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Simulation of tillage, crop residue mulch and nitrogen interactions on yield and water use efficiency of wheat (*Triticum aestivum*) using DSSAT model

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ABSTRACT

Field experiment was conducted during *rabi* season for two years (2014-15 and 2015-16) on wheat cultivar HD-2967 in a sandy loam soil (Inceptisol) for simulation of evapotranspiration, crop water use efficiency (WUE) and yield of wheat under different tillage (Conventional tillage (CT) and no tillage (NT)), residue (maize residue @ 5 t ha^{-1} (R_+) and without residue (R_0)) and nitrogen (60, 120 and 180 kg N ha^{-1}, representing 50% (N_{60}), 100% (N_{120}) and 150% (N_{180}) of the recommended dose of nitrogen for wheat (*Triticum aestivum* L.), respectively management practices using DSSAT (v 4.6) model. Experimental data of the years 2014-15 and 2015-16 was used for the calibration and validation of the model, respectively. The results showed no significant difference in grain and biomass yield due to tillage and crop residue mulch but it increased significantly with increase in the N levels. The WUE of wheat was also not influenced by tillage but increased significantly with the increase in N levels. The DSSAT model could satisfactorily simulate grain yield (R^2 = 0.759), biomass yield (R^2= 0.728) and seasonal ET (R^2= 0.904) in wheat but simulation of WUE (R^2= 0.414) was not significant under different tillage, residue and nitrogen management with acceptable level of accuracy.

Key words: Conservation agriculture, DSSAT, Evapotranspiration, Water use efficiency, Wheat

Crop simulation models can be used extensively to understand and assess the change in crop growth and yield at various levels of management and climatic variability conditions. They can serve as useful tools in taking critical decisions with respect to efficient use of inputs, *viz*. water, nutrient, tillage for achieving the goal of sustainable agricultural intensification. The Decision Support System for Agro-technology Transfer (DSSAT) is an assemblage of various models, which links the decision support system with crop simulation models (Ngwira *et al.* 2014). DSSAT 4.6 has algorithms which can simulate the influence of conservation agricultural practices such as crop residue cover and tillage on soil properties and plant development. The other advantage of DSSAT 4.6 is that it has a separate program driver named as Seasonal Analysis, which has the ability to analyze and compare the different management practices biophysically and economically to suggest the selection of the most efficient management practice (Ngwira *et al.* 2014). Crop simulation models have to be calibrated using parameters of local conditions and need to be validated for its effectiveness to adequately simulate the effects of the main factors limiting yields in a region. Thus, the objective was to study the effect of tillage, residue and N management on yield and water use efficiency of wheat and to calibrate and validate the DSSAT version 4.6 model for seasonal evapotranspiration, water use efficiency and yield of wheat (*Triticum aestivum* L.).

MATERIALS AND METHODS

Field experiment was conducted in the MB-4C farm of ICAR-Indian Agricultural Research Institute, New Delhi (28^0 35'N latitude, 77^0 12'E longitude and at an altitude of 228.16 m above mean sea level) with wheat as a test crop during the years 2014-15 and 2015-16.The weather condition during crop growth period of the years 2014-15 and 2015-16 are depicted in Table 1.The soil of the experimental site was sandy loam (Typic Haplustept) of Gangetic alluvial origin, very deep (>2 m), flat and well drained. The soil was mildly alkaline, non-saline, low in organic C (Walkley and Black C) and available N, and medium in available P and K content. The surface soil (0–15 cm) has bulk density 1.58 Mg m^{-3}; hydraulic conductivity (saturated) 1.01 cm h^{-1}, saturated water content (0.41 m^3m^{-3}), EC (1:2.5 soil/

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water suspension) 0.36 dS m^{-1}; organic C 4.2 g kg^{-1}; total N 0.032%; available (Olsen) P 7.1 kg ha^{-1}; available K 281.0 kg ha^{-1}; sand, silt and clay, 64.0, 16.8 and 19.2%, respectively. The bulk density varied from 1.58 Mg m^{-3} in the 0-15 cm layer to 1.72 Mg m^{-3} in the 90-120 cm layer. Available soil moisture content ranged from 24.6-28.3% (0.033 MPa) to 9.7-12.9% (1.50 MPa) in different layers of 0-120 cm soil depth.

The treatments comprising two levels of tillage as main plot factor (Conventional tillage (CT) and no tillage (NT)), two levels of residue as subplot factors (maize residue @ 5 t ha^{-1} (R_+) and without residue (R_0)), and three levels of Nitrogen as sub-sub plot factors (60, 120 and 180 kg ha^{-1}, representing 50% (N_{60}),100% (N_{120}) and 150% (N_{180}) of the recommended dose of nitrogen for wheat, respectively) were evaluated in a split-split plot design with three replications. Wheat crop (cv. HD 2967) was sown on 16^{th} and 28^{th} November during the years 2014 and 2015, respectively, by a tractor drawn no-till seed drill (at a depth of 4-5 cm) with a row spacing of 22.5 cm at a seed rate of 100 kg ha^{-1} and harvested on 17^{th} April 2015 and 5^{th} April 2016, respectively. In CT treatment, the plot was ploughed once with disc plough and once with duck-foot tine cultivator followed by leveling and sowing by seed drill. In NT treatments, the seed was directly sown using an inverted T type no-till seed drill. Maize residue was applied manually at the rate of 5 t ha^{-1} under R_+ treatment after CRI stage. Nitrogen was supplied as urea in three splits, i.e. 50% at sowing, 25% at CRI stage and rest 25% at flowering stage. Five irrigations were applied at critical growth stages, *viz*. CRI, tillering, jointing, flowering and grain filling stage.

