Journal of Agrometeorology 15 (1) : 43-50 (June 2013)

Simulation of growth and yield of four wheat cultivars using WOFOST model under middle Gujarat region

S. K. MISHRA*, A. M. SHEKH, S.B. YADAV, ANIL KUMAR, G.G. PATEL, V. PANDEY and H. R. PATEL

Department of Agricultural Meteorology, B. A. College of Agriculture
Anand Agricultural University, Anand, Gujarat-388110
**Corresponding author: sudhirmet@yahoo.com*

ABSTRACT

WOFOST is a mechanistic crop growth simulation model capturing the complex effect of climate, genotype and agronomic variable through several functions. Results showed that mean observed days to anthesis were 57.9 ± 2.5, 61.1 ± 2.1, and 59.5 ± 1.6 during 2009-10, 2010-11 and for pooled data, while simulated days to anthesis were 60.3 ± 3.9, 62.8 ± 2.0 and 61.6 ± 2.2, respectively. The values of RMSE for simulated maximum LAI were 0.11, 0.08 and 0.08 for 2009-10, 2010-11 and for pooled data, respectively. The observed mean yields were 3406 ± 223, 3757 ± 684 and 3581 ± 430 kg ha^{-1} during 2009-10, 2010-11 and for pooled analysis while, respective simulated mean yields were 3496 ± 435, 4061 ± 684 and 3778 ± 494 kg ha^{-1}. Likewise, measured above ground production were 8349 ± 752, 8495 ± 953 and 8422 ± 796 kg ha^{-1} during 2009-10, 2010-11 and for pooled data, while corresponding simulated biomass were 8787 ± 698, 8910 ± 733 and 8889 ± 653 kg ha^{-1}, respectively. The very low value of correlation coefficient r=0.30 and standard deviation ± 4.26 proves the failure of WOFOST model for simulation of harvest index during 2009-10. However, during second year and for pooled analysis the model efficiently and accurately simulated the harvest index. The model performance was somewhere underestimated or overestimated but found within quite acceptable limits. The WOFOST model may be used for simulation and forecasting the yield of wheat.

Key words : WOFOST, Wheat, Simulation

Among the various production commodities of basic importance, agricultural production is the one which is subjected to wide and irregular fluctuations of output. Wheat (*Triticum aestivum* L.) is one of the most important staple food crop cultivated in at least 43 countries and provides 20% of food calories to the mankind, covering 223.6 million hectares area and producing 690.0 million tones with an average productivity of 3.08 tha^{-1} (Anon., 2010a). The major wheat growing countries are USSR, USA, China, India, Canada, Australia, France, Turkey and Pakistan. In India, wheat is next to paddy in area and production, grown over an area of 27.75 million hectares with an annual production of 80.68 million tones. India rank second after China in wheat growing countries. It is considered to be the backbone of the food security in India. Wheat is cultivated in almost all the states of India, but its extensive cultivation is confined to Uttar Pradesh, Punjab, Haryana, Rajasthan, Madhya Pradesh and Gujarat. Gujarat accounts an area of 10.91 lakh hectares under wheat production, about 25.9 lakh tones grains with an average productivity of 2.8 t ha^{-1} as against 2.6 t ha^{-1} productivity of the nation (Anon., 2010b). Wheat is grown more or less in all the districts in the state. However, the productivity of wheat in Gujarat is lower as compared to Punjab and Haryana, because the short winter season does not provide congenial climatic conditions for the growth. All aspects influencing yield cannot be taken care of at a 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. This is evidently time consuming and expensive. Under these circumstances, development or even validation of simulation model could be the best alternative to study production constraints of crops.

