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# Effect of Possible Futuristic Climate Change Scenarios on Productivity of Some *kharif* and *rabi* Crops in the Central Agroclimatic Zone of Punjab

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**ABSTRACT**

Dynamic crop growth simulation models CERES-Rice for rice crop, PNUTGRO for groundnut, SOYGRO for soybean, CERES-Wheat for wheat crop, and CHICKPGRO for gram were used to study the effect of climate change on growth and yield of crops at Ludhiana under non-limiting water and nitrogen availability conditions representing central Agroclimatic zone of Punjab. Analysis of recent 30 year historical weather data of Ludhiana has revealed an increase in minimum temperatures (0.07°C/year), decrease in maximum temperatures (0.02 °C/year) and an increase in rainfall (10.5 mm/year). Keeping in view the changes in climate variability, growth and yield of these crops were simulated under selected synthetic climatic scenarios of changes in temperature (maximum and minimum) and solar radiation. In general with an increase in temperature above normal, the phonological stages of *rabi* season crops (wheat and gram) were advanced, whereas similar changes in *kharif* season crops (rice, groundnut and soybean) were less sensitive. With an increase in temperature upto 1.0 °C the yield of rice, wheat, and groundnut decreased by 3, 10, and 4% respectively. However, some increase in temperature was found favourable for yield of gram and soybean. An increase in solar radiation by 5% increased the yield of rice, wheat, groundnut, gram and soybean by 6, 3, 8, 4 and 2% respectively. The interaction effect of increasing minimum temperature but decreasing maximum temperature revealed that the growth and yield of crops was adversely affected by increasing minimum temperatures while, the decreasing maximum temperatures were able to partially counteract the adverse effect only upto a certain limit. When the mean temperature increased by 1.0 °C and solar radiation decreased by 5% from normal, the grain yield of wheat, rice, groundnut and soybean decreased by 14, 9, 7 and 0.5% respectively from normal.

## Introduction

The past decade has witnessed a rapid increase in the awareness of global climatic changes and triggered widespread apprehension amongst scientist and governments about the implications for their part of the globe (Gadgil, 1996). The major environmental concern regarding increased concentration of $CO_2$ and other trace gases is their greenhouse potential, i.e. their ability to trap solar energy in the atmosphere thereby causing global warming and other changes in the world's climate (Houghton *et al*., 1996). Wigley (1989) projected a warming of 0.5 °C by 1995-2005, 1.5 °C by 2015-2050 and 3.0 °C by 2050-2100. Hume and Cattle (1990) have reported that although the solar radiation received at the surface will be variable geographically but on an average it is expected to decrease slightly by about 1 percent. Hundal and Prabhjyot-Kaur (2002a) also reported a gradual increase in minimum temperature of (0.07 °C per year) over the past 30 years at Ludhiana. Hundal and Prabhjyot-Kaur (2002b) analysed rainfall data at different locations in Punjab and reported that five yearly moving average trend in annual rainfall showed an overall increase of about 120mm at Amritsar, 150mm at Ludhiana, 150mm at Patiala and 140mm at Bathinda, during past 30 years.

Recent studies on plausible changes in climate explored by global climate models (GCMs) suggest that in addition to thermal stress due to global warming, stress on water availability in tropical Asia is likely to be exacerbated in future (IPCC, 1996). Rao *et al* (1994) conducted a study on implications of climate change for India and concluded that cereal production is estimated to decrease and nutrition security of the population-rich but land-hungry region of India would be hampered. The effects of increased levels of $CO_2$ are generally beneficial to vegetation (Farquahar, 1997) though global warming and other climatic changes may have a range of negative or positive impacts depending on complex interactions among managed and unmanaged ecosystems (Watson *et al*., 1996).

