Journal of Agrometeorology 21 (3) : 254-261 (September 2019)

Evaluating InfoCrop model for growth, development and yield of spring wheat at farmers' field in semi-arid environment

RAJKUMAR DHAKAR[1*], VINAY KUMAR SEHGAL[1], DEBASISH CHAKRABORTY[1], JOYDEEP MUKHERJEE[1] and S. NARESH KUMAR[2]

[1]Division of Agricultural Physics, [2]Centre for Environmental Sciences and Climate Resilient Agriculture, ICAR-Indian Agricultural Research Institute, New Delhi - 110012, India

[*]Corresponding Author: rajdhakar.iari@gmail.com

ABSTRACT

Evaluation of crop simulation model for growth and development of crops at farmers' field is uncommon, as large variability exists in management practices at farmers' fields. Present study was attempted to evaluate the suitability of InfoCrop v2.1 model for prediction of growth, development and yield of wheat crop at farmers' fields using two years data i.e. 2015-16 & 2016-17. A total of 42 farmers' fields were selected in Pataudi block of Haryana state. The large variability in wheat sowing date (1-Nov to 25-Dec), seed rate (87 to 150 kgha^{-1}), N application rate (70 to 195 kgha^{-1}) and number of irrigations (5-8) were observed in farmers' field. InfoCrop model could able to predict well days to anthesis and physiological maturity within an acceptable error of 5% (RMSE~3 days). Measured leaf area index (LAI) matched well with simulated LAI (RMSE ~ 0.5). The agreement between observed and model simulated wheat grain yield was found to be satisfactory (nRMSE ~ 6-8%). We conclude that InfoCrop-wheat model satisfactorily simulate the growth, development and yield of wheat crop under varied management practices at farmers' fields, and hence can be applied for agricultural applications for farmers

***Key words**: LAI, dynamic model, total dry matter, D-index*

Among the cereals, wheat is an important staple food crop of world as well as India. Wheat is the second most widely cultivated crop in India due to its wider adaptability in tropical to temperate environments. Wheat is mainly grown as winter crop in India. The total area under the crop is about 30.5 million hectares in the country (DES, 2017). Wheat production stood at record 98.30 million tonne in the year 2016-17 (DES, 2017). However, wheat production has been fluctuating due to weather and climate variability (Bal *et al.,* 2004; Jalota *et al.,* 2013). Crop models are an excellent tool to understand the effects of weather parameters, soil properties and crop management practices on yield, yield prediction, irrigation scheduling etc. Dynamic crop simulation models are process based and they employ various established theories and processes in the model to simulate the effect of weather, soil and crop components on growth and yield of crops (Boote *et al.,* 2013; Kumar *et al.,* 2013; Bemal *et al.,* 2013; Shamim *et al.,* 2012; Dass *et al.,* 2012). System modelling was initially popular in engineering science but had its origin in 1960s in agricultural science with pioneer work of physicist, C.T. de Wit of Wageningen University. The work of modeler at Wageningen University was continually evolved and led to development of many models like MACROS, SUCROS, BACROS etc. The workers from India also contributed to development of these models through collaborative project of IBSNAT and SARP. Apart from this, Indian efforts started with the development of a wheat crop model which was developed by the IARI and it was further developed as WTGROWS (Aggarwal *et al.,* 1994). Subsequent efforts by Aggarwal and his colleagues at IARI led to development of a generic model for annual crops in a tropical environments called InfoCrop (Aggarwal *et al.,* 2006a,b). Once any crop simulation model is calibrated and validated using independent dataset (Jones *et al.,* 2001), it can be used to simulate variety of agricultural applications (Jalota *et al.,* 2012).

Crop simulation models are widely calibrated and validated at the research experimental fields. However, validation/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, diversity in management practices followed and unavailability of precise measurements. Validation of model at farmers' field is prerequisite for their applicability at farm scale. Therefore, the aim of present study is to evaluate performance of InfoCrop model for simulation of phenology, growth, development and yield of wheat crop at the farmers' field level.

MATERIALS AND METHODS

Model description

InfoCrop is a generic crop model which simulates the effect of genotype, weather, agronomic management, water, nitrogen, carbon and pests on the growth, development and yield of the crops in tropical agro-environments (Aggarwal *et al.,* 2006). The InfoCrop-wheat v2.1 was used in this study. The source code was provided by the model developer from CESCRA, ICAR-IARI. The model was written in Fortran Simulation Translator (FST) language (Kraalingen et al. 1995). The compiler FSTWin 4.2 was used to compile the program. The basic structure of InfoCrop involving growth and development processes follows the structure of MACROS (Penning de Vries *et al.,* 1989). The details on the structure of the model and processes accounted by the model are elaborated in Aggarwal *et al.,* (2006a).

