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Calibration and validation of InfoCrop model for phenology, LAI, dry matter and yield of wheat

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ABSTRACT

Present experiment was conducted (2015-16 and 2016-17) comprising different levels of water stress and environmental conditions for the model parametrization and validation of Info Crop-wheat v2.1 model. The model was calibrated and validated for popular wheat variety HD-2967 under semi-arid environmental conditions. The important genetic coefficients were generated and model fine-tuned for simulating phenology, leaf area index (LAI), dry matter and yield of wheat crop. The result showed that the model simulated the phenology in terms of days to 50% anthesis and days to physiological maturity very accurately with root mean squared error of 2.26 and 1.36 days, respectively. The model could also able to simulate temporal course of LAI and biomass very satisfactorily. The errors in simulating final biomass and yield were also within the acceptable limit of 10%. We conclude that InfoCrop model is reasonably suitable to simulate the developmental stages, leaf area expansion, dry matter and yield of wheat crop in semi-arid environment hence it can be utilized for undertaking various crop management applications.

Keywords: Biomass, Crop development, D-index, Mechanistic model, Parameterization

Crop simulation models are extensively used to comprehend the influence of meteorological parameters, soil properties, crop genotype and crop management practices on various agricultural applications (Dhakar *et al.* 2019). 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 (Jones *et al.* 2016). The model must be validated before its use, i.e. model output has to be compared with independent observation datasets. Models are frequently validated with all or some of the data used for model development or calibration (Jones *et al.* 2001), whereas independent data, not used in model development, should be used (McCarl 1984). While validating the crop models, in most of the cases comparison of simulated yield with observed yield from short-term field experiments is a standard procedure. Aggarwal *et al.* (1994) validated WTGROWS under potential production environments and found that the model simulated wheat yields accurately at most places with no point outside ±1 standard deviation and with an R^2 value of 0.74. Singh *et al.* (2008) evaluated the crop models like CERES and CropSyst of wheat for interaction of water and nitrogen. The comparison of three different models in their physiological processes, viz. AquaCrop, WOFOST and CropSyst was carried out for evaluating the ability of the model to simulate growth of sunflower under different water regime in Mediterranean environment (Todorovic *et al.* 2009). Ahmed *et al.* (2016) calibrated and validated APSIM-wheat and CERES-wheat model for spring wheat under rainfed condition. It was observed that both models were able to accurately simulate anthesis and maturity days, maximum leaf area index, biomass and grain yield, with normalized root mean square error (RMSE) less than 10%, D-index greater than 0.80 and model efficiency above 80% in most cases. Dhakar *et al.* (2018) reviewed the seven most popular crop simulation models for their process and responses under water deficit stress in field crops.

The present study aimed to calibrate and validate indigenous crop model, i.e. InfoCrop for simulating growth, development and yield of popular wheat variety HD-2967 in semi-arid environment.

MATERIALS AND METHODS

Field experiment detail: Two years field experiments (*rabi* 2015-16 and 2016-17) were conducted at research farm of ICAR-Indian Agricultural Research Institute, New Delhi. In the field experiment, wheat (cv. HD 2967) was grown in

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split plot design with irrigation as main treatment and date of sowing as sub plot treatment. Three levels of irrigation were provided as I5: 5 irrigations (crown root initiation (CRI), tillering, booting, flowering and milking stages), I3: 3 irrigations (CRI, tillering and flowering stages) and I1: 1 irrigation (CRI stage). Two levels of date of sowing were imposed to create variation in growing environmental conditions. The two levels of date of sowing were D1: Timely sown (20th Nov 2015) and D2: Late sown (9th Dec 2015) during *rabi* 2015-16 and D1: Timely sown (17th Nov 2016) and D2: Late sown (7th Dec 2016) during 2016-17. NPK nutrients were applied as per recommended dose of fertilizers, i.e.120: 60:60 kg/ha. The crop was raised as per recommended package of practice. Nitrogen was applied as urea fertilizer in three split doses (50% as basal during sowing, 25% during CRI stage and 25% during flowering stage). However, in case of one irrigation (I1) treatment, urea was applied as 50% basal and 50% as top dress during CRI stage synchronizing with irrigation. The 100 percent P and K were applied as basal dose at the time of sowing. The recommended cultural practices of weeding and plant protection measures were followed.

Field observation and measurements

Phenology: Phenological stages of the crop were identified visually through regular visit to field and their dates were recorded. The thermal time requirement in term of heat units was calculated for sowing to germination, germination to anthesis and anthesis to physiological maturity phenophases.

