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Sensitivity analysis of growth and yield attributes of chickpea to the temperature under actual condition using DSSAT model

Vimal Pandey, AK Singh, Krishna Deo, Adita Mishra and Gulab Singh

Abstract
A field experiment was conducted during the *Rabi* season of 2011-12 to access the sensitivity analysis of growth and yield attributes of chickpea to the temperature under actual condition using DSSAT model in silty loam soil at student's instructional Farm, N.D. University of Agriculture & Technology, Kumarganj, Faizabad. The experiment was conducted in split plot design and replicated 4 times with three dates of sowing viz. D_1 (26th October), D_2 (10th November) and D_3 (25th November), and three varieties *viz.* V_1 (Pusa-362), V_2 (PG-186) and V_3 (Awarodhi). DSSAT crop growth simulation model used for calibration. The historical data of the year 2009-10 and 2010-11 used for improving model tuning. The yield and yield attributes, phonological stages, test weight, harvest index as simulated by model were compared with the observed data. The result revealed that the model underestimated the test weight, LAI, first pod initiation, physiological maturity and overestimated rest of the parameters. Decrease of maximum temperature and minimum temperature by 1^0C over normal temperature increased the simulated grain yield of chickpea. Higher percent change 35.8% and 34.4% from base yield of 2340 kg^{-1} was recorded with decrease of maximum temperature and minimum temperature respectively by 3 ^{0}C over normal temperature obtained during the crop period.

Keywords: Chickpea, DSSAT, maximum temperature, minimum temperature, crop simulation model, sensitivity

Introduction
Chickpea (*Cicer arietinum* L.) is the premier pulse crop of Indian sub-continent. India is the largest chickpea producer as well as consumer in the world. In UP its total area is 0.27 million-hectare, production 0.22 million ton and productivity is 805kg/ha. The UN declared 2016 the international year of pulses. (Agriculture Statistics, 2016-17) [3]. Chickpea is one of the most important pulse crop of India. It is also known as Bengal gram / gram in English and is popularly called as Chana in Hindi. Chickpea requires cool and dry weather for optimum growth and development. Chickpea is a good source of protein (21.1%) carbohydrate (61.5%), fat (4.5%), minerals (calcium, phosphorus, iron) and vitamins. It is a superb energy umbrella for the people as dietary protein, for the livestock as green nutritious fodder and feed and for the soil as a mini nitrogen plant and green manure. It also helps in enhancing the soil quality for subsequent cereal crop. In India, acid exudates from the leaves were used medicinally for bronchitis, cholera, constipation, diarrhea, dysentery, snakebite, sunstroke and warts. The productivity of chickpea is curtailed due to biotic and abiotic stresses.

DSSAT is a computerized system to help resource planners and farmers make decisions as they seek solutions to specific agricultural problems. It is a result of the International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) project supported by the U.S. Agency for International Development from 1983 to1993. It has subsequently continued to be developed through collaboration among scientist, from the University of Florida, the University of Georgia, University of Guelph, University of Hawaii, the International Center for Soil Fertility and Agriculture Development, Iowa State University and scientists associated with ICASA. DSSAT was designed so that users can (1) input, organize, store data on crops, soils, and weather, (2) retrieve, analyze and display data, (3) calibrate and evaluate crop growth models and (4) evaluate different management practices at a site. Input requirements for DSSAT include weather, soil condition, plant characteristics and crop management. The minimum weather input requirements of the model are daily solar radiation (MJ $m^{-2}d^{-1}$), maximum and minimum temperature (^{0}C) and precipitation (mm).

Soil inputs include albedo, evaporation limit, mineralization, photosynthesis factors, pH, drainage and runoff coefficients.
The model also requires water holding characteristics, saturated hydraulic conductivity, bulk density and organic carbon for each individual soil layer. The model required calibrated genetic coefficients of desire crop and cultivar. Management input information includes plant population, planting depth, and date of planting. Latitude is required for calculating day length. The model simulates phenological development, biomass accumulation, and its partitioning, leaf area index, root, stem, leaf-growth, the water and N-balance from planting to harvest on daily or desired time steps In this paper attempt has been made to calibrate and validate to genetic coefficient of chickpea cultivar using DSSAT model.