WOFOST (World Food Study) is a member of the family of crop growth models developed in Wageningen by the school of C.T. de Wit. Related models are SUCROS (Simple and Universal CROp growth Simulator), MACROS (Modules of Annual CROp Simulator) and ORYZA1. WOFOST is a mechanistic model that explains crop growth on the basis of the underlying processes, such as photosynthesis, respiration and how these processes are influenced by environmental conditions. This model

Table 1: Soil characteristics of Anand used as input in WOFOST

S. No.	Parameters	Descri-ption
1.	Soil texture	Sandy loam
2.	Organic carbon (%)	0.39
3.	Field capacity (%)	18.0
4.	Permanent wilting point (%)	5.0
5.	Saturation moisture content (%)	0.43
6.	Bulk density (%)	1.5

simulates the daily growth of specific crops, using the selected weather and soil data. Each simulation is conducted for specific boundary conditions, which comprise the crop calendar and the soil's water and nutrient status. WOFOST follows the hierarchical distinction between potential and limited production. Light interception and CO_2 assimilation are the growth driving processes, and crop phenological development is the growth controlling process. WOFOST calculates first the instantaneous photosynthesis at three depths in canopy, which is subsequently integrated over the depth of the canopy and over the light period, to arrive daily total canopy photosynthesis. After subtracting maintenance respiration, assimilates are partitioned amongst roots, leaves, stems and storage organs, using partitioning factors that are a function of the phenological development stage of the crop (Spitters et al., 1989). Fraction portioned to the leaves, determines leaf area development and hence dynamics of light interception. Dry weights of plant organs are obtained by integrating their growth rates over time.

MATERIALS AND METHODS

For calibration and validation of WOFOST crop growth and yield simulation model data on different growth and yield attributes were collected by conducting the field experiments in two consecutive *rabi* seasons during 2009-10 and 2010-11 at the research farm of the Department of Agrometeorology, AAU, Anand (Gujarat), India situated at 22°35' N latitude and 72°55'E longitude and at an altitude of 45.1 m above mean sea level. The experiment was laid out in split plot design with a combination of four varieties viz., GW 322 (V_1), GW 496 (V_2) and GW 366 (V_3) and GW 1139 (V_4) and four different dates of sowing 1st Nov. (D_1), 15th Nov. (D_2), 30th Nov. (D_3) and 15th Dec. (D_4). The daily weather data were recorded at agrometeorological observatory situated about 50 meters away from the experimental site. The soil samples of experimental field were collected and analyzed for preparation of soil file use as input of the model. The soil file in WOFOST contains information on soil physical characteristics (Boogaard *et al.*, 1998). Two types of soil files can be used in WOFOST. Files with extension "NEW" can be used in simulation of water-limited crop growth with free drainage as well as with groundwater influence, while the soil files with extension "AWC" can only be used for simulation with free drainage. There is no influence of groundwater in the study areas, therefore in this study AWC soil file has been used. Physical soil characteristics have been estimated based on soil texture and organic carbon content (Saxton and Rawls, 2006). The soil characteristics used in WOFOST model are listed below in Table 1. The WOFOST model requires fourteen major parameters which were obtained by running the model iteratively till the cultivar showed observed and predicted variation less than 10%. The calibrated genetic coefficients separately for each cultivars used for validation of WOFOST model are given in Table 2. The different test criteria viz., mean of observed and simulated values, standard deviation (SD), mean absolute error (MAE), mean bias error (MBE), root mean square error (RMSE) and mean percent error (PE) were used to evaluate the performance of model for simulation of phenology and yield characters of all four wheat cultivars.

RESULTS AND DISCUSSION

Days taken to anthesis

The accurate simulation of phenological development of a crop is crucial for accurate simulation of crop growth and yield. Thus, evaluation of the phasic development is the most important and the first step in any study aimed at assessment of the performance of a simulation crop model. Results showed that mean observed days to anthesis were 57.9 ± 2.5, 61.1 ± 2.1, and 59.5 ± 1.6 during 2009-10, 2010-11 and for pooled data, while simulated days to anthesis were 60.3±3.9, 62.8 ± 2.0 and 61.6 ± 2.2, respectively. The values of errors as computed in terms of MAE, MBE, RMSE and percent errors showed that model performed better in 2010-11 than in 2009-10. Deviations were higher in 2009-10. The range of mean error percents of days to anthesis (mean of four dates of

