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Simulating dry biomass of forage sorghum using CERES-Sorghum model

SUCHIT K. RAI* and B.R.D. GUPTA
Department of Geophysics, B.H.U., Varansi-221005

ABSTRACT

The field study data of forage sorghum from different locations were used to validate CERES-Sorghum model. Model simulated anthesis duration $\pm$ 3 days under normal conditions and without bias (-0.8 to –2.1 days). However, model tended to overestimate anthesis duration under moisture stress conditions. Leaf area index (LAI) was overestimated as much as 50% higher than the observed values between 35 and 50 days after planting. The model performed satisfactorily in simulating total dry biomass (TDM), but it generally underestimated TDM (Bias= -1815.1 kg ha^{-1}) in response to different sowing date. TDM could be well predicted in response to historical weather variability in different agro climatic conditions.

Key Words: CERES-Sorghum model, forage sorghum, genetic coefficient, validation

India has traditionally been a livestock rearing country, which accounts for about 15% of the total livestock population of the world geographical area. The increasing population pressure and its ramifications resulted in a demand for more food thus diverting the attentions of farmers and rendering the forage farming a secondary priority. Among various forage crops, sorghum is an important dual purpose crop and in India it represents about 30% of world acreage and 83% that of in south East Asia. It is cultivated in the states of Maharashtra, Karnataka, Madhya Pradesh, Andhra Pradesh, Rajasthan, Taminlnadu and Gujarat on an average of 12.6 million hectare of land with a production of 11.0 million tonnes (Rana *et al.*, 1998).

In order to sustain the higher production and minimise the environmental degradation, understanding of crop growth in relation to varying resource inputs and agro-environments for management options is required. Plant ·growth model by dynamically simulating interactions among climatic, soil, crops and management, offer the best opportunity for developing guidelines when previous experience is limited (Rosenthal and Gerik, 1990).

Forage sorghum lacks in availability of well validated and tested growth model for different agro-ecological zones to identify appropriate resource management

*Present address: Indian Grassland and Fodder Research Institute, Jhansi-284003

for sustainable fodder and grain yield. Ferraris and Vanderlip (1986) showed that SORGF, a grain sorghum growth model (Arkin *et al.* 1976) could be used to simulate forage (Sweet) sorghum growth. Also the SORKAM a grain sorghum model has been used to simulate forage sorghum development and growth (Fritz *et al.* 1997). Till date none of the available model was tested and validated for forage sorghum in Indian regions. Keeping this in view, here an attempt has been made to validate CERES- Sorghum model (Ritchie and Algarswamy, 1989) for forage sorghum crop in the semi-arid region of India

MATERIALS AND METHODS

Input data

To validate CERES sorghum model, data sets were selected from field experiment at different locations (Jhansi, Hisar, Delhi, Pantnagar, Akola and Rahuri) drawn from different years (Table 1). The data cover a wide range of Indian semi-arid conditions and mimic many of the environments found in semi arid parts of the country. All sets contained forage dry biomass at 50% flowering date. The experiments particularly at Jhansi consisted three different dates of sowing incorporated leaf area index values at different interval of days during 1996 and 1997. Planting dates ranged from 5th July to 15th September, plant population ranged from approximately 110000 –300000 plants per hectare. The long term observed daily weather data on maximum and minimum temperature, solar radiation (derived from sunshine hours data) and rainfall for simulation are obtained from India Meteorological Department (IMD), Pune and Indian Grassland and Fodder Research Institute, Jhansi. Data on the soil parameters such as soil albedo, soil water drainage constant, field capacity, wilting point, initial soil moisture, organic carbon and pH in different layers as well as maximum root depth have been used to simulate the forage dry biomass (Table 2). Management practices (plant population, plant row spacing and nitrogen application) were kept as obtained from the experiments record.

Validation comparisons

Observed and simulated values (Anthesis, LAI and Biomass) were statistically compared at all sites. The model was evaluated by regressing simulated parameters on measured values. If the determination of coefficient was significant then 't'-test was made to determine, whether the slope and intercept are different from 1 and 0, respectively (Heinger *et al.* 1997). Also Bias and RMSE (Root Mean Sum of Square) were used to evaluate overall performance of the model (Retta *et al.* 1996).

$$\text{Bias} = 1/N\ \Sigma\ (S_i - O_i)$$

$$\text{RMSE} = \sqrt{1/N}\ \Sigma\ (S_i - M_i)^2$$

RESULTS AND DISCUSSION

Model calibration

The CERES family of crop models contain several genetic coefficients, which describe how the development of any

