Journal of Agrometeorology 18 (1) : 100-105 (June 2016)

Simulating the impact of climate change on chickpea yield under *rainfed* and irrigated conditions in Madhya Pradesh

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ABSTRACT

CROPGRO-chickpea model calibrated and validated with data collected from the experiments conducted with two cultivars (JG 315 and JG 11) of chickpea at Jabalpur (irrigated) and Tikamgarh (*rainfed*) during 2009-10 and 2010-11, was used to study the impact of climate change on phenology, growth and yield of chickpea. It was found that model closely simulated the phenological event as well as biomass. The model underestimated seed yield of both the cultivars but more error was involved in simulation of JG 11. Under *rainfed* conditions there was large differences between observed and simulated. Under climate change scenarios (increasing maximum temperature by +1 to +3 °C, minimum temperature by+0.5 to 2.5°C and CO_2 from 400 to 600ppm); the seed yield of the chickpea cultivars would increased by 102.8 and 187.7 per cent under irrigated conditions at Jabalpur. The large variability in yield was noted under *rainfed* as compared to irrigated conditions.

Key words: Calibration, validation, simulation, CHIKPGRO model, climate change, phenology, yield,.

Climate change is one of the most important global issue all over the world and much more attentions have been paid to evaluate or eliminate its detrimental effects. To evaluate the effects of climate change, different crop models and scenarios have been developed and used across the world. The Decision Support System for Agro-technology Transfer (DSSAT) has been found to be most widely used decision support system which included models for cereals, legumes, oilseed, vegetable crops (Hoogenboom*,* 2000). Though different workers have evaluated the CROPGRO model for other crops viz. Pandey *et al.* (2001), Suriharan *et al*. (2008) and Patel *et al*. (2013) validated the CROPGRO model for groundnut. Bhatia *et al*. (2008) for soybean (*Glycine max* L. Merr.).

Chickpea occupy a very significant place in farming all over India and have the growing area of 9.91 million hectares with an annual production of 8.22 million tones and average productivity is 895 kg ha^{-1} (Anonymous 2012). Madhya Pradesh share 33 per cent of total chickpea area and 38 per cent of total production (Anonymous, 2014).

To estimate the impact of climate change on predominate chickpea cultivars of Madhya Pradesh, five climate change scenario (taking business as usual scenario approach) was simulated and their impact on yield were analyzed.

MATERIALS AND METHODS

The input data required for running the crop simulation model(CROPGRO-Chickpea) of DSSAT V4.5 includes crop data, daily weather data, soil data and crop specific genetic coefficients.

Crop data

To evaluate the model, field experiments were conducted at Jabalpur (Lat. 23^0 09'N and Long.79^0 58'E. and altitude of 411m m.s.l.) with six dates of sowing (D_1**:** October 11, D_2**:**October 26, D_3**:**November11, D_4**:**November26, D_5**:**December11, D_6**:** December 26) and two varieties (JG 315 and JG 11) during *rabi* seasons of 2009-10 and 2010-11. Two irrigation (40mm); one at branching and one at pod filling stages in addition to the pre-sowing irrigation were applied. The same cultivars under *rainfed* conditions were grown at Tikamgarh(Lat. 24^o 40'N., Long. 77^o 80'E. and altitude 324m m.s.l.). during *rabi* 2009-10 and 2010-11. Sowing of the above two varieties of chickpea was done on 10th, 17th November in 2009, 30th October and 4th November in 2010. A recommended dose of fertilizer 20-60-20 kg ha^{-1} NPK was applied uniformly at the time of sowing. One pre-sowing irrigation was applied in the crop at Tikamgarh.

