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Evaluation of DSSAT Model ver 4.5 for Soybean under Varied Environmental Conditions at Pune

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ABSTRACT

Field experiments were carried out at research farm of Department of Agricultural Meteorology, College of Agriculture, Pune during kharif seasons of 2012 and 2013 on the clayey soil (medium black) to study evaluation of SOYGRO model with four sowing times (I FN of June S_1, II FN of June S_2, I FN of July S_3 and II FN of July S_4) to create different set of environmental conditions for weather variability and three varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3) was laid out in split plot design (SPD) with four replications.

The evaluation of CROPGRO-soybean model performance in respect of phenological phases was found to be highly reliable. Plant height and LAI was found to be slightly overestimated except that plant height prediction was well matched for MACS-450 (V_2).

The observed and predicted mean error per cent of seed yield was underestimated during both the years for all the varieties. The percentage error (PE) was 57.40, 30.27 and 21.53 in 2012 and 18.05, 12.28 and 10.23 in 2013 for varieties JS- 335 (V_1), MACS-450 (V_2) and DS-228 (V_3), respectively, while the degree of agreement was overestimated during both the years. The prediction for seed yield was slightly overestimated for the all varieties. The comparison of observed and predicted simulated yield parameters viz., straw yield and harvest index showed that the model slightly overestimated by for all the varieties. The straw yield was mostly overestimated but it was underestimated when crop sown delayed. The model is capable of predicting the seed yield and harvest index reliably in the cultivars DS-228 (V_3) and MACS-450 (V_2). Seed yield was slightly overestimated in JS-335 (V_1) and MACS-450 (V_2).

Key words: *DSSATv4.5, CROPGRO-soybean model, Evaluation, Genetic coefficient*

INTRODUCTION

In Maharashtra, mainly the cultivation of soybean is under rainfed condition. It is observed that in most of the years harvesting period of *kharif* soybean is coupled with post monsoon rains resulted in affecting its quality. It is also observed that germination of soybean was considerably affected to the extent of 11 to 20 % [2]. This has alarmed for finding proper time for sowing so as skip the crop from rains at harvest. Delayed sowing may result in yield reductions to the magnitude of 17-39 % [5]. Delayed sowing of soybean also significantly reduced the protein and oil content of soybean[3].

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Crop simulation model have the potential for its use as a tool in agricultural research directed for better farm performance, which simulates duration of crop growth and phasic development, plant morphological development, biomass growth rate and partitioning and yield with reasonable accuracy. The model to be used with confidence should be validated for the soil and climatic environment of the area where it could be used. Validation is necessary to test the suitability of the model for the intended purpose. It was reported that application of the CERES- wheat model to yield predictions, the model predicted the grain yield from 80 to 115 % (mean 97.5%) of the observed grain yield[4].

Crop models can be used to evaluate crop performance under diverse environment and management scenarios. Crop growth models can be used to predict crop performance in regions where the crop has not been grown before or not grown under optimal conditions. It also facilitates to have pre-harvest estimate of any crop's production. Simulation models can be used to meaningfully reduce additional experimentation and decision making to increase yield. Using crop simulation models, the effects of climate change and climatic variability on crop growth and yield have also been predicted[6]. Crop simulation modeling for soybean crop has not been attempted in western Maharashtra agro-ecosystem in this regard. The present study aimed to use the field experiment data sets for understanding the existing crop-weather-management relationships of soybean.

MATERIALS AND METHODS

A field experiments on soybean crop was conducted during *kharif* seasons of 2012 and 2013 at the research farm of Department of Agricultural Meteorology, College of Agriculture Pune. It is located on 18^o 32\` N latitude and $73^o$ 51\` E longitude. The altitude of the Pune is 557.7 m above mean sea level. The average annual rainfall of the place is 670.0 mm.

The experiment was laid out in a split plot design (SPD) with a combination of four dates of sowing (fortnight interval) *viz*., I^{st} FN June (S_1), II^{nd} FN June (S_2), I^{st} FN July (S_3) and II^{nd} FN July (S_4) and three varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3) to validate the CROPGRO-Soybean model. The crop was fertilized at the rate of 25 kg N and 75 kg P_2O_5 per hectare as a basal dose and remaining dose of 25 kg N was applied two weeks late.

