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Assessment of Rice Yield Sensitivity to Changing Weather Conditions in Prayagraj Using DSSAT V4.7.5 Crop Simulation Model

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The Field experiments were conducted during 2012-19 to determine the effect of changing weather such as (Tmax, Tmin, Tavg, Solar radiation and CO_2 concentration) on grain yield, LAI, Anthesis days and maturity days of four rice cultivars i.e (Swarna sub 1, Sarjoo 52, Pant Dhan 4 and NDR 359) at the college of forestry farm , SHUATS Prayagraj. The DSSAT-CERES rice model was calibrated and validated, for the cultivars under Prayagraj conditions and it was observed that the values i.e Percent error, RMSE, nRMSE and Pearson correlation coefficient (r) were good in agreement and within permissible limit. Among all the four varieties NDR 359 yields more followed by pant dhan 4, Swarna sub 1 and sarjoo-52. The result revealed that by increasing temperature

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(Tmax, Tmin, Tavg) for all the variety and phenophases the yield got reduced but under increased condition of Solar radiation and CO_2 concentration the yield got increased. In case of LAI same result was observed but during the phenophase of flowering to maturity stage of the crop there was no effect found. During the interaction between changing weather with anthesis days and maturity days it was found that the anthesis days and maturity days got increased with increased in Tmax and Tavg. Other weather parameter has no effect on it. The interaction of weather parameter with the yield, LAI, anthesis days and aturity days were found significant at 5% or 1% level for all the four varieties and henophases. The research outcome indicates that, the future farming will be challengeable due to climate change, we must prepare with suitable varieties and crop management plan to tackle the situation.

Keywords: DSSAT CERES-rice model; climate change; yield; sensitivity analysis; temperature; solar radiation; CO_2 concentration.

1. INTRODUCTION

Rice is the most important food for half of the world's population especially in Asia [1]. In India Rice occupies about 23.3% of gross cropped area of the country. Among the rice growing countries in the world, India stands first in rice area (44 million ha) and second in rice production (112.91 million metric tons) after China [2]. It contributes 21.5 per cent of global rice production. Uttar Pradesh is the fourth largest state in country. The state has almost 5.86-million-hectares of land under rice cultivation producing about 12.5 million tonnes of rice. The state ranks 3rd in the country in production of rice. In Prayagraj district, rice is produced in an area of 171824 hectare with a production of 370562 MT and productivity of 21.57 q/ha. [3].

As climate change deals with future issues, the use of Crop Simulation Models proves a more scientific approach to study the impact of climate change on agricultural production. The decision support system for agrotechnology transfer (DSSAT) was originally developed by an international network of scientists, cooperating in the International Benchmark Sites Network for Agrotechnology Transfer project [4-7], to facilitate the application of crop models in a systems approach to agronomic research. DSSAT models simulate growth, development, and yield of crops as a function of soil-plant-atmosphere-management dynamics. The CERES-Rice model of the DSSAT modeling system is an advanced physiologically based rice crop growth simulation model and has been widely applied to understanding the relationship between rice and its environment [8] and [9] have provided a detailed description of the model. The model uses a detailed set of crop specific genetic coefficients, which allows the model to respond to diverse weather and management conditions [10].

Weather plays an important role in agricultural production. It has a profound influence on crop growth, development and yields. Weather factors contribute to optimal crop growth, development and yield. Climate is the primary determinant of agricultural productivity [11]. Changes in temperature, CO_2, and precipitation under the scenarios of climate change for the next 30 years present a challenge to crop production. Understanding these implications for agricultural crops is critical for developing cropping systems resilient to stresses induced by climate change [12]. The optimum temperature for rice cultivation is between 25°C and 35°C. Any further increase in mean temperatures during sensitive stages may reduce rice yields drastically. In tropical regions, the temperature increase due to the climate change is probably near or above the optimum temperature range for the physiological activities of rice [13]. In temperate regions, rice growth is impressed by limited period that favours its growth [14]. Increasing trend of daily maximum temperature may decrease the rice spikelet fertility, which can cause reduction of the yield while the increasing trend of atmospheric CO_2 concentration could increase the rice yield [15]. High temperatures would induce sterility and lead to low harvest index and grain yield.

2. MATERIALS AND METHODS

Prayagraj is taken as the representative experimental site in Uttar Pradesh. The experiment was carried out at College of Forestry farm, Sam Higginbottom University of Agriculture, Technology and Sciences, Naini, Prayagraj. It is situated at 25.4358° N latitude, 81.8463° E longitude and at an altitude of 98 m (322 ft) above mean sea level.

2.1 Weather Data

For the study the daily weather parameters like Tmax, Tmin, Solar radiation and Rainfall were collected from Meteorological unit, Department of Environmental Sciences and NRM, College of Forestry, SHUATS, Naini, Prayagraj from 1st January 2012 – 1st January 2020.

2.2 Soil Data

Soil data Layer wise (0 – 120 cm) data of soil physical and chemical properties which includes Bulk density, Hydraulic conductivity, organic carbon content, clay and silt content etc. of Prayagraj district was collected from India Meteorological Department, New Delhi.

2.3 Crop Management Data

Crop management data which is required for DSSAT input from 2012-2019 taken from College of Forestry, SHUATS, of four rice varieties. The data was used first calibration and then validation of the model. Planting date of the rice crop was 2nd June for all the four cultivars.

2.4 Cultivars

In this study there were four cultivars used i.e. Swarna sub 1, Sarjoo-52, Pant dhan 4 and NDR-359). The genetic coefficients of Cultivars were taken from India Meteorological Department, New Delhi, then again, they were calibrated for Prayagraj condition via trial-and-error method, which is presented in the Table 1.