Table 1: Data sets used for validating CERES - Sorghum for seven locations in India

Stations	References	Variety	No of years	Plant population range	Planting dates
Jhansi	Rai (1997)	PC-6 and HC-136	1996-98	150000-300000	5 Jul.-15 Sept.
	AICSIP	HC-136, PC-6 , HC-171,	1986-97	180000-250000	5 Jul.- 10 Aug.
Hisar	AICSIP	HC-136	1985-96	110000-280000	20 Jun.- 2 Jul.
Delhi	AICSIP	HC-136	1981-92	110000-280000	2 Jun.-15 Jul.
Akola	AICSIP	HC-136	1985-92	110000-280000	25 Jun.-21 Jul.
Rahuri	AICSIP	HC-136	1985-92	110000-280000	25 Jun.-10 Jul.
Pantnagar	AICSIP	HC-136	1985-92	110000-280000	25 Jun.-27 Jul.

Table 2: Soil parameters at selected stations used in the validation of CERES –Sorghum model

S.No.	Stations	Soil depth (cm)	Lower/Upper limit (mm)	Saturated water content (mm)	Extractable water content (mm)
1	Jhansi	120	164/279	414	114
2	Hisar	120	133/273	383	140
3	Delhi	120	178/293	311	115
4	Pantnagar	105	86/216	325	128
5	Akola	120	317/514	638	197
6	Rahuri	120	347/524	602	177

genotype is influenced by environmental factors such as minimum and maximum temperature, day length, soil water and nitrogen contents or those, which characterize certain aspects of the life cycle or morphology of the cultivar. Using software GENCALC, the coefficient for 3 forage cultivars were estimated iteratively by running the model initially with most appropriate matched values listed in model. The coefficients were determined in a pre-set sequence, starting with those that relate to developmental aspects and then their growth aspects. The genetic coefficients of forage sorghum was obtained through above procedure are depicted in Table 3.

Model validation

Anthesis duration for the sowing from 5th July to 1st August during both the years (1996 and 1997) was predicted well at Jhansi. The deviation of simulated anthesis duration from observed was ± 1 and ± 3 days during 1996 and 1997 respectively for both cultivars for the sowing from 5th July to 1st August. However, the greatest error

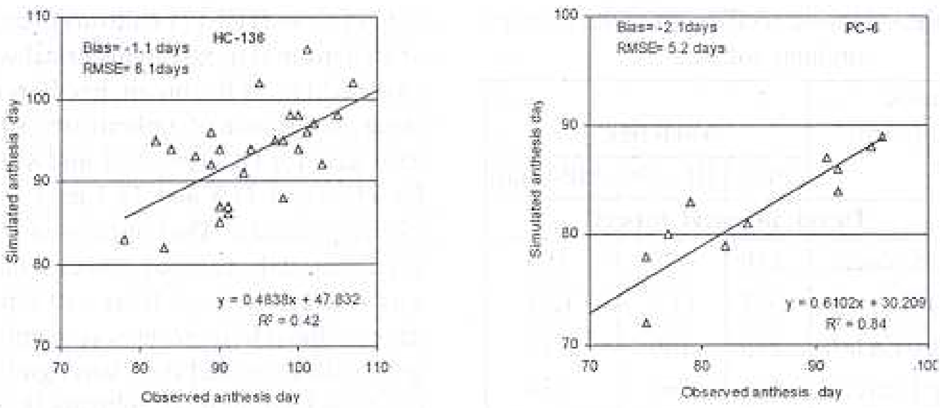
Table 3: Genetic coefficients of three forage sorghum cultivars

Genetic coefficient	Varieties		
	PC-6	HC-136	MP-Chari
Developmental aspect			
P_1 (°C day)	350	380	290
P_2O (h^{-1})	12.2	11.9	12.4
P_2R (°Cd h^{-1})	135	140	80
P_5 (°C day)	520	560	650
Growth aspect			
G_1	8	9	9
G_2	5.5	6.0	4.5
PHINT	60	62	56