The different phenological phases of plant development and the observations thereof were recorded by visiting the field frequently from sowing to harvesting. Leaf area index were calculated by measuring the leaf area with leaf area meter (LI-COR 3100) at various phenophases. To assess the above ground biomass production the leaves, stem, pod were separated and initially shade dried. Anthesis day, day of first pod, day of first seed, day of physiological maturity, plant height (m), maximum LAI, seeds per pod, seeds per m^{-2}, seed yield, and straw yield were recorded and harvest index was calculated for validation of the model.

Calibration and validation of the CROPGRO-Soybean model

Model calibration is the adjustment of parameters so that simulation values compare well with observed values. Ten genetic coefficients (Table 1) that influence the occurrence of growth and stages in the CROPGRO-Soybean models for all three genotypes were derived iteratively, by manipulating the relevant coefficients to achieve the best possible match between the simulated and observed field data of both the years.

Validation is the comparison of the results of model simulations with observations from crop that were not used for the calibration. Beyond comparisons, several statistical measures *viz*, root mean square error (RMSE), percentage error (PE) were used to evaluate the association between predicted and observed values using following formulae. PE is ratio of RMSE to mean observed value expressed as percentage. If the PE is less than ten per cent, the prediction is acceptable. The degree of agreement (D) is used mainly to determine the relative superiority of models, it can be used as a descriptive parameter of model performance. The more (D) approaches unity (1), the more accurate the model is.

$$PE = \frac{RMSE}{\bar{O}} \times 100$$

Besides the above test criteria, error per cent was also calculated in different treatment under study to express the deviation more scientifically.
This is as follow:
Error % = {(Predicted – Observed) / Observed} * 100

Table 1: Genetic coefficients development for soybean cultivars

Sr. No.	Growth and development aspects of the soybean crop	JS-335 (V_1)	MACS-450 (V_2)	DS-228 (V_3)
1.	Time between plant emergence and flower appearance (Photothermal days)	25.3	26.5	26.8
2.	Time between first flower and first pod (photothermal days)	8	8	8
3.	Time between first flower and first seed (photothermal days)	18	19.3	20.1
4.	Time between first seed (R5) and physiological maturity (photothermal days)	32.3	32.66	32.37
5.	Time between first flower and end of leaf expansion (days)	20	20	20
6.	Specific leaf area of cultivar under standard growth conditions	385	397	399
7.	Maximum weight per seed (g)	0.15	0.14	0.15
8.	Seed filling duration for pod cohort at standard growth conditions (photothermal days)	22.8	23.1	24.2
9.	Average seed per pod under standard growing conditions (#/pod)	2.2	2.09	2.21
10.	Threshing percentage. The maximum ratio of (seed/(seed+shell)) at maturity	78	78	78

RESULTS AND DISCUSSION

The accuracy of final yield prediction depends on timely predictions of critical growth stages beginning with emergence. However, predicting soybean phenology is difficult because of lack of understanding of sensitivity to temperature and photoperiod during development. The results presented in Table 2 showed the comparison of observed and simulated phenological parameters *viz*., anthesis day, first pod day, first seed day, physiological maturity of soybean. The prediction deviation of anthesis day was underestimated during both the crop seasons. The mean error percent varied from -2.65 to -5.00, -2.56 to -4.82 and -2.91 to -2.82 during both the year for the varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), respectively.

The percentage error (PE) was recorded 2.65, 2.56 and 3.09 in 2012 and 5.00, 4.82 and 2.95 in 2013 for varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), respectively. Similarly, the degree of agreement was 0.74, 0.67 and -1.78 in 2012 and -1.0, -0.45 and 0.79 in 2013 for the varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), respectively. Therefore, the days for antheis predicted was well matched with observed days.

The mean number of first pod day was nearly matched during both the crop seasons. The mean error percent varied from -2.59 to -3.99, -2.05 to -2.94 and -2.35 to -2.71 during both the years for the varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), respectively.

The percentage error (PE) was 2.76, 2.05 and 2.47 in 2012 and 3.98, 3.11 and 2.83 in 2013 for varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), respectively, while, the degree of agreement was 0.89, 0.88 and -0.56 in 2012 and 0.52, 0.41 and 0.83 in 2013 for the varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), respectively. Therefore, the predicted first pod day was well matched with observed days.

The mean error per cent of first seed day was varied from -2.88 to -2.43, -0.85 to -2.39 and -1.83 to -2.13 during both the years for the varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), respectively.

