Article

Application of DSSAT crop model for wheat crop growth simulation in some wheat growing districts of northern India

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Abstract

Process based Crop growth simulation models are being used as a potential decision support tool for informed decision making by policy makers and researchers. Calibration and validation of a crop growth simulation model is the fundamental process before applying the model projections to a new location. CERES crop growth simulation model has been used by a number of researchers worldwide to simulate wheat growth. This study is undertaken to calibrate and validate CERES model on DSSAT (Decision Support System for Agro Technology Transfer) platform for six predominantly wheat growing districts of Northern India.

Keywords crop simulation model; DSSAT; CERES; phenology; leaf area index.

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1 Introduction

Crop simulation models integrate the interdisciplinary knowledge gained through field experimentation and technological innovations in the fields of biological, chemical and physical science relating to agricultural production system. Therefore, these models can increase understanding and management of the agricultural system in a holistic way. Crop simulation models have been used to investigate the performance of different cultivars at a range of sowing dates in relation to different soil and climate scenarios. The Decision Support System for Agro Technology Transfer (DSSAT4.5) is a comprehensive decision support system that includes the Cropping System Models CERES-wheat. The CSM-CERES-Wheat, a part of Decision Support System for Agrotechnology Transfer (DSSAT) Cropping System Model V4.5, has been used in this study. The model has been documented extensively since its initial development and evaluation. The ability of DSSAT to evaluate management and genetic options is a potential tool for studying the impacts of climate change and assessing useful adaptation strategies to mitigate the potentially negative effects of climate variability such as sowing date, row spacing, plant density, irrigation and fertilization. It has been successfully employed over the last 20 years worldwide in many range of applications, including climate change, precision agriculture and crop

management such as nitrogen fertilization, irrigation and sowing date (Arora et al., 2007; Biswal et al., 2014; Cabrera et al., 2007; Rinaldi et al., 2007; Rinaldi and Ubaldo, 2007; Brassard and Singh, 2008; Thorp et al., 2008; Timsina et al., 2008; Luo et al., 2009; Ventrella et al., 2009; Ventrella et al., 2012; Iqbal et al., 2011). It simulates the effects of weather, genotype, soil properties and management on wheat growth and development, yield, soil and plant water and nitrogen dynamics. The crop growth model considers phase-wise development with nine growth stages, from pre-sowing to harvest, in relation to thermal time. The model calculates biomass accumulation as the product of radiation use efficiency and photo-synthetically active intercepted radiation. The number of growing leaves is a function of leaf appearance rate (phyllochron interval, degree days) and duration of grain filling. Organ extension depends on potential organ growth and is limited by sub-optimal temperature and water and nitrogen stresses. Partitioning coefficients of dry biomass in plant parts are influenced by phase-wise development. Grain yield is modeled as a product of grain number, plant population, and grain mass at physiological maturity. Daily soil water balance is modeled in relation to rainfall/irrigation, runoff, infiltration, transpiration and drainage from the soil profile.

Based on these considerations, the overall objective of this study was to evaluate the performance of DSSAT-CERES wheat model for wheat crop over major wheat growing region in North India.

2 Methodology

2.1 Study area

Six major wheat growing districts in Northern India were selected for this study namely Patiala in Punjab, Bhiwani in Haryana, Agra in Uttar Pradesh, Bharatpur in Rajasthan,Morena in Madhya Pradesh and Rohtas in Bihar state respectively.

2.2 Meteorological data

The maximum and minimum temperatures from Automatic Weather Station of IMD (Indian Meterological Department) were used in the study. The data has been downloaded from the IMD website and the weekly averages were generated for the test sites. Since the historical data from AWS is not available, the nearby meteorological observatory data is being used. Daily average maximum, minimum temperature (0°C), rainfall (mm/day) and solar radiation (MJ/m2) are the prerequisites for running DSSAT CERES model. For model calibration and validation, historical weather data (IMD) from 1998 to 2013 were used, while for rabi 2013-14, IMD AWS data have been used.

Soil input. Layer-wise soil attributes like texture, sand (%), silt (%), clay (%), bulk density (g/cm³), field capacity (cm³/cm³), permanent wilting point (cm3/cm3), saturated soil water content (cm³/cm³), saturated hydraulic conductivity (cm/h), organic carbon (%), pH and electrical conductivity (dS/m) are required to run the model. The NBSSLUP soil map and secondary information from district database maintained by CRIDA (Central Research Institute for Dry Land Agriculture) and WISE global soil database (Gijsman et al., 2007) have been used for preparing the respective district soil input files.

Calibration and validation of CERES-DSSAT. Required weather and soil files were prepared according to DSSAT format and crop simulation was carried out for the six above mentioned districts. Standard management practices were followed to simulate the wheat yield. As district level yield was compared, the simulated yield was averaged over a number of sowing dates and soil conditions. Simulations were iterated taking 3 sowing dates for each location. The soil condition was also varied in different simulations taking the major soil of the district as the representative one. Thus, the simulated yield was averaged over a district and compared with the observed average yield for the corresponding year.

The growth and development modules of the CERES model use different sets of species, ecotype and cultivar coefficients (P1V, P1D, P5, G1, G2, G3 and PHINT) which define the phenology and crop growth in

time domain. The DSSAT-CERES wheat model was calibrated and validated for HD 2329 variety (one of the most popular varieties of the region) from 1998 to 2009. For calibration, the cultivar coefficients were obtained sequentially, starting with the phenological development parameters related to flowering and maturity dates (P1V, P1D, P5 and PHINT) followed by the crop growth parameters related with kernel filling rate and kernel numbers per plant (G1, G2 and G3) (Hunt and Boot, 1998; Hunt et al., 1993). The trial and error method was used to determine genetic coefficients manually for all the six districts (Godwin and Singh, 1998). These parameters were adjusted to minimize root mean square error (RMSE) between simulated and measured data. The description of the cultivar coefficients used by DSSAT-CERES wheat model is as follows (Table 1).

