*Original Research Paper*

# Calibration and Evaluation of DSSAT-CERES Model for *Kharif* Sorghum Genotypes


## Abstract

**Background:** Sorghum (*Sorghum bicolor* (L.) Moench) is one of the world's most important nutritional cereal crops and also the major staple food and fodder crop of millions of people in semi-arid tropics. It is considered as the 'King of millets' and extensively grown in Africa, China, USA, Mexico and India.
**Aims:** The present study evaluate the current generation of crop models require calibration of model vis-à-vis cultivar specific coefficients thus need calibration when a new genotype or cultivar is introduced.

**Study design:** The field experiment from which the data for modeling was used, was conducted during Kharif seasons of 2011 and 2012 under All India Coordinated Research Project (AICRP) on Sorghum at Main Agricultural Research Station, Dharwad, India.

**Results and discussion:** Anthesis and physiological maturity perfectly matched after calibration (2011 data) as well as for 2012 data, which showed that model could simulate phenology with high accuracy as it showed minimum RMSE of 0 and 1.41 for anthesis and maturity for the year 2011 (calibration) and 2.94 and 1.29 for anthesis and maturity, respectively for the year 2012 (evaluation). Four Kharif sorghum cultivars as listed above were screened across three dates of sowing. The genetic coefficients of these four cultivars within DSSAT-CERES Sorghum model were calibrated with data (that included phenology, biomass and yield components) collected from the experiment conducted during the year 2011.

**Conclusion:** This exercise of calibration of crop specific parameters of four kharif sorghum genotypes using DSSAT-CERES-Sorghum model followed by evaluation of model using another independent set of data showed that DSSAT-CERES-Sorghum performed well and the model could be used as decision support tool for all those optimized four genotypes for various applications viz., optimizing dates of sowing, population, spacing and inputs.




## INTRODUCTION

Sorghum (*Sorghum bicolor* (L.) Moench) is one of the world's most important nutritional cereal crops and also the major staple food and fodder crop of millions of people in semi-arid tropics. It is considered as the 'King of millets' and extensively grown in Africa, China, USA, Mexico and India. Sorghum ranks fourth among the world's most important cereal crops after wheat, rice and maize. During 2015-16, world sorghum grain production was about 57 million tonnes with an area and productivity of 38.16 million ha and 1493 kg $ha^{-1}$, respectively (Anon., 2016).

In India, it is cultivated in *kharif, rabi* and summer seasons. In India it's a major dryland crop currently grown over an area of about 2.26 million hectares during *kharif* with a production of 2.30 million tonnes and at a productivity of 1014 kg $ha^{-1}$. About 85 per cent of total production is concentrated in Maharashtra, Karnataka and Andhra Pradesh. In Karnataka, the *kharif* and *rabi* area accounts for 1.16 and 9.31 lakh ha, respectively with a production of 1.60 lakh tonnes in *kharif* and 10.14 lakh tonnes in *rabi* season. The average productivity of *kharif* and *rabi* sorghum is 1379 and 1089 kg $ha^{-1}$, respectively (Anon., 2015). Over the years area, production and productivity has decreased due to introduction of cash crops, crops suited for mechanized production as well as changing food habits.

Crop simulation models are principal tools needed to bring agronomic sciences into information sciences. With these crop models, it became possible to simulate a living plant through the mathematical and conceptual relationship which governs its growth in the Soil – Water – Plant - Atmosphere continuum. Crop simulation models explain much of the interaction between the environment and the crops. The crop growth models are helpful to assess the impact of climate change on the stability of crop production under different management options (Hoogenboom *et al*., 1995). Crop growth simulation models provide means to quantify the effect of climate on soil, crop growth, productivity and sustainability of agriculture production. These tools can reduce the need for expensive and time consuming field experimentation and can be used to analyze yield gaps in various crops including sorghum. Crop simulation model is quite useful as it forms an association between crop process analysis and performance assessment in which process operation are in their natural circumstances. Crop models can be used for crop forecasting with potential in forecasting production scenarios (Matthews *et al*., 2002). Crop models can help researchers, policymakers and farmers to make appropriate decisions on crop management practices, marketing strategies and food security of a country with a deterministic view on the import-export policy. However, current generation of crop models require calibration of model vis-à-vis cultivar specific coefficients thus need calibration when a new genotype or cultivar is introduced, therefore this study was taken up.