The percentage error (PE) was 3.18, 3.43 and 2.16 in 2012 and 2.53, 2.50 and 2.22 in 2013 for varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), respectively, while, the degree of agreement was 0.72, 0.95 and -0.56 in 2012 and 0.85, 0.48 and 0.48 in 2013 for the varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), respectively. Therefore, the predicted first seed day was well matched with observed values.

The mean error per cent of physiological maturity was varied from -1.85 to -1.58, -1.05 to -1.54 and -0.73 to -1.19 during both the years for the varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), respectively.

The percentage error (PE) was 1.89, 1.27 and 0.95 in 2012 and 1.94, 1.76 and 1.22 in 2013 for varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), respectively, while, the degree of agreement was 0.36, 0.57 and 1.00 in 2012 and 0.31, 0.77 and 1.00 in 2013 for the varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), respectively. Therefore, the predicted values were well matched with observed values. Since all the growth stages were predicted by the model with per cent error less than 10%, it can be concluded that phenology was well predicted by the model.

The results presented in Table 3 showed the comparison of observed and simulated phenological parameters and yield attributes *viz*., plant height, leaf area index, seeds per pod and seeds per square meter of soybean.

The data related to plant height expressed in metres (as expressed in the model). The observed and predicted mean error per cent of plant height varied from 17.17 and 13.87, 9.38 and 5.69 and 29.99 and 27.02 during both the years for the varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), respectively.

The percentage error (PE) was 18.39, 9.99 and 30.24 in 2012 and 14.99, 6.53 and 27.49 in 2013 for varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), respectively, while, the degree of agreement was 1.00 in all the varieties. The prediction was slightly overestimated for the variety JS-335 (V_1) and DS-228 (V_3) due to higher per cent error but the values of variety MACS-450 (V_2) with less than 10% PE it was well matched with observed.

The observed and predicted mean error per cent of leaf area index was varied from -8.2 and 15.53, -20.77 and 12.56 and 15.22 and 52.17 during both the years for the varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), respectively.

The percentage error (PE) was 14.56, 21.19 and 21.41 in 2012 and 18., 13.31 and 54.58 in 2013 for varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), respectively, while, the degree of agreement was 1.00, 0.91 and 0.90 in 2012 and 0.90, 0.97 and 0.10 in 2013 for the varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), respectively. The prediction was overestimated by all the varieties.

The mean number of seeds pod^{-1} was nearly overestimated during both the crop seasons. The mean error per cent varied from -7.61 to -16.9, -7.74 to -15.67 and -23.23 to -30.09 during both the year for the varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), respectively.

The percentage error (PE) was 15.17, 12.88 and 25.08, in 2012 and 20.01, 17.73 and 31.04 in 2013 for varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), respectively, while, the degree of agreement was 1.00, 1.00 and 0.83 in 2012 and 0.99, 0.93 and 0.77 in 2013 for the varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), respectively across different sowing management. Therefore, the prediction was slightly overestimated for the variety JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3). Similar results match with Anil Kumar *et al.*[1] and Singh *et al.*[7].

The observed and predicted mean error per cent of seeds per square meter was varied from 1.63 to 1.41, 0.85 to 1.31 and 1.36 to 2.23 during both the years for the varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), respectively.

The percentage error (PE) was 2.12, 0.99 and 1.51 in 2012 and 1.56, 1.53 and 2.53 in 2013 for varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), respectively, while, the degree of agreement was 0.88, 0.97 and 0.99 in 2012 and 0.93, 0.99 and 0.92 in 2013 for the varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), respectively. The prediction was well matched with the observed values.

The results presented in Table 4 showed the comparison of observed and simulated yield parameters *viz*., seed and straw yields, threshing per cent and harvest index of soybean.

The observed and predicted mean error per cent of seed yield was varied from 57.05 and 18.34, 32.18 and 12.3 and 21.28 and 10.25 during both the years for the varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), respectively.

The percentage error (PE) was 57.40, 30.27 and 21.53 in 2012 and 18.05, 12.28 and 10.23 in 2013 for varieties JS-335 (V_1), MACS-450 (V_2) and DS- 228 (V_3), respectively, while, the degree of agreement was -14.16, -2.54 and -2.25 in 2012 and -4.35, -4.90 and 0.36 in 2013 for the varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3) across different sowing management. Therefore, the prediction was slightly overestimated by for the varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3). Similar results were reported by Singh *et al.*[7].