Weather data

The daily weather data of the year from 2009 to 2011

Table 1: Climate change scenario selected for the study

Climate change scenarios	Maximum temperature(°C)	Minimum temperature(°C)	CO_2 concentration (ppm)
S1	+1.0	+0.5	400
S2	+1.5	+1.0	400
S3	+2.0	+1.5	450
S4	+2.5	+2.0	500
S5	+3.0	+2.5	600

Table 2: Genetic coefficients chickpea cultivars JG 315 and JG 11

Genetic Parameter	Description	JG 315	JG 11
CSDL	Critical Short Day Length below which reproductive development progresses with no daylength effect (for short day plants) (hour)	11.30	10.10
PPSEN	Slope of the relative response of development to photoperiod with time (positive for short day plants) (1/hour)	-.143	-.143
EM-FL	Time between plant emergence and flower appearance (R1) (photothermal days)	30.3	30.1
FL-SH	Time between first flower and first pod (R3) (photothermal days)	8.0	8.0
FL-SD	Time between first flower and first seed (R5) (photothermal days)	14.9	14.8
SD-PM	Time between first seed (R5) and physiological maturity (R7) (photothermal days)	39.0	44.0
FL-LF	Time between first flower (R1) and end of leaf expansion (photothermal days)	34.0	34.0
LFMAX	Maximum leaf photosynthesis rate at 30^{0}C, 350 vpm CO_2, and high light (mg CO_2/m^2 s)	1.10	1.30
SLAVR	Specific leaf area of cultivar under standard growth conditions (cm^2/g)	150.0	150.0
SIZLF	Maximum size of full leaf (three leaflets) (cm^2)	8.90	9.2
XFRT	Maximum fraction of daily growth that is partitioned to seed + shell	1.0	1.0
WTPSD	Maximum weight per seed (g)	0.210	0.183
SFDUR	Seed filling duration for pod cohort at standard growth conditions (photothermal days)	26.0	20.0
SDPDV	Average seed per pod under standard growing conditions (#[seed]/pod)	1.60	1.40
PODUR	Time required for cultivar to reach final pod load under optimal conditions (photothermal days).	18.0	10.0
THRESH	The maximum ration of seed (seed/seed + shell) at maturity	85.0	85.0
SDPRO	Fraction protein in seed (g[protein]/g[seed])	0.216	0.216

were collected from Agromet Observatory situated nearby (within 100 meter) the experimental plots.

Soil data

Physical and chemical parameters of soil are required. The soil albedo, soil water drainage constant, filed capacity, wilting point, layer wise information on initial soil moisture, organic carbon, pH and sand, silt and clay information were collected from Jabalpur and Tikamgarh.

Climate change Scenarios

The climate change scenario were selected as per fifth assessment report of IPCC (2013), in which increase in maximum surface air temperature by 3.0^{0}C and minimum air temperature by 2.5^{0}C with combination of CO_2 increase upto 600 ppm have been projected. These are given in Table 1. The climate change was incorporated in the model input files through modified weather and then yield were simulated under five climate change scenarios under irrigated and *rainfed* conditions.

Test summary statistics like mean and standard deviation were also calculated. RMSE tests the accuracy of the model (Loague and Green, 1991) and set of RMSE values were calculated. A smaller RMSE indicated less deviation of the simulated from the observed values. The Coefficient of

Table 3: Measured and simulated major development events, biomass and yield under irrigated (a) and *rainfed* (b) conditions

