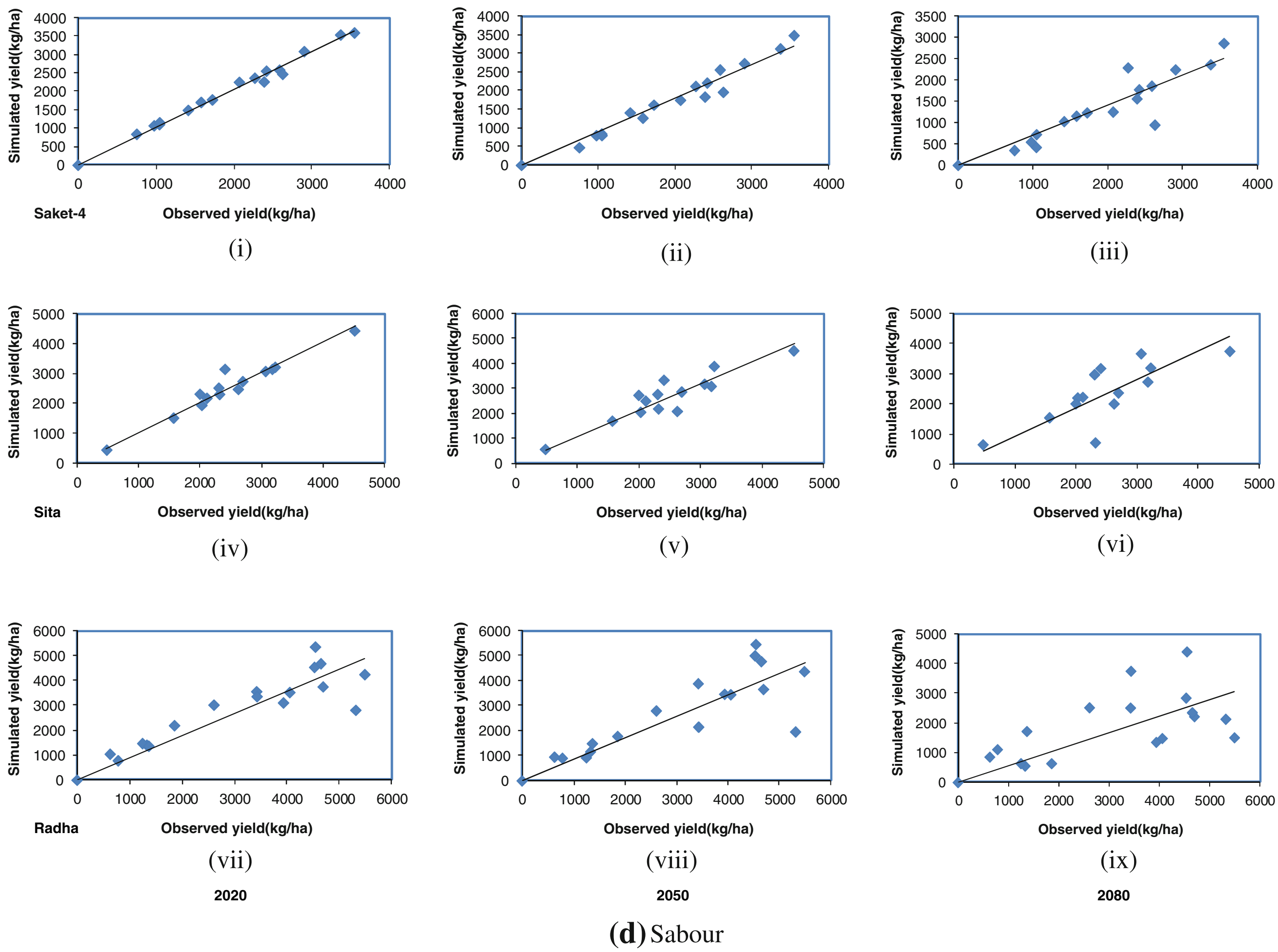


Fig. 2 continued

2050 for Saket-4 and Sita varieties but a meager decrease of 1 % for Radha. For 2080 time period, yield of rice declined in an increasing order from short to long duration varieties from 12 to 33 %.

Station-wise average yield showed maximum decline to the tune of 34 % for 2080 at Pusa representing zone I followed by almost 24 % decline at Sabour (zone III B). Madhepura (zone II) and Patna (zone III A) showed an increase in yield ranging from 2 to 7 % and 1.7 to 4.5 %, respectively, up to 2050 time period (Table 5).

Rice, primarily a kharif season crop, grown from middle of June to Oct–Nov concomitant with monsoon season in this region, enjoys a favourable mean temperature around 30 °C. Optimum temperature for rice during flowering is around 22–29 °C. Simulation of impact on rice yield in different time periods revealed that the conditions are favourable for rice crop up to 2020 with moderate increase in temperature and CO_2 in the atmosphere, evidenced by increase in economic yield due to increased grain number. During 2050 time period, yield showed a stagnant to

Table 5 Stations and varieties wise change (%) from baseline yield in rice

Varieties	Time periods		
	2020	2050	2080
Saket-4	2.5	2.1	−12.1
Sita	0.7	3.8	−23.6
Radha	−0.4	−1.0	−33.4
Stations			
Pusa	0.5	−1.5	−34.2
Madhepura	2.2	6.9	−15.3
Patna	1.7	4.5	−19.5
Sabour	−1.2	−4.7	−23.8

declining trend. This decline in yield may be attributed to beneficial effect of CO_2 masked by increasing temperature. However; a sharp decline in grain number, grain yield and harvest index was seen in all varieties beyond 2050 even with high CO_2 concentrations and temperature (Tables 6, 7, 8). This increase in temperature might be responsible for