Table 2: Model parameters used for calibration of WOFOST

Coeffi-cients	Description	GW 322	GW 496	GW 366	GW 1139
TBASEM	Lower threshold temp. for emergence (°C)	5.0	5.0	5.0	5.0
TSUMEM	Temperature sum from sowing to emergence (°C)	130	105	105	135
TSUM1	Temperature sum from emergence to anthesis (°C)	1238	1200	1150	1350
TSUM2	Temperature sum from anthesis to maturity (°C)	998	1010	950	1000
DLO	Optimum day length for development (hour)	10	10	10	10
TDWI	Initial total crop dry weight (kg ha^{-1})	210	210	208	210
LAIEM	Leaf area index at emergence	0.136	0.137	0.135	0.137
SPAN	Life span of leaves growing at 35 °C (day)	31.3	31	30	31.5
CVL	Efficiency of conversion into leaves (kg ha^{-1})	0.685	0.7	0.685	0.7
CVO	Efficiency of conversion into storage organs (kg ha^{-1})	0.80	0.75	0.709	0.85
CVR	Efficiency of conversion into roots (kg ha^{-1})	0.694	0.69	0.694	0.7
CVS	Efficiency of conversion into stems (kg ha^{-1})	0.662	0.662	0.662	0.7
RML	Relative maintenance respiration rate of leaves (kgCH_2O kg^{-1} d^{-1})	0.03	0.03	0.031	0.015
RMO	Relative maintenance respiration rate of storage organs (kg$CH_2O$$kg^{-1}$$d^{-1}$)	0.01	0.01	0.01	0.015
RMR	Relative maintenance respiration rate of roots (kgCH_2O kg^{-1} d^{-1})	0.015	0.015	0.015	0.015
RMS	Relative maintenance respiration rate stems (kgCH_2O kg^{-1} d^{-1})	0.015	0.015	0.015	0.015

sowing) for wheat cultivar GW 322 were 4.1, 2.81 with mean of 3.31%, for GW 496 it were 4.38, 3.38 with mean of 4.04%, for cultivar GW 366 it were 3.33 to 4.01 with mean of 3.16% and for GW 1139 it were 4.38 and 2.01 with mean of 3.30% (Table 3). The results (Fig.1) showed that the WOFOST model overestimated the days to anthesis in wheat during both the years of study including the pooled data analysis with the respective value of correlation coefficient r=0.92** (2009-10), r=089* (2010-11) and r=0.77 (pooled). The results are in good agreement with the findings of Mishra *et al.*, (2010) for days to anthesis in wheat as simulated by WTGROWS and InfoCrop wheat models.

Days taken to maturity

The performance of WOFOST model in terms of simulated days to maturity was found superior in the year 2010-11 to that in 2009-10 and also in case of pooled data with the deviation of ±4.76, ±4.11 and ±3.65 (Table 3). Again a high value of correlation coefficient r=0.77, r=0.78* and r=0.83* was found during both the years and pooled data analysis (Fig.2). Tongyai (1994) also reported reasonable agreement between simulated and observed days to maturity with RMSE=4.8 and SE=4.6 d for a range of varieties.

Maximum leaf area index (LAI)

The overall results showed that the LAI was underestimated by the model for wheat cultivars GW 1139 and GW 366 and whereas, overestimated for the cultivars GW 322 and GW 496 (Fig.3). The correlation coefficient and mean error percent was r= 0.75* and -1.7% during 2009-10, r=0.75* r=0.91** and -0.4% in 2010-11 and r=0.86 and -1.1% pooled data analysis. The performance of the model in simulating the LAI on pooled basis was good as magnitudes of error percent remain less than 7.0% in most of the cases. The cultivar GW 322 recorded more or less highest error percent irrespective of sowing dates. However, there was no definite trend of error percent was found among the treatment consisting of four different dates of sowing and four different sowing environments. The values of RMSE for simulated

Table 3: Test criteria for evaluation of model for different growth and yield parameters of wheat

