Evaluation of CHIKPGRO model in semi arid and sub-humid climatic conditions of Madhya Pradesh

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सार – मध्यप्रदेश के जबलपुर और टीकमगढ़ में रबी 2009-10 और 2010-11 के दौरान विभिन्न तापीय और नमी स्थितियों में प्रक्षेत्र प्रयोग किए गए। जबलपुर और टीकमगढ़ में चने की दो लोकप्रिय और अधिकांश क्षेत्रों में उगाई जाने वाली किस्मों (जे.जी. 315 और जे.जी.11) के लिए चिकपीग्रो मॉडल का अंशांकन और सत्यापन किया गया। सत्यापन जबलपुर (सिंचित स्थितियों में) में सन 2010-11 की बुआई की छह तिथियों के लिए, और टीकमगढ़ (बारानी स्थितियों में) सन 2009-10 के दौरान बुआई की दो तिथियों के लिए किए गए। इस मॉडल ने कार्यिकी परिपक्वता को छोड़कर सभी फसल के प्रमुख दृष्टिगोचर घटनाओं को सिंचित स्थितियों में अधिआकलन तथा बारानी स्थितियों में न्यूनआकलित किया। इस मॉडल ने अधिकतम पर्ण क्षेत्रफल सूचकांक (एल.ए.आई.), जैवसंहित उपज, फली भार, दानों की संख्या प्रति वर्ग मीटर, दानों की उपज को अधिआकलित किया तथा सिंचित स्थितियों में दानों के भार को न्यूनआकलित किया। सत्यापन त्रुटि सिंचित स्थितियों की अपेक्षा बारानी स्थितियों में अधिक पाई गई। मॉडल द्वारा फसल की उपज और जैवसंहति के अनुरूपण में सिंचित और बारानी स्थितियों में भिन्न भिन्न प्रकार से प्रदर्शन दिया। मॉडल ने तापीय और नमी प्रतिबलों को प्रत्यक्ष खेत में पछेती बुआई और बारानी स्थितियों की तुलना में अनुरूपित स्थितियों के अंतर्गत अधिक आकलित किया। अनुरूपण स्थितियों में प्रजाति जे.जी. 11 ने प्रजाति जे.जी 315 की तुलना में उपज और जैवसंहति का अधिक आकलन किया। इस मॉडल के निष्पादन की जाँच सी.आर.एम., आर.एम.एस.ई. और प्रत्यक्ष एवं अनुरूपित मानों के प्रतिशत अंतर के आधार पर की गई।

ABSTRACT. Based on field experiments conducted under different thermal and moisture regimes during *rabi* 2009-10 and 2010-11 at Jabalpur and Tikamgarh district of Madhya Pradesh, CHIKPGRO model was calibrated and validated for two popular and widely grown chickpea cultivars (JG 315 and JG11). Validations were done on the crop grown under the six dates of sowing in 2010-11 at Jabalpur (irrigated) and under two dates of sowing (2009-10 and 2010-11) at Tikamgarh (*rainfed*). The model overestimated the major phenological events under irrigated and underestimated in *rainfed* conditions, except the physiological maturity. The model also overestimated maximum LAI, biomass, seed yield and unit seed weight under irrigated conditions and underestimated in *rainfed,* conditions. The validation error was higher in *rainfed* conditions than irrigated conditions. The model simulated cultivars yield and biomass in irrigated and *rainfed* conditions differently with same genetic coefficients. The model simulated higher thermal and moisture stress than the actual field conditions under late sown conditions. The cultivar JG 11 had shown slightly more difference in simulation of yield and biomass as compared to JG 315. The model performance was tested with help CRM, RMSE and percentage difference between observed and simulated values.

Key words – Calibration, Validation, CHIKPGRO model, DSSAT 4.6, Phenology, Yield, Simulation.

