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Calibration and validation of InfoCrop simulation model for growth and yield of Indian mustard varieties at Allahabad

Vijender Singh, Satyendra Nath and Yogesh Kumar*[1]

College of Forestry, Sam Higginbottom University of Agriculture, Technology & Sciences, Allahabad-211007, UP, India

[1]Department of Agricultural Meteorology, College of Agriculture, CCS Haryana Agricultural University, Hisar 125004, Haryana, India

**Corresponding author:yogeshgujjar62@gmail.com*

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Abstract

Field experiment was carried out at SHUATS, Allahabad, to study calibration and validation of InfoCrop model with the data sets generated respectively during *Rabi* season of 2016-17. The main plot treatments and sub-plot treatment consisted three dates of sowing and cultivars (D_1- 25th October, D_2- 5th November and D_3- 15th November) and (V_1- Parasmani, V_2- Varuna and V_3- SRM 777) using split plot design. The results revealed that simulation of growth and yield parameters were compared with observed data and results concluded that the model overestimates all the parameters within the acceptable range (<15%) with significant accuracy. Therefore, the validated InfoCrop can be used for prediction of phenology, estimates actual and potential yield and it provide management option in resilience towards changing climatic conditions.

Key words: *climate change, InfoCrop model, Indian mustard, sensitivity analysis, validation*

Introduction

Rapeseed-mustard (*Brassica spp*.) is a major group of oilseeds crop of the world being grown in 53 countries across the six continents, Indian mustard (*Brassica juncea*) is the second important oilseed crop in India after groundnut sharing 27.8 % in India's oilseed production. Indian-mustard is much sensitive to climatic variables; hence, climate change could have a significant effect on its production. One month delay in sowing from mid-October resulted in the loss of 40.6 % in seed yield (Lallu *et al*., 2010). Weather parameter is very important which influence growth and yield of a mustard crop, therefore, largely governed by the change in growing environment such as date of sowing and water availability. LAI (Leaf area index) plays an important role for crop growth based on its interception and utilization of PAR (Photosynthetically active radiation) for producing dry matter (Kumar *et al*., 2007) and with the delay in planting date, the higher mean temperature was experienced during flowering which led to accelerating the decrease of LAI and reduction of the flowering period (Poureisa and Nabipour, 2007).

According to IPCC assessment report (AR_4), global average temperature has increased by 0.74 ^{0}C over the last 100 years and projection of an increase in temperature about 1.8 to 4 ^{0}C by 2100. Global losses may account for 1 to 5 % of GDP, but developing countries with tropical and sub-tropical climate are likely to suffer more losses. Temperature increases are likely to be higher during winter season and precipitation is likely to decrease (IPCC, 2007). IPCC and its global studies indicate that considerable probability of loss in crop production in India with increases in temperature (IPCC, 2014). InfoCrop simulation model is one of the user-friendly systems, dynamic crop growth model developed under Indian condition. This model has the capability to estimate the actual and potential yield, yield gaps and also to assess the impacts of climate variability and climate change. The model simulates the crop growth processes viz., phenology, photosynthesis, respiration, leaf area growth, assimilates partitioning, source-sink balance, nutrient uptake partitioning and transpiration (Aggarwal *et al*., 2006). InfoCrop model has been used for simulating potential rain-fed yields. It is used to optimize management, dates of planting, variety, irrigation and nitrogen fertilizer, assessing interactions among genotype, environment, management, and pests, yield forecast, yield loss assessment due to pests and greenhouse gas emissions (Aggarwal *et al*., 2004).

