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Projection of Yield of Rice Crop over Prayagraj with Future Climatic Scenario

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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 purpose of this study was to evaluate the effects of climate change on productivity of rice cultivars Swarna sub-1, Sarjoo-52, Pant Dhan 4, and NDR-359 for the years 2030, 2050, 2070, and 2090 for the Prayagraj district of Uttar Pradesh using the Marksim and DSSAT crop simulation model under four different climate change scenarios, namely RCPs 2.6, 4.5, 6.0, and 8.5. The model evaluation indicated good performance with both calibration (PE=2.43,6.26,4.31,3.79, RMSE= 132.79, 345.13, 237.44, 237.85, nRMSE = 2.53, 7.31, 4.46, 3.97) and validation (PE =3.58, 10.03, 4.28, 6.09, RMSE = 197.88, 456.35, 238.37, 366.52, nRMSE = 3.95, 10.55, 4.67, 6.39) for Swarna sub-1, Sarjoo-52, Pant Dhan 4 and NDR-359 cultivars respectively, which showed good agreement between anticipated and observed values. For the Prayagraj region, NDR-359 yields the most among the four varieties, followed by Pant Dhan 4, Swarna Sub-1, and Sarjoo-52. By examining the future climate data that MarkSim's weather generator downloaded, it was noticed that all other weather variables, such as solar radiation, average maximum and minimum temperature

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increases while rainfall decreases. The findings of the study reveal that, among all projection scenarios, the grain yield is greater for RCP 2.6 and lowest for RCP 8.5. Analysis of the expected climate scenario data with yield revealed that the yield was higher in 2030 and lower in 2050. Additionally, it was observed that again in 2090 the yield gets increased for RCP 2.6 & decreased for RCP 4.5,6.0 & 8.5. Among all the four cultivars the yield of Sarjoo-52 will be reduced for RCP 4.5,6.0 & 8.5 for the year of 2050,2070 & 2090.These findings may offer insightful information about possible climate change effects on rice yield and suitable adaptive strategies to minimize the negative effects of future climate change.

Keywords: MarkSim; DSSAT CERES-Rice; RCPs; climate change; rice yield.

1. INTRODUCTION

Agriculture may be impacted by the effects of global climate change, such as variable rainfall, harsh weather, rising temperatures, notable fluctuations in solar radiation, and rising greenhouse gas emissions. Climate change is causing significant pressures for the entire planet. According to the sixth assessment report of IPCC, in the next 20 years, global warming is expected to reach or exceed 1.5 0 C above the 1800s [1]. The expected effect of climate change includes increase in temperature and uncertainties in rainfall.

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. Adams et al. [2]. Climate change and agriculture are interrelated processes, both of which take place on a global scale. Study on climate alone would appear surreal without realizing the value of science in climate simulations for which a quantitative assessment of climate’s impact is required [3].

The most significant food crop in the world is rice (*Oryza sativa* L.), which directly feeds more than 78% of the world's population, including nearly all of east and Southeast Asia. Asia produces 90% of the world's rice, which is farmed there in quantities of close to 640 million tones. India is the country with the largest area under rice cultivation (43.2 million ha) and the second largest producer of rice in the world. Using the population projections from the United Nations and income projections from the Food and Agricultural Policy Research Institute (FAPRI), global rice demand is estimated to rise from 439 million tons (milled rice) in 2010 to 496 million tons in 2020 and further increase to 555 million tons in 2035. This is an overall increase of 26% over the following 25 years, but as population growth slows and people diversify their diets away from rice, the pace of growth will fall from 13% during the first 10 years to 12% over the following 15 years.

