Prediction of Growth and Yield of Late Sown Wheat Using DSSAT (v4.5) Model under Western Zone of Haryana

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A B S T R A C T

The aim of this study was the calibration and validation of DSSAT model (v4.5) for late sown wheat in western zone of Haryana. The DSSAT model was calibrated with the field experimental data of *rabi* 2010-11 having 3 levels of irrigation (one irrigation at crown root initiation [CRI], two irrigations at CRI and heading and four irrigations at CRI, late tillering, heading and milking) and 5 nitrogen levels (0, 50, 100, 150 and 200 kg N/ha) and validated with data of experiment *rabi* 2011-12 conducted at Hisar (29°10' N and 75°46' E). The model performance was evaluated using average error (Bias), root mean square error (RMSE), normalized root mean square error (nRMSE), index of agreement (d-stat) and coefficient of determination (r^2), and it was observed that DSSAT model was able to predict the growth parameters (maximum leaf area index and total effective tillers), yields (grain, straw and biomass) and harvest index with reasonably good accuracy (error % less than ±15).

Introduction

Wheat (729.8 million tons) is second to rice as the main human food crop (FAO, 2014-15). In India, wheat is cultivated extensively in North-Western and Central zones. The area, production and productivity of wheat in India and Haryana during 2014-15 is 31.46 mha, 86.53 mt, 2749 kg ha^{-1} and 2.60 mha, 10.35 mt, 3980 kg ha^{-1}, respectively (Anonymous, 2014-15). Late sowing of wheat is a major problem in the rice-wheat and cotton-wheat cropping system (Khan *et al.*, 2010). Late sowing wheat face low temperature in the earlier part and high temperature stress in the later part of the growing season (Alam *et al.*, 2013).

Crop growth simulation models provide the means to qualify the effects of climate, soil, management on crop growth, productivity and sustainability of agricultural production (Nain and Kersebaum, 2007). Among the numerous crop growth models, the most widely used are the DSSAT (Decision Support System for Agrotechnology Transfer) crop growth model, has been in use for more than 20 years which integrates the effects of soil, weather, and

management (Jones *et al*., 2003). DSSAT grew out of the International Benchmark Sites Network for agrotechnological Transfer (IBSNAT) in the 1980s, with the first official released in 1989 (DSSATv2.1). DSSAT was developed in University of Hawaii, Honolulu, Hawaii in United States (USA). The DSSAT model offers wide opportunities for studies of interactions between plants and ambient, nitrogen, plant varieties, irrigation, carbon (Thorp *et al*., 2008). To find an effective way to save water in the wheat-growing season without markedly reducing wheat yield, DSSAT-wheat was calibrated, validated and used to simulate water use by winter wheat (Yang *et al*., 2006). The DSSAT model can be used for a variety of tasks in simulating water regime and nitrogen doses.

In India, the DSSAT-CSM-CERES-Wheat v4.0 model was calibrated using the historical weather data of a 36 year period (1970–2005) to estimate the long-term mean and variability of potential yield, drainage, runoff, evapotranspiration, crop water productivity and irrigation water productivity (Timsina *et al*., 2008). This capability of DSSAT model makes it more suitable to predict response of the complex system affected by many factors such as crop growth and crop yield in wake of variable soil potential (Solaimani, 2009). Validation of crop dynamic model for any crop and any area will be greater applicable to predict the crop growth parameters as well as yield components in advance which are important for planning as well as management.

The scientific information on crop growth modeling under different growing conditions on wheat crop in Haryana state is limited. Hence, keeping all these points in view, the present investigation entitled "Prediction of growth and yield of late sown wheat using DSSAT (v4.5) model under western zone of Haryana" was undertaken.

