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Impact of projected climate change on rice production in Punjab (India)

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The combustion of fuel, biomass burning, production of synthetic chemicals and deforestation are enhancing the greenhouse effect by changing the chemical composition of the atmosphere. The greenhouse gases (GHGs) are presently increasing at the rate of 1 per cent for CH_4, 0.4-0.5 per cent CO_2 and 0.2-0.3 per cent for N_2O (Baker 1989). At this rate the concentration of CO_2 will exceed 370 ppm by the year 2030. The combined effect of other GHGs viz., CH_4, N_2O, CFC_{11}, CFC_{12} and O_3 is equivalent to an additional 40-50 ppm increase of CO_2 (Bach 1989). During next 60 years their concentration will result in greenhouse situation equivalent to a CO_2 doubling in the first half of the 21st century which indicates changing trend of the global climate over a longer period. The realistic models of climate which combined atmospheric and oceanic models indicated global warming to the tune of 0.5 to 0.7 K for the period 1850-1980. This warming agrees well with the observed Northern Hemisphere warming of 0.6 K in this period. During next century average rate increase in global temperature is projected as 0.3°C per decade with a range of 0.2 to 0.5°C (Kellogg 1983). The Intergovernmental Panel on Climate Change (IPCC) concluded that global mean surface air temperature has increased by 0.3-0.6°C over the last century with the five global average warmest years being in the 1980s (Martin 1993).

The increased level of CO_2 from 340 to 680 ppm could increase the yield of major crops by 10-15 per cent especially in C_3 plants like rice (Allen 1990) but the beneficial effects can be negated as the incidence photosynthetically Active Radiation (PAR) is likely to decline by 1 per cent (Hume & Cattle 1990). The increased temperature will lead to forced maturity and poor harvest index due to limited water supply (Yadav *et al.* 1987). The water stress during grain filling period may result in decline of grain yield. Higher temperature coupled with increased CO_2 concentration could result in photosynthetic acclimation because of the imbalance in the source/sink ratio.

The change in climate would have a direct bearing on the food production and, therefore, the magnitude of this change in climate and its consequences will be matter of great concern for the scientists, planners and policy makers so as to regulate the food supply and to maintain its reserves for the future. So this type of study will be of great interest for the potential food production areas like that of Punjab which is a bread basket of India as it contributes 60 per cent of rice towards national grain pool. The variability in rice yield in Punjab will influence the national food reserves, grain distribution policies and price regulations.

Punjab being a very small state has very narrow range of both latitudinal and longitudinal extent which are to the tune of 29°33 N - 32°31 N and 73°55 E - 76°55 E, respectively. So, both ways, i.e. north to south and east to west, throughout the state during rice crop season very little difference in maximum and minimum air tempera-

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ture is observed. Therefore, the weather file data for the CERES RICE model was taken from a representative station (Ludhiana) for a period of 20 years. The weather data for the normal rice crop season (May-November) was collected and the normal was obtained through average of 20 years period (1970-1990). Hume & Cattle (1990) has reported only 1 per cent decline in solar radiation so it was kept normal. Since rice crop in Punjab is only grown under assured irrigation conditions, it was also assumed that the crop will be grown under non-limiting (optimum) supply of water and nutrients and only maximum and minimum air temperature values were changed uniformly for the crop season by 0.5, 1.0, 1.5, 2.0°C over the normal. The yields thus obtained will be potential yields under five climatic scenarios. For this the simulation technique (CERES RICE model), being cheap and easy, was selected. This model has already been validated under Punjab conditions. This model predicted the grain yield from 71-120 per cent (mean 95 per cent) of the actual yield on the basis of weather, soil and crop data. The CERES RICE model was one of the models developed through IBSNAT project which can predict growth and yield of rice varieties under all agroclimatic conditions. The following six input files were created to run the model.

1. Daily weather including solar radiation, maximum and minimum air temperature and precipitation.

2. Soil properties including single values of drainage, run off, evaporation, radiation reflection coefficient, values at several depth increments of soil water content at upper limit, at lower limit of available water and at saturation.

3. Initial conditions of soil water content, nitrogen content at several depth increments.

4. Management practices like variety, plant density, planting date, irrigation and nitrogen fertilization.

5. Latitude of production area to evaluate day length during the cropping season.

6. Genetic coefficients, thermal time from emergence to the end of juvenile stage (P1), rate of photo-induction (P2R), optimum photoperiod (P2), thermal time for grain filling (P5), conversion efficiency from sunlight to assimilates (G1), tillering rate (TR) and grain size (G2).

