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Impact of projected climate on yield of soybean using CROPGRO-Soybean model in Madhya Pradesh

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ABSTRACT

A field experiment was conducted during *kharif* season, 2016 at Jabalpur, Madhya Pradesh to validate CROPGRO- Soybean model for variety JS 20-29 and assess its productivity under future climate change scenarios. Genetic coefficients were generated and evaluated using two-year (2014 and 2015) datasets and validated with 2016 experimental data under different dates of sowing. A good agreement between observed and simulated seed yield (D=0.75, RMSE = 239.2) and biological yield (D = 0.83, RMSE = 391.8) was obtained. The climate change projection scenario of RCP 2.6 and 8.5 were used to assess its impact on seed yield in different districts of Madhya Pradesh. An increase in seed yield from baseline under RCP 2.6 pathway was simulated in all the districts whereas under RCP 8.5 pathway, marginal decline in seed yield was simulated by 2020. By 2050, however, a decline in seed yield was simulated under both RCP pathways, which may be due to increase in the rate of greenhouse gas emissions.

Key words : CROPGRO-Soybean model, DSSAT, genetic coefficients, soybean variety, sowing window, RCP 2.6 and 8.5

Soybean (*Glycine max* (L) Merrill) is an important oilseed and legume crop in India with an area of 12.20 Mha, production of 11.99 Mt and yield of 983 kg ha^{-1} (Agricultural Statistics at a Glance, 2015). In Madhya Pradesh, its area for cultivation is 55.46 lakh ha with production and productivity of 60.3 lakh tonnes and 1086 kg ha^{-1} respectively (SOPA, 2015*)*. The major constraints for low productivity includes poor seed viability and non-availability of early maturing, photo-insensitive, high yielding varieties with resistance to biotic and abiotic stresses (Bhatnagar and Karmakar, 1995). Agrawal *et al.* (2009) reported the variability of soybean productivity in relation to rainfall variability in Madhya Pradesh.

Crop simulated models are being used now-a-days to explore the research gaps that may be helpful in bringing agronomic sciences into information sciences. Prabhjyot Kaur *et al.* (2004) and Singh *et al.* (2010) evaluated "SOYGRO" model for predicting growth and yield of soybean in Punjab and Haryana. The DSSAT CROPGRO-Soybean model simulates growth, development and yield of a crop growing on a uniform area of land under prescribed or simulated management as well as the changes in soil, water and nitrogen that take place under cropping system over time (Jones *et al*. 2003). In this study, CROPGRO-Soybean model was used to generate and validate genetic coefficients of soybean variety JS 20-29 under different thermal environments to assess the impact on soybean productivity under future climatic change scenarios.

MATERIALS AND METHODS

A field experiment was conducted at Research farm of College of Agricultural Engineering, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur (23°102 N, 79°562 E and 411.78 m above mean sea level) Madhya Pradesh during *kharif* 2016 season with soybean variety JS20-29, sown on four dates (June 17, 30, July 12, 26). CROPGRO-Soybean model was calibrated based on the two years (2014 and 2015) experimental soybean, soil and weather datasets and subsequently validated with the datasets of the year 2016. Fifteen genetic coefficients were developed for growth and development aspects of soybean JS 20-29 variety (Table 1). The model performance was evaluated through relative deviation, root mean square error (RMSE), and D-value (Willmott, 1982) as a test criteria.

For futuristic climate, two Representative Concentration Pathways (RCP) with lowest (2.6) and highest (8.5) greenhouse gas emissions along with baseline, each

Table 1: Genetic coefficients of Soybean variety 'JS 20-29' obtained in calibration experiment using CROPGRO-Soybean model in DSSAT programme

Symbol	Description	Genetic Coefficients of variety JS 20-29
	Development aspects	
CSDL	Critical Short Day Length below which reproductive development progresses with no day length effect (for short day plants) (hr)	11.81
PPSEN	Slope of the relative response of development to photoperiod with time (positive for short day plants) (One hr^{-1})	0.200
EM-FL	Time between plant emergence and flower appearance (R1) (photothermal days)	15.7
FL-SH	Time between first flower and first pod (R3) (photothermal days)	4.5
FL-SD	Time between first flower and first seed (R5) (photothermal days)	11.7
SD-PM	Time between first seed (R5) and physiological maturity (R7) (photothermal days)	37.5
FL-LF	Time between first flower (R1) and end of leaf expansion (photothermal days)	18
SFDVR	Seed filling duration for pod cohort at standard growth conditions (photothermal days)	22.0
PODUR	Time required for cultivar to reach final pod load under optimal conditions (photothermal days)	7
	Growth aspects	
LF-MAX	Maximum leaf photosynthesis rate at 30 C, 350 vpm CO_2, and high light (mg CO_2 m^{-2} sec^{-1})	1.030
SLAVR	Specific leaf area of cultivar under standard growth conditions (cm^2 g^{-1})	375
SIZLF	Maximum size of full leaf (three leaflets) (cm^2)	137.0
XFRT	Maximum fraction of daily growth that is partitioned to seed + shell	1.0
WTPSD	Maximum weight per seed (g)	0.180
SDPDV	Average seed per pod under standard growing conditions (Number pod^{-1})	1.70

