



Evaluating InfoCrop model at mustard (*Brassica juncea*) crop field for multistage yield estimation

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ABSTRACT

A field experiment was conducted at research farm of Indian Agricultural Research Institute, New Delhi during *Rabi* 2016–17 and 2017–18. Three varieties of mustard [*Brassica juncea* (L.) Czern and Coss] RH-406, P. Tarak and Girraj were sown on three different dates for generating different weather conditions during different growth stages. InfoCrop-mustard model was calibrated from the observation taken from *rabi* 2016–17 sown mustard crop of same variety under same treatment. Model validation was done from the observation taken during *Rabi* 2017–18 sown crops under similar treatments. Simulation of phenology, LAI, biomass and seed yield was done by the InfoCrop-mustard model for RH-406, P. Tarak and Girraj cultivar of mustard sown at IARI, New Delhi research farm. Simulation of LAI, biomass and seed yield was done by the InfoCrop-mustard for RH-406 and Girraj cultivar of mustard in the farmer's field. Biomass and seed yield estimation was done by InfoCrop-mustard model for *rabi* 2017–18 crops at anthesis and at pod formation stage. Results showed that Infocrop-mustard model could able to simulate growth, development and yield of mustard crop. The mustard biomass and yield estimation done by the InfoCrop at pod formation stage had more promising results than at anthesis stage. We conclude that InfoCrop-mustard model satisfactorily simulate the growth, development and yield of mustard crop at farmer's field, and hence can be applied for agricultural applications for farmer's field and multistage mustard yield estimation.

Keywords: Biomass, InfoCrop-mustard model, LAI, Mustard, Seed yield

Mustard [*Brassica juncea* (L.) Czern and Coss] is the second most important oilseed crop grown in north-west part of India during *rabi*. The growth and development of mustard crop is highly sensitive to weather variables (Goyal *et al.* 2018). Weather is an important uncontrollable factor influencing crop growth and development. Crop simulation models are extensively used to understand the influence of meteorological parameters, soil properties, crop genotype and crop management practices on various agricultural applications. Dynamic mechanistic crop models are process based and they utilize established physiological processes to mimic the influence of environmental conditions on growth and yield of crops (Boote *et al.* 2013). InfoCrop is designed to simulate effect of weather variables, soil properties, management practices, pests and diseases on crop growth and biophysical parameters (Aggarwal *et al.* 2006). Crop simulation models are widely calibrated and

validated at the research experimental fields. However, evaluation of crop simulation models at farmers' fields is rare. In comparison to experimental fields, the situation of farmer's fields is more challenging owing to large scale variability in sowing conditions, management practices and unavailability of precise measurements. Therefore, the aim of present study is to evaluate performance of InfoCrop model for simulation of phenology, growth, development and yield of mustard crop at the farmers' field.

MATERIALS AND METHODS

The InfoCrop-mustard v2.1 model was used in this study. The details on the structure of the model and processes accounted by the model are elaborated in Aggarwal *et al.* (2006). A field experiment was conducted at the experimental farm of ICAR-Indian Agricultural Research Institute, New Delhi located at 28°64'23" North latitude and 77°15'27" East longitude with altitude of 228.6 meter amsl during *Rabi* 2016–17 and 2017–18. Three Mustard cultivars P.Tarak, RH-406 and Girraj were sown on three different dates timely sown (10th Oct 2016), late sown (25 October 2016) and very late sown (10 November 2016) to generate different weather conditions during different phenological stages (*Rabi* 2016–2017 and 2017–18). The experiment design was split plot design with date of sowing as the main

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plot treatment and cultivars as sub-plot treatment. Field experiment data for *rabi* 2016–17 was used for calibrating the model. The model was calibrated for days to emergence, days to 50% anthesis, days to physiological maturity, LAI, biomass and yield. For calibrating InfoCrop-mustard model, the parameters were adjusted for mustard sown on first date during *rabi* 2016–17. The genetic coefficients were estimated using the best fit method, i.e. by iteratively varying the values of the coefficients to produce a close match between simulated and measured values (within 10% range).