1. Introduction

Indian population is predominantly vegetarian and pulses form an integral part of the vegetarian diets and adequately meet the protein requirements. Chickpea occupies a very significant place in farming all over India and has the largest pulse growing area of 8.22 million ha. Though, India ranks first in acreage and production of chickpea in the world, its average yield is very low (881 kg/ha). In India, Madhya Pradesh shares 33 per cent of total chickpea area and 38 per cent of total production (Anonymous, 2014). Crop simulation models based on physical plant processes are made use to simulate the effects of changes in growing environment on plant growth and development on daily basis. The Decision Support System for Agro-technology Transfer (DSSAT)

has been found to be most widely used decision support system and included many cereals, legumes, oilseed, vegetable crops (Hoogenboom *et al.*, 2004). It includes CROPGRO model also. CROPGRO model is a dynamic simulation model that simulates the growth and yield of wide range of leguminous crops, such as soybean, peanut, groundnut and chickpea. Singh and Virmani (1996) developed CHIKPGRO (CROPGRO-Chickpea) model in India but it has not been extensively evaluated, particularly in central parts of India.

However, different workers have evaluated the CROPGRO model for pulses and oilseed crops. Pandey *et al.* (2001) validated the 'CROPGRO' model for groundnut at Gujarat. Bhatia *et al.* (2008) has assessed the scope for enhancing productivity of soybean (*Glycine max* L. Merr.) using CROPGRO-Soybean model at Indore. Suriharan *et al.* (2008) evaluated the CROPGRO-Peanut model. For research planning, a validated model with known genetic constants for widely accepted and popular varieties can be a powerful tool for studying the performance of crop models under diverse cultural practices and management inputs (Boote *et al.*, 1996). Water availability and temperature are the two major environmental variables that determine the chickpea yield. Simulation of chickpea growth and yield under varying temperature and moisture regimes was not carried out in contrasting climatic conditions of Madhya Pradesh. Thus, CHIKPGRO model's robustness; under changing thermal and moisture regimes is lacking. Very few studies were reported in the literature on CHIKPGRO model testing and secondary data were used for calibration and validation. Keeping the above facts in view, the present study has been undertaken to evaluate the CHIKPGRO model with primary data for popular, widely grown cultivars under different thermal and moisture regimes in Madhya Pradesh.

2. Data and methodology

To evaluate the model; field experiments were conducted at Jabalpur under irrigated with six dates and at Tikamgarh under *rainfed* conditions with two dates of sowing during *rabi* 2009-10 and 2010-11 of Madhya Pradesh, respectably. Split plot design was adopted and the treatments were replicated three times during all the six dates of sowing starting from nearly first fortnight of October to second fortnight of December at Jabalpur. The main plot treatments consisted of six dates of sowing each at the 15 days interval and these sowing dates were denoted by D1(11 Oct), D2(26 Oct), D3(11 Nov), D4(27 Nov), D5(10 Dec) and D6(25 Dec). The sub plot treatments comprised of 2 level of varieties (V1-JG 315 and V2-JG 11) at Jabalpur (23° 09' North latitude and 79° 58' East longitude at an altitude of 411 meter mean sea level). Two irrigations (40 mm); one at branching and one

at pod filling stages in addition to the pre-sowing irrigation were applied in chickpea at Jabalpur. Sowing of the above two varieties of chickpea was done on 10th, 17th November in 2009, 30th October and 4th November in 2010 at Tikamgarh (24° 40' N latitude, 77° 80' E longitude and 324 meter height above m.s.l.). One pre-sowing irrigation was applied in the field. A recommended dose of fertilizer 20-60-20 kg NPK per ha was applied uniformly at the time of sowing in both the years at both the places.

The CHIKPGRO (CROPGRO-Chickpea) model embedded in DSSAT v 4.6 is a dynamic crop growth simulation model and a model CD was obtained from Agromet-Service Cell of Ministry of Earth Sciences, New Delhi. The major components of the CROPGRO-Chickpea model are the vegetative and reproductive development, carbon balance, water balance and nitrogen balances, which relate the flow of mass and information between different subroutines. Input files are classified into three major parts such as weather, soil and crop management. The required crop parameters (Phenology, growth and yield), soil and weather parameters were collected for Jabalpur and Tikamgarh for model initialization. The CHIKPGRO model requires crop parameters average as well as time course data and the required parameters were collected through field experiments. The daily weather data were collected from respective Agromet Observatory situated within 1 km radius from crop fields. The files for model initialization were created with the help of Xbuild tool of the model. The permissible or tolerance percentage error considered is upto 20 per cent for model performance. If the difference between simulated and observed values is/are above 20 per cent than the model performance was reported as poor and if the difference lies within 20 per cent range, good or acceptable is reported in the text.