Leaf Area Index (LAI): The LAI was measured non-destructively by using plant canopy analyzer (LAI-2000) instrument (Welles and Norman 1991). Average field wheat LAI on a given date was computed by averaging multiple LAI observations of that field after excluding outliers.

Specific leaf area (SLA): The area of leaves was measured using leaf area meter (LICOR 3100). The SLA is calculated as ratio of leaf area and dry weight of leaves.

Canopy Light Extinction Coefficient (k): Canopy light extinction coefficient was calculated as the slope of regression line between LAI and ln(1-*f*IPAR), where *f*IPAR is fraction of intercepted photosynthetically active radiation.

Above-ground biomass (AGB): Dry above-ground biomass was measured periodically during the entire crop growth duration using destructive sampling. AGB and crop yield at harvest also measured on unit area (per m^2) basis and also expressed as kg/ha.

Biomass and grain yield at harvest: Final biomass and grain yield was determined from two samples of mature wheat crop were harvested from 1 × 1 m^2 area in each plot.

Description of InfoCrop model: In this study, we used the InfoCrop wheat v2.1 model. InfoCrop is a production level-4 model, which can simulate the influence of varied range of environmental conditions in terms 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 model was compiled from source code written in Fortran Simulation Translator (FST) language (Kraalingen *et al.* 1995). The compiler FSTWin 4.2 was used to compile the program. Growth and development processes of InfoCrop follow the basic structure of MACROS (Penning de Vries *et al.* 1989). The growth and physiological processes accounted by the model are elaborated in Aggarwal *et al.* (2006).

Model performance measures: Evaluation of model performance was done in terms of root mean square error (RMSE), normalized root mean square error (nRMSE) and index of agreement (D-index).The RMSE was calculated as:

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

where, M_i and S_i are observed and simulated value of a variable, respectively.

The ratio of RMSE and mean of observed variable provides the nRMSE. 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.

RESULTS AND DISCUSSION

Model calibration: Parameterization or calibration of

Table 1 Genetic coefficients specified in InfoCrop-wheat v2.1 for the variety HD-2967

Genetic coefficients	Value	Genetic coefficients	Value
T_{base} germination phase (°C)	3.6	Root growth rate (mm)	25
T_{base}-vegetative phase (°C)	4.5	Slope of grain number/m^2 to dry matter during grain formation stage (Grains/kg/day)	23500
T_{base}-grain filling phase (°C)	7.5	Potential grain weight (mg/grain)	44
AGDD -germination phase (Degree-days)	75	Nitrogen content of grain	0.02
AGDD - vegetative phase (Degree-days)	905	Sensitivity of crop to flooding (Scale (0-1))	1
AGDD-grain filling phase (Degree-days)	405	Sensitivity of grain setting to high temperature (Scale (0-1))	1
Specific leaf area (dm^2/mg)	0.0022	Sensitivity of grain setting to low temperature (Scale (0-1))	1
Relative growth rate of leaf area (^{o}C/d fraction)	0.008	Index of nitrogen fixation (Scale (0-1))	1
Maximum RUE (g/MJ/day)	2.8	Sensitivity to photoperiod (Scale (0-1))	1
Light extinction coefficient (ha soil/ha leaf fraction)	0.50		

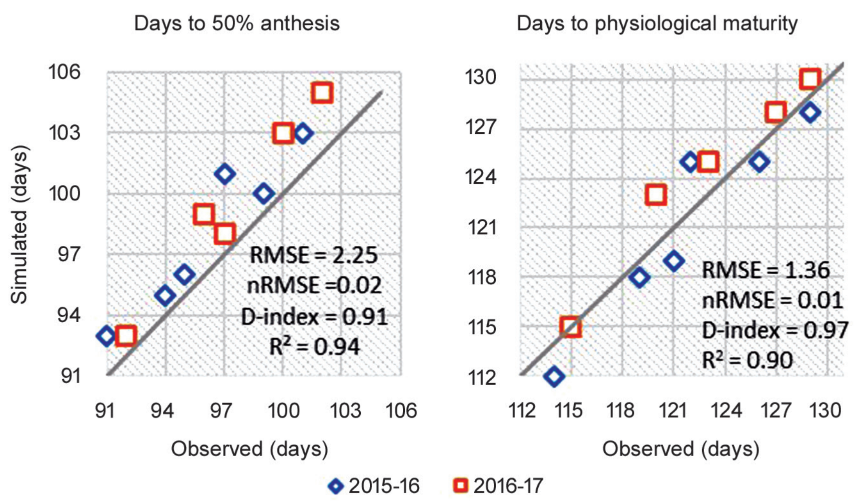

Fig 1 Observed versus InfoCrop-wheat simulated days to 50% anthesis and days to physiological maturity for HD-2967 wheat cultivar under different treatment of sowing date.

