J. Agr. Met. 48(5): 811 – 814, 1993

Effect of Probable Increase in Carbon Dioxide and Temperature on Wheat Yields in India

P.K. Aggarwal and S.K. Sinha

Water Technology Center
Indian Agricultural Research Institute
New Delhi - 110 012, India

Abstract

Effect of increase in carbon dioxide and temperature on growth, development, water use and grain yield of wheat was simulated for several locations of India using a dynamic crop growth simulation model, WTGROWS. Long term average weather data and average soil properties for various agro-ecological zones were input in the model. The effect of climate change on productivity was dependent upon the magnitude of temperature change. At 425 ppm CO_2 concentration and no rise in temperature, grain yield at all levels of production increased significantly. In northern India, a 1°C rise in mean temperature had no significant effect on potential yields but irrigated and rainfed yields increased in most places. An increase of 2°C in temperature reduced potential grain yields at most places. The effect on irrigated and rainfed productivity varied with location. The natural climatic variability also had considerable effect on the magnitude of response to climate change. Evapotranspiration was reduced in irrigated as well as rainfed environments.The responses to climate change were closely related to the effects of increased temperature on crop duration.

Key words: climate change, crop-weather model, wheat, productivity, CO_2, temperature

1. Introduction

Wheat is an important cereal crop of India and is grown from 15° to 32 °, from 72 E to 92 E and from sea level to fairly high altitudes. Wheat crop season extends from late October to early May. More than eighty percent wheat is irrigated although not all areas receive the desired number of irrigations. The fertilizer applications are modest, ranging from very small amounts to 120 Kg/ha. The average productivity of wheat ranges from 650 Kg/ha to 4500 Kg/ha depending upon the region. The total production of wheat in 1991 was 56 M tons. It is estimated that the demand for wheat is likely to be 72 M and over 100 M tons by 2000 and 2025 AD, respectively.

Since wheat is grown at widely varying latitudes, the crop experiences different temperatures during the crop season. The mean temperatures during crop season is 16°C in northern region, 20°C in eastern and 23°C in central and peninsular India. Due to intensive cropping practiced in most irrigated areas, a large proportion of wheat is sown later than the optimal time. Due to this delay, grain filling period occurs in relatively higher temperatures. Since the main features of probable climate change are increase in temperature and carbon dioxide, we have examined in this paper the effects these projected changes will have on wheat growth, development and yield.

2. Methodology

Climate change scenarios- Inter- Government Panel on Climate Change of WMO has estimated that CO_2 levels are rising by 1.8 ppmv per year (Houghton 1991). Mean temperature increase is expected to be 0.3°C per decade for India. Rainfall is assumed to remain same during winter season. Therefore, for 2030 AD, it is estimated that CO_2 level will be 425 ppm and temperature will increase by 1.25°C over 1990 base values. Temperature increase may be still higher in specific regions while maintaining an average temperature increase of 1.7° C within the grid (Sinha and Swaminanthan 1991). For the present paper, we have assumed climate change scenario for 2030 AD as predicted by IPCC. Since there is uncertainty about the magnitude of temperature rise, analysis has been done assuming a uniform rise in mean temperature of 0, 1 and 2°C all over India.

Simulation. The methodology followed in this paper is similar to the one described by Aggarwal (1991). We have used a dynamic crop growth simulation model WTGROWS, developed to describe the effect of various climatic factors and their variability, soil characteristics, agronomic management and physiological factors on wheat growth, development, water and nitrogen use.(Aggarwal et al 1992 in preparation). The primary structure of the model is based on MACROS (Penning de Vries et al. 1989) as adapted for determining wheat production potential in South-East Asia by Aggarwal and Penning de Vries (1989).The model includes the effect of temperature on all major physiological processes and assumes a 30 % increase in the rate of gross photosynthesis and specific leaf weight for the doubling of CO_2. Increase in CO_2 also effects transpiration due to increased resistance to water loss (Penning de Vries et al 1989). The magnitude of plant responses to higher CO_2 on a long term basis is still under investigation in many laboratories. In future, these could provide better data for use in the models.