Model parameterization

A field experiment was conducted in the experimental farm (MB-4C) of Division of Agricultural Physics of Indian Agricultural Research Institute, New Delhi (coordinates 28°38'23"N, 77°09'27"E) during the rabi season of 2015-16 and 2016-17. Wheat (cv. HD 2967) was raised following recommended practices in split plot design with irrigation as main treatment and date of sowing as sub plot treatment. The irrigation treatments were I5: five irrigations (crown root initiation (CRI), tillering, booting, flowering and milking stages), I3: three irrigations (CRI, tillering and flowering stages) and I1: one irrigation (CRI stage). The two dates of sowing treatments were D1: Timely sown (20th Nov 2015) and D2: Late sown (9th Dec 2015) during *rabi* season 2015-16 and D1: Timely sown (17th Nov 2016) and D2: Late sown (7th Dec 2016) during 2016-17. The non-stressed treatment (D1I5) of field experiment for the season 2016-17 was used for calibrating the model. The model was calibrated for days to emergence, days to 50 % anthesis, days to physiological maturity, growth profile of LAI, maximum LAI, biomass and yield. The genetic coefficients used for calibrating the model are listed in Table 1 and the measured genetic coefficients are expressed as bold letter. For rest of genetic coefficients, their default value was used.

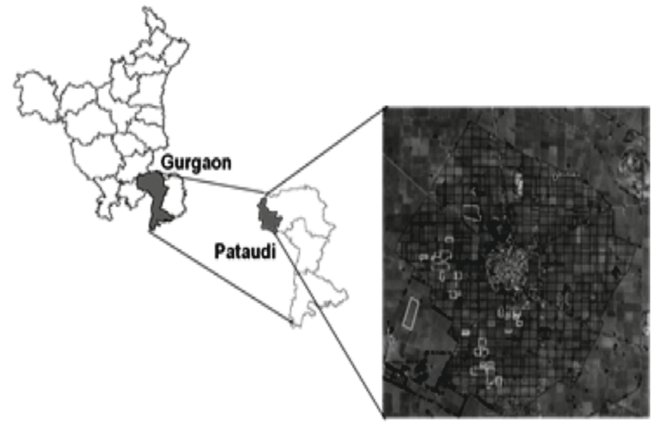

Fig. 1: Study area showing selected fields (while outline) overlaid on satellite image in a village.

Model validation at farmers' fields

The study was conducted for the farmers' fields situated in Mumtazpur and Lokra villages of Pataudi block of Gurgaon district, Haryana, India (Fig. 1). The location of each plot was recorded with a hand-held high-sensitivity GPS receiver (GARMIN 76CSx) at the center of every field.

The periodical observations on phenology (emergence, 50% flowering and physiological maturity), LAI, final biomass and yield were collected from selected farmers' fields. The data on management practices such as sowing date, seed rate, variety and amount and date of fertilizer and irrigation given are also collected for the selected fields. The soil sampling was also done to measure soil physical properties. These data were used to validate the InfoCrop model at farmers' fields.

Model performance measures

Performance of the model was evaluated using root mean square error (RMSE), normalized root mean square error (nRMSE) and index of agreement (D-index). The RMSE was calculated using following formula:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(O_iE-_i)^2}{N}} \quad (1)$$

The nRMSE was calculated as ratio of RMSE and mean of observed variable. The D-index developed by Willmott (1981) is a standardized measure of the degree of model prediction error and varies between 0 and 1. A value of 1 indicates a perfect match, and 0 indicates no agreement at all. It is calculated as:

Table 1: Varietal coefficients specified in Info Crop for the variety HD-2967

S.No.	Genetic coefficients	value	S.No.	Genetic coefficients	value
1	T_{base} germination phase (°C)	3.6	11	Root growth rate (mm)	25
2	T_{base}-vegetative phase (°C)	4.5	12	Slope of grain number/m^2 to dry matter during grain formation stage (Grains/kg/day)	23500
3	T_{base}-grain filling phase (°C)	7.5	13	Potential grain weight (mg/grain)	44
4	AGDD -germination phase (Degree-days)	75	14	Nitrogen content of grain	0.02
5	AGDD - vegetative phase (Degree-days)	905	15	Sensitivity of crop to flooding (Scale (0-1))	1
6	AGDD-grain filling phase (Degree-days)	405	16	Sensitivity of grain setting to high temperature (Scale (0-1))	1
7	Specific leaf area (dm^2/mg)	0.0022	17	Sensitivity of grain setting to low temperature (Scale (0-1))	1
8	Relative growth rate of leaf area (^{o}C/d fraction)	0.008	18	Index of nitrogen fixation(Scale (0-1))	1
9	Maximum RUE (g/MJ/day)	2.8	19	Sensitivity to photoperiod (Scale (0-1))	1
10	Light extinction coefficient (ha soil/ ha leaf fraction)	0.50			

