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Growth, phenology and yield modeling for wheat-fallow cropping system in Gujarat

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ABSTRACT

CropSyst is a daily time step crop growth simulation model that can be used to study the effect of cropping systems management on crop productivity and environment. A total five years experimental field observations (2009-10 to 2013-14) comprising four sowing dates, viz. November 1, 15, 30 and Dec 15 for wheat-fallow crop rotations were used to simulate the growth, phenology and yield for wheat cultivar GW 322 at Anand (Gujarat). Among the five years observations, initial two years observations (2009-10 and 2010-11) were used for model parameterization and remaining year's observations (2011-12 to 2013-14) were used for model performance evaluation. The results indicated that the model was able to predict the wheat phenology precisely in terms of mean bias error (MBE) and root mean square error (RMSE) which was less than 6 days for all the phenological stages except maturity date on Dec 15 sowing. Nov 15 sowing has resulted in maximum grain and biological yield and found to be optimum date for sowing followed by Nov 30 for this region while Dec 15 resulted in highest yield reduction. It was also observed that CropSystmodel was efficient in simulation of yield and biomass of wheat crop during various years of observations. The model has efficiently predicted grain and biological yield with ±10% of model error for wheat crop. However, it failed to predict the leaf area index (LAI) precisely. It may also be concluded that the model error were less for early and normal sown crops but increased with the delay in sowing.

Key words: CropSyst, Phenological stages, RMSE, Simulation model, Wheat-fallow

In the present era of technology, crop simulation models have become an essential tool to understand the interactions of genetics, physiology and environment integration across disciplines and organization of data. Their application in agricultural research is increasing day by day since they have proved to be valuable for policy makers by providing them an estimate for soil erosion, effects of climatic change and large-area yield forecasts (Boote *et al.* 1996) and can be used to predict crop performance in regions where the crop has not been grown before. They are of crucial importance to study the effect of a scenario which is difficult to observe in field conditions such as changes in temperature or rainfall pattern or adaptation strategies to climate change (Rauff and Bello 2015). CropSyst is a multi-year, multi-crop and daily time step simulation model to study the effect of climate, soils and management on cropping systems productivity and the environment (Stockle *et al.* 2003). The input data requirement for CropSyst includes location, weather, soil, crops and management data in separate files. A simulation control file combines these input files to produce specific simulation runs. Furthermore, the control file also determines the simulation start and end date define the crop rotations to be simulated, and set the values of all parameters requiring initialization.

Wheat is a major staple food of India which is grown more or less in all the districts of Gujarat. However, the productivity of wheat in Gujarat is lower as compared to neighboring states, e. g. Punjab and Haryana, as the shorter winter does not provide congenial climatic conditions for wheat growth that can be minimized by modifying the crop-management practices. However, it will require extensive and planned field experimentation but still all aspects influencing yield cannot be taken care of at one time in the field experiment since such a step will lead to statistical complexity and has to go a long way to arrive at some concrete results. Therefore, an attempt has been made in this experiment to simulate growth, phenology and yield modeling for wheat-fallow cropping system for Anand District in Gujarat (India).

MATERIALS AND METHODS

Experimental data: The field observations conducted at research farm of Anand Agricultural University, Anand

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(Latitude 22°35' N, Longitude 72°55' E and 45.1 m above mean sea level) were used for the study. A total of five years experimental field observations (2009-10 to 2013-14) comprising four sowing dates, viz. Nov 1, 15, 30 and Dec 15 for wheat-fallow crop rotation were used to simulate the growth, phenology and yield for wheat cultivar GW 322 at Anand (Gujarat) while keeping the same levels of treatment and management practices. The recommended agronomic practices were adopted for wheat-fallow crop rotation during all the years under study. Among the total years of observations, initial two years (2009-10 and 2010-11) were used for model calibration and parameterization and remaining year's observations (2011-12 to 2013-14) were used for validation of the CropSyst model.

Weather data: Daily weather data for maximum and minimum temperature (°C), relative humidity (%), solar radiation (MJ/m^2/day), wind speed (m/s) and rainfall (mm) during the crop growth period for Anand were obtained from the observatory of the Anand Agricultural University, Anand. The observatory is located close to experimental farm with total distance less than 250 m from the experimental field.

Soil data: Soil samples at different depth (starting from surface upto 120 cm) were collected from the experimental field and the soil physico-chemical properties of the composite samples were analyzed (Table 1). At top soil layer the proportion of sand and clay was maximum (80.19 and 13.36%, respectively) which decreased with lower layers up to 90 cm but, again increased at 120 cm depth. Proportion of the silt in different depth was entirely different from the sand and the silt. Among different depth, the soil pH varied between 7.5 and 7.6. Though, top layer was rich in the permanent wilting point (0.076 m^3/m^3), field capacity (0.173) and water potential at field capacity (-15.43 kPa) but, air entry potential (-0.365 J/kg) and bulk density (1.452 Mg/m^3) was very poor.

