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Simulating the impact of climate change on growth and yield of wheat

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ABSTRACT

Under various climate change scenarios, the shifts in the optimal date of sowing of wheat for sustaining the wheat yields were evaluated for various agro-ecological regions by using wheat growth simulator, WTGROWS. Variability in the amounts of winter rains received could influence the rainfed wheat yields under normal weather as well as rising temperature (1-3 °C) situations. The results were different for different agro-ecological regions. The effect of winter season rainfall variability/change diminished as the soil moisture availability through irrigation amounts applied to the soil increased. Radiation–temperature interaction was seen through final above-ground biomass and grain yield at New Delhi and Patna environments. The differences were more significant in grain yield.

Key words: WTGROWS-model, wheat yield, climate change, sowing date

Wheat is a major *rabi* crop and is sensitive to various biotic and abiotic stresses. Its productivity is spatially different. The differences in yields are primarily due to prevailing weather, inter-seasonal climatic variability, soil conditions and agricultural inputs like nitrogen, water and pesticides (Midmore *et al.*, 1984; Aggarwal and Kalra, 1994; Ortiz-Monasterio *et al.*, 1994). The inter-seasonal climatic variability, in terms of the changes in temperature, rainfall, radiation etc., show differential growth and yield response over locations (Sinha and Swaminathan, 1991). Climate change is a concern, and researchers are engaged in under standing its impact on growth and yield of crops, and also identifying the suitable options to sustain the crops' productivity under climate change scenarios. Crop growth models can simulate the growth and yield of crops under various biotic and abiotic stresses, and can be conveniently used for climate change studies (Kalra and Aggarwal, 1994; Das and Kalra, 1995). The altered agronomic management practices to adjust in the changed environment need to be identified (Aggarwal *et al.*, 1998; Kalra *et al.*, 2002). Wheat growth simulator (WTGROWS), has been developed and intensively tested for diverse agro-environments within the country (Aggarwal

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et al., 1994), and present study deals with the use of this model to understand the impact of climate change on growth and yield of wheat in various agro-environments. The shifts in the optimal date of sowing of wheat for different agro-environments in relation to temperature rising scenarios was also evaluated by using WTGROWS.

MATERIAL AND METHODS

The normal weather data for various wheat growing locations within the country were compiled. Wheat growth simulator, WTGROWS was run for different dates of sowing under normal as well as temperature rise (1-3 °C) for the locations north of 25 °N latitude with the diverse agro-ecologies (Table 1). The prime objective of this study was to identify the optimal date of sowing for getting maximum yield under normal condition, as well its shifting with the temperature rise. For working out the optimal sowing dates for the locations, the date of sowing was assumed between 280-360 Julian days, with 5-days increment level. Subsequently the effect of temperature rise (1-3 °C) on percent reduction in yield over the control (no temperature rise) was evaluated as a function of latitude.

The variability in the winter rains (arising due to western disturbances) was evaluated through simulated growth and yield of wheat (rainfed and irrigated with variable water supply) at locations under temperature rise scenarios. For this purpose, four diverse locations viz. Patna (Eastern region), Kanpur (Central region) Jalundhar and Delhi (Northern region) were selected. The uncertainties in winter rains were assumed between (–) 15 to 20% of the normal rains for the respective locations with 5% increment level. Three temperature rising conditions (1-3 °C) were included along with control (no temperature rise). Interaction of variability in winter rains and temperature rise were evaluated through percent change in yield over control (normal condition) by using WTGROWS-model.

Under normal temperature conditions (no temperature change), the effect of variability in winter rains under different irrigation levels (rainfed, limited, moderate and adequate) were evaluated for the above locations using same model.

The radiation change and temperature rise interaction was evaluated through growth and yield response of wheat for New Delhi and Patna environments. For this purpose, daily temperature change range from (–) 2 to 3 °C (with increment level of 1 °C) and daily radiation change, expressed as fraction of the normal values, ranged from 0.6 to 1.25. The reduced amount of solar radiation reaching the earth surface is assumed to be due to aerosol presence in the atmosphere. The interaction effect of temperature and radiation change was also evaluated through grain yield and above-ground biomass (at maturity) for New Delhi and Patna environments by running the same model. For these studies, normal agronomic management practices were considered for running of the crop model.