Model validation at farmers' fields: Experiment was conducted for farmers' fields situated in the Satara and Mukundpura village of Bharatpur district, Rajasthan. The GPS position (latitude and longitude) was recorded at the center of every selected field. Twenty farmers were selected to validate InfoCrop-mustard v2.1 model from Mukundpura and Satara village, Bharatpur, Rajasthan. Information on crop variety, sowing time and management practices were collected from the different farmers from the selected area. Surface soil moisture in the farmers' field at the depth of 0–15 cm was recorded by gravimetric method. The LAI was measured non-destructively by plant Canopy Analyzer LAI 2200 (LI-COR, Lincoln, Nebraska). Average mustard LAI on a given date was computed by averaging multiple LAI observations of that field. Two samples of mature mustard crop were harvested from 1×1 m² area in each plot and allowed to dry in air. The weight of total biomass (grains plus straw) in each plot was measured using a spring balance. After thrashing and winnowing by small mechanical thrasher, the weight of grains was taken to estimate grain yield. All the observation on farmers' field was taken at regular interval with the help of KVK, Khumer (Bharatpur).

Model performance: Performance of the model was evaluated using root mean square error (RMSE), normalized root mean square (nRMSE) and percentage deviation.

RMSE is often used to measure the difference between estimated values from the model and actual observed values from the experiment. By this test, model performance during the calibration as well as validation period can be determined.

$$RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^N (P_i - O_i)^2}$$

nRMSE expressed in percentage, values close to zero indicates better model performance. The estimation is considered excellent with value of nRMSE <10%, good if 10–20%, fair if 20–30%, poor if >30%.

$$nRMSE = \frac{100}{M} \sqrt{\frac{1}{N} \sum_{i=1}^N (P_i - O_i)^2}$$

Percent Deviation is the difference between predicted and observed yield with reference to observed yield. The positive value of percent deviation shows overestimation and negative value shows underestimation of a model.

$$\text{Percent deviation} = \frac{P_i - O_i}{O_i} \times 100$$

where, P_i is the predicted value, O_i is the observed value; N

is the number of observations and M is mean of observed value.

RESULTS AND DISCUSSION

Weather during crop growing period at experimental field: Weather during crop growing period *rabi* 2016–17 and 2017–18 at experimental farm is shown in Fig 1 and Fig 2. The maximum temperature was between 18 to 35°C and minimum temperature was between 3 to 23°C in both the crop growing year. The figure clearly showed the decreasing value of maximum and minimum temperature till 2nd standard meteorological week (SMW) afterward they followed the increasing trend till crop physiological maturity during both the growing year. It was important to notice that the maximum temperature during early crop growing period was higher during 2016–17 than 2017–18, but at the time of maturity maximum temperature during 2017–18 was little bit more than during 2016–17 crop seasons. On the contrary, the minimum temperature during 2017–18 was higher than during 2016–17 crop season till reproductive stage of mustard and thereafter there was drastic increase in minimum temperature during 2017–18 crop season. Maximum relative humidity was nearly constant throughout the crop growing season during both the crop growing year. The peaks of minimum relative humidity were obtained on 50th, 1st, 4th, 7th, and 9th SMW in both the years. A smoother curve of temperature and relative humidity showed less variation during 2017–18 and more variation during 2016–17 crop growing period. The rainfall received during the entire crop growing period was 119.7 mm during *rabi* 2016–17 and 13.4 mm during *rabi* 2017–18. There were five rainy days during *rabi* 2016–17 and two rainy days during *rabi* 2017–18. A good amount of rainfall (39.1 mm) received at 40th SMW in 2016–17 which met the pre sowing irrigation requirement. The year 2016–17 was wet in terms of amount and distribution of rainfall. Weekly mean bright sunshine hours ranged between 0.2 hours at 45th SMW and 9.0 hours at 13th SMW. The major drops in bright sunshine hours were recorded in 42nd, 43rd and 44th SMW due to fog and cloudiness in both the years.