Error per cent by simulated straw yield (expressed as by product in the model). The mean error per cent of straw yield varied from -38.89 to -16.39, -53.07 to -23.06 and -31.69 to 10.53 during both the years for the varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), respectively.

The percentage error (PE) was 40.81, 52.95 and 31.85 in 2012 and 19.30, 25.01 and 15.32 in 2013 for varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), respectively, while, the degree of agreement was -8.42, -26.26 and -33.35 in 2012 and -1.53, -3.05 and 0.53 in 2013 for the varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3) across different sowing management. Therefore, the prediction was slightly overestimated by for the varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3). The results corroborate with the findings of Singh *et al.*[7].

The observed and predicted mean error per cent of threshing percentage was varied from 0.3 and -4.6, 1.36 and 1.25 and 0.72 and -1.91 during both the years for the varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), respectively.

The percentage error (PE) was 1.58, 1.58 and 3.15 in 2012 and 5.00, 2.08 and 1.93 in 2013 for varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), respectively, while, the degree of agreement was 0.99, 0.80 and 0.95 in 2012 and -0.75, 0.96 and 0.05 in 2013 for the varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3) across different sowing management. Therefore, the prediction was well matched with the observed values for the variety JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3) of both the years.

The mean error per cent of harvest index yield varied from 79.2 and 16.63, 73.21 and 17.78, 35.05 and -059 during both the years for the varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), respectively.

The percentage error (PE) was 80.16, 71.86 and 35.10 in 2012 and 18.11, 19.81 and 5.59 in 2013 for varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), respectively, while, the degree of agreement was 0.98, 0.98 and 0.99 in 2012 and 1.00 for the varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3) across different sowing management. Therefore, the prediction was slightly overestimated for the variety JS-335 (V_1) and MACS-450 (V_2) but with less than 10% PE. It was well matched with observed values in DS-228 (V_3).

Therefore, the prediction with less than 10% PE was well matched with observed values in all the varieties across different sowing management. The model is capable of predicting the seed yield and harvest index reliably in the cultivars of DS-228 (V_3) and MACS-450 (V_2). Seed yield was slightly overestimated in JS-335 (V_1) and MACS-450 (V_2).

The evaluation of the model on an overall basis revealed that the model simulation performance in respect of phenological phases was found to be highly reliable. Plant height and LAI was found to be slightly overestimated except that plant height prediction was well matched for MACS-450 (V_2). By and large the model performance for the year 2012 and 2013 was found good during *kharif* season for soybean crop under Pune location.

Table 2: Simulated and observed (days after sowing) phenological stages by the CROPGRO model for soybean crop during *kharif* 2012 and 2013 at Pune

