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Sensitivity of wheat crop to projected climate change in non-traditional areas

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ABSTRACT

An attempt has been made to quantify the effect of projected climate change on wheat production in non-traditional wheat areas comprising states of Gujarat, Maharashtra, Madhya Pradesh and Rajasthan that contribute about 20 per cent of national wheat production. InfoCrop model was calibrated and validated using research farm data of Vasad, District Anand (Central Gujarat) and were used for climate change impact study using PRECIS downscaled, weather data of baseline period (1961-1990) and A2a scenario for projected period (2071-2100). Different crop management were tried for simulation in order to identifying adaptation options. Average annual maximum temperature for the projected period is likely to be higher than the base period by 3.96°C with maximum of 5.78°C for November and minimum 2.44°C for May. Similarly, the average minimum temperature is likely to rise by 4.36 °C with maximum increase of 5.94°C during December and minimum rise of 2.76°C during July. Average annual rainfall for central Gujarat region is likely to increase by 36 percent.

Under irrigated condition, each degree rise in average temperature over crop growing period will take toll of 3.02 q of wheat in already low yield area, similarly under restricted managements conditions one degree rise in temperature will reduce yield by about 2.0 q ha^{-1} under restricted irrigation management conditions. Further already short crop duration (100-105 days) is likely to further shorten by 15 to 20 days under projected climatic condition for A2a scenario. None of the management practices like shifting in sowing date, number of irrigation and amount of nitrogen tried for adaptation options was found beneficial and in all cases there was substantial yield loss.

Key words: Non traditional areas, climate change, impact study, baseline, adaptation

Wheat is the second most important cereal crop in the world. Wheat is grown over large tract in India with an area of about 28 million ha and as per the latest estimates released by Ministry of Agriculture for year 2009-10, wheat production has reached record 80.71 million tonnes, marginally higher than the earlier best of 80.58 million tonnes achieved in 2008-09 (Annonymus, 2010). Though the main contribution comes from Indo -Gangetic Plains (IGP), that we call traditional wheat area, there is good contribution from non-traditional areas like M. P., Rajasthan, Gujarat, and Maharashtra. These non-traditional areas not only contribute about 20 % (*http://dacnet.nic.in*, assessed on 29th July, 2010) of national wheat production, but are also hub of some high quality wheat.

Some latest work using output of Had CM$_3$ model for A2a scenario, downscaled for local condition using PRECIS, reports a higher magnitude of temperature rise (4 - 5 °C) by the end of century (Tripathi *et al.*, 2009 and Boomiraj *et al.*, 2010). As per fourth assessment report of IPCC (Intergovernmental Panel on Climate Change), global average temperature increased by 0.74°C over the last 100 years and projected temperature increase is about 1.8 to 4°C by 2100. It is obvious that these projected changes would affect the crop performance to a varying degree.

Several mechanistic models have been used to estimate potential yield and assess the effect of climate change (Boote and Tollenar, 1994; Hundal and Kaur, 1997; Ritchie *et al.*, 1998; Aggarwal *et al.*, 2000). Most of the mechanistic models though generic in nature, have been developed using data sets from temperate or mediterranion climate and crop coefficients used hence are suitable for those climatic conditions. In this paper an attempt was made to quantify the effect of climate change on wheat production in non-traditional areas and to evaluate different adaptation options using user friendly version of the Info Crop (Aggarwal *et al.*, 2004), a generic simulation model developed for tropical condition is used.

MATERIALS AND METHODS

Data requirement of Info Crop

Weather data: Model requires daily weather data of minimum and maximum air temperature (°C), solar radiation (k Jm^{-2}d^{-1}), vapour pressure (k Pa), wind speed (ms^{-1}) and rainfall (mm).

For calibration and validation of the model, observed weather data of all required parameter obtained from Agromet Observatory located at Central Soil and Water Conservation Research and Training Institute, Research Centre, Vasad were used. Priestley Taylor method for computing reference evapotranspiration that do not require vapour pressure or wind speed data was selected while running the model keeping in view of uncertainty of quality of computed vapour pressure. Bright sunshine hour data were converted to radiation data using the Angstrom equation.

Soil data: InfoCrop model requires soil input data for three layers. Top layer of in built soil data file of similar texture (sandy loam) were modified in Masters (facility for data uploading) using actual soil data of experimental site. Default values were used for deeper profile as it is far beyond the active root growth and less likely to affect crop growth in short run.