## MATERIAL AND METHODS

**Description of the Study Area**

The field experiment from which the data for modeling was used, was conducted during Kharif seasons of 2011 and 2012 under All India Coordinated Research Project (AICRP) on Sorghum at Main Agricultural Research Station, Dharwad, located at $15^0$ $26^{'}$ North latitude, $75^0$ $07^{'}$ East longitude and at an altitude of 678 m above mean sea level (MSL). This station comes under the Northern Transitional Zone, No-8 of agro- climatic zones of Karnataka and lies between the Western Hilly Zone (Zone-9) and Northern Dry Zone (Zone-3). The average annual rainfall from 1985-2014 was 722.80 mm, and rainfall during Kharif 2011 and 2012 (June-September) was 598.60 and 339 mm, respectively, representing two different situations; 2011 was above normal year, and 2012 was rain deficit and relatively warmer year (Table-1).

**Source of experimental data**

This experiment involved three dates of sowing *viz*., 15 June, 30 June and 15 July, and four genotypes *viz.,* CSV-17, CSV-23, CSH-16 and CSH-23 sown at a spacing of 45x15 cm. Five tons per ha of well decomposed compost was applied 3 weeks before sowing and incorporated into the soil by disc ploughing. Recommended dose of fertilizer (100:75:25 kg N, $P_2PO_5$, $K_2O$ $ha^{-1}$) was applied to each treatment; 50 % of total N and full dose of P and K were applied as basal during sowing and remaining 50 % of N was applied as top dressing at 30 DAS. The soil of the experimental site was deep black clay with pH 7.61, EC 0.51 dS $m^{-1}$, organic carbon content 0.59 %, available N 225.0 kg $ha^{-1}$, $P_2O_5$ 19 kg $ha^{-1}$ and $K_2O$ 322 kg $ha^{-1}$ with a total profile depth of 180 cm. The data on phenology (days to 50 % flowering and physiological maturity), grain yield, stover yield and total above ground biomass collected during experimentation were borrowed from the AICRP on Sorghum team and used for model calibration and evaluation.

**Model Description**

Decision Support Systems for Agro-technology Transfer (DSSAT) is a process oriented dynamic crop simulation model. This model operates on a daily time step and simulates crop growth and development of different crops including sorghum (Jones *et al.*, 2003). Model requires four main types of input data: weather, soil, crop and management. The daily weather data includes maximum and minimum temperature, rainfall and solar radiation, soil data includes texture, colour, slope, nitrogen and organic matter content across layers. Crop data includes cultivar specific genetic coefficients with information on development (phenology) biomass accumulation, grain yield and yield attributes, and management data includes, namely soil preparation, planting dates, spacing, plant density, fertilization amounts and timing or other agricultural practices which were followed for the crop as per the recommendations of the university for NTZ.

**Statistical approach of model evaluation**

**Root mean square error**

The root mean square error (RMSE) values indicate how much the model over or under estimate compared to observed measurements. Lower the RMSE values higher the performance of model. RMSE tests the accuracy of the model and set of RMSE values were calculated using the below formulae.

$$\text{RMSE} = \sqrt{\left[\frac{1}{n} + \sum_{i=1}^{n} (Pi - Oi)^2\right]}$$

$Pi$ = Predicted yield, n = number of samples

$Oi$ = Observed yield, $\bar{O}$ = mean of all $Oi$ values.

A smaller RMSE means less deviation of the simulated values from the observed values, thus indicates better performance.