To efficiently study the effect of weather parameters on rice crop, the whole duration of rice crop is divided in to four phases as listed below. By applying phase wise in environmental modification, the difference can be seen and analysed.

Phase 1 : Germination – Transplanting
Phase 2 : Transplanting – Panicle initiation
Phase 3 : Panicle initiation – Flowering (Anthesis duration)
Phase 4 : Flowering – Maturity (Maturity duration)

2.5 Calibration and Validation of the Model

Model calibration is the adjustment of parameters, so that simulated values compare well with observed values. Before models can be applied with confidence, they need to be calibrated and validated for the varieties and environment of interest. Validation is determined by statistical analysis. It is used to check the accuracy of the model. Statistical based criteria provide a more objective method for evaluation of the performance of the models [16]. Here in this study only crop yield data is used for validation of the model. For the validation of the model Percent Error, RMSE, nRMSE and r were calculated.

2.6 Significance Test

The Pearson correlation is the most widely used correlation statistic and linear regression analysis used to measure the degree of the relationship between linearly related variables which is widely used in climate research, will be employed in this study to find out significance level of 0.05 and 0.01 (indicates 5% and 1% risk respectively) trends with the help of IBM SPSS statistics package.

2.7 Sensitivity of Field to Changing Climate

During the growing season, the mean temperature, the maximum and minimum temperature, rainfall distribution pattern, and diurnal changes, or a combination of these, may be highly correlated with grain yields [17,18] state that temperature affects the duration of crop growth and consequently the time during which incident radiation can be intercepted and transformed to dry matter. Effects of increase in temperature, solar radiation and CO_2 concentration on rice yield and other parameters assessed by increasing the maximum, minimum and average temperature by +1, +2, +3, +4, +5 °C, solar radiation by +1.0, +1.5, +2.0, +2.5, +3.0 MJ/day and CO_2 concentration by +20, +40, +60, +80, +100 ppm respectively.

Table 1. Genetic coefficient of four varieties used in DSSAT

Cultivar	P1	P2R	P5	P2O	G1	G2	G3	G4
SWARNA SUB 1	750.0	150.0	400.0	11.3	59.0	0.0220	1.00	1.00
SARJOO - 52	450.0	170.0	365.0	12.2	47.0	0.0238	1.00	1.00
PANT DHAN 4	830.0	160.0	300.0	11.4	45.0	0.0300	1.00	1.00
NDR 359	500.0	200.0	450.0	12.5	62.0	0.0190	1.00	1.00

3. RESULTS

3.1 Calibration and Validation of Model

Calibration of model is done for 2 years 2012 and 2013 and model is validated from 2014 to 2019 for the cultivar to check the accuracy of model under Prayagraj condition. The actual and simulated yield data from the year of 2012 – 2019 for all the four varieties are given below in the table 2. The percent error, root mean square error, normalized root mean square error and Pearson correlation coefficient for the year (2012-2019) show that simulated yield values were in good agreement with the observed yield values. Average percent error, RMSE, nRMSE and r value are 3.29, 183.78, 3.62, 0.828 and 9.08, 431.24, 9.75, 0.542 respectively, for Swarna sub 1 and Sarjoo-52 variety. For Pant dhan 4 and NDR 359 rice cultivar average percent error, RMSE, nRMSE and r value are 4.29, 238.14, 4.61, 0.778 and 5.52, 338.96, 5.84, 0.71 respectively, which shows that model is suited well for these variety under Prayagraj condition.

3.2 Impact of Changing Weather on Various Growth Phases

3.2.1 Sensitivity of rice yield to changing weather

The average yield data of 8 years for four rice crop varieties with changing maximum temperature, average temperature, minimum temperature, solar radiation and CO_2 conc. for four phenophases under Prayagraj condition presented in Table 3. The Table 3 shows decreasing trend of yield with increasing in temperature for all varieties. In case of increase in solar radiation and CO_2 conc. the Table 3 shows increasing trend of yield for all varieties and phenophases. Maximum yield reduced during germination – transplanting stage followed by transplanting to panicle initiation stage for all the four variety. Among all the cultivars NDR-359 yield was reduced to -29.44% followed by Swarna sub 1 (-19.41%), Pant dhan 4 (-14.95%) and Sarjoo-52 (-13.44%). When minimum temperature increased, the rice yield was decreased to - 4.52% in case of Pant dhan 4 followed by Sarjoo 52 (-3.96%), NDR 359 (-3.15%) and Swarna sub 1 (-1.45%). In case of increased in average temperature the yield of NDR 359 cultivar got reduced to - 41.38% followed by Sarjoo-52 (-26.55%), Pant dhan 4 (-19.49%) and Swarn sub 1 (-14.37%). Increased in solar radiation, the crop yield got increased. Among all cultivar Sarjoo-52 it was (15.39%), Pant dhan 4 (11.12%), Swarna sub 1 (11.09%) and NDR 359 (3.05%). Increased in CO_2 concentration, the crop yield of Sarjoo 52 (8.49%), NDR 359 (7.46%), Pant dhan 4 (7.26%) and Swarna sub 1 (7.19%) got increased.