Soil moisture content was determined gravimetrically in the soil samples collected from 0-15, 15-30, 30-45, 45-60, 60-90 and 90-120 cm soil depth at 15 days intervals during crop growth.

Evapo-transpiration (ET) by wheat crop was computed using water balance method.

$$ET = P + I + C_p - D_p - R - \Delta S \quad (1)$$

$$ET = P + I + C_p - D - (S_f - S_i) \quad (2)$$

where, P is precipitation, I is depth of irrigation, C_p is contribution through capillary rise from the water table, D is deep percolation loss, R is runoff, ΔS is change in soil moisture storage in the profile, S_f is final moisture storage in the profile at harvest, S_i is initial moisture storage in the profile at sowing. Since the depth of groundwater was very low (6-8 m), C_p was assumed negligible. D was computed using Darcy's law. There was no runoff (R) from the field as all the plots were provided with bunds.

$$\text{So, } ET = P + I - D - (S_f - S_i) \quad (3)$$

Water use efficiency (WUE) (kg ha^{-1} mm^{-1}) was computed using eq 4.

$$WUE = GY/ET \quad (4)$$

where, GY = Grain yield (kg ha^{-1}) and ET = Evapotranspiration (mm).

CERES-Wheat (incorporated within the DSSAT version 4.6, Decision support system for Agro-technology Transfer, Jones *et al*. 2003), used in the present study is a dynamic mechanistic model that calculates phenological development and growth of wheat with daily time step in response to environmental factors like soil and climate, and management factors like crop variety, fertilization, planting conditions, irrigation, etc. Input requirements for CERES-Wheat include weather and soil conditions, plant characteristics, and crop management (Hunt *et al*. 2001). We have calibrated and validated this model from the data collected from field experiments on wheat crop for the year 2014-15 and 2015-16, respectively, to simulate the evapotranspiration, water use efficiency, grain and biomass yield of wheat under different tillage, residue and nitrogen management systems. Calibration was done using yield data, maximum LAI, harvest index and days to flowering values for the year 2014-15. Local soil and weather parameters, initial conditions of experiment and management practices were used for running the model. 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 (within 10%) between simulated and measured grain and biomass yield. The seven critical genetic coefficients and some ecotype coefficients for the model have been calibrated as presented in Table 4.The model was validated with an independent dataset generated during field experiment on tillage, residue and nitrogen interaction during the year 2015-16.

All the data were statistically analyzed using analysis of variance (ANOVA) as applicable to split-split plot design (Gomez and Gomez 1984) using SAS software. The significance of the treatment effects was determined using F-test and the difference be tween the means was estimated by using least significance difference at 5% probability level. The observed and model predicted data were compared using the statistical estimates like prediction error (PE), coefficient of determination (R^2), root mean square error (RMSE), coefficient of residual mass (CRM), index of agreement (d index) (Willmott 1982), mean systematic error (MSEs) and mean unsystematic error (MSEu).

$$\text{Prediction error, } PE = ((P_i - O_i)/O_i) \times 100 \quad (5)$$

where, P_i is predicted value, O_i is observed value. Prediction is considered to be excellent if PE value is close to zero.

The root mean square error (RMSE) was used to calculate the fitness between the estimated and measured results.

$$RMSE = \sqrt{\frac{1}{n}\sum_{i-1}^{n}\left(P_i - O_i\right)^2} \quad (6)$$

The normalized RMSE is expressed as RMSE as a percentage over the mean observed value.

$$nRMSE = (RMSE/\bar{O}) \times 100 \quad (7)$$

where, P_i is predicted value, O_i is observed value, $\bar{O}$ is observed mean and n is number of samples. The nRMSE (%) shows the relative difference between the predicted and observed data. The prediction is considered excellent, good, fair and poor for the nRMSE< 10%, 10–20%, 20–30% and > 30%, respectively (Jamieson *et al.* 1991). Coefficient of residual mass (CRM) statistics gives the degree to which the prediction is over or under estimated. Positive value of CRM indicates that the model underestimates the observed value, whereas a negative value of CRM indicates a tendency to overestimate.

$$CRM = \frac{\sum_{i-l}^{n}\left(O_i - P_i\right)}{\sum_{i-l}^{n} O_i} \tag{8}$$

$$\text{Index of agreement } d = 1 - \frac{\sum_{i-l}^{n}\left(P_i - O_i\right)^2}{\sum_{i-l}^{n}\left(\left|P_i^{'}\right| + \left|O_i^{'}\right|\right)} \tag{9}$$

where, $P_i' = P_i - \bar{O}$; $O_i' = O_i - \bar{O}$

$$\text{Mean systematic error } \frac{1}{n}\sum_{i=l}^{n}\left(\hat{P}_i - O_i\right)^2 \tag{10}$$

$$\text{Mean unsystematic error } \frac{1}{n}\sum_{i=l}^{n}\left(P_i - \hat{P}_i\right)^2 \tag{11}$$

where, $\hat{P}_i$ = Estimated P_i , determined by fitting a linear equation between P_i and O_i. For a good model simulation, the systematic error (MSEs) should approach zero, while the unsystematic error (MSEu) should approach the RMSE (Wilmott 1982).

RESULTS AND DISCUSSION

Weather

It was observed that during *rabi* 2015-16, the crop experienced higher maximum temperature during the months of December, January, March and April by 9.7, 22.4, 13.2 and 14.2%, respectively than that of *rabi* 2014-15 (Table 1). During the year 2014-15, the crop received total rainfall of 315.8 mm and effective rainfall of 229.3 mm, whereas during the year 2015-16, the crop received only 2.8 mm of rainfall. The month of March was the wettest month for the year 2014-15 with the rainfall of 201.8 mm. The average bright sunshine hours during the month of November and December in 2015-16 were less than that of 2014-15.