The crop performance under five climatic scenarios (Table 1) showed that under normal weather scenario the 45 days old seedlings transplanted on 15th of June took 153 days to complete its life span. The crop attained maximum Leaf Area Index (LAI) of 6.2 with total biomass of 10.22 t ha^{-1}. Under this scenario the potential grain yield simulated by the CERES RICE model will be 6.13 t ha^{-1} by attaining 494 grains per ear and 18846 grains m^{-2}.

Under the slight warming scenario the rise in temperature by 0.5°C over the normal will cut short the life span of the crop by two days only. It will reduce the maximum LAI, biomass, grains per ear, grains m^{-2} and grain yield by 1.1, 1.3, 2.4, 3.2 and 3.2 per cent, respectively, while the increase in the straw yield will be a fraction of one per cent (0.7) only.

In case of moderate warming scenario the average temperature rise of 1°C is expected around the year 2020. This will reduce the crop duration by three days over the normal and it will have negative effect on yield contributing characters of the crop. Maximum reduction (6.1 per cent) will be observed in case of grains per ear, followed by a reduction of about five per cent in grains m^{-2} and grain yield. The reduction in biomass, maximum

Table 1. Rice crop response to variations in temperature.

Climate Scenarios	Temperature Change	Yield and Yield Attributes						
		Crop Duration (Days)	Grain Yield ($kgha^{-1}$)	Grains (m^{-2})	Grains (Ear^{-1})	Max (LAI)	Biomass ($kgha^{-1}$)	Straw ($kgha^{-1}$)
		(% deviation over normal scenario)						
Extreme warm	+2.0°C	-3.3	-8.4	-8.4	-12.4	-3.9	-7.4	-6.4
Greater warm	+1.5°C	-2.6	-8.2	-8.2	-8.3	-3.9	-6.5	-4.7
Moderate warm	+1.0°C	-2.0	-4.9	-4.9	-6.1	-2.4	-3.6	-2.2
Slight warm	+0.5°C	-1.3	-3.2	-3.2	-2.4	-1.1	-1.3	-0.7
Normal weather	Normal	153	6136	18846	494	6.2	10220	4943

LAI and straw yield will be to the tune of 3.6, 2.4 and 2.2 per cent, respectively.

Greater warming scenario may occur around 2035 when the expected rise in temperature will be by 1.5°C. This change will have considerable negative effect on the crop performance. The crop duration will be shortened by four days over normal. The grains per ear will reduce by 8.3 per cent. The grains m^{-2} and grain yield will be reduced by 8.2 per cent. The reduction in biomass, maximum LAI and straw yield will be 6.5, 3.9 and 4.7 per cent, respectively.

Under extreme warming scenario the average rise in temperature by 2°C over the normal is expected by the middle of next century with almost doubling of CO_2 in comparison to 1990 level. This change in temperature will enhance the maturity of five days over the normal. Maximum reduction (12.4 per cent) will be observed in grains per ear followed by a 8.4 per cent reduction in grains m^{-2} and grain yield. The biomass will reduce by 7.4 per cent. Maximum LAI and straw yield will reduce by 3.9 and 6.4 per cent, respectively.

The results showed a decline in crop duration, grains m^{-2}, grain yield, maximum LAI, grains per ear, biomass and straw yield with each 0.5°C increase in temperature over the normal during the crop season.

Under the warm climatic scenarios, the reduced source size (leaf area) coupled with poor sink strength (as depicted by the number of grains per ear) reduced number of effective tillers (as indicated through lesser number of grains m^{-2}) and shorter period of harvesting solar radiation (crop duration) resulted in considerable decline in biomass and grain yield of rice crop over the normal. Dhiman *et al.* (1985) and Saini & Nanda (1987) found that increased temperature hasten the rate of leaf scenescence resulting in reduction in leaf area. Similarly the decrease in crop life span and grain yield with increase in temperature is in confirmation with the findings of Mavi & Chaurasia (1974), Bagga & Rawson (1977); Singh *et al.* (1991); Wardlaw (1970); Wardlaw *et al.* (1989); Hundal *et al.* (1993).

The model simulation revealed that warming scenarios will have an adverse effect on rice production through the advancement in maturity and reduction of source size coupled with poor sink strength in Indian Punjab. But further studies are needed to simulate the combined effect of temperature, CO_2 and rainfall changes on rice crop performance.

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