***Crop management data**:* The management data required, like date of sowing, seed rate and spacing, depth of sowing, amount and time of irrigation, amount and time of fertilizer application, climatic controls etc., were obtained from field management records of research farm Vasad for wheat cultivar GW-476.

Calibration and validation

Field observed data of phenology and yield of four sets of data distributed over two crop seasons (2002-03 and 2003-04) under different nitrogen and irrigation managements were used for calibration. As first steps of calibration, the model was run for fourteen popular wheat varieties for which in-built calibration parameters were provided with model using weather, soil and crop management parameters of experimental site. Variety Sonara 64 was found relatively close to the observed values of phenology and yield for the four sets of data of variety GW-476. Calibration parameters of Sonara 64 in model were further fine tuned to get best possible match with observed data of GW-476 used for calibration. Sixteen independent datasets spread over six year period (2002-03 to 2008-09) under different management practices involving nitrogen and irrigation levels were used for validation in terms of total crop growth duration and yield. Mismatch of observed and simulated data were further back propagated and calibration were done with another four sets of data that were used earlier for validation.

Climate change study

For climate change impact study, weather data for A2a scenario, was derived using PRECIS downscaled model prepared by Indian Institute of Tropical Meteorology, Pune in a grid size of 0.4 degree. Two periods of 30 years each, one for baseline *i.e.* 1961-1990 (here after referred as baseline period) and another for A2a projected scenario *i.e.* 2071 - 2100 (hereafter referred as projected scenario period) were considered for climate change quantification and impact study.

***Weather data preparation for climate change study*:** Differences were observed between PRECIS base line daily weather data and actual weather data for the same period (Tripathi *et al.,* 2009). With assumption and common consensus in the network project, about the differences between PRECIS baseline (1961-1990) and projected (2071-2100) are to be relied for climate change, thirty year monthly average of daily weather data for baseline period were subtracted from corresponding projected A2a scenario data for various parameters and the differences obtained were used for computing weather data for projected period using actual observed data. In case of rainfall, though no satisfactory method could be evolved but percentage difference of monthly sum of 30 year average data, between projected output and baseline output were used as correction factor as practiced in network project. For baseline data, actual weather data from Agromet Observatory for 30 year period have been used.

For computing weather data (except daily rainfall) for projected period from actual observed data of baseline period, following method was used.

$$X_{pni} = X_{oni} + \Delta_i + (\Delta_{i+1} - \Delta_i)*n/N_i$$

$$\Delta_i = \hat{A}_{pi} - \hat{A}_{bi}$$

X_{pni} = Weather parameter of nth day starting from middle (15th) of ith month for projected period (2071-2100)

X_{oni} = Observed weather parameter of nth day starting from middle (15th) of ith month for baseline period (1961-1990)

$\hat{A}_{pi}$ = Average of 30 years (2071-2100) monthly average of daily weather parameter for projected period

$\hat{A}_{bi}$ = average of 30 years (1961-1990) monthly average of daily weather parameter for baseline period.

n ranges from 0 to N_{i} ,

N_i = number of days between middle of ith and (i+1)th months

For computation of rainfall data of projected scenario period, the percentage increments (change) of monthly rainfall in projected model scenario over model baseline were used as multiple to the observed rainfall data of baseline period.

$$R_{pni} = R_{oni}{}^{*}(1+ (R_{pi\,avg} - R_{oi\,avg}) / R_{oi\,avg})$$

R_{pni} = nth day (from beginning of month) computed rainfall of ith month for projected period

Table 1: Final value of parameters subjected to calibration

Relative growth rate of leaf area	0.008
Specific leaf area ($dm^2 mg^{-1}$)	0.0018
Radiation use efficiency ($g MJ^{-1}$)	2.7
Slope of storage organ/grain number/m^2 of dry matter during grain formation stage.	16000
Optimum temperature (°C)	25°C
Maximum temperature (°C)	40
Root growth rate ($mm day^{-1}$)	25

Table 2: Validation statistics for crop duration and crop yield

Parameters	*R^2*	*RMSE*	*CRM*	*ME*
Crop duration (up to physical maturity)	0.79	2.5	-0.001	0.67
Crop yield	0.82	2.4	-0.006	0.701

R_{oni} = n^{th} day (from beginning of month) observed rainfall of i^{th} month under baseline period.