Simulation techniques are easy and time saving for studying the influence of climatic variability on growth, development and yield of the crops. Peart *et al* (1989) employed simulation technique for studying the effect of climate change on crop yields in south eastern USA. Several such attempts have been made for predicting yield of wheat (Mearns *et al*., 1996), soybean (Haskett *et al*.,1997), rice (Bachelet and Geym, 1993; Olszyk *et al*., 1999) soybean and maize (Sinclair and Rawlins, 1993) and wheat, rice, maize and groundnut (Hundal and Prabhjot-Kaur, 1996) under modified climatic conditions. In this study, the effects of increasing / decreasing temperature and increasing decreasing radiation amounts and interaction of temperature and radiation on growth and yield of crops under Punjab conditions are presented by using dynamic plant growth and yield simulation models.

## Materials and Methods

### *Crop Model*

Crop growth and yield were simulated with dynamic simulation models of CERES-Rice (Ritchie *et al*, 1989 and Mallick, 2001), CERES-Wheat (Godwin *et al*, 1990), PNUTGRO (Boote *et al*, 1987), SOYGRO (Pickering *et al*, 1995) and CHICKPGRO for rice, wheat, groundnut, soybean and gram, respectively under modified climatic scenarios. These models require weather, soil and crop data for simulating the crop phenology, growth and various yield characteristics. The crop models used in the study: CERES-Rice (Prabhjyot-kaur and Hundal, 2001), CERES-Wheat (Hundal and Prabhjyot-Kaur, 1997), PNUTGRO (Prabhjyot-Kaur and Hundal, 1999) and SOYGRO (Prabhjyot-Kaur and Hundal, 2002) have been validated under Ludhiana (Punjab) environmental conditions for the commonly sown cultivars.

The soil and weather data used in the study were collected from Punjab Agricultural University, Ludhiana, located at 30°54′N latitude and 75°48′E longitude at an elevation of 247 m above sea level. This location represents the central irrigated plains of the Indian Punjab in which rice and wheat are the major crops.

### *Climatic Scenarios*

Normals of historical weather data were worked out for maximum and minimum temperatures, rainfall and solar radiation for Ludhiana (Punjab) on daily basis from January to December using data for the past 30 years (1970-1999) obtained from the meteorological observatory of the Punjab Agricultural University.

Rice, wheat, groundnut, soybean and chickpea are grown under irrigated conditions in Punjab and hence optimum (non-limiting) moisture conditions were assumed. The simulations were made with the assumption that nutrition was non-limiting and there were no losses from insect-pests.

On the basis of climatic variability trends observed in the state, anticipated synthetic scenarios of increase or decrease from normal temperature, interactions of maximum and minimum temperature and solar radiation were generated for the simulation study. One variable at a time was modified and its effect on crop growth and yield was simulated while taking all the other climate variables to be normal. The major reason for using incremental variable scenarios being that they capture a wide range of potential changes. Subsequently, the combination of two variables was interactively modified to assess their combinent effect on crop growth and yield.

## Results and Discussion

### *Temperature Effects*

The phenological development, growth and yield attributes of crops were simulated when both maximum and minimum temperatures were increased or decreased by 0.5, 1.0, 2.0 and 3.0°C from normal while keeping the other climate variables constant. Phenological development of *kharif* crops, i.e., rice, groundnut and soybean was not much affected by increase or decrease in temperature of 1.0°C from normal (Table 1). On the other hand, phenological development of wheat and gram (*rabi* crops) revealed more drastic changes as the phenology was significantly advanced by increasing temperature but was delayed by decreasing temperature.

The growth and yield of crops was reduced by an increase in temperature but increased with decrease in temperature from normal (Table 2). Both the reduction and the increase were more for *rabi* crops (wheat and gram) than for *kharif* crops (rice, groundnut and soybean). With an increase in temperature by 1.0 to 2.0°C, the simulated maximum leaf area index (LAI) in rice decreased by 3.5 to 9.2%, in groundnut by 3.4 to 5.8%, in soybean by 0.3 to 3.0% and in wheat by 18.4 to 29.2% from normal; biomass yield in rice decreased by 2.3 to 5.0% in groundnut by 2.7 to 5.4%, in soybean by 1.2 to 3.4%, in wheat by 13.7 to 22.9%, and in gram by 8.8 to 15.1% from normal; grain/seed yield in rice decreased by 2.8 to 9.6%, in groundnut by 4.5 to 10.6%, and in wheat by 9.8 to 18.0% from normal. However, in gram crop, with an increase in temperature by 1.0 to 2.0°C, the simulated maximum leaf area index (LAI) increased by 17.9 to 37.0%, biomass yield increased by 8.8 to 15.1%, seed yield increased by 8.1 to 16.0% while seed yield in soybean also increased by 2.3 to 2.4% from normal.