3. Results and discussion

3.1. *Climatic conditions*

The average maximum temperature during the month of May-June varied between 45.5 to 46.4 °C, while the average minimum temperature varied between 8.2 to 8.7 °C during December-January, which was the coldest month of the year at Jabalpur. The average annual rainfall of this region is about 1350 mm which is mostly received between June to September and a little rainfall (75 to 175 mm) in October to May. The climate of Jabalpur is sub-humid type. At Tikamgarh the average maximum temperature during the month of May-June varies between 43.0 to 45.0 °C, while the average minimum temperature varies between 3.0 to 4.5 °C during December-January,

TABLE 1

Jabalpur experiments data used for calibration

2009-10	Sowing date	Harvesting date	Total irrigation (mm)	Rainfall (mm)	Average temperature (°C)	
					Maximum	Minimum
D$_1$	11 Oct 2009	29 Feb 2010	40	92.7	27.1	10.8
D$_2$	26 Oct 2009	02 Mar 2010	40	93.5	26.3	10.0
D$_3$	11 Nov 2009	08 Mar 2010	40	93.5	26.1	10.0
D$_4$	27 Nov 2009	13 Mar 2010	80	40.6	26.9	10.0
D$_5$	10 Dec 2009	28 Mar 2010	80	40.6	27.9	10.8
D$_6$	25 Dec 2009	07 Mar 2010	80	20.4	29.5	12.0

TABLE 2

Genetic coefficients of JG 315 and JG 11

Genetic Parameter	Description	JG 315	JG 11
CSDL	Critical Short Day Length below which reproductive development progresses with no day length 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)	-0.143	-0.143
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 °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

which are the coldest months of the year. The average annual rainfall is about 1000 mm which is mostly received between June to September and a little rainfall (90 mm) is also obtained during October to May. Climate of Tikamgarh is semi-arid type.

3.2. *Model calibration*

The genetic coefficients of chickpea cultivars JG 315, JG 11, are not provided in the CHIKPGRO model. The cultivar specific parameters (genetic coefficients) were estimated using Bayesian techniques using the GLUE (Generalized Likelihood Uncertainty Estimation) software tool available in the new version of DSSAT V4.6. The calibration was done by following the two step process by the model, first step to define known information about the parameter. The information of JG 74 a *desi* cultivar; genetic coefficients; which is available in the model was taken as known information. Through the GLUE tool a new probability distribution of parameters were calculated by running the model (Jianqiang *et al*., 2010) with experimental data of the year 2009-10 of Jabalpur and the details of input data used are given in Table 1.

TABLE 3

Comparison of observed (O) and simulated (S) crop parameters at Jabalpur

Date of sowing	Emergence (days)		First flowering (days)		First pod (days)		Physiological maturity (days)		Maximum LAI		Seed yield (kg/ha)	
	O	O-S	O	O-S	O	O-S	O	O-S	O	O-S	O	O-S
Jabalpur 2009-10 (Cultivar - JG 315)												
D1-11 Oct	5	1	44	3	57	0	132	17	4.03	0.68	2221	-570
D2- 6 Oct	6	1	41	-2	53	-5	122	14	4.07	0.01	2709	422
D3-11 Nov	5	1	50	5	69	2	111	1	5.68	2.1	2536	432
D4-27 Nov	7	2	47	5	71	8	99	-6	4.41	1.04	1851	-55
D5-10 Dec	6	1	52	3	68	1	101	-3	3.92	0.47	1563	-237
D6-25 Dec	7	2	50	1	63	-2	92	-7	3.97	0.21	1117	-103
Jabalpur 2009-10 (Cultivar – JG 11)												
D1-11 Oct	5	1	48	8	59	6	128	15	3.50	-0.97	2509	-630
D2- 6 Oct	7	2	43	-1	57	3	119	8	4.11	0.15	2743	-32
D3- 1 Nov	5	0	51	4	69	8	109	-3	4.91	1.16	2650	165
D4- 27 Nov	8	2	46	-4	71	8	101	-5	4.16	1.18	2135	65
D5-10 Dec	6	1	53	1	69	6	99	-5	3.81	0.78	1913	-86
D6-25 Dec	7	2	50	-1	61	0	90	-9	3.60	0.32	1351	-34