In India, rice accounts for around 23.3% of the total area under cultivation. India is the world's leader in terms of rice output (112.91 million metric tones) and rice acreage (44 million ha) [4]. It makes up 21.5% of the world's rice 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 [5-8], to facilitate the application of crop models in a systems approach to agronomic research. The DSSAT modelling system's CERES-Rice model is a sophisticated physiologically based rice crop growth simulation model that has been extensively used to comprehend the interaction between rice and its environment. The model has been thoroughly described by Ritchie et al. [9] and Hoogenboom et al. [10]. The model employs a comprehensive set of crop-specific genetic coefficients, enabling the model to react to various environmental and management factors [11].

The effects of climate change on rice production have wide-ranging effects on food security across the country. Various studies evaluating the possible effects of climate change on crop production have used global circulation models and process-based crop models, such as CERES-Rice. To get around general circulation models' coarse resolution, MarkSim DSSAT Weather File Generator uses general circulation models to not only downscale but also produce daily weather [12]. The CERES-rice model was driven by the generated daily weather data that is typical of future climatic scenarios. Marksim's weather generator has been utilized in this instance to simulate how the climate would change in the future in terms of temperature, rainfall, and solar radiation. Representation

Concentration Pathways (RCP) data for Prayagraj were used for four future years, namely 2030, 2050, 2070 & 2090 which were used in Fifth Assessment Report of IPCC [13]. The Representative Concentration Pathways (RCP) scenarios are a result of the collaboration of various modelling groups, including climate modelers, integrated assessment modelers, terrestrial ecosystem modelers, and experts in emission inventories, and they produce an extensive data set with high spatial resolution for the time period extending up to 2100 [14,15]. Future climate will be forecasted by climate models, and crop models will simulate crop growth and production using other climate-predicted inputs such information on the properties of the soil, management techniques, and agronomic traits. Using a combination of the MarkSim daily weather generator and DSSAT-CERES-Rice to predict future rice production with various RCPs (RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5) for the years 2030, 2050, 2070, and 2090, the goal of this study was to evaluate climate change scenarios that have an impact on rice production in the Prayagraj region. The findings of this study can be used by farmers, researchers, and policymakers to identify the best methods for managing rice production in order to prepare for and adapt to future climate change.

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 located at 25.4358° N latitude, 81.8463° E longitude and at an altitude of 98 m (322 ft) above mean sea level. Daily meteorological elements including Tmax, Tmin, solar radiation, and rainfall were gathered for the study from Meteorological unit, Department of Environmental Sciences and NRM, College of Forestry, SHUATS, Naini, Prayagraj from 1st January 2012 – 1st January 2020. Information about the soil Layer-by-layer (0 to 120 cm) on the physical and chemical characteristics of the soil for the Prayagraj district, including its bulk density, hydraulic conductivity, organic carbon content, clay and silt content, etc., was collected from the India Meteorological Department, New Delhi. Crop management information for four varieties of rice that is needed for DSSAT input from 2012 to 2019 was obtained from College of Forestry, SHUATS. The model was calibrated using the data first, and then it was validated. The rice crop was planted on June 2nd for all four cultivars.

2.1 Cultivars

In this study there are four cultivars are used such as (Swarna sub-1, Sarjoo-52, Pant Dhan 4 & NDR-359). The genetic coefficients of Cultivars are calibrated for Prayagraj condition via trial and error method, which is presented in the Table 1.

2.2 Calibration and Validation of the Model

Model calibration is the process of changing parameters to ensure that simulated and observed data are closely comparable. Statistics are used to determine validation. It is employed to evaluate the model's precision. 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 and nRMSE was calculated.

$$\text{Percent Error} = \frac{|\mathrm{E} - \mathrm{T}|}{|\mathrm{T}|} \times 100$$

$$\text{RMSE} = \sqrt{\frac{1}{\mathrm{n}}\sum_{\mathrm{i=1}}^{\mathrm{n}}(\mathrm{O_i} - \mathrm{M_i})\text{^}2}$$

$$\text{nRMSE} = \sqrt{\frac{1}{\mathrm{n}}\sum_{\mathrm{i=1}}^{\mathrm{n}}(\mathrm{O_i} - \mathrm{M_i})\text{ ^}2} \times \frac{100}{\bar{\mathrm{O}}}$$