Long-term average monthly weather data of 72 locations spread all over the wheat growing regions of the country were used for the analysis. The daily weather data was estimated by linear interpolation. In addition, daily weather data of last 18 years for New Delhi was used for estimating effect of climatic variability on grain yield and evapotranspiration in changed climate. Rainfall during crop season is small (50-100 mm). A representative rainfall distribution was used for the analysis. The geographical distribution of soils was obtained from the agro-ecological zones map of India (Sehgal et al 1990). In the present analysis, soil was assumed to be 150 cm deep and at 80% of the field capacity at the time of sowing.

The effect of climate change on productivity was simulated for normally sown crops at three levels of production-

1. **potential productivity** assuming no effect of water and nutrient stresses on crop growth.

2. **irrigated productivity**, assuming application of 120 (80+40) Kg/ha N and five irrigations during crop season.

3.**rainfed productivity**, assuming no irrigation and 50 Kg/ha basal N application.

The simulations were made for varieties of two maturity class - early duration (80-85 days to anthesis in New Delhi) and medium duration (90-100 days to anthesis). The highest yield obtained from these simulations was assumed to be the productivity in that scenario.

3. Results and Discussion

The potential yields in present weather varied from 2.7 t/ha to 8.0 t/ha depending upon the region. The irrigated and rainfed yields were lower and varied from 2.0 t/ha to 6.0 t/ha and from 0.5 t/ha to 4.5 t/ha, respectively. The effect of climate change on productivity was dependent upon the magnitude of temperature change. Figure 1 shows the effect of different scenarios on grain yield of irrigated wheat. At 425 ppm CO_2 concentration and no rise in temperature, grain yield at all levels of production increased significantly at all places. A 1°C rise in mean temperature had no significant effect on potential yields. Irrigated yields, however, showed a small increase in most places where current yields are greater than 3.5 t/ha. In central and peninsular India, where current irrigated yields are between 2 and 4 t/ha, the response varied from a significant decrease to a significant increase. Rainfed yields, however, showed a significant increase. An increase of 2°C in temperature reduced potential grain yields at most places (Figure 2). Relatively, for all places where current potential yields are above 5 t/ha, such as in northern India, the reduction was much smaller compared to places with lower potential productivity. In fact, for a few locations there was a small increase or no significant effect. Table 1 shows the mean yields for current and changed climate scenarios according to latitude. In sub-tropical (above 23 °) environments there was a small decrease in potential yields (1.5 to 5.8%) but in tropical locations the decrease was 17-18%. Irrigated yields were slightly increased for latitudes greater than 27 ° but were reduced at all other places. The decrease in yield was much higher in lower latitudes. Several locations, particularly where current rainfed yields are greater than 2 t/ha showed a very significant increase in rainfed yields with climate change (Figure 2). These locations are mostly above 27 °; the mean increase here was 28.57% (Table 1). Between 25 and 27 ° although rainfed yields in current

Figure 1. Effect of magnitude of temperature increase on grain yields of irrigated wheat in present and changed climate.

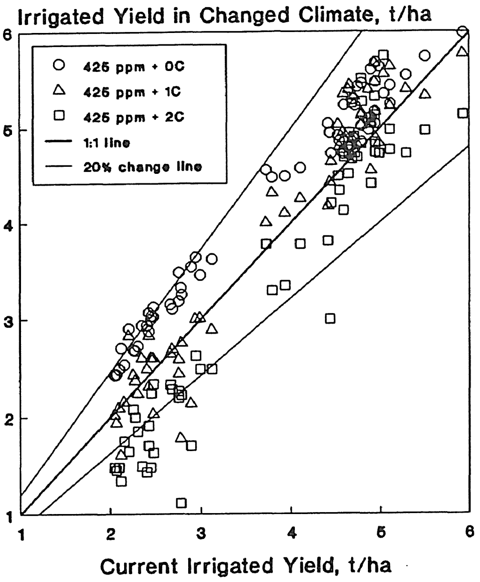


Figure 2. Effect of climate change (425 ppm CO_2 and 2° C increase in mean temperature) on potential, irrigated and rainfed productivity of wheat.