O = Observed, S = Simulated

TABLE 4

Measured and simulated anthesis days, first pod day, first seed days and physiological maturity days (2010-11)

Treatments	Anthesis days		First pod days		First seed days		Physiological maturity days	
	S	O	S	O	S	O	S	O
D_1V_1	35	31	44	41	56	46	115	128
D_1V_2	36	34	47	43	55	48	119	125
D_2V_1	37	39	49	57	65	66	107	115
D_2V_2	38	41	52	59	62	69	109	113
D_3V_1	48	42	63	64	77	72	109	109
D_3V_2	49	44	64	66	74	74	110	107
D_4V_1	50	44	65	63	77	68	103	99
D_4V_2	51	46	66	64	76	70	101	96
D_5V_1	49	47	60	58	71	63	100	91
D_5V_2	49	48	62	60	70	65	102	89
D_6V_1	42	41	52	51	64	55	90	80
D_6V_2	43	43	55	52	63	56	93	78
Mean	44	42	57	57	68	63	105	103
RMSE	3.66		3.75		6.83		8.71	
CRM	-5.4		-0.15		-7.71		-2.17	

TABLE 5

Measured and simulated seed yield, pod weight, seed number and unit weight of seed at maturity (2010-11)

Treatments	Seed yield at harvest maturity (kg [dm]/ha)		Pod weight at maturity (kg [dm]/ha)		Seed number at maturity (no/m^2)		Unit weight of seed at maturity (g(dm)/unit)	
	S	O	S	O	S	O	S	O
D_1V_1	2099	1502	2746	2091	1268	1111	0.184	0.148
D_1V_2	2081	1524	2960	2116	1203	1021	0.173	0.191
D_2V_1	1396	1027	1897	1611	821	992	0.170	0.132
D_2V_2	1780	1382	2381	2044	1059	1028	0.178	0.156
D_3V_1	1425	1237	2174	2420	984	1560	0.163	0.153
D_3V_2	1689	1326	2316	2394	1151	1157	0.164	0.195
D_4V_1	1082	1058	1930	1821	1287	1245	0.084	0.119
D_4V_2	1482	1092	2175	1691	1628	969	0.091	0.137
D_5V_1	1057	937	1950	1201	1433	791	0.081	0.139
D_5V_2	1135	795	2005	1254	1972	609	0.072	0.164
D_6V_1	763	814	1373	1082	1033	637	0.074	0.138
D_6V_2	727	805	1466	1449	1598	732	0.046	0.164
Mean	1393	1125	2114	1765	1286	988	0.123	0. 153
RMSE	357.32		488.14		579.69		0.056	
CRM	-23.78		-19.83		-30.24		19.38	

In the second step the genetic coefficients for new cultivars were estimated after 9000 runs through maximum likelihood estimator and presented in Table 2. The GLUE tool first fixed the phenological coefficients and in subsequent steps fixed the yield and in the last steps other coefficients were fixed.

These genetic coefficients are further used for model validation. Earlier to this calibration work Srivastava (2003) has calibrated the CHIKPGRO - model at Central and North-west India. Singh *et al*. (2005) evaluated the CHIKPGRO (CROPGRO-Chickpea) model for chickpea cultivars JG 74 and K 850 at Baster plateau in Chhattisgarh of central India. They estimated the cultivar specific genetic coefficients following the procedure described by Hunt (1993).

3.3. *Model estimation under calibration*

The model estimated parameters were compared with experimental data of the year 2009-10 of Jabalpur and deviation from experimental data was presented in Table 3. It is clear from the Table 3 that in early sown (11th October) and late sown (in December) conditions; differences in simulated and observed parameters (LAI & seed yield) were high (greater than 20%). This error could not be minimized after a large number of reruns of the CHIKPGRO model during fixing of the genetic coefficients.

3.4. *Model validation*

Accuracy of the model simulation and performance of genetic coefficients were assessed by running model with independent data set. Validations were done with six dates of sowing dates of Jabalpur (irrigated) during 2010-11 and two dates of sowing during 2009-10 and 2010-11 of Tikamgarh (*rainfed*) and reported in this study. The simulated data were compared with experimental data and agreement has been checked by CRM, RMSE and also by percentage difference between observed and simulated values.