Parameters	OM	SDo	SMY	SDs	MAE	MBE	RMSE	PE
	Days to anthesis (days)							
2009-10	58	2.49	60	3.89	2.5	2.38	0.83	4.03
2010-11	61	2.11	63	2.04	1.75	1.75	0.55	2.89
Pooled	60	1.59	62	2.19	2.06	2.06	0.64	3.45
	Days to physiological maturity (days)							
2009-10	106	4.4	109.88	4.76	4.25	4.13	1.42	3.93
2010-11	112	4.33	113.13	4.11	2.38	1.25	0.83	1.15
Pooled	109	3.97	111.5	3.65	3.06	2.69	0.96	2.5
	Maximum leaf area index							
2009-10	3.9	0.56	3.8	0.6	0.38	-0.08	0.11	-1.75
2010-11	3.8	0.65	3.8	0.71	0.25	-0.01	0.08	-0.36
Pooled	3.8	0.52	3.8	0.57	0.25	-0.04	0.08	-1.15
	Grain yield (kg ha^{-1})							
2009-10	3406	223.36	3496	435.49	303.88	90	89.87	2.5
2010-11	3757	683.99	4061	684.47	303.81	303.81	91.95	8.48
Pooled	3581	429.8	3778	493.93	210.69	196.91	69.54	5.45
	Above ground biomass (kg ha^{-1})							
2009-10	8349	751.55	8787	698.35	535.44	438.44	174.67	5.49
2010-11	8495	953.23	8910	733.24	555.69	415.44	181.25	5.4
Pooled	8422	795.93	8849	653.18	467.56	426.94	163.22	5.38
	Harvest index (%)							
2009-10	41.08	2.42	40.04	4.26	3.15	-1.05	4.01	-2.45
2010-11	42.93	3.82	42.62	4.11	1.47	-0.31	1.71	-0.72
Pooled	42.38	3.06	41.35	3.27	1.66	-1.02	1.98	-2.39

maximum LAI were 0.11, 0.08 and 0.08 for 2009-10, 2010-11 and for pooled data, respectively.

Grain yield

Results showed that observed mean yields were 3406 ± 223, 3757 ± 684 and 3581 ± 430 kg ha^{-1} during 2009-10, 2010-11 and for pooled analysis while, respective simulated mean yields were 3496±435, 4061±684 and 3778±494 kg ha^{-1}. The mean absolute error (MAE) were 304, 304 and 211 kg ha^{-1}, while RMSE (Root mean square error) were as 90, 92 and 70 kg ha^{-1} during 2009-10, 2010-11 and for pooled analysis, respectively (Table 3). The MAE and RMSE were lower during the year 2009-10 than 2010-11 and pooled analysis. Similarly, the lower PE (percent error) also followed the same trend like MAE and RMSE with 2.50, 8.48 and 5.45 values during 2009-10, 2010-11 as well as pooled data analysis. Likewise, the correlation coefficient (Fig. 4) during 2009-10, 2010-11 and pooled basis was r=0.70*, r=0.98** and r=0.95**, respectively. WOFOST is a mechanistic crop growth simulation model capturing the complex effect of climate, genotype and agronomic variable through several

