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Climate Change Impact on Chickpea Yield over a Sub Humid Climatic Environment

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***Abstract* – Agriculture is being affected adversely by exposure to accumulation of Green House Gases in the atmosphere and potential warming. Present study deals with impact of climate change on chickpea in a subhumid climatic environment using Info Crop model. Simulation studies done, based on the results of the field experiments at Pusa and Patna. Simulation was performed with HadCM3 factors with current climate as baseline at two centres located in agroclimatic zones (I and III) of Bihar for different future time periods. The results showed that under changed climate, at Pusa sowing of chickpea on 15th November, 22nd November and on 29th November showed upward trend in yield from baseline upto 2080. However the yields increase was at declining rate in future time periods. At Patna, simulated yield showed a declining trend from the baseline yield except during the planting window of 22nd November. The simulation study indicates that zone I (Pusa) is more favourable for chickpea as compared to zone III (Patna).**

***Keywords* – Bihar, Chickpea, Dates Of Sowing, Model, Scenarios.**

I. Introduction

Chickpea (*Cicer arietinum* L.) is an important food legume crop. It is cultivated for food and fodder on a large scale in arid and semiarid regions. Globally, chickpea production is confined mainly into three regions: West Asia, North Africa and the Indian subcontinent region. In the Indian subcontinent region, the crop experiences cool frosty nights in the early vegetative stage and warm to hot air temperature during the day over the reproductive phase [1], [2]. Chickpea occupies 38% of area (6.3 million hectare) under pulses and about 50% of total pulse production (5.1 million ton) of India. More than 85% of chickpea is grown under rainfed areas and also grown on conserved soil moisture after the harvest of *kharif* crop. Area, production and productivity of chickpea in Bihar are 0.072 million ha, 0.062 million ton and 835 kg/ha respectively.

In Bihar chickpea is sown from the mid November to mid December and grows mainly on stored moisture which progressively decreases with crop growth. However, sowing is often delayed when grown in sequence with kharif crops. Yield decline has been reported in wheat which is a major rabi crop due to combined effect of CO_2 and temperature in future climate scenario [3]. However rabi maize shows an increased yield performance due to interaction of various physiological and environmental factors [4]. Water stress and high temperature are major factors limiting growth reported [5]. The crop experiences water stress from late vegetative phase to maturity. Higher grain yields of chickpea are expected when the crop is irrigated with one or two irrigations. Irrigation at the stages like branching and pod development is very crucial for better growth and yield of crop. Date of sowing is also an important agronomic factor affecting productivity of crop owing to changes in environmental conditions to which phenological stages of crop is exposed.

Sowing date affects yield by influencing day length and temperature. Effects of five sowing dates on the fresh and dry yields of two important Israeli chickpea cultivars were observed [6]. Several researchers reported the suitability of early maturing Kabuli chickpea varieties for delayed sowing [7]. Seed yield decreased as sowing date delayed from mid-October to late December [8], [9]. Gram crop sown on 15th November produced satisfactory yield compared to late sown crop in December [10]. Inappropriate planting date causes the vegetative and reproductive growth period of plant to counter unsuitable conditions of day length or temperature [11]. The delayed sowing in such cases results in drastic reduction in yield.

Generally, chickpea adapts to high temperatures, however, heat stress during reproductive phase can cause significant yield loss. The current chickpea-growing area is under threat from increasing temperature and so, production may extend to cooler regions. The south Asian crop may also experience high temperatures in the seedling phase if planted early [4], [12]. In south India, if the rainy season (kharif) is extended, then the chickpea sowing in the rabi season delayed [13]. The detrimental effects of high temperature on various growth and reproductive stages are difficult to assess if growing conditions are favourable for few days as the plant continues vegetative growth but sets fewer pods [14]. In north India, chickpea grain yield decreased by 53 kg ha^{-1} in Uttar Pradesh and 301 kg ha^{-1} in Haryana per degree increase in seasonal temperature [15]. Most chickpea genotypes do not set pods when temperatures reach >35°C [16]. However, there is considerable variation among genotypes for response to high temperature.