To study the impact of climate change on different crops needs simulation model. It helps to quantify the effects of climate, soil, and management on crop growth, productivity and sustainability of agricultural production. These tools can reduce the expensive and time-consuming field experimentation as they can be used to extrapolate the results of research conducted in one season or location to another season, location or management (Boomiraj *et al*., 2007). InfoCrop model can successfully simulate the growth and yield of the mustard crop across different locations in India. The simulated yield of mustard was found to be sensitive to changes in atmospheric CO_2 and temperature variation (Boomiraj *et al*., 2010). This study was undertaken with the objectives to quantify InfoCrop model on the mustard crop at Allahabad conditions, which show considerable potential to evaluate crops, varieties and genotypes of mustard, cropping pattern and genetic potential for yield. The scientific information on simulation of growth and yield in mustard crop using modeling in Uttar Pradesh is lacking. Hence, keeping in view the importance of the study, the present investigation was carried out.

Materials and Method

Experimental Details

The experimental field data (2016-17) of Allahabad station comprising three dates of sowing (*Rabi*: D_1-25th Oct., D_2-5th Nov. and D_3-15th Nov.) and varieties (V_1- Parasmani, V_2-Varuna and V_3- SRM 777) through the field experiment laid out split-plot design was used for model calibration and validation. The package and practices for Indian mustard cultivation were followed as per the Sam Higginbottom University of Agriculture, Technology, and Sciences, Allahabad. Validation of model was performed by using different data sets on such as phenology, total dry matter, grain yield, harvesting index and test weight from the field experiment conducted at Sam Higginbottom University of Agriculture, Technology and Sciences, Allahabad.

InfoCrop v.2.0 model

InfoCrop is a dynamic crop-yield simulation model. This

Table 1: List of inputs required for InfoCrop

Input variables	Acronyms	Unit
Site data		
Latitude	LAT	Degree
Longitude	Long	Degree
Altitude	Alt	Meter
Daily weather data		
Date/year	dd-mm-yy	
Station number		
Julian days	JD	Days
Solar radiation	RDD	KJ m^{-2}
Maximum temperature	TMAX	°C
Minimum temperature	TMIN	°C
Vapour pressure	VP	K Pa
Wind Speed	WDST	$msec^{-1}$
Rainfall	TRAIN	Mm
Relative humidity morning	RHMIN	%
Soil texture/district master parameters		
pH of soil	PHFAC	
Electrical conductivity	EC	ds/m (0 to 1)
Slope	SLOPE	%
Thickness of layer	TKL	Mm
Sand content	SAND	%
Silt content	SILT	%
Clay content	CLAY	%
Saturation fraction	WCST	0 to 1
Field capacity fraction	WCFC	0 to 1
Wilting point fraction	WCWP	0 to 1
Saturation hydraulic conductivity	KSAT	mm/day
Bulk density	BDL	mg/m^3
Organic carbon	SOC	%
Soil moisture fraction at sowing	WCL	0.1 to 0.4

Initial soil ammonium	NHAPL	(1 to 40 kg/ha)
Initial soil nitrate	NOAPL	(1 to 50 kg/ha)
Crop data		
Crop name	Acronyms	Unit
Input sowing depth	SOWDEP	Cm
Input seed rate	SEEDRT	kg ha^{-1}
Maximum possible crop duration		
Default sowing date	DATEB	Julian days of the year
Crop/variety management data		
Thermal time for germination	TTGERM	degree day
Thermal time for seedling emergence to anthesis	TTVG	degree day
Thermal time for anthesis to maturity	TTGF	degree day
Base temperature	TGBD	℃
Optimum temperature	TOPT	℃
Maximum temperature	TMAX	℃
Relative growth rate of leaf area	LAII	°C/d
Specific leaf area	SLAVAR	m^2/mg
Index of greenness of leaves		Scale 0.8 to 1.2
Extinction coefficient of leaves at flowering		ha soil/ha leaf fraction
Radiation use efficiency	RUE	g/MJ/day
Root growth rate	RWRT	mm/d
Sensitivity of crop to flooding	FLDLCRP	Scale 1 to 1.2
Index of nitrogen	NI	Scale 0.7 to 1.0
Slope of storage organ number/m^2 to dry matter during storage organ formation	SOPOT	Storage organ/kg/day
Potential storage organ weight	POTGWT	mm/grain
Nitrogen content of storage organ	NUPTK	Fraction
Sensitivity of storage organ setting to low temperature	TPHIGH	Scale 0 to 1.5
Sensitivity of storage organ setting to high temperature	TPLOW	Scale 0 to 1.5

model was developed by Aggarwal (2009) at Center for Application of Systems Simulation, IARI, New Delhi. The inputs required for InfoCrop v. 2.0 model are listed separately in Table 1.

