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Impact assessment of climate change on wheat yield in Gujarat using CERES-wheat model

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ABSTRACT

CERES-wheat model was calibrated and validated with the field experimental data generated during the years 2004-05 and 2005-06 for wheat (cv. GW-496) at Anand. The results revealed that grain yield as simulated by the CERES-wheat model under higher temperatures regimes showed a gradual decrease in yield, while the lowering the temperatures increased the yield. The impact of maximum temperature was found to be more than that of minimum temperature. Increase in daily solar radiation (1 to 3 MJm^{-2}), resulted into increase in yield while decrease in solar radiation decreased the yield to the tune of 18 to 50 per cent over the base yield under optimal condition. The combined effect of radiation and temperatures was net reduction in yield. However, under higher CO_2 concentration, the net effect was found to increase the wheat yield. When carbon dioxide (CO_2) concentration was doubled, the grain yield increased up to 68 and 57 per cent under optimal and sub-optimal condition, respectively over the base yield.

Key words: CERES-wheat, simulation, climate change, radiation, CO_2 concentration

Wheat (*Triticum aestivum* L.) is one of the most important staple food crops of India and being grown under diverse set of agro-climatic conditions. Wheat growth is influenced by several factors such as genetic make up of the crop, soil, water regimes, agro-climatic environment. Use of crop simulation model provides a suitable tool to evaluate crop growth as affected by various management and environmental factors and their interaction. Similarly, possible effects of climate change on plant growth can be estimated and evaluated using the crop growth simulation models. Pathak *et al.* (2003) reported that decrease in solar radiation by 1.7 $MJm^{-2} day^{-1}$ reduced rice and wheat yields from 10.9 to 10.3 and 8.3 to 7.5 t ha^{-1}, respectively while increased minimum temperature by 1.7°C decreased yields of rice and wheat from 10.9 to 10.0 and 8.3 to 8.1 t ha^{-1}, respectively. Akula (2003) revealed from the results of WTGROWS model that increase in temperature of 1° to 5°C above the mean temperature decreased grain yield of wheat correspondingly from 5737 kg ha^{-1} to 4583 kg ha^{-1}. Looking to the above, an attempt has been made in the present investigation to analyze the impact of climate change on wheat yield using CERES-wheat model.

MATERIALS AND METHODS

The CERES-wheat model was calibrated and validated with the data sets generated during *rabi* seasons of 2004-2005 and 2005-2006, through field experiment laid out in strip plot design with four replications on loamy sand soils of the Agronomy Farm, B.A. College of Agriculture, Anand Agricultural University, Anand. The genetic coefficient of wheat cultivar GW-496 was used from the previously calibrated and validated CERES-wheat model (Patel, 2004). The crop yield obtained under normal date of sowing (15th Nov.) and having given six irrigations at critical growth stages and following recommended package of practices of crop under mean weather conditions (Table 1) was considered as optimal yield. While the crop yield obtained under similar condition with limited irrigation (Three irrigations given at CRI- Crown Root Initiation, BT-Booting and ML-Milking stages) was considered as sub optimal condition. This situation is observed in many parts of the state where irrigation facilities are not adequate. CERES-wheat model was subjected to simulate the wheat yield under hypothetical weather condition that may be arising due to climate change. The climate scenario simulated for temperatures (± 1 to ± 3°C), radiation (± 1 to ± 3 $MJm^{-2} day^{-1}$) and CO_2 (440, 550 and 660 ppm against present concentration of 330 ppm) were well within the range of projected climate scenario by IPCC (Anon., 1995). Looking to the complexity in climatic pattern the yield was simulated due to change in individual parameters as well as in combination with other one or two. The analysis has been worked out also for all possible combinations under limited irrigation conditions (Sub-optimal condition).

RESULTS AND DISCUSSION

Effects of temperature, solar radiation and CO_2 concentration

Results on effects of minimum and maximum temperatures, solar radiation and CO_2 concentration on simulated grain yield of wheat under optimal and sub-optimal conditions and its comparison with the base yield are presented in Table 2 and graphically depicted in Fig. 1.