Grain yield of wheat

During the year 2014-15, the mean grain yield of wheat (4282 kg ha^{-1}) was more than that of the year 2015-16 (3158 kg ha^{-1}) (Table 2). The reduction in the grain yield of wheat by 35.6% during the year 2015-16 than that of the year 2014-15 may be attributed to the occurrence of lower rainfall and higher maximum temperature during the crop growing season 2015-16 than that of 2014-15. Neither the tillage treatment nor the crop residue mulch significantly influenced grain yield of wheat in both the years of study. However, nitrogen levels significantly influenced the grain yield of wheat in both the years. Application of 180 kg N ha^{-1} significantly increased the grain yield of wheat by 25.8% and 36.5% than that of 60 kg N ha^{-1}during the year 2014-15 and 2015-16, respectively. Although application of 180 kg N ha^{-1}significantly increased the grain yield of wheat by 11% than that of 120 kg N ha^{-1}during the year 2015-16, but these treatments were statistically at par during the year 2014-15. Effect of tillage, residue and nitrogen interaction was not significant on grain yield of wheat during both the years of study. No significant difference between CT and NT with respect to grain yield of wheat may be attributed to the fact that the experiment was only two years old. However, Ghosh *et al.* (2015) reported that under conservation agriculture in a sandy-loam soil having maize-wheat rotation, the equivalent yield of wheat was 47% higher than that of conventional agriculture.

Biomass yield of wheat at harvest

During the year 2014-15, the mean above ground biomass yield of wheat (10869 kg ha^{-1}) was more than that of the year 2015-16 (8730 kg ha^{-1}) (Table 2). Similar to the grain yield of wheat, the biomass yield of wheat during the year 2015-16 was lower than that of the year 2014-15 by 24.5% because of low rainfall receipt during the year

Table 1 Monthly weather condition during wheat growth during the year 2014-15 and 2015-16

Month	Max. Temp. (°C)		Min. Temp. (°C)		Max. RH (%)		Min. RH (%)		Sunshine hours		Rainfall (mm)		Evaporation (mm)	
	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16
November	28.3	28.1	10.6	11.9	84.3	90.3	37.6	47.4	5.7	2.4	0	2.2	3.1	3.4
December	20.6	22.6	6.7	6.1	93.8	93.9	59.0	49.7	4.4	3.5	26.4	0.0	2.1	2.8
January	16.9	20.7	6.8	6.5	96.0	95.9	68.8	59	2.3	2.4	35.8	0.0	1.9	2.5
February	24.6	24.6	10.6	8.1	91.9	88.7	48.0	53	5.1	5.7	0	0.0	2.6	3.0
March	27.2	30.8	13.1	13.7	90.8	88.2	51.0	54	6.9	6.8	201.8	0.6	3.7	5.1
April	33.9	38.7	19.2	19.1	76.6	67.7	43.4	45	7.2	7.8	51.8	0.0	6.8	8.2

2015-16.The effect of tillage and crop residue mulch was not significant on biomass yield of wheat during both the years of study. Application of 180 kg N ha^{-1} significantly increased the biomass yield of wheat by 37.9% and 34.9% than that of 60 kg N ha^{-1}during the year 2014-15 and 2015-16, respectively. Application of 180 kg N ha^{-1}significantly increased the biomass yield by 12.7% than that of 120 kg N ha^{-1} during the year 2015-16, but these two treatments were statistically at par during the year 2014-15 with respect to biomass yield of wheat. During both the years of study, effect of tillage, residue and nitrogen interaction was not significant for the biomass yield of wheat. During high rainfall year (2014-15), the grain and biomass yield of wheat under CT was higher than that of NT by 7.6 and 2.7% whereas during low rainfall year (2015-16), grain and biomass yield of wheat under NT was higher than that of CT by 4 and 6.2%, respectively. This finding is in agreement with Lopez-Bellido *et al.* (1998). During high rainfall year (2014-15), there was no significant difference between 120 and 180 kg N ha^{-1} with respect to grain and biomass yield of wheat. However, during low rainfall year (2015-16), application of 180 kg N ha^{-1} significantly increased the grain and biomass yield of wheat by 11 and 12.7%, respectively than that of 120 kg N ha^{-1}.

Seasonal evapotranspiration and water use efficiency

During the year 2014-15, seasonal evapotranspiration ranged from 280.9 to 444.4 mm with a mean value of 371.5 mm, whereas during the year 2015-16, it ranged from 163.8 to 275.8 mm with a mean value of 219.5 mm (Table 3). The seasonal evapotranspiration during the year 2014-15 was significantly higher than that of the year 2015-16 by 76.9%. This was mainly attributed to higher rainfall received during the year 2014-15 than the year 2015-16. Averaged over crop residue mulch and nitrogen management, evapotranspiration under CT (386.1 mm) was higher than NT (357.0 mm) by 8.2% during the year 2014-15, whereas during the year 2015-16, cumulative evapotranspiration were 221.4 and 217.7 mm under CT and NT, respectively. Averaged over tillage and nitrogen levels, evapotranspiration under crop residue mulch (416.8 mm) was higher than non-mulch (326.3 mm) by 27.7% during the year 2014-15, whereas during the year 2015-16, evapotranspiration under crop residue mulch (175.9 mm) was less than that of non-mulch (263.1 mm) by 49.6%. Alvarez and Steinbach (2009) reported that no tillage system covered with crop residues had higher infiltration rate, lower evapotranspiration, higher available water content and, thus, higher water use efficiency than tillage system. Averaged over tillage and residue management, evapotranspiration due to 60, 120 and 180 kg N ha^{-1} were 387.8, 357.3 and 369.6 mm, respectively during the year 2014-15 and 207.8, 222.1 and 228.6 mm, respectively during the year 2015-16.