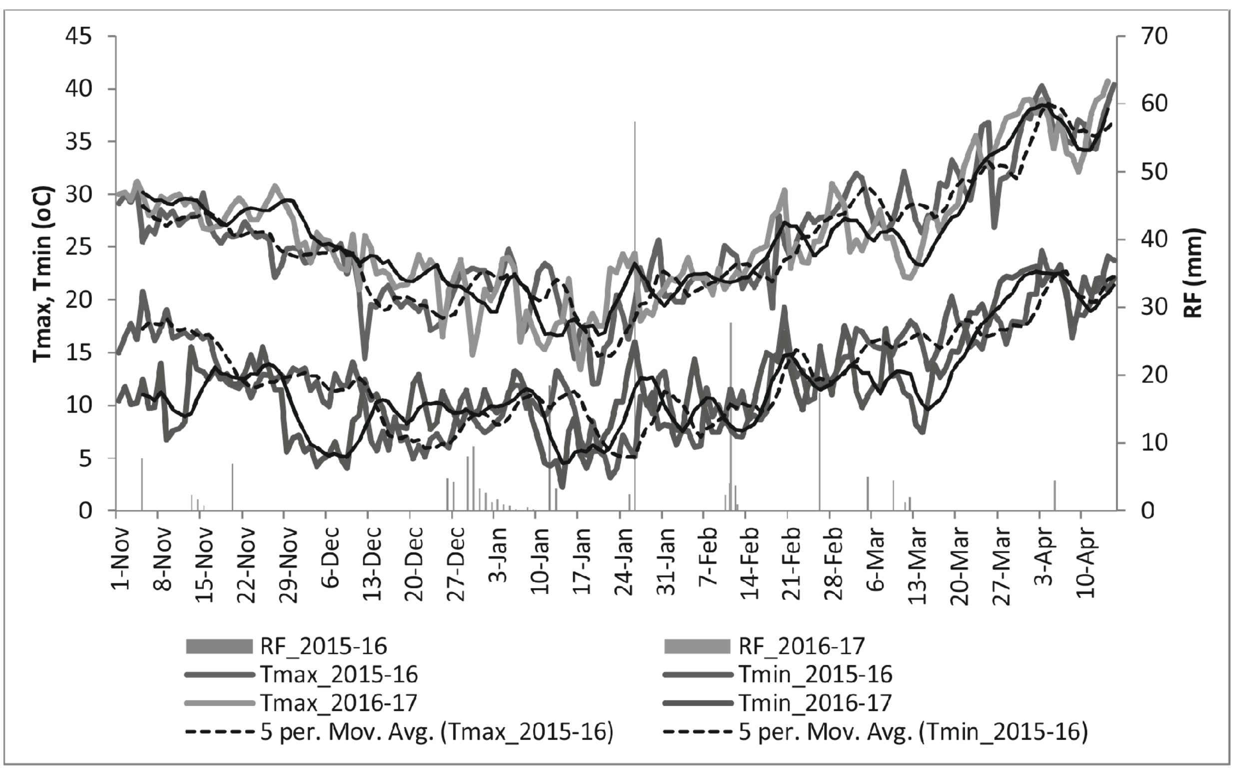

Fig. 2: Meteorological conditions prevailed during growing season of year 2015-16 and 2016-17.