The simulated grain yield of wheat by CERES-wheat model under incremental units of maximum temperature (1 to 3°C) showed gradual decrease in yield ranging from 3546 to 2646 kg ha^{-1} (8 to 31 %) under optimal condition. Similarly, under sub-optimal condition, yield reduction was recorded to the extent of 2841 to 2398 $kgha^{-1}$ (9 to 23 %). In general, increase in maximum temperature from 1 to 3°C significantly reduced the wheat yield. The reduction in yield was mainly due to reduction in duration of anthesis and grain filling with rise in ambient temperature and vice versa as reported by Aggarwal and Kalra (1994) and Muchow *et al*. (1997). Similarly, Pathak *et al*. (2003) and Patel (2004) also reported based on the sensitivity

Table 1: Monthly mean weather condition during crop growing season (November to March)

Months	Solar radiation ($MJm^{-2} day^{-1}$)	MaxT (°C)	MinT (°C)	Rainfall (mm)
November	27.3	32.5	14.3	0.0
December	27.7	27.8	11.2	0.0
January	28.7	28.0	11.1	0.0
February	28.4	33.4	14.1	0.0
March	26.6	33.1	16.5	0.0

Table 2: Simulated wheat yield due to varying temperature, solar radiation and CO_2 concentration under optimal and sub optimal conditions

Change in parameters	Simulated grain yield ($kgha^{-1}$)		% Change from base optimal (3837 $kgha^{-1}$) and sub optimal (3112 kg ha^{-1}) yield	
MaxT (°C)	**Optimal**	**Sub-optimal**	**Optimal**	**Sub-optimal**
3	2646	2398	-31	-23
2	3091	2668	-19	-14
1	3546	2841	-8	-9
-1	4206	3190	10	3
-2	4485	3358	17	8
-3	4817	3641	26	17
MinT (°C)				
3	3288	2874	-14	-8
2	3460	2948	-10	-5
1	3692	3039	-4	-2
-1	4118	3140	7	1
-2	4226	3195	10	3
-3	4581	3234	19	4
Solar radiation (MJ $m^{-2}day^{-1}$)				
3	5387	2454	40	-21
2	5111	2709	33	-13
1	4523	3085	18	-1
-1	3156	2985	-18	-4
-2	2503	2503	-35	-20
-3	1903	1903	-50	-39
CO_2 concentration (Base value 330 ppm)				
440	4630	3695	21	19
550	5687	4327	48	39
660	6465	4876	68	57

analysis of CERES-wheat model that higher maximum temperature decreased wheat yield significantly. Similarly in case of gradual down scale of maximum temperature in the range of -1 to -3 °C, totally reverse trend was observed. Similar trend was also noticed in case of increase and decrease in minimum temperature under optimal and sub-optimal conditions. However, the magnitude of effect was quite less (-14 to +19 %) than those due to maximum temperature (-31 to +26 %). Under limited irrigation condition (sub optimal) the effect was less than that under optimal condition. This showed that wheat yield was found to be highly sensitive to change in temperature under irrigated as well as under limited irrigation conditions.

The increase in solar radiation from 1 to 3 $MJm^{-2} day^{-1}$ resulted in increase in yield of wheat from 18 to 40 percent while reduction in solar radiation by –1 to –3 MJ $m^{-2} day^{-1}$ caused decrease in wheat yield to the tune of –18 to –50 per cent. However, under sub-optimal conditions the yield was found to decrease both under elevated as well as reduced solar radiation. This showed that under limited irrigation condition (sub-optimal), the higher solar radiation receipt may have adverse effect through heating and thereby reduction in yield. It may be noted that under lower solar radiation regime, the yields under optimal and sub-optimal conditions are same. The overall response of varying radiation to grain yield of wheat showed that the model was more sensitive to radiation than it was to temperature. These findings have been in conformity with the findings of Akula (2003) using WTGROWS and InfoCrop models for wheat.