**Table 1: Mean monthly meteorological data for the experimental years (2011 and 2012) and mean of past 30 years (1985-2014) at UAS, Dharwad**

| Month | Rainfall | | | Maximum Temperature | | | Minimum Temperature | | | Solar Radiation | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2011 | 2012 | 1985-2014 | 2011 | 2012 | 1985-2014 | 2011 | 2012 | 1985-2014 | 2011 | 2012 | 1985-2014 |
| May | 66.60 | 3.80 | 68.40 | 34.70 | 35.70 | 35.20 | 21.30 | 21.50 | 21.20 | 23.29 | 23.58 | 21.57 |
| June | 194.00 | 43.40 | 109.70 | 27.50 | 30.20 | 29.60 | 21.30 | 21.20 | 21.10 | 17.96 | 18.21 | 17.64 |
| July | 131.00 | 112.20 | 134.20 | 26.90 | 27.30 | 27.20 | 20.60 | 20.80 | 20.70 | 15.48 | 15.90 | 15.74 |
| August | 124.20 | 90.00 | 105.20 | 26.70 | 27.20 | 26.80 | 20.70 | 20.50 | 20.40 | 15.85 | 16.38 | 15.67 |
| September | 82.80 | 89.60 | 103.60 | 28.10 | 28.20 | 28.40 | 19.90 | 19.70 | 20.00 | 19.50 | 17.94 | 14.87 |
| **Total** | **598.60** | **339.00** | **521.10** | **28.78** | **29.72** | **29.44** | **20.76** | **20.74** | **20.68** | **18.42** | **18.40** | 17.09 |

## RESULTS AND DISCUSSION

### Model calibration and validation

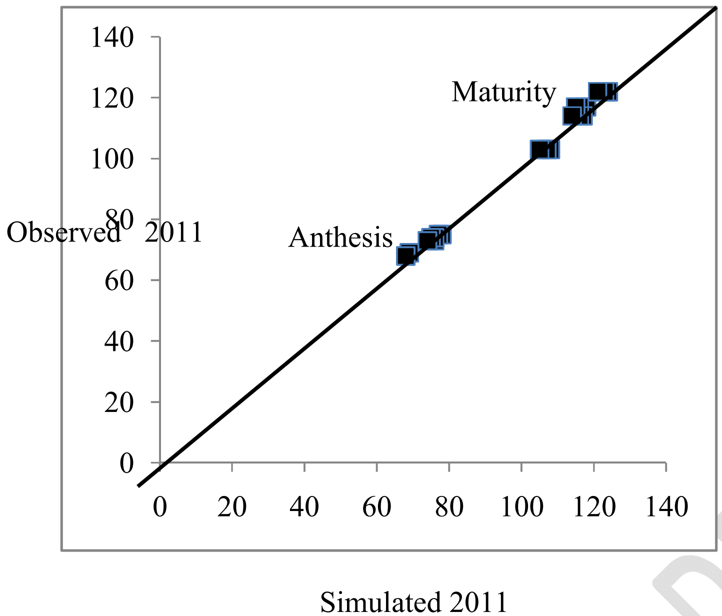
Calibration is a process of adjusting and/or optimizing model parameters, especially cultivar specific genetic coefficients, so that model simulated outputs match well with observed data from the experimentation for a given cultivar before the model is used for other application using those cultivars. Whereas, Validation is the testing of crop models across the situation. In this project four Kharif sorghum cultivars as listed above were screened across three dates of sowing. The genetic coefficients of these four cultivars within DSSAT-CERES Sorghum model were calibrated with data (that included phenology, biomass and yield components) collected from the experiment conducted during the year 2011. The genetic coefficients for the varieties used in the present simulation studies were optimized using Gencalc (Mavromatis *et al.*, 2001), a semi-automated program embedded within DSSAT to optimize genetic coefficients, followed by manual method. The optimized coefficients after calibration process are presented in Table-2 and the description of each coefficient is presented in Table-3. Whereas, the same type of data collected from the experiment during Kharif 2012 was used for validation/evaluation of the model.