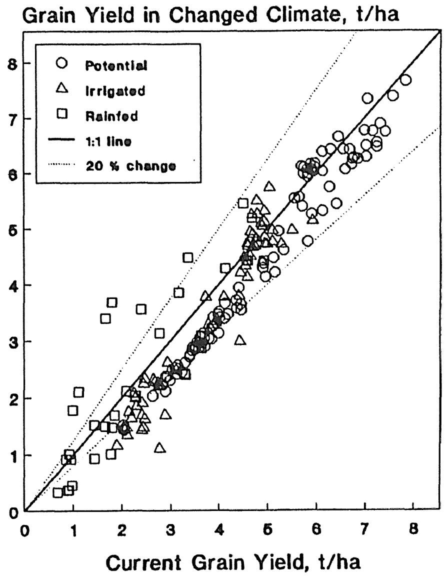
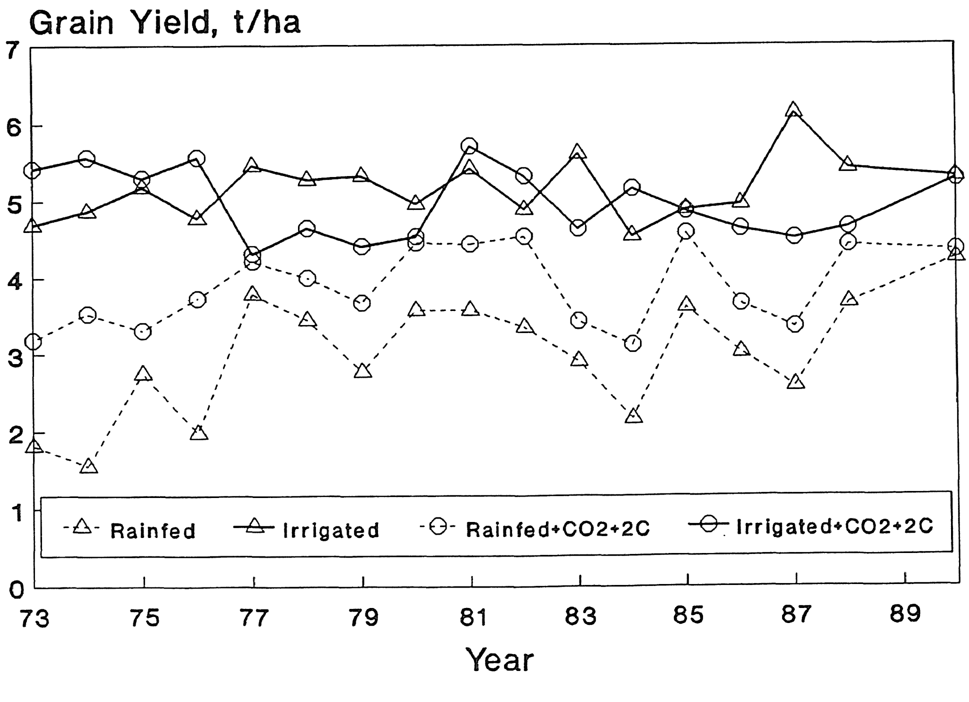


Table 1. Grain yields (t/ha) of wheat in current weather and percent change in response to climate change (425 ppm CO_2, 2°C increase in mean temperature) in different regions of India.