with 30 replications for the year 2020 and 2050 were used in the study. The futuristic weather data of the major soybean growing districts of the state viz., Betul, Dewas, Shivpuri, Ujjain and Jabalpur was used in the model. The output from the replicated data was averaged for further analysis.

RESULTS AND DISCUSSION

Evaluation of model

The observed and simulated data on days to physiological maturity, seed yield and biological yield at different sowing dates (Table 2) show that the model satisfactorily simulate actual field value at D3 sown date with low levels of deviation (4.8 %) and RMSE (4.0 kg ha^{-1}) for physiological maturity, however, D-value of D1 (0.89) is higher then D3 (0.45) sown date. The seed yield exhibited lowest deviation RMSE and D-values in D2 sown date (-5.1 %, 66.2 kg ha^{-1} and 0.95) followed by D4 sown date (8.1 %, 85.3 kg ha^{-1} and 0.94). The biological yield also exhibited lowest deviation, RMSE and D-values in D2 sown date in comparison to other dates. Evaluation of economic and biological yield exhibited a good accuracy with lower RMSE and D-value (Table 2).

Validation of model

During validation period the observed and simulated seed and biological yield (Fig. 1 and 2) show that the RMSE and D-value were 239 $kgha^{-1}$ and 0.75 for seed yield and biological yield as 391 kg ha^{-1} and 0.83 indicating a close agreement between simulated and observed values, respectively. Thus it can be used for simulating yield of soybean variety JS 20-29 under different environments.

Impact of climate change on soybean yield

Futuristic seed yield of the CROPGRO-Soybean year 2020 and 2050 were compared with baseline (Table 3). RCP 2.6 with less greenhouse gas emissions results an increase in seed yield from baseline among normal sowing dates in

Table 2: Simulated and observed days to physiological maturity, seed and biological yield of soybean (variety JS 20-29) at different sowing dates

Sowing dates	Simulated	Observed	Relative deviation (%)	RMSE	D-valve
		Physiological Maturity (days)			
D1- 17th June	96	88	9.09	8.00	0.89
D2 - 30th June	91	84	8.33	7.00	0.55
D3- 12th July	87	83	4.81	4.00	0.45
D4 - 26th July	79	74	6.75	5.00	0.49
		Seed yield (kg ha^{-1})			
D1- 17th June	1346	1125	46.30	426.07	0.20
D2 - 30th June	1003	1357	-5.11	66.28	0.95
D3- 12th July	1023	1136	-9.94	189.25	0.82
D4 - 26th July	507	469	8.10	85.33	0.99
		Biological yield (kg ha^{-1})			
D1- 17th June	2719	2936	-7.39	245.03	0.88
D2 - 30th June	3193	3115	2.50	209.15	0.69
D3- 12th July	2913	3593	-18.92	427.25	0.83
D4 - 26th July	1259	1963	-35.86	572.25	0.90

Table 3: Simulated seed yield for soybean variety JS 20-29 for baseline, 2020 and 2050 at different locations of Madhya Pradesh

Districts	Sowing dates	Baseline (kg ha^{-1})	2020				2050			
			RCP 2.6 (kg ha^{-1})	RD (%)*	RCP 8.5 (kg ha^{-1})	RD (%)*	RCP 2.6 (kg ha^{-1})	RD (%)*	RCP 8.5 (kg ha^{-1})	RD (%)*
Jabalpur	June 17	4096	4168	1.76	4093	-0.07	4072	-0.59	4050	-1.12
	June 30	3756	3812	1.49	3771	0.40	3698	-1.54	3744	-0.32
	July 12	3588	3609	0.59	3568	-0.56	3571	-0.47	3603	0.42
	July 26	3041	3089	1.58	3046	0.16	3020	-0.69	3008	-1.09
Betul	June 17	4068	4105	0.91	4067	-0.02	4034	-0.84	4067	-0.02
Dewas	June 17	3845	4079	6.09	3975	3.38	3631	-5.57	3696	-3.88
Shivpuri	June 17	4080	4223	3.50	4109	0.71	4100	0.49	3889	-4.68
Ujjain	June 17	3922	4105	4.67	4040	3.01	3730	-4.90	3812	-2.80