3.2.2 Sensitivity of Leaf Area Index (LAI) to changing weather

For all the four phases of crop, the leaf area index for rice varieties with changing maximum temperature, average temperature, minimum temperature, solar radiation and CO_2 under Prayagraj condition presented in Table 4. Table 4 shows decreasing trend of LAI with increasing trend of maximum, average andminimum temperature for all varieties. There was increasing trend of LAI with increasing solar radiation and CO_2 for all varieties. For the last phase of crop growth (Flowering - Maturity), there was no increase / decrease of leaf area index as we change all the weather parameters (T max, T avg, T min, SRAD and CO_2 conc.). Maximum LAI reduced during germination – transplanting stage for all the four variety. Among all the cultivars NDR-359, LAI was reduced to -29.88% followed by Sarjoo-52 (-18.13%), Pant dhan 4 (-14.07%) and Swarna sub 1 (-13.75%). When minimum temperature increased, the rice crop LAI was decreased i.e., -7.02% in case of Swarna sub 1 followed by Sarjoo 52 (-6.29%), NDR 359 (-2.62%) and Pant dhan 4 (-2.38%). In case of increased in average temperature the LAI of NDR 359 got reduced to -52.49% followed by Sarjoo-52 (-46.07%), Pant dhan 4 (-42.11%) and Swarn sub 1 (-41.15%). Increased in solar radiation, the LAI got increased. Among all cultivar Sarjoo-52 it was (10.04%), Swarna sub 1 (3.86%), NDR 359 (2.98%) and Pant dhan 4 (2.20%). Increased in CO_2 concentration, the LAI of Sarjoo 52 (4.81%), Swarna sub 1 (1.88%), Pant dhan 4 (1.56%) and NDR 359 (1.55%) got increased.

3.2.3 Sensitivity of anthesis days to changing weather

Table 5 shows the variation in anthesis days due to effect of increase in all the weather parameters (T max, T avg, T min, SRAD and CO_2 conc.) on four rice varieties (Swarna sub-1, Sarjoo-52, Pant dhan-4, NDR 359). All the varieties showed increase in Anthesis days as increase in maximum and average temperature during Germination – flowering stage of crop. For the period of Flowering to Maturity, there was no increase / decrease of Anthesis days as we changed all the weather parameters (T max, T min, SRAD and CO_2 conc.). As it is the last stage there was no more effect of weather parameters on anthesis duration. There is no effect of (T min, SRAD and CO_2conc.) on anthesis days. In case of increased in maximum temperature the anthesis days of NDR 359 got increased to (45.45%) followed by Swarn sub 1 (19.75%), Pant dhan 4 (16.53%) and Sarjoo-52 (15.88%). Increased in average temperature, the anthesis days also got increased. Among all the cultivar, in case of NDR 359 it was (45.45%), Swarna sub 1 (29.49%), Pant dhan 4 (26.09%) and Sarjoo-52 (18.66%).

3.2.4 Sensitivity of maturity days to changing weather

The maturity days of four rice crop varieties with changing maximum temperature and average temperature from (1.0 -5.0°c) under Prayagraj condition presented in Table 6. Table 6 shows increasing trend of maturity days with increasing in Tmax and Tavg for all varieties and phenophases. There is no effect of changing (T min, SRAD and CO_2 conc.) on maturity days. Among all the cultivars maturity days of NDR-359 was increased to 35.54% followed by Pant dhan 4 (14.67%), Swarna sub 1 (13.87%) and Sarjoo-52 (13.55%). In case of average temperature increased, the rice maturity days were also increased i.e 39.87% for NDR 359 followed by Swarna sub 1 (20.12%), Sarjoo-52 (19.08%) and Pant dhan 4 (18.29%).

4. DISCUSSION

This section describes the overall analysis of four rice cultivars (Swarna sub-1, Sarjoo-52, Pant dhan 4 and NDR 359) with the phenophases under Prayagraj condition. Calibration and validation of DSSAT CERES – rice model for grain yield was done for all four cultivars. By comparing observed grain yield with simulated yield, the result concluded that all the values were in acceptable range of less than 15% for percent error, in excellent range of less than 10% for normalized root mean square error and Pearson correlation coefficient value is also nearer to 1. Thus, the DSSAT rice crop model can be successfully used for simulating growth and yield of all the four rice varieties for Prayagraj condition. Among all the four varieties NDR 359 yields more followed by pant dhan 4, Swarna sub 1 and sarjoo-52 for Prayagraj condition.

Weather condition affected crop production both directly and indirectly. Temperature is considered to be one of the dominant factors that affect the growth and yield of rice. the impact of climate change on high yield rice varieties was studied by Karim et al. [19] using the CERES rice model and several scenarios and sensitivity analysis. They found that high temperatures reduced rice yields in all seasons in most arid locations. Increased CO_2 levels increased rice yields and reduction of rice yields due to high temperature in all season was observed by Karim et al., [19]. This study showed that increasing temperature resulted decreasing yield. To know the effect, whole crop growth period was divided into four stages. Each stage showed that decreasing yield with increasing temperature. For increasing maximum temperature resulted decreasing yield. For the varieties of Sarjoo-52 and Pant dhan 4 the yield was more during panicle initiation – flowering (Anthesis) period. The yield is more during maturity period for the varieties Swarna sub 1 and NDR 359. Increasing minimum temperature results in decreasing yield. In case of the crop growth period, with the effect of minimum temperature the yield was more in maturity period followed by panicle initiation – flowering, transplanting- panicle initiation and germination to transplanting stage for all the varieties. The results of solar radiation and CO_2 concentration were opposite as compared with temperature. As the solar radiation increased simultaneously the yield of all four varieties also increased. For the variety of Pant dhan 4 and NDR 359 Transplanting – panicle initiation stage yields more and for Swarna sub 1 and sarjoo-52 germination – transplanting stage yields more. Hendrey and Kimball [20] reported that higher CO_2 concentration increases growth and yield, mainly through their effect on the photosynthetic processes of the crop. Increased CO_2 concentrations and decreased temperature increased growth duration and yield, while increased temperature shortened growth duration and reduced yield. Increasing the CO_2 concentration by 100 ppm and 400 ppm from the standard CO_2 concentration of 380 ppm led to 16.8% and 54.2% increase in grain yield, respectively [21]. According to Hunsaker et al. [22] high carbon dioxide concentrations increase water use efficiency which has a major effect on yield. The yield increases with increasing CO_2 concentration. Germination – transplanting stage yields more followed by transplanting – panicle initiation, anthesis duration than maturity period for all the four varieties. When we analyse the yield data with changing weather for stage wise growth of crop with SPSS software for significance test, the result presented in the Table 7 showed all the data are significant.