Region	Potential yield		Irrigated yield		Rainfed yield	
	Current	% change	Current	% change	Current	% change
> 27 N	6.66	- 3.85	4.89	+3.7	2.95	+28.6
25-27 N	5.84	- 1.54	4.78	- 4.4	3.34	- 7.2
23-25 N	5.86	- 5.6	4.18	-10.76	1.17	-19.6
20-23 N	4.18	-18.4	2.29	-18.3	0.51	-11.8
< 20 N	3.69	-17.3	2.43	-21.4	0.97	-23.9

Figure 3. Effect of climate change on grain yield of irrigated wheat in different years at New Delhi.



weather are high, there was a significant decrease in changed climate (Table 1).

The above results are based on mean long term weather data. The effect of climate change for a location may however vary depending upon the climatic variability. The effect of increase in CO_2 to 425 ppm and a 2°C rise in mean temperature was studied on irrigated and rainfed productivity and evapotranspiration for crops sown on 15 November every year for the period 1973 to 1990. Mean grain yield decreased by 6.2 % in irrigated environments and increased by 31 % in rainfed environments. However, depending upon the year, irrigated yields in changed climate were more, same or less than the current yields (Figure 3). Rainfed yields were always higher than the current yields, irrespective of the year.

In all years, climate change reduced evapotranspiration both in irrigated as well as rainfed environments. The mean ET for irrigated and rainfed treatments was 352 and 240 mm in current weather and 302 and 221 mm in changed climate. This reduction in ET, accompanied by CO_2 induced higher growth rates, resulted in considerable improvement in water use efficiency and hence in grain yield.

The above mentioned results were closely related to the effects of changed climate on crop duration. Depending upon the magnitude of temperature increase, crop duration, particularly the period upto anthesis, was reduced. In northern India, because of this reduction in pre-anthesis duration, grain filling was often shifted to relatively cooler temperatures of February thus enabling the crop to maintain reasonable grain filling duration in changed climate. In addition, the improved WUE and growth rates helped the crops to maintain adequate rates of growth. The simulations showed that if the crops are allowed to maintain same crop duration as in current weather, the effects of climate change are insignificant (data not shown).

4. Conclusions

The effect of climate change on wheat productivity is dependent upon the magnitude of temperature change. A one degree increase in temperature throughout the crop season will have no effect or slightly increase productivity in irrigated as well as rainfed environments, particularly in northern India wheat belt. A two degree increase in temperature will reduce potential yields but will have small effect on irrigated yields in northern India. ET will be significantly reduced in changed climate. Relatively, the effect of climate change will be more pronounced in central India where yield potential is already low. The crop responses to climate change are related to the effect of temperature on crop duration.

References

Aggarwal, P.K. 1991. Agro-ecological zoning using crop simulation models: Characterization of wheat environments of India. In *Systems Approach to Agricultural Development* (eds. F.W.T. Penning de Vries and P.S. Teng). Kluwer Academic Publishers, Netherlands, 97-109. (in press).

Aggarwal, P.K. and Penning de Vries, F.W.T. 1989: Potential and water limited wheat yields in rice based cropping systems in southeast asia. *Agric Systems*, **30**,49-69.

Houghton, J.H. 1991. Scientific assessment of climate change: summary of the IPCC working group I report. In *Climate change: science, impacts and policy* (eds. J. Jager and H.L. Ferguson). Cambridge university press, Cambridge, 23-44.

Penning de Vries, F.W.T., Jansen, D.M., Ten Berge, H.F.M. and Bakema, A.H.: 1989. *Simulation of ecophysiological processes in several annual crops*. Simulation Monographs. PUDOC, Netherlands, 217p.

Sinha, S.K. and Swaminathan, M.S. 1991: Deforestation, climate change and sustainable nutrition security: A case study of India. *Climatic Change* **19**, 201-209.

Sehgal, J.L., Mandal, D.K., Mandal, C. and Vadivelu, S.: 1990. *Agro-ecological regions of India*. Tech. Bull. NBSS Publ. 24, India, 24, 73p