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Calibration and validation of DSSAT 4.5 model for wheat in north-west Bihar

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ABSTRACT

Wheat (*Triticum aestivum L.*) is a very important irrigated *rabi* crop in Bihar with 2.25 Mha area, 5.21 Mton of production and the average productivity of about 2328 kgha^{-1}. Fluctuating temperatures and terminal heat load during its growth period interfere with normal growth and productivity potential of the crop. In this backdrop, the present investigation was conducted at Dr. Rajendra Prasad Central Agricultural University, Pusa, Samastipur (25.98^{0}N, 85.67^{0}E, 52 m amsl) to calibrate and validate the DSSAT 4.5 crop simulation model for wheat. For this purpose, field experiments were conducted during *rabi* seasons of 2010-11 and 2011-12 with five dates of sowing *viz.* 15th November, 25th November, 5th December, 15th December and 25th December using two popular cultivars, HD 2824 and HD 2733. The days to anthesis and maturity, leaf area index, above ground biomass production and grain yield as simulated by the model were validated with observed data. Results revealed that the model estimated the days to anthesis and maturity for both the cultivars closely with observed data. Test criteria calculated for the two cultivars suggested that the model performance was better for HD 2733 than for HD 2824. The model satisfactorily simulated the phenology and yield of wheat cultivars and hence it can be used in undertaking suitable management practices and yield prediction under changing climatic condition in Bihar.

Key words: DSSAT, wheat, simulation, calibration, validation.

INTRODUCTION

Wheat is a very important *rabi* crop in Bihar with 2.25 Mha area and 5.21Mton of production. The average productivity of the crop in the state is about 2328 kgha^{-1}. It is grown all over Bihar mainly as an irrigated crop. However, the productivity of the crop is higher in north Bihar than south Bihar owing to favourable soil and thermal condition across the districts of north Bihar during the growing season. The sowing of wheat is done under both normal (15 November to 10 December) and late conditions (10 - 31 December). About 80 percent sowing is achieved under normal sowing condition and the rest under late-sown condition. As per study conducted under All India Coordinated Research Project on Agrometeorology (ICAR) at Dr. Rajendra Prasad Central Agricultural University, Pusa, the average temperature is showing an increasing trend@0.05 ^{0}C per year during *rabi* season (Sattar, 2010). Moreover, growing of wheat in Bihar has become vulnerable to produce low owing to the problem of heat stress (heat load) occurring early (during December) and late (during end of February to March) in the season. The terminal heat load associated with dry westerly wind during reproductive phase of wheat crop causes serious problem resulting in non-setting of grains, which creates panic among the farmers and the policy makers alike. Thus, the productivity of wheat sown in inappropriate time is curtailed due to fluctuating temperature condition during its growth period.

The crop growth simulation models have considerable potential to evaluate crops, varieties under a crop, cropping system and prediction of genetically potential yield (Boote *et al.,* 1987. Various researchers (Prasada Rao *et al.*; 1994, Kovacs *et al.*; 1995, Choudhury *et al.*; 2008, Dettori *et al.*; 2011, Parmer *et al.*; 2013, Ji *et al.* 2014) tried to validate DSSAT model for various crops under different agro-ecological conditions. It is a comprehensive decision support system that contains the sub-model CERES (Crop Estimation through Resource and Environment Synthesis)-Wheat in it (Jones *et al.,* 2003; Hoogenboom *et al.,* 2004). In Bihar, the work on crop modelling involving wheat crop is meagre and the DSSAT model needs to be validated under agroclimatic condition of the state to develop strategies for better crop management, yield forecasting and use it in formulating agro-advisory for the farmers under changing climatic condition. In the present study, it has been attempted to calibrate and validate the DSSAT model for wheat crop grown at Pusa, Samastipur which falls under North west alluvial plain zone of Bihar.