RESULTS AND DISCUSSION

In general, the optimal sowing dates in the regions of north-west India were relatively earlier when compared with the regions in the eastern part (Fig. 1). With increase in temperature by 1-3 °C, the

Table 1: Locations of study with latitude and longitude

Sl. No.	Location	Latitude (degree – N)	Longitude (degree - E)
1.	Agra	27.2	78.0
2.	Chandigarh	30.7	76.8
3.	Delhi	28.6	77.2
4.	Hissar	29.2	75.7
5.	Jalundhar	31.3	75.6
6.	Kanpur	26.5	80.4
7.	Pantnagar	29.0	79.5
8.	Patna	25.5	85.2
9.	Saharanpur	29.9	77.5
10.	Samastipur	25.9	85.8

optimal sowing dates advanced by 5-8 days per degree rise in temperature. The degree of advancement was lower in the relatively colder regions. Attainable wheat yields in various regions under temperature change (1-3 °C) scenarios, clearly indicated a greater reduction in yields with the magnitude of the temperature rise. The reduction in wheat yields had association with the latitudes (Fig.2). At higher latitudes, the percent reduction was relatively lower under 2-3 °C change; whereas reverse in trends was noticed under 1 °C rise in seasonal temperatures.

Interaction of temperature with the rainfall changes was simulated by WTGROWS-model for wheat grown at different locations under rainfed condition. The sowing dates for locations were the optimal dates under the control condition. The changes in the rainfall were designed for the per cent reduction/increase in the rainfall amounts, but the numbers of the rainy day events during the growing period were not altered. The per cent change in the wheat yield from the corresponding value under the control (no rainfall change) is shown for the respective temperature change scenario. The interaction effect of the rainfall and temperature on wheat yield in various agro-environments is depicted in the Fig. 3.

Under normal temperature condition (no change) at Jullundur wheat yield was reduced by 4-5 per cent due to 5-15 per cent less rainfall, while, yield increased by 8-19 per cent due to increase in amount of rainfall by 10-20 per cent. However at Patna 15 per cent reduction in rainfall caused 5 per cent decrease and 20 per cent increase in rainfall yielded 5 per cent more over normal, where as the increase in yield was only 2 per cent at Delhi. Beyond it there was no significant change in yield whereas, 10-15 per cent decrease in rainfall caused 4-7 per cent reduction in yield over normal. No noticeable effect of change in rainfall on wheat yield was obtained at Kanpur.

Under 1 °C temperature rise condition at Patna 5-15 per cent decrease in rainfall caused 7-15 per cent reduction in wheat yield over normal, whereas, an increase of

