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Evaluation of DSSAT-CERES Maize Model for Northern Transitional Zone of Karnataka

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Abstract

Two field experiments on maize were conducted during the rainy seasons (Kharif) of 2015 and 2016 at the Main Agricultural Research Station, University of Agricultural Sciences Dharwad, Karnataka, India. One experiment included four hybrids across three levels of nitrogen Expt-1 and the other experiment included the same four hybrids across three dates of sowing (Expt-2), both the experiments were repeated for two seasons (2015 and 2016). For the calibration of DSSAT-CERES maize model and Expt-1 from 2015 and Expt-2 from 2016 seasons to optimize four hybrids genetic coefficients observed data on phenology, grain yield, and yield components were used by employing DSSAT Gencalc software. The calibrated model was further evaluated using another two independent data sets separately; Expt-1 from 2016 and Expt-2 from 2015, hence model performance here is discussed separately for each experiment. During evaluation for Expt-2 from 2015 the model predicted both days to anthesis and maturity of all the four tested hybrids across dates of sowing with the mean RMSE values of ±1.5 and ±5.7 days. Similarly, the index of agreement (d-stat) values for anthesis and maturity were 1.00 and 0.998, respectively, which is categorized as excellent. This is further proved by the very high index of agreement (d-stat) of 0.999 for total above ground biomass, yield traits and grain yield. With regard to second independent data set of Expt-2 from 2015, the model predicted both days to anthesis and maturity with the mean RMSE values of ±2.4 and ±3.7 days, respectively; which is further asserted by very high index of agreements (d-stat) of 0.999 and 0.999 for anthesis and maturity, 0.999 for total above ground biomass, 0.999 for yield traits, and 0.999 for grain yield. On the whole DSSAT-CERES maize model performed exceedingly well for Northern Transitional Zone of Karnataka and can be used as decision support system tool in agriculture and to study the impacts of climate change on maize crop.

Key words : Maize, DSSAT-CERES model, model calibration, model validation, decision support system.

Agronomic research has focused on formalizing and summarizing knowledge of growth and yield of field crops including maize. When mathematical principles are combined to be presented as a cause-effect process, the relationship can be referred as a mechanistic model. Mechanistic representations may be combined in logical segments to provide a simulation of all or part of a complex system (Reckman *et al.*, 1996). A crop model can be defined as a quantitative scheme for predicting the growth, development and yield of a crop, given a set of variables (Monteith, 1996).

Crop simulations are now being used in agronomy for research, education, extension and crop management (Van Evert and Campbell, 1994). A thorough review on potential uses and limitations of crop models was published in Agronomy Journal (1996) by the ASA. Whistler *et al*. (1986) and Hoogenboom (2000) described a wide range of major areas in which the application of models is well established. Several maize models such as Hybrid maize, Root Zone Water Quality Model (RZWQM), Agricultural Production Systems Simulator (APSIM), Model for World Food Studies i.e. WOFOST and Agricultural Land Management Alternatives with Numerical Assessment Criteria (ALMANAC) had been

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used for simulation of crop growth, yield and evaluation management strategies.

Ritchie *et al*. (1998) studied growth, development and yield of cereal crops included Decision Support System for Agro-technology Transfer (DSSAT) using CERES Crop simulation model. The CERES model has been tested over a wide range of environments. Results obtained showed that when the weather, cultivar and management information are reasonably quantified, the yield results are usually within acceptable limit.

Simulation models are thought to be an indispensable tool for supporting scientific research, crop management, and policy analysis (Fischer *et al*., 1999; Hammer *et al*., 2002; Hansen, 2002). However, validation of such models needs to be conducted because these are developed under very specific edaphic and climatic conditions that do not necessarily prevail in other regions of the world. Therefore, before the model can be adopted or used in other locality, evaluation or validation study must be undertaken to establish its credibility (Balderama and Bareng, 2009).

Soler *et al*. (2007) evaluated the Cropping System Model (CSM)-CERES-Maize for its ability to simulate growth, development, grain yield for four different maturity maize hybrids grown off-season in a subtropical region of Brazil, under rainfed and irrigated conditions. The evaluation of the CSM-CERES-Maize showed that the model was able to simulate phenology and grain yield for the four hybrids accurately, with normalized RMSE (expressed in percentage) less as compared to 15 per cent. Total biomass and LAI were also reasonably well simulated, especially for the hybrids Exceler, DAS CO32, and DKB 333B.