Stage	Cultivar/Date of sowing	2012			2013			2012			2013			2012			2013		
		O	P	E %	O	P	E %	O	P	E %	O	P	E %	O	P	E %	O	P	E %
		JS 335						MACS 450						DS 228					
Anthesis day	S_1- (I FN of June)	39	38	-2.56	41	39	-4.88	40	39	-2.5	42	40	-4.76	44	43	-2.27	46	45	-2.17
	S_2- (II FN of June)	38	37	-2.63	41	39	-4.88	39	38	-2.56	43	41	-4.65	44	42	-4.55	46	45	-2.17
	S_3- (I FN of July)	37	36	-2.7	40	38	-5	38	37	-2.63	41	39	-4.88	42	41	-2.38	44	43	-2.27
	S_4- (II FN of July)	37	36	-2.7	38	36	-5.26	39	38	-2.56	40	38	-5	41	40	-2.44	43	41	-4.65
	Mean	38	37	-2.65	40	38	-5	39	38	-2.56	42	40	-4.82	43	42	-2.91	45	44	-2.82
	PE			2.65			5			2.56			4.82			3.09			2.95
	D			0.74			-1			0.67			-0.45			-1.78			0.79
First pod day	S_1- (I FN of June)	51	49	-3.92	52	50	-3.85	50	49	-2	52	51	-1.92	56	55	-1.79	57	56	-1.75
	S_2- (II FN of June)	48	47	-2.08	52	50	-3.85	49	48	-2.04	52	50	-3.85	54	53	-1.85	57	56	-1.75
	S_3- (I FN of July)	46	45	-2.17	50	48	-4	48	47	-2.08	51	49	-3.92	52	51	-1.92	56	54	-3.57
	S_4- (II FN of July)	46	45	-2.17	47	45	-4.26	48	47	-2.08	48	47	-2.08	52	50	-3.85	53	51	-3.77
	Mean	48	47	-2.59	50	48	-3.99	49	48	-2.05	51	49	-2.94	54	52	-2.35	56	54	-2.71
	PE			2.76			3.98			2.05			3.11			2.47			2.83
	D			0.89			0.52			0.88			0.41			-0.56			0.83
First seed day	S_1- (I FN of June)	63	62	-1.59	65	64	-1.54	63	66	4.76	65	64	-1.54	72	72	0	74	73	-1.35
	S_2- (II FN of June)	61	60	-1.64	64	63	-1.56	62	61	-1.61	64	63	-1.56	70	69	-1.43	73	72	-1.37
	S_3- (I FN of July)	61	58	-4.92	62	60	-3.23	61	59	-3.28	63	61	-3.17	69	67	-2.9	71	69	-2.82
	S_4- (II FN of July)	59	57	-3.39	59	57	-3.39	61	59	-3.28	61	59	-3.28	67	65	-2.99	67	65	-2.99
	Mean	61	59	-2.88	63	61	-2.43	62	61	-0.85	63	62	-2.39	70	68	-1.83	71	70	-2.13
	PE			3.18			2.53			3.43			2.5			2.16			2.22
	D			0.72			0.85			0.95			0.48			-0.56			0.48
Physiological maturity	S_1- (I FN of June)	99	98	-1.01	99	99	0	99	99	0	101	100	-0.99	110	110	0	112	111	-0.89
	S_2- (II FN of June)	96	94	-2.08	98	97	-1.02	96	95	-1.04	99	98	-1.01	106	105	-0.94	109	108	-0.92
	S_3- (I FN of July)	93	91	-2.15	96	94	-2.08	94	93	-1.06	98	96	-2.04	103	102	-0.97	105	104	-0.95
	S_4- (II FN of July)	92	90	-2.17	93	90	-3.23	96	94	-2.08	95	93	-2.11	101	100	-0.99	101	99	-1.98
	Mean	95	93	-1.85	97	95	-1.58	96	95	-1.05	98	97	-1.54	105	104	-0.73	107	106	-1.19
	PE			1.89			1.94			1.27			1.76			0.95			1.22
	D			0.36			0.31			0.57			0.77			1			1

Table 3: Simulated and observed (days after sowing) phenological stages by the CROPGRO model for soybean crop during *kharif* 2012 and 2013 at Pune