MATERIALS AND METHODS

The field experiment was conducted during *rabi* seasons of 2010-11 and 2011-12 at Pusa Farm of Dr. Rajendra Prasad Central Agricultural University, Pusa, Samastipur, Bihar (25.98^{0} N, 85.67^{0} E, 52 m amsl) with five dates of sowing *viz.* 15th November, 25th November, 5th December, 15th December and 25th December and two popular cultivars of wheat *viz.*, HD 2824 and HD 2733. The growth and yield attributes such as days to anthesis, days to maturity, leaf area index (LAI), above ground dry matter production and grain yield were used for calibration of DSSAT 4.5 model. With required data of wheat crop grown as per recommended package and practices followed in the region, and data on weather and soil characteristics of the experimental site, the model was run several times. The genetic coefficients of wheat cultivars namely, HD 2824 and HD 2733 were estimated by genetic sub-model of the DSSAT 4.5 with repeated interactions until a close match between simulated and observed parameters of phenology and yield was obtained (Table 1).

Mean Absolute Error (MAE) , Root Mean Square Error (RMSE) and Percent Error (PE) were used as test criteria. These parameters were calculated according to following equations (Willmot,1982):

$$MAE = \frac{\sum_{i=1}^{M} \left(S|imi - Oi| \right)}{M}, \quad \text{.............................(Eq 1)}$$

$$RMSE = \left[\frac{\Sigma (Pi - Oi)^2}{M} \right]^{0.5} \quad \text{...................................(Eq 2)}$$

PE=[(Sim- Obs)/Obs]* 100 ....(Eq 3)

Here,

Obs = Observed values

Sim = Simulated values

Correlation coefficients were also estimated between the simulated and observed parameters on pooled basis.

M= total number of observations

RESULTS AND DISCUSSION

Phenology

The observed days taken to attain anthesis for both the cultivars HD 2824 and 2733 of wheat were 84 days, whereas the simulation output of the model were 91 and 88 days, respectively (Table 2). The model estimated days to anthesis within 105.4 to 107.6 per cent of the observed days to anthesis over two cultivars. The test criteria such as MAE, RMSE and PE showed that model performance was better for HD 2733 as compared to HD 2824. The average error per cent of days taken to anthesis for HD 2824 was 7.6 as against 5.4 per cent observed for HD 2733. The correlation coefficient between simulated and observed values on pooled basis across five dates of sowing over two years was r=0.97 (Fig. 1). Dettori *et al.* (2011) validated DSSAT model for three wheat cultivars under Mediterranean climatic condition and soil types of Southern Sardinia, Italy and observed that the model showed a quite good performance in predicting anthesis date. In case of days to maturity, observed values for the two cultivars were 127 and 126 days, respectively, while the model simulated 129 days for the both. The error percent for days to maturity was 1.7 percent for HD 2733 and 8.6 percent for HD 2824 indicating the performance of the model was better in

Table 1: Genetic coefficients of HD 2824 and HD2733 cultivars of wheat used in the DSSAT model

Sl No	Parameters	Genetic coefficients (GC)	Values of the GC of cultivars	
			HD 2824	HD2733
1.	P1V	Days at optimum vernalizing temperature required to complete vernalization	19	20
2.	P1D	Percentage reduction in development rate in a photoperiod 10 hour shorter than the threshold relative at the threshold.	84	88
3.	P5	Grain filling (excluding lag) phase duration	600	550
4.	G1	Kernel number per unit canopy weight at anthesis (mg/g)	18	17
5.	G2	Standard kernel size under optimum conditions (mg)	40	38
6.	G3	Standard non stressed dry weight (total including grain) of a single tiller at maturity (g)	1.5	1.5
7.	PHINT	Interval between successive leaf tip appearances.	95	95

case of HD 2733. The model also determined days to maturity within 100.9 to 101.7 per cent of the values over two cultivars. The correlation coefficient for observed and simulated values was r=0.98 being significant at 1% level of significance (Fig. 2).

Leaf area Index (LAI)

The results showed that the LAI was underestimated by the model for both the cultivars HD 2824 and HD 2733 (Table 2). The model estimated LAI slightly better for the cultivar HD 2824 as compared to HD 2733. The observed values of LAI for the two cultivars were 4.8 and 4.7, respectively. The model simulated the LAI for the two cultivars as 4.6 and 4.5. The model was also able to assess the leaf area index within 95.7 to 95.8 percent of the observed values over two cultivars. The error per cent of LAI was 4.1 per cent for HD 2824 and 4.3 for HD 2733. However, no definite trend was obtained among sowing environments. The RMSE values for simulated LAI were 0.88 and 0.63 for HD 2824 and HD 2733, respectively. Ji *et al*. (2014) reported good agreement between simulated and observed LAI values of wheat crop in an experiment pertaining to performance evaluation of DSSAT model in Northwest China.