InfoCrop-wheat model was done based on measurements taken from non-stressed treatment (D1I5) of field experiment during 2016-17. The measured parameters of model are represented as bold letter while other parameters are fine-tuned using iterative method. 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 (Table 1).

Validation of InfoCrop-wheat model at research experimental field: The model performance was evaluated by comparing model simulations with independent experimental datasets which were not used in model calibration. The phenology, time course of LAI and biomass, final biomass and grain yield were used in this study for model validation as described in following sub-sections.

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 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.

The comparison of observed versus InfoCrop simulated days taken to 50% anthesis and days to physiological maturity along with 1:1 line as scatter plot (Fig 1). The results showed that observed days to 50% anthesis was varied between 91 to 105 days for HD-2967 wheat cultivar under different treatments considering both years' data (Fig 1). InfoCrop model on an average overestimated the occurrence of 50% anthesis in wheat crop by 2.25 days as evident from RMSE. Higher deviation in 50% anthesis was observed in treatments which experienced water stress due to deficit irrigations. Days to physiological maturity was also precisely simulated by InfoCrop-wheat model in both the years. The precision is evident from very low RMSE (1.36 days) and higher D-index of 0.97. The better precision in phenology simulation may be attributed to model accounting the effect of water stress and photoperiod on thermal time accumulation.

Leaf Area Index: In InfoCrop model in 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).

Validation of InfoCrop model for time course of LAI in HD-2967 under different treatments in both years are presented as scatter-plots (Fig 2) along with 1:1 line between observed and simulated LAI. Results showed a good agreement between observed and simulated LAI during the whole crop growth period as exhibited by high R^2. Model performed better in 2016-17 for LAI simulation than that in 2015-16. The RMSE of LAI prediction was 0.79 in 2015-16 compared to that of 0.32 in 2016-17. Similarly, nRMSE of LAI prediction was lesser for 2016-17 (11%) than for 2015-16 (25%). Overall D-index of model for LAI varied between 0.92 and 0.98. It implies that model very well simulate LAI profile of wheat.

Temporal dynamics of biomass production: InfoCrop utilizes the radiation use efficiency (RUE) based approach for dry matter production. Maximum RUE (RUEMAX)

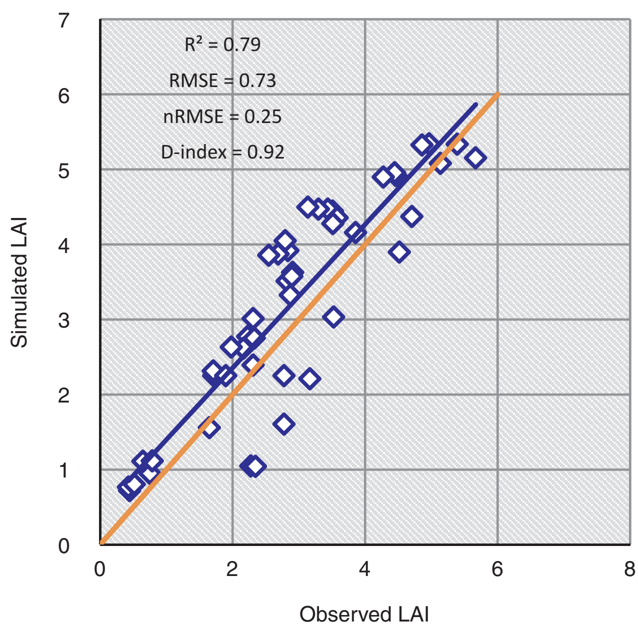

Fig 2 Observed versus InfoCrop-wheat simulated LAI in HD-2967 wheat cultivar under different treatment of sowing date and irrigation levels.