Calibration of the model

The models were run and validated by comparing the predicted output with observed parameters. Deviation of predicted from observed was calculated and accuracy of the model to predict different crop parameters was quantified, then the simulated was for the further study. The genetic coefficient of mustard for InfoCrop model is given in Table 2.

Validation

Validation of model will be performed by using different data sets on phenology, biological yield, seed yield, harvesting index and test weight from experiments conducted at Research farm, School of Forestry and Environment, SHUATS, Allahabad. For judging the performance of the InfoCrop model, validation results on major crop growth parameters such as phenology during crop growth and grain yield will be tested using various statistical parameters viz., mean absolute error (MAE), mean bias error (MBE), root mean square error (RMSE), and error %.

Table 2: Categorization of genetic coefficient of mustard for InfoCrop v.2.0 model

Genetic constant description	Acronyms	Unit
Thermal time for germination to emergence	TTGERM	degree day
Thermal time for seedling emergence to anthesis	TTVG	degree day
Thermal time for anthesis to maturity	TTGF	degree day
Specific leaf area of variety	SLAVAR	Fraction
Maximum number of grains per hectare	GNOMAX	grains per hectare

$$MAE = \sum_{i=1}^{n} [1P_i - O_i 1]/n$$

$$MBE = \sum_{i-1}^{n} [P_i - O_i]/n$$

$$RMSE = \left[\sum_{i=1}^{n} (P_i - O_i)^2 / n \right]^{1/2}$$

Error % = {(P – O) / O} * 100

Where, O = observed, P = simulated.

Sensitivity analysis

Sensitivity analysis are used to simulate the impact of change in maximum temperature (T_{max}) and minimum temperature (T_{min}), seasonal rainfall and elevated CO_2 concentration within a range of ±5 ºC, ±10 % and 415 to 640 ppm, respectively, on the seed yield of three varieties of Indian mustard (*Brassica juncea*) *viz.* SRM 777, Varuna and Parasmani in context of changing climatic conditions.

Results and Discussion

Validation of Info Crop model

The model was calibrated and simulated in different plots of Parasmani, Varuna and SRM 777 in both sowing dates and season. Validation of model performed by different data sets on phenology, total dry matter, grain yield, harvesting index and test weight were simulated. Test criteria for various parameters of Mustard cv. SRM 777, Varuna and Parasmani using InfoCrop model during 2016-17.

Phenology

Test criteria of Phenology of mustard varieties using InfoCrop model during 2016-17 are presented in Table 3.

Table 3: Test criteria of mustard phenology using InfoCrop model during 2016-17.

Parameters	Days to start flowering (days)			Days to maturity (days)		
Variety	PARASMANI	VARUNA	SRM 777	PARASMANI	VARUNA	SRM 777
OMV	37.33	44.6	45.00	144.33	145.63	149.00
SMV	3.06	1.53	1.80	4.51	4.16	4.58
SDo	39.67	48.67	49.67	150.67	149.67	156.33
SDs	5.86	1.52	1.52	7.71	2.51	7.02
MAE	1.03	2.00	3.67	1.33	8.33	4.33
MBE	2.07	4.67	3.67	6.00	3.33	4.33
RMSE	2.10	3.43	4.00	5.52	9.76	7.42
PE	5.06	6.30	10.04	4.71	4.67	4.88

Days to start flowering (days)