Above ground biomass and Grain yield

For both the cultivars, the model overestimated the above ground biomass production, which were 9054 and 9678 kg ha^{-1} for HD 2824 and HD 2733, respectively when data were pooled over the wheat growing seasons of 2010-11 and 2011-12 (Table 2); the corresponding simulated values for the cultivars were 9608 and 9957 kg ha^{-1}, respectively. The model predicted above ground biomass within 102.9 to 106.1 per cent of the observed biomass over two cultivars under study. However,

Table 2: Test criteria of various parameters of wheat

Parameters	Observed		Simulated		MAE		RMSE		PE	
	HD 2824	HD 2733	HD 2824	HD 2733	HD 2824	HD 2733	HD 2824	HD 2733	HD 2824	HD 2733
Days to anthesis (days)	84.1	83.7	90.5	88.2	0.65	0.90	2.05	2.01	7.6	5.4
Days to maturity (days)	127.6	126.4	128.7	128.6	0.12	0.44	0.38	0.98	8.6	1.7
LAI	4.8	4.7	4.6	4.5	0.028	0.020	0.88	0.63	-4.1	-4.3
Dry matter (kg ha^{-1})	9054	9678	9608	9957	55.4	27.9	175.19	88.20	6.1	2.9
Grain yield (kg ha^{-1})	4714.9	4694.3	4804.5	4754.8	8.96	12.2	28.33	27.19	1.9	1.2

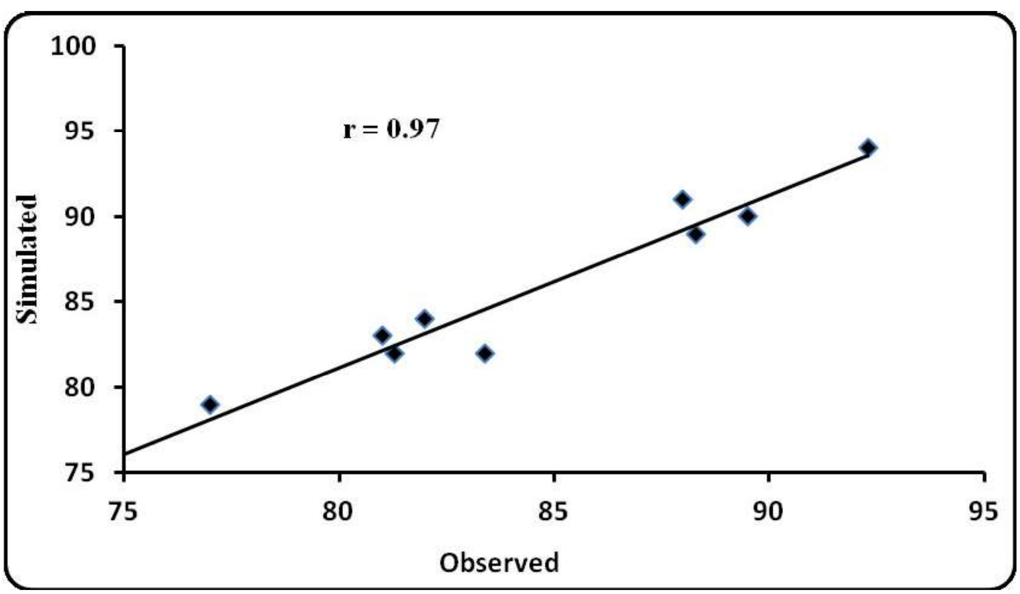

Fig. 1: Simulated and observed days to anthesis in wheat cultivars under different dates of sowing