Validation of InfoCrop-mustard model at experimental field

Phenological stage: In the InfoCrop-mustard model, phenology of the crop was simulated for three different mustard cultivars (P Tarak, RH-406 and Girraj) which are based on accumulation of degree days instead of calendar days. The accumulated degree days is modified by the maximum temperature, minimum temperature and photo-period during crop growing period. The InfoCrop-mustard model was validated for three developmental stages, i.e. germination, 50% anthesis and physiological maturity for all cultivars with different sowing dates. There was hardly one day difference between observed and simulated value. InfoCrop-mustard model overestimated the days for germination to 50% anthesis. The RMSE value simulation by InfoCrop-mustard model for germination days was <1, for all cultivars. The results showed that observed and

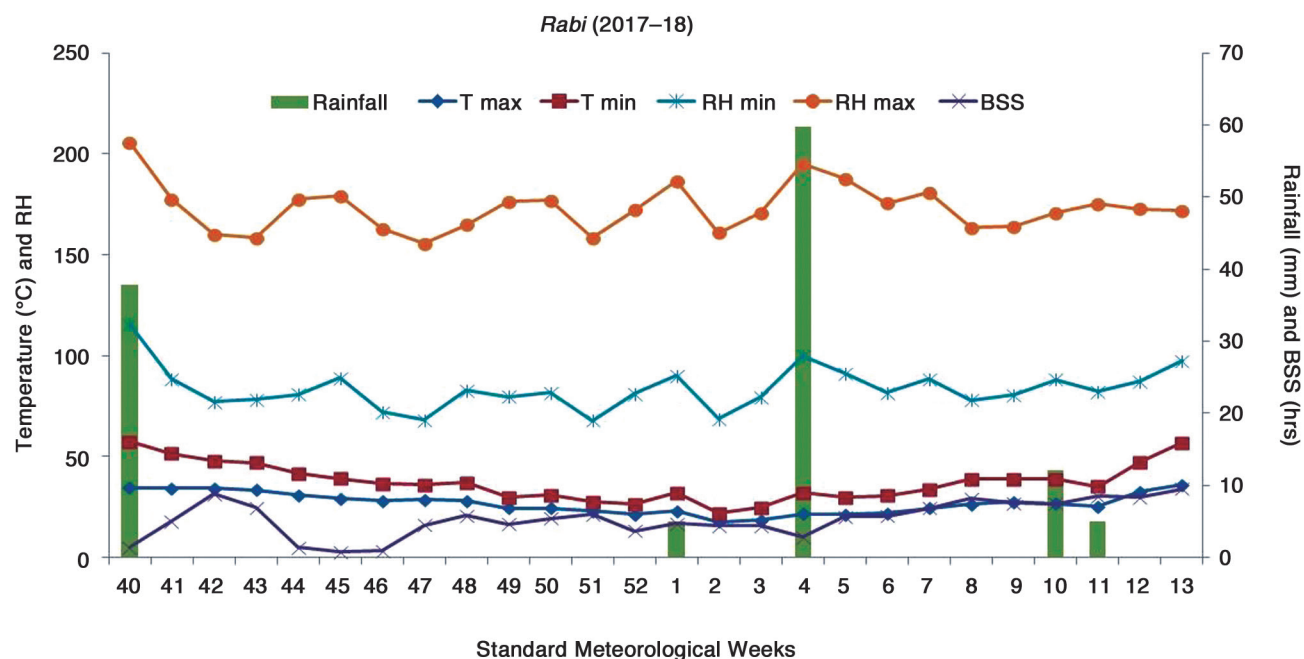


Fig 1 Weather at experimental field during crop growing period *rabi* 2016–17.

