Impact of Climate Change on Rice Production in Nalgonda District, Andhra Pradesh using ORYZA 2000 Model

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Abstract

The study attempts to estimate the potential impact of climate change on rice production in Nalgonda district using ORYZA 2000 model. The model has been verified with the observations of field experiments conducted in Agricultural Research Station, Kampasagar, Nalgonda District for a particular variety BPT 5204. At existing mean seasonal temperature the model predicted increased yield with increased CO_2 concentrations. However, a decrease in yield was noticed with increase in temperature levels at existing CO_2 levels (383 ppm). The model predicted a reduction in rice yield under the scenario of increase in temperature as well as CO_2 concentrations.

Global concern about the adverse effects of changing climate on agricultural productivity is raising (Adams *et al.,* 1998). Simulation analysis by using different models has shown that increasing CO_2 concentration in the atmosphere has a positive effect on crop biomass production, but its net effect on rice yield depends on the rising of the temperature (Peng *et al.,* 2004; Kim *et al.,* 2003; Sheehy *et al.,* 2006; Tao *et al.,* 2008). Thus an assessment of the potential impacts of increasing CO_2 levels and temperature on rice productivity is needed. In Andhra Pradesh the temperatures are projected to increase by at least 3^0C throughout the state due to climate change during 2041 to 2060 (Sreenivas and Raji Reddy, 2009). This increase may occur across the seasons of the year. This study was under taken to assess the impact of climate change on rice yield using ORYZA 2000 model

Materials and Methods

This study attempts to determine the potential impact of climate change, namely changes in CO_2 and temperature, on the rice yield in Nalgonda district of Andhra Pradesh. Nalgonda is one of the rice producing district of Andhra Pradesh having 194,000 ha of area with 603,000 tonnes production and 3.11 t/ha of productivity. The district experienced average seasonal temperature of 26.6^o C and 511 mm of rainfall during cropping season in 2007. The mean seasonal temperature of 27.0 and 28.0^{o}C and rainfall of 903 and 553mm was recorded during the years 2008 and 2009, respectively.

The ORYZA 2000 crop growth model was used to simulate the effect of temperature and CO_2 on rice yield in a situation where nutrient and water were assumed to be non-limiting. In this model BPT 5204 variety was used which is the most common rice variety planted by farmers in Nalgonda district. The model was validated with the experimental data for variety BPT 5204, with the application of 120 kg N/ha. The model was used to simulate the potential rice yields under three scenarios: scenario 1 constant temperature with different levels of CO_2 concentration (340 ppm, 383 ppm, 415 ppm, 492 ppm, 565 ppm and 640 ppm); scenario 2 with constant Co2 concentration of 383 ppm with different temperature increase (1^o, 2^o, 3^o and 4^{o}C) and scenario 3 was with the interaction of CO_2 and temperature. The present level of CO_2 (383 ppm) was taken as reference level of CO_2 to compare the change in yield.

The data input required for the simulations by using the ORYZA 2000 crop growth model included; experimental data (taken from annual reports of Agricultural research Station, Kampa Sagar, Nalgonda), crop production data, soil condition and weather data. The experimental data contained information on the run modes of ORYZA 2000, the site and experimental conditions of the simulation run and any observed variables.

The model follows a daily rate calculation scheme for dry matter production of the plant organs and rate of phenology development.by integrating these rates over time, the dry matter production of the crop is simulated

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though growing period. Phenology development is explained through development stage (DVS) of a plant which is defined by its physiological age and characterized by the formation of the various organs and their appearance. Finally development stages are calculated by integrating the development rates and expresses in degree days. The crop data file contains all the parameter values that characterize the rice crop. Crop management data or experimental data, i.e., sowing date, transplanting date, harvest date, amount of fertilizer applications, collected from the annual reports of the Agricultural Research station, Kampa sagar, Nalgonda. The model was calibrated for BPT 5204 and the development rate parameters like development rate in juvenile phase (DVRJ=0.000341, 0.000350 and 0.000356), development rate in photoperiod-sensitive phase (DVRI=0.000758), development rate in panicle development (DVRP=0.000796, 0.000801 and 0.000796) and development rate in reproductive phase (DVRR=0.002771, 0.0002896 and 0.002898), were set respectively for 2007, 2008 and 2009 in the present study. The light use efficiency for minimum temperature and maximum temperature values 0.54 and 0.36, respectively (Bouman *et al.,* 2001) were used in this study.

The soils data file containd all data to run the soil-water balance module. The soil data*, i.e.,* soil type, soil texture, hydraulic conductivity, soil moisture *etc.* were taken from the experiments conducted on the Agricultural Research Station, Kampa sagar, Nalgonda. Weather variables such as daily values of maximum temperature, minimum temperature, vapour pressure, wind speed, sunshine hours and rainfall are collected from Agricultural Research Station, Kampasagar, Nalgonda is used as weather input file.