Khaliq (2008) stated that the use of simulation models to predict the likely effects of climate change on crop production is, of necessity, an evolving science. As both general circulation models and crop simulation models become more sophisticated, as more high quality historical weather data for a larger number of sites become available, and as better physiological data become available to model maize responses to climate change variables, predictions will become more accurate.

To study the impact of future climate on the crop productivity models can be used effectively and efficiently. DSSAT-CERES maize model is one of the supportive tools to study the future

Table 1. Optimized genetic coefficients of tested maize hybrids after calibration

Code	Hybrids			
Genetic coeffic-ients	**Nithya-shree**	**NK-6240**	**GH-0727**	**900-M-Gold**
P_1	254.0	250.0	250.0	254.2
P_2	0.270	0.270	0.270	0.270
P_5	880.4	878.7	875.0	863.7
G_2	945.0	950.0	870.0	965.0
G_3	8.00	8.00	8.00	8.00
PHINT	38.70	38.70	38.90	36.01

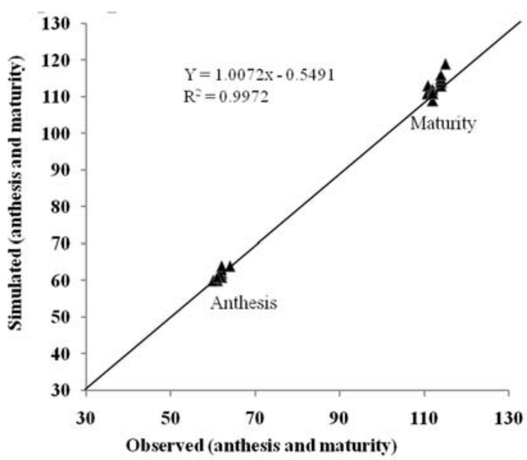

Fig. 1. Observed and simulated days to anthesis and anthesis and maturity DS Vs H (Expt-2) of 2016

crop production and productivity status of the given area, and accordingly devise adaptation strategy. Crop simulation models (viz., DSSAT model) are being used to study and predict the future productivity potential of a crop, cropping systems, for a given area within the shortest possible time. The DSSAT-CERES maize model has not been used for evaluating the currently widely adapted maize hybrids in Northern Transition Zone of Karnataka. Therefore the objective of this work was to evaluate the performance of DSSAT-CERES maize model for the currently ruling maize hybrids.

Materials and Methods

Two field experiments on maize were conducted during the two successive rainy seasons (Kharif) of 2015 and 2016 at the Main Agricultural Research Station, University of Agricultural Sciences Dharwad, Karnataka, India. One experiment included four hybrids and three levels of nitrogen (Expt-1) repeated twice (2015 and 2016), and the other experiment included the same four hybrids across three dates of sowing (Expt-2) repeated twice (2015 and 2016). Observations on phenology, total above ground biomass, anthesis and maturity, yield components and yield were collected. The DSSAT-CERES maize model was calibrated using two independent sets of field experiment data i.e. observed data on phenology, grain yield and yield components from Expt-1 of 2015 and Expt-2 from 2016 seasons were used employing Gencalc software. Here the performance of DSSAT-CERES maize model was discussed separately for both the independent data sets. The calibrated model was evaluated separately for another two independent data sets; Expt-1 from 2016 followed by Expt-2 from 2015.

Result and discussion

The calibration of DSSAT-CERES maize model for the newly tested four hybrids was done using observed data on anthesis, physiological maturity, total above ground biomass, yield component, and grain yield from four hybrids across N levels experiment from 2015 (Expt-1) and hybrids across dates of