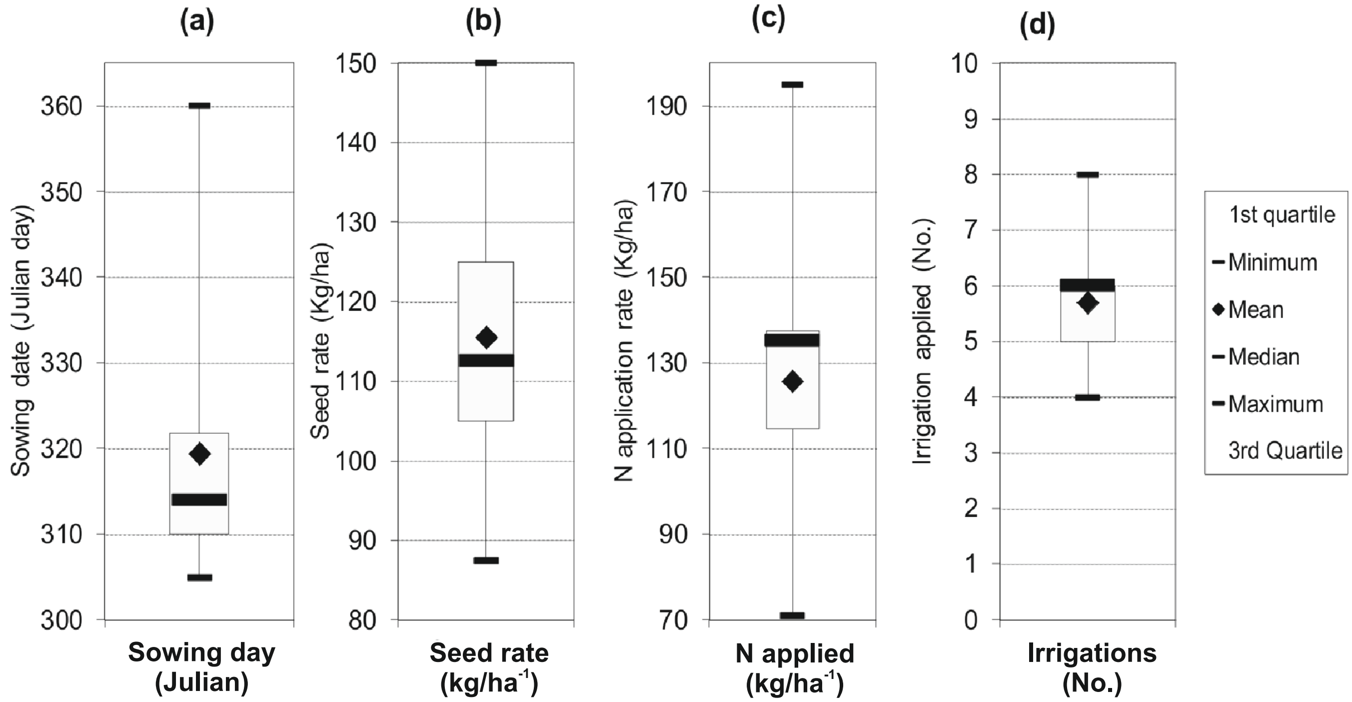

Fig. 3: Variability in management practices (a) sowing date, (b) seed rate, (c) N application rate and (d) number of irrigations followed in farmers' fields of study area

$$D\text{-}index = 1-\frac{\sum_{i=1}^{n}(E_iO-_i)^2}{\sum_{i=1}^{n}(|E_iO\overline{-}_i|+|O_iE\overline{-}_i|)^2} \qquad (2)$$

Where, O_i= in-situ measurement of i th field, E_i= predicted value of ith field, $\overline{O_i}$ = average of in- situ measurements over all fields and N = number of selected fields.

RESULTS AND DISCUSSION

Meteorological conditions

Weather data from automatic weather station (AWS) situated at KVK, Sikohpur was used for running the simulation model. The daily meteorological conditions viz., maximum temperature (Tmax), minimum temperature (Tmin) and rainfall prevailed during growing season (1-November to 15-April) for both years (2015-16 and 2016-17) are shown in Fig. 2. Tmax and Tmin were almost 2-3 °C higher in the year 2015-16 than that of 2016-17 during 2nd fortnight of Feburary, which coincides with anthesis to milking stage of wheat crop. The total amount of rainfall received during season 2016-17 was 135 mm, compared to that of 77mm during 2015-16. Overall, crop experienced more favorable meteorological condition during the season 2016-17 compared to that of during 2015-16.

Variability in management practices

The data on management practices followed by the farmers were collected and results are presented in Fig. 3a-d. The dominating variety of the study area was HD-2967. However, our sampling sites also covered the varieties like HD-3086, PBW 373, WH 711, WR 544 and CSW 18. Results showed that farmers sow the wheat crop ranging from very early (1st Nov) to very late (25th Dec), thus large variability in sowing date was observed in the farmers field of Mumtazpur and Lokra (Fig. 3a). Median date of sowing was 310 Julian day. The standard deviation in seed rate was about 14 kgha^{-1} with the mean value of 115 kgha^{-1} (lowest was 87 kgha^{-1} and highest150 kgha^{-1}) (Fig. 3b). Likewise, the application of N (kgha^{-1}) varied from very low (70) to as high as (195) with mean value of 126 kgha^{-1} (Fig. 3c). Low variability in number of irrigation given to the crop was observed, as most of the farmers provided the 5 to 6 irrigations to wheat crop (Fig. 3d).

Phenological development

In the InfoCrop model, phenology of the crop is calculated based on thermal time accumulated during three phases viz., sowing to seedling emergence, seedling emergence to anthesis and anthesis to physiological maturity. The accumulated

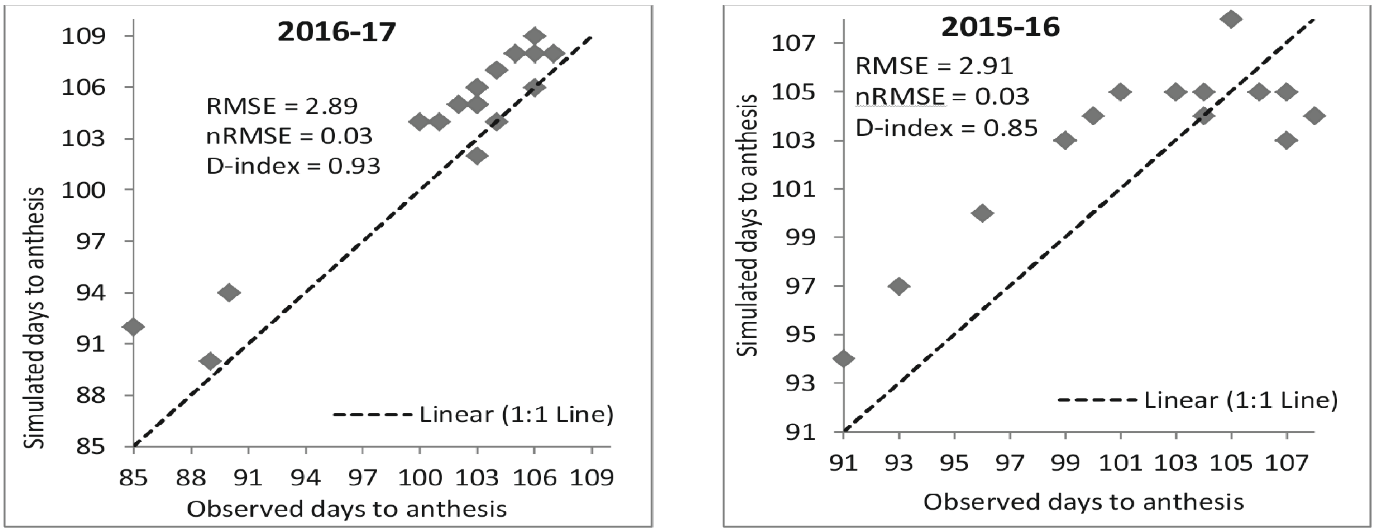

Fig. 4: Observed versus InfoCrop-wheat simulated days to 50% anthesis in wheat cultivars under different management conditions