3.4.1. *Jabalpur*

Model simulation

The comparison of simulated and observed days to anthesis, first pod, first seed and physiological maturity were carried for both the cultivars and combined results are presented in Table 4.

The model overestimated the days to anthesis (-5.4%), days to first pod (-0.15%), days to first seed (-7.71%) and the days to physiological maturity (-2.17 %). Yadav *et al*. (2012) evaluated PNUTGRO model for groundnut at Gujarat and also reported similar findings. They also reported that the model overestimated the days to first pod in timely sown and underestimated in

TABLE 6

Simulated and measured tops weight, by-product, LAI maximum and harvest index (2010-11)

Treatments	Tops weight at maturity [kg (dm)/ha]		By-product Produced (stalk) at maturity [kg (dm)/ha]		LAI maximum		Harvest index (%)	
	S	O	S	O	S	O	S	O
D_1V_1	4117	3456	2320	1954	3.41	4.20	50.90	43.36
D_1V_2	4016	3456	2100	1932	3.17	2.83	59.80	43.78
D_2V_1	3431	2962	2040	1932	2.60	2.20	40.70	34.67
D_2V_2	3837	3333	1960	1950	2.61	2.09	49.00	42.06
D_3V_1	3818	3265	2630	2528	2.27	2.49	45.50	35.37
D_3V_2	3773	3141	2380	2315	2.21	3.53	46.10	36.52
D_4V_1	3286	3024	2100	1966	2.45	2.59	32.90	35.10
D_4V_2	3328	3086	2150	1994	2.42	2.37	39.80	35.29
D_5V_1	3036	2839	2080	1901	2.78	2.50	32.70	32.75
D_5V_2	2830	2530	1870	1735	3.05	1.85	32.90	31.49
D_6V_1	2676	2535	1810	1721	2.81	2.09	28.50	31.80
D_6V_2	2777	2469	1750	1664	2.95	2.01	25.20	31.62
Mean	3410.42	3008	2099.17	1966.0	2.73	2.56	39.50	36.15
RMSE	437.84		157.18		0.701		6.13	
CRM	-13.38		-6.77		-6.44		-9.26	

late sown treatments. The chickpea crop received 8 rain events (rainy days) during 2009-10; while during 2010-11 the crop received 6 rain events (rainy days) at Jabalpur; which may be lengthen the day to anthesis in first year of experiment. The model did not accurately simulate the rainfall impact and hence there were large differences in anthesis date, which was observed during third and fourth dates of sowing. Yadav *et al.* (2012) also indicated increase in dates of anthesis under higher moisture regime and hence the growers of semi-arid regions apply irrigation in chickpea to delay the flowering.

Under the twelve simulation results (six dates of sowing and two cultivars), mean difference was of 0.15 per cent between observed and simulated data for first pod date. The actual difference of first pod date varied from 7 day to 8 days (under second date of sowing). Expect the second date of sowing; model performance was within the acceptable limit (20%) in the estimation of days to first pod. The result was in conformity with the findings of Singh and Virmani (1996). They reported that the first pod day values were predicted within +3 days of observed values for the cultivars Annigeri and JG 74.

The model did not accurately simulate the first seed day for an early sowing date (before 20th October). The difference between first flower and first seed day was 13 days; while the mean difference between first flowering and first seed was 21 days and model was not able to simulate an early seed initiation, which was not within the acceptable limit. This error in simulation was also reported by Pedersen *et al.* (2004). The prediction of duration from sowing to physiological maturity was over predicted by model with a mean difference of 2.71 per cent between observed and simulated physiological maturity. The model under predicated the days to physiological maturity for first two dates of sowing (during October sowing) for both the cultivars and large difference was noted between observed and simulated physiological maturity days.

The model also over predicted the crop phenology for the rest of the sowing dates, which varied between 0 (anthesis) to 13(physiological maturity) days. Boote *et al.* (2002) also pointed out this error and reported that model could not accurately simulate the physiological maturity especially in the irrigated situations. This may be due to the effect of thermal and moisture regime in combination or separately, which determines the phenological development of chickpea, while the model only accounted for thermal environmental changes.