The observed mean values of days to start flowering for three mustard cv. Parasmani, Varuna and SRM 777 were 37.33, 44.6 and 45.0, whereas the model simulated 39.67, 48.67 and 49.67 days respectively. Different test criteria involving difference measures to locate and quantify errors viz. MAE, MBE, RMSE, and PE computed for mustard varieties suggested that model was better for SRM 777 followed by Varuna and Parasmani for simulation of days to start of flowering. The mean percent error was observed higher for cv. SRM 777 (10.04) followed by Varuna (6.30) and Parasmani (5.06). This shows that model simulation was found better for cv. SRM 777 as compared to others in case of simulation of days to start flowering (days). Similar 41trend was observed for other test criteria for days to start flowering such as MAE, MBE, and RMSE. This clearly showed that model performance was found good for SRM 777 as compared to Varuna and Parasmani for simulation of days to start flowering. However, model overestimated the days to start flowering (days).

Days to maturity (days)

Days to maturity for Parasmani, Varuna and SRM 777 were observed as 144.33, 145.63 and 149.00 days while model simulated 150.67, 149.67 and 143.00 days, respectively. SRM 777 performed better and the model overestimated the days to maturity. The average percent error was overestimated by the model for mustard varieties. The mean percent error was observed higher for cv. SRM 777 (4.88) followed by Varuna (4.67) and Parasmani (4.71). This show that day to maturity simulation was found good for cv. SRM 777. The similar trend was observed by carrying out other tests such as MAE, MBE, and RMSE for days to maturity. The simulation performance of the model in respect of days taken to maturity was found good with an acceptable level.

Growth and yield parameter

Test criteria for growth and yield of mustard varieties using InfoCrop model during 2016-17 are presented in Table 4.

Test weight

The test weight obtained for cv. Parasmani, Varuna and SRM 777 were 4.66, 4.75 and 4.95 g, while model simulated higher values *i.e.* 5.91, 5.34 and 6.57 g, respectively. The average percent error for test weight was found 5.56 (Parasmani), 4.42 (Varuna) and 3.14 (SRM 777), respectively. The evaluation of MAE and MBE was found lower for cv. SRM 777 followed by Varuna and Parasmani except for MBE of SRM 777, respectively, but cv. Parasmani holds higher RMSE (0.57) values as compared to Varuna (0.42) and SRM 777 (0.51). The overall performance of test weight simulation was found under accepted range; however model overestimated the test weight.

Seed yield

The grain yield obtained for cv. Parasmani, Varuna, and SRM 777 were 1138.23, 121.32 and 1284.4 kg ha^{-1} while model simulated higher yield *i.e.* 1382.67, 1465.67 and 1451.67 kg ha^{-1} respectively. The test criteria computed by MAE, MBE, RMSE, and PE for both the cultivars suggested model performance was better for SRM 777 as compared to Varuna and Parasmani. The average percent error for grain yield of both the cultivars was overestimated by the model. The average percent error for grain yield was found 4.96 (SRM 777), 10.58 (Varuna) and 8.60 % (Parasmani), respectively. The mean percent error was found lower for SRM 777. The average error as computed by MAE (101.33), MBE (102.33) and RMSE (58.27) found lower for SRM 777 as compared to other cultivars. This shows that the evaluation of the model on an overall basis revealed that the yield simulation was found good with an acceptable level for mustard.

Biomass yield

The performance parameters for cv. SRM 777 was higher than Varuna and Parasmani for simulated biomass yield. The average percent error of biomass yield of all varieties was overestimated by the model. The average percent error for biomass yield was found 10.18 (SRM 777), 12.62 (Varuna) and 11.43 % (Parasmani), respectively. The average error as computed by MAE (1320.0), MBE (1320.0) and RMSE (1473.25) found lower for Parasmani as compared to other varieties. The biomass yield simulation was found good with an acceptable level for mustard.

Harvesting Index

The model performance in a simulation of Harvest Index was found good for cv. SRM 777(0.87 error %) as

Table 4: Test criteria of yield and its attributes of mustard varieties using InfoCrop model during 2016-17.