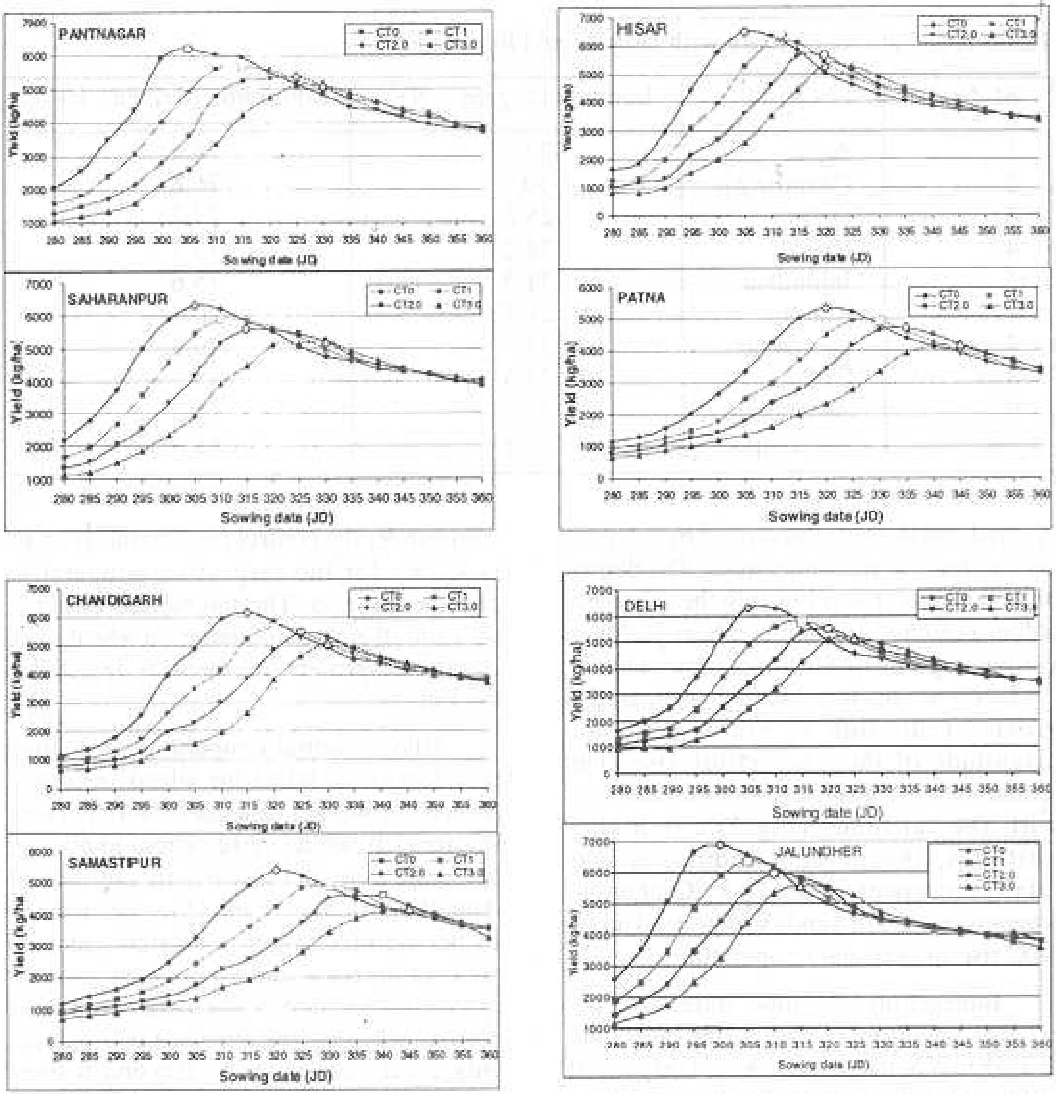

Fig. 1 : Effect of sowing dates and temperature rise (CT) on attainable yield of wheat in different agro-environments

5-20 percent rainfall yielded 2-12 per cent more yield over normal. However at Delhi 11-15 per cent reduction in yield was caused by 5-15 per cent decrease in rainfall. There was no noticeably decrease in yield over normal due to 5-15 per cent reduction in rainfall at Jullundur, but an increase of 5-14 per cent in yield over normal was noticed due to 10-20 per cent increase in rainfall.

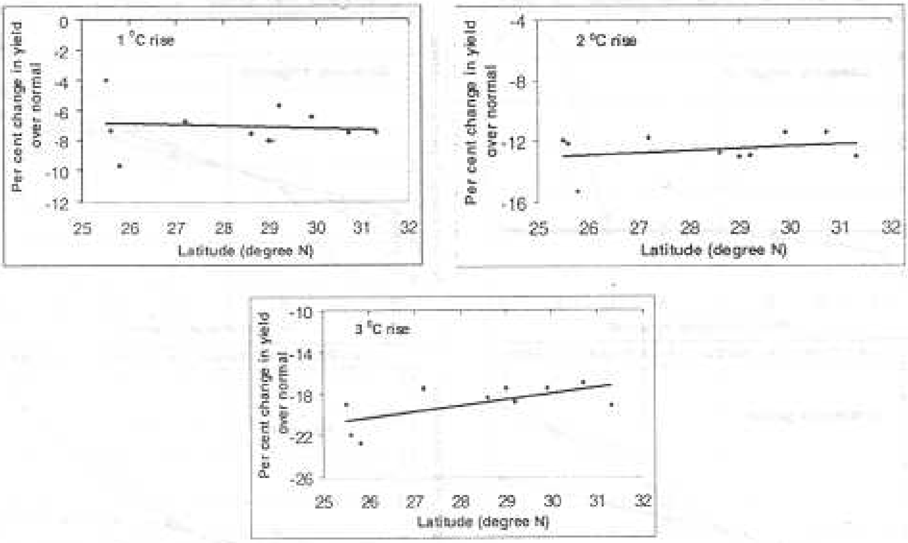

Fig. 2 : Effect of temperature rise on per cent change in attainable yield of wheat with latitude