During the year 2014-15, WUE of wheat ranged from 8.06 to 17.38 kg ha^{-1}mm^{-1} with an average value of 11.86 kg ha^{-1}mm^{-1}, whereas in the year 2015-16, WUE of wheat ranged from 10.49 to 21.25 kg ha^{-1}mm^{-1} with an average value of 14.95 kg ha^{-1}mm^{-1} (Table 3). Thus WUE in low rainfall year (2015-16) was higher than that of high rainfall year (2014-15) by 28.6%. This was due to low ET during the year 2015-16 than that of the year 2014-15. During both the years, effect of tillage on WUE was not statistically significant. However, Alvarez and Steinbach (2009) reported

Table 2 Grain and Biomass yield of wheat at harvest as influenced by tillage, residue and nitrogen management

Treatment	Grain yield (kg ha^{-1})		Biomass yield (kg ha^{-1})	
	2014-15	2015-16	2014-15	2015-16
Effect of tillage				
CT	4439$^{A\#}$	3096^{A}	11106^{A}	8467^{A}
NT	4125^{A}	3220^{A}	10633^{A}	8992^{A}
Effect of residues				
R_0	4319^{A}	3143^{A}	10649^{A}	8687^{A}
R_+	4245^{A}	3173^{A}	11090^{A}	8772^{A}
Effect of nitrogen				
N_{60}	3727^{B}	2636^{C}	8800^{B}	7388^{C}
N_{120}	4429^{A}	3241^{B}	11672^{A}	8837^{B}
N_{180}	4691^{A}	3598^{A}	12137^{A}	9963^{A}
LSD (Tillage)	NS	NS	NS	NS
LSD (Residues)	NS	NS	NS	NS
LSD (Nitrogen)	445.8*	322.6*	517.3*	579.7*
LSD(T×R×N)	NS	NS	NS	NS

#Values in a column followed by same letters are not significantly different at $p<0.05$ as per DMRT; * Significant at $p<0.05$

Table 3 Seasonal evapotranspiration and water use efficiency of wheat as influenced by tillage, residue and nitrogen management

Treatment	Seasonal evapotranspiration (mm)		Water use efficiency (kg ha^{-1}mm^{-1})	
	2014-15	2015-16	2014-15	2015-16
Effect of tillage				
CT	386.1^{A}	221.4^{A}	11.58^{A}	14.39^{A}
NT	357.0^{A}	217.7^{A}	12.15^{A}	15.51^{A}
Effect of residues				
R_0	326.3^{A}	263.1^{A}	13.45^{A}	11.91^{B}
R_+	416.8^{A}	175.9^{A}	10.28^{A}	17.99^{A}
Effect of nitrogen				
N_{60}	387.8^{A}	207.8^{A}	9.78^{B}	13.10^{B}
N_{120}	357.3^{A}	222.1^{A}	12.76^{A}	15.34^{A}
N_{180}	369.6^{A}	228.6^{A}	13.05^{A}	16.42^{A}
LSD (T)	NS	NS	NS	NS
LSD(R)	NS	NS	NS	2.40
LSD(N)	NS	NS	1.23*	1.80
LSD (T×R×N)	NS	NS	2.47*	NS

#Values in a column followed by same letters are not significantly different at $p<0.05$ as per DMRT; * Significant at $p<0.05$

higher WUE under NT than that of CT. During the year 2014-15, effect of crop residue on WUE was not significant, whereas during the year 2015-16, application of crop residue mulch significantly improved the WUE of wheat by 51.1%. Low rainfall received during the year 2015-16 than that of 2014-15 may be responsible for this difference.

The WUE of wheat increased significantly with increase in nitrogen levels in both the years. This shows synergistic interaction between water and nitrogen with respect to WUE of wheat. This finding is in agreement with Oweis *et al.* (2000), Pandey *et al.* (2001) and Pradhan *et al.* (2014). Application of 180 kg N ha^{-1} significantly increased WUE of wheat than that of 60 kg N ha^{-1} by 33.4% and 25.3% during the year 2014-15 and 2015-16, respectively. Application of 120 kg N ha^{-1} significantly increased WUE than that of 60 kg N ha^{-1} by 30.4% and 17.1% during the year 2014-15 and 2015-16, respectively. During both the years of study, there was no significant difference between 120 and 180 kg N ha^{-1} with respect to WUE. During the year 2014-15, interaction between tillage and crop residue mulch significantly influenced WUE of wheat. NT with crop residue mulch (19.33 kg $ha^{-1}mm^{-1}$) registered higher WUE than NT without crop residue mulch (11.70 kg ha^{-1} mm^{-1}). However, during the year 2015-16, interaction between tillage and crop residue mulch was not significant on WUE of wheat.