Parameters	Test weight (g)			Seed yield (kg/ha)			Biomass (kg/ha)			HI (%)		
Variety	PARASMANI	VARUNA	SRM 777	PARASMANI	VARUNA	SRM 777	PARASMANI	VARUNA	SRM 777	PARASMANI	VARUNA	SRM 777
OMV	4.66	4.75	4.95	1138.23	1214.32	1284.4	9891.0	10067.67	13186.0	11.50	12.58	13.47
SMV	0.88	0.88	0.89	396.99	396.11	400.56	1379.74	1389.25	1388.16	1.04	0.96	0.71
SDo	5.91	5.34	6.57	1382.67	1465.67	1451.67	10211.0	11313.33	12335.67	12.63	12.76	15.15
SDs	1.09	0.63	0.46	365.84	43.24	31.0	2181.04	1470.74	1300.63	0.40	1.76	0.22
MAE	0.50	0.35	0.31	209.0	105.67	101.33	1320.0	1245.67	1449.67	0.11	0.47	-0.87
MBE	0.50	0.35	0.38	209.0	105.67	102.33	1320.0	1373.67	1449.67	1.09	1.38	0.87
RMSE	0.57	0.42	0.51	220.51	208.05	58.27	1473.25	1649.55	1463.98	1.18	1.66	0.95
PE	5.56	4.42	3.14	8.60	10.58	4.96	11.43	12.62	10.18	1.96	4.19	3.31

Where OMV: observed mean value, SMV: simulated mean value, SDo: standard deviation of observed, SDs: standard deviation of simulation, MAE: mean absolute error, MBE: mean bias error, RMSE: root mean square error, PE: Percent error.

compared to Varuna (1.38 error %) and Parasmani (8.19 error %). More or less similar results were obtained in terms of other test criteria such as MAE, MBE, and RMSE for simulation of harvest index. Model underestimated the simulation results for cv. SRM 777 and Varuna and overestimated for Parasmani. Model performance was found good for cv. SRM 777 compared to other cultivars for HI simulation.

Sensitivity analysis

The increase in CO_2 concentration from 390 to 490 ppm enhanced the crop yield. Increase in CO_2 from 390 to 490 ppm with no change in temperature has resulted in 13–32 % increase in yield of mustard but further increase in CO_2 concentration reduced the percent increase in yield. Increase in rainfall during crop season, indicated the scope for improved dry matter production and increase in grain number.

Temperature

The increased in daily maximum temperature up to 3 ºC resulted in increased in yield of mustard (figure 1). In plants, warmer temperature accelerates growth and development leading to less time for carbon fixation and biomass accumulation before seed set resulting in poor yield (Rawson, 1992; Morison, 1996). Similar results were supported by Singh *et al*. (2008), Easterling *et al*. (2007), Roy *et al*. (2005), Fischer *et al*. (2007), Mall *et al*. (2004), Long *et al*. (2006), Morrison and Stewart (2002), Chaudhari *et al*. (2009), Kumar *et al*. (2010), Bhagat *et al.* (2007) and Aggarwal *et al*. (2006).

The highest benefits in increased in yield was obtained by increasing minimum temperature from 2 ºC above and -1 ºC below from the crop season 2016-17. Similar results were supported by Singh *et al*. (2008), Easterling *et al*. (2007), Kumar *et al*. (2010), Chaudhari *et al*. (2009).

Rainfall

There was an increase in rainfall by 10 to 20 per cent in comparison to crop season 2016-17. It simulated the increased yield but after beyond it adversely affected crop growth and yield (figure 1). Similar results were reported by earlier workers Mall *et al*. (2004) and Singh *et al*. (2008).