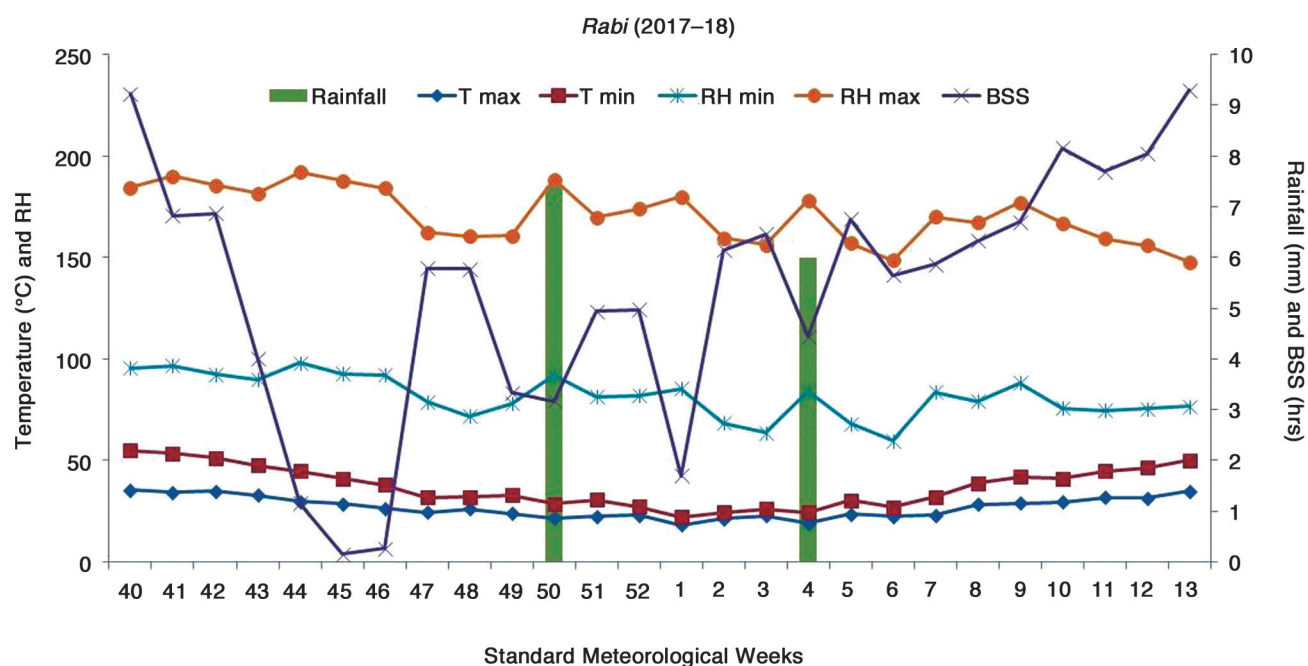


Fig 2 Weather at experimental field during crop growing period *rabi* 2017–18.

simulated duration for 50% anthesis occurred between 50 to 55 days for P. Tarak, 64 to 70 days for RH-406 and 63 to 71 days for Girraj under normal late and very late sowing. InfoCrop-mustard model on an average underestimate first date of sowing and overestimated second and third sowing for all cultivars. Days simulated for physiological maturity was underestimate for P. Tarak and overestimate for RH-406 and Girraj. RMSE values for simulation of days for physiological maturity was 0.89 for P. Tarak, 1.67 for RH-406 and 1.34 for Girraj. Better precision in simulation of

phenology may be attributed to model accounting the effect of date of sowing on thermal time accumulation.

Leaf Area Index: In InfoCrop model during initial stage of development when LAI is less than 0.75, leaf growth rate is mainly influenced by temperature and moderated by nitrogen stress and not by water stress. Thereafter, growth rate in LAI (RLAI) is calculated based on initial LAI (LAI), leaf area growth rate (GLAI), death rate of LAI (DLAI) and net loss of LAI due to pests (LALOSS). The simulated value of LAI was higher than observed value in different cultivars

during both the year. Higher deviation was observed in LAI value during late sown crop along with the 1:1 scattered line, this may be due to the temperature stress condition at later stage of development. LAI was overestimated compared to observed value by InfoCrop-mustard simulation model because premature leaf senescence due to reduction in the crop duration was not fully diverted to leaf area by the model. Value of RMSE and nRMSE for simulation of LAI by InfoCrop-mustard model was 0.59, 0.64 and 0.59; 18.4, 14.8 and 18.4 for P.Tarak, RH-406 and Girraj during 2016–17 and 2017–18 crop season, respectively.

Above ground biomass and seed yield: A good agreement was found between simulated and observed value of accumulation in above ground biomass and seed yield. InfoCrop utilizes the radiation use efficiency (RUE) based approach for dry matter production. Maximum RUE (RUEMAX) is input in the model as a function of crop/cultivar. The RUEMAX of plant is affected by abiotic (temperature, CO₂, nitrogen and water stress) and biotic (pest and disease) factors. Value of RMSE for simulation of biomass by InfoCrop-mustard model during both the year was 1186, 920 and 1265 kg/ha and value of nRMSE was 15.87, 10.74 and 14.7 for P. Tarak, RH-406 and Girraj respectively. For simulation of seed yield during both the year value of RMSE was 189 kg/ha, 201 kg/ha and 200 kg/ha and nRMSE value was 14.04, 11.64 and 12.47 for P. Tarak, RH-406 and Girraj respectively. Value of nRMSE was less than 15 for model simulation of above ground biomass and seed yield for different treatments. The deviation from observed biomass and grain yield were highest in delay sowing during both the years. It implies that model accuracy was precise for simulating the above ground biomass and seed yield of mustard.