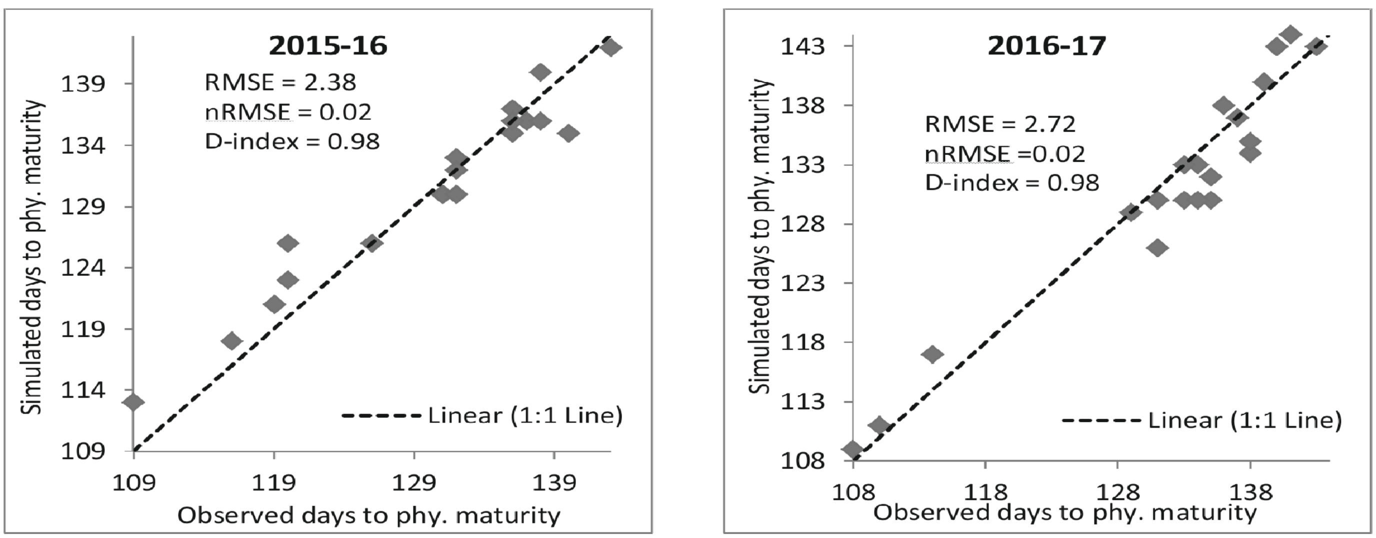

Fig. 5 : Observed versus InfoCrop-wheat simulated days to phiysiological maturity in wheat cultivars under different management conditions.

thermal time is modified by the photo-period and water stress. The model was validated for two developmental stages i.e. days to 50% anthesis and days to physiological maturity.

Days to 50% anthesis

The comparison of observed versus simulated days taken to 50% anthesis along with 1:1 line as scatter plot is shown in Fig. 4. The results showed that observed days to 50% anthesis varied between 85 to 108 days for wheat cultivars under different management practices considering both years data. Info Crop model overestimated on an average 3 days of occurrence of 50% anthesis in wheat crop as evident from RMSE. The performance of model was better in the year 2016-17 than in 2015-16 which is supported by higher D-index of 0.93 in former year than later. It may be attributed to favorable environmental conditions (more rainfall and lower temperatures) experienced by the crop during 2016-17. The early occurrence of anthesis of wheat was observed for fields with late sowing of crop. The lower values of days to anthesis is slightly more overestimated by the InfoCrop model than that of the higher values.

Days to physiological maturity

The performance of model for days taken to reach physiological maturity by wheat crop at farmers' field under different management practices was carried out by comparison of observed and model simulated values (Fig. 5). The observed days to physiological maturity varied between 108 to 143 days. The results showed that model satisfactorily simulated the days taken to physiological maturity and the errors were within the reasonable range of +/- 5 percent (normalized RMSE = 2%). The d-index of the model was also quite high in both the years.