*RD is the relative deviation between, RCP scenarios and baseline

Dewas, Jabalpur, Shivpuri and Ujjain districts. Betul district exhibit lesser seed yield from baseline. However, yield levels decline in RCP 8.5 under normal sowing date among Betul and Jabalpur districts. For 2050, seed yield decline in all the selected districts under both RCPs, exhibiting this variety may not fit for the longer period in the 2050s. As suggested, increase in greenhouse gases (GHG) also increase air temperature, which ultimately reduce crop duration causing early flowering and shortening of grain filling period (Mall *et al.,* 2004). Soybean yield improves in cooler and wetter climate with higher concentration of carbon dioxide. Decrease in temperature from current climate by 1°C and increase rainfall by 10 per cent favoured seed yield however yield reduced under decrease rainfall with increase in temperature (Mohanty *et al.,* 2017). Beside this, change in weather cause favourable environment for incest-pests and

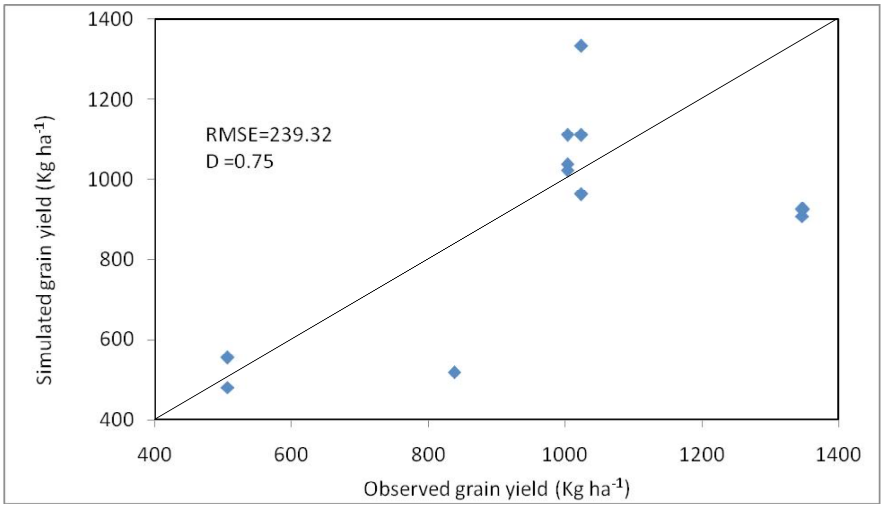

Fig. 1: Validation of simulated and observed seed yield of soybean variety, JS 20-29 at Jabalpur, M.P.

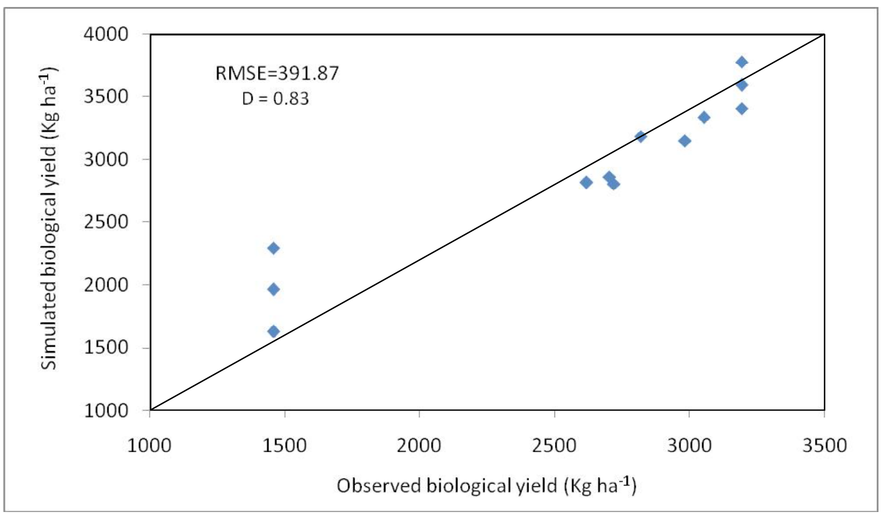

Fig. 2: Validation of simulated and observed biological yield of soybean variety, JS 20-29 at Jabalpur, M.P.

diseases thereby affecting seed yield. Therefore, increase in temperature due to rise of GHGs along with more rainfall variability affect soybean production in the coming decades.

CONCLUSION

Test criteria revealed that the model performance in respect of phenology and yield was satisfactory with minimum error. Soybean variety, JS 20-29 may prove better till 2020, yield levels decline by the year 2050 due to rise in greenhouse gas emission levels. Overall, a good agreement exhibited between observed and simulated datasets, which conclude that this model was adequate to simulate the possible effect of climate change on soybean yield.

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