$R_{pi\ avg}$ = 30 year average of monthly sum of rain fall of i_{th} month under projected condition

$R_{oi\ avg}$ = 30 year average of monthly sum of actual observed rainfall of i_{th} month under baseline period.

Impact assessment and adaptation options

Thirty years weather data for projected period obtained by the above method along with 30 year actual observed data suitably adjusted to the baseline period (1961-1900) were used for climate change impact study on wheat cultivar GW-476. CO_2 concentration for A2a scenario was taken 682 ppm (IPCC, 2007). For purpose of evaluating different adaptation options and indentify best adaptation mechanism, different realistic hypothetical set of crop managements data were used for climate change impact study using InfoCrop simulation model.

RESULTS AND DISCUSSION

Calibration of model

The plant parameters obtained after calibration were: base temperatures from sowing to germination, germination to 50% flowering and 50% flowering to physiological maturity were taken as 3.6°C, 4.5°C and 7.5°C; while growing degree days for the same period were 70, 900 and 390 respectively. Other calibration parameter subjected to change were as follows (Table1).

Rest of the parameters subjected to calibration were retained as such since the values provided by developer for cultivar are not measured in routine.

Validation of model

Sixteen data sets for yield and crop duration up to physiological maturity were used for validation. Crop yields were satisfactorily simulated by the model as evidenced from high degree of co-linearity ($r = 0.90$ and $R^2 = 0.82$). The Nash-Sutcliffe Model efficiency (ME) is well represented with value calculated to be 0.701 for crop yield and 0.67 for crop growth duration (Table 2). Higher R^2 and ME show that the 'Info Crop' model adequately confirms to observed trend in crop growth duration as well as yield. Though in all crop season subjected to validation there was overestimation of crop duration as well as crop yield as exhibited statistically by negative coefficient of residual mass (CRM) (-0.001 for crop duration and -0.006 for yield). Slight overestimation by model is quite possible as field observed data generally fails to capture all possible biotic and abiotic stress even under highly controlled conditions.

Climate change impact study

A2a scenario is marked by continuous population rise regionally oriented economic development along with slowest and most fragmented technological development. CO_2 concentration is likely to reach to 682 ppm by 2080 and taken as representative for the impact study period (2071 to 2100). Average annual maximum temperature for the projected period is likely to be higher than the base period temperature by 3.96°C with maximum of 5.78°C for November and minimum 2.44°C for May. Similarly, the average minimum temperature is likely to rise by 4.36 °C with maximum increase of 5.94°C during December and minimum rise of 2.76°C during July. Solar radiation, vapour pressure and wind speed are also likely to increase marginally (Table 3). Rainfall is likely to increase by about 37% confined to four monsoon months with maximum rise for July and as such the *Kharif* crop are

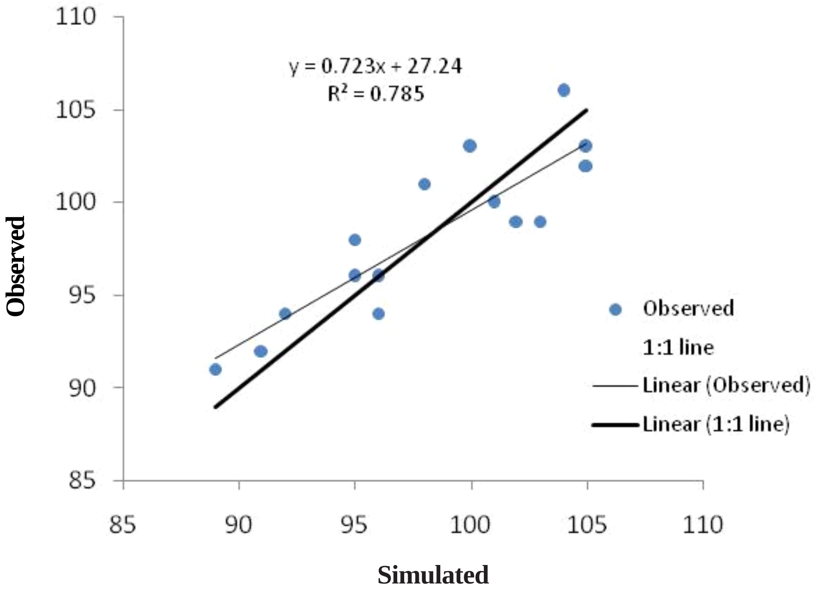

Fig. 1 : Comparison of model simulated and observed crop duration (days)