M_i: model output & O_i: observations value
$\bar{O}$: mean of the observations.
E= Experimental value and T= Theoretical value

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	0.019	1.00	1.00

2.3 Projection of Future Climate Scenario

The IPCC used the Representative Concentration Pathway (RCP) as the trajectory for greenhouse gas concentrations (not emissions) in its Fifth Assessment Report (AR5) [13]. We can get the meteorological data for a specific year (2030, 2050, 2070, 2090) using RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5, and use DSSAT to see changes in crop yield. MarkSim DSSAT is a weather file generator that generates simulated daily weather data specifically designed for use in the tropics, including rainfall, maximum and minimum temperatures and solar radiation. It provides the necessary future climatic scenario with various RCP values. We obtained future weather data for the appropriate year from the MarkSim DSSAT weather file generating software by using the latitude and longitude of the experimental area, the choice of climate models, scenario, and year. The variations in yield and all other parameters can be seen using this projected weather data in the DSSAT weather dataset. Comparison with current simulated value is used to calculate the difference.

DSSAT CERES-Rice Model: 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 Agro technology Transfer project IBSNAT [5]; Tsuji [6]; Uehara [7]; Jones et al. [8], to facilitate the application of crop models in a systems approach to agronomic research. CERES-rice model simulates rice response to climate variables [17,18].

MarkSim- DSSAT weather file generator: MarkSim is a daily weather generator based on a third order Markov model for rainfall that is especially adapted to the tropics. It works from a set of interpolated climate surfaces to fit a Markov model to the estimated climate data. The **MarkSim GCM web application** uses the well-known MarkSim application Jones and Thornton [12]; Jones et al [19] working off a 30 arc-second climate surface derived from WorldClim. Point and click on the map and up to 99 WTG files are prepared ready for use with **DSSAT.** Download and unpack to a directory on your machine and they are ready for use with the DSSAT4 crop modelling system [19]. This work was developed by the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).

2.4 Climate Change Scenario

MarkSim DSSAT weather generator (http://gisweb.ciat.cgiar.org/MarkSimGCM/) was used to produce daily weather data for the Prayagraj region, including solar radiation, rainfall, maximum and minimum temperatures. The ensemble data of seventeen climate models (BCC-CSM, BCC-CSM 1-1-M, CSIRO-Mk3-6-0, FIO-ESM, GFDL-CM3, GFDL-ESM2G, GFDL-ESM2M, GISS-E2-H, GISS-E2-R, HadGEM2-ES, IPSL-CM5A-LR, IPSL-CM5A-MR, MIROC ESM, MIROC-ESM-CHEM, MIROC5, MRI-CGCM3 and NorESM1-M) were downloaded in DSSAT friendly format for RCP 2.6, 4.5, 6.0 and 8.5 for the year 2030, 2050, 2070 and 2090. The RCPs include a strict mitigation scenario (RCP2.6), two intermediate scenarios (RCP4.5 and RCP6.0), and one scenario (RCP8.5) with very high GHG emissions. (IPCC 2014).

3. RESULTS AND DISCUSSION

3.1 Calibration and Validation of Model

To assess the model's accuracy in Prayagraj conditions, the model was calibrated for two years 2012 to 2013, and then validated from 2014 to 2019. For each of the four varieties, the actual and simulated yield data from the years 2012 to 2019 are shown in Table 2. Average percent error, root mean square error, and normalized root mean square error were determined to evaluate the models' performance. The model assessment demonstrated satisfactory performance with calibration (PE =2.43, 6.26, 4.31, 3.79, RMSE = 132.79, 345.13, 237.44, 237.85, nRMSE=2.53, 7.31, 4.46, 3.97) and validation (PE =3.58, 10.03, 4.28, 6.09, RMSE= 197.88, 456.35, 238.37, 366.52, nRMSE = 3.95, 10.55, 4.67, 6.39) for Swarna sub-1, Sarjoo-52, Pant Dhan 4 and NDR-359 cultivars respectively, demonstrating good agreement between expected and actual values. It proves the model is appropriate for these cultivars in the Prayagraj environment.