The effects of elevated carbon dioxide on simulated grain yield of wheat under optimal and sub-optimal conditions are presented in Table 2. Results showed that under gradual increase in CO_2 concentration from 440 to 660 ppm, the yield levels increased to the tune of 21 to 68 per cent under optimal condition, whereas, under sub-optimal condition similar response were observed with slightly lower magnitude (19 to 57 %). This shows that under climate change scenario, CO_2 enhancement proved beneficial for higher productivity. Idso and Idso (2000) have also reported that increased CO_2 concentration had resulted in mean yield increases of 70% for cereals. The increase in yield under increase in concentration in CO_2, may be due to most plants growing in experimental environments with increased levels of atmospheric CO_2, exhibit increased rates of net photosynthesis and reduced stomatal opening. Partial stomatal closure leads to reduced transpiration per unit leaf area and, combined with enhanced photosynthesis, often improves water-use efficiency. Thus, by itself, increased CO_2, can increase yield and reduce water use. Lal *et al*. (1998) observed that a 3°C rise in temperature (under elevated CO_2 concentration) nearly cancelled out positive effect of elevated CO_2 on the wheat and rice yields as studied through use of CERES-wheat and rice models for NW India.

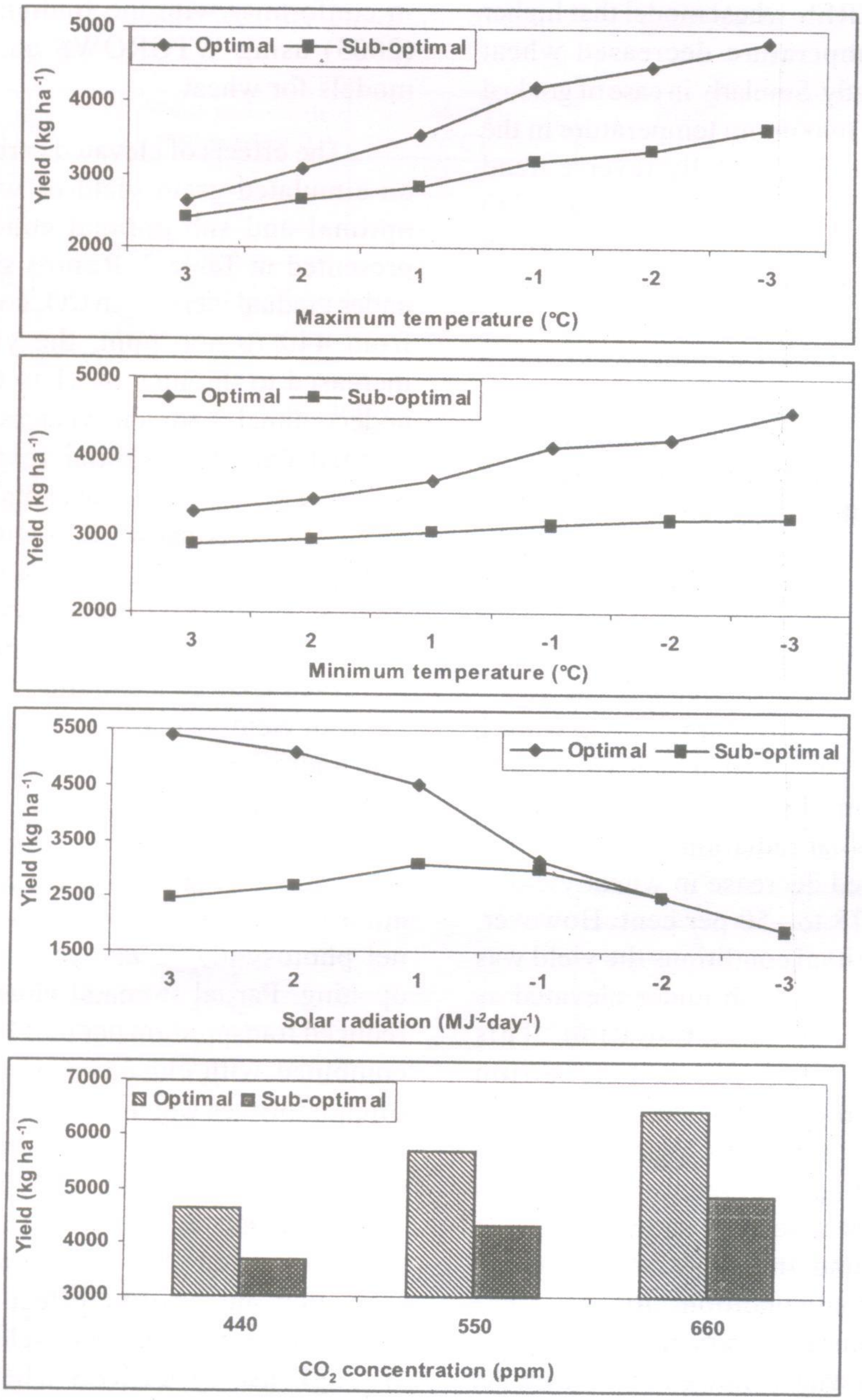

Fig. 1: Effect of climate change on grain yield of wheat under optimal and sub optimal conditions

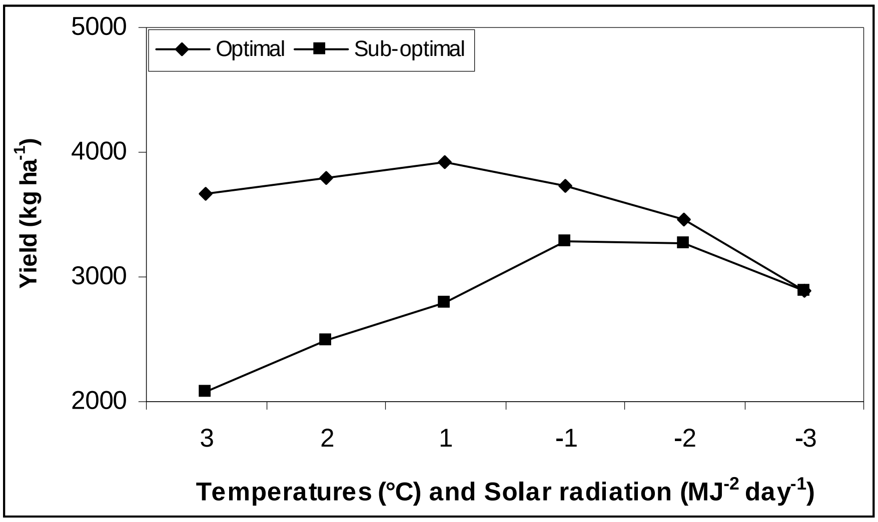

Fig. 2: Combined effect of changes in temperature and solar radiation on grain yield of wheat under optimal and sub optimal conditions

Combined effect of temperature and solar radiation

Under optimal condition, the effect of increase in temperatures was found to be nullified by similar increase in solar radiation (MJm^{-2} day^{-1}), as it is evident from the effect on yield (+2 to -4 %), while decreasing temperature and radiation had negative effect (-3 to -25 %) on grain yield (Table 3). This showed that the favourable effect of lower temperature was suppressed by negative effect of lower solar radiation regimes. Under sub-optimal condition, the decrease in yield up to 33 per cent was observed due to increase in both temperature and radiation by 3 units, while lowering of temperature and radiation had marginal effect (+6 to -7 %) on wheat yield (Fig. 2). It can further be revealed that due to lowering of temperature and radiation by 3 units the wheat yields under optimal condition was same as that of under sub-optimal condition.