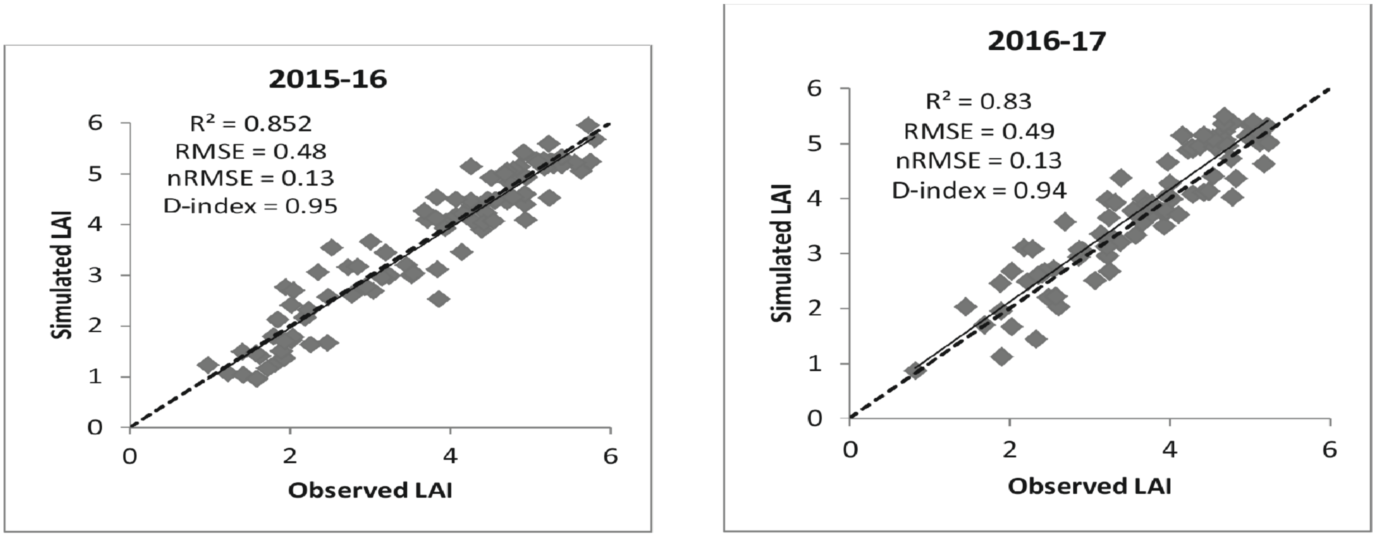

Fig. 6: Observed versus InfoCrop-wheat simulated leaf area index in wheat cultivars under different management conditions.

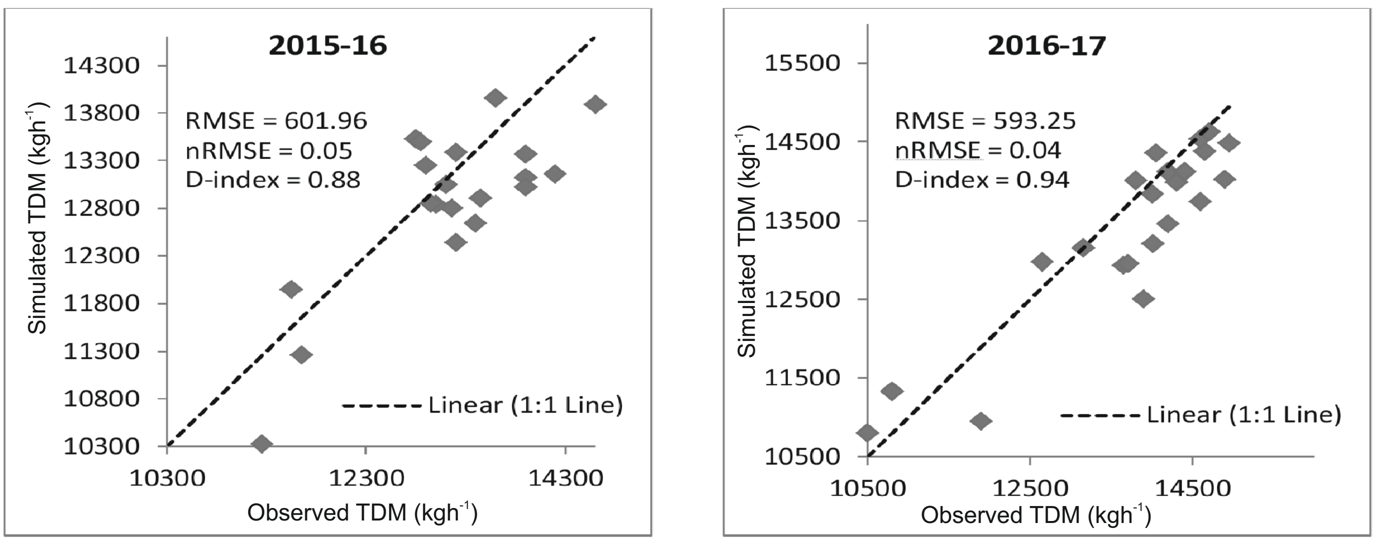

Fig. 7: Observed versus InfoCrop-wheat simulated total dry matter in wheat cultivars under different management conditions