Calibration of DSSAT model

The relationship between the observed and simulated grain yield and biomass yield of wheat under different tillage, residue and nitrogen management during the calibration of DSSAT model for the year 2014-15 are depicted in Fig. 1a and 1b, respectively. The mean observed grain yield of wheat was 4282 kg ha^{-1} as against mean simulated grain yield 3934 kg ha^{-1}. The prediction error ranged from 1.5% (NT R_+ N_{180}) to -24.5% (CT R_+ N_{60}) with a mean value of -8.1%. The observed grain yield of wheat accounted for 73.1% variation of the simulated grain yield of wheat. The coefficient of residual mass (CRM) was 0.081. The positive value indicates that model under-predicted the grain yield of wheat. The mean observed biomass yield of wheat was 10870 kg ha^{-1} as against mean simulated biomass yield of 10521 kg ha^{-1}. The prediction error ranged from -10.9% (NT R_0 N_{120}) to 35.3% (NT R_0 N_{60}) with a mean value of -1.8%. The observed above ground biomass yield of wheat accounted for 70.2% variation in the simulated biomass yield of wheat with a d-index of 0.984. The Root Mean Square Error (RMSE) between the observed and simulated biomass yield of wheat during calibration was 1027.1 kg ha^{-1}, which accounted for 9.4% of the mean observed biomass yield of wheat. The CRM was 0.032. The positive value indicates that model under-predicted the biomass yield of wheat.The seven critical genetic coefficients and some ecotype coefficients for the model have been calibrated and presented in Table 4.

Validation of DSSAT model

During the validation, the mean observed grain yield of wheat was 3158 kg ha^{-1}as against mean simulated grain yield of 3009 kg ha^{-1} (Table 5). The prediction error ranged from 22.0 (CT R_+ N_{180}) to -22.7% (NT R_+ N_{60}) with a mean value of -5.6%.The evaluation of the DSSAT model with respect to grain yield showed that observed grain yield of wheat accounted for 75.9% variation in the simulated grain yield of wheat. The RMSE between the observed and simulated grain yield of wheat was 412 kg ha^{-1}, which accounted for 13% of the mean observed grain yield of wheat, which indicates fair agreement between the observed and simulated grain yield of wheat. The CRM was 0.047 and positive value indicates that model under-predicted the grain yield of wheat. However, Singh *et al.* (2008) observed that the measured grain yield of wheat account for 88% variation of simulated grain yield by CERES-Wheat in sandy-loam soil with RMSE of 0.63 t ha^{-1}. Arora *et al.* (2007) reported nRMSD of 25% between observed and DSSAT simulated grain yield of wheat in sandy loam soil. Timsina *et al.* (2008) reported nRMSE of 15.1% and d-index of 0.92 between observed and DSSAT simulated grain yield of wheat in sandy-loam soil of Punjab, which is in order with the present study. Rezzoug *et al.* (2008)

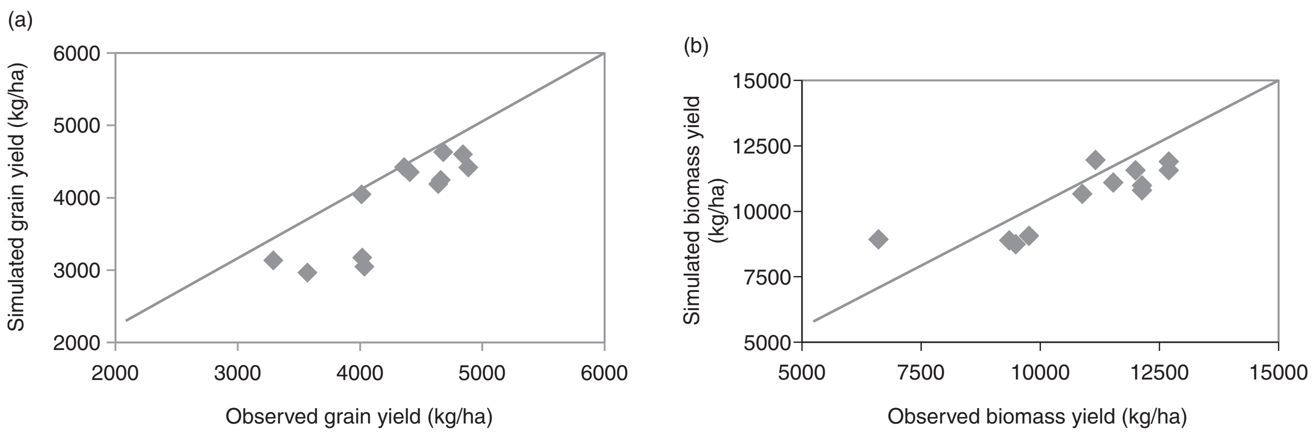

Fig 1 a. Observed and simulated grain yield of wheat during calibration. b. Observed and simulated biomass yield of wheat during calibration.

Table 4 Genotype and ecotype coefficients for wheat (cv HD 2967) calibrated for DSSAT model

Parameter	Acronym	Value
Genotype coefficients		
Days,optimum vernalizing temperature, required for vernalization	P1V	09.87
Photoperiod response (% reduction in rate/10 h drop in pp)	P1D	93.71
Grain filling (excluding lag) phase duration (°C.d)	P5	500.3
Kernel number per unit canopy weight at anthesis (#/g)	G1	13.46
Standard kernel size under optimum conditions (mg)	G2	46.80
Standard, non-stressed mature tiller wt (incl grain) (g dwt)	G3	1.900
Interval between successive leaf tip appearances (°C.d)	PHINT	100.0
Ecotype coefficients		
Duration of phase end juvenile to terminal spikelet (PVTU)	P1	410
Duration of phase terminal spikelet to end leaf growth (TU)	P2	230
Duration of phase end leaf growth to end spike growth (TU)	P3	150
Duration of phase end spike growth to end grain fill lag (TU)	P4	150
Vernalization effect (fr)	VEFF	0.2
Minimum grain N (%)	GN%MN	1.4
Standard grain N (%)	GN%S	2.4
PAR extinction coefficient	KCAN	0.90
Area of standard first leaf (cm^2)	LA1S	2.5
PAR conversion to dm ratio, after last leaf (g/MJ)	PARU2	3.0
PAR conversion to dm ratio, before last leaf stage (g/MJ)	PARUE	3.0
Final leaf senescence ends	LSPHE	6.0
Tiller production starts	TIL#S	3.5
Specific leaf area, standard first leaf (cm^2/g)	SLAS	450
Tiller initiation (rate) factor	TIFAC	1.5
Tillering phase end stage (Growth stage)	TIPHE	2.5