The entire analysis of four rice cultivars (Swarna sub-1, Sarjoo-52, Pant Dhan 4 & NDR-359) with the expected climate in Prayagraj conditions is discussed in this section. Calibration and validation of DSSAT CERES – rice model was done for all four cultivars with the help of grain yield. The results showed that all the values were within excellent limits of less than 10% for normalized root mean square error, and within acceptable limits of less than 15% for percent error. As a result, the DSSAT rice crop model may be used to accurately predict the yield and growth of all four rice types under Prayagraj conditions. For the Prayagraj region, NDR-359 produces the most among the four cultivars, followed by Pant Dhan 4, Swarna Sub-1, and Sarjoo-52.

3.2 Projection of Future Climate Scenario

3.2.1 Climate change projection

The yearly values were calculated using daily weather data from the four estimated RCP scenarios for the years 2030, 2050, 2070, and 2090. These data are shown in Tables 3 to 6. The RCP 2.6 scenario is anticipated to result in a 0.1° C increase in annual minimum temperature and a 0.4° C increase in annual maximum temperature in 2030 compared to the current temperature. Along with an increase in solar radiation of 0.4 MJ/day, the amount of rainfall has decreased by around 102 mm. For the RCP 4.5 scenario, the mean solar radiation increases by 0.4 MJ/day, the mean annual maximum temperature decreases by 118 mm, and the mean annual minimum temperature increases by 0.6°C. Comparing the RCP 6.0 scenario to the current meteorological scenario, there is a rise of 0.4 MJ/day. According to this scenario, the mean annual maximum temperature will rise by 0.4°C, the mean annual minimum temperature will drop by 0.1 °C, and the annual rainfall would reduce by 107 mm. The mean solar radiation increases by 0.4 MJ/day in RCP scenario 8.5 for the year 2030.

The mean annual maximum temperature has increased by 0.6°C, the mean annual minimum temperature has increased by 0.3°C, and the mean annual rainfall has decreased by 106 mm. Table 3 shows the anticipated weather for 2030, including solar radiation, temperature, and rainfall. The annual maximum temperature is predicted to rise by 0.7°C and the annual minimum temperature by 0.4°C from the present temperature scenario in 2050 under the RCP 2.6 scenario. Along with an increase in solar radiation of 0.4 MJ/day, the amount of rainfall has decreased by around 86 mm. According to the RCP 4.5 scenario, annual rainfall is decrease by 105 mm and mean annual maximum temperature, minimum temperature and solar radiation increase by 1.2°C, 0.8°C and 0.5 MJ/day respectively. Comparing the RCP 6.0 scenario to the current weather condition, there is a rise of 0.3 MJ/day solar radiation. The mean annual maximum temperature is projected to rise by 0.9° C, the mean annual minimum temperature by 0.6° C, and the annual rainfall is projected to decline by 93 mm under this scenario. The mean solar radiation increases by 0.3 MJ/day in RCP 8.5 for the year 2050. The mean annual maximum temperature has increased by 1.6°C, the mean annual minimum temperature has increased by 1.4°C, and the mean annual rainfall has decreased by 86 mm. The annual maximum temperature is predicted to rise by 0.8°C and the annual minimum temperature by 0.4°C from the existing temperature scenario in 2070 under the RCP 2.6 scenario.