Crop models are effective tools to test the suitability of a crop for a particular region. Modeling can save resources like time, energy and money by simulating the growth and yield of crops by using parameters, coefficients, and management practices just like in the field experiments conducted virtually.

The present study was undertaken to simulate the yield of chickpea varieties through InfoCrop model for zone I and zone III of Bihar representing a sub humid climatic environment. The objective of the study is to simulate yield changes under future time periods with different dates of sowing to assess ideal sowing time.

II. MATERIALS AND METHODS

Study area

Bihar lies in the eastern region of India extending from $24^0$20'10" to $27^0$31'15" N latitude and $83^0$19'50" to $88^0$17'40" E longitude, covering a total area of 94,163 sq. km lying at an average altitude of 52.73 m above sea level. Pusa is located at 25.85° N; 85.78° E with an altitude of 38 meters and Patna is located at 25.58° N; 85.25° E with an altitude of 41 meters and above mean sea level in Zone I and Zone III of Bihar respectively.

Climate change scenario

The IPCC's (Intergovernmental Panel on Climate Change) Special Report on Emission Scenario (SRES) describes future scenarios predicting greenhouse gas emissions. The SRES set comprises of four scenario families, viz. A1, A2, B1, and B2 [17]. A2 scenario selected for the current study is a high emission scenario. CO_2 concentration for SRES A2 scenario increases from the current levels of 370 ppm to 682 ppm for 2080. General Circulation Models (GCMs) are tools designed to simulate time series of climate globally, accounting for effect of greenhouse gases (GHGs) in the atmosphere [18]. GCM predictions of Hadley Centre Coupled Model ver.3 (HadCM3) from A2 scenario are incorporated individually, as per the equations 1 and 2, into each year of historical weather data (baseline) to generate 2020, 2050 and 2080 time periods. Baseline taken for the study is from year 1981 to 2010 (30 years).

Expected change in temperature

= T base + T HadCM3 outputs ....(1)

Expected change in rainfall

= R base x (1+ % HadCM3 outputs) ....(2)

Crop, Soil and Weather Data

Crop data was taken for Pusa and Patna from the field experiments conducted at respective stations in two seasons (2009-10 and 2010-11). Crop growth, yield and phenological observations taken are used in the study for chickpea genotypes BG-256 for Pusa and Vijay in Patna. Thermal time was calculated based on the stages of growth and duration of the varieties [19]. The soils were sandy loam (pH-8) and clay loam (pH-7.2) for Pusa and Patna respectively. Simulations were performed under irrigated conditions (2 irrigations) for different dates of sowing. Weather data for the period 1981-2010 was compiled and taken as baseline to simulate the yield for future time periods.

The Crop Model Description

The generic crop model InfoCrop ver. beta developed at IARI, Pusa is used [20]. Infocrop is a decision support system (DSS), designed to simulate the effects of weather, soils, agronomic management (including planting, nitrogen, residues and irrigation) and major pests on crop growth and yield. The Infocrop model is designed to use a minimum set of soil (soil type, pH, organic matter, bulk density etc.), weather, genetic and management information (sowing date, sowing depth, transplanting date, irrigation, fertilizer, etc.). It integrates on a daily basis and therefore requires daily weather data (maximum temperature, minimum temperature, rainfall, solar radiation, vapour pressure and wind speed). The model calculates the crop development phases and morphological development as a function of temperature, day length and genetic characteristics (Table 1).