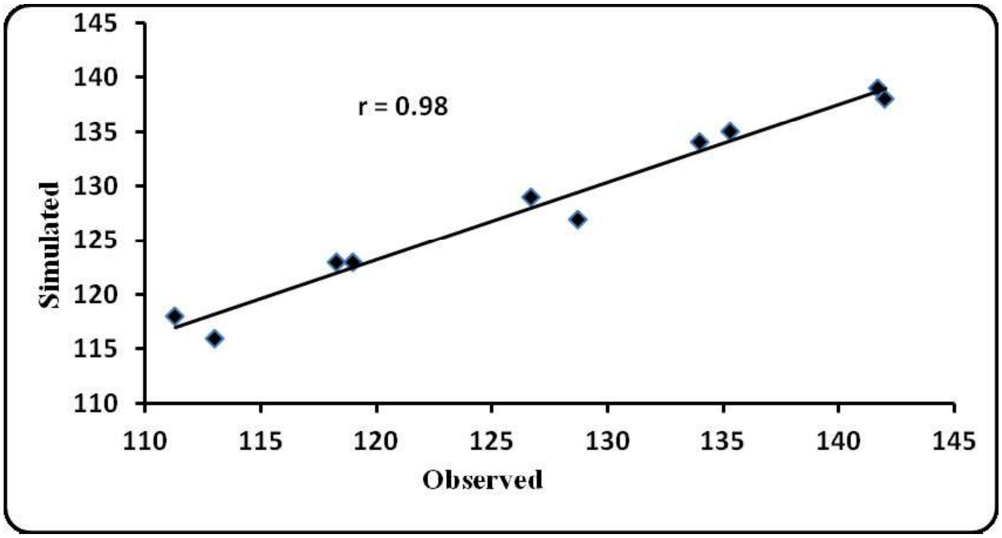

Fig. 2: Simulated and observed days to maturity in wheat cultivars under different dates of sowing.

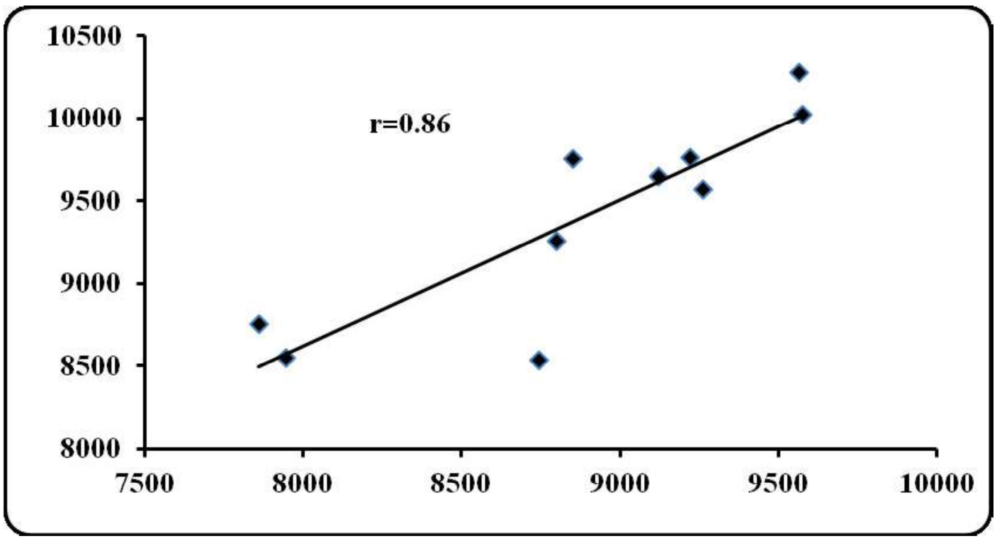

Fig. 3: Simulated and observed above ground biomass (kg ha^{-1}) of wheat cultivars under different dates of sowing.