Along with an increase in solar radiation of 0.5 MJ/day, the amount of rainfall has decreased by around 83 mm. According to the RCP 4.5 scenario, the mean solar radiation is up 0.6 MJ/day, the mean annual maximum temperature is up 1.7°C, the mean annual minimum temperature is up 1.2°C, and the mean annual rainfall is down 76mm. Comparing the RCP 6.0 scenario to the current meteorological scenario, there is a rise of 0.3 MJ/day. In this scenario, the mean annual maximum temperature rises by 1.5 °C, the mean annual minimum temperature goes up by 1.3 °C, and the mean annual rainfall falls by 67 mm. The mean solar radiation increases by 0.3 MJ/day under RCP scenario 8.5 for the year 2070. The mean annual maximum temperature has increased by 2.8°C, the mean annual minimum temperature has increased by 2.6°C, and the mean annual rainfall has decreased by 57 mm.

Projected climate scenario for the year 2030, 2050, 2070, 2090 showed that all the parameters like solar radiation, average maximum and minimum temperature increases and rainfall decreases. For the year 2030 an increase of 0.4 MJ/day in solar radiation, 0.4-0.6 °C in maximum temperature, 0.1-0.3°C average minimum temperature and decrease of 102-118 mm rainfall for all the four scenarios as compared with present weather. For the year 2050 for all the four-scenario rainfall amount decreases from 86-105 mm and other parameters increases as solar radiation 0.3-0.5 MJ/day, maximum temperature 0.7-1.6°C and minimum temperature 0.4-1.4°C. During 2070 the rainfall amount decreases from 57-83 mm and solar radiation, average maximum temperature, average minimum temperature increases from 0.3-0.5 MJ/day, 0.8-2.8°C, 0.4-2.6°C respectively. During the period of 2090 the solar radiation increases from 0.4-0.6 MJ/day, maximum temperature 0.8-4.0°C, minimum temperature 0.3-4.0°C and rainfall decreases from 12-77 mm under different RCP scenario.

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 %
Calibration												
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
Avg P.E (%)	2.43			6.26			4.31			3.79		
RMSE	132.79			345.13			237.44			237.85		
nRMSE	2.53			7.31			4.46			3.97		
Validation												
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
Avg P.E (%)	3.58			10.03			4.28			6.09		
RMSE	197.88			456.35			238.37			366.52		
nRMSE	3.95			10.55			4.67			6.39		
Average Yield (2012-19)	5063.5	5112.5	3.29	4420.87	4792.75	9.08	5154.87	5232.5	4.29	5795	5811.87	5.52

NOTE: Avg P.E (%)= (Average Percent Error), RMSE=(Root Mean Square Error), nRMSE =(Normalised Root Mean Square Error)

Table 3. Projected Weather of solar radiation, temperature and rainfall in 2030

Variable	2019 weather scenario	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5
Mean Solar Radiation, (MJ/day)	18.4	18.8	18.8	18.8	18.8
Mean Annual Maximum Temperature, (°C)	32.7	33.1	33.3	33.1	33.3
Mean Annual Minimum Temperature, (°C)	20.4	20.5	20.6	20.5	20.7
Annual Rainfall, (mm)	1097	995	979	990	991

Table 4. Projected Weather of solar radiation, temperature and rainfall in 2050

Variable	2019 weather scenario	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5
Mean Solar Radiation, (MJ/day)	18.4	18.8	18.9	18.7	18.7
Mean Annual Maximum Temperature, (°C)	32.7	33.4	33.9	33.6	34.3
Mean Annual Minimum Temperature, (°C)	20.4	20.8	21.2	21	21.8
Annual Rainfall, (mm)	1097	1011	992	1004	1011

Table 5. Projected Weather of solar radiation, temperature and rainfall in 2070

Variable	2019 weather scenario	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5
Mean Solar Radiation, (MJ/day)	18.4	18.9	19	18.7	18.7
Mean Annual Maximum Temperature, (°C)	32.7	33.5	34.4	34.2	35.5
Mean Annual Minimum Temperature, (°C)	20.4	20.8	21.6	21.7	23
Annual Rainfall, (mm)	1097	1014	1021	1030	1040