A decrease in temperature by 1.0 to 2.0°C led to an increase in simulated maximum leaf area index (LAI) in rice by 3.1 to 5.2% and in

**Table 1.** Effect of increase or decrease in temperature from normal on deviations in phenology (days) of crops

| Phenological stages | Temperature level | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | -3.0°C | -2.0°C | -1.0°C | -0.5°C | Normal* | +0.5°C | +1.0°C | +2.0°C | +3.0°C |
| **Rice** | | | | | | | | | |
| Heading date | +5 | +2 | 0 | 0 | 223 | 0 | 0 | +1 | +4 |
| Maturity date | +12 | +6 | +2 | 0 | 263 | +1 | +1 | +1 | +5 |
| **Groundnut** | | | | | | | | | |
| Flowering date | 0 | 0 | -1 | 0 | 197 | 0 | 0 | +3 | +4 |
| Podding date | 0 | 0 | -1 | 0 | 218 | 0 | +1 | +5 | +4 |
| Maturity date | +6 | +2 | -1 | 0 | 285 | 0 | +2 | +5 | +9 |
| **Soybean** | | | | | | | | | |
| Flowering date | 0 | 0 | -1 | -1 | 239 | +1 | +2 | +3 | +4 |
| Podding date | 0 | 0 | 0 | 0 | 260 | +1 | +2 | +3 | +3 |
| Maturity date | +2 | +1 | 0 | 0 | 294 | +1 | +1 | +2 | +2 |
| **Wheat** | | | | | | | | | |
| Anthesis date | +25 | +17 | +8 | +3 | 41 | -3 | -6 | -12 | -16 |
| Maturity date | +22 | +15 | +8 | +4 | 81 | -3 | -6 | -12 | -17 |
| **Gram** | | | | | | | | | |
| Flowering date | +35 | +22 | +11 | +4 | 08 | -4 | -7 | -19 | -23 |
| Podding date | +34 | +23 | +12 | +5 | 30 | -4 | -9 | -16 | -22 |
| Maturity date | +27 | +18 | +9 | +4 | 99 | -5 | -8 | -16 | -24 |

*Julian day

**Table 2.** Effect of increase or decrease in temperature from normal on deviations (per cent) in growth and yield attributes of crops

| Grain/yield | Temperature level | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| attributes | -3.0°C | -2.0°C | -1.0°C | -0.5°C | Normal | +0.5°C | +1.0°C | +2.0°C | +3.0°C |
| **Rice** | | | | | | | | | |
| Maximum LAI | +7.69 | +5.24 | +3.15 | +1.22 | 5.72• | -1.75 | -3.50 | -9.26 | -12.94 |
| Grain yield | +26.81 | +15.15 | +8.07 | +6.56 | 6692♦ | -0.16 | -2.82 | -9.59 | -10.14 |
| Biomass yield | +19.93 | 9.92 | +4.35 | +2.93 | 11717♦ | -0.94 | -2.35 | -5.02 | -6.06 |
| **Groundnut** | | | | | | | | | |
| Maximum LAI | +17.10 | +11.65 | +6.02 | +3.76 | 5.32• | -1.13 | -3.38 | -5.82 | -7.70 |
| Seed yield | +27.75 | +16.53 | +6.21 | +5.31 | 998♦ | -4.01 | -4.51 | -10.62 | -13.13 |
| Biomass yield | +20.50 | +12.33 | +4.98 | +4.37 | 11467♦ | -2.19 | -2.79 | -5.42 | -7.91 |
| **Soybean** | | | | | | | | | |
| Maximum LAI | +3.05 | +3.21 | +0.76 | -0.15 | 6.55• | -0.31 | -0.31 | -3.05 | -7.63 |
| Seed yield | +9.85 | +7.38 | +7.16 | +6.26 | 1982♦ | -2.75 | -9.87 | -18.02 | -27.03 |
| Biomass yield | +20.84 | +16.07 | +9.12 | +4.11 | 7369♦ | -4.60 | -13.76 | -22.87 | -32.35 |
| **Wheat** | | | | | | | | | |
| Maximum LAI | +41.08 | +27.84 | +11.62 | +5.14 | 3.70• | -5.94 | -18.38 | -29.19 | -38.90 |
| Grain yield | +9.85 | +7.38 | +7.16 | +6.26 | 4932♦ | -2.75 | -9.87 | -18.02 | -27.03 |
| Biomass yield | +20.84 | +16.07 | +9.12 | +4.11 | 13304♦ | -4.60 | -13.76 | -22.87 | -32.35 |
| **Gram** | | | | | | | | | |
| Maximum LAI | -30.30 | -21.30 | -10.11 | -7.86 | 0.89• | +7.86 | +17.97 | +37.08 | +47.19 |
| Seed yield | -17.87 | -13.94 | -7.24 | -7.04 | 1449♦ | +0.21 | +8.14 | +16.01 | +17.87 |
| Biomass yield | -23.50 | -16.17 | -7.51 | -6.14 | 3808♦ | +2.25 | +8.85 | +15.15 | +14.20 |