Leaf area index is the projected area of leaves over a unit of land. Changing weather directly or indirectly effect the leaf area index which ultimately effect yield. The crop period was divided into four phases the flowering – maturity period, has no changes in leaf area index with changing temperature, solar radiation and CO_2 concentration etc. Leaf area index decreased with increase of maximum temperature. Maximum leaf area index was found in panicle initiation – flowering duration followed by transplanting – panicle initiation then germination – transplanting for all four varieties. Among all the varieties NDR-359 has more leaf area index followed by pant dhan 4, Swarna sub 1 and Sarjoo-52. For increase in average temperature the leaf area index goes on decreasing. Among the crop periods Panicle initiation – flowering stage has more leaf area index compare to all other stages. Leaf area index decreases with the increase of minimum temperature. For the variety of Swarna sub 1 leaf area index was more during Germination – transplanting duration and for other three varieties during the period of Panicle initiation – flowering the leaf area index was more. Increasing solar radiation results increase in leaf area index. Pant dhan 4 and NDR 359 variety showed high leaf area index during panicle initiation – flowering stage. Van Keulen [23] using a simulation model predicted that an increase of 20% in total global radiation resulted in 10–20% increase in grain yield of rice. In a simulation study on the effect of solar radiation on growth of wheat and rice, it was revealed that the maximum Leaf Area Index was reduced by 7.6% in wheat and 5.9% in rice when the solar radiation was decreased by 10.0% from normal. On the other hand, with increase in radiation by 10%, LAI increased in wheat by 7.1% Hundal and Kaur [24]. As per the analysis it showed that leaf area index value increases as CO_2 concentration increases. Pant dhan 4 and NDR 359 variety have more leaf area index during panicle initiation – flowering stage and Sarjoo-52 have more leaf area index during germination – transplanting period. By analysing the data of Leaf area index with changing weather for stage wise growth of crop using SPSS software for significance test, the results are presented in the Table 8. It showed all the data were significant and r value is nearly equal to 1. The stage of flowering – maturity has no changes in the value of leaf area index with changing weather [25-27].

Anthesis days are very crucial period for crop growth. Changing temperature has effect on anthesis days but there is no effect of solar radiation and CO_2concentration on this. During the period of flowering – maturity there was not seen any changes regarding anthesis days. As the maximum temperature increases the anthesis day time period also increases. On the view of crop growth period there were high anthesis days seen in germination – transplanting followed by transplanting – panicle initiation and panicle initiation – flowering. For the variety of Swarna sub 1 and Pant dhan 4 high anthesis days were found during Transplanting – Panicle initiation, for NDR 359 panicle initiation – Flowering and during Germination – Transplanting phase Sarjoo-52 variety found high anthesis days value. The data of Anthesis days with changing weather were analysed for stage wise growth of crop with SPSS software for significance test, the results are presented in the Table 9. It showed all the data were significant and r value are nearly equal to 1. The stage of flowering – maturity has no changes in the value of Anthesis days with changing weather. Except temperature all other weather parameters have no effect on anthesis days of a crop.

Maturity days come under last stage in which crop gets mature. There is no effect of solar radiation and CO_2 concentration on maturity days of a crop. Only factor is as the temperature increases maturity days also get increase. For the period of Panicle initiation – flowering NDR 359 variety has high maturity days. Likewise, as average temperature increases it results in increasing maturity days. The variety Swarna sub 1 and Sarjoo-52 showed high maturity days value during germination – transplanting. For the duration of Panicle initiation – flowering and Transplanting – Panicle initiation NDR 359 and Pant dhan 4 has high maturity value respectively. The data of maturity days with changing weather were analysed for stage wise growth of crop with SPSS software for significance test, the results are presented in the Table 10. It showed all the data were significant and r value is nearly equal to 1. Except temperature (maximum and average) all other weather parameters has no effect on maturity days of a crop.

Table 2. Comparison of cultivars observed value with simulated value of grain yield for the year 2012 – 2019