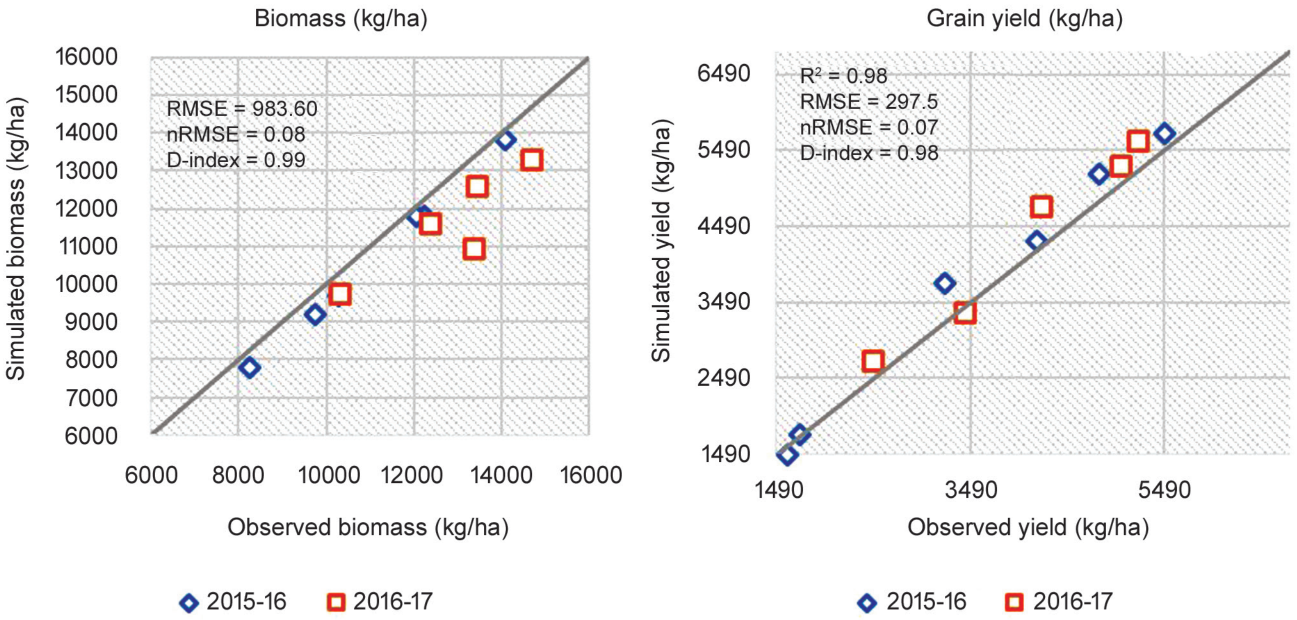

Fig 3 Observed versus InfoCrop-wheat final biomass and grain yield and in HD-2967 wheat cultivar under different treatment of sowing date and irrigation levels.

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. Behavior of InfoCrop for simulating temporal dynamics of above-ground total dry matter of wheat was also evaluated against temporal *in-situ* measurement of total dry matter under different treatment for both the years (data not shown). The results showed that InfoCrop model was able to simulate the temporal changes in TDM in different treatments satisfactorily. It can also be seen that model is sensitive to delay in sowing and irrigation treatments. With the delay in sowing and lesser irrigations, TDM decreased in both the years of study.

Final biomass, grain yield and harvest index: InfoCrop model underestimated the total aboveground dry matter in both the seasons (Fig 3). However, the estimated error was within the acceptable range of 10%. The RMSE was about 984 kg/ha for mean total dry matter and normalized RMSE was 8%. The model efficiency (D-index) was 0.99 implying a good agreement between the measured and predicted value. Model satisfactorily simulated the grain yield under different treatments. The model showed the normalized RMSE of 7%, RMSE of 298 kg/ha and D-index of 0.98 for grain yield predictions (Fig 3). Model showed the good agreement between measured and simulated harvest index of wheat under different treatment (R^2 = 0.95) but largely overestimated it. The model showed the normalized RMSE of 14%, RMSE of 0.046 and D-index of 0.99 for harvest index predictions.

The current study evaluated the performance of InfoCrop model responses to simulate phenology, temporal course of LAI and dry matter, final biomass and economic yield of wheat through two years field experiments. The field experiment was conducted to create variation in environmental condition through different water stress and date of sowing treatments. The result showed that calibrated InfoCrop model could able to capture well the variability in wheat growth, development and yield in semi-environment conditions. The model could predict well days to anthesis and physiological maturity with the RMSE of less than 3 days. Temporal course of LAI and dry matter showed good agreement between observed and model simulated values. Model predicted total dry matter and economic yield satisfactorily with RMSE of 984 and 298 kg/ha, respectively. 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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