• Maximum LAI (No unit) ♦ Grain/biomass yield (kg/ha)

wheat by 11.6 to 27.8% from normal; simulated biomass yield in rice by 4.3 to 9.9%; in groundnut by 4.9 to 12.3%, in soybean by 0.8 to 1.1% and in wheat by 9.1 to 16.1%; grain/seed yield in rice by 8.0 to 15.1%, in groundnut by 6.2 to 16.5%, and in wheat by 7.2 to 7.4% from normal. On the other hand, with a decrease in temperature by 1.0 to 2.0°C, the simulated maximum leaf area index (LAI) in gram decreased by 10.1 to 21.3%, biomass yield decreased by 7.5 to 16.1%, seed yield decreased by 7.2 to 13.9% while seed yield in soybean also decreased by 1.6 to 4.3% from normal.

### *Solar Radiation Effects*

The effects of increase or decrease in solar radiation on growth and yield of crops are shown in Table 3. In general, increase in solar radiation favoured the growth and yield whereas the decrease in solar radiation favoured reduction in growth and yield of crops. With an increase in solar radiation by 5.0%, the simulated maximum leaf area index (LAI) increased in rice by 2.6%, in groundnut by 5.8%, in wheat by 4.0%, and in gram by 2.2% from normal; biomass yield increased in rice by 4.6%, in groundnut by 7.4%, in soybean by 1.0%, in wheat by 3.9% and in gram by 3.6% from normal; grain/seed yield increased in rice by 6.2%., in groundnut by 7.7%, in soybean by 2.3%, in wheat by 3.6%, and in gram by 3.5% from normal. On the other hand, with a decrease in solar radiation by 5.0%, the simulated maximum leaf area index (LAI) decreased in rice by 2.7%, I groundnut by 1.1% and in wheat by 4.5% from normal; biomass yield decreased in rice by 4.4% in groundnut by 2.7%, in soybean by 2.8%, in wheat by 4.3%, and in gram by 4.0% from normal; grain/seed yield decreased in rice by 6.0%, in groundnut by 3.1%, in soybean by 2.8% in wheat by 3.8%, and in gram by 4.0% from normal.

**Table 3.** Effect of increase or decrease in radiation from normal on deviations (per cent) in growth and yield attributes of crops