Materials and Methods

An experiment was conducted during 2010-11 and 2011-12 at CCS Haryana Agricultural University, Hisar (India) to study prediction of growth and yield of late sown wheat using DSSAT (v4.5) model under western zone of Haryana located in Indo-Gangetic plains of North-West India with a latitude of $29^0 10'$ North and longitude of $75^0 46'$ East at 215.2 meters above mean sea level. The soil of the field was sandy loam, having 0.39% OC and pH 7.95. It was low in available N (156.1 kg/ha), medium in available P (10.5 kg/ha) and rich in available K (306.4 kg/ha). The experiment consisting of three irrigation frequencies *viz.* one irrigation at CRI (I_1), two irrigations at CRI and heading (I_2) and four irrigations at CRI, late tillering, heading and milking (I_3) in main plots and five nitrogen doses *viz.* control *i.e.* 0 kg N/ha (F_0), 50 kg N/ha (F_1), 100 kg N/ha (F_2), recommended dose of nitrogen *i.e.* 150 kg N/ha(F_3) and 200 kg N/ha(F_4) in sub-plots was laid out in strip plot design with four replications. Nitrogen was applied in the form of urea during both the year. Nitrogen was applied in two splits: Half of the nitrogen was applied as basal and half as top dressed after 1st irrigation. The recommended dose of phosphorus (60 Kg P_2O_5 ha^{-1}) was applied through di-ammonium phosphate (DAP) at time of sowing while in control treatment phosphorous was applied in the form of single super phosphate (SSP). Wheat *cv.* WH 1021 was sown with the help of seed drill in rows 18 cm apart at the rate of 125 kg/ha. Crop was sown on 18th December during both the years of the experimentation. Irrigation was applied in the field as per treatments. The weeds were removed by long tine hoe at 40 days and later by hand pulling.

The DSSAT model requires daily weather data of maximum and minimum air temperature (˚C), solar radiation (k Jm^{-2}d^{-1}), vapour pressure (kPa), wind speed (ms^{-1}) and

rainfall (mm). The daily meteorological data were recorded at the agro-meteorological observatory located near to the Research Farm of Chaudary Charan Singh Haryana Agricultural University, Hisar.

Calibration of the model

The latest version of DSSAT is DSSATv4.5, which we used in our calibration and validation was developed in 2010. Calibration of model involves adjusting certain model parameters or relationships to make the model work for any desired location. The model requires cultivar specific genetic coefficients. The details of these coefficients are given in Table 1. For calibration of DSSAT model one year (2010-11) data set was used and for validation, data sets of 2011-12 experiments were used. Validation of model was done by using data sets on total no. of effective tillers, LAI, biomass, grain yield and harvest index from experiments conducted at Research Farm Hisar.

Model validation

To test the accuracy of model with the cultivar used the model was run with observed crop management data from field, weather and soil data and calibrated cultivar genotypic coefficients, the predicted wheat grain yield were compared with actual grain yield.

Different statistical tools were used to evaluate the performance of the model in predicting various parameters. The statistical analysis of Ambrose and Rosech (1982) was used to calculate the average error or Bias (Eqn. 1) and root mean square error (Eqn. 2) between the simulated and observed values. Normalized RMSE (nRMSE) gives a measure (%) of the relative difference of simulated versus observed data. The simulation is considered excellent with a normalized

RMSE (Eqn. 3) is less than 10%, good if the normalized RMSE is greater than 10% and less than 20%, fair if normalized RMSE is greater than 20 and less than 30%, and poor if the normalized RMSE is greater than 30% (Jamieson *et al*., 1991). M is the mean of observed variable.

The index of agreement (d) proposed by Willmott *et al*. (1985) was estimated in (Eqn.4). According to the d-statistic, the closer the index value is to one, the better the agreement between the two variables that are being compared and vice versa.

$$\text{Bias} = \sum_{i=1}^{n} \frac{(S_i - O_b)}{n} \qquad \text{Eqn. 1}$$

$$\text{RMSE} = \sqrt{\sum_{i=1}^{n} \frac{(Si - Ob)^2}{n}} \qquad \text{Eqn. 2}$$

$$\text{nRMSE} = \sqrt{\sum_{i=1}^{n} \frac{(Si - Ob)^2}{n}} \times \frac{100}{M} \qquad \text{Eqn. 3}$$

$$\text{d} = 1 - \left[\frac{\sum_{i=1}^{n} (Si - Ob)^2}{\sum_{i=1}^{n} (|S_i'| + |O_b'|)^2} \right] \qquad \text{Eqn. 4}$$

Besides the above test criteria, error percent was also calculated in different treatment under study to express the deviation more scientifically.