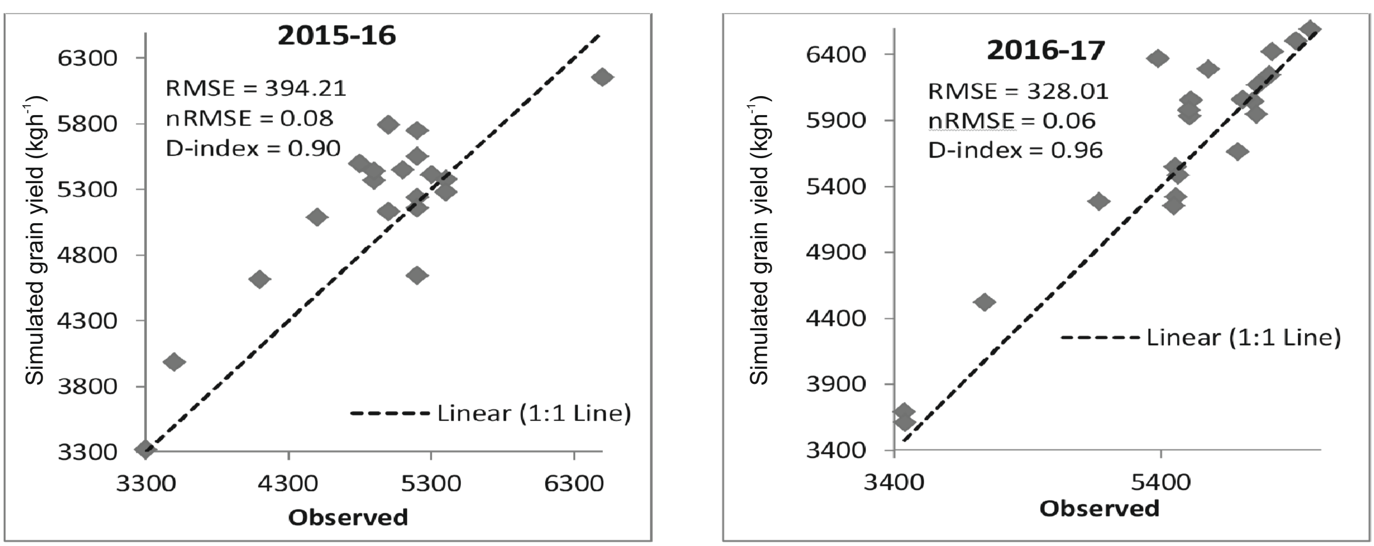

Fig. 8: Observed versus InfoCrop-wheat simulated grain yield in wheat cultivars under different management conditions

Leaf Area Index (LAI)

InfoCrop model during the 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 (LAII), leaf area growth rate (GLAI), death rate of LAI (DLAI) and net loss of LAI due to pests (LALOSS) (Aggarwal *et al.* 2004). Fig. 6 shows the performance of InfoCrop-wheat model in terms of simulation of LAI. Model simulated LAI matches well with in-situ measured LAI and seems to be performed satisfactory in both the seasons. The RMSE of LAI prediction was of the order of 0.15 with normalized RMSE of about 13 percent. D-index of model for LAI prediction was about 0.94 and 0.95 in 2015-16 and 2016-17, respectively.

Total dry matter (TDM)

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, CO_2, nitrogen stress and water stress) and biotic factors. Water stress reduces RUE almost in proportion to severity. The total dry matter at harvest is greatly influenced by management practices, as it varied from 10 tha^{-1} to 15 tha^{-1} in farmers' fields (Fig. 7). Measured and model simulated total dry matter showed a good agreement and estimated errors were within the acceptable range. The RMSE was about 600 $kgha^{-1}$ for mean total dry matter and normalized RMSE was 4-5%. The model efficiency (d-index) was 0.88 and 0.94 for the season 2015-16 and 2016-17, respectively.

Grain yield

In Info Crop model, source-sink balance is considered in determining grain yield. Grain yield of wheat is also greatly influenced by different management practices and it varied between 3.3 tha^{-1} and 6.6 tha^{-1} in farmers' fields. Results of fitting between measured and model simulated grain yields at farmers' fields are displayed as scatter plot (Fig. 8). It shows a good agreement between the two and errors were also within the acceptable limit of 10%. The RMSE were 394 $kgha^{-1}$ and 328 $kgha^{-1}$ for grain yield in the season 2015-16 and 2016-17, respectively. D-index of model for grain yield was greater than 0.90 for both the years. Grain yield was largely overestimated in the year 2015-16, while both under/over estimation occurred in the year 2016-17. Aggarwal *et al.* (2006) showed that Info Crop model could able to simulate dry matter and yield of wheat with RMSE of 4-5%. Krishnan *et al.* (2016) evaluated the web-based InfoCrop wheat model for growth and development of wheat and its performance found to be satisfactory. All previous studies on evaluating of InfoCrop model were at the research experimental field. To the best of our knowledge, no previous study evaluated the InfoCrop wheat model at farmer's field scale which encompasses range of management practices followed by the farmers. This study clearly shows that InfoCrop-wheat model is very suitable for simulating farmer's field conditions. The applications developed based on InfoCrop will have high confidence of their use.

CONCLUSIONS

This study was aimed at evaluating the performance of InfoCrop model for simulating growth, development and yield of wheat crop under varied management practices followed at farmer fields. The large variability in management practices such as sowing date, seed rate, rate of nitrogen application and number of irrigation provided to the wheat crop were observed in farmers' fields of Pataudi block, Haryana. The calibrated InfoCrop model could able to simulate well the phenology of wheat crop at farmers' field. The model was able to predict the growth (LAI and above ground biomass) within the reasonable error limits. The model also performed very well in predicting grain yield under varied management practices at farmers' field as shown by low nRMSE and high value of D-index. Hence, model can be applied for undertaking different recommendations for farmers in the study region with a high level of confidence.