Treatments	Day to anthesis				Days to physiological maturity				Biomass(kg ha^{-1})				Seed yield (kg ha^{-1})			
a)Irrigated	O	S	RMSE	CRM(%)	O	S	RMSE	CRM(%)	O	S	RMSE	CRM (%)	O	S	RMSE	CRM (%)
Variety																
JG 315	44	47	4.7	-8.2	107	103	16.5	3.9	3013.5	3394.0	426.2	-12.6	1095.8	1320.8	336.4	-20.5
JG -11	43	45	4.1	-5.1	105	104	15.4	0.5	3002.5	3426.8	449.2	-14.1	1154.0	1527.0	438.6	-32.3
Date of sowing																
D1	33	36	3.2	-9.2	127	107	25.7	19.6	3456.0	4066.5	612.6	-17.7	1713.0	2212.5	480.5	-36.2
D2	38	40	2.6	-6.3	124	108	16.1	12.9	3147.5	3634.0	486.8	-15.5	1204.5	1588.0	383.8	-31.8
D3	43	48	5.5	-12.8	108	110	2.1	-1.4	3203.0	3795.5	593.8	-18.5	1281.5	1557.0	289.1	-21.5
D4	45	53	8.5	-18.9	98	107	9.8	-9.7	3055.0	3307.0	252.2	-8.2	1075.0	1282.0	276.3	-19.3
D5	48	49	1.6	-3.2	90	101	11.2	-12.2	2684.5	2933.0	253.8	-9.3	866.0	1159.0	340.3	-33.8
D6	42	43	0.7	-1.2	79	92	12.7	-15.8	2502.0	2726.5	239.5	-9.0	809.5	745.0	65.9	8.0
b) *Rainfed*																
Variety																
JG 315	44	40	5.5	8.0	125	116	12.3	6.8	3065	2495	807.2	18.6	1075	813	372.6	24.4
JG -11	46	42	8.0	10.3	113	107	8.9	5.3	3445	2895	795.6	16.0	1218	950	383.6	22.0
Date of sowing																
D1	41	38	5.3	7.9	120	113	10.8	6.0	3883	3370	730.6	13.2	1198	940	365.9	21.5
D2	49	45	80.1	10.2	118	110	10.7	6.2	2628	2020	866.4	23.1	1095	822	390.0	25.0

O=Observed, S=Simulated

Table 4: Percentage change in yield under different climate change scenarios in irrigated and *rainfed*

Treatments	S1	S2	S3	S4	S5
a) Irrigated					
Variety					
JG-315	+102.8	+110.9	+121.3	+129.4	+137.5
JG -11	+138.5	+150.6	+165.9	+172.1	+187.6
Date of sowing					
D1	+208.6	+217.9	+231.5	+242.0	+256.6
D2	+158.4	+184.7	+217.0	+240.9	+265.3
D3	+160.0	+165.4	+173.7	+184.8	+200.7
D4	+83.2	+105.7	+118.3	+127.1	+137.7
D5	+91.6	+100.1	+119.5	+116.6	+129.2
D6	+22.0	+10.6	+1.6	-7.1	-14.1
b) Rainfed					
Variety					
JG 315	+61.8	+66.6	+73.2	+77.2	+96.7
JG -11	+87.3	+91.6	97.2	+100.6	+108.3
Date of sowing					
D1	+177.1	+183.5	+195.0	+204.1	+215.45
D2	+127.5	+143.5	+165.5	+183.2	+205.20
D3	+57.6	+60.8	+64.3	+70.8	+80.50
D4	+52.0	+59.2	+60.3	+62.5	+65.45
D5	+34.4	+35.7	+39.8	+33.8	+35.10
D6	-1.5	-8.1	-13.7	-21.2	-13.40

residual mass (CRM) was used to measure the tendency of the model to over estimate or under estimate the measured values. The CRM is defined by

$$CRM=100 \times [SO_i-SS_i]/ SO_i$$

Where, O= observed variable, S= simulated variable

A negative CRM indicates a tendency of the model towards over estimation (Xevi *et al*., 1996).

RESULTS AND DISCUSSION

Calibration and Validation of CROPGRO mode

The genetic coefficients for chickpea cultivars JG 315 and JG 11 were adopted from Silawat *et al.*(2016) and are given in Table 2. The model performance was assessed by running the model with independent crop data set for all six sowing days and two varieties at both the places Tikamgarh (*rainfed*) and Jabalpur (irrigated). The corresponding mean values of simulation results are reported in Table 2 and compared with experimental data and agreement has been checked by RMSE and CRM values.