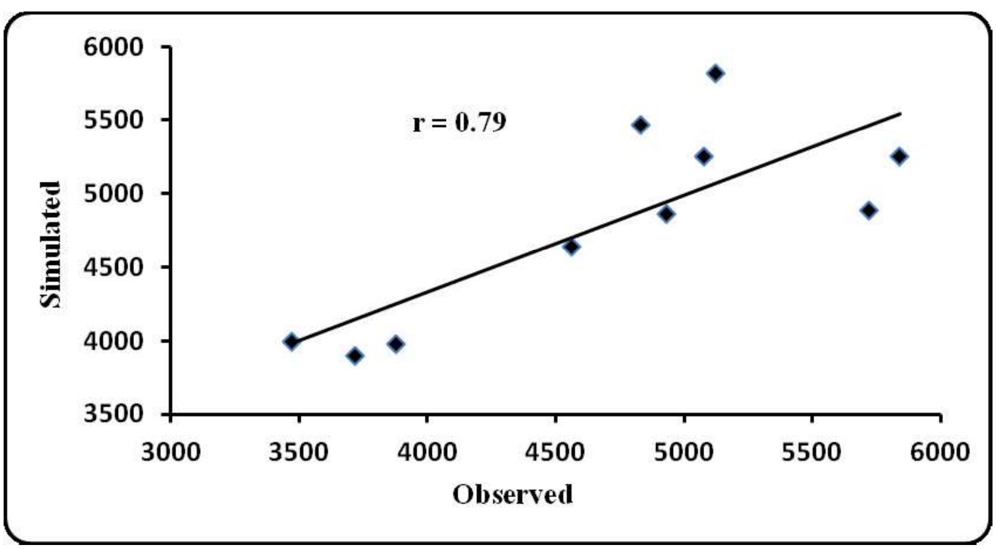

Fig. 4: Comparison of simulated and observed grain yields (kg ha^{-1}) of wheat cultivars under different dates of sowing.

calculated MAE, RMSE and PE showed that the model simulation of above ground biomass was better for HD 2733. The average error per cent were 6.1 per cent for HD 2824 and 2.9 per cent for HD 2733. The correlation coefficient between observed and simulated biomass was r=0.86 (Fig. 3) The grain yields recorded for the two cultivars were 4715 and 4694 kg ha^{-1} while the model simulated 4804 and 4756 kg ha^{-1}, respectively showing correlation coefficient r=0.79 between observed and simulated values (Table 2 & Fig. 4). The average errors were 1.9 per cent for HD 2824 and 1.2 per cent for HD 2733 indicating that the model performance was satisfactory in predicting the yield of the crop. The model estimated grain yield within 101.3 to 101.9 per cent of the observed yields. The test criteria estimated for grain yields of the cultivars showed that the model performance was better for HD 2733. While validating CERES-wheat model for cultivar HD 2329 under Ludhiana conditions in Punjab, Hundal and Kaur (1997) demonstrated that the model predicted grain yields within 80 to 115 percent of the observed yields and biomass within 98 to 128 percent of its observed values. In contrast, Dhaliwal *et al.* (1997) after validating CERES-wheat simulation model in Punjab for the same wheat cultivar of HD 2329 reported that the grain yields estimated by the model ranged between 85 to 94 per cent of the observed yields. They further observed that the performance of prediction of total above ground biomass was overestimated by the model. Contrary, the performance of the model under study estimated above ground biomass and grain yields quite satisfactorily within 102.9 to 106.1 and 101.3 to 101.9 per cent of the values, respectively. Dettori *et al.* (2011) observed quite satisfactory performance of DSSAT model in predicting wheat yield in Sardinia, Italy**.** While evaluating the utility of DSSAT model for wheat in Guanzhong Plain of Northwest China, Ji *et al*. (2014) also observed that above ground biomass and grain yields closely matched with the observed values and suggested that the model could be satisfactorily used to assess and optimize the winter wheat yield in the region.

CONCLUSION

The model satisfactorily simulated the phenology, above ground biomass and grain yield of wheat cultivars. The model predicted grain yields within 101.3 to 101.9 per cent of observed yields and predicted above ground biomass within 102.9 to 106.1 per cent of the observed values over two cultivars. This showed the utility and robustness of DSSAT model in dry sub-humid climate of Bihar. Apart from yield prediction, the validated model could be used for prediction of crop phenology, potential and actual yields and also for enhancing crop yields through better management practices under changing climatic condition.

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