reported RMSE of 0.7 and 0.79 t ha^{-1} during calibration and validation of DSSAT model in sandy clay loam soil under hot summer Mediterranean climate. Wu *et al.* (2013) observed R^2=0.94, Model efficiency=0.92 and nRMSE= 8.2% during validation of the DSSAT model for grain yield of wheat in clayey soil. Andarzian *et al.* (2014) reported an R^2 of 0.97 between observed and DSSAT simulated grain yield with nRMSE of 11.8% and d-index of 0.71 in silty clay soil under semi-arid environment.

The mean observed biomass yield of wheat at harvest was 8730 kg ha^{-1} as against mean simulated biomass yield of 8470 kg ha^{-1} (Table 5). The prediction error ranged from 11.1 (CT R_+ N_{180}) to -15.5% (CT R_0 N_{60}) with a mean value of -3.3%.The evaluation of the DSSAT model with respect to biomass yield of wheat indicated that the observed above ground biomass yield of wheat accounted for 72.8% variation in the simulated biomass yield of wheat. The RMSE between the observed and simulated biomass yield of wheat was 854.1 kg ha^{-1}, which accounted for 9.8% of the mean observed biomass yield of wheat. Since nRMSE was less than 10%, it indicates very good agreement between the observed and simulated biomass yield of wheat. The CRM was 0.03 and the positive value indicates that model under-predicted the biomass yield of wheat. However, Singh *et al.* (2008) reported that the measured biomass yield of wheat accounted for 93% variation of simulated biomass yield by CERES-Wheat in sandy loam soil with RMSE of 1.27 t ha^{-1}, whereas Arora *et al.* (2007) reported nRMSD of 14% between observed and DSSAT simulated biomass yield of wheat in a sandy loam soil. Andarzian *et al.*(2014) reported an R^2 of 0.86 between the observed and DSSAT simulated biomass yield with nRMSE of 3.4% and d-index of 0.92 in silty clay soil under semi-arid environment. Attia *et al.* (2016) reported an R^2 of 0.92, nRMSE of 12.42%, CRM of −0.04, d-index of 0.98 and model efficiency of 0.91 while validating DSSAT model with respect to biomass yield of wheat in clay loam soil, whereas during calibration, R^2 was 0.87, nRMSE was 9.61%, CRM was -0.05, d-index was 0.95 and efficiency was 0.79.

The observed and simulated evapotranspiration (ET) and water use efficiency (WUE) of wheat under different tillage, residue and nitrogen management during the year 2015-16 are presented in Table 6. The mean observed ET was 219.5 mm as against mean simulated ET of 187.9 mm. The prediction error ranged from -25.3% (CT R_0 N_{180} and NT R_0 N_{180}) to 1.6% (NT R_+ N_{120}) with a mean value of -12.1%. Evaluation of the model with respect to seasonal ET showed that the model could account 90.4% variation in the observed seasonal ET. The RMSE between the observed and simulated ET was 44.6 mm, which accounted for 20.3% of the mean observed ET of wheat. Since nRMSE <30%, it indicates good agreement between the observed and simulated ET of wheat (Jamieson *et al*. 1991). RMSEs and RMSEu were 12.9 and 1.27 mm, respectively. Since RMSEs was higher than RMSEu, the error in model prediction was more than that of the experimental error. The d-index was 0.97. The CRM was 0.144 and the positive value indicate

Table 5 Validation of the DSSAT model to simulate grain yield and biomass yield of wheat for the year 2015-16

Treatment	Observed grain yield (kg ha^{-1})	Simulated grain yield (kg ha^{-1})	Prediction error (%)	Observed biomass yield (kg ha^{-1})	Simulated biomass yield (kg ha^{-1})	Prediction error (%)
CTR_0N_{60}	2836	2195	-22.6	7905	6681	-15.5
CTR_0N_{120}	3187	3150	-1.2	8556	8811	3.0
CTR_0N_{180}	3592	3928	9.4	9479	10478	10.5
CTR_+N_{60}	2412	2195	-9.0	6801	6675	-1.9
CTR_+N_{120}	3203	3170	-1.0	8370	8820	5.4
CTR_+N_{180}	3343	4077	22.0	9693	10770	11.1
NTR_0N_{60}	2592	2094	-19.2	7324	6433	-12.2
NTR_0N_{120}	3028	2928	-3.3	8434	8343	-1.1
NTR_0N_{180}	3622	3530	-2.5	10422	9622	-7.7
NTR_+N_{60}	2702	2088	-22.7	7522	6398	-14.9
NTR_+N_{120}	3544	3024	-14.7	9989	8551	-14.4
NTR_+N_{180}	3833	3725	-2.8	10259	10059	-1.9
Mean	3158	3009	-5.6	8730	8470	-3.3
Statistics	R^2 = 0.759; RMSE=412.0 ; nRMSE= 13.0; D= 0.98 ; CRM = 0.047 ; RMSEs= 66.2 ; RMSEu = 98.8			R^2 = 0.728; RMSE=854.1 ; nRMSE= 9.8; D= 0.99 ; CRM = 0.030 ; RMSEs= 85.6 ; RMSEu = 246.6		

