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Assessment of Impact of Temperature and CO_2 on Growth and yield of Rice Crop using DSSAT Model

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A B S T R A C T

Assessment of impact of temperature and CO_2 on growth and yield of rice crop using DSSAT model has been made to assess the impact of these two parameters on the productivity of rice crop at south Gujarat region. For this purpose CERES-Rice model v4.6.1 was used in which the experimental result of rice during *kharif*, 2016 used as baseline to assess the rice yield under different climatic variability. Crop production is inherently to variability in climate. Temperature and CO_2 are two important parameters related to climatic variability, which affect crop yield of a particular region However, on the basis of study carried out in the region, the model was run and rerun for temperature increase or decrease by 1 or 2 ^{0}C and CO_2 concentration increase or decrease 100 or 200 ppm. The deviation in rice productivity from 2016 was estimated and analysed to assess the effect of temperature and CO_2. Simulated rice yield revealed the reduction in yield by -3.25 to -9.47% at increase in maximum temperature at 1 or 2 ^{0}C, while decrease in maximum temperature at 1 or 2 ^{0}C yield increase up to 5.93%. If the minimum temperature in decreased at 1 or 2 ^{0}C the yield increase by +1.23 to 26.56%. while increased CO_2 in the level of 100 and 200 ppm showed gradual yield increment about +5.84 to +7.11% and +9.95 to +13.73%, respectively.

Introduction

Rice (*Oryza sativa* L.) is one of the most important food crops of Asia and three fifth home of the humanity (Auffhammer *et al.*, 2012). Climate change is one of the primary concern for humanity in the 21th century. Indian agriculture is facing many challenges, climate variability being one of them. With only five per cent of the country's population and six per cent of the country's geographical area, Gujarat contributes to about 12 per cent of agricultural production in India. IPCC projects a probability of 10-40 per cent loss in crop production in India by 2080-2100 due to global warming. India's first National Communication to the UNFCCC suggests that an increase in CO_2 to 550 ppm will increase the yield of rice, wheat, legumes and oilseeds by 10-20 per cent. Yields of wheat, soybean, mustard, groundnut, and potato are likely to decline by 3-7 per cent with a one degree rise in temperature. On the west coast, there is a probability of improvements in yields of chickpea, maize, sorghum, millets and also, coconuts. Due to reduced frost, losses in potato, mustard and vegetables in the north-west India will be less. Global atmospheric carbon dioxide concentration has been estimated that it will increase to the level 970 micro mol^{-1} by the end of the century (Prentice *et al.,* 2001, IPCC, 2001). The globally averaged surface air temperature is projected to increase by 1.4-5.8 ^{o}C over the period 1991 to 2100 (IPCC, 2001). Climatic variability is expected to impact crop yield both in positive and negative ways, though the magnitude may vary from place to place.

This change would impact agricultural production especially rice crop which is mainly grown in south Gujarat region. Since both carbon dioxide concentration and temperature are among the most important environmental variables that regulate physiological and phonological processes in plants, it is critical to evaluate the effect of CO_2 concentration and air temperature on the growth and yield of rice crop. Crop growth models have considerable potential in exploration of crop management and policy decision for implementations and adapting to current and future climate change (Boote *et al.,* 1996; Tsuji *et al.,* 1998). In Gujarat state, the summer temperature varies between 25 ^{0}C and 45 ^{0}C while the winter temperature ranges between 15^{0}C and 35^{0}C degrees. The average annual rainfall over the State varies widely from 300 mm in the Western half of Kutch to 2,100 mm in the Southern part of Valsad district and the Dangs. The total number of rainy days varies from one part of the State to another, ranging from a minimum of 16 days in Kutch to a maximum of 48 days in Surat and the Dangs. Projected scenarios also indicate rise in global mean temperatures in the range of 1.1 to 6.4 ^{0}C and Sea Level Rise (SLR) in the range of 0.18 to 0.59 m by 2100 (IPCC, 2007). An analysis of instrumental records, globally for over one and a half century, has revealed that the earth has warmed by 0.74^{o} (0.56 to 0.92) ^{0}C during the last 100 years, with 12 of the last 13 years being the warmest. According to AR4, the rise in temperature by the end of the century with respect to 1980-1999 levels would range from 0.6 ^{0}C to 4.0 ^{0}C and the sea level may rise by 0.18 m to 0.59 m during the same period and increase in anthropogenic greenhouse gas concentrations, globally (IPCC, 2007a). An increase of 0.07 ^{0}C in mean temperatures over Gujarat in the past 40 years (1969- 2005) with a comparative higher increase over Coastal Saurashtra region (1969-2008) has been observed. Another analysis by Ray *et al.,* (2009) over the cold and heat wave conditions over Gujarat shows a considerable decrease in cold wave conditions for the past decade indicating an increase in night temperature and an increase in heat wave conditions except for Ahmedabad, Bhuj and Okha. As compared to 103 cold wave conditions in Saurashtra and Kutch for the period 1969-1978, the period 1999-2008 only recorded 13 cold wave conditions. Heat wave conditions have shown an increase over the southern part of the Gujarat and a decrease over the northern parts. Along the coastal stations of Saurashtra an appreciable rise in heat wave conditions have been observed. Analysis of rainfall data shows a decreasing trend of five per cent per 100 years in the western part, including Saurashtra and Kutch and the Gujarat subdivision. Analysis of temperature trends reveal that maximum temperature has increased by 0.2- 0.9 ^{0}C per decade. The highest rate of increase (0.9 ^{0}C) was found in Saurashtra (GoG, 2011). In India, and in particular homogenous regions of the east coast, west coast and the Indian peninsula, a significant increasing trend in frequency of hot days as well as decreasing trends in frequency of cold days, during the pre-monsoon season over the period 1970-2005, has been observed (Kothawale and Rupa Kumar, 2005). According to Parthasarthy (1984), monsoon rainfall is trend-less during the last four decades, particularly on an all India scale, but Rupa Kumar *et al.,* (1994) brought out regional monsoon rainfall trends in the past century. Ray *et al.,* (2009) reported that averages of mean maximum temperature over Gujarat indicate an increase by 0.11 ^{0}C for and averages of mean minimum temperatures over Gujarat show an increasing trend of 0.107 ^{0}C. Saurashtra and Kutch also show higher increase in night temperature as compared to other regions using station wise analysis. Despite of rapid advancement in agriculture sector, weather is still key factor impacting crop productivity and declining yield (Sapkota *et al.,* 2010)