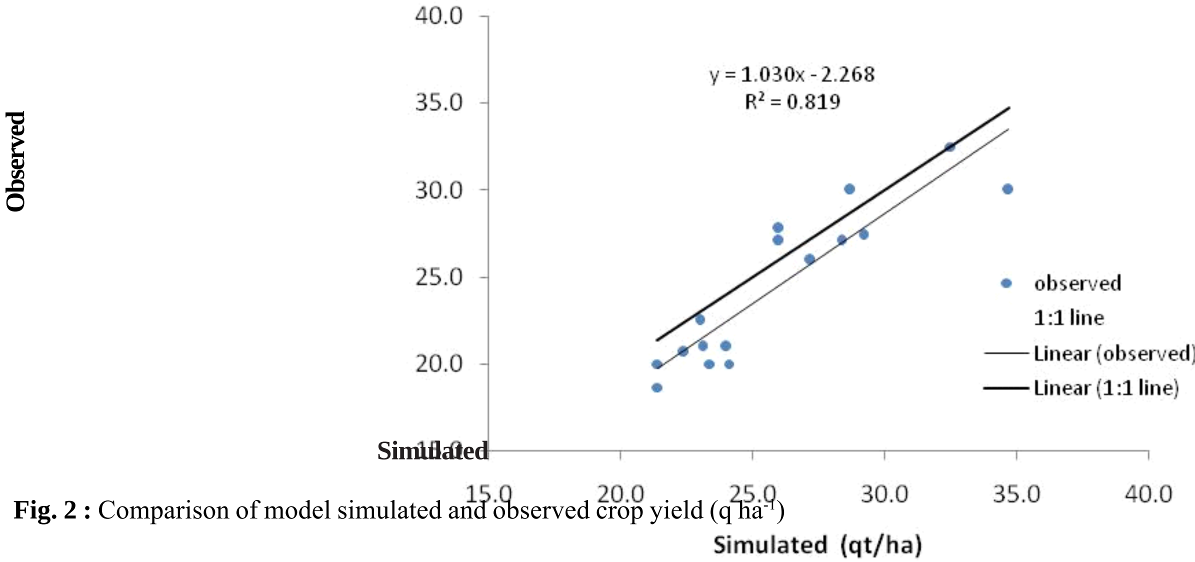

Fig. 2 : Comparison of model simulated and observed crop yield (q ha^{-1})

likely to be benefited. In spite of residual soil moisture, *Rabi* season crop is not likely to be benefitted, virtually because of scanty of rains during the season.

Simulations were done for 30 year base line period (1961-1990) and 30 year projected period (2071-2100) using corresponding scenario. Since the model output for baseline or projected weather data are not meant for daily or weekly or even monthly analysis as it is a general climatic representative, yield of individual year was not put to statistical analysis or comparison. Percentage changes in yield with coefficient of variation under seven different management conditions including adaptations options are sown in Table 4.

Average yield obtained under controlled condition was 29.5 q ha^{-1} and with a mean increase in average temperature by 5.1°C during crop duration, yield is likely to reduce to 13.4

Table 3: Climate change (difference of projected and baseline) parameters for central Gujarat condition

Months	ΔT_{max} (°C)	ΔT_{min} (°C)	ΔSrad ($KJm^{-2}d^{-1}$)
Jan	4.07	5.03	-409.5
Feb	4.62	5.8	-538.2
Mar	4.16	5.59	-680.0
April	3.55	4.3	-257.5
May	2.76	3.91	-587.5
June	3.42	3.3	-167.6
July	2.44	2.76	-793.2
Aug	2.84	2.93	-17.3
Sept	3.63	3.83	279.9
Oct	5.17	4.35	451.0
Nov	3.78	4.86	351.6
Dec	5.09	5.64	-115.8
Average	3.96	4.36	-207.0

(ΔT_{max}, ΔT_{min}, ΔSrad, ΔVP, ΔWS, Δppt* are change in daily maximum
radiation, vapour pressure wind speed and monthly rainfall (*: monthly

q ha^{-1} under normal practices of irrigated wheat in non-traditional area. It employs that each degree rise in temperature will take a toll of 3.02 q of wheat in these areas. Simulated average yield for restricted irrigation (Management option 2- one pre-sowing and one life saving irrigation and 80 kg nitrogen) under controlled condition is 21 q ha^{-1} and likely to reduce to 11q ha^{-1} for projected period employing thereby that each degree rise in average temperature during crop duration will reduce yield by about 2.0 q ha^{-1}. The study indicated that existing short crop duration (100-105 days till physiological maturity) of wheat in these areas is further likely to be shortened by 15 to 20 days under different management practices. Fast accumulation of GDD under projected period may lead to shortened phenophages. Though there would be an increase in photosynthetic activity/biomass accumulation under the elevated CO_2, probably it may not be sufficiently compensating the yield loss due to rise in temperature as is evidenced from these losses being in range of 47 to 67 % under different management practices (Table 4).