This is as follows:

Error % = {(Si – Ob) / Ob} * 100
Whereas,
$S_i' = Si - M$
$O_b' = Ob - M$
n, is the number of observations
Si, is the simulated values
Ob, is the observed values
M is the mean of observed variable

Results and Discussion

Comparison of grain yield

The grain yield was simulated by the calibrated DSSAT model. Mean measured grain yield of wheat ranged between 1498 kg ha^{-1} (I_1F_0) to 4791 kg ha^{-1} (I_3F_4) among irrigation levels and dose of nitrogen combinations in 2011-12, while model simulated grain yield ranged 1249 kg ha^{-1} (I_1F_0) to 5012 kg ha^{-1} (I_3F_4) (Table 2 and fig. 1a). The model underestimated the grain yield at lower doses of fertilizer *i.e.* 0 kg Nha^{-1} and 50 kg Nha^{-1} and overestimated at higher doses of fertilizer *i.e.* 150 and 200 kg N^{-1} at all the irrigations levels. Error percent ranged between -16.62 (I_1F_0) to 11.89 (I_2F_4). The calculated values of statistical indices, average error (Bias), root mean square error (RMSE), normalized RMSE (nRMSE), index of agreement (d) and coefficient of determination (r^2) were -3.93 kg ha^{-1}, 226.3 kg ha^{-1}, 6.81%, 0.99 and 0.97, respectively.

The error was within range *i.e.* +15 to -15% in all combinations of irrigation and dose of nitrogen. DSSAT underestimated the results at lower dose of nitrogen or without nitrogen application because of poor response of DSSAT without nitrogen, but at higher doses of nitrogen DSSAT responded very well. The calculated values of statistical indices, average error (Bias), root mean square error (RMSE), normalized RMSE (nRMSE), index of agreement (d) and coefficient of determination was quite well during 2011-12. Generally, the simulation is considered excellent with a normalized RMSE is less than 10%, good if the normalized RMSE is greater than 10% and less than 20%, fair if normalized RMSE is greater than 20 and less than 30%, and poor if the normalized RMSE is greater than 30%. According to the d-statistic, the closer the index value is to one, the better the agreement between the two

variables that are being compared and vice versa. Similarly, the closer the r^2 value is to one showed a good match between two variables. Similar results have been reported by Timsina *et al.*, 2008 and Andarzian *et al.*, 2014. Aforementioned indexes imply the robustness of the model in simulating wheat yields and harvest index of wheat.

Comparison of biomass of late sown wheat

The biological yield was simulated by the calibrated DSSAT model. Mean measured biological yield of wheat varied from 4616 kg ha^{-1} (I_1F_0) to 11372 kg ha^{-1} (I_3F_4) among irrigation levels and dose of nitrogen combinations in 2011-12, while model simulated biological yield ranged between 4184 kg ha^{-1} (I_1F_0) to 11856 kg ha^{-1} (I_3F_4) (Table 2 and Fig. 1b). The model underestimated the biological yield at lower doses of fertilizer *i.e.* 0 kg Nha^{-1} and 50 kg Nha^{-1} and overestimated at higher doses of fertilizer *i.e.* 150 and 200 kg N^{-1} at all the irrigations levels during both the years of study. Error percent ranged between -11.61 (I_2F_0) to 10.17 (I_1F_4), respectively. The calculated values of statistical indices *viz.*, average error (Bias), root mean square error (RMSE), normalized RMSE (nRMSE), index of agreement (d) and coefficient of determination (r^2) were 86.32 kg ha^{-1}, 463.6 kg ha^{-1}, 5.38%, 0.99 and 0.98, respectively.