Material and Methods

Geographically, the experimental site is situated at $26^{0}47'$ N latitude, $82^{0}12'$ E longitude and at an attitude of 113 meters above mean sea level (MSL) in the Indo-Gangetic plain. The site comes under sub-tropical climate and often subjected to extremes of weather condition i.e. cold winter and hot summer. Faizabad district enjoys sub humid climate and received average annual rainfall about 1100 mm. On an average about 85 per cent of the total rainfall is received during South-West monsoon period i.e. from June to September. However, occasionally 5 to 10 per cent showers occurs during winter season. The experiments was laid out in split plot design (SPD). Nine treatment combinations comprised of three sowing date viz., D_1 (26th October), D_2 (10th November) and D_3 (25th November) were kept in main plot and three varieties viz., V_1 (Pusa-362), V_2 (PG-186) and V_3 (Awarodhi) were kept as sub plot treatment.
The package and practices for cultivation was followed as per the recommendation of crop parameters such as yield and yield attributes, LAI, harvest index and phenology were used for calibration of the DSSAT ver 4.6 model. Various statistical and mathematical techniques for developing these relationships have been used as the term 'crop weather model. Using mathematical/statistical/computational techniques in the simulation models used the biological soil (physical/ chemical) and micrometeorological systems are considered. To evaluate the performance of the DSSAT crop growth simulation model in chickpea, first of all it was calibrated with historical crop data. To determine the genetic coefficients (Table No 1) of chickpea crop and varieties, the sensitivity test was approached by changing their values to determine the variation in the magnitude of output. For the normal sowing date and varieties each of the genetic coefficients was interactively increased/ decreased from the given value and the simulated values of the relevant growth and yield parameters were compared with the observed values. Then, those values of the genetic coefficients that was found most realistically simulated the growth and yield of chickpea were selected.

Result and Discussion

Phenological stages

Calibration was done with the historical data of the year 2009-10 and 2010-11 for improving model tuning. It is obvious from the data presented in Table No.2 revealed that in validation error percent were recorded lowest in pusa-362 and PG-186 under Nov. 10th sowing. It is also obvious from the data that Pusa-362 recorded lowest error percent over PG-186 and Awarodhi in Nov. 10th sowing. While highest error percent was observed in delayed sowing of 25th Nov. Error percent increased with delay in sowing. Model provides accurate prediction of days taken to anthesis in case of mid sown crop. The similar results were obtained by Patel *et al.*, 1998 [8]. Data with regard to calibration and validation of simulated days taken to first pod formation from observed in chickpea varieties sown under different dates of sowing. It is raveled from the table No 3. The days taken to first for formation of chickpea, during 2010-11 in Pusa-362 and in Awarodhi. While validating them during 2011-12, it is evident that lowest error percent in Pusa-362 was recorded under 26th Oct. sown crop. Second date of sowing i.e. 10th Nov. of Pusa-362 under stimated the model. Error percent increased with delay in sowing. Overall model overestimated days taken to first pod formation in all the varieties sown under different dates of sowing. Reddy *et al.*, 2000 [9] also observed. Error percentage worked out between simulated and observed first seed formation of chickpea. Result reveal that in calibration with historical data of year 2009-10, lowest error percent between observed and simulated under Pusa-362 and PG-186 were recorded in 10th Nov. sowing. It is obvious from the data presented in Table No. 4 reveal that in validation, error percent in Pusa-362 ranged between 9.68 (D_1V_1) to 11.67(D_1 V_1); while in PG-186 error percent ranged between 8.26 to 9.6. The lowest error percent (9.68) was recorded under timely sown crop. Reddy *et al.*, 2000 [9]. Also reported similar results. Data with respect to calibration and validation of simulated days taken to physiological maturity from observed in chickpea varieties sown in different dates of sowing for the year 2009-10 to 2011-12 are presented in Table No.5 Error percentage between simulated and observed was worked out for days taken to physiological maturity of chickpea. In calibration of Pusa-362 during the year 2009-10, and 2010-11, the lowest error percent was recorded in Nov.10th sown crop. Overall model overestimated the Days taken to physiological maturity in all dates of sowing of the chickpea variety used under study. The similar results were also obtained by Patel *et al.*, 1998 [8].