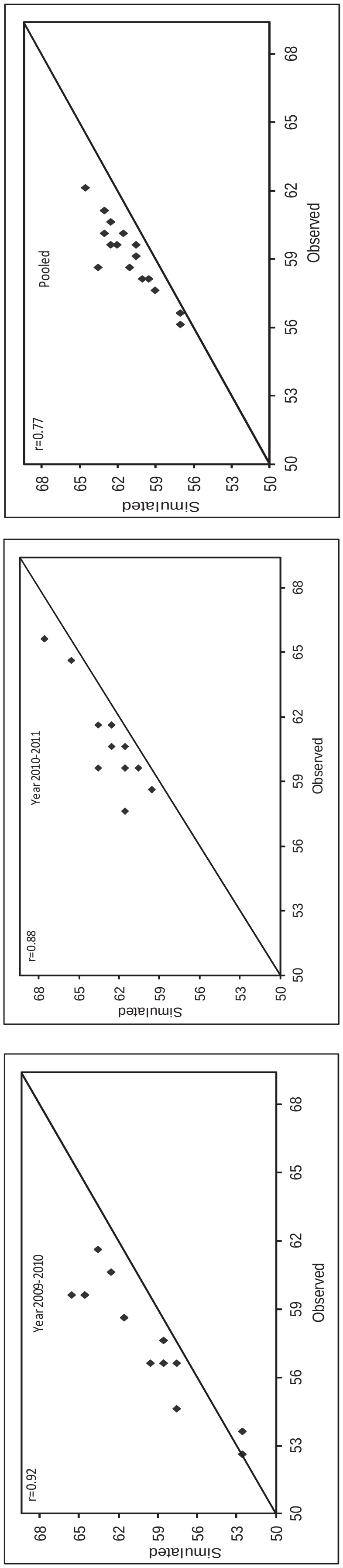

Fig. 1: Simulated and observed days to anthesis in various wheat cultivars under different dates of sowing

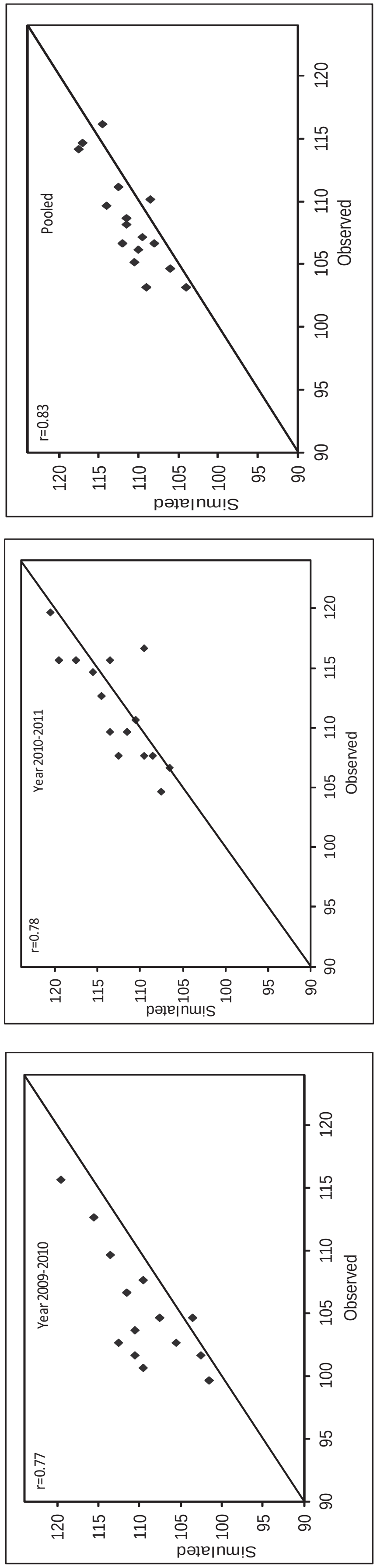

Fig. 2: Simulated and observed days to maturity in various different dates of sowing