| Grain/yield attributes | Radiation level (Per cent deviation from normal) | | | | | | |
|---|---|---|---|---|---|---|---|
| | -5.0 | -2.5 | -1.0 | Normal | +1.0 | +2.5 | +5.0 |
| **Rice** | | | | | | | |
| Maximum LAI | -2.79 | -1.39 | -0.52 | 5.72• | +0.52 | +1.57 | +2.62 |
| Grain yield | -6.00 | -3.00 | -1.19 | 6692♦ | +1.19 | +3.19 | +6.20 |
| Biomass yield | -4.44 | -2.19 | -0.86 | 11717♦ | +0.86 | +3.03 | +4.63 |
| **Groundnut** | | | | | | | |
| Maximum LAI | -1.13 | +0.56 | +1.69 | 5.32• | +3.01 | +4.13 | +5.82 |
| Seed yield | -3.11 | -0.40 | +1.30 | 998♦ | +3.41 | +5.01 | +7.72 |
| Biomass yield | -2.78 | -0.20 | +1.33 | 11467♦ | +3.37 | +4.89 | +7.40 |
| **Soybean** | | | | | | | |
| Maximum LAI | 0.00 | 0.00 | 0.00 | 6.55• | -0.15 | -0.31 | -0.61 |
| Seed yield | -2.87 | -1.36 | -0.50 | 1982♦ | +0.55 | +1.26 | +2.32 |
| Biomass yield | -2.89 | -1.39 | -0.05 | 7369♦ | +0.53 | +0.91 | +1.03 |
| **Wheat** | | | | | | | |
| Maximum LAI | -4.59 | -2.16 | -0.81 | 3.70• | +0.81 | +2.16 | +4.05 |
| Grain yield | -3.85 | -1.90 | -0.75 | 4932♦ | +0.75 | +1.84 | +3.65 |
| Biomass yield | -4.38 | -2.12 | -0.83 | 13304♦ | +0.83 | +2.02 | +3.95 |
| **Gram** | | | | | | | |
| Maximum LAI | 0.00 | -1.12 | 0.00 | 0.89• | 0.00 | 0.00 | +2.25 |
| Seed yield | -4.00 | -1.93 | -0.76 | 1449♦ | +0.69 | +1.79 | +3.59 |
| Biomass yield | -4.02 | -1.94 | -0.76 | 3808♦ | +0.76 | +1.89 | +3.68 |

• Maximum LAI (No unit) ♦ Grain/biomass yield (kg/ha)

### *Maximum and Minimum Temperature Interaction Effects*

When the maximum temperature decreased by 0.25 to 1.0°C from normal and minimum temperature increased simultaneously from 1 to 3 °C from normal keeping the other climate variables constant, the phenology of rice, wheat and gram were advanced by as much as 1 to 15 days (Table 4). When the minimum temperature increased by 1.0 to 3.0 °C and maximum temperature decreased by 0.25 to 1.0 °C from normal, the heading in rice was advanced by 1 to 4 days while the physiological maturity was advanced by 2 to 8 days from normal; in groundnut physiological maturity was advanced by 1 to 3 days from normal; in wheat both the anthesis and maturity were advanced by upto 8 days from normal; and in gram flowering was advanced by 2 to 11 days while podding and physiological maturity were advanced by 2 to 15 days from normal. Whereas under similar interactive scenario of decreasing maximum temperature and increasing minimum temperature the phenological development of soybean was delayed by 1 to 3 days from normal.

The effect of increasing minimum temperature and decreasing maximum temperature on simulated maximum LAI, biomass yield and grain/ seed crops was studied. In general, maximum LAI, biomass yield and grain/seed yield of crops were adversely affected by increasing the minimum temperature from normal. However these adverse effects were partially counteracted by decreasing maximum temperature from normal. When minimum temperature increased by 1.0 °C and maximum temperature decreased by 0.25 to 1.0 °C from normal, the deviations in growth and yield attributes were low and the yields were not affected significantly. At further higher levels of increase in minimum temperature, reductions in