Comparison of straw yield of late sown wheat

The straw yield was simulated by the calibrated DSSAT model. Mean measured straw yield of wheat varied from 3118 kg ha^{-1} (I_1F_0) to 6581 kg ha^{-1} (I_3F_4) among irrigation levels and dose of nitrogen combinations in 2011-12, while model simulated straw yield ranged between 2935 kg ha^{-1} (I_1F_0) to 6844 kg ha^{-1} (I_3F_4) (Table 2 and Fig. 1c). Similarly, like grain yield and biological yield, the

model underestimated the straw yield at lower doses of fertilizer *i.e.* 0 kg Nha^{-1} and 50 kg Nha^{-1} and overestimated at higher doses of fertilizer *i.e.* 150 and 200 kg N^{-1} at all the irrigations levels during both the years of study. Error percent ranged between -10.22 (I_2F_0) to 9.17 (I_1F_4). The calculated values of

statistical indices, average error (Bias), root mean square error (RMSE), normalized RMSE (nRMSE), index of agreement (d) and coefficient of determination (r^2) were 90.25 kg ha^{-1}, 271.2 kg ha^{-1}, 5.12%, 0.99 and 0.98.

Table.1 Genetic coefficients of DSSAT-wheat model (v4.5) for Hisar conditions (variety- WH 1021)

PARAMETERS	DESCRIPTION OF PARAMETERS	values
P1V	**Vernalization sensitivity coefficient:** Relative amount that development is slowed for each day of unfulfilled vernalization, assuming that 50 days of vernalization is sufficient for all cultivars	**1**
P1D	**Photoperiod sensitivity coefficient (% reduction/h near threshold**): Relative amount that development is slowed when plants are grown in one hour photoperiod shorter than the optimum (which is considered to be 20 hours)	**73**
P5	**Grain filling duration coefficient [(Thermal time from the onset of linear fill to maturity (°C d)]:** Degree days above a base of 1°C from 20 °C days after anthesis to maturity	**650**
G1	**Kernel number coefficient:** Kernel number per unit weight of stem (less leaf blades and sheaths) plus spike at anthesis (g^{-1})	18
G2	**Kernel weight coefficient:** Kernel filling rate under optimum conditions (mgday^{-1})	**43**
G3	**Tiller death or spike number coefficient:** Non-stressed dry weight (g) of a single stem (excluding leaf blades and sheaths) and spike weight (g) when elongation ceases	**4.0**
PHINT	**Phyllochron interval:** Thermal time required between emergences of two successive leaf tips (°C day)	**100**

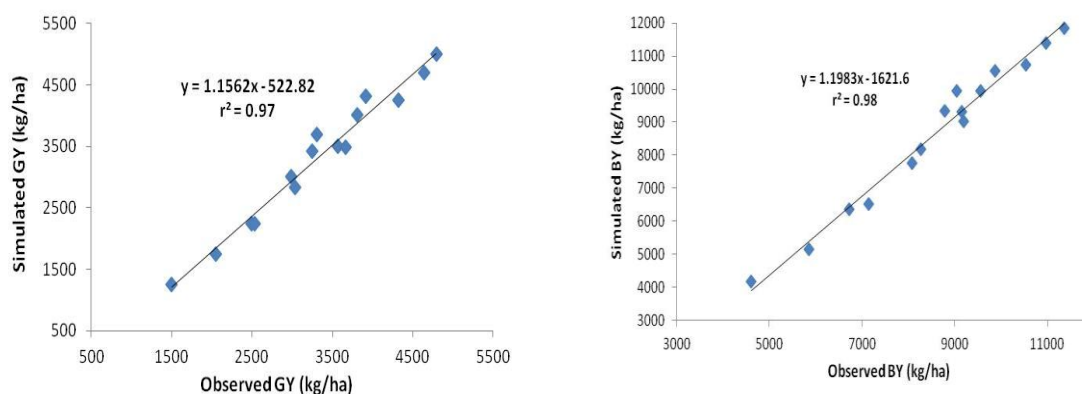**Table.2** Comparison of observed and predicted yield (kg/ha) of wheat (WH 1021) by DSSAT model (2011-12)