**Table 2: Calibrated genotypic coefficients for four kharif sorghum cultivars**

| Parameters | CSV-17 | CSV-23 | CSH-16 | CSH-23 |
|---|---|---|---|---|
| P1 | 220.0 | 340.0 | 335.0 | 300.0 |
| P2 | 85.0 | 70.0 | 80.0 | 90.0 |
| P2O | 12.50 | 12.50 | 12.50 | 12.50 |
| P2R | 43.70 | 85.0 | 90.0 | 90.0 |
| PANTH | 617.50 | 570.5 | 580.5 | 580.5 |
| P3 | 130.50 | 142.5 | 135.5 | 140.5 |
| P4 | 70.50 | 81.5 | 95.0 | 81.5 |
| P5 | 540.0 | 590.0 | 650.0 | 570.0 |
| PHINT | 49.00 | 49.0 | 49.0 | 49.0 |
| G1 | 10.00 | 5.0 | 5.0 | 5.0 |
| G2 | 4.5 | 6.0 | 6.0 | 6.0 |

**Table 3: Description of genetic coefficients of kharif sorghum cultivars**

| Coefficient code | Description |
|---|---|
| **P1** | Thermal time from seedling emergence to the end of the juvenile phase (expressed in degree days above base temperature). |
| **P2** | Thermal time from the end of the juvenile stage to heading under short days (degree days above base temperature). |
| **P2O** | Critical photoperiod or the longest day length (in hours) at which development occurs at a maximum rate. |
| **P2R** | Extent to which phasic development leading to heading (expressed in degree days) is delayed for each hour increase in photoperiod above P2O. |
| **PANTH** | Thermal time from the end of heading to fertilization (degree days above base temperature). |
| **P3** | Thermal time from to end of flag leaf expansion to fertilization (degree days above base temperature). |
| **P4** | Thermal time from fertilization to beginning of grain filling (degree days above base temperature). |
| **P5** | Thermal time from beginning of grain filling to physiological maturity (degree days above base temperature). |
| **PHINT** | Phylochron interval; the interval in thermal time between successive leaf tip appearances (degree days). |
| **G1** | Scaler for relative leaf size |
| **G2** | Scaler for partitioning of assimilates to the head. |



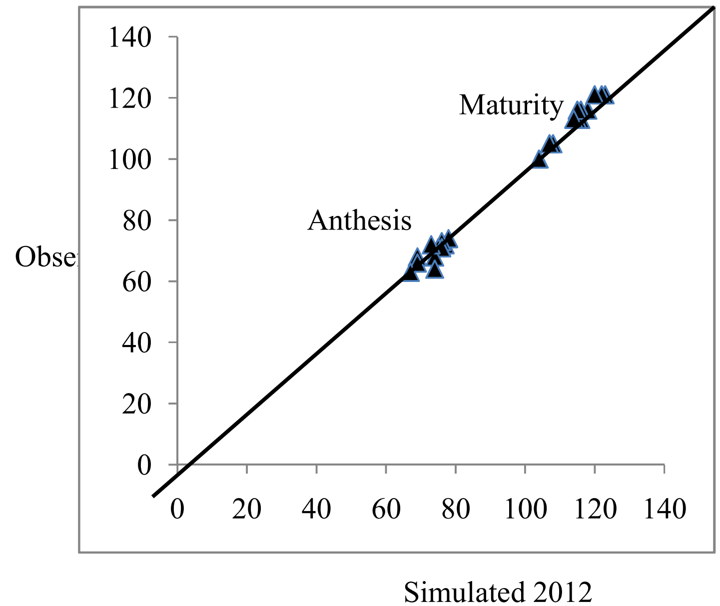




**Figure 1: Simulated and observed phenology of kharif sorghum on 1:1 scale for the year 2011 (Calibration, left fig.) and 2012 (Validation, right fig.)**