Table 6 Validation of the DSSAT model to simulate evapotranspiration and water use efficiency of wheat for the year 2015-16

Treatment	Observed evapo-transpiration (mm)	Simulated evapo-transpiration (mm)	Prediction error (%)	Observed water use efficiency (kg ha^{-1} mm^{-1})	Simulated water use efficiency (kg ha^{-1} mm^{-1})	Prediction error (%)
CTR_0N_{60}	247.4	193.6	-21.7	11.5	11.3	-1.4
CTR_0N_{120}	268.7	203.3	-24.4	11.9	15.5	30.7
CTR_0N_{180}	275.8	205.9	-25.3	13.0	19.1	46.7
CTR_+N_{60}	172.9	166	-4.0	13.9	13.2	-5.3
CTR_+N_{120}	179.8	178.8	-0.5	17.8	17.7	-0.7
CTR_+N_{180}	183.5	183.2	-0.2	18.2	22.3	22.4
NTR_0N_{60}	247.0	191.9	-22.3	10.5	10.9	3.9
NTR_0N_{120}	264.9	202.7	-23.5	11.4	14.4	26.0
NTR_0N_{180}	274.9	205.3	-25.3	13.2	17.2	30.5
NTR_+N_{60}	163.8	164.1	0.2	16.5	12.7	-23.0
NTR_+N_{120}	175.1	177.9	1.6	20.2	17	-16.0
NTR_+N_{180}	180.4	181.9	0.8	21.3	20.5	-3.5
Mean	219.5	188	-12.1	15.0	16.0	6.9
Statistics	R^2 = 0.904; RMSE=44.6 ; nRMSE= 3.14; D= 0.97 ; CRM = 0.144 ; RMSEs= 12.9 ; RMSEu = 1.27			R^2 = 0.414; RMSE=3.14 ; nRMSE= 2.0; D= 0.98 ; CRM = -0.069 ; RMSEs= 0.48 ; RMSEu = 0.77		

that model under-predicted the ET of wheat. The coefficient of determination (R^2) between the observed and simulated ET was good (0.904).This indicates that DSSAT model could satisfactorily simulate ET of wheat under present condition. However, Arora *et al.* (2007) reported RMSD of 25 mm and nRMSD of 9% between the observed and DSSAT simulated ET in sandy loam soil of Punjab, whereas Attia *et al.* (2016) reported R^2 of 0.81, nRMSE of 11.9%, CRM of 0.14, d-index of 0.73 and efficiency of 0.36 while validating ET of wheat in clay loam soil under semi-arid environment.

The mean observed WUE of wheat under different tillage, residue and nitrogen management was 15 kg ha^{-1}mm^{-1} as against mean simulated WUE of 16 kg ha^{-1}mm^{-1}. The prediction error ranged from -23% (NT R_+ N_{60}) to 46.7% (CT R_0 N_{180}) with a mean value of 6.9%. Evaluation of the model with respect to WUE of wheat showed that the RMSE between the observed and simulated WUE of wheat was 3.14 kg ha^{-1}mm^{-1}, which accounted for 21.0% of the mean observed WUE of wheat. The nRMSE value indicates fair agreement between the observed and simulated WUE of wheat. RMSEs and RMSEu were 0.48 and 0.77 kg ha^{-1}mm^{-1}, respectively. The d-index was 0.98. The CRM was -0.069 and the negative value indicate that model over-predicted the WUE of wheat. The coefficient of determination (R^2) between the observed and simulated WUE was low (0.414), which indicates that DSSAT model could not satisfactorily simulate WUE of wheat under present condition. This may be due to the fact that prediction error for simulated grain yield was greater under nitrogen stress treatment, *i.e.* 60 kg N ha^{-1}, which resulted in poor WUE prediction. This indicates that the model does not perform efficiently under nitrogen stress condition. However, Lu *et al.* (2009) reported that the prediction error between observed and DSSAT simulated WUE of wheat ranged from -6.65 to 5.77% under different tillage treatment.

Conclusions

It can be concluded that conventional tillage and no tillage treatments were statistically similar with respect to grain yield and biomass yield and WUE of wheat during both the years of study. The grain yield, biomass yield and WUE increased with increase in the N levels. During high rainfall year (2014-15), the irrigated wheat responded up to 120 kg N ha^{-1}, whereas during low rainfall year (2015-16) the crop responded up to 180 kg N ha^{-1}. During the high rainfall years the effect of crop residue mulch on WUE was not significant, whereas during low rainfall year, crop residue mulch could significantly increase the WUE than no mulch treatment. Crop simulation model DSSAT (ver 4.6) could satisfactorily simulate grain yield (R^2 = 0.759), biomass yield at harvest (R^2= 0.728) and seasonal ET (R^2= 0.904) in wheat (cv HD2926) but could not simulate WUE of wheat (R^2= 0.414) with acceptable level of accuracy under different tillage, residue and nitrogen management practices. So the validated model can be used to predict optimum tillage, residue and nitrogen interaction for achieving higher yield of wheat under different climatic conditions of Indogangetic plain region.

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REFERENCES

Acharya C L, Hati K M and Bandyopadhyay K K. 2005. Mulches. (*In*) Hillel, D, Rosenzweig, C, Powlson, D S, Scow, K M, Singer, M J, Sparks, D L and Hatfield, J (Ed.). *Encyclopedia of Soils in the Environment*, pp 521-532. Elsevier Publication.