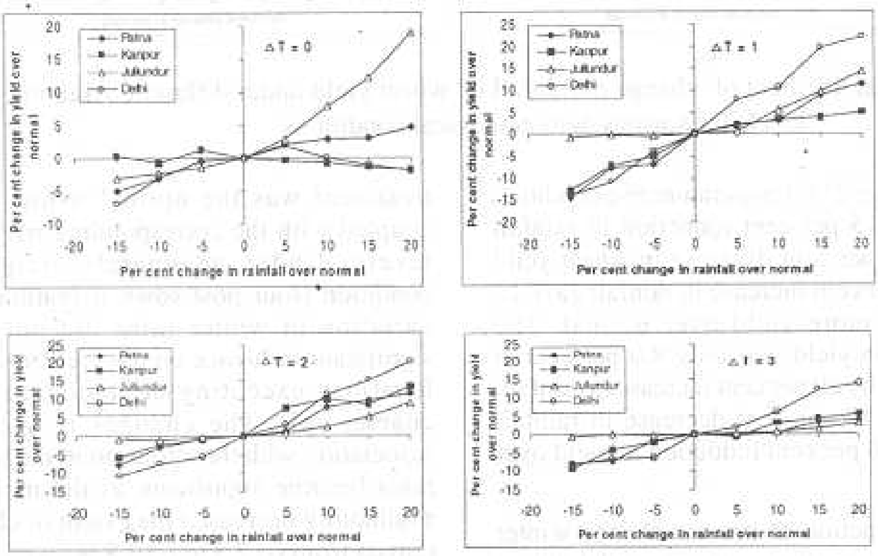

Fig. 3: Effect of changes in amount of winter rains on per cent change in yield of wheat under temperature rise

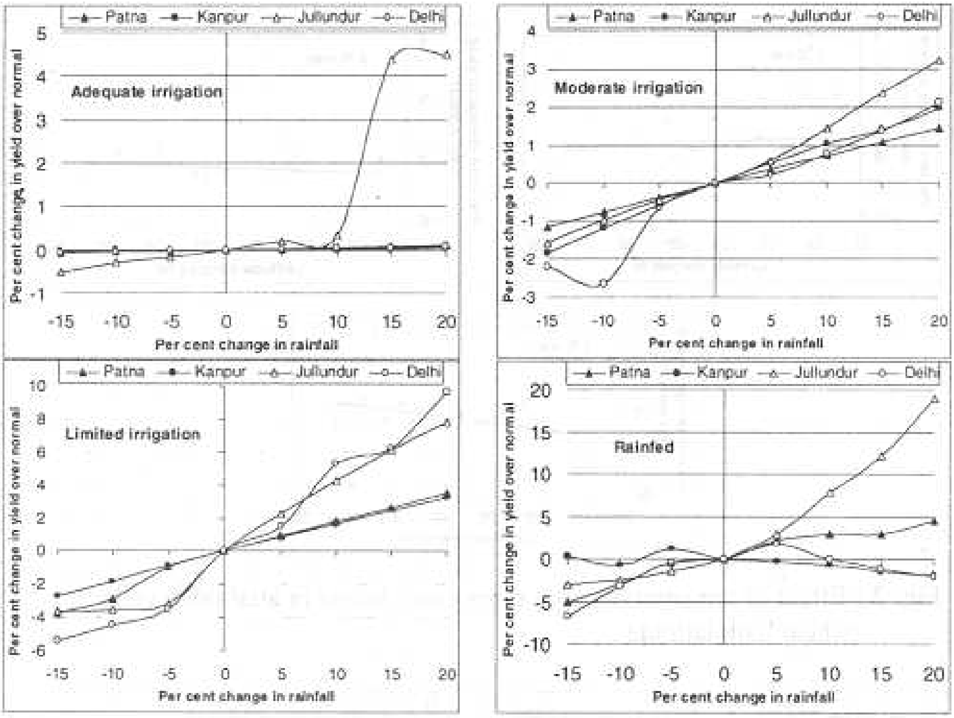

Fig. 4: Effect of change in rainfall on wheat yield under different irrigation levels for various agro-ecological conditions

Under 2 °C temperature rise condition at Patna 15 per cent reduction in rainfall caused 8 per cent decrease in wheat yeild and 20 per cent increase in rainfall gave 12 per cent more yield over normal. The increase in yield was only 8.0 per cent at Jullundur by 20 per cent increase in rainfall, whereas, 15 per cent decrease in rainfall caused 5.0 per cent reduction in yield over normal.