Figure-1 here shows 1:1 alignment of both simulated and observed data for anthesis and maturity in number of days after sowing. Both anthesis and physiological maturity perfectly matched after calibration (2011 data) as well as for 2012 data, which showed that model could simulate phenology with high accuracy as it showed minimum RMSE of 0 and 1.41 for anthesis and maturity for the year 2011 (calibration) and 2.94 and 1.29 for anthesis and maturity, respectively for the year 2012 (evaluation).

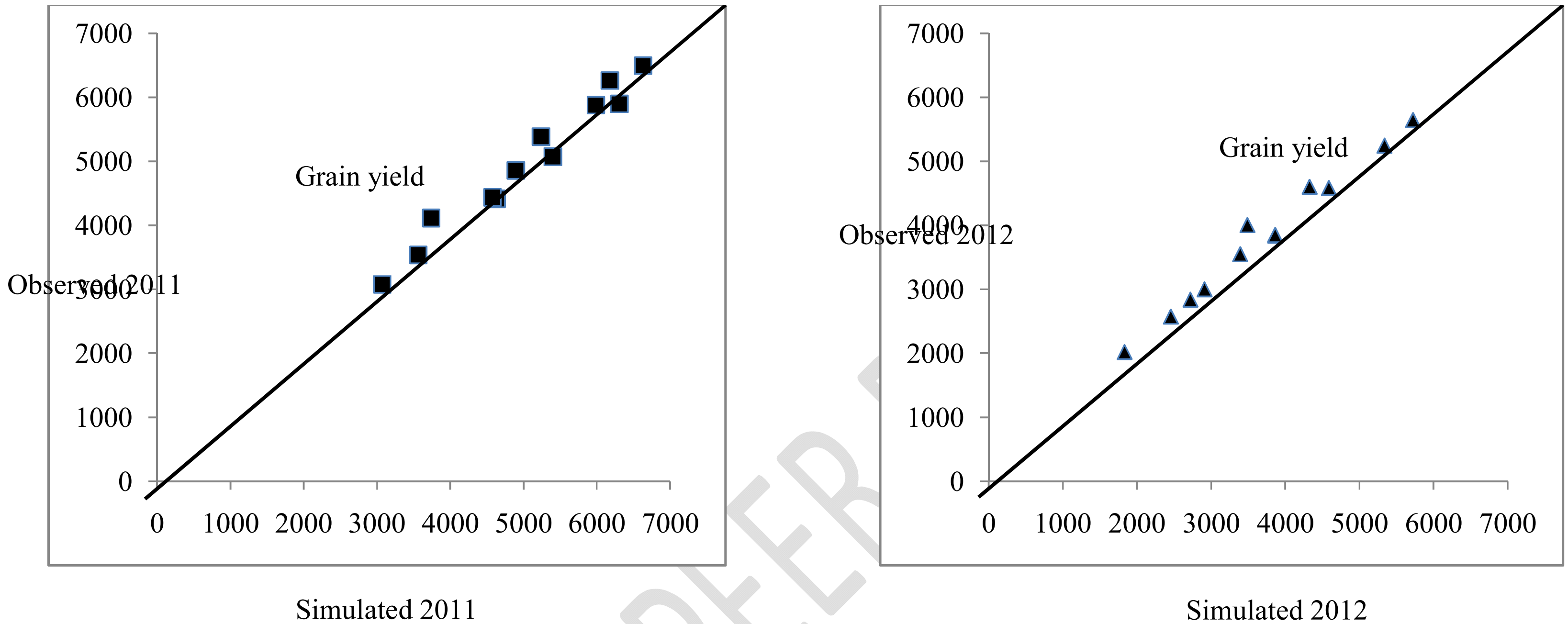



**Figure 2: Simulated and observed grain yield of kharif sorghum on 1:1 scale for the year 2011 (Calibration, left fig.) and 2012 (Validation, right fig.)**

Figure-2 here shows 1:1 alignment of both simulated and observed data for grain yield. Grain yield of sorghum perfectly matched after calibration (2011 data) as well as for 2012 data, which showed that model could simulate grain yield with high accuracy as it showed minimum RMSE of 97.17 for the year 2011 (Calibration) and 51.76 for the year 2012 (evaluation).