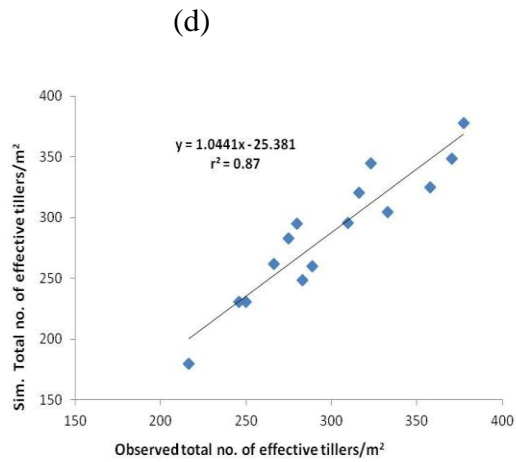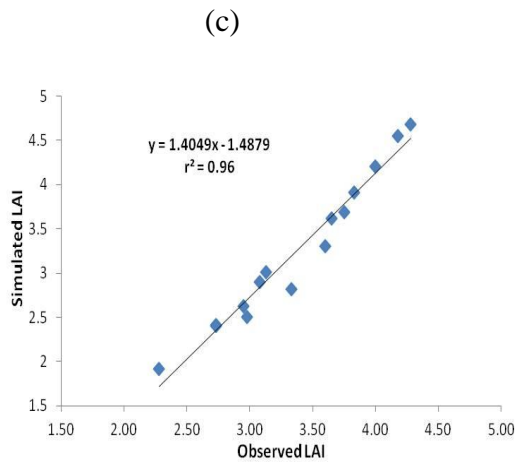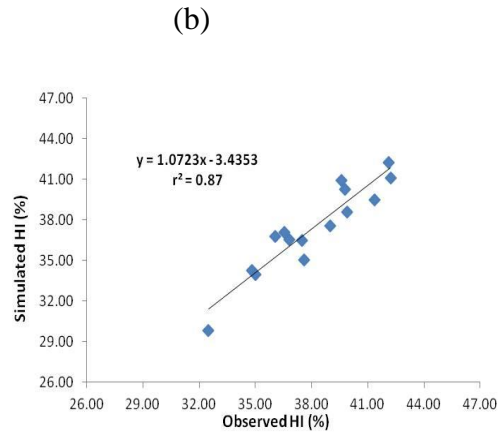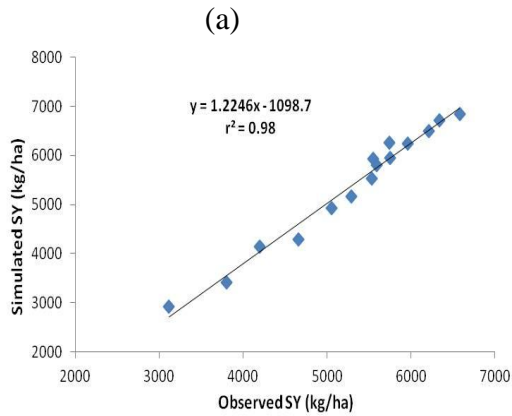| Treatments	Grain yield (kg/ha)			Biomass (kg/ha)			Straw yield (kg/ha)			Harvest Index (%)		
	Obs.	Sim.	Error %	Obs.	Sim.	Error %	Obs.	Sim.	Error %	Obs.	Sim.	Error %
Variety: WH 1021												
I_1F_0	1498	1249	-16.62	4616	4184	-9.36	3118	2935	-5.87	32.50	29.85	-8.14
I_1F_1	2491	2245	-9.88	7152	6545	-8.49	4661	4300	-7.75	34.82	34.30	-1.48
I_1F_2	2984	3015	1.04	8270	8195	-0.90	5286	5180	-2.00	36.06	36.79	2.02
I_1F_3	3240	3426	5.74	8793	9362	6.47	5553	5936	6.90	36.81	36.59	-0.59
I_1F_4	3305	3698	11.89	9046	9965	10.17	5741	6267	9.17	36.54	37.11	1.55
I_2F_0	2050	1759	-14.20	5855	5175	-11.61	3805	3416	-10.22	35.00	33.99	-2.88
I_2F_1	3035	2841	-6.39	8088	7781	-3.80	5053	4940	-2.24	37.50	36.51	-2.63
I_2F_2	3564	3507	-1.60	9152	9325	1.89	5588	5818	4.12	39.01	37.61	-3.59
I_2F_3	3803	4012	5.50	9557	9963	4.25	5754	5951	3.42	39.79	40.27	1.21
I_2F_4	3910	4325	10.61	9873	10567	7.03	5963	6242	4.69	39.60	40.93	3.36
I_3F_0	2531	2240	-11.50	6731	6384	-5.15	4200	4144	-1.33	37.62	35.09	-6.72
I_3F_1	3665	3485	-4.91	9199	9032	-1.82	5534	5547	0.23	39.88	38.59	-3.25
I_3F_2	4321	4251	-1.62	10533	10752	2.08	6212	6501	4.65	41.37	39.54	-4.43
I_3F_3	4635	4699	1.38	10977	11423	4.06	6342	6724	6.02	42.23	41.14	-2.58
I_3F_4	4791	5012	4.61	11372	11856	4.25	6581	6844	3.99	42.13	42.27	0.33
Mean	2994			8033			5038			36.78		
SD	996			2059			1077			3.03		
CV%	33.27			25.64			21.39			8.25		
Bias	-3.933			86.32			90.25			-0.684		
RMSE	226.3			463.6			271.2			1.683		
nRMSE (%)	6.81			5.38			5.12			4.42		
d	0.99			0.99			0.99			0.99		