TABLE 7

Measured and simulated anthesis day, first pod day and physiological maturity days (2009-10 and 2010-11)

Treatments	Anthesis days				First pod days				Physiological maturity days			
	2009-10		2010-11		2009-10		2010-11		2009-10		2010-11	
	S	O	S	O	S	O	S	O	S	O	S	O
D_1V_1	32	36	41	43	64	67	63	68	118	125	117	128
D_1V_2	34	40	44	45	59	62	60	63	108	113	109	115
D_2V_1	37	39	51	57	61	68	63	70	114	121	116	125
D_2V_2	38	41	50	59	58	63	59	64	106	110	104	113
Mean	35	39	47	51	62	65	61	66	112	117	112	120
RMSE	16.20		5.43		3.26		4.74		5.89		9.07	
CRM	9.5		8.8		5.0		6.7		4.9		7.8	

TABLE 8

Measured and simulated seed yield, top weight and unit weight of seed at maturity (2009-10 and 2010-11)

Treatments	Seed yield at harvest maturity [kg (dm)/ha]				Tops weight at maturity [kg (dm)/ha]				Unit weight of seed at maturity [g(dm)/unit]			
	2009-10		2010-11		2009-10		2010-11		2009-10		2010-11	
	S	O	S	O	S	O	S	O	S	O	S	O
D_1V_1	700	1000	1010	1250	3160	3710	3350	3900	0.08	0.10	0.09	0.11
D_1V_2	960	1200	1090	1340	3320	3870	3650	4050	0.09	0.12	0.10	0.13
D_2V_1	690	950	850	1100	1890	2450	1580	2200	0.07	0.09	0.08	0.10
D_2V_2	858	1100	890	1230	2370	2890	2240	2970	0.09	0.10	0.09	0.11
Mean	802	1063	960	1230	2685	3220	2705	3280	0.08	0.10	0.09	0.11
RMSE	261		273		545		587		0.02		0.03	
CRM	32.48		28.12		20.30		21.26		24.24		25.00	

The observed and simulated values of growth and yield attribute are shown in Table 5 and Table 6. Model underestimated the unit seed weight by 19.38 and over estimated seed yield (-23.78%), pod weight (-19.83%) and number of seed/m^2 (-30.24 %) at Jabalpur. The simulated data indicated that seed yield was over estimated under all the sowing dates, except last date of sowing. During last (D_6) date of sowing model under predicted the seed yield. The first and second date of sowing showed large difference (30 %) between simulated and observed seed yield (Table 5). Under late sown conditions, model estimated lower unit seed weight, which was not observed in field recorded data. The model reduced the unit seed weight in late sown conditions and thus increased the seed number and to get the seed yield. To get the seed yield; the model multiply the seed number and unit seed weight with a factor ranging from 8 to 10. However, to get the seed yield the multiplier factor varied from 5 to 9.5 in the data collected from field experiments. Agrawal (2011) reported that yield reduction was observed in all the chickpea genotypes sown in December at Jabalpur region of Madhya Pradesh. It indicates that under thermal stress conditions, the model assume the severity of stress more than what actually exists in the field conditions.