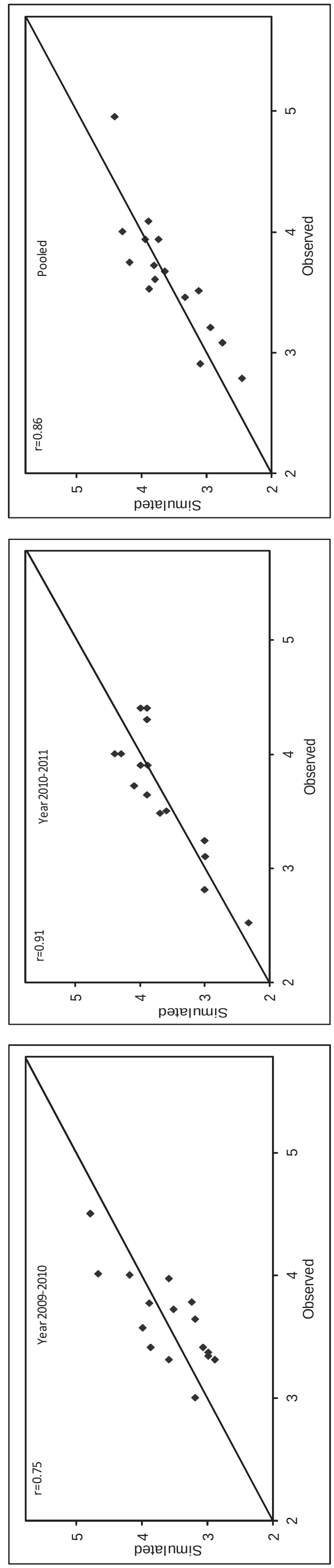

Fig. 3: Simulated and observed maximum leaf area index in various wheat cultivars under different dates of sowing

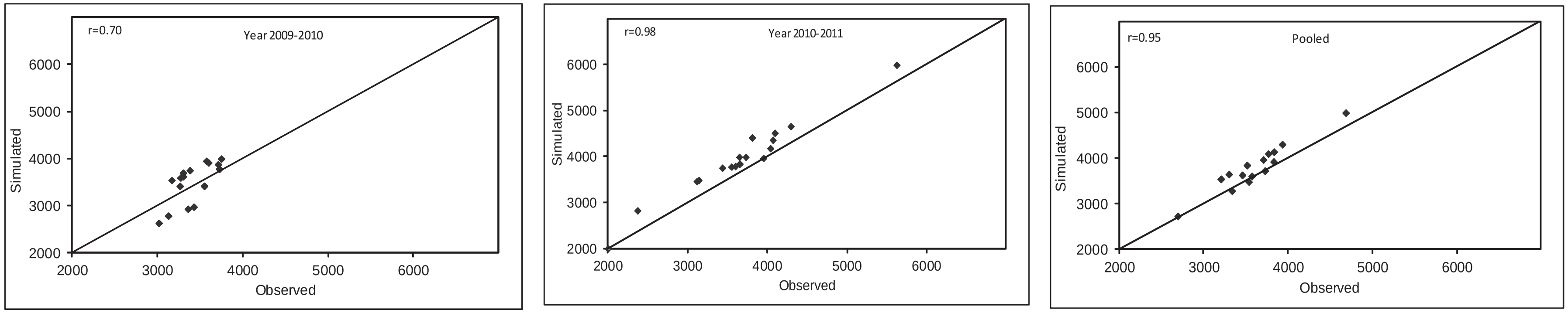

Fig. 4: Comparison of model simulated and observed grain yield (kg/ha) in various wheat cultivars under different dates of sowing