CO_2 concentration

CO_2 concentration elevated 390 to 490 ppm from the present CO_2 concentration. It showed the positive impact on yield. An increase in crop yield in mustard crop after

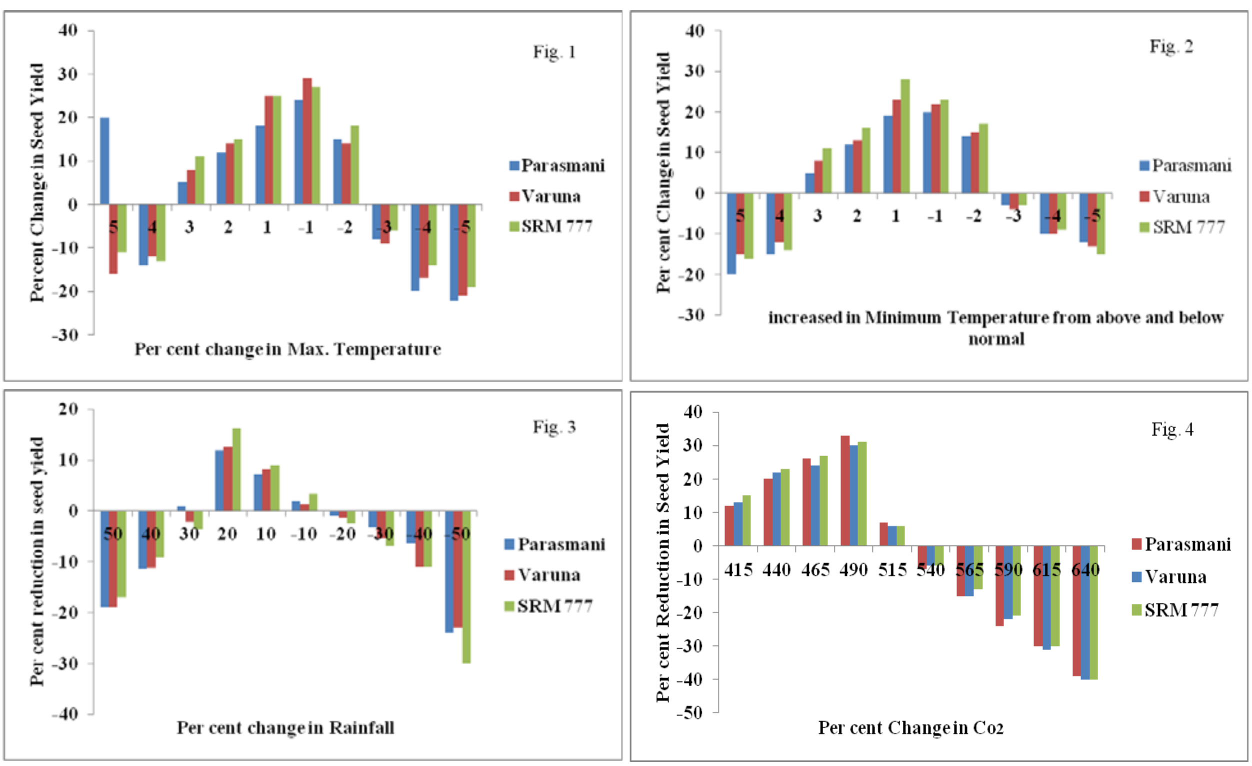

Figure 1: Depicting the InfoCrop simulation results of impact of change in (1) maximum temperature (T_{max}) (2) minimum temperature (T_{min}) (3) seasonal rainfall and (4) elevation in CO_2 concentration on the seed yield of all three varieties of mustard during the *Rabi*- 2016-2017.

490 ppm of CO_2 concentration, it produced warming effect which results decline in yield (figure 1). Similar results were reported by earlier workers Uperty *et al*. (2003), Rotter and Van de Geijn (1999).

Conclusion

Simulation of mustard phenology, growth and yield attributes by InfoCrop model was within the acceptable limit. Therefore, the validated InfoCrop model can further be used for prediction of crop growth, phenology, potential and actual yield of the mustard crop under changing climate scenarios.

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