The annual maximum temperature is projected to rise by 0.8°C and the annual minimum temperature by 0.3°C from the existing temperature situation in 2090 under the RCP 2.6 scenario. Along with a rise in solar radiation of 0.5 MJ/day, there has been an about 77 mm decrease in rainfall. For RCP 4.5 scenario the mean solar radiation is increase by 0.6 MJ/day, mean annual Maximum Temperature by 1.9° C, Mean Annual Minimum Temperature by 1.5° C and Annual Rainfall is decrease by 52 mm. Comparing the RCP 6.0 scenario to the current weather, there is a rise of 0.4 MJ/day. In this case, the mean annual maximum temperature will rise by 2.1°C, the mean annual minimum temperature will increase by 1.9°C, and the mean annual rainfall will decrease by 38 mm. The mean solar radiation increases by 0.4 MJ/day in RCP 8.5 for the year 2090. The mean annual maximum temperature has increased by 4.0°C, the mean annual minimum temperature has increased by 4.0°C, and the mean annual rainfall has decreased by 12 mm.

3.3 Future Scenario of Rice Production

3.3.1 Future scenario of rice yield under projected climate change for Swarna Sub-1 variety

Future yield of Swarna Sub-1 rice variety in under the projected climate RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5 scenarios for 2030, 2050, 2070 and 2090 are given in Table 7. It displays the yield's percentage increase or reduction compared to the current yield.

For the year 2030, the changes in yield of + 10.95, + 9.74, + 8.15, + 6.80 as compare with present average yield under RCP 2.6, 4.5, 6.0 and 8.5 scenarios, respectively. The percent change in yield during the year 2050 as +9.15, +12.65, +6.47, +4.53 and for the year 2070 as +10.05, + 10.79, + 4.94, 0.91 under RCP 2.6, 4.5, 6.0 and 8.5 scenarios respectively. The percent change in yield from the current yield in 2090 is +10.99, +10.64, +4.61, and -3.11, respectively, for the RCP 2.6, 4.5, 6.0, and 8.5 scenarios.

3.3.2 Future scenario of rice yield under projected climate change for Sarjoo-52 variety

Table 8 shows the anticipated yield of the Sarjoo-52 rice variety for the RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5 climate projection scenarios for 2030, 2050, 2070, and 2090. According to the current yield, it displays the percent of increase or decrease in yield with respect to the present yield. According to the RCP 2.6, 4.5, 6.0, and 8.5 scenarios, the yield will change by +5.96, -0.79, +1.25, and +3.40 percent by 2030 compared to the present average yield. Under the RCP 2.6, 4.5, 6.0, and 8.5 scenarios, the yield percent change for the year 2050 and 2070 were respectively + 6.21, -4.09, -4.02, -6.57, and + 0.20, -1.46, - 6.32, -9.11. As compare to the present yield, the percent change in yield during the year 2090 is + 3.40, -3.90, -8.86, - 12.43 with RCP 2.6, 4.5, 6.0 and 8.5 scenarios respectively.

3.3.3 Future scenario of rice yield under projected climate change for Pant Dhan 4 variety

Projection yield of Pant Dhan 4 rice variety in under the projected climate RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5 scenarios for 2030, 2050, 2070 and 2090 are given in Table 9. It shows the percent of increase or decrease in yield with respect to the present yield.

For the year 2030, the changes in yield of + 12.86, +10.43, + 11.33, +10.47 as compare with present average yield under RCP 2.6, 4.5, 6.0 and 8.5 scenarios respectively. The percent change in yield during the year 2050 as + 10.03, + 10.12, + 5.67, + 6.47 and for the year 2070 as + 13.93, +7.28, + 7.09, +8.69 under RCP 2.6, 4.5, 6.0 and 8.5 scenarios, respectively. As compare to the present yield, the percent change in yield during the year 2090 is + 17.04, +6.28, + 5.65, + 2.71 with RCP 2.6, 4.5, 6.0 and 8.5 scenarios, respectively.