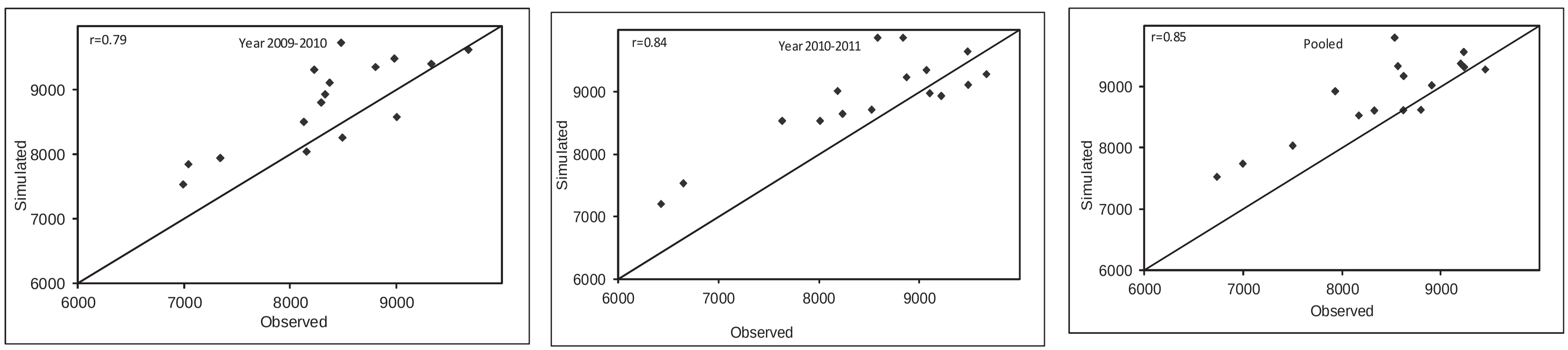

Fig. 5: Observed and simulated above ground biomass production (kg/ha) in various wheat cultivars under different dates of sowing

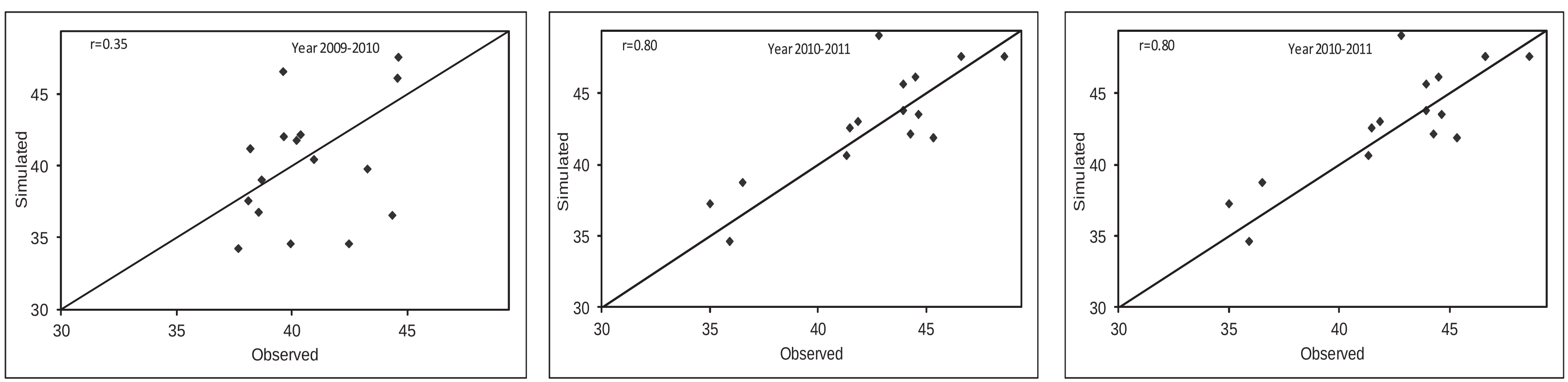

Fig. 6: Simulated and observed harvest index in various wheat cultivars under different dates of sowing

functions. Perhaps, such a variation could be intrinsic to the model. Timsina *et al*. (1995) reported simulated grain yield of Pant 4 were within 1 to 15% of observed yields. Similar result was recorded by Seino (1995) for comparing the simulated and observed yield of wheat crop.

Above ground production

The measured above ground biomass production were 8349±752, 8495 ± 953 and 8422±796 kg ha^{-1} during 2009-10, 2010-11 and for pooled data, while corresponding simulated biomass were 8787±698, 8910±733 and 8889±653 kg ha^{-1}, respectively. Deviation was less in 2009-10, as compared to 2010-11 and pooled basis. The average errors as computed by MAE were 535, 556 and 468 kg ha^{-1}, while RMSE values were 175, 181 and 163 kg ha^{-1} during 2009-10, 2010-11 and for pooled data, respectively. MBE was lowest during 2009-10. Likewise, the correlation coefficient between observed and simulate above ground production during 2009-10, 2010-11 and pooled basis was r= 0.79*, r= 0.84*and r=0.85*, respectively (Fig. 5).