Calibration, validation, and simulation for locations

The model has been validated by comparing the simulated yield with the observed yield for three years. The model was calibrated using genetic coefficients for the crop, soil parameters and adjusting the simulated yield with observed yield. Calibration in case of chickpea variety Vijay for Patna and BG-256 for Pusa locations was done on the basis of data available from experimental records. The results of validation are presented in table 2. Simulation was performed based on the calibration and validation for different future scenarios. The coefficient of efficiency is calculated by the model (equation 3) [21].

$$E = 1.0 - \left(\frac{\sum_{i=1}^{N} (O_i - P_i)^2}{\sum_{i=1}^{N} (O_i - \bar{O})^2} \right) \quad (3)$$

Table I: Generic coefficients for chickpea crop simulation

S. No.	Parameters used for simulation	Chickpea	
		Vijay	**BG-256**
1.	Type of grain	Small bold	Medium bold
2.	100 seed weight	18.3	29.6
3.	Duration	120-125	110-120
4.	Thermal Time (^{0}C days)		
a	Sowing to Germination	112	112
b	Germination to 50% flower Initiation	1100	1050
c	50% flower Initiation to Physiological Maturity	1275	1225
5.	Radiation Use Efficiency (gmMJ^{-1}day^{-1})	1.8	1.8
6.	Specific Leaf Area(dm^2 mg^{-1})	0.0014	0.0016
7.	Potential Storage Organ Weight (mg seed^{-1})	180	200
8.	Date of Sowing	22 November	22 November
9.	Date of Harvesting	28 March	20 March

Table II. Validation of model

S.No.	Chickpea	Coefficient of Efficiency (%)	RMSE (kg ha^{-1})	MAE (kg ha^{-1})	R^2
1	Vijay	72	88.5	79.0	1.00
2	BG-256	78	40.5	32.9	0.99

III. Results and Discussion

Variability of temperature of selected stations during winter season (Nov-April)

Analysis of weather data during the study period showed inter-annual variation in weather variables. Minimum temperature increased significantly at rate of 0.13 ˚C per year for Patna, whereas showed decrease of 0.033 ̊C per year for Pusa. An increase of maximum temperature is observed at the rates of 0.19 ˚C and 0.12 ˚C per year is observed for Patna and Pusa respectively (Table III), however, significant increase is observed only for Patna. Results point towards gradual warming up with time. Changes in temperature have profound effect on crop productivity as increase in temperature causes water stress in crop, which may lead to lower seed yield.

Table III: Variation in temperature (maximum and minimum) for zone I and zone III during rabi season (1981-2010)

	Pusa (Zone I)		Patna (Zone III)	
	Min. T	Max.T	Min. T	Max.T
Mean	13.6	27.9	14.5	29.0
r^2	-0.202	0.468	0.628	0.634
Slope	-0.033	0.12	0.13	0.19
Sig. level	42.47	82.8	94.8	95.1

Table IV. Simulated chickpea seed yield (kg ha^{-1}) for baseline and future scenarios

Date of sowing	**Pusa**			
	Baseline	2020	2050	2080
15-November		1387.3	1217.5	1084.1
22-November	1156.9	1433.3	1359.0	1234.4
29-November		1187.5	1247.2	1188.9
6-December		1043.9	1131.1	1081.8
	Patna			
15-November		2039.6	1605.2	1267.0
22-November	2078.2	2149.4	1824.2	1457.0
29-November		2049.1	1791.0	1468.6
6-December		1670.2	1349.7	1064.7

Impacts of climate change on yield of chickpea genotypes

Pusa: At Pusa, sowing of chickpea on 22nd November showed an increase of simulated yield from the baseline upto 23.9, 17.5 and 6.7 % for 2020, 2050 and 2080 time periods. An increase in yield from the baseline is also observed by advancing the sowing by one week i.e. on 15th November (Table 3) except for 2080 period. However, the percentage of increase reduced to 19.9 during 2020 and 5.2 in 2050. During 2080, one week advance sowing showed a yield decline of 6.3%. On the contrary, if sowing is delayed by one week i.e. on 29th November this increase in seed yield further reduced to 2.6, 7.8 and 2.8 % respectively for 2020, 2050 and 2080 respectively. Two weeks delayed sowing (6^{th} December) caused a decline in seed yield to 9.8% (2020), 2.2% (2050) and 6.5% (2080) presented in fig.1.