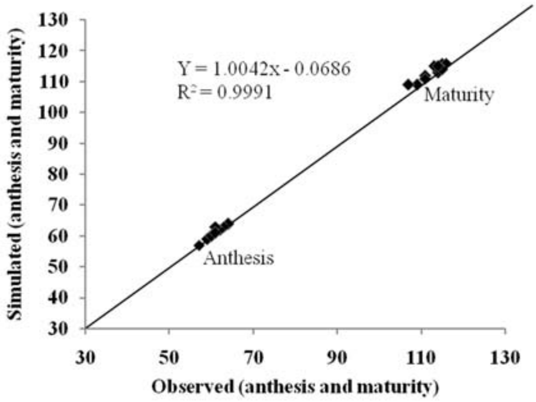

Fig. 1. Observed and simulated days to anthesis and anthesis and maturity DS Vs H (Expt-2) of 2016

Table 2. Observed and simulated values of anthesis and maturity dates for Expt-1 (2016)

Treat-ments	Anthesis date (DAS)			Maturity date (DAS)		
	Obs.	Sim.	% devi-ation	Obs.	Sim.	% devi-ation
N_1H_1	62	62	0.0	111	119	-7.2
N_1H_2	62	62	0.0	114	119	-4.4
N_1H_3	60	62	-3.3	111	118	-6.3
N_1H_4	61	61	0.0	112	117	-4.5
N_2H_1	62	62	0.0	112	119	-6.3
N_2H_2	62	62	0.0	114	119	-4.4
N_2H_3	61	62	-1.6	112	118	-5.4
N_2H_4	64	61	4.7	115	117	-1.7
N_3H_1	60	62	-3.3	112	119	-6.3
N_3H_2	62	62	0.0	114	119	-4.4
N_3H_3	61	62	-1.6	112	118	-5.4
N_3H_4	64	61	4.7	116	117	-0.9
Mean	62	62	0	113	118	-5
RMSE	1.5			5.7		
d-stat	1.00			0.998		
NRMSE	2.47			5.04		

Table 3. Observed and simulated values of grain yield and total shoot biomass for Expt-1 (2016)

Treat-ments	Grain yield ($kg\ ha^{-1}$)			Total shoot biomass ($kg\ ha^{-1}$)		
	Obs.	Sim.	% deviation	Obs.	Sim.	% deviation
N_1H_1	7500	8332	-11.1	15500	14677	5.3
N_1H_2	9050	8368	7.5	18300	14694	19.7
N_1H_3	7650	7779	-1.7	15300	14332	6.3
N_1H_4	8580	8393	2.2	17200	14503	15.7
N_2H_1	9042	8332	7.9	19450	14677	24.5
N_2H_2	9302	8368	10.0	18210	14694	19.3
N_2H_3	7620	7779	-2.1	14945	14332	4.1
N_2H_4	9070	8393	7.5	18200	14503	20.3
N_3H_1	9080	8332	8.2	18100	14677	18.9
N_3H_2	9310	8368	10.1	18000	14694	18.4
N_3H_3	7600	7779	-2.4	15100	14332	5.1
N_3H_4	9050	8393	7.3	18300	14503	20.7
Mean	8571	8218	4	17217	14552	15
RMSE	644.2			3010.2		
d-stat	0.999			0.986		
NRMSE	7.52			17.5		

sowing experiment from 2016 season (Expt-2) by employing Gencalc software (Table 1).

Where; P1 is thermal time from seedling emergence to the end of the juvenile phase (NK-6240 and GH-0727showed the same values, whereas Nithyashree and 900-M-Gold recorded values of 254.0 and 254.2; P2 is extent to which development (expressed as days) is delayed for each hour increase in photoperiod above the longest photoperiod at which development proceeds at a maximum rate all the four tested hybrids showed the same value of 0.270; P5 is thermal time from silking to physiological maturity (expressed in degree days above a base temperature of 8 °C showed a considerable difference among the tested hybrids; the highest value of 880.4 followed by 863.7 were recorded by Nithyashree and 900-M-Gold,while the lowest value (875) was recorded by GH-0727. G2 is maximum possible number of kernels per plant among the tested hybrids 900-M-Gold followed by NK-6240 recorded 965 and 950 maximum possible kernel, respectively. The lowest value 870 was recorded by GH-0727; G5 is Kernel filling rate during the linear grain filling stage and under optimum conditions (mg/day) was not varied among the tested hybrids. PHINT is phyllochron interval; the interval in thermal time (degree days) between successive leaf tip appearances there was a slight difference among the hybrids on this trait the highest value was recorded by GH-0727 followed by NK-6240 and Nithyashree.