**Table 4.** Effect of increasing minimum temperature and decreasing maximum temperature on deviations (days) in phenology of crops

| Phenological stages | Minimum temperature | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | At + 1.0 °C | | | At + 2.0 °C | | | At + 3.0 °C | | |
| | Maximum temperature | | | Maximum temperature | | | Maximum temperature | | |
| | -0.25 °C | -0.5 °C | -1.0 °C | -0.25 °C | -0.5 °C | -1.0 °C | -0.25 °C | -0.5 °C | -1.0 °C |
| **Rice** | | | | | | | | | |
| Heading date | -1 | -1 | -2 | -2 | -3 | -3 | -4 | -4 | -4 |
| Maturity date | -2 | -2 | -3 | -4 | -5 | -4 | -7 | -8 | -8 |
| **Groundnut** | | | | | | | | | |
| Flowering date | 0 | 0 | -1 | 0 | 0 | 0 | +1 | 0 | 0 |
| Podding date | 0 | 0 | -1 | 0 | 0 | 0 | +1 | 0 | 0 |
| Maturity date | -2 | -2 | -3 | -2 | -2 | -3 | -1 | -2 | -3 |
| **Soybean** | | | | | | | | | |
| Flowering date | +1 | +1 | +1 | +1 | +1 | +1 | +3 | +3 | +2 |
| Podding date | +1 | +1 | +1 | +1 | +1 | +1 | +2 | +2 | +2 |
| Maturity date | 0 | 0 | 0 | 0 | 0 | 0 | +1 | +1 | +1 |
| **Wheat** | | | | | | | | | |
| Anthesis date | -2 | -2 | 0 | -6 | -4 | -3 | -8 | -8 | -6 |
| Maturity date | -1 | -1 | +1 | -5 | -4 | -3 | -8 | -7 | -6 |
| **Gram** | | | | | | | | | |
| Flowering date | -3 | -3 | -2 | -5 | -5 | -6 | -11 | -10 | -9 |
| Podding date | -4 | -4 | -2 | -10 | -10 | -7 | -15 | -14 | -13 |
| Maturity date | -4 | -4 | -2 | -10 | -9 | -8 | -15 | -14 | -13 |

growth and yield were greater and more so in *rabi* season crops (wheat and gram) than in *Kharif* season crops (rice, groundnut and soybean).

### *Temperature and Radiation Interaction Effects*

The effect of increasing temperature (by 1, 2 and 3 °C from normal), and decreasing radiation levels (by 1, 2 and 5%) on maximum LAI, biomass and grain yield of crops was explored. When temperature increased by 1 °C and radiation levels decreased by 1, 2.5 and 5% from normal, the maximum LAI decreased respectively, in rice by 4.0, 4.9 and 6.6%, in groundnut by 1.3, 2.2 and 3.9%, and in wheat by 19.2, 20.8 and 23.2% from normal. Under same levels of temperature and radiation, the grain/seed yield decreased respectively, in rice by 4.0, 5.8 and 8.9%, in groundnut by 2.7, 4.2 and 6.8% and in wheat by 10.7, 11.9 and 14.1% from normal, whereas the biomass yield in rice decreased by 3.3, 4.7 and 7.1% in groundnut by 0.9, 2.4 and 4.9%, and in wheat by 14.7, 16.1 and 18.4% from normal. The interactive effects of increasing temperature and decreasing radiation revealed a cumulative adverse effect on growth and yield of rice, groundnut, soybean and wheat. While similar response was not observed for gram.

### *Limitations of Simulation Study*

The objective of this study using the simulation models for rice, groundnut, soybean, wheat and gram was to assess the effect of probabilistic climate change scenarios on growth duration and yield of crops. Crop simulation models are able to analyse how weather and genetic traits can affect the potential productivity under given set of management practices. The major limitations of such simulation studies are listed below:

- The effect of nutrients other than nitrogen are not simulated.

- The temperature are increasing as a consequence of greenhouse gases including carbon deoxide. The positive role of carbon dioxide in enhancing photosynthesis and yield of $C_3$ crops is expected to counteract the negative effects of increase in temperature and decrease in solar radiation. Such interactive effects of carbon dioxide increase are not accounted for in some simulation studies.
- The adverse effects of extreme weather hazards, weeds, insect-pests and disease damage are not considered in simulation models.
- Moreover, rise in ambient air temperature coupled with enhanced precipitation levels may create favourable conditions for pest and disease infestation in tropical countries like India. Such interactions are not accounted for in simulation studies.

However, despite limitations such simulation studies can guide us in assessing the effect of climate changes on direction of changes in phonological development, growth and yield of crops but the results should be viewed in lighted of above limitations.

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