Validation of InfoCrop-mustard model at farmers' field:

To validate InfoCrop-mustard model at farmer's field 20 farmers were selected from Mukundpura and Satara village of Bharatpur district. There was variation in cultivars, sowing dates and management practices for mustard growing area at farmer's field. The dominating variety in the study area was RH-406 and Girraj. There were about 20 days variation in date of sowing from 10th to 26th of October. But apart from that there was less variation in fertilizer application and irrigation scheduling. At farmer's field observed values of LAI varied between 3.3 to 4.4, biomass ranged between 6800 to 9000 kg/ha and seed yield ranged from 1650 to 2350 kg/ha for cultivar RH-406. Cultivar Girraj had LAI between 3.1 to 4.5, above ground biomass between 6800 to 8800 kg/ha and seed yield between 1620 to 2240 kg/ha.

Weather conditions at Farmer's field during Rabi 2017–18: Weather data collected from KVK, Kumher Agro-met observatory during Rabi 2017–18 crop season is shown in Fig 3. The maximum temperature was between 12.5 to 40°C and minimum temperature was between 1.9 to 21.5°C. Maximum relative humidity ranged between 54 to 97% and minimum relative humidity ranged between 15 to 88%. The rainfall received during the entire crop growing period was 3.8 mm. weekly mean bright sunshine hours was ranged between 0.2 to 9.2 hours. The average wind speed varied from 0.67 to 8.67 km/hour during the crop grown period.

Simulation of Leaf Area Index (LAI), above ground biomass and seed yield at farmer's field: At farmer's field InfoCrop-mustard model overestimate the peak value of LAI. At farmer's field simulation done for LAI by InfoCrop-mustard model had RMSE value 0.83 and 0.65 and nRMSE value 21.0 and 16.1 for RH-406 and Girraj respectively. A good agreement was found between simulated and observed peak value of LAI at Mukundpura and Satara village during 2017–18 crop season. Model performance for simulation