This was in agreement with Ahmed *et al.* (2017) who worked in Bangladesh on calibration and validation of decision support system for agro-technology transfer model for simulating growth and yield of maize; they used four adapted maize cultivars, BARI Hybrid Maize-7, BARI Hybrid Maize-9, NK-40 and

Table 4. Observed and simulated values of No. of grains m^{-2} and No. of grains per cob for Expt-1 (2016)

Treat-ments	No. of grains m^{-2}			No. of grains cob^{-1}		
	Obs.	Sim.	% deviation	Obs.	Sim.	% deviation
N_1H_1	2586	2422	6.3	323	303	6.2
N_1H_2	2586	2433	5.9	323	304	5.9
N_1H_3	2391	2261	5.4	299	283	5.4
N_1H_4	2524	2498	1.0	315	312	1.0
N_2H_1	2583	2422	6.2	323	303	6.2
N_2H_2	2584	2433	5.8	323	304	5.9
N_2H_3	2485	2261	9.0	307	283	7.8
N_2H_4	2668	2498	6.4	333	312	6.3
N_3H_1	2752	2422	12.0	344	303	11.9
N_3H_2	2660	2433	8.5	333	304	8.7
N_3H_3	2303	2261	1.8	289	283	2.1
N_3H_4	2586	2498	3.4	323	312	3.4
Mean	2559	2404	6	320	301	6
RMSE	174.6			21.4		
d-stat	0.998			0.998		
NRMSE	6.82			6.69		

Table 6. Observed and simulated values of days to anthesis and maturity Expt-2 (2015)

Treat-ments	Anthesis date (DAS)			Maturity date (DAS)		
	Obs.	Sim.	% devi-ation	Obs.	Sim.	% devi-ation
DS_1H_1	64	60	6.3	114	111	2.6
DS_1H_2	64	60	6.3	115	111	3.5
DS_1H_3	59	60	-1.7	109	111	-1.8
DS_1H_4	61	59	3.3	114	110	3.5
DS_2H_1	63	59	6.3	116	111	4.3
DS_2H_2	62	59	4.8	115	110	4.3
DS_2H_3	61	59	3.3	109	110	-0.9
DS_2H_4	60	58	3.3	111	109	1.8
DS_3H_1	60	61	-1.7	111	111	0.0
DS_3H_2	61	60	1.6	113	111	1.8
DS_3H_3	57	60	-5.3	107	110	-2.8
DS_3H_4	61	59	3.3	114	109	4.4
Means	61	60	2	112	110	2
RMSE	2.7			3.4		
d-stat	0.999			0.999		
NRMSE	4.36			3.02		

Pioneer. The authors reported that the genotypic coefficient P1 was 225°C day for BARI Hybrid Maize-7 and BARI Hybrid Maize-9, while that was 226°C day for PIONEER and NK-40. The P2 was same for all the varieties and P5 was 956°C day for BARI Hybrid Maize-7 and BARI Hybrid Maize-9, while that was 965 for PIONEER and 964 for NK-40. According to the same authors there was considerable variation among the cultivars in G2 and G3 but PHINT were the same amongst the cultivars.

The model predicted both days to anthesis and maturity of all the four tested hybrids across dates of sowing with the mean RMSE values of ±1.5 and ±5.7 days. Similarly the index of agreement (d-stat) values for anthesis and maturity were 1.00 and 0.998; and NRMSE of 2.47, 5.04%, and R2 of 0.99 respectively, which is categorized as excellent (Table 2; figure 1 and 2).

On contrary to our work (Ahmed *et al*., 2017) in Bangladesh reported that validation of simulated days to anthesis was over estimated compared to simulated values irrespective of cultivars where error percentages ranged from 3.75% to 4.94% during the 2015-16, respectively; whereas the days to maturity was in conformity to our work.