The model thus, could not able to predict the observed biomass accurately and always predicted a higher dry matter (excepting the last date of sowing) with
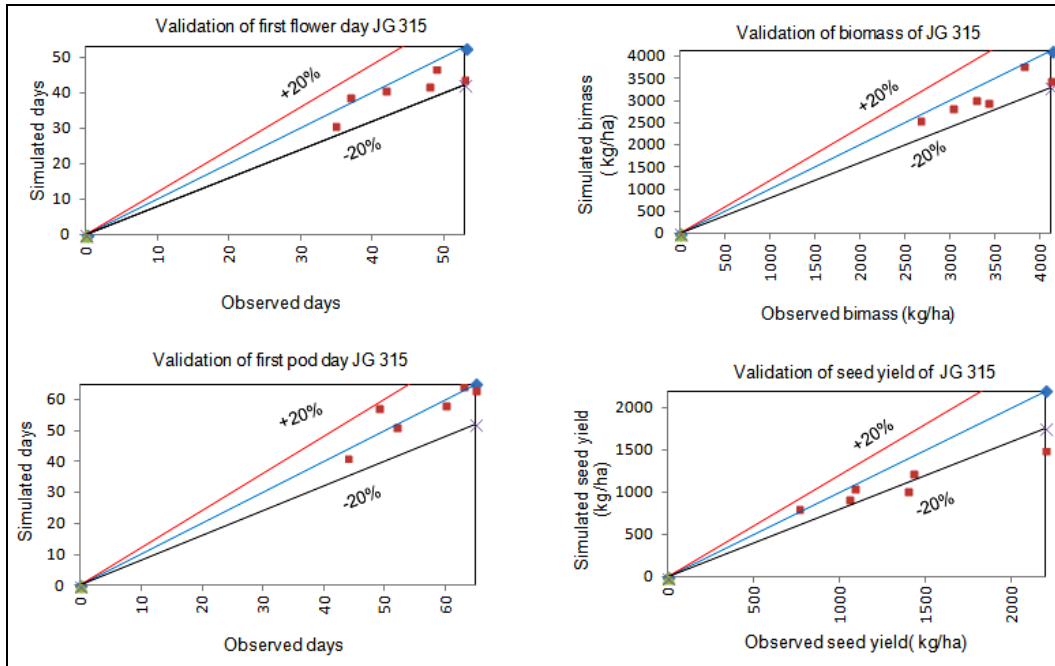
Fig. 1. Departure of observed and simulated points from 1:1 line of chickpea genotype JG 315
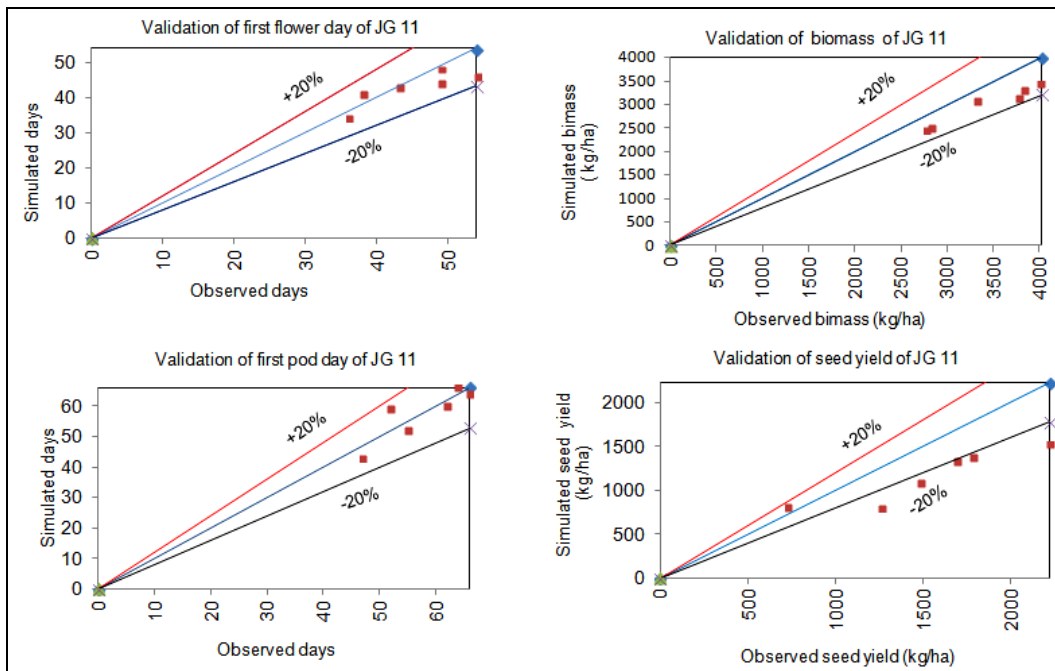

Fig. 2. Departure of observed and simulated points from 1:1 line of chickpea genotype JG 11

a mean percentage error of 13.4 (Table 6). Pedersen *et al.* (2004) reported overestimation of total dry matter production and seed yield by CROPGRO-Soybean model. Model over estimated the pod weight and maximum

difference between observed and simulated result was observed for the first date of sowing. This is because the crop had maximum reproductive phase from first seed initiation to physiological maturity in first date of sowing

for both the cultivars. The RMSE for seed yield was 357 kg/ha, which indicates that the model performance may not within the acceptable limit for predicting seed yield under irrigated condition at central Indian region. The model simulated seed number/m^2 and pod weight with large error with the RMSE values of 580 and 488 respectively. From the Table 6, it was found that there was higher difference in observed and simulated top weight, which was noted for both cultivars with first date of sowing (D1) and for lower differences for rest 5 date of sowing.The model overestimated the by-product produced (-6.77%), LAI   (-6.44%) and harvest index (-9.26%). Similar results were reported by Pandey *et al.* (2001).