Table 1 Physico-chemical properties for the experimental soil profile

Soil parameter	Depth			
	0-30 cm	30-60 cm	60-90 cm	90-120 cm
Sand (%)	80.19	79.95	79.10	79.20
Silt (%)	6.50	7.20	8.89	8.48
Clay (%)	13.36	12.85	12.01	12.32
pH	7.5	7.5	7.5	7.6
Permanent wilting point (m^3/m^3)	0.076	0.074	0.067	0.063
Field capacity	0.173	0.168	0.152	0.148
Bulk density (Mg/m^3)	1.452	1.489	1.664	1.682
Water potential at Field Capacity (kPa)	-15.43	-14.748	-14.475	-12.843
Saturated hydraulic conductivity (m/day)	2.543	2.449	1.371	1.541
Air entry potential (J/kg)	-0.365	-0.39	-0.519	-0.585

Parameterization of crop cultivars in the model: For simulating any crop cultivar in CropSyst, the crop module requires genetic parameters that describe the growth and development characteristics for the cultivar. These genetic coefficients for the wheat cultivar GW 322 were estimated after obtaining a close match between observed and predicted values for various phenological stages and yield attributes, e.g. leaf area index (LAI), plant biomass, grain yield etc. Subsequently, these coefficients were used to validate the model performance.

Statistical analysis: The model performance was analyzed using following two statistical characteristics.

The mean bias error (MBE) can be defined as:

$$MBE = \frac{1}{n}\sum_{i=1}^{n}\left(P_i - O_i\right)$$

Ideally, MBE should be zero which reflects a perfect estimation. A positive value for MBE reflects over-estimation while a negative value is an underestimation.

Similarly, the root mean square error (RMSE) may be calculated as:

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

where P_i and O_i are the i^{th} predicted and observed values, respectively.

The value of RMSE can always be positive and zero in the case of perfect agreement. Low values of RMSE are considered appropriate for model prediction.

RESULTS AND DISCUSSION

Model calibration: It is evident from the data that there was a good agreement between observed and simulated values for most of the phenological stages including grain as well as biological yield (Table 2). However, the simulated Leaf Area Index (LAI) has shown significant difference from actual. Difference between observed and simulated physiological maturity was only 2-5 days. Average observed and simulated phenological events described that model under estimated the days to flowering by 2.3 days under early (01 Nov) sowing and over estimated by 2.7 days for late (15 Dec) sowing (Not presented here). Likewise, simulated days to grain filling were 2 to 3. 4 days more than observed. But, deviation for days to maturity was 0. 3 to 5. 7 days. The late sowing showed maximum difference in simulation of the phenological stages of the wheat.

Model validation: The statistical analysis confirmed that CropSyst model predicted various growth characters and wheat yield attributes reasonably well except leaf area index. The mean absolute error (MAE) for different phenological stages (Table 3) varied between 1. 33 to 3. 33 for days to flowering, 2. 00 to 3. 33 for grain filling and 1. 00 to 5. 67 for grain maturity. Subsequently RMSE values have also varied between 1. 29 days to 5. 80 days for flowering, 2. 16 to 3. 56 days for grain filling and 1. 29 to 5. 80 for maturity. Grain yield and biological yield results (Table 4) showed a RMSE less than or equal to 2. 84 and 6. 12 respectively among all the treatments. It may be concluded from the data that CropSyst model was satisfactorily able to simulate different phenological stages, viz. days to flowering, grain filling and maturity for all the sowing dates during years of observations. Benli *et al.* (2007) and Singh *et al.* (2008) have also found promising results by using CropSyst for wheat based cropping systems. On an average, low MBE and RMSE values were found for normal and early sown wheat crop as compared to late sown wheat. This finding has also been supported by Pal *et al.* (2015) who reported that CERES-wheat model was found better with crop sown on 20 Nov than 15 Dec and 9 Jan for wheat crop in *Tarai* region of Uttarakhand, India.

Among the date of sowing treatments, better growth and yield characters have been recorded for Nov 15 followed by Nov 1 and Nov 30 sowing dates. On the other hand, Dec 15 sowing of wheat crop resulted in significant reduction of yield. The reason for this could be attributed due to change in the crop growth environment due to delayed sowing and also because of high temperatures that could result in accelerating crop development and shortening of the crop growth cycle. Under these circumstances cumulative intercepted solar radiance and biomass production were decreased. Delayed sowing beyond the optimum range led to reduced grain weight which has also been reported by Andarzian *et al.* (2015).