Year	Swarna Sub 1			Sarjoo-52			Pant Dhan-4			NDR- 359		
	Actual Yield (kg/ha)	Simulated Yield (kg/ha)	Percent Error %	Actual Yield (kg/ha)	Simulated Yield (kg/ha)	Percent Error %	Actual Yield (kg/ha)	Simulated Yield (kg/ha)	Percent Error %	Actual Yield (kg/ha)	Simulated Yield (kg/ha)	Percent Error %
2012	5118	5023	1.85	4796	4688	2.25	5349	5060	5.40	5725	5558	2.91
2013	5371	5209	3.01	4635	5111	10.26	5283	5454	3.23	6238	6530	4.68
2014	5246	5552	5.83	4581	5196	13.42	5472	5636	2.99	6021	6545	8.70
2015	5460	5236	4.10	4093	4644	13.46	5016	5393	7.51	6107	5726	6.23
2016	5127	5310	3.56	4412	4939	11.94	5164	5395	4.47	5514	5847	6.03
2017	4813	4930	2.43	4257	4649	9.20	4837	4902	1.34	5397	5110	5.31
2018	4941	5139	4.00	4329	4584	5.89	5320	5505	3.47	6202	5815	6.23
2019	4432	4501	1.55	4264	4531	6.26	4798	4515	5.89	5156	5364	4.03
Average	5063.5	5112.5	3.29	4420.87	4792.75	9.08	5154.87	5232.5	4.29	5795	5811.87	5.52
RMSE	183.78			431.24			238.14			338.96		
nRMSE	3.62			9.75			4.61			5.84		
r	0.828			0.542			0.778			0.71		

NOTE: RMSE=(Root Mean Square Error), nRMSE =(Normalised Root Mean Square Error) and r =(Pearson correlation coefficient)

Table 3. Effect of changing weather parameters on yield (percentage basis) of four rice cultivars for four phenophases

		Germination – Transplanting				Transplanting – Panicle initiation				Panicle initiation – Flowering				Flowering – Maturity			
		Swarna Sub 1	**Sarjoo-52**	**Pant Dhan-4**	**NDR-359**	**Swarna Sub 1**	**Sarjoo-52**	**Pant Dhan-4**	**NDR-359**	**Swarna Sub 1**	**Sarjoo-52**	**Pant Dhan-4**	**NDR-359**	**Swarna Sub 1**	**Sarjoo-52**	**Pant Dhan-4**	**NDR-359**
CTRL	kg/ha	5112.5	4792.75	5232.5	5811.87	5112.5	4792.75	5232.5	5811.87	5112.5	4792.75	5232.5	5811.87	5112.5	4792.75	5232.5	5811.87
Tmax	+1	-0.23	0.04	-0.38	-5.51	-0.40	0.05	-0.40	-5.69	0.86	0.79	0.91	0.43	0.02	-0.07	-0.48	-1.19
	+2	-1.57	1.65	0.15	-7.85	-0.63	0.96	1.38	-10.01	-0.02	-0.07	0.27	-0.18	-0.53	-0.71	-0.73	-2.55
	+3	-4.91	-1.32	-1.26	-7.03	-4.00	-1.08	-3.24	-11.32	-0.13	-0.65	-0.28	-0.50	-1.04	-1.17	-1.39	-3.00
	+4	-11.98	-6.36	-6.84	-16.43	-8.04	-4.37	-6.63	-14.24	-1.41	-1.14	-1.02	-0.60	-1.33	-1.94	-1.03	-4.51
	+5	-19.41	-13.44	-14.95	-29.44	-11.30	-8.40	-10.65	-23.34	-2.94	-1.38	-1.80	-1.17	-2.42	-2.67	-2.04	-5.63
Tmin	+1	-0.77	-2.22	-2.36	-1.31	-0.52	-2.19	-2.30	-1.38	-0.22	-0.56	-1.08	-1.77	-0.11	-0.07	-0.62	-0.36
	+2	-1.45	-3.95	-4.52	-2.81	-1.07	-3.96	-4.31	-3.15	-0.51	-1.17	-1.87	-1.90	-0.13	-0.19	-0.99	-0.43
	+3	-	-	-	-	-	-	-	-	-0.97	-1.50	-2.39	-3.05	-0.20	-0.23	-1.44	-0.98
Tavg	+1	-2.07	-2.71	-1.38	-6.64	-1.87	-1.73	-1.48	-6.30	-0.87	-0.51	-0.15	-2.66	0.05	-0.82	-0.04	-0.97
	+2	-4.67	-3.51	-2.37	-6.73	-3.64	-1.85	-0.80	-12.27	-1.65	-1.26	-0.30	-5.85	-1.19	-1.26	-0.92	-2.05
	+3	-11.00	-8.09	-7.38	-16.59	-9.49	-3.68	-5.77	-11.87	-1.86	-1.82	-0.80	-7.10	-1.95	-2.38	-2.74	-3.60
	+4	-4.34	-20.60	-12.40	-27.80	-4.94	-12.84	-11.91	-21.90	-4.90	-2.28	-2.12	-8.50	-3.40	-3.81	-3.51	-3.91
	+5	-14.37	-26.55	-18.17	-41.38	-13.79	-24.63	-19.49	-35.32	-8.03	-2.94	-7.36	-10.07	-5.41	-5.81	-5.16	-4.93
SRAD	+1.0	3.33	5.80	3.46	1.83	3.48	5.64	3.86	1.89	1.68	2.39	2.57	0.20	0.43	0.04	0.24	-0.86
	+1.5	5.68	9.19	5.93	1.51	5.15	8.24	5.96	2.77	3.08	3.69	3.84	0.22	0.66	0.24	0.38	-1.21
	+2.0	7.25	10.86	7.57	1.48	7.10	10.92	8.24	3.30	4.19	5.05	5.09	0.32	0.92	0.44	0.53	-1.41
	+2.5	8.72	12.92	9.86	3.33	8.35	12.88	9.92	4.17	5.58	5.84	5.98	0.37	1.20	0.47	0.70	-1.78
	+3.0	11.09	15.39	11.12	3.05	9.50	14.57	10.63	3.36	6.56	7.14	7.24	1.12	1.44	0.62	0.85	-2.00
CO_2	+20	1.31	1.75	1.28	1.43	1.63	1.63	1.26	1.35	0.78	0.85	0.85	0.77	0.04	0.04	0.07	0.06
	+40	2.62	3.42	2.74	3.45	2.94	3.23	2.68	2.76	1.55	1.73	1.70	1.49	0.09	0.09	0.15	0.11
	+60	3.98	5.20	4.14	4.76	4.23	4.90	4.06	4.09	2.29	1.87	2.55	1.44	0.13	0.14	0.22	0.16
	+80	5.49	6.71	5.67	5.68	5.71	6.61	5.78	5.07	3.16	3.51	3.48	3.13	0.18	0.19	0.30	0.23
	+100	6.71	8.49	7.18	6.99	7.19	8.24	7.26	7.46	4.03	4.46	2.25	4.05	0.23	0.14	0.38	0.28