Table 6 Projected mean crop growth and yield parameters of Saket-4 for different future time periods

Saket-4	Duration (days)	Days to anthesis	Total dry matter (kg/ha)	Grain yield (kg/ha)	Grain number	Harvest index
Pusa						
Baseline	110	81	7,788	3,796	154451977	0.49
2020	108	81	8,060	3,909	159394000	0.49
2050	108	82	8,496	3,869	158557827	0.46
2080	112	85	9,096	3,221	126010346	0.35
Madhepura						
Baseline	109	80	9,037	4,339	167982041	0.48
2020	107	80	8,598	4,259	161494241	0.50
2050	106	79	9,288	4,389	167493128	0.47
2080	108	83	10,256	3,938	154067659	0.38
Patna						
Baseline	109	80	5,995	3,189	130352183	0.53
2020	107	80	6,135	3,243	130815730	0.53
2050	108	81	6,717	3,378	137890943	0.50
2080	113	86	7,233	3,034	121076214	0.42
Sabour						
Baseline	108	79	4,844	2,042	93486306	0.42
2020	106	78	4,908	2,107	95690044	0.43
2050	107	80	4,815	1,811	88847350	0.38
2080	111	84	4,656	1,413	68666500	0.30

Table 7 Projected mean crop growth and yield parameters of Sita for different future time periods

Sita	Duration (days)	Days to anthesis	Total dry matter (kg/ha)	Grain yield (kg/ha)	Grain number	Harvest index
Pusa						
Baseline	127	94	7,447	4,005	168783896	0.54
2020	124	93	7,528	3,972	165345639	0.53
2050	123	94	8,268	3,930	162523091	0.48
2080	127	100	8,943	2,240	83063361	0.25
Madhepura						
Baseline	126	92	7,084	3,878	162775007	0.55
2020	123	92	7,152	3,906	166810369	0.55
2050	120	92	8,365	4,136	191118038	0.49
2080	123	97	9,023	3,207	131422207	0.36
Patna						
Baseline	125	90	5,414	2,957	133876187	0.55
2020	122	90	5,556	3,011	140027427	0.54
2050	122	92	6175	3,127	149998743	0.51
2080	127	98	6,440	2,246	90423033	0.35
Sabour						
Baseline	123	92	5,488	3,059	114408147	0.56
2020	121	92	5,460	3,111	117017947	0.57
2050	121	93	5,896	3,252	123488747	0.55
2080	125	98	6,747	2,967	111997807	0.44

drastic decline in yield during 2080 time period. High temperature effect results in reduced spikelet number and spikelet sterility are reported [25].

The reason for yield decline may be attributed to higher respiration rate under high temperature and high temperature induced spikelet sterility. This is in agreement with

Table 8 Projected mean crop growth and yield parameters of Radha for different future time periods

Radha	Duraion (days)	Days to anthesis	Total dry matter (kg/ha)	Grain yield (kg/ha)	Grain number	Harvest index
Pusa						
Baseline	150	106	6,329	3,644	135239719	0.58
2020	146	106	6,354	3,625	142479622	0.57
2050	143	108	6,839	3,472	131810459	0.51
2080	149	116	7,506	2,066	72529822	0.28
Madhepura						
Baseline	154	107	6,638	3,896	139792717	0.59
2020	147	106	6,620	4,011	148261083	0.61
2050	143	107	7,200	4,202	159785523	0.58
2080	145	113	7,722	2,946	103600310	0.38
Patna						
Baseline	153	106	6,382	3,655	148909533	0.57
2020	148	106	6,605	3,711	163137727	0.56
2050	145	107	7,075	3,736	165922310	0.53
2080	151	115	6,949	2,640	99559410	0.38
Sabour						
Baseline	152	106	5,469	3,172	106798694	0.58
2020	147	106	4,904	2,957	105340818	0.60
2050	143	107	4,849	2,820	100617106	0.58
2080	148	115	5,471	1,921	66204871	0.35

previous studies [9, 16] where yield losses by simultaneous increase in CO_2 and temperature due to high-temperature-induced spikelet sterility were observed.

The reproductive development of rice might be directly affected by elevated CO_2 and higher temperature resulting in delay in maturity due to higher temperature regimes beyond 2050. This can be overcome to certain extent by short and medium duration varieties under future climate change scenarios. This will also help in following timeliness of operations in succeeding wheat crop benefiting the predominant rice–wheat cropping system of this region.

Conclusions

All the varieties of rice showed decline in yield under changed climate, but the performance of short duration variety of rice in the four representative stations of Bihar outshines others in being the variety showing the least decline in productivity. It can be concluded that the yield of rice may increase marginally over the present yields, with the current varieties and ongoing practices in the beginning of the twentyfirst century. But, if the meteorological variables behave as predicted by the climate change scenarios then the increased levels of CO_2 concentration may not be able to maintain the current levels of rice yield. As evident from Table 5, absolute values of economic yield of Saket-4 gave maximum values for all stations under study, except at Sabour. Radha was affected most due to the changed climate scenarios. Thus, it can be suggested that shortening the duration of popular high-yielding varieties by breeding methods and breeding for heat tolerance may be some of the mitigation options in future. Advancing the crop cycle to escape the terminal heat stress and use of short duration varieties are probable options of adaptation for maintaining the future rice crop productivity and food security in this region.

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