The model predicted all the four tested hybrids across the N rates and showed excellent performance with respect to grain yield which is depicted by the highest index of agreement (d-stat) value of 0.999 and NRMSE value of 7.5 %, respectively (Table 3). The evaluation of the model also showed a good agreement in the total above ground biomass which was asserted by the highest index of agreement values of 0.986 and NRMSE value of 17.5%, respectively (Table 3). This was in agreement with the work of Balderama *et al*. (2017) who

Table 7. Observed and Simulated values of grain yield and total shoot biomass for Expt-2 (2015)

Treat-ments	Grain yield (kg ha^{-1})			Total shoot biomass (kg ha^{-1})		
	Obs.	Sim.	% devi-ation	Obs.	Sim.	% devi-ation
DS_1H_1	9000	8467	5.9	17350	17049	1.7
DS_1H_2	9167	8505	7.2	20583	17088	17.0
DS_1H_3	7600	7892	-3.8	16200	16457	-1.6
DS_1H_4	9220	8259	10.4	18005	17017	5.5
DS_2H_1	9745	9017	7.5	19191	17974	6.3
DS_2H_2	10050	9058	9.9	19750	18013	8.8
DS_2H_3	8100	8403	-3.7	16500	17639	-6.9
DS_2H_4	10050	8858	11.9	19685	17892	9.1
DS_3H_1	8533	8017	6.0	17772	17481	1.6
DS_3H_2	9250	8053	12.9	18600	17517	5.8
DS_3H_3	8017	7474	6.8	16108	16835	-4.5
DS_3H_4	9533	7564	20.7	19167	16846	12.1
Means	9022	8297	8	18243	17317	5
RMSE	3.4			1568.7		
d-stat	0.999			0.999		
NRMSE	3.02			8.60		

Table 8. Observation and Simulation values of No. of grains m^{-2} and per cob for Expt-2 (2015)

Treat-ments	No. of grains m^{-2}			No. of grains cob^{-1}		
	Obs.	Sim.	% devi-ation	Obs.	Sim.	% devi-ation
DS_1H_1	2903	2721	6.3	363	340	6.3
DS_1H_2	2619	2733	-4.4	327	342	-4.6
DS_1H_3	2235	2536	-13.5	279	317	-13.6
DS_1H_4	2881	2724	5.4	360	341	5.3
DS_2H_1	3045	2905	4.6	381	363	4.7
DS_2H_2	2956	2919	1.3	369	365	1.1
DS_2H_3	2454	2779	-13.2	306	347	-13.4
DS_2H_4	3140	2999	4.5	392	375	4.3
DS_3H_1	2510	2652	-5.7	314	331	-5.4
DS_3H_2	2721	2663	2.1	340	333	2.1
DS_3H_3	2586	2472	4.4	323	309	4.3
DS_3H_4	2979	2570	13.7	372	321	13.7
Mean	2752	2723	0	344	340	0
RMSE	206.5			25.8		
d-stat	0.999			0.999		
NRMSE	7.50			7.51		

was conducted study in Philippines to estimate the genetic coefficient of hybrid corn cultivar in 2013-2015 using Ceres-Maize Model of DSSAT software. They reported that the validation process was successful as manifested by the goodness of fit between actual and simulated biomass from the five validation sites. The R^2 ranged from 0.86 to 0.97 with d-stat ranging from 0.71 to 0.98 and RMSEs were low which ranged from 1,718 to 5,725 kg ha^{-1} of biomass further the grain yield from the five plots. Actual and simulated yield showed high goodness of fit with R^2, RMSE and d-stat of 0.82, 1,118.40 kg ha^{-1}, and 0.89, respectively.

Soler *et al.* (2007) conducted a research in subtropical environment in Brazil reported that the evaluation of the CSM-CERES-Maize model for simulating the duration from planting to silking revealed similar average values for the four hybrids between observed and predicted values, such as 58 days for observed and 59 days for simulated for irrigated conditions and 59 days for both observed and simulated for the rainfed conditions. The coefficient of determination (r^2) between the simulated and observed duration from planting to anthesis for the four hybrids in the three experiments was 0.96, with the slope of the regression equation not statistically different from one and the intercept not different from zero ($P = 0.05$). In addition, the normalized RMSE was low (1.6%).