Note: Unit - SRAD (Solar radiation) in MJ/day, Maximum (Tmax), minimum (Tmin) and average temperature (Tavg) in °C and CO_2 concentration in ppm.

Table 4. Matrix of changing weather parameters on LAI (percentage basis) of four rice cultivars for the phenophases

		Germination – Transplanting				Transplanting – Panicle initiation				Panicle initiation – Flowering			
		Swarna Sub 1	Sarjoo-52	Pant Dhan-4	NDR-359	Swarna Sub 1	Sarjoo-52	Pant Dhan-4	NDR-359	Swarna Sub 1	Sarjoo-52	Pant Dhan-4	NDR-359
CTRL		5.06	4.06	5.83	6.79	5.06	4.06	5.84	6.79	5.06	4.06	5.84	6.79
Tmax	+1	-1.58	-1.36	-1.60	-2.40	-1.58	-1.68	-2.38	-1.86	-1.29	-0.44	-1.52	-1.08
	+2	0.40	-2.59	-3.31	-5.35	-0.85	-1.36	-3.23	-5.91	-2.04	-0.35	-3.13	-1.96
	+3	-2.47	-6.04	-4.60	-13.27	-1.84	-5.38	-5.60	-11.24	-3.15	-0.44	-4.52	-2.70
	+4	-5.84	-11.22	-8.06	-20.89	-4.55	-8.14	-6.02	-18.61	-5.04	-1.23	-5.37	-3.19
	+5	-13.75	-18.13	-14.07	-29.88	-12.23	-14.62	-6.88	-25.06	-6.63	-3.16	-6.57	-3.75
Tmin	+1	-0.69	-1.36	-0.51	-1.00	-1.09	-1.11	-0.66	-1.00	-0.69	-0.62	-0.46	-0.31
	+2	-1.48	-2.10	-1.03	-1.74	-1.48	-2.84	-1.35	-1.44	-3.07	-1.11	-1.04	-0.52
	+3	-3.07	-5.06	-2.23	-2.62	-3.07	-6.29	-2.38	-2.33	-7.02	-2.34	-2.03	-0.71
Tavg	+1	-2.57	-3.53	-2.66	-2.40	-3.32	-4.14	-2.80	-2.96	-2.45	-1.16	-2.03	-1.56
	+2	-5.30	-7.84	-6.30	-10.14	-4.55	-5.67	-6.23	-8.85	-3.34	-2.02	-4.26	-2.33
	+3	-9.75	-16.47	-11.23	-22.29	-9.50	-12.77	-11.16	-19.71	-5.88	-3.30	-6.57	-3.31
	+4	-22.12	-29.10	-23.89	-36.28	-20.38	-22.32	-20.36	-30.58	-9.08	-6.14	-8.40	-4.02
	+5	-41.15	-46.07	-42.11	-52.49	-36.46	-38.35	-36.85	-44.61	-12.07	-10.46	-10.90	-4.66
SRAD	+1.0	0.89	3.87	0.17	0.18	0.40	3.58	-0.49	-0.38	0.91	1.53	1.02	0.80
	+1.5	2.37	6.34	0.34	-0.56	1.13	5.43	-0.83	-1.49	1.29	2.02	1.44	1.44
	+2.0	2.67	7.89	0.51	-1.15	1.13	7.89	-1.69	-1.86	1.54	2.86	1.77	0.69
	+2.5	3.11	9.12	0.51	-2.47	1.38	8.20	-2.20	-2.03	2.27	3.45	1.91	2.61
	+3.0	3.86	10.04	0.77	-2.33	2.37	9.12	-2.55	-2.77	2.81	4.07	2.20	2.98
CO_2	+20	0.10	1.11	0.34	-1.00	0.30	0.79	0.02	-0.38	0.45	0.57	0.23	0.18
	+40	0.30	2.34	0.51	-1.30	0.69	2.34	0.54	-0.38	0.71	1.13	0.62	0.35
	+60	0.49	3.08	0.56	-1.59	0.69	2.96	0.36	-1.12	0.91	1.41	1.05	0.47
	+80	0.69	3.82	0.77	-1.74	1.29	3.58	0.71	-1.30	1.11	2.00	1.39	1.18
	+100	1.09	4.81	1.03	-2.03	1.88	3.87	1.22	-2.40	1.40	2.64	1.56	1.55

Note: Unit - SRAD (Solar radiation) in MJ/day, Maximum (Tmax), minimum (Tmin) and average temperature (Tavg) in °C and CO_2 concentration in ppm

Table 5. Model output of maximum and average temperature on anthesis days (percentage basis) of four rice cultivars for the phenophases