It may be concluded from the results that after the parameterization, CropSyst was able to simulate the phenology and yield characteristics of wheat and the predictions by CropSyst model were reasonably accurate and they were in close proximity with the observed values. Therefore CropSyst model can be effectively used for simulating the growth and yield of wheat crop. In addition to this, this model can be further used to decide and finalize various crop management activities such as irrigation scheduling and optimal fertilizer management. Furthermore,

Table 2 Simulated and observed phenological dates, grain and biological yield for GW322 during 2009-10 and 2010-11 (calibration)

Cropping year	Days taken to flowering (DAS)		Days taken to grain filling (DAS)		Days taken to maturity (DAS)		LAI		Grain yield (q/ha)		Biological yield (q/ha)	
	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.
2009-10	59	59	78	80	113	115	3.51	2.48	38.48	38.61	93.25	85.80
2010-11	59	60	82	86	113	118	3.3	3.04	42.38	44.85	90.66	99.66

Table 3 Average observed and simulated days to flowering, grain filling, and maturity for different sowing dates validation

Planting dates	Data type	Days to flowering (DAS)			Days to grain filling (DAS)			Days to maturity (DAS)		
		Mean	MAE	RMSE	Mean	MAE	RMSE	Mean	MAE	RMSE
1 Nov	Obs	63.0	2.33	3.51	81.3	2.00	2.16	118.0	1.00	1.29
	Sim	60.7			83.3			117.7		
15 Nov	Obs	66.0	1.33	1.63	82.0	2.33	2.38	114.7	2.67	2.71
	Sim	64.7			84.3			117.3		
30 Nov	Obs	63.0	3.00	3.87	82.3	3.00	3.00	115.7	2.67	2.83
	Sim	66.0			85.3			118.3		
15 Dec	Obs	62.0	3.33	3.74	83.3	3.33	3.56	112.0	5.67	5.80
	Sim	64.7			86.7			117.7		

Obs, Observed; Sim, simulated.

Table 4 Average observed and simulated leaf area index, grain yield and biological yield for different sowing dates validation

Planting dates	Data type	Leaf Area Index (LAI)			Grain yield (kg/ha)			Biological yield (kg/ha)		
		Mean	MAE	RMSE	Mean	MAE	RMSE	Mean	MAE	RMSE
1 Nov	Obs	3.27	0.61	0.65	41.04	1.92	2.10	91.15	3.16	3.72
	Sim	2.65			40.94			89.73		
15 Nov	Obs	3.20	0.51	0.57	49.92	1.71	2.02	105.30	5.04	5.38
	Sim	3.27			50.36			108.52		
30 Nov	Obs	3.23	0.75	1.04	44.03	2.70	2.84	89.79	4.74	5.33
	Sim	3.96			45.75			94.53		
15 Dec	Obs	2.67	1.29	1.30	40.77	2.51	2.64	89.32	5.75	6.12
	Sim	3.96			43.28			95.08		

Obs, Observed; Sim, simulated.

the optimum sowing window for wheat is during Nov 1–30 in this region. Moreover, model evaluations might also be required for additional cultivars which are released for this region.

REFERENCES

Andarzian B B, Hoogenboom G, Bannayan M, Shirali M and Andarzian B B. 2014. Determining optimum sowing date of wheat using CSM-CERES-Wheat model. *Journal of the Saudi Society of Agricultural Sciences* **149**(2): 189–99.

Benli B, Pala M, Stockle C and Oweis T. 2007. Assessment of winter wheat production under early sowing with supplemental irrigation in a cold highland environment using CropSyst simulation model. *Agricultural Water Management* **93**(1): 45–53.

Boote K J, Jones J W and Pickering N B. 1996. Potential uses and limitations of crop models. *Agronomy Journal* **88**(5): 704–16.

Pal R K, Rawat K S, Singh J and Murty N S. 2015. Evaluation of CSM-CERES-wheat in simulating wheat yield and its attributes with different sowing environments in Tarai region of Uttarakhand. *Journal of Applied and Natural Science* **7**(1): 404–9.

Rauff K O and Bello R. 2015. A review of crop growth simulation models as tools for agricultural meteorology. *Agricultural Sciences* **6**: 1098–105.

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**(7): 776–86.

Stöckle C O, Donatelli M and Nelson R. 2003. CropSyst, a cropping systems simulation model. *European Journal of Agronomy* **18**(3-4): 289–307.