Yield and yield attributs

Error percentage was worked out between simulated and observed seed yield (kg ha^{-1}) of chickpea. In calibration with historical data of year 2009-10 and 2010-11 error percent recorded in the order of Pusa-362 $<$ PG-186 $<$ Awarodhi. Lowest error percent obtained between simulated or observed seed yield was recorded in Pusa-362 sown on Nov.10th followed by PG-186 under same date of sowing. It is obvious from the data presented in Table No 6 revealed that in validation error percent in Pusa-362 ranged between 3.52(D_1V_1) to 6.44 (D_2V_1) while in PG-186 it ranged between 6.42(D_1V_2) to 10.37 (D_3V_2). Lowest error percent was recorded in timely sown crop (Oct 26th). Lowest error % during 2011-12 was recorded in D_2V_3 (Nov.10th sowing with Awarodhi) and % error in estimated yield increased with delayed sowing. In calibration with historical crop data of year 2009-10. the error percent was recorded in the magnitude of Pusa-362 $<$PG-186 $<$Awarodhi. Lowest error percent was recorded in Pusa-362. Model underestimated during 2010-11 in Pusa-362 and Awarodhi sown on 26th Oct. in validation all the varieties under study overestimated the model (Kumar *et al.*, 1999) [6]. Data pertaining to calibration and validation of simulated biomass yield (kg ha^{-1}) from observed in chickpea varieties sown in different dates of sowing during the year 2009-10 to 2011-12 are presented in Table No. 7. Error percentage was worked out between simulated and observed biomass yield (kg ha^{-1}) of chickpea. In validation error percent in Pusa-362 ranged between -2.55(D_1V_1) to -6.23(D_3V_1) 2011- respectively. There was no any specific trend in error percent in different dates of sowing in varietal treatment of validation under different dates of sowing. Lowest error percent in Pusa-362 during 2011-12 was recorded in D_1V_1 and increased with subsequent delay in sowing. Overall model underestimated the biomass yield in all the dates of sowing of the chickpea variety used under present study. The similar results were obtained by Boote *et al.*, 2002 [4].

Sensitivity analysis of chickpea to maximum temperature under actual condition

Sensitivity analysis of chickpea to maximum temperature under actual condition over normal temperature are presented in Table No. 8. It is evident from the Table that the simulated pod yield decreased with successive increase of maximum temperature by 1^0 Cover normal. While successive decrease of maximum temperature by 1^0 Cover normal temperature increased the simulated grain yield of chickpea. Consequently, higher percent change from base yield of 2340 kg^{-1} change (35.8%) was recorded with decrease of maximum temperature by 3^0 Cover normal temperature obtained during the experimental crop period. Data pertaining to sensitivity analysis of chickpea to minimum temperature over normal temperature are presented in Table No 9. It is evident from the Table that the simulated pod yield decreased with successive increase of minimum temperature by 1^0C over normal. While successive decrease of T minimum by 1^0C over normal temperature during crop period increased the simulated grain yield of chickpea. Consequently, higher % change (34.4) from base yield (2340 kg ha^{-1}) was recorded with decrease of minimum temperature by 3^0C over normal temperature recorded during crop period.

Conclussion

DSSAT model overestimated the days taken to anthesis, first pod formation, first seed formation, and days taken to physiological maturity, yields while model underestimated the biomass yield of chickpea crop. Therefore, the model can be used for predicting chickpea yield and phenological events under agroclimatic conditions. The model may also to be used to improve and evaluate the current practices of chickpea growth management to increases the crop production.

Table 1: Genetic coefficient of Chickpea cultivar for eastern Uttar Pradesh agro climatic region

Parameter		Pusa-362	PG-186	Awarodhi
Critical Short-Day Length below which reproductive development progresses WITH day length effect (for long day plants) (hour)	CSDL	11.00	11.00	12.00
Slope of the relative response of development to photoperiod with time (negative for long day plants) (1/hour)	PPSEN	-.143	-.143	-.143
Time between plant emergence and flower appearance (R1) (photo thermal days)	EM-FL	36.0	38.0	42.0
Time between first flower and first pod (R3) (photo thermal days)	FL-SH	9.0	11.0	7.0
Time between first flower and first seed (R5) (photo thermal days)	FL-SD	17.0	14.0	14.0
Time between first seed (R5) and physiological maturity (R7) (photo thermal days)	SD-PM	38.00	38.00	26.00
Time between first flower (R1) and end of leaf expansion (photo thermal days)	FL-LF	40.00	43.00	32.00
Maximum leaf photosynthesis rate at 30 C, 350 vpm CO_2, and high light (mg CO^2/m2-s)	LFMAX	1.700	1.700	1.600
Specific leaf area of cultivar under standard growth conditions (cm2/g)	SLAVR	150.	150.	160.
Maximum size of full leaf (three leaflets) (cm^2)	SIZLF	10.0	10.0	11.0
Maximum fraction of daily growth that is partitioned to seed + shell	XFRT	1.00	1.00	1.00
Maximum weight per seed (g)	WTPSD	0.285	0.182	0.198
Seed filling duration for pod cohort at standard growth conditions (photo thermal days)	SFDUR	29.0	22.0	23.0
Average seed per pod under standard growing conditions (#/pod)	SDPDV	1.00	1.40	1.80
Time required for cultivar to reach final pod load under optimal conditions (photo thermal days)	PODUR	18.0	18.0	18.0
The maximum ratio of (seed/ (seed +shell)) at maturity. Causes seed to stop growing as their dry weights increase until shells are filled in a cohort. (Threshing percentage).	THRSH	85.0	85.0	86.0
Fraction protein in seeds (g(protein)/g(seed))	SDPRO	.216	.216	.216