The overestimation of biomass by the model may be due to use of higher temperature value (on and above 30 °C of maximum temperature) in the temperature response function, which is adopted for simulation of maximum photosynthesis. The eight year chickpea crop and daily temperature data collected at Jabalpur, it was observed that maximum temperature above 30 °C during vegetative to end of reproductive phase may have negative impact on biomass and seed yield of chickpea.

3.4.2. *Tikamgarh*

To validate the CHIKPGRO model, *rainfed* experiments on two cultivars (JG 315 and JG11) under two dates of sowing were carried out at Tikamgarh. The major phenological events both observed and simulated are presented in Table 7 and major growth and yield parameters in Table 8. The deviations between the simulated and observed values were high for *rainfed* conditions than under irrigated condition at Jabalpur. The model was found to be underestimated the phenological events and major growth and yield parameters at Tikamgarh under *rainfed* conditions.

Ruiz *et al.* (2001) calibrated the CROPGRO-Soybean model under *rainfed* conditions in Galicia, northwest Spain. They simulated (after calibrating the model for non-limiting water conditions) soybean yield using *rainfed* field data sets, the model simulated more severe water stress than what actually occurred. It was noted that the model over estimated the response of moisture and thermal stresses. Pedersen *et al.* (2004) also reported that CHROPGRO-Soybean model's under predicted the early vegetative growth, seed and biomass yield.

3.5. *Chickpea cultivar simulation*

The model simulation results of growth and yield attributes of JG 315 and JG11 were done separately at Jabalpur and sown in Figs. 1 & 2. It is clear from figures that the model simulates JG 315 growth and yield attributes comparatively with less error than JG11. Simulated value of biomass and yield of JG 315 has involved less error than cultivar JG11 both under irrigated conditions. The above results suggest that the estimated genetic coefficients could not exhibit similar simulated pattern of development and yield parameters of same cultivar under different thermal and moisture environments. The phenological events were overestimated and underestimated for both the cultivars under different thermal conditions. This might be due to error in temperature response function adopted in the model. This indicates that under thermal stress conditions, the model accesses the severity of stress more than what actually exists. The model did not accurately simulate the rainfall impact also and hence there are large differences in anthesis date for third and fourth date of sowing at Jabalpur. Pedersen *et al.* (2004) while evaluating CROPGRO-Soybean model in the upper Midwest in USA reported that this model underestimates total biomass and grain yield at harvest. They reported that the modified parameter's (Changes in temperature response function for leaf expansion rate and base temperature for pod addition), improved model performance and decreased root mean square error (RMSE) and increased biomass and grain yield by 13 and 20 per cent. Further the ranges adopted for defining the genetic coefficients may also need modification so that actual phonological dates of more chickpea varieties can be more accurately simulated, which can improve the model performance.

4.   Conclusions

(*i*)   The CHIKPGRO model overestimated maximum LAI, biomass and seed yield under irrigated conditions at Jabalpur and underestimated under *rainfed* conditions at Tikamgarh. The simulated results under wider thermal regime and *rainfed* conditions involve more error.

(*ii*)   The deviation between the simulated and observed values was high for early as well as later sown crop. The effect of rainfall was not fully accounted by the model in simulation of anthesis dates.

(*iii*) The model performed differently in simulating the yield and biomass of the cultivars. The cultivar JG 11 has shown slightly more difference in simulation of yield and biomass as compared to cultivar JG 315 under irrigated condition and vice versa in *rainfed* conditions.

(*iv*) The model may be improved to estimate the unit seed weight and harvest seed number at acceptable levels.

(*v*) The thermal response function adopted in the model may be modified. The model reduced the unit seed weight in late sown conditions and thus increased the seed number and hence more error crept in simulation of seed yield. This a major limiting factor for yield estimation through this model in late sown and *rainfed* conditions. Overall, present study shows an optimistic path to handle the biased and under performance of the CHIKPGRO model, which may be rectified through some simple parameters adjustments. However, the challenge lies in infusing outcomes of these findings in the model for its wider application.

Acknowledgements

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