in simulating anthesis duration occurred for late sowing (6.09.1996), which had a simulated anthesis of 120 (129) days compared with an actual anthesis of only 76 (87) days for cultivars PC-6 (HC-136). According to the field situations, these plants were under severe water deficit condition from the panicle initiation to anthesis. For the other locations under study, validation results revealed that the simulated anthesis duration for combination of sowing date and locations matched reasonably well with observed values (Fig. 1). However model slightly underestimated anthesis duration. Duration to anthesis for combinations of 4 sowing dates, 3 cultivars and 6 locations ranged 68 to 112 and 67 to 106 days for observed and simulated duration, respectively during 1981 to 1997. The percent deviation lying within the range of -10 to 15, -8 to 9.2, -8 to 21 % for HC-136, PC-6 and HC-171 cultivars irrespective of stations in response to historical weather variability. The mean predicted and observed duration of anthesis was 94.7 and 93.6 days for HC-136, 77.1 and 81.4 days for PC-6 and 71.8 and 73.3 days for HC-171 respectively. Thus agreement between simulated and observed anthesis duration was reasonably good (bias= -0.8 to -2.1 days), although intercept was significantly greater than zero and slope was significantly less than 1 for all three cultivars (Fig. 1)

In general model estimated pattern of leaf area index (LAI) at Jhansi over the time accurately for both varieties and for all transplanting range during 1996 and 1997 (Fig. 2a). LAI was generally overestimated at measured LAI between 1.25 and 4.3. The slope did not differ significantly from 1 for both cultivars, but all two had intercepts greater than 0. The mean difference between predicted and observed LAI was 0.43 (0.58) with standard deviation of ± 0.77 (± 1.1), respectively for cultivar PC-6 (HC-136) for combination of years and sowing dates. Predictability of total dry biomass (TDM) was better for both cultivars than LAI (Fig. 2b), but the predicted values are generally higher than the observed values between 35 to 50 days after sowing. The observed and predicted TDM ranged between 50 and 12550 (100 and 14650 kg ha^{-1}) kg ha^{-1} and 80 and 12760 (80 and 13700 kg ha^{-1}) kg ha^{-1} respectively for PC-6 (HC-136) cultivar. All two had intercepts greater than zero.

The trend of simulated TDM was well matched with the observed TDM for sowing



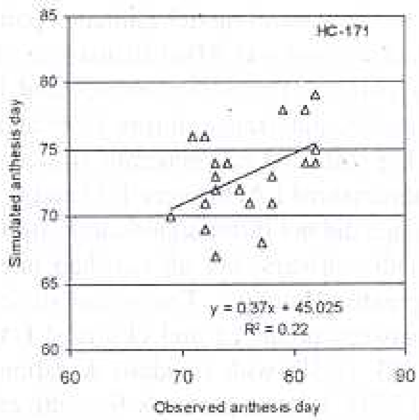


Fig.1 : Simulated vs. observed anthesis days of three cultivars of forage sorghum