Combined effect of temperature, solar radiation and CO_2 concentration

Model simulation was also carried out for combined effect of temperature, solar radiation and different levels of CO_2 concentration (440, 550 and 660 ppm) under optimal and sub optimal condition (Table 4). The results revealed that at CO_2 concentration of 440 ppm, the wheat yield was found to generally increase (-2 to 23 %) with either increase or decrease of temperature and radiation up to 3 units under optimal condition. Under sub-optimal condition, however, the favourable effects

Table 3: Simulated wheat yield due to combined effect of temperature and solar radiation under optimal and sub optimal conditions

Change in temperatures (°C) and SAR (MJ $m^{-2}day^{-1}$)	Simulated grain yield ($kgha^{-1}$)		% Change from base optimal (3837 $kgha^{-1}$) and sub optimal (3112 kg ha^{-1}) yield	
	Optimal	Sub-optimal	Optimal	Sub-optimal
3	3670	2083	-4	-33
2	3790	2486	-1	-20
1	3917	2799	2	-10
-1	3738	3292	-3	6
-2	3453	3273	-10	5
-3	2892	2892	-25	-7

Table 4: Simulated wheat yield due to interaction effect of temperature, solar radiation and CO_2 concentration under optimal and sub optimal conditions

Change in temperatures (°C) and SAR (MJ $m^{-2}day^{-1}$) and CO_2 at different level	Simulated grain yield ($kgha^{-1}$)		% Change from base optimal (3837 $kgha^{-1}$) and sub optimal (3112 kg ha^{-1}) yield	
440 ppm	Optimal	Sub-optimal	Optimal	Sub-optimal
3	4369	2410	14	-23
2	4699	2896	22	-7
1	4726	3287	23	6
-1	4550	3920	19	26
-2	4255	3929	11	26
-3	3776	3776	-2	21
550 ppm				
3	5125	2730	34	-12
2	5593	3307	46	6
1	5778	3784	51	22
-1	5452	4602	42	48
-2	5161	4642	35	49
-3	4707	4695	23	51
660 ppm				
3	5781	3015	51	-3
2	6332	3476	65	12
1	6541	4226	70	36
-1	6229	5201	62	67
-2	5950	5262	55	69
-3	5537	5439	44	75

were observed only under down scaling of the temperature and radiation regimes, the total effect being -23 to 26 per cent. At higher CO_2 concentration of 550 ppm, the net effect on yield was favourable (23 to 51 %) irrespective of whether temperature and radiation increased or decreased under optimal condition, while under sub-optimal condition, the negative effect (-12 %) was observed at higher temperature and radiation (+ 3 units) regimes. Under doubling of CO_2 concentration (660 ppm) scenario, increase in yield levels are quite high (42 to 70 % under optimal condition and -3 to +75 % under sub-optimal condition) due to changes in both temperature and radiation by $\pm$ 3 units (Table 4).

The interaction effect of temperature, radiation and CO_2 concentration revealed that the response under optimal condition was quite different than that under sub-optimal condition. Under optimal condition the highest benefits are obtained at level of CO_2 concentration combined with 1 unit increase in temperature and radiation. The percentage change in yield decreased both ways i.e. either increasing or decreasing the parameters from the mean values. The percentage change in yield under sub-optimal condition was found to have increasing trend with decreasing (+3 to -3 units) temperature and radiation at higher levels of CO_2 concentration.

CONCLUSION

In nutshell, increase in temperature significantly reduced the wheat yield while decrease in temperature increased the yield. The effect of maximum temperature on yield was more than that of minimum temperature. The higher radiation receipt and lower radiation receipt caused decrease in yield under optimal condition whereas, negative effect was seen under sub-optimal condition due to either increase or decreasing radiation. The combined effect of temperature and solar radiation were very marginal at the lower side of yield. This was due to positive effect of one being nullified by the negative effect of the other. The interaction effect of temperature, radiation and CO_2 concentration revealed that beneficial effect can be harvested at 1 unit increase in both temperature and radiation at all levels of CO_2 concentration under optimal condition.

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