Table 2: Calibration of observed days taken to anthesis of chickpea from simulated values under different dates of sowing and varieties

Date of sowing Year	Varieties								
	Pusa -362(V_1)			PG-186 (V_2)			Awarodhi(V_3)		
	Obs.	Sim.	Error %	Obs.	Sim.	Err. %	Obs.	Sim.	Err. %
2009-10									
D_1	105	116	10.48	104	113	8.65	103	108	4.85
D_2	102	110	7.84	102	111	8.82	101	103	1.98
D_3	91	101	10.99	88	101	14.77	89	96	7.87
2010-11									
D_1	104	114	9.62	105	114	8.57	102	109	6.86
D_2	101	113	11.88	101	113	11.88	100	110	10.0
D_3	89	96	7.87	87	100	14.94	90	94	4.44
Validation of observed days taken to anthesis of chickpea from simulated values under different dates of sowing and varieties									
2011-12									
D_1	105	111	5.71	104	110	5.77	105	112	6.67
D_2	102	106	3.92	102	107	4.90	103	111	7.77
D_3	88	95	7.95	87	93	6.90	92	97	5.43

Table 3: Calibration of observed days taken to first pod formation of chickpea from simulated values under different dates of sowing and varieties

Date of sowing Year	Varieties								
	Pusa-362(V_1)			PG-186 (V_2)			Awarodhi (V_3)		
	Obs.	Sim.	Error %	Obs.	Sim.	Error %	Obs.	Sim.	Error %
2009-10									
D_1	115	125	8.70	116	127	9.48	113	121	7.08
D_2	111	122	9.91	112	122	8.93	113	114	1.79
D_3	102	110	7.84	97	108	11.34	101	109	7.92
2010-11									
D_1	115	123	6.96	116	124	6.90	114	120	5.26
D_2	111	119	7.21	112	117	4.46	111	118	6.31
D_3	97	109	12.37	97	104	7.22	99	107	8.08
Validation of observed days taken to first pod formation of chickpea from simulated values under different dates of sowing and varieties									
2011-12									
D_1	116	118	1.72	116	126	8.62	115	123	6.96
D_2	113	112	-0.88	114	119	4.39	113	125	10.62
D_3	95	125	8.70	96	127	9.48	99	121	7.08

Where, D_1-26th October, D_2-10th November and D_3-25th November

Table 4: Calibration of observed days taken to first seed formation of chickpea from simulated values under different dates of sowing and varieties

Date of sowing Year	Varieties								
	Pusa -362(V_1)			PG-186 (V_2)			Awrodhi(V_3)		
	Obs.	Sim.	Error %	Obs.	Sim.	Error %	Obs.	Sim.	Error %
2009-10									
D_1	124	134	8.06	124	139	12.10	123	132	7.32
D_2	121	128	5.79	122	134	9.84	120	129	7.50
D_3	110	118	7.27	105	118	12.38	108	115	6.48
2010-11									
D_1	125	139	11.20	124	138	11.29	125	133	6.40
D_2	122	137	12.30	120	128	6.67	119	124	4.20
D_3	110	117	6.36	105	113	7.62	107	117	9.35
Validation of observed days taken to first seed formation of chickpea from simulated values under different dates of sowing and varieties									
2011-12									
D_1	124	136	9.68	125	137	9.60	125	131	4.80
D_2	120	134	11.67	121	131	8.26	122	128	4.92
D_3	110	121	10.00	109	119	9.17	111	116	4.50

Table 5: Calibration of observed days taken to physiological maturity of chickpea from simulated values under different dates of sowing and varieties