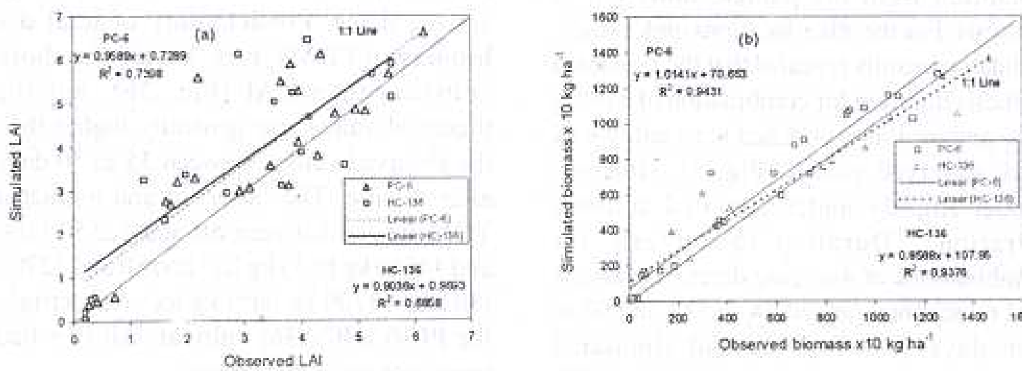
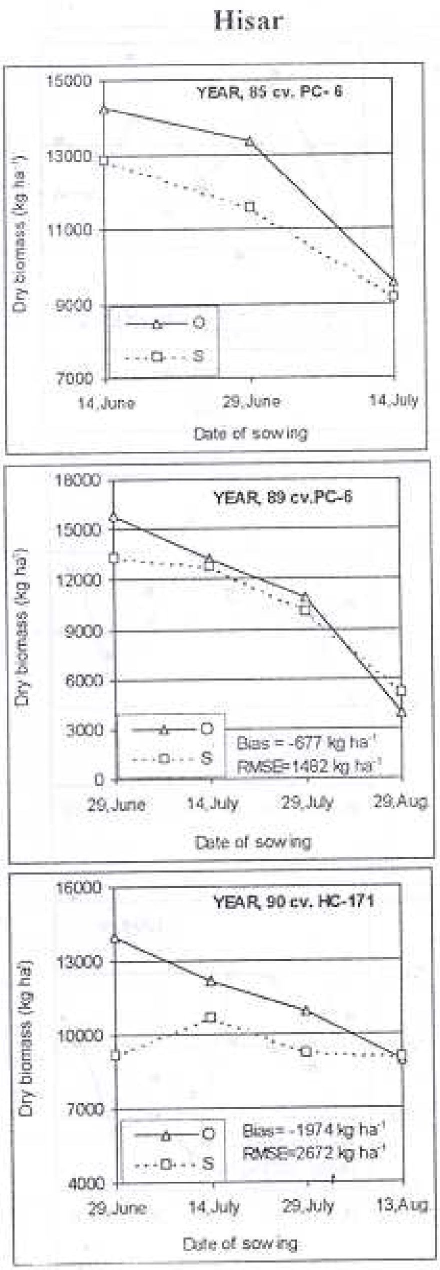
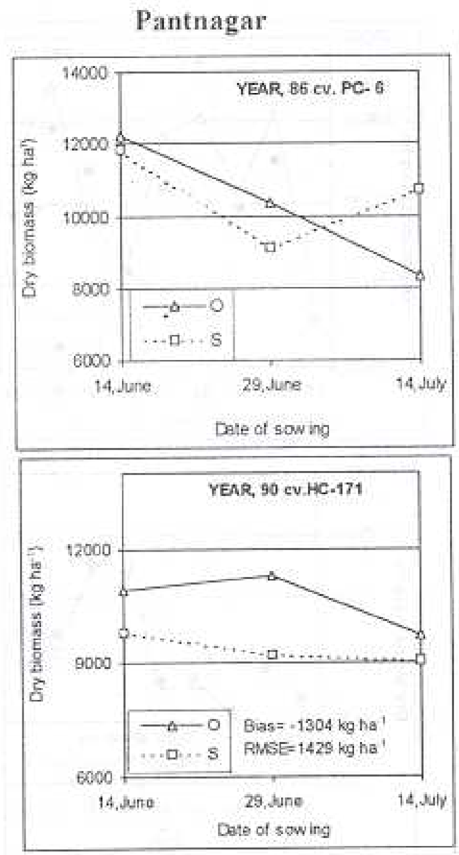


Fig. 2 : Simulated vs. observed (a) LAI and (b) dry biomass for forage sorghum cultivars at Jhansi





When Data set Pooled ,

Bias= -1018 kg ha^{-1}; RMSE=1815 kg ha^{-1}

When data set pooled on monthly basis

June : (Bias = -1919 kg ha^{-1}; RMSE= 2294 kg ha^{-1})

July : (Bias = -469 kg ha^{-1}; RMSE= 1334 kg ha^{-1})

August : (Bias = 664 kg ha^{-1};, RMSE = 844 kg ha^{-1})

Fig. 3: Simulated (S) and observed (O) dry biomass of forage sorghum cultivars under different date of sowing