Interaction of percent change winter rains with varying moisture availability at four diverse locations was evaluated through changes in yield over control (Fig. 4). The control for each irrigation treatment was the normal winter rains coupled with the corresponding irrigation levels. Under adequately irrigation condition (four post sown irrigation), the variation in winter rains did not have significant influence on the yield at all the locations excepting at Jalundhar with coarser soil. The changes in yield in association with the variation in the winter rains became significant as the moisture availability decreased the extent of change ranged from (-) 2.3 to (-) 3.8 % (with 15 % decrease in winter rains to 1.5–3.2 % (with 20 % increase in the winter rains) under moderately irrigated condition (two post

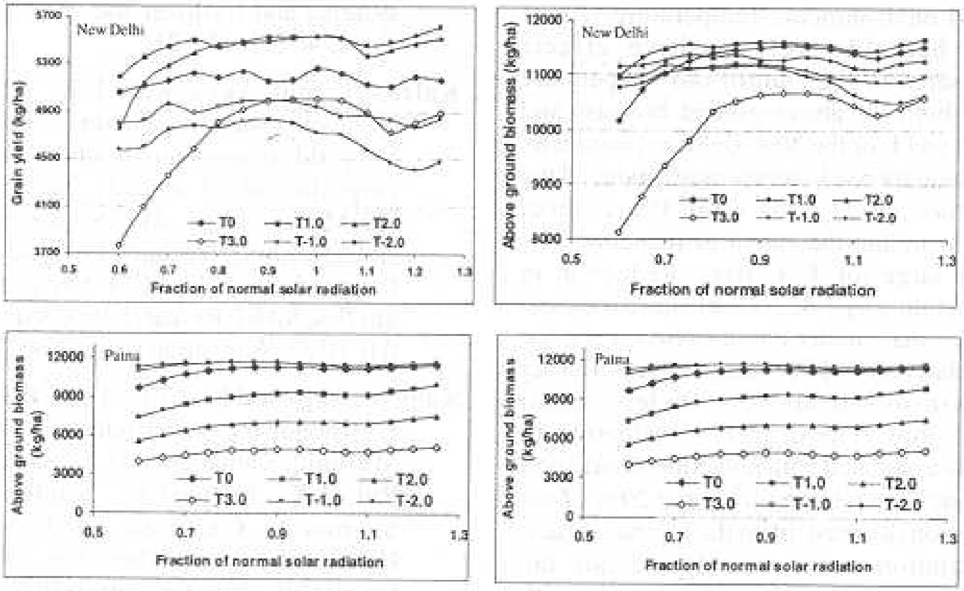

Fig. 5 : Radiation and temperature change interaction on growth and yield of wheat at New Delhi and Patna environment

sown irrigation at CRI and flowering stages). The extent of changes in yield over control was nominal for all the four locations even under this level of irrigation treatment. But under limited moisture avaibility (one post sown irrigation at CRI stage) the range of variation increased. The range became more wider under rainfed condition (no post sown irrigation).

It is well known fact that solar radiation is the only source of energy either directly or indirectly for the ecosystem in the universe. Recently it has been noticed that due to anthropogenic activities, interception of radiation on the earth surface has been disturbed. WTGROWS was used to evaluate the interaction of radiation with temperature for wheat in New Delhi and Patna environments (Fig.5). The management practices assumed were for maximum attainable wheat yields. Daily change in radiation from (–) 40% to 25% was considered at 5% interval for both the locations to run the model to evaluate the maximum possible effect of radiation change with the interaction of projected temperature change on wheat yield. Interaction of the radiation with temperature change ranging from (–) 2.0 to 3.0 with an incremental value of 1°C was associated. The results were compared for above-ground biomass at harvest and final grain yield.

In general, the above-ground biomass and grain yield reduced gradually with reduction in the radiation from the normal value, the trend was more consistent for Patna environment in comparison to New

Delhi environment. Temperature rise of 1°C had relatively positive effects compared to the control (no temperature rise) both for above-ground biomass and grain yield for the New Delhi environment. Subsequent rise in temperature reduced the biomass and yield over the control treatment and the extent of reduction was quite large for 3 °C rise. Reduction in temperature by 1 & 2 °C enhanced the yield and biomass under Patna environment due to relatively higher temperatures during growth of wheat crops under normal conditions. The degree of reduction in yields associated with reduction in radiation amounts is not large till around 20 % of the radiation decrease from the normal values. Simulation results clearly indicate the significant interaction of radiation with temperature as far as growth and yield of crops are concerned.

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