Keeping the above in view, an attempt was made to assess the impact of climatic variability in respect of temperature and CO_2 concentration on the productivity of rice by comparing model crop yields simulated with use of weather series presenting the present climate and climatic variability.

Materials and Methods

Study site

The experiment was conducted in *Kharif* seasons (2016) on the dark grayish brown soil at college farm, N. M. College of Agriculture, Navsari Agricultural University, Navsari represented by latitude, longitude and altitude of 20°57′ N, 72°54′ E and 16 m above mean sea level respectively. Two cultivars of rice *viz.,* NAUR-1 and GNR-3 having long and medium duration respectively were sown on two different dates transplanting at an interval of ten days starting from 18th June to 28th June to enable the crop to get exposed to different thermal conditions during its various phenological stages. The crop was grown under rainfed condition in the seasons and recommended agronomic practices were followed for both the cultivars. The experiment was laid out in a split plot design with four replications.

Crop model

To investigate physiological response of the rice to change in climate, crop growth model CERES-Rice version 4.6 was used in this study.

Input data to CERES-Rice model

Weather data of study area were collected from the observatory of N. A. U., farm, Navsari Agricultural University, Navsari. This includes maximum and minimum temperature, precipitation and solar radiation. The experimental data rice of rice cultivar GNR-3 and NAUR-1 for the year 2016 were used for the purpose of genetic coefficients, crop management and soil data.

Climate change scenario

The growth and yield of rice under current weather and CO_2 condition as well as under different changing scenario with increase or decrease temperature and CO_2 was simulated using CERES-Rice model.

Modification was introduced to CERES-Rice in order to account for the effect of increase or decrease temperature and atmospheric CO_2 on crop productivity.

Simulation analyses

Simulation was run under different scenario of climate variables with traditional crop management in the study zone. The impact of temperature and CO_2 induce climate variability on crop production, expressed in yield due to increase or decrease in climatic variables, and are presented as deviation percentage change in average yield over the baseline 2016.

Results and Discussion

Impact of temperature on rice yield

The analysis indicated that the rice yield is sensitive to climatic variability. The increase in maximum temperature by 1 °C resulted the maximum reduction of the yield was recorded up to 4.86% at 75 kg nitrogen level and 4.86% at 100 kg nitrogen level. The increase in maximum temperature by 2 °C resulted the maximum reduction of the yield was recorded 7.93% at 75 kg nitrogen level and 9.47% at 100 kg nitrogen level. The negative effect of rising temperature on yield may be due to the fact that warmer temperature speed plant development during the earlier part of season, potentially causing the beginning of grain filling to physiological maturity. These finding are in good supported to report of Nyang *et al.,* (2014). While decrease in maximum temperature by 1 °C resulted the positive effect on yield, the yield increase up to 5.93% at 75 kg nitrogen level and 6.22% at 100 kg nitrogen level. By 2 °C decrease in maximum temperature resulted up to 3.38% at 75 kg nitrogen level and 6.86% at 100 kg nitrogen level yield increase was recorded.