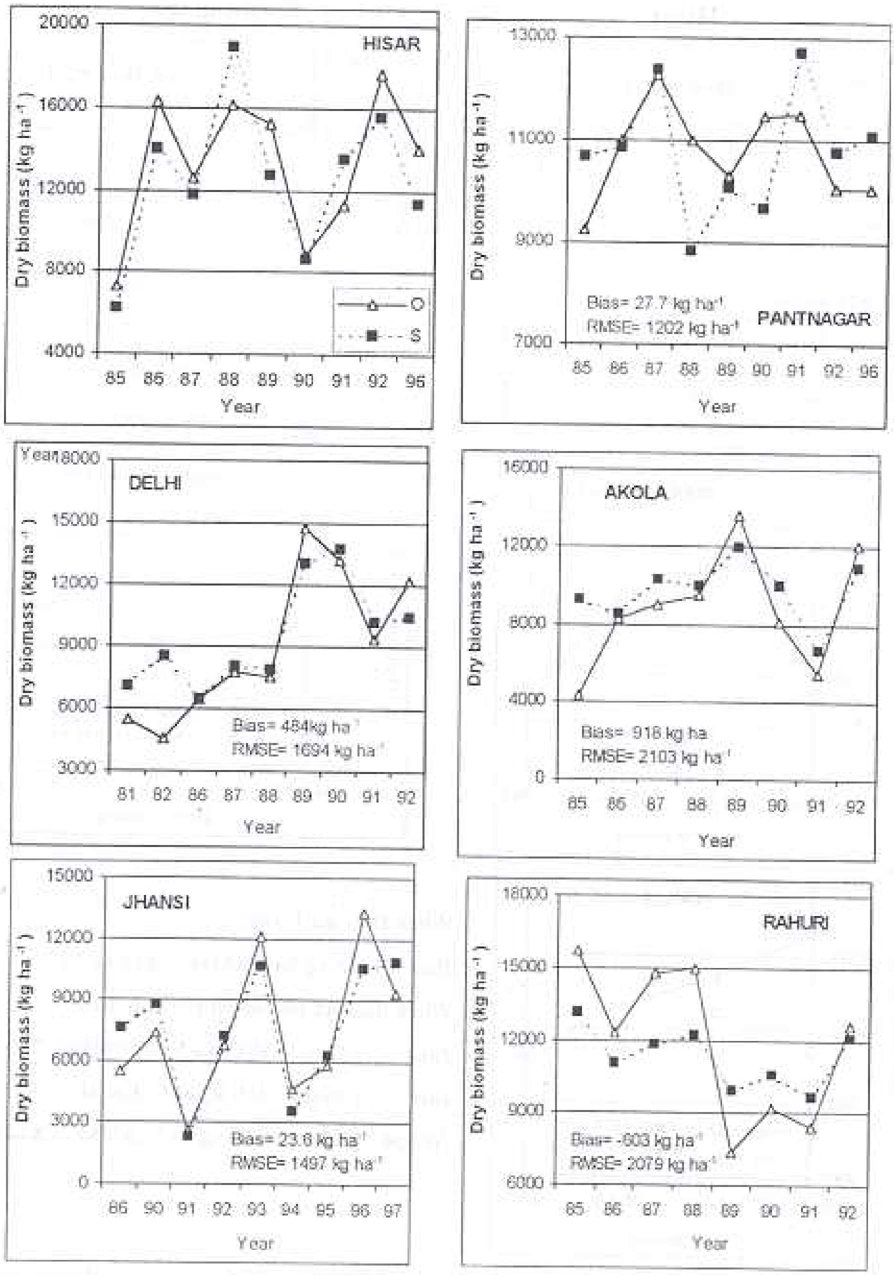


Fig. 4: Yearwise simulated (S) and observed (O) dry biomass of forage sorghum cultivar (HC - 136) at different locations

dates ranged between 14 June to 13 August at both Hisar and Pantnagar locations (Fig. 3). The over and under estimation of the predicted TDM ranged 1.6 to 28.5 and 3.2 to 34.5 % respectively. In 83% cases, the percent deviation between observed and simulated TDM ranged between 3.5 to 15 %. The mean predicted and observed TDM was 11179.2 and 10160.6 kg ha^{-1} respectively. The mean difference between predicted and observed TDM was - 1018 kg ha^{-1} with standard deviation of $\pm$ 1548.6 kg ha^{-1}. Validation of the model confirms that the TDM could be predicted fairly well, when the crop was sown during the month of July and August at these two locations (Fig. 3). Although model slightly under estimated (bias=-469 kg ha^{-1}) and overestimated (bias=664 kg ha^{-1}) TDM during July and August sowing respectively. But TDM was highly underestimated during June (bias= -1919 kg ha^{-1}) sowing. The model performed satisfactorily, accounting for 70 % of the TDM variability in combination of variety, date of sowing and agroclimatic conditions. Although, the slope (0.59) and intercept (3464) differed significantly from 0 and 1, respectively.

The simulated TDM were comparable with observed TDM in response to year to year variation in weather at different locations (Fig. 4). Deviation of simulated TDM from observed values ranged -12 to 37, -2 to 20, -19 to 15, -11 to 29.4 (except in year 1982, 88%.) -11 to 23 (except in the year 1985) and -19 to 35 % at Jhansi, Hisar, Pantnagar, Delhi, Akola and Rahuri respectively. Higher deviation (100 %) at Akola during 1985 was noticed due to incidence of pest and disease as reported at the experimental sites. While at Pantnagar, the underestimation is below more than 20 % is due to higher nitrogen leaching during the vegetative phase because of heavy rainfall causing nitrogen stress at the end of leaf growth stage. The bias (17.4 kg ha^{-1}) value by combining all data points suggests that model has skill to predict TDM in response to historical weather variability.

CONCLUSION

The study revealed that the anthesis duration was simulated without bias by CERES-sorghum model for forage cultivars. The model has skill to simulate dry biomass in response to historical weather variability and date of sowing.

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