Results and Discussion

The impact of CO_2 levels on rice yield was noted for Nalgonda district for the three years with increase in CO_2 concentration without change in temperature. Since 383 ppm is present CO_2 level in atmosphere, it was used as check to compare the simulated yields at different levels of CO_2. With increase in CO_2 concentration from 340 to 640 ppm, the percent change in simulated yield of rice was from -5.6, 3.6, 10.7, 16.2 and 20.3 at 340, 415, 490, 565 and 640 ppm of CO_2, respectively, during 2007. Similarly, the change in yield ranged from -1.2, 2.7, 7.1, 10.0 and 12.4 and -2.2, 1.5, 4.5, 8.0 and 11.8 during 2008 and 2009, respectively (Table 1). The high CO_2 concentration to be present in the atmosphere under global warming could be harnessed to increase the productivity of the rice crop. Rice crop is sensitive to changes in carbon dioxide concentration. Being a C_3 plant, rice holds an edge over C_4 plants due to increase in photosynthetic rates under expected enhanced CO_2 concentrations. The increased levels of CO_2 from 340 to 680 ppm could increase the yield of major crops by 10 to 15 per cent especially in C_3 plants like rice (Allen, 1990). Parry *et al.* (2004) suggested that increase in atmospheric CO_2 concentration could produce beneficial effects on grain production. It could also increae photosynthetic rates and decrease in stomata conductance and transpiration rates (Vaghefi *et al.,* 2011).

Table 1: Simulation output to show effect of CO_2 concentration on rice yield (t/ha) in Nalgonda district

CO_2 concen-tration (ppm)	2007		2008		2009		Mean	
	Yield	% change	Yield	% change	Yield	% change	Yield	% change
340	6.92	-5.6	7.92	-1.2	8.02	-2.2	7.62	-2.9
383	7.33	0.0	8.02	0.0	8.20	0.0	7.85	0.0
415	7.60	3.6	8.24	2.7	8.31	1.5	8.05	2.6
490	8.12	10.7	8.59	7.1	8.56	4.5	8.42	7.3
565	8.52	16.2	8.81	10.0	8.85	8.0	8.73	11.2
640	8.82	20.3	9.01	12.4	9.16	11.8	9.00	14.7

*The simulated yield with existing level of CO_2 (383 ppm) in atmosphere is taken as base for calculating per change in yield.

The impact of temperature on rice yield in Nalgonda district is presented in Table 2. Increase in temperature from 1°C to 4°C above the mean temperature resulted in decrease in rice yields. When temperature increased by 1°C above the mean temperature, the per cent decrease in rice yield varied from -3.7, -8.9 and -9.1 during 2007, 2008 and 2009, respectively. The impact of temperature on rice yield was more during the year 2009, compared to 2007 and 2008. This could be due to variation in mean minimum and maximum temperature. During 2009 Nalgonda experienced higher minimum and maximum temperatures compared to 2007 and 2008. The increased temperature leads to forced maturity and poor harvest index due to limited water supply. The water stress under the warm climate reduced source size (leaf area) coupled with poor sink strength (number of grains/ear) reduced number of effective tillers and shorter period (crop duration) resulted in considerable decline in grain yield of rice crop over normal. The increasing temperature at flowering inhibits swelling of the pollen grains which is the driving force behind anther dehiscence and therefore high temperature would induce spikelet sterility and increase in instability of the rice yield (Matsui and Omasa, 2002)..

Table 2 : Simulated output of impact of temperature on grain yield (t/ha) of rice in Nalgonda district

Temperature raise over mean temperature	2007		2008		2009		Mean	
	Yield	per cent change	Yield	per cent change	Yield	per cent change	Yield	per cent change
0°C	7.33	-	8.02	-	8.20	-	7.85	-
1°C	7.06	-3.7	7.30	-8.9	7.45	-9.1	7.27	-7.3
2°C	6.85	-6.5	6.54	-18.4	6.54	-20.2	6.65	-15.3
3°C	5.93	-19.1	5.88	-26.7	5.08	-38.0	5.63	-28.2
4°C	4.86	-33.7	4.98	-37.8	3.74	-54.4	4.53	-42.3

*Yield at normal temperature predicted by the model was 7.33, 8.02 and 7.85 t/ha during 2007, 2008 and 2009.

Rice productivity under global warming also suggested that the productivity of rice and other tropical crops will decrease as temperature increases. Peng *et al.* (2004) reported that the yield of rice crops in the Philippines decreased by as much as 15 percent for each 1°C increase in the growing season mean temperature.