	Cultivar/Date of sowing	2012			2013			2012			2013			2012			2013		
		O	P	E %	O	P	E %	O	P	E %	O	P	E %	O	P	E %	O	P	E %
		JS 335						MACS 450						DS 228					
Plant height (m)	S_1- (I FN of June)	0.57	0.71	24.51	0.59	0.69	16.95	0.63	0.72	13.65	0.65	0.69	6.15	0.61	0.8	30.99	0.63	0.8	26.83
	S_2- (II FN of June)	0.57	0.65	13.69	0.59	0.65	10.17	0.62	0.66	6.97	0.63	0.67	6.35	0.6	0.76	27.09	0.62	0.76	22.98
	S_3- (I FN of July)	0.53	0.61	14.45	0.54	0.61	12.96	0.6	0.64	7.38	0.59	0.62	5.08	0.55	0.71	28.56	0.57	0.7	22.32
	S_4- (II FN of July)	0.5	0.58	16.06	0.52	0.6	15.38	0.56	0.61	9.52	0.58	0.61	5.17	0.49	0.65	33.33	0.51	0.69	35.96
	Mean	0.54	0.64	17.17	0.56	0.64	13.87	0.6	0.66	9.38	0.61	0.65	5.69	0.56	0.73	29.99	0.58	0.74	27.02
	PE			18.39			14.29			9.99			6.53			30.24			27.49
	D			1			1			1			1			0.99			1
Leaf area index	S_1- (I FN of June)	2.91	2.7	-7.3	3.09	3.9	26.33	3.4	2.87	-15.46	3.64	4.17	14.41	2.98	3.99	34.12	3.2	5.37	68.08
	S_2- (II FN of June)	2.77	2.36	-14.72	2.94	3.47	18.2	3.02	2.53	-16.16	3.18	3.69	16.07	2.96	3.55	19.83	3.12	4.86	55.78
	S_3- (I FN of July)	2.54	2.86	12.49	2.82	2.99	6.16	2.95	2.06	-30.28	3.09	3.25	5.03	2.66	2.91	9.3	2.91	4.29	47.57
	S_4- (II FN of July)	2.22	1.7	-23.25	2.43	2.71	11.43	2.53	1.99	-21.19	2.69	3.09	14.75	2.61	2.55	-2.35	2.8	3.84	37.25
	Mean	2.61	2.41	-8.2	2.82	3.27	15.53	2.97	2.36	-20.77	3.15	3.55	12.56	2.8	3.25	15.22	3	4.59	52.17
	PE			14.56			18.1			21.19			13.32			21.41			54.58
	D			1			0.9			0.91			0.97			0.9			0.1
Seeds per pod	S_1- (I FN of June)	2.55	2.1	-17.65	2.95	2.1	-28.81	2.58	2.27	-11.84	2.86	2.27	-20.56	3.1	2.13	-31.29	2.99	2.13	-28.8
	S_2- (II FN of June)	2.6	2.1	-19.23	2.35	2.1	-10.64	2.8	2.27	-18.93	2.9	2.27	-21.72	2.68	2.13	-20.37	3.38	2.13	-36.89
	S_3- (I FN of July)	1.95	2.1	7.97	2.52	2.1	-16.58	2.43	2.27	-6.39	2.67	2.27	-14.98	2.87	2.13	-25.85	3.08	2.13	-30.73
	S_4- (II FN of July)	2.13	2.1	-1.52	2.38	2.1	-11.58	2.14	2.27	6.2	2.4	2.27	-5.42	2.52	2.13	-15.39	2.8	2.13	-23.93
	Mean	2.31	2.11	-7.61	2.55	2.1	-16.9	2.48	2.27	-7.74	2.71	2.27	-15.67	2.79	2.13	-23.23	3.06	2.13	-30.09
	PE			15.17			20.01			12.8			17.73			25			31
	D			1			0.99			1			0.93			0.83			0.77
Seeds per m^{-2}	S_1- (I FN of June)	2713	2796	3.06	3215	3249	1.06	2280	2308	1.23	2379	2402	0.97	2904	2940	1.24	3291	3313	0.67
	S_2- (II FN of June)	2495	2509	0.56	3024	3088	2.12	1999	2013	0.7	2433	2494	2.51	2805	2868	2.25	3217	3295	2.42
	S_3- (I FN of July)	2296	2301	0.22	2994	3047	1.77	1959	1961	0.1	2379	2409	1.26	2805	2817	0.43	2928	3056	4.37
	S_4- (II FN of July)	2110	2167	1.63	2595	2613	0.69	1803	1828	1.39	2194	2205	0.5	2629	2669	1.52	3035	3079	1.45
	Mean	2403	2443	1.63	2957	2999	1.41	2010	2028	0.85	2346	2379	1.31	2786	2824	1.36	3118	3186	2.23
	PE			2.12			1.56			0.99			1.53			1.51			2.53
	D			0.88			0.93			0.97			0.99			0.99			0.92

Table 4: Simulated and observed (days after sowing) phenological stages by the CROPGRO model for soybean crop during *kharif* 2012 and 2013 at Pune