3.3.4 Future scenario of rice yield under projected climate change for NDR-359 variety

The anticipated yield of the NDR-359 rice variety under the projected climatic RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5 scenarios is shown in Table 10 for the years 2030, 2050, 2070, and 2090. According to the current yield, it displays the yield's percent increase or decrease. Under the RCP 2.6, 4.5, 6.0, and 8.5 scenarios, the changes in yield for the year 2030 were +19.53, +16.69, +18.74, and +14.73 when compared to the average yield at the time. According to the RCP 2.6, 4.5, 6.0, and 8.5 scenarios, the yield will change by a percent in 2050 (+17.15, +17.96, +13.33, +13.13), and in 2070 (+13.85, +15.86, +12.21, +10.25) respectively. As compare to the present yield, the percent change in yield during the year 2090 is +19.85, +14.64, +10.01, + 3.40 with RCP 2.6, 4.5, 6.0 and 8.5 scenarios respectively.

For the variety of Swarna Sub-1 under the scenario of RCP 2.6 yield increased for 2030, after that for 2050 and 2070 yield decreased compare to 2030 and again yield increased in 2090. For RCP 6.0 & 8.5 yield increased in 2030 after that the percentage of increasing yield starts decreasing up to 2090. In RCP 4.5 yield increased up to 2050 then the yield starts decreasing. Similar findings have also been observed by Arunrat et al. [20] studied the predicted local-scale impact of climate change on rice yields to suggest that all rice yields under RCP 6.0 (2080–2090) will tend to increase by 0.7%, while under RCP 8.5, rice yields will decrease by 8.4%. Increasing rice yields under a changing climate are predicted to occur in response to carbon fertilization under higher future CO_2 levels [21].

A positive impact on yield can be seen for Sarjoo-52 under the scenario of RCP 2.6 and for other RCPs (RCP 4.5, 6.0 & 8.5) adverse effect on yield was found for 2050, 2070 & 2090 in comparison to current yield. This is similar to predictions by Su et al*.* [22] based on field experiment data and the novel ORYZA version 3. For the cultivar of Pant Dhan 4, RCP 4.5 showed increase in yield during 2030 after that for the year of 2050, 2070 & 2090 it starts decreasing compare to 2030 yield. For RCP 2.6 the yield of 2030 increased then for 2050 the yield reduced some extent again for 2070 & 2090 the yield got increased. For RCP 6.0 & 8.5 yield increased in 2030 and after that it starts decreasing. Similar kind of results have also been observed by [23] who reported that, the impact of climate change on rice crop yields could be positive in some agricultural provinces and adverse in others. NDR-359 Variety under the scenario of RCP 2.6, the yield increased in 2030 up to +19.53% and again it shows decreasing for 2050 and 2070 (+17.15% & +13.85%) and again on 2090 the

Table 6. Projected Weather of solar radiation, temperature and rainfall in 2090

Variable	2019 weather scenario	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5
Mean Solar Radiation, (MJ/day)	18.4	18.9	19	18.8	18.8
Mean Annual Maximum Temperature, (°C)	32.7	33.5	34.6	34.8	36.7
Mean Annual Minimum Temperature, (°C)	20.4	20.7	21.9	22.3	24.4
Annual Rainfall, (mm)	1097	1020	1045	1059	1085

Table 7. Predicted yield and percent change in yield of Swarna Sub-1 variety under four scenarios of climate change for 2030, 2050, 2070, 2090

Scenario	2030		2050		2070		2090	
	Yield	Change (%)	Yield	Change (%)	Yield	Change (%)	Yield	Change (%)
Present	5112		5112		5112		5112	
RCP 2.6	5672	+10.95	5580	+9.15	5626	+10.05	5674	+10.99
RCP 4.5	5610	+9.74	5759	+12.65	5664	+10.79	5656	+10.64
RCP 6.0	5529	+8.15	5443	+6.47	5365	+4.94	5348	+4.61
RCP 8.5	5460	+6.80	5344	+4.53	5159	+0.91	4958	-3.01