Date of sowing Year	Varieties								
	Pusa -362(V_1)			PG-186 (V_2)			Awarodhi (V_3)		
	Obs.	Sim.	Error %	Obs.	Sim.	Err. %	Obs.	Sim.	Err. %
2009-10									
D_1	151	162	7.28	154	165	7.14	151	165	9.27
D_2	147	154	4.76	146	152	4.11	143	154	7.69
D_3	136	148	8.82	137	148	8.03	139	142	2.16
2010-11									
D_1	151	164	8.61	153	162	5.88	150	167	11.33
D_2	146	151	3.42	145	157	8.28	145	151	4.14
D_3	135	141	4.44	137	143	4.38	139	144	3.60
Validation of observed days taken to physiological maturity of chickpea from simulated values under different dates of sowing and varieties									
2011-12									
D_1	151	154	1.99	154	164	6.49	151	167	10.60
D_2	147	151	2.72	145	153	5.52	143	152	6.29
D_3	137	142	3.65	137	146	6.57	138	140	1.45

Table 6: Calibration of observed seed yield (kg ha^{-1}) of chickpea from simulated values under different dates of sowing and varieties

Date of sowing Year	Varieties								
	Pusa -362(V_1)			PG-186 (V_2)			Awarodhi (V_3)		
	Obs.	Sim.	Error %	Obs.	Sim.	Error %	Obs.	Sim.	Error %
2009-10									
D_1	2273	2412	6.12	2040	2231	9.36	2130	2235	4.93
D_2	2050	2134	4.10	1870	2013	7.65	1990	2251	13.12
D_3	1870	2013	7.65	1760	1954	11.02	1820	2013	10.60
2010-11									

D_1	2265	2413	6.53	2120	2251	6.18	2150	2245	4.42
D_2	2070	2140	3.38	1835	1910	4.09	2015	2140	6.20
D_3	1865	2015	8.04	1835	2013	9.70	1805	2013	11.52
Validation of observed seed yield (kg ha^{-1}) of chickpea from simulated values under different dates of sowing and varieties									
2011-12									
D_1	2270	2350	3.52	2010	2139	6.42	2105	2312	9.83
D_2	2080	2214	6.44	1850	2037	10.11	2000	2014	0.70
D_3	1180	1230	4.24	1716	1894	10.37	1814	2014	11.03

Table 7: Calibration of observed to biomass yield (kg/ha) of chickpea from simulated values under different dates of sowing and varieties

Date of sowing Year	Varieties								
	Pusa -362(V_1)			PG-186 (V_2)			Awarodhi (V_3)		
	Obs.	Sim.	Error %	Obs.	Sim.	Error %	Obs.	Sim.	Error %
2009-10									
D_1	5590	5423	-2.99	5180	4980	-3.86	5280	4895	-7.29
D_2	5158	4986	-3.33	4850	4654	-4.04	5043	4810	-4.62
D_3	4945	4820	-2.53	4697	4521	-3.75	4815	4621	-4.03
2010-11									
D_1	5665	5428	-4.18	5175	4841	-6.45	5222	4780	-8.46
D_2	5150	4902	-4.82	4800	4521	-5.81	5050	4703	-6.87
D_3	4930	4632	-6.04	4670	4456	-4.58	4780	4521	-5.42
Validation of observed to biomass yield (kg/ha) of chickpea from simulated values under different dates of sowing and varieties									
2011-12									
D_1	5500	5360	-2.55	5018	4520	-9.92	5250	4812	-8.34
D_2	5220	4964	-4.90	4829	4421	-8.45	5019	4721	-5.94
D_3	4940	4632	-6.23	4610	4478	-2.86	4770	4562	-4.36

Table 8: Sensitivity analysis of chickpea (DSSAT) model to maximum temperature under actual condition

Max Temperature (^{0}C) over normal temp. during crop period	Simulated pod yield (kgha^{-1})	% change from base (2340 kgha^{-1}) yield
1	2219	-5.2
2	2014	-13.9
3	1852	-20.9
-1	2563	9.5
-2	2784	19.0
-3	3178	35.8

Table 9: Sensitivity analysis of chickpea (DSSAT) model to minimum temperature under actual condition

Minimum Temperature (^{0}C) over normal temp. during crop period	Simulated pod yield (kgha^{-1})	% change from base (2340 kgha^{-1}) yield
1	2089	-10.7
2	1912	-18.3
3	1766	-24.5
-1	2561	9.4
-2	2789	19.2
-3	3145	34.4

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