Furthermore according to these authors model for simulating the duration from planting to physiological maturity, showed identical average values for the four hybrids between observed and simulated values, 129 days for irrigated conditions and 128 days for rainfed conditions. For the four hybrids, the normalized RMSE was low, e.g., 0.7 per cent. Furthermore, the r^2 was high, e.g., 0.99, with a slope of the regression equation that was not statistically different from one and the intercept

Table 9. Observed and Simulated values of single grain weight for Expt-2 (2015)

Treatments	Single grain weight (g)		
	Obs.	Sim.	% deviation
DS_1H_1	0.308	0.311	-1.0
DS_1H_2	0.349	0.311	10.9
DS_1H_3	0.340	0.311	8.5
DS_1H_4	0.317	0.303	4.4
DS_2H_1	0.317	0.310	2.2
DS_2H_2	0.338	0.310	8.3
DS_2H_3	0.328	0.302	7.9
DS_2H_4	0.320	0.294	8.1
DS_3H_1	0.342	0.302	11.7
DS_3H_2	0.360	0.302	16.1
DS_3H_3	0.310	0.302	2.6
DS_3H_4	0.320	0.294	8.1
Mean	0.329	0.304	7.32
RMSE	0.03		
d-stat	0.997		
NRMSE	8.94		

was not different from zero (P = 0.05), confirming the ability of the CSM-CERES-Maize model for simulating the duration from planting to physiological maturity of maize grown off-season in a subtropical environment.

The model outputs were excellent with respect to number of grains m^{-2} and number of grains/cob which was in conformity with the highest index of agreement values (0.998 and 0.998) and NRMSE values (6.82 and 6.69 %), respectively (Table 4).

The model validation result showed the model predicted the unit grain weight well Expt-1 (2016) (Table 5), which can be clearly observed from the smallest RMSE value of ± 0.022 g , highest index of agreement value of 0.9998, and the smallest NRMSE value of 6.47 which categorizes model performance as excellent.

The model validation result showed that it is highly efficient with respect to the anthesis and maturity of the 2015 DS Vs. hybrid experiment evaluation, which was clearly seen from the very smallest RMSE value of (± 2.7 and 3.4), the highest index of agreement values of 0.999and 0.999, and the smallest NRMSE values of 4.36 and 3.02% which are categorized under excellent category (Table 6).

Evaluation of the performance of the model in prediction of the grain yield and total above ground biomass showed that the grain yield was very much closer to the observed data which is revealed by the lowest RMSE value of (±3.4 kg/ha), index of agreement value of (0.999), and the NRMSE value of (3.02%) which showed the simulation of the parameter fall under excellent category; and also the model was highly effective in predicting the total above ground biomass which can be seen from the statistical parameters; index of agreement value (0.998) and NRMSE value of 8.6%, respectively which are the effective measure of model capability in predicting the parameters (Table 7).

Table 8 shows that the model evaluation was excellent in predicting the parameters with respect to No. of grains m^{-2} and No. of grains/cob which was in a very closer value which can be asserted from the statistical parameters which recorded lowest RMSE values of (±206.5 and 25.8 grains), highest index of agreement values of (0.998 and 0.998), and NRMSE values of (7.50 and 7.51%), respectively.

The evaluation of the DSSAT-CERES-maize model perfectly validates in predicting single grain weight of field data of 2015 season of DS vs. H (Table 9). This can be asserted by the lower value of RMSE (±0.03g), the highest index of agreement value of 0.999 and NRMSE value of (8.94%), respectively showed the highest performance the model in predicting very closely to the observed data. Our work was in agreement with Ahmed *et al*. (2017) who reported the performance of the DSSAT-CERES model after its calibration was satisfactory and the results were within significant limits and also were similar to the results of (Jones and Thornton, 2003) and (Ma *et al*., 2006).

Conclusion

Maize has taken an important place among cereal crops of India after the introduction of hybrid genotypes and its potential to productivity. It is necessary to understand the growth behaviour of hybrid maize in different production environment, especially to address future climate change impacts. Since crop growth model plays an important role in describing variability study performances. The DSSAT CERES maize model was calibrated and validated for Northern Transition Zone of Karnataka environment using field experimental data. The performance of the model was evaluated through phenology, total above ground biomass at harvest, grain yield, and yield components. The simulated results were in close agreement with the observed values and these were within the acceptable statistical significance limit. Simulated and observed phenology and yields were in close agreement with the observed values. It can be inferred that the DSSAT CERES maize model can be successfully employed for simulating the growth and yield of maize hybrids grown under various growth factors, including evaluation of the climate change impact analysis in Northern Transition Zone of Karnataka.

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