		Germination – Transplanting				Transplanting – Panicle initiation				Panicle initiation – Flowering			
		Swarna Sub 1	**Sarjoo-52**	**Pant Dhan-4**	**NDR-359**	**Swarna Sub 1**	**Sarjoo-52**	**Pant Dhan-4**	**NDR-359**	**Swarna Sub 1**	**Sarjoo-52**	**Pant Dhan-4**	**NDR-359**
CTRL		98.75	89.75	105.87	124.87	98.75	89.75	105.87	124.87	98.75	89.75	105.87	124.87
Tmax	+1	1.39	2.09	1.65	1.70	1.27	1.39	1.18	1.30	0.38	0.70	0.47	0.20
	+2	4.94	5.43	4.60	6.41	4.18	3.90	4.01	5.71	1.14	2.09	1.42	1.10
	+3	8.35	8.50	8.03	9.41	7.09	7.10	7.20	8.01	2.66	3.06	2.60	15.32
	+4	12.41	12.26	11.81	11.91	10.63	10.45	5.55	9.71	3.42	4.46	4.60	37.34
	+5	19.75	15.88	16.53	14.01	14.30	13.37	6.02	11.71	4.81	5.57	7.44	45.45
Tavg	+1	1.90	1.81	1.65	1.50	1.27	1.39	1.18	1.20	0.25	0.70	0.47	0.20
	+2	5.70	5.57	4.60	6.21	4.81	4.74	4.49	4.60	1.39	2.23	1.42	1.10
	+3	10.51	10.58	8.03	10.21	8.73	9.05	8.50	9.41	3.04	3.62	2.60	15.32
	+4	17.34	15.88	11.81	11.90	14.18	13.79	14.99	13.91	4.68	5.71	4.60	37.34
	+5	21.77	22.28	16.53	13.41	29.49	18.66	26.09	17.92	7.34	8.77	6.97	45.45

Table 6. Model output of maximum and average temperature on Maturity days (percentage basis) of four rice cultivars for the phenophases

		Germination – Transplanting				Transplanting – Panicle initiation				Panicle initiation – Flowering				Flowering – Maturity			
		Swarna Sub 1	**Sarjoo-52**	**Pant Dhan-4**	**NDR-359**	**Swarna Sub 1**	**Sarjoo-52**	**Pant Dhan-4**	**NDR-359**	**Swarna Sub 1**	**Sarjoo-52**	**Pant Dhan-4**	**NDR-359**	**Swarna Sub 1**	**Sarjoo-52**	**Pant Dhan-4**	**NDR-359**
CTRL		128	124.5	131.25	152.37	128	124.5	131.25	152.37	128	124.5	131.25	152.37	128	124.5	131.25	152.37
Tmax	+1	1.66	1.81	1.90	1.15	1.37	1.41	1.52	0.90	0.68	1.00	0.95	0.33	0.29	0.50	0.38	0.06
	+2	4.30	4.72	4.67	5.41	3.52	3.84	4.38	3.88	1.86	2.71	2.19	0.90	0.67	1.00	0.95	0.23
	+3	7.32	7.53	7.90	7.30	6.15	6.53	6.67	9.02	3.13	4.52	3.94	1.97	0.98	1.71	1.24	0.49
	+4	10.45	10.54	10.69	9.43	8.98	9.34	6.95	10.66	4.39	5.84	4.10	33.01	1.46	2.21	1.71	0.66
	+5	13.87	13.55	14.67	10.99	13.28	12.35	7.14	11.80	5.86	7.97	6.19	34.54	1.76	2.91	1.90	0.82
Tavg	+1	1.27	1.51	1.81	0.90	0.78	1.20	1.43	0.49	0.39	0.80	0.76	0.33	0.29	0.10	0.57	0.13
	+2	4.40	4.72	4.67	4.68	3.71	4.22	4.63	3.97	1.76	2.71	2.19	1.48	0.59	1.00	1.05	0.22
	+3	8.59	8.84	7.82	7.43	7.32	7.83	7.71	6.56	3.81	4.92	3.90	12.31	1.17	1.91	1.33	0.32
	+4	14.45	13.45	10.97	8.29	13.38	12.15	12.67	8.45	5.76	6.12	5.90	32.32	1.86	3.11	1.90	0.34
	+5	20.12	19.08	14.86	11.38	19.12	20.08	18.29	11.14	8.40	11.13	8.00	39.87	2.71	4.42	2.38	0.36

Note: Unit - SRAD (Solar radiation) in MJ/day, Maximum (Tmax), minimum (Tmin) and average temperature (Tavg) in °c and CO_2 concentration in ppm.

Table 7. Relationship between weather variables and grain yields for all the phonological stages at Prayagraj

Weather variables	Correlation coefficient (r)															
	Germination – Transplanting				Transplanting – Panicle initiation				Panicle initiation – Flowering				Flowering – Maturity			
	Swarna Sub 1	Sarjoo-52	Pant Dhan-4	NDR-359	Swarna Sub 1	Sarjoo-52	Pant Dhan-4	NDR-359	Swarna Sub 1	Sarjoo-52	Pant Dhan-4	NDR-359	Swarna Sub 1	Sarjoo-52	Pant Dhan-4	NDR-359
Tmax	-0.928**	-0.838*	-0.847*	-0.916*	-0.944**	-0.854*	-0.888*	-0.971**	-0.853*	-0.879*	-0.850*	-0.899**	-0.959**	-0.981**	-0.935**	-0.995**
Tavg	-0.999*	-0.997*	-1.00*	-0.999*	-1.00*	-0.998*	-0.999*	-0.997*	-0.986*	-0.993**	-0.988*	-0.952*	-0.968*	-0.982*	-0.994**	-0.960*
Tmin	-0.827*	-0.944**	-0.963**	-0.962**	-0.875*	-0.884*	-0.925**	-0.956**	-0.929**	-0.998**	-0.814*	-0.983**	-0.963**	-0.972**	-0.973**	-0.990**
SRAD	0.998**	0.994**	0.998**	0.898*	0.997**	0.996**	0.993**	0.923**	0.996**	0.999**	0.999**	0.828*	0.999**	0.962**	0.998**	-0.992**
CO_2	1.00**	1.00**	1.00**	0.993**	0.999**	1.00**	0.999**	0.993**	1.00**	0.982**	0.858*	0.968**	1.00**	0.918**	1.00**	0.999**