The decrease in minimum temperature by 1 °C resulted similar evident of the effect on yield, the effect on yield increase up to 5.54% at 75 kg nitrogen level and 5.85% at 100 kg nitrogen level was recorded by model. In case of 2 °C resulted the positive effect on higher yield, the yield increases up to +26.56% at 75 kg nitrogen level and 27.12% at 100 kg nitrogen level. With a decrease in temperature, vegetative and grain filling periods became longer and produced higher yields, The similar results was found Oteng *et al.,* (2012) and Pandey *et al.,* (2007).

The combine effect of maximum and minimum temperature was also studied from CERES model. When the increase in maximum temperature up to 1 °C and decrease in minimum temperature of 1 °C resulted the negative effect on yield up to the -0.55 to -16% difference at 75 kg nitrogen level and -0.58% to -0.37% difference at 100 kg nitrogen level from its optimal conditioned yield magnitude. The increase in maximum temperature and decrease in minimum temperature by 2 °C was resulted negative effect on yield up to -2.08 to -1.20% differences at 75 kg nitrogen level and -1.38 to +2.33% differences at 100 kg nitrogen level from its optimal condition. Result of simulated yield and growth parameter clearly indicated that decline in yield due to the temperature stress was compensated thought increase temperature. The similar result was found in Pal *et al.,* (2012) observed that a 2 ^{o}C increase in temperature in wheat or rice resulted in 15-17 percent decrease in grain yield of both crops but beyond that the decrease was very high in wheat (Table 1 and 2).

Impact of carbon dioxide (CO_2)

The effect of carbon dioxide on simulated rice yield at 75 kg and 100 kg nitrogen level are presented in table 3.

The increase in CO_2 concentration by 100 ppm resulted the increment of the yield was recorded by +5.84 to 6.79% and +5.29 to +7.11% at 75 and 100 kg of nitrogen levels.

Table.1 The impact of temperature on simulated yield (q ha^{-1}) of rice at 75 kg nitrogen level

Date of transplanting	Cultivar	Optimal Condition	Tmax (+1°C)	Tmax (+2°C)	Tmax (-1°C)	Tmax (-2°C)	Tmin (-1°C)	Tmin (-2°C)	Tmax (+1°C) Tmin (-1°C)	Tmax (+2°C) Tmin (-2°C)
18th june	NAUR-1	51.89	49.92 (-3.79%)	48.58 (-6.81%)	52.90 (+1.94%)	52.96 (+2.06%)	53.04 (+2.21%)	59.20% (+14.08%)	52.41 (-1.00%)	51.74 (-0.28%)
	GNR-3	56.57	53.90 (-4.71%)	54.76 (-3.19%)	56.48 (-0.15%)	56.88 (+0.54%)	56.72 (+0.26%)	64.08% (+13.27%)	56.63 (+0.10%)	57.78 (+2.13%)
	Average % change		-4.25%	-5.00%	-1.04%	+1.3%	+1.23%	13.67%	-0.55%	-1.20%
28th June	NAUR-1	51.17	47.43 (-7.30%)	45.75 (-10.2%)	52.89 (+3.36%)	52.94 (+3.45%)	53.26 (+4.08%)	63.37% (+23.84%)	51.16 (-0.01%)	49.96 (-2.36%)
	GNR-3	55.00	53.66 (-2.43%)	51.88 (-5.67%)	59.68 (+8.50%)	56.83 (+3.32%)	58.85 (+7.00%)	71.11% (+29.29%)	55.18 (+0.32%)	56.00 (+1.81%)
	Average % change		-4.86%	-7.93%	+5.93%	+3.38%	+5.54%	+26.56	-1.06%	-2.08%

Table.2 The impact of temperature on simulated rice yield (q ha^{-1}) at 100 kg nitrogen level

Date of TransPlanting	Cultivar	Optimal Condition	Tmax (+1°C)	Tmax (+2°C)	Tmax (-1°C)	Tmax (-2°C)	Tmin (-1°C)	Tmin (-2°C)	Tmax (+1°C) Tmin (-1°C)	Tmax (+2°C) Tmin (-2°C)
18th June	NAUR-1	53.52	51.50 (-3.77%)	50.79 (-5.10%)	54.64 (+2.09%)	54.76 (+2.31%)	54.91 (+2.59%)	61.40% (+14.72%)	54.10 (+1.08%)	53.20 (-0.59%)
	GNR-3	58.45	55.34 (-5.32%)	57.04 (-2.41%)	58.36 (-0.15%)	58.79 (+0.58%)	58.74 (+0.49%)	66.98% (14.59%)	58.40 (-0.08%)	59.73 (+2.18%)
	Average % change		-4.54%	-3.75%	-1.12%	+1.44%	+1.54%	+14.65%	-0.58%	-1.38%
28th June	NAUR-1	51.47	47.67 (-7.38%)	45.61 (-11.9%)	53.22 (+3.40%)	53.49 (+3.92%)	53.56 (+4.06%)	63.77% (+23.89%)	51.42 (-0.09%)	50.00 (2.85%)
	GNR-3	55.07	53.69 (-2.50%)	51.19 (-7.04%)	60.05 (+9.04%)	60.47 (+9.80%)	59.28 (+7.64%)	71.79% (+30.36%)	55.43 (+0.65%)	56.07 (+1.81%)
	Average % change		-4.94%	-9.47%	+6.22%	+6.86%	+5.85%	+27.12%	-0.37%	-0.37%