Whereas, I_1 = one irrigation at CRI stage, I_2 = Two irrigations at CRI and heading stage, I_3 = 4 irrigations at CRI, late tillering, heading and milking stage and F_0 = 0 kg N/ha, F_1 = 50 kg N/ha, F_2 = 100 kg N/ha, F_3 = 150 kg N/ha and F_4 = 200 kg N/ha.

Table.3 Comparison of observed and predicted leaf area index (LAI) and total no. of effective tillers/m^2 of late sown wheat by DSSAT model

Treatments	Leaf Area Index (LAI)			Total effective tiller/m^2		
	Obs.	Sim.	Error %	Obs.	Sim.	Error %
Variety: WH 1021						
I_1F_0	2.28	1.92	-15.79	216	180	-16.84
I_1F_1	2.73	2.42	-11.36	250	231	-7.51
I_1F_2	2.95	2.63	-10.85	266	262	-1.65
I_1F_3	3.08	2.9	-5.84	275	283	3.01
I_1F_4	3.13	3.02	-3.51	280	295	5.51
I_2F_0	2.73	2.41	-11.72	246	231	-6.07
I_2F_1	3.33	2.82	-15.32	289	260	-9.91
I_2F_2	3.60	3.31	-8.06	309	296	-4.33
I_2F_3	3.75	3.69	-1.60	316	321	1.47
I_2F_4	3.83	3.92	2.35	323	345	6.72
I_3F_0	2.98	2.51	-15.77	283	249	-12.03
I_3F_1	3.65	3.62	-0.82	333	305	-8.41
I_3F_2	4.00	4.21	5.25	358	325	-9.21
I_3F_3	4.18	4.56	9.09	370	349	-5.79
I_3F_4	4.28	4.69	9.58	377	378	0.16
Mean	3.05			276		
SD	0.71			49.66		
CV%	23.50			17.93		
Bias	-0.124			-12.15		
RMSE	1.074			21.41		
nRMSE (%)	31.9			7.14		
D	0.94			0.99		

Fig.1 Comparison of simulated (DSSAT model) and measured results of (a) grain yield (GY) (b) biological yield (BY) (c) Straw yield (SY) (d) harvest index (HI) (e) leaf area index (LAI) (f) effective tillers of late sown wheat in 2011-12

(a)

(b)

(c)

(d)

(e)

(f)