Table 8. Predicted yield and percent change in yield of Sarjoo-52 variety under four scenarios of climate change for 2030, 2050, 2070, 2090

Scenario	2030		2050		2070		2090	
	Yield	Change (%)	Yield	Change (%)	Yield	Change (%)	Yield	Change (%)
Present	4792		4792		4792		4792	
RCP 2.6	5078	+5.96	5090	+ 6.21	4802	+0.20	4955	+3.40
RCP 4.5	4754	-0.79	4596	-4.09	4722	-1.46	4605	-3.90
RCP 6.0	4852	+1.25	4599	-4.02	4489	-6.32	4367	-8.86
RCP 8.5	4955	+3.40	4477	-6.57	4355	-9.11	4196	-12.43

Table 9. Predicted yield and percent change in yield of Pant Dhan 4 variety under four scenarios of climate change for 2030, 2050, 2070, 2090

Scenario	2030		2050		2070		2090	
	Yield	Change (%)	Yield	Change (%)	Yield	Change (%)	Yield	Change (%)
Present	5232		5232		5232		5232	
RCP 2.6	5905	+12.86	5757	+10.03	5961	+13.93	6124	+17.04
RCP 4.5	5778	+10.43	5762	+10.12	5613	+7.28	5561	+6.28
RCP 6.0	5825	+11.33	5529	+5.67	5603	+7.09	5528	+5.65
RCP 8.5	5780	+10.47	5571	+6.47	5687	+8.69	5374	+2.71

Table 10. Predicted yield and percent change in yield of NDR-359 variety under four scenarios of climate change for 2030, 2050, 2070, 2090

Scenario	2030		2050		2070		2090	
	Yield	Change (%)	Yield	Change (%)	Yield	Change (%)	Yield	Change (%)
Present	5811		5811		5811		5811	
RCP 2.6	6946	+19.53	6808	+17.15	6616	+13.85	6965	+19.85
RCP 4.5	6781	+16.69	6855	+17.96	6733	+15.86	6662	+14.64
RCP 6.0	6900	+18.74	6586	+13.33	6521	+12.21	6393	+10.01
RCP 8.5	6667	+14.73	6574	+13.13	6407	+10.25	6009	+3.40

yield increased (+19.85%). For RCP 6.0 & 8.5 yield increased during 2030 and then it shows decreasing compare to the yield of 2030.These results are nearly in same line with those of [24,25]. This study helps for knowing about the future climate, future crop yield and take necessary steps to rectify it [26-32].

4. CONCLUSION

To forecast future rice yield under several scenarios that used an ensemble of 17 global climate models under four different RCPs, we combined the MarkSim daily weather generator with the DSSAT-CERES Rice model. Increasing maximum and minimum temperatures, shifting rainfall patterns and variability, and intensifying solar radiation were all consistently seen in the future climate projections under various RCPs, with RCP 8.5 indicating the highest incremental change. As the year 2100 approaches, all meteorological variables, including SRAD, Tmax, Tmin, and rainfall, have changed. When the statistics from the expected climate scenario were analysed, the yield for 2030 was higher and for 2050 it was lower. It was also found that again in 2090 the yield gets increased for RCP 2.6 & decreased for RCP 4.5,6.0 & 8.5. For Prayagraj condition NDR-359 was found to have a better output potential than other cultivars. In order to conduct a thorough analysis of crop behavior in unconventional areas under changing climate scenarios and to frame and implement timely regional, national, and international policy, effective crop simulation models must be integrated with long-range location-specific climate projection tools. This will enable the important crops to avoid the adverse effects of climate change. Programs for raising public and farmer knowledge are necessary to develop a sense of responsibility among the public and governments. It is necessary to perform additional area-based studies to comprehend the regional effects of climate change.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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