	Cultivar/Date of sowing	2012			2013			2012			2013			2012			2013		
		O	P	E %	O	P	E %	O	P	E %	O	P	E %	O	P	E %	O	P	E %
		JS 335						MACS 450						DS 228					
Seed yield	S_1- (I FN of June)	1807	2759	52.73	2776	3167	14.07	2355	2824	19.94	2973	3241	9.02	2700	3307	22.5	3188	3426	7.47
	S_2- (II FN of June)	1570	2547	62.28	2567	2966	15.56	2359	2619	11.02	2771	3036	9.56	2487	3014	21.19	2984	3293	10.35
	S_3- (I FN of July)	1470	2349	59.77	2303	2770	20.26	1722	2250	30.66	2575	2891	12.28	2225	2633	18.32	2828	3170	12.07
	S_4- (II FN of July)	1307	2005	53.4	2106	2600	23.46	1348	2253	67.11	2363	2796	18.34	1987	2446	23.1	2615	2907	11.16
	Mean	1538	2415	57.05	2438	2876	18.34	1946	2487	32.18	2670	2991	12.3	2350	2850	21.28	2904	3199	10.26
	PE			57.4			18			30.2			12.2			21.5			10.2
	D			-14.1			-4.35			-2.54			-4.9			-2.25			0.36
Straw yield	S_1- (I FN of June)	3210	2157	-32.81	2387	2400	0.57	3814	2070	-45.72	2489	2270	-8.78	3961	2830	-28.55	2561	3140	22.6
	S_2- (II FN of June)	3287	1780	-45.84	2660	2200	-17.3	3652	1730	-52.63	2777	2180	-21.49	3470	2560	-26.2	2453	2960	20.67
	S_3- (I FN of July)	3177	2500	-21.3	2477	1920	-22.48	3552	1520	-57.21	2627	1850	-29.58	3328	2290	-31.19	2620	2590	-1.13
	S_4- (II FN of July)	3087	1370	-55.62	2362	1740	-26.34	3283	1420	-56.74	2633	1780	-32.39	3346	1980	-40.81	2421	2420	-0.02
	Mean	3190	1952	-38.89	2471	2065	-16.39	3575	2178	-53.07	2631	2020	-23.06	3526	2415	-31.69	2514	2778	10.53
	PE			40.81			19.3			52.95			25.01			31.85			15.32
	D			-8.42			-1.53			-26.26			-3.05			-33.35			0.53
Threshing %	S_1- (I FN of June)	66.87	68.13	1.88	71.33	69	-3.27	70.84	71.19	0.49	73.81	72.67	-1.54	69.07	67.74	-1.93	67.74	66.24	-2.21
	S_2- (II FN of June)	71.91	70.31	-2.23	74.68	69	-7.61	72.78	73.24	0.63	69.83	71.98	3.08	63.51	66.43	4.6	67.71	66.94	-1.14
	S_3- (I FN of July)	66.07	66.68	0.92	72.43	70.12	-3.19	68.62	70.44	2.65	72.43	73.6	1.62	62.45	64.29	2.95	69.78	68.18	-2.29
	S_4- (II FN of July)	68.41	68.82	0.6	72.86	69.69	-4.35	71.58	72.76	1.65	71.89	73.21	1.84	67.57	65.72	-2.74	67.98	66.62	-2
	Mean	68.32	68.49	0.3	72.83	69.45	-4.6	70.96	71.91	1.36	71.99	72.87	1.25	65.65	66.05	0.72	68.3	67	-1.91
	PE			1.58			5			1.58			2.08			3.15			1.98
	D			0.99			-0.75			0.8			0.96			0.95			0.05
Harvest Index	S_1- (I FN of June)	0.36	0.56	55.22	0.54	0.56	3.96	0.38	0.57	49.25	0.55	0.58	6.04	0.41	0.53	30.8	0.55	0.52	-6.24
	S_2- (II FN of June)	0.32	0.58	78.88	0.49	0.57	15.88	0.39	0.6	52.83	0.5	0.58	15.71	0.42	0.54	29.39	0.55	0.52	-5.43
	S_3- (I FN of July)	0.32	0.58	83.35	0.48	0.59	22.05	0.33	0.59	80.43	0.5	0.6	20.79	0.4	0.53	32.48	0.52	0.55	5.59
	S_4- (II FN of July)	0.3	0.59	99.34	0.47	0.59	24.64	0.29	0.61	110.3	0.47	0.61	28.58	0.37	0.55	47.53	0.52	0.54	3.73
	Mean	0.32	0.58	79.2	0.5	0.58	16.63	0.35	0.59	73.21	0.5	0.59	17.78	0.4	0.54	35.05	0.54	0.53	-0.59
	PE			80.16			18.11			71.86			19.81			35.1			5.59
	D			0.98			1			0.98			1			0.99			1

CONCLUSIONS

The CROPRO Soybean Model predicted the seed yield quite reliably in varieties DS-228 (V_3) and MACS-450 (V_2) during the year 2013 and seed yield was slightly overestimated in varieties JS-335 (V_1) and MACS-450 (V_2) during both the years. The model calibration and validation results from two year field study revealed that 'SOYGRO model' can be used to predict soybean phenology, growth and yield parameters under different environment with reasonably satisfactory predictions. This model was within the acceptable limits for Pune conditions for the prediction of yield and yield attributes of soybean crop.

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