Comparison of harvest index of late sown wheat

Harvest index was simulated by the DSSAT model. Mean measured harvest index of wheat varied from 32.5% (I_1F_0) to 42.2% (I_3F_3) among irrigation levels and dose of nitrogen combinations in 2011-12, while model simulated harvest index ranged between 29.8% (I_1F_0) to 42.3 (I_3F_4) (Table 2 and Fig. 1d). The model underestimated the harvest index at lower doses of fertilizer *i.e.* 0 kg Nha^{-1} and 50 kg Nha^{-1} and overestimated at higher doses of fertilizer *i.e.* 150 and 200 kg N^{-1} at all the irrigations levels during both the years of study. Error percent ranged between -8.14 (I_1F_0) to 3.36 (I_2F_4) in 2011-12. The calculated values of statistical indices, average error (Bias), root mean square error

(RMSE), normalized RMSE (nRMSE), index of agreement (d) and coefficient of determination (r^2) were -0.68, 1.68, 4.42%, 0.99 and 0.87.

Comparison of leaf area index (LAI) of late sown wheat

Leaf area index (LAI) was simulated by the DSSAT model (Table 3 and Fig. 1e). Mean measured LAI of wheat varied from 2.28 (I_1F_0) to 4.28 (I_3F_4) among irrigation levels and dose of nitrogen combinations in 2011-12, while model simulated LAI ranged between 1.92 kg ha^{-1} (I_1F_0) to 4.69 (I_3F_4). CERES-Wheat underestimated the LAI at one irrigation levels with all the dose of fertilizer. Error percent ranged between -15.79 (I_1F_0) to 9.58 (I_3F_4) in 2011-12. The calculated values

of statistical indices, average error (Bias), root mean square error (RMSE), normalized RMSE (nRMSE), index of agreement (d) and coefficient of determination (r^2) were -0.124, 1.074, 31.9%, 0.94 and 0.96.

Comparison of total no. of effective tillers/m^2

Total no. of effective tillers/m^2 was simulated by the DSSAT model. Mean measured total effective tillers of wheat varied from 216 (I_1F_0) to 377 (I_3F_4) among irrigation levels and dose of nitrogen combinations during 2011-12, while model simulated total effective tiller/m^2 ranged between 180 (I_1F_0) to 378 (I_3F_4) (Table 3 and Fig. 1 f). The model underestimated the total effective tillers at lower doses of fertilizer *i.e.* 0 kg Nha^{-1} and 50 kg Nha^{-1} and overestimated at higher doses of fertilizer *i.e.* 150 and 200 kg N^{-1} at all the irrigations levels. Error percent ranged between -16.84 (I_1F_0) to 6.72 (I_2F_4). The calculated values of statistical indices, Bias, RMSE, nRMSE, d-stat and r^2 were -12.15, 21.41, 7.14%, 0.99 and 0.87, respectively.

Leaf area index (LAI) and total effective tillers/m^2 was very well simulated by DSSAT model (Table 3 and Fig. 1e and f). DSSAT underestimated the growth parameters like LAI, effective tillers and nitrogen uptake at lower dose of nitrogen because of less yields. Normalized RMSE (nRMSE) was less than 10% except in all parameters except LAI, where nRMSE was very high. But index of agreement was very close to one, it indicate the vigourness of the model. Similarly, the value of coefficient of determination (r^2) was 0.96 for LAI, 0.87 for total no. of effective tillers/m^2 and 0.95 for total nitrogen uptake indicates the robustness of the model.

In conclusion, the model underestimated the grain, biological, straw yield, harvest index,

total number of effective tillers, LAI at control *i.e.* 0 kg N/ha and lower N rates *i.e.* 50 kg N/ha in combination with all irrigations levels but overestimate all these parameters with higher dose of N *i.e.* 150 and 200 kg N/ha with all irrigation levels. The error was within -15 to +15% in almost all parameters. The value of statistical indices, *i.e.* root mean square error, normalized root mean square error, index of agreement and coefficient of determination indicates the robustness of the model in simulation of wheat yield. However, model needs still improvement in simulation of late sown wheat in Hisar condition.

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