Irrigated conditions (Jabalpur) : Table 3 shows that the model overestimated the anthesis days by 1 to 8 days across the variety and locations. The model underestimated the physiological maturity by 1 to 20 days across the different dates of sowing. The maximum difference was found for D1 sowing date. Except the early sown crop, the model showed the robustness in simulation of major phenological events.

Rainfed conditions (Tikamgarh) : At Tikamgarh, under irrigated conditions, the model underestimated the anthesis days with CRM ranging between 8 and 10 per cent and also the physiological maturity with CRM of 5 to 6 per cent (Table 3). The deviations between the simulated and observed biomass values were high for *rainfed* conditions.

The model performance for yield simulation for both the cultivars under *rainfed* condition was not within the acceptable limit (±20%). The model overestimated both the biomass and yield under irrigated conditions and under estimated the biomass and yield under *rainfed* conditions. These results indicated that modification may be incorporated in the model for acceptable yield simulation results. The crop models were generally calibrated for non-limiting water conditions. In addition, other changes could also be made to accurately predict the observed water stress.

Impact of climate change on seed yield

The per cent change in seed yields of chickpea cultivars simulated under all the five climate change scenarios are presented in Table 4. It may be seen that the seed yield of chickpea was found to increase under all climate change scenarios. The yield increased with increase in CO_2 concentration as well as with temperature.

Irrigated condition : Under irrigated conditions at Jabalpur the impact on seed yield of two cultivars varied between 102 and 187 per cent. Between the cultivars JG-11 was found to have more beneficial effect (138 to 187%) than that of cultivar JG-315(102 to 137%). The increase in CO_2 concentration and maximum and minimum temperature had a profound influence on yield at different date of sowing and variety. In general the increase in CO_2 concentration and maximum and minimum temperature has increased the seed yield. Srivastava (2003), also reported a high impact (40-50 per cent increase in yield) with doubling of CO_2 concentration on the productivity of chickpea at Raipur. Vanaja *et al.* (2011) reported that seed yield of pigeonpea improved from 22.8 g^{-1} plant at ambient to 42.4 g^{-1}plant at 700ppm, thereby showing an increment of 85.9 per cent with enhanced CO_2.

Under irrigation conditions among the different dates of sowings, the impact was found to be beneficial in all except in extremely late sown condition (Dec.26). The highest seed yield increase (+200 to 256%) was obtained under D1. With delay in sowing the impact of climate change was found to decrease. Under very late sown condition(D6) , the impact of climate change under S1, S2 and S3 scenarios was positive while under S4 and S5 scenarios it was negative. Thus under irrigated conditions the beneficial effect of climate change was observed (Table 4). This result indicated that for maximization of chickpea yield the early sowing date is recommended under climate change conditions also.

Rainfed condition : The chickpea yield simulated under projected climate change scenarios (Table 4) showed beneficial effect in most of the cases under rainfed condition also. In this case variety, JG-11 was found to have more (87 to 108 %) beneficial effect than variety JG-315(61 to 97%). Under different dates of sowing the impact on seed yield was similar to that observed under irrigated conditions. However, quantitatively, it was slightly lower. The maximum beneficial effect was observed under early sown (D1- Oct-11) crop. Under very late condition (D6) the impact on seed yield was negative.

Seed yield variability was found to be large increased in case of climate change and large variability was noted under *rainfed* condition as compared to irrigated condition. Hajarpoor *et al.* (2014) simulated the impact of changing climate on chickpea at four major producing dry areas of Iran with different sowing dates. They reported that chickpea yield would increase between 37-89 per cent in *rainfed* conditions under the future climate in all sites.

CONCLUSION

The impact of climate change on chickpea yield was found to be favourable. The cultivar JG-11 would be more benefited than JG-315. The early sown (Oct.) crop would be maximum benefited. With delay in sowing, the beneficial effect will decrease. Under irrigated conditions the yield increase would be more that that under *rainfed* conditions. However, such results need to be used cautiously as the model has its inherent error in simulation.

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Received : May 2015 ; Accepted : April 2016