Table.3 The impact of carbon dioxide on simulated rice yield at 75 kg and 100 kg nitrogen level

Date of Trans-planting	**Cultivar**	**Nitrogen levels**									
		75 kg ha^{-1}					100 kg ha^{-1}				
		Optimal Condition	CO_2 (+100 ppm)	CO_2 (+200 ppm)	CO_2 (-100 ppm)	CO_2 (-200 ppm)	Optimal condition	CO_2 (+100 ppm)	CO_2 (+200 ppm)	CO_2 (-100 ppm)	CO_2 (-200 ppm)
18th june	NAUR-1	51.89	55.08 (+6.14%)	57.09 (+10.02%)	45.88 (-11.58%)	27.10 (-47.77%)	53.52	56.85 (+6.22%)	59.60 (+11.36%)	47.38 (-11.47%)	27.64 (-48.35%)
	GNR-3	56.57	59.71 (+5.55%)	62.17 (+9.89%)	50.44 (-10.83%)	30.52 (-46.04%)	58.45	61.71 (+5.57%)	64.56 (+10.45%)	48.08 (-17.74%)	31.22 (-46.58%)
	Average % change		+5.84%	+9.95%	-11.20%	-46.90%		+5.89%	+10.90%	-14.60%	-47.46%
28th June	NAUR-1	51.17	54.55 (+6.60%)	58.08 (+13.50%)	44.87 (-12.31%)	27.77 (-45.72%)	51.47	54.91 (+6.68%)	58.27 (+13.28%)	44.89 (-12.78%)	27.78 (-46.02%)
	GNR-3	55.00	58.84 (+6.98%)	62.68 (+13.96%)	48.08 (-12.58%)	30.02 (-45.41%)	55.07	59.23 (+7.55%)	62.87 (+14.16%)	48.20 (-12.47%)	30.04 (-45.45%)
	Average % change		+6.79%	+13.73%	-12.44	-45.56%		+7.11%	+13.72%	-12.62%	-45.73%

The increase in CO_2 concentration by 200 ppm causes the increment the yield was recorded by +9.95 to +13.73% and +10.9 to +13.72% at 75 and 100 kg nitrogen level. Nyang *et al.,* (2014) reported that positive effect of CO_2 on rice growth and yield. CO_2 affects the rice plant by elicing two direct physiological response *viz.* enhance rate of photosynthesis and reduced stomatal conductance. Greater photosynthesis allows greater carbon gain and biomass accumulation. While decrease in CO_2 concentration by 100 ppm resulted the negative effect on yield, the yield decrease up to 11 to 14% at 75 and 100 kg nitrogen level. By 200 ppm decrease in CO_2 concentration resulted the highly negative effect was recorded, it was seen that up to 45 to 47% yield was decreased. This may be due to the lower photosynthesis allows lower CO_2 gain and biomass accumulation. These finding are in supported to the report of Hadiya *et al.*, (2015).

Zhao *et al.*, (2006) has analysed the impact of historical climate change on rice production in the Yangtze River zone. It pointed out that under the climate warming, high temperature, especially continuous high temperature during the period of flowering stage and late milk stage, mainly affected middle rice. Therefore, the remarkable increase of number of days with extreme high temperature would further threaten the production of single-season rice and double-season late rice in the study area. CO_2 enrichment is likely to increase the photosynthetic rate, and thus biomass production, which in turn may positively affect assimilated allocation to reproductive organs (Wassmann *et al.*, 2009).

Future climate change is expected to impact rice production in south Gujarat region to a greater extent. Rice yields are increase in maximum temperature (1 to 2°C) resulted that the reduced the simulated yield 3.25 to 9.47%, while Decrease in daily maximum temperature results the increase simulated yield up to +3.47%, Reduction (1 to 2 °C) of minimum temperature also increase the simulated grain yield 1.23 to 5.85%, The combine effect of maximum (+1 to +2 °C) and minimum temperature (-1 to -2 °C) resulted that the reduction in grain yield 0.16 to -0.58%, and increase in CO_2 concentration (+100 to +200 ppm) in CERES model resulted that the increase the simulated yield 5.84 to 13.73%, Decrease in CO2 concentration (-100 to -200 ppm) results the decreasing simulated yield -11.20 to -47.46%. There is need to develop strategies which could be helpful in mitigation of the change in climatic variability.

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