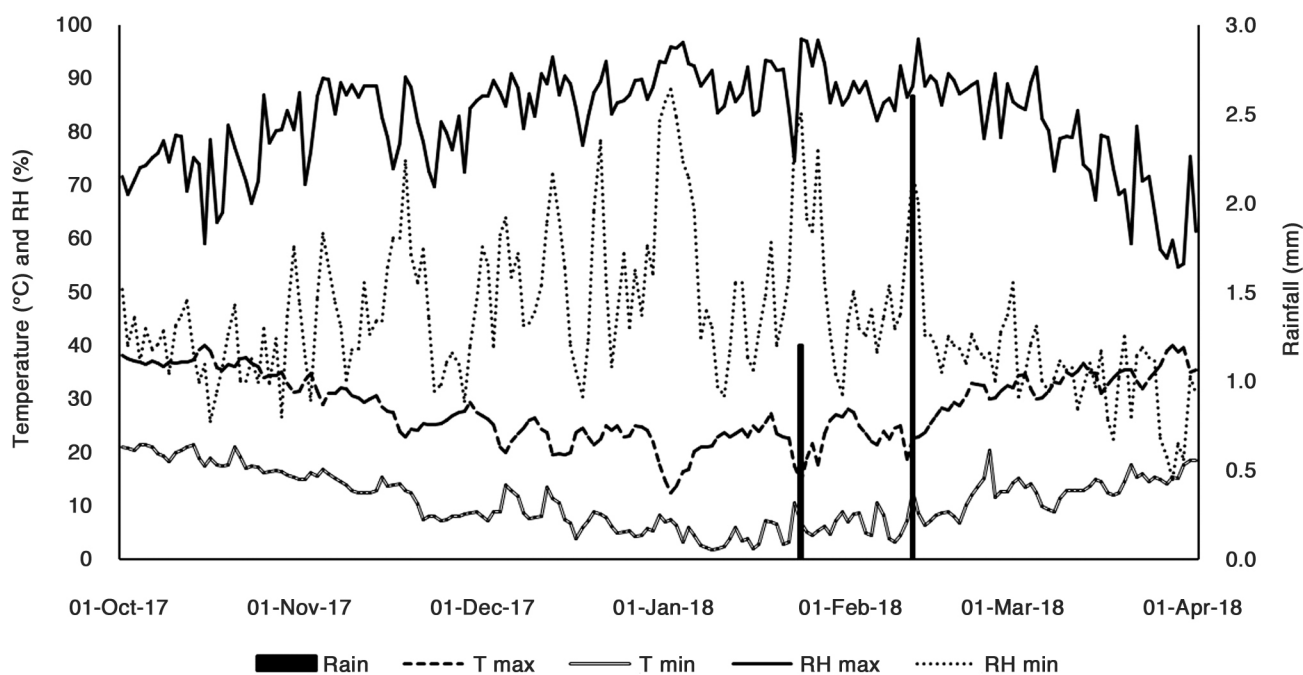


Fig 3 Weather at KVK, Kumher (near Farmer's field) during rabi 2017–18.

of LAI at farmer's field was fair with nRMSE value 21% for RH-406 and good for Girraj with nRMSE value 16.1%.

The simulation of above ground biomass was validated for farmer's field. Observed value showed a good agreement well along the 1:1 scattered line. The observed above ground biomass at harvest was influenced by management practices and had value between 6800 to 9000 kg/ha in farmers' fields during 2017-18 crop season. The simulated value of above ground biomass was ranged between 7200 to 10350 kg/ha. Value of RMSE for simulation of above biomass was 1268.4 and 1348.8 kg/ha and nRMSE was 16.4 and 17.7 for RH-406 and Girraj respectively at Mukundpura and Satara village of Bharatpur district in farmer's field. InfoCrop-mustard model overestimate above ground biomass. The model estimation was good having value of nRMSE < 20% for simulation of above ground biomass at farmer's field.

In InfoCrop mustard model, source-sink balance is considered in determining seed yield. Mustard seed yield is influenced by date of sowing and weather variables during crop growing season. Observed seed yield was between 1650 to 2350 kg/ha for RH-406 and 1620 to 2240 kg/ha for Girraj at Mukundpura and Satara village of Bharatpur district at farmer's field. The RMSE value for seed yield simulation was 351.0 kg/ha for RH-406 and 327.8 kg/ha for Girraj during crop growing season 2017-18. nRMSE value for model simulation for seed yield was 18.3 for RH-406 and 17.3 for Girraj. Results showed that InfoCrop-mustard model perform better for simulating seed yield as compared

to above ground biomass and LAI. Value of RMSE for model simulation for seed yield and biomass was 197.2 and 1133.8 kg/ha and nRMSE value was 12.62 and 13.57%. This showed that Infocrop-mustard model perform good for simulating seed yield and biomass at farmer's field having nRMSE value < 15%. Several researchers calibrate and validate the InfoCrop simulation model for different crops at different regions (Aggarwal *et al.* 2006, Keerthi *et al.* 2017, Gill *et al.* 2018)

Estimation of biomass and seed yield of mustard at different growth stage: Percentage deviation of above ground biomass estimation done at anthesis stage was lowest for normal sown (18.6, 16.3 and 16.7%) followed by late sown (25.6, 25.4 and 23.6%) and very late sown (40.2, 34.9 and 30.1%) crop for P.Tarak, RH-406 and Girraj, respectively. Percentage deviation of estimated seed yield done at pod formation stage by observed yield was lower than percentage deviation of estimated yield done at anthesis stage by observed yield. Percent deviation of estimated seed yield done at pod formation stage by observed yield was 9.1, 19.9 and 26.9% for P. Tarak, 10.6, 16.2 and 26.3% for RH-406, 9.8, 15.0 and 22.8% for Girraj in normal, late and very late sown crop respectively. Mustard yield estimation done by InfoCrop-mustard had RMSE value 2144.9 and 1443.2 kg/ha for P Tarak, 2392.4 and 1668.1 kg/ha for RH-406, 2077.3 and 1412.0 kg/ha for Giriraj at anthesis and at pod formation stage respectively (Table 1). Value of nRMSE for above ground biomass estimation done at pod