(= 5% level of significance and** = 1% level of significance)*

Table 8. Relationship between weather variables and leaf area index for the phonological stages at Prayagraj

Weather variables	Correlation coefficient (r)											
	Germination – Transplanting				Transplanting – Panicle initiation				Panicle initiation – Flowering			
	Swarna Sub 1	Sarjoo-52	Pant Dhan-4	NDR- 359	Swarna Sub 1	Sarjoo-52	Pant Dhan-4	NDR- 359	Swarna Sub 1	Sarjoo-52	Pant Dhan-4	NDR- 359
Tmax	-0.844*	-0.949**	-0.952**	-0.975**	-0.8348	-0.936**	-0.979**	- 0.982**	-0.991**	-0.837*	-0.995**	-0.989**
Tavg	- 0.973*	-0.957*	-0.974*	-0.999**	-0.973*	-0.964*	-0.988*	-0.992**	-0.951*	-0.969*	-0.984*	-0.983*
Tmin	-0.919**	-0.960**	-0.928**	-0.974**	-0.925**	-0.946**	0.940**	-0.977**	-0.989**	-0.947**	-0.999**	-0.990**
SRAD	0.986**	0.989**	0.985**	-0.888*	0.952**	0.981**	-0.969**	-0.964**	0.992**	0.998**	0.974**	0.894*
CO_2	0.990**	0.994**	0.962**	-0.952**	0.975**	0.970**	0.946**	-0.936**	0.984**	0.993**	0.993**	0.969**

(= 5% level of significance and ** = 1% level of significance)*

Table 9. Relationship between weather variables and anthesis days for the phonological stages at Prayagraj

Weather variables	Correlation coefficient (r)											
	Germination – Transplanting ANTHESIS				Transplanting – Panicle initiation				Panicle initiation – Flowering			
	Swarna Sub 1	Sarjoo-52	Pant Dhan-4	NDR-359	Swarna Sub 1	Sarjoo-52	Pant Dhan-4	NDR-359	Swarna Sub 1	Sarjoo-52	Pant Dhan-4	NDR-359
Tmax	0.976**	0.997**	0.989**	0.992**	0.991**	0.993**	0.870*	0.988**	0.978**	0.994**	0.980**	0.843*
Tavg	0.987**	0.986**	0.989**	0.982**	0.926**	0.987**	0.949**	0.988**	0.969**	0.977**	0.968**	0.932**
Tmin	-	-	-	-	-	-	-	-	-	-	-	-
SRAD	-	-	-	-	-	-	-	-	-	-	-	-
CO_2	-	-	-	-	-	-	-	-	-	-	-	-

(= 5% level of significance and ** = 1% level of significance)*

Table 10. Relationship between weather variables and maturity days for the phonological stages at Prayagraj

Weather variables	Correlation coefficient (r)															
	Germination – Transplanting				Transplanting – Panicle initiation				Panicle initiation – Flowering				Flowering – Maturity			
	Swarna Sub 1	Sarjoo-52	Pant Dhan-4	NDR-359	Swarna Sub 1	Sarjoo-52	Pant Dhan-4	NDR-359	Swarna Sub 1	Sarjoo-52	Pant Dhan-4	NDR-359	Swarna Sub 1	Sarjoo-52	Pant Dhan-4	NDR-359
Tmax	0.989**	0.994**	0.988**	0.991**	0.973**	0.989**	0.962**	0.981**	0.989**	0.991**	0.980**	0.843*	0.996**	0.994**	0.997**	0.988**
Tavg	0.978**	0.984**	0.995**	0.987**	0.970**	0.966**	0.980**	0.990**	0.978**	0.965**	0.989**	0.930**	0.978**	0.977**	0.997**	0.957**
Tmin	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SRAD	-	-	-	--	-	-	-	-	-	-	-	--	-	-	-	-
CO_2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

(= 5% level of significance and ** = 1% level of significance)*

5. CONCLUSION

The impact of climate change on rice yield, LAI, anthesis and maturity days for the four rice cultivars and for four phenophases has been analysed by using the DSSAT crop simulation model. The study undertaken could be concluded with the facts that weather changes affect the rice varieties yield and its attributes. Elevated temperature beyond the threshold adversely affects the growth and development of rice crops, which ultimately determines yield. As the temperature increased the yield and LAI decreased and as solar radiation and CO_2 concentration increased the yield and LAI increased. As temperature increases the anthesis and maturity days also get increased. There is no effect of solar radiation, CO_2 concentration and minimum temperature on anthesis and maturity days for four rice cultivars as taken. Model calibration and validation showed that all the four varieties (Swarna sub-1, Sarjoo-52, Pant dhan 4, NDR-359) were suitable for Prayagraj condition and NDR-359 was high yielding variety among all the four. The findings will help rice breeders to develop thermo-tolerant rice cultivars to cope with future climate change and obtain high yields for fulfil the demand of the rice-based community.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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