Patna: In case of Patna (Fig 2), 22nd November sowing of chickpea showed an increase in simulated yield from the baseline to 3.4% for 2020 only, whereas during 2050 and 2080, yield is declined to the tune of 12.2 and 29.9 % respectively. Advanced sowing of crop by one week (15th November) caused reduction in simulated yield upto 1.9, 22.8 and 39% for 2020, 2050 and 2080 respectively. Delayed sowing by one week and two weeks further declined the yield ranged from 1.4-19.6% in 2020, 13.8 to 35.1% during 2050 and 29-48.8% for 2080. This means that upto 2080 simulated seed yield may reduce to almost 50% by delayed sowing from the present date of sowing (22 November).

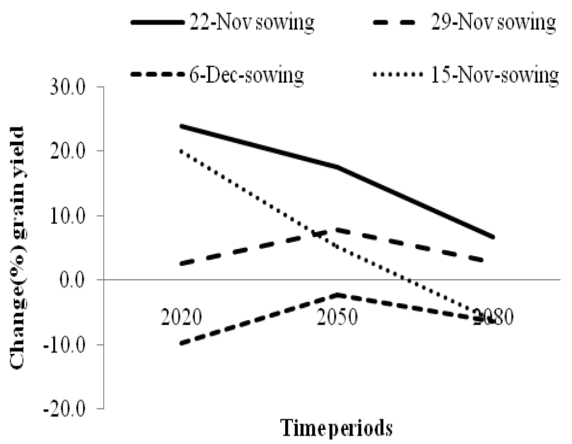


Fig.1. Change in yield (%) for chickpea var. BG-256 for Pusa location (Zone 1)

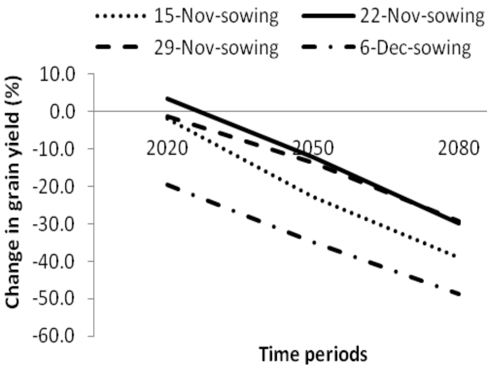
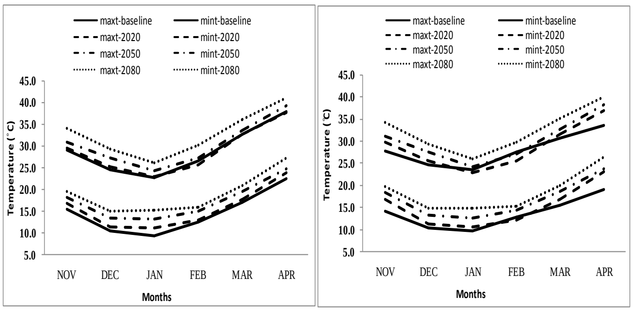


Fig 2. Change in yield (%) for chickpea var.Vijay at Patna location (Zone III)

Thus, at Pusa sowing of chickpea on 15th November, 22nd November and on 29th November showed upward trend in yield from baseline upto 2080. As fig. 3 shows that during February and March months, maximum temperature of 2020 and 2050 time periods is lower than that of baseline period. This may lead to increasing yield in 2020 and 2050 time periods. Whereas, during 2080 time period, yield is showing a declining rate of increase due to pronounced increase in maximum and minimum temperature observed as is evident from fig.3.

At Patna, simulated yield may increase only upto 3-4% during 2020; thereafter it may show decline from m the baseline yield for future time periods with all dates of sowing. As it is evident from fig 3, both maximum and minimum temperature during 2020 remained almost same as baseline in Patna. However, minimum temperature during 2050 and 2080 remained almost 3^0C and 4^0C higher from baseline, which may be the reason for sharp decline in yield observed during future time periods.

From the observed results for different dates of sowing it is evident that the ideal planting time for current as well as future time periods is around 22nd November in both the locations. Pusa shows more congenial environment for growth and yield of chickpea as compared to Patna location.



Pusa Patna

Fig 3. Changes in maximum and minimum temperature during crop season for baseline and future time periods for Pusa and Patna

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