The results of the interaction effects of temperature and CO_2 concentration on simulated rice yield in Nalgonda are presented in Supplementary Table 1. The grain yield increased with increased levels of CO_2 from 340 to 640 ppm, whereas increase in temperature from 1°C to 4°C above normal temperature drastically reduced the grain yield. The temperature raise was 1°C and 2°C above the mean, with increase in CO_2 concentration from 340 to 640 ppm the grain yield increased from -8.0 to 13.9 and -11.2 to 5.8 per cent, respectively during 2007. Increase in CO_2 concentration was able to nullify the negative deviation in growth and yield of rice caused by increase in temperature. The per cent change in grain yield was -22.5 to -5.2 and -38.3 to -18.3 with increase in temperature 3° and 4°C above mean and CO_2 concentration increased from 340 to 640 ppm, respectively during 2007 was unable to nullify the adverse effect of temperature.

Different CO_2 concentrations in combination with 1° to 2°C raise in temperature above existing level changed the rice yield from -11.1 to 3.8 and -20.7 to 1.4, respectively during 2008. With increase in temperature 3° and 4°C in combination with increased levels of CO_2 the per cent change in rice yield ranged from -30.2 to -20.0 and -42.6 to -32.5 during 2008. The per cent change in rice production was more in the year during 2009. With the raise in temperature from 1° to 2°C above mean in combination with increased levels of CO_2 concentration the per cent change in rice yield varied from -14.4 to 6.2 and -22.8 to -3.1, respectively during 2009. Varied CO_2 concentration in combination with temperature 3° and 4°C above mean resulted in reduced rice yields ranged from -40.2 to -35.8 and -55.9 to -43.2.

Increasing atmospheric CO_2 concentration only could have beneficial effects on rice production. Potentially great negative effects are also possible, if maximum daily atmospheric temperatures also rise. With increasing temperatures at higher CO_2 levels the decline in rice production will be much higher. Substantial reduction in rice yield as a result of increased temperature will not usually be compensated by increased level of CO_2. The results of this study are in consistent with the findings of Srivastava et *al.* (2006) while working with CERES-Rice model.

The analysis showed that the model is sensitive to the changes in temperature and CO_2 concentration, and therefore, could be used for simulating the effect of changes in weather parameters on rice yields. ORYZA 2000 could successfully use weather data to predict the future crop yields under different management practices. The decline in expected yields due to temperature raise is likely to be compensated by the increased in yields due to high atmospheric CO_2 concentrations. The study also suggested to develop rice varieties tolerant to higher temperature likely to be encountered under the changed climatic scenario. The results indicated that there would be negative effects on rice production and yield as well as on future food supply. Thus policies need to be formulated to mitigate climate change and farm practices need to be adopted to overcome the adverse effects of climate change for ensuring sustainable farm income and self- sufficiency level.

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Supplementary Table1: Combined effects of temperature and CO_2 concentration on rice yield (t ha^{-1}) in Nalgonda district

CO_2 conc (ppm)	Temperature raise																							
	2007								2008								2009							
	1°C	% change	2°C	% change	3°C	% change	4°C	% change	1°C	% change	2°C	% change	3°C	% change	4°C	% change	1°C	% change	2°C	% change	3°C	% change	4°C	% change
340	6.74	-8.0	6.51	-11.2	5.68	-22.5	4.53	-38.3	7.13	-11.1	6.36	-20.7	5.60	-30.2	4.60	-42.6	7.01	-14.4	6.32	-22.8	4.90	-40.2	3.61	-55.9
383	7.06	-3.7	6.85	-6.5	5.93	-19.1	4.86	-33.7	7.30	-8.9	6.54	-18.4	5.88	-26.7	4.98	-37.8	7.45	-9.1	6.54	-20.2	5.08	-38.0	3.74	-54.4
415	7.36	0.4	6.98	-4.8	6.13	-16.4	4.93	-30.3	7.42	-7.4	6.76	-14.5	5.99	-25.3	5.19	-35.3	7.43	-5.7	6.95	-15.1	5.37	-34.5	3.90	-51.3
490	7.64	4.2	7.13	-0.5	6.36	-11.9	5.01	-26.8	7.73	-3.6	6.96	-12.5	6.13	-23.6	5.24	-34.7	7.97	-2.7	7.36	-10.2	5.55	-31.1	4.03	-49.7
565	8.05	9.8	7.31	2.2	6.46	-8.6	5.13	-22.3	8.01	0.0	7.01	-5.6	6.33	-21.1	5.32	-33.6	8.39	2.4	7.57	-7.6	5.75	-28.7	4.13	-45.3
640	8.35	13.9	7.46	5.8	6.52	-5.2	5.23	-18.3	8.32	3.8	7.13	1.4	6.42	-20.0	5.41	-32.5	8.70	6.2	7.95	-3.1	5.90	-35.8	4.22	-43.2

*Yield at mean temperature and 383 ppm were 7.73, 8.02 and 8.33 t ha^{-1} respectively