Table 1 Estimation of above ground mustard biomass at anthesis and at pod formation stage

Cultivar	Sowing time	Biomass (kg/ha)		Percentage deviation	RMSE (kg/ha)	nRMSE
		Observed	Estimated			
<i>Estimation at anthesis</i>						
P Tarak	First sowing	8900	10551	18.6	2144.9	27.6
	Second sowing	7830	9839	25.6		
	Third sowing	6600	9253	40.2		
RH-406	First sowing	10820	12587	16.3	2392.4	25.1
	Second sowing	9540	11964	25.4		
	Third sowing	8200	11058	34.9		
Girraj	First sowing	9990	11657	16.7	2051.3	22.8
	Second sowing	9220	11392	23.6		
	Third sowing	7760	10094	30.1		
<i>Estimation at pod formation</i>						
P.Tarak	First sowing	8900	9706	9.1	1443.2	18.6
	Second sowing	7830	9392	19.9		
	Third sowing	6600	8376	26.9		
RH-406	First sowing	10820	11969	10.6	1668.1	17.5
	Second sowing	9540	11083	16.2		
	Third sowing	8200	10355	26.3		
Girraj	First sowing	9990	10975	9.8	1412.0	15.7
	Second sowing	9220	10598	15.0		
	Third sowing	7760	9524	22.8		

Table 2 Estimation of mustard seed yield at anthesis and at pod formation stage

Cultivar	Sowing time	Seed yield (kg/ha)		Percentage deviation	RMSE (kg/ha)	nRMSE
		Observed	Estimated			
<i>Estimation at anthesis</i>						
P Tarak	First sowing	1900	2196	15.6	449.1	30.6
	Second sowing	1453	1810	24.5		
	Third sowing	1051	1675	59.4		
RH-406	First sowing	2374	2648	11.5	539.3	29.0
	Second sowing	1904	2203	15.8		
	Third sowing	1310	2152	64.2		
Girraj	First sowing	2192	2580	17.7	504.2	29.2
	Second sowing	1789	2183	22.0		
	Third sowing	1204	1880	56.1		
<i>Estimation at pod formation</i>						
P Tarak	First sowing	1900	2052	8.0	292.0	19.9
	Second sowing	1453	1685	15.9		
	Third sowing	1051	1474	40.3		
RH-406	First sowing	2374	2560	7.8	336.6	18.1
	Second sowing	1904	2164	13.7		
	Third sowing	1310	1798	37.1		
Girraj	First sowing	2192	2292	4.6	318.56	18.4
	Second sowing	1789	2102	17.5		
	Third sowing	1204	1647	36.8		

formation stage was less than 20% and more than 20% at anthesis stage. This indicates that model performed good for estimating mustard above ground biomass at pod formation stage. A good agreement was found between observed and estimated value for normal sowing compared to late and very late sowing.

Percentage deviation of seed yield estimation done by InfoCrop-mustard model at anthesis stage by observed yield was 15.6, 11.5 and 17.7% for first sown crop, 24.5, 15.8 and 22.0% for second sown crop and 59.4, 64.2 and 56.2% for third sown crop for P.Tarak, RH-406 and Girraj, respectively. Percent deviation of estimated seed yield done at pod formation stage by observed yield was 8.0, 15.9 and 40.3 for P Tarak, 7.8, 13.7 and 37.1 for RH-406 and 4.6, 17.5 and 36.8 for Girraj in first, second and third sown crop respectively. Value of nRMSE was less than 20% for seed yield estimation done at pod formation stage and between 25 to 30% for seed yield estimation done at anthesis stage for all cultivars. This indicates that InfoCrop-mustard model perform good for estimating seed yield at pod formation stage (Table 2). Several researchers use crop simulation models for different crop such as, CERES-Maize (Quiring *et al.* 2008); InfoCrop-mustard (Vashisth *et al.* 2015); InfoCrop-maize (Vashisth *et al.* 2018) and InfoCrop-wheat (Vashisth *et al.* 2019). The InfoCrop-mustard v2.1 model performed very well in estimating LAI, above ground biomass and seed yield of mustard crop under varied management practices at farmers' field as shown by low

nRMSE value. Hence, model can be applied for undertaking different recommendations for farmers in the study region with a high level of confidence.

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