Harvest index (HI)

The test criteria for model evaluation described that observed harvest index (HI) during 2009-10, 2010-11 and pooled basis were 41.08, 42.93 and 42.38% with standard deviation of 2.42, 3.82 and 3.06, respectively. The simulated HI was 40.04, 42.62 and 41.35 with deviation of 4.26, 4.11 and 3.27 during 2009-10, 2010-11 and pooled basis, respectively. It was seen that the model could not simulate better the harvest index fro the crop sown during first year. The very low value of correlation coefficient in this year (r=0.30) reveals that there was not very good association between observed and simulated harvest index during the first year sown crop. The ±4.26 standard deviation also proves the failure of WOFOST model during 2009-10. However, during second year sown crop as well as for pooled analysis the model again efficiently and accurately simulated the harvest index. The large variation in the values of harvest index might also be due to the effect of lodging as reported by Moot *et al*., (1996). The various test criteria as presented in Table 3 showed that the overall performance of model in simulating the harvest index was found to be good.

SUMMARY AND CONCLUSION

Second date of sowing (D_2-15th November) was found to be optimum for higher grain yield production of all the wheat cultivars selected in this study however, under adequate management package and practices the cultivar GW 322 performed best. Grain yield of wheat, anthesis date, days to maturity, harvest index were satisfactorily simulated by the WOFOST model for all selected cultivars of wheat sown under varying environmental condition. This clearly showed the robustness of the WOFOST model for growth and yield simulation of wheat crop. WOFOST can be used to estimate crop production, to indicate yield variability, to evaluate the effects of climate changes or soil fertility changes, and to determine the limiting biophysical factors.

REFEENCES

Anonymous (2010a). Agricultural Statistics at a Glance, Ministry of Agriculture, Govt. of India, New Delhi.

Anonymous (2010b). District wise area, production and yield of important food and non food crops in Gujarat state for the years 2006-07 and 2007-08. Directorate of Agriculture, Gujarat state, Gandhinagar.

Boogaard, H. L., C. A. Van Diepen, R. P. Roetter, J. M. C. A. Cabrera and H.H. Van Laar (1998). WOFOST 7.1; User's guide for the WOFOST 7.1 crop growth simulation model and WOFOST Control Center 1.5. DLO Winand Staring Centre, Wageningen, The Netherlands.

Mishra, S. K., Lunagariya, M. M., Karande, B.I., Patel, H.R. and Pandey, V. (2010). Calibration and validation of WOFOST (v 7.1) simulation crop model in wheat crop under middle Gujarat region. *J. Agrometeorol.*, 11 : 165-170.

Moot, D. J., Jamieson, P. D., Henderson, A. L., Ford, M. A. and Porter, J. R. (1996). Rate of change in harvest index during grain filling of wheat. *J. Agril. Sci.*, **126** (a): 387-395.

Saxton, K. E. and W. J. Rawls (2006). Soil water characteristic estimates by texture and organic matter for hydrologic solutions. *Soil Sci. Soci. America J.,* 70(5): 1569-1578.

Seino, H. (1995). The impacts of climatic warming on cereal crop production in Japan. *J. Agril. Meteorol.*, **51** (2): 131-138.

Spitters, C. J. T., Keulen, H. van, Kraalingen, D. W. G. Van, (1989). *A simple and universal crop growth simulator: SUCROS 87*. In: R. Rabbinge, S.A. Ward & H.H. van

Laar (Eds.) Simulation and systems management in crop protection. Simulation Monographs, Pudoc, Wageningen, The Netherlands.

Timsina, J., Singh, U., Singh, Y. and Lansigan, F. P., (1995). Addressing sustainability of rice-wheat systems: testingand applications of CERES and SUCROS models. In: Proc. Int. Rice Res. Conf. 13-17 Feb. 1995. IRRI, LosBanos, Philippines. pp. 633-656.

Tongyai, C. (1994). Impact of climate change on simulated rice production in Thailand. *In:* Rosenzweig, C and Iglesias, A (Eds.), Implications of Climate Change for International Agriculture: Crop Modelling Study. US Environmental Protection Agency. EPA 230-B-94-003, Washington DC, USA

Received : February 2013 ; Accepted : April 2013