ACKNOWLEDGEMENTS

The first author acknowledges his employer, ICAR-Central Research Institute for Dryland Agriculture, Hyderabad, for granting study leave to undertake PhD study. Authors acknowledge the research facilities extended by Head, Division of Agricultural Physics, Indian Agricultural Research Institute, New Delhi. This work was funded by ICAR-National Innovations on Climate Resilient Agriculture (NICRA) project and facilities provided under IARI in-house Project [IARI:NRM:14:(04)].

REFERENCES

Aggarwal, P.K., Kalra, N., Singh, A.K. and Sinha, S.K. (1994). Analyzing the limitations set by climatic factors, genotype, water and nitrogen availability on productivity of wheat I. The model description, parametrization and validation. *Field Crops Res.*, *38*(2): 73-91.

Aggarwal, P.K., Banerjee, B., Daryaei, M.G., Bhatia, A., Bala, A., Rani, S., Chander, S., Pathak, H. and Kalra, N. (2006a). Info Crop: a dynamic simulation model for the assessment of crop yields, losses due to pests, and environmental impact of agro-ecosystem in tropical environments. 1. Model description. *Agric. Syst*., 89: 1-25.

Aggarwal, P.K., Kalra, N., Chander, S. and Pathak, H. (2006b). InfoCrop: A dynamic simulation model for the assessment of crop yields, losses due to pests, and environmental impact of agro-ecosystems in tropical environments. I. Performance of the model. *Agric. Syst.*, 89: 47-67.

Bal, S.K., Mukherjee, J., Mallick, K. and Hundal, S.S. (2004). Wheat yield forecasting models for Ludhiana district of Punjab state. *J. Agrometeorol.*, 6(spl.issue): 161-165.

Boote, K.J., Jones, J.W., White, J.W., Asseng, S., Lizaso, J.I. (2013). Putting mechanisms into crop production models. *Plant Cell Environ.,* 36(9): 1658-1672.

Bemal S, Singh D. and Singh S. (2013). Impact analysis of climate variability on rice productivity in eastern agroclimatic zone of Haryana by using DSSAT crop model. *J. Agrometeorol.,* 15 (Spl Issue-II): 80-84.

Dass, A., Nain, A.S., Sudhishri, S., Chandra, S. (2012). Simulation of maturity duration and productivity of two rice varieties under system of rice intensification using DSSAT v 4.5/CERES-Rice model. *J. Agrometeorol.,* 14(1): 26-30.

DES (2017). Directorate of Economics and Statistics, Ministry of Agricultural Cooperation and Farmers Welfare, Government of India.

Jalota, S.K., Kaur, H., Ray, S.S., Tripathi, R., Vashisht, B.B. and Bal, S.K. (2012). Mitigating Future Climate Change Effects by Shifting Planting Dates of Crops in Rice-Wheat Cropping System. *Reg. Environ. Change,* 12(4): 913-922.

Jalota, S.K., Kaur, H., Ray, S.S., Tripathi, R., Vashisht, B.B. and Bal, S.K. (2013). Past and General Circulation Model-driven future trends of climate change in Central Indian Punjab: ensuing yield of rice-wheat cropping system. *Curr. Sci.,* 104(1): 105-110

Jones, J.W., Keating, B.A. and Porter, C.H. (2001). Approaches to modular model development. *Agric. Syst.*, 70(2-3): 421-443.

Krishnan, P., Sharma, R.K., Dass, A., Kukreja, A., Srivastav, R., Singhal, R.J., Bandyopadhyay, K.K., Lal, K., Manjaiah, K.M., Chhokar, R.S. and Gill, S.C. (2016). Web-based crop model: Web InfoCrop–Wheat to simulate the growth and yield of wheat. *Comput. Electron. Agr.*, 127: 324-335.

Kumar K., Singh S. and Singh D. (2013). Seasonal climatic variability and its impact assessment on wheat productivity using crop modeling techniques in Haryana. *J. Agrometeorol.,* 15 (Spl Issue-I): 25-29.

Penning De Vries, F.W.T., Jansen, D.M., Ten Berg, H.F.M. and Bakema A. (1989). Simulation of Eco physiological Processes of Growth in several Annual Crops. Simulation Monograph 29. Pudoc, Wageningen, and IRRI, Los Banos.

Shamim, A., Shekh, A.M., Vyas. P., Patel, H.R. and Lunagaria, M.M. (2012). Simulating the phenology, growth and yield of aromatic rice cultivars using CERES-Rice model under different environments. *J. Agrometeorol.,* 14(1): 31-34.

Van Kraalingen, D.W.G. (1995). The FSE system for crop simulation, version 2.1 (No. 1). AB-DLO.

Willmott, C.J. (1981). On the validation of models. *Phys. Geogr.* 2(2): 184-194.

Received : July 2019 : Accepted : August 2019