Alvarez R and Steinbach H S. 2009. A review of the effects of tillage systems on some soil physical properties, water content, nitrate availability and crops yield in the Argentine Pampas. *Soil and Tillage Research* **104:** 1-15.

Andarzian, B, Hoogenboom, G, Bannayan, M, Shirali, M and Andarzian, B. 2014.Determining optimum sowing date of wheat using CSM-CERES-Wheat model. *Journal of Saudi Society of Agricultural Sciences*14: 189-199.

Arora, V K, Singh, H and Singh, B. 2007. Analyzing wheat productivity responses to climatic, irrigation and fertilizer-nitrogen regimes in a semi-arid sub-tropical environment using the CERES-Wheat model. *Agricultural Water Management* **94:**22-30.

Attia A, Rajan N, Xue Q, Nair S, Ibrahim A and Hays D. 2016. Application of DSSAT-CERES-Wheat model to simulate winter wheat response to irrigation management in the Texas High Plains. *Agricultural Water Management* **165**: 50-60.

Dahiya R, Ingwersen J and Streck T. 2007. The effect of mulching and tillage on the water and temperature regimes of a loess soil, Experimental findings and modeling. *Soil and Tillage Research* **96**: 52-63.

Ghosh B N, Dogra P, Sharma N K, Bhattacharyya R and Mishra, P K. 2015. Conservation agriculture impact for soil conservation in maize–wheat cropping system in the Indian sub-Himalayas. *International Soil and Water Conservation Research* **3**: 112–118.

Gomez K A and Gomez A A.1984. *Statistical Procedures for Agricultural Research- An IRRI Book*. John Wiley and Sons, New York.

Govaerts B, Sayre K D, Lichter K, Dendooven L and Deckers J. 2007. Influence of permanent raised bed planting and residue management on physical and chemical soil quality in rainfed maize/wheat systems. *Plant and Soil* **291**:39–54.

Hunt L A, White J W and Hoogenboom G. 2001. Agronomic data: advances in documentation and protocols for exchange and use. *Agricultural Systems* **70**: 477-492.

Jamieson P D, Porter J R and Wilson D R. 1991. A test of computer simulation model ARCWHEAT1 on wheat crops grown in New Zealand. *Field Crops Research* **27**: 337–350.

Jones, J W, Hoogenboom, G, Porter, C H, Boote, K J, Batchelor, W D, Hunt, L A, Wilkens, P W, Singh, P W, Gijsman, A J and Ritchie, J T. 2003. DSSAT cropping system model. *European Journal of Agronomy* **18**:235-265.

Lo´pez-Bellido L, Fuentes M, Castillo J E and Lo´pez-Garrido F J. 1998.Effects of tillage, crop rotation and nitrogen fertilization on wheat-grain quality grown under rainfed Mediterranean conditions. *Field Crops Research* **57**: 265–276.

Lu X, Nangia V, Mu X, Wang F, Sui Y, Gao P and Yao Y. 2009. Field-scale simulation of winter-wheat leaf area index, soil moisture and water-use efficiency in West Henan, China. *Journal of Environmental Hydrology* **17**: 1-11.

Ngwira A R, Aune J B and Thierfelder C. 2014. DSSAT modelling of conservation agriculture maize response to climate change in Malawi. *Soil and Tillage Research* **143**: 85-94.

Oweis S, Zhang H and Pala M. 2000. Water use efficiency of rainfed and irrigated bread wheat in a Mediterranean environment. *Agronomy Journal* **92**: 231–238.

Pandey R K, Maranville J W and Admou A. 2001. Tropical wheat response to irrigation and nitrogen in a Sahelian environment. I. Grain yield, yield components and water use efficiency. *European Journal of Agronomy* **15**: 93–105.

Pradhan S, Chopra U K, Bandyopadhyay K K, Singh R, Jain A K and Chand I. 2014.Effect of deficit irrigation and nitrogen levels on water productivity and nitrogen use efficiency of wheat (*Triticum aestivum*) in a semi-arid environment. *Indian Journal of Agricultural Sciences* **84**: 887-891.

Rezzoug W, Gabrielle B, Suleiman A, Benabdeli K. 2008. Application and evaluation of the DSSAT-wheat in the Tiaret. region of Algeria. *African Journal Agricultural Research* **3(4)**: 284-296.

Singh A K, Tripathy R and Chopra U K. 2008. Evaluation of

CERES-Wheat and CropSyst models for water–nitrogen interactions in wheat crop. *Agricultural Water Management* **95**: 776-786.

Timsina J, Godwin D, Humphreys E, Singh Y, Singh B, Kukal S S and Smith D. 2008. Evaluation of options for increasing yield and water productivity of wheat in Punjab, India using the DSSAT-CSM-CERES-Wheat model. *Agricultural Water Management* **95**: 1099-1110.

Verhulst N, Govaerts B, Verachtert E, Castellanos-Navarrete A, Mezzalama M, Wall P C, Chocobar A, Deckers J and Sayre K D. 2010. Conservation agriculture, improving soil quality for sustainable production systems. (*In*) *Advances in Soil Science*, Food Security and Soil Quality, pp 137–208. (eds R. Lal & B. A. Stewart).

Willmott C J. 1982. Some comments on the evaluation of model performance. *Bulletin American Meteorological Society* **63**: 1309–1313.

Wu C, Anlauf R and Ma Y. 2013. Application of the DSSAT Model to simulate wheat growth in Eastern China. *Journal of Agricultural Sciences* **5(5):**198-208.