Table 1 Cultivar coefficients for wheat in DSSAT CERES.							
P1V	Days at optimum vernalizating temperature required to complete vernalization						
P1D	Percentage reduction in development rate in a photoperiod hour shorter than the threshold						
	relative to that at the threshold						
P5	Grain filling (excluding lag) period duration (GDD)						
G1	Kernel number per unit canopy weight at anthesis (g_1)						
G2	Standard kernel size under optimum condition (mg)						
G3	Standard non-stressed dry weight (total, including grain) of a single tiller at maturity (g)						
PHINT	Phyllochron interval (GDD)						

In addition, ancillary datasets viz., historical data of crop statistics, crop calendar of the district, pricing policy, soil and land degradation, and irrigation infrastructure were also used for analysis.

3 Results and Discussion

The Root Mean Square Error (RMSE) and correlation coefficients r^2 values for different districts are presented in Table-2.

	Table 2 Rivibe a	ind 1 values for ob	served vs. sinidia	teu uistriet average	wheat yield.	
Districts	Patiala	Bhiwani	Rohtas	Morena	Bharatpur	Agra
RMSE (kg/Ha)	283	249	277	204	317	267
r^2	0.65	0.61	0.56	0.65	0.64	0.66

Table 2 RMSE and r² values for observed vs. simulated district average wheat yield

Start-of-Season information for rabi wheat 2013-14 was retrieved from the field observations. The wheat sowings were observed mostly in the second fortnight of November in the districts of Patiala, Agra, Morena and Bhiwani and it is advanced (first fortnight of November in Bharatpur and delayed up to second fortnight of December in Rohtas district. Simulation was carried out with previously calibrated cultivar HD2329 and AWS recorded weather data. Daily simulated LAI, yield and total dry matter were averaged over the years in order to arrive at normal LAI, Yield and TDM respectively for each district. These normals were compared with the simulated values for Rabi 2013 and the result is presented in Fig.3. The overview of wheat growth simulation for the six districts is presented in Table 3. Maximum LAI was observed in Bhiwani at around 81 days after planting where as minimum LAI was observed in Morena and Agra. In Rohtas, LAI reaches the maximum value about one week before and the duration of the crop is shorter than other districts. Although in Rohtas, grain formation starts a bit earlier than other districts but the yield is significantly low. Maximum yield is

SL.	PARAMETER	PATIAL A	AGR A	BHIWA NI	ROHTA S	BHARATPU R	MORENA
1.	Emergence (DAP)	4	4	4	4	3	4
2.	Anthesis (DAP)	97	92	98	86	94	91
3.	Maturity (DAP)	141	136	141	120	144	133
4.	Product wt (kg dm/ha), no loss	4454	2627	4625	2361	4102	2620
5.	Product unit weight (g dm)	27	0.023	0.026	0.019	0.026	0.022
6.	Product number $(no./m^2)$	16497	11420	17790	12429	15778	11909
7.	Product number (no./group)	13	10.8	14.2	9.2	12.0	10.9
8.	Product harvest index (ratio)	0.34	0.23	0.33	0.23	0.31	0.22
9.	Maximum leaf area index	2.8	2.1	3.1	2.8	2.8	2.2
10.	Final leaf number(one axis)	13.9	13.8	14	14.0	14.1	14.4
11.	Final shoot number $(no./m^2)$	127	1060	1256	1353	1320	1093
12.	Canopy (tops) wt (kg dm/ha)	1315	11626	13977	10447	13445	12138
13.	Vegetative wt (kg dm/ha)	8651	9000	9351	8085	9343	9518
14.	Root wt (kg dm/ha)	515	439	568	598	499	470
15.	Assimilate wt (kg dm/ha)	1557	1326	1610	1264	1548	1392
16.	Senesced wt (kg dm/ha)	88	74	94	106	97	83
17.	Reserves wt (kg dm/ha)	4972	5825	5177	4426	5787	6411

observed in Bhiwani followed by Patiala whereas minimum was observed in Rohtas followed by Agra and Morena. Total Dry Matter (TDM) also shows a similar trend as of yield.

Table 3 Overview of wheat growth simulation.

Progression of the simulated wheat crop attributes like leaf area index, yield and total dry matter content is presented in Fig. 1(a) to 1(c). The bio-physical parameters are plotted against the days after sowing. This follows a normal distribution curve.



Fig.1 (a) Progression of LAI, Yield and TDM for wheat crop in 2013-14.



Fig. 1(b) Progression of Yield for wheat crop in 2013-14.



Fig.1 (c) Progression of Yield for wheat crop in 2013-14.

Comparison of growth simulation for 2013 with long term averages for all 6 districts is presented in Fig. 2a-2f.







Fig. 2(b) Bharatpur.



Fig. 2(c) Bhiwani.











Fig. 2(f) Rohtas.

The simulated wheat LAI and yield were lower than the simulated long term normals in Agra and Morena. In Patiala, the simulated wheat growth for 2013 is at par with the long term average with respect to LAI, TDM and yield. Simulated growth attributes for wheat crop in 2013 at Bharatpur, Rohtas and Bhiwani were found to be better than the long term average values.

4 Conclusion

In conclusion, the wheat crop prospects in all the six districts in terms of both condition and yield potential are found to be normal with reference to historical years of 2008 and 2013. Hence the yield prospects are good. CERES-DSSAT wheat model calibrated and validated for the study region and the model performance is good in terms of wheat yield and phenology. The improvements in the crop models in terms of spatialization may give better comparison.

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