None of the management practices tried for adaptation augured well and in all cases there were substantial yield loss (Table 4). Wheat being a C_3 crop is probably not efficient in taking advantage of elevated CO_2 unlike C_4 crops. Since the weather conditions in non-traditional areas are not suitable for wheat cultivation and further rise of temperature to the tune of 5.1°C will worsen the situation. Daily maximum temperatures for projected period may frequently reach beyond maximum temperature limit (40°C) for initial as well as later stage of crop growth for some of the non-traditional areas. Model simulation was unable to progress once it encounters temperature beyond maximum limit provided as important plane parameter. To avoid the situation, maximum limit of temperature for crop growing was then set to 42°C in model, which is subjected to further investigation of plant response under elevated temperature beyond 40°C. The climate change would not only reduce yield but crop performance will also be highly unstable as evidenced from considerably higher coefficients of variation (47 to 94%) even under unlimited supply of water and nitrogen. The results are in line with the common finding across the globe for reduced wheat yield under climate change situation (Pachauri, 2007; Meza and Silva, 2008; Kaur and Hundal, 2007; Kaur and Hundal, 2009) but differs those with reports of better response of elevated CO_2 under drier conditions (Ludwig *et al.*, 2006). Most of the studies referred were conducted for traditional wheat belt or temperate conditions and results could not be corroborated for non-traditional wheat areas like that of Gujarat.

CONCLUSIONS

Crop simulation model could capture the process of crop growth. Wheat in non-traditional areas like Gujarat is likely to suffer badly due to projected climate change. Crop yield is likely to reduce by 47 to 68% under different management practices. Increased photosynthetic activity would not compensate for respiration losses even under unlimited supply of moisture and nitrogen. Yield reduction will further worsen by high degree of instability as evidenced by higher CV (47 to 94%). Under common management

Table 4 : Relative performance of crop under projected A2a scenario (2071-2100) as compared to baseline period (1961-1990) for different management practices

Managements practices	**% change in yield**	**CV %**	
		1961-1990	**2071-2100**
Management 1- Common Irrigation (one pre sowing and six during crop season*) with 100 kg nitrogen in two splits	-52.8	17.9	52
Management 2- One pre-sowing and one life saving irrigation and 80 kg nitrogen in single dose)**	-47.3	18.1	47
Adaption options			
Management 3- Restricted supply of irrigation (one pre-sowing and three during crop growing season, 100 kg nitrogen/ha in two splits	-60	18.2	51
Management 4 -Unlimited supply of water and nitrogen	-55.6	18.3	60.2
Management 5 - Management 1 along with advancing the sowing by 10 days for projected period	-58.1	-	72.9
Management 6 – Management 1 along with delay in sowing by 10 days for projected period	-67.7	-	94.2
Management 7 - Management 2 along with advancement of sowing by 10 days for projected period	-52.2	-	47
Management 8 - Management 2 along with delay in sowing by 10 days for projected period	-67.4	-	56.3

**Common practice for irrigated wheat on medium textured soil*

*** Common practice of growing wheat on residual moisture/pre-sowing irrigation and one life sowing irrigation on black soils*

practices of irrigated agriculture, the likely reduction in yield per degree rise in temperature is 3.02 q ha^{-1}. For already low yielding management practice of growing wheat on residual moisture/pre-sowing irrigation and one life saving irrigation, each degree rise in temperature is likely to reduce yield by 2.0 q ha^{-1}. Crop duration is likely to reduce by 15 to 20 days under different management scenario. None of the management practices tried for adaptation worked satisfactorily and in all cases there was substantial yield loss. The interpretation is based on simulated results of the model developed using crop response coefficient for existing climatic setup. Therefore the results are subjected to correction if crop response coefficients get changed under elevated CO_2 and temperature condition for which, several experiments are being conducted through network project on climate change and also independently by different organisations.

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