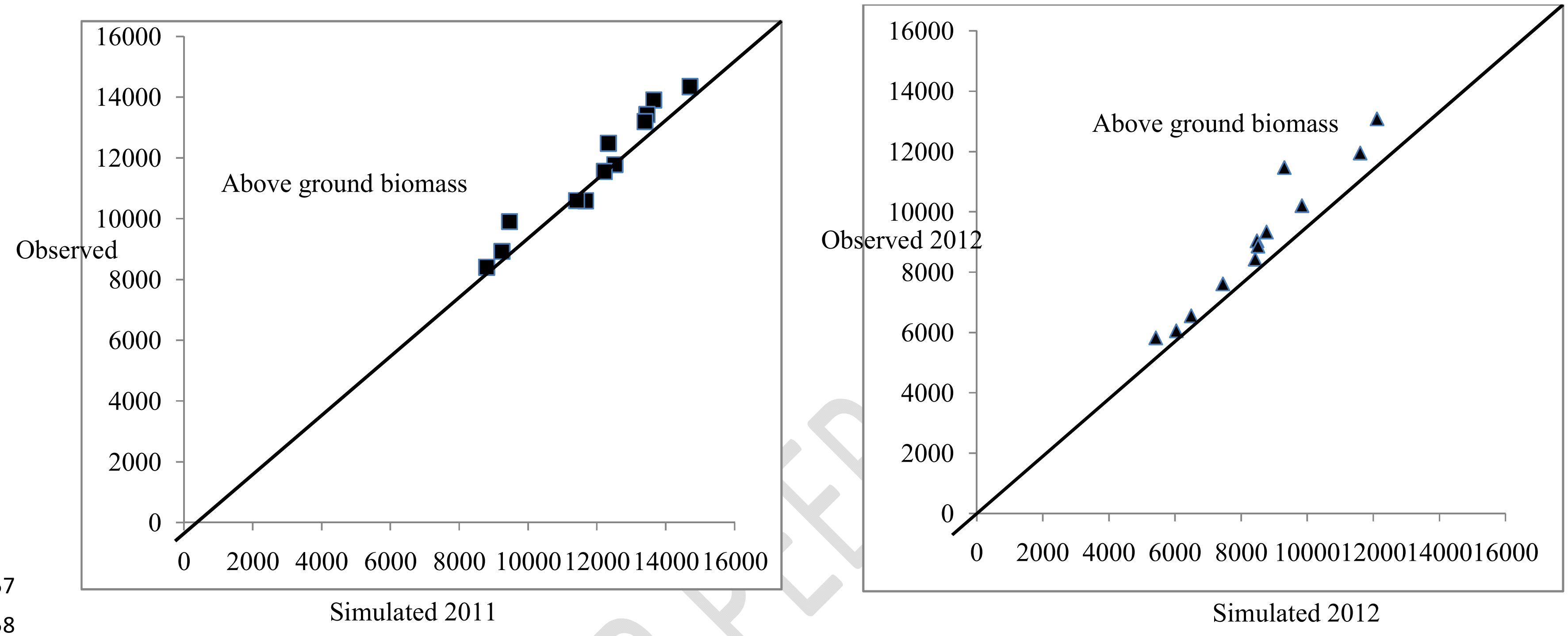



**Figure 3: Simulated and observed above ground biomass of kharif sorghum on 1:1 scale for the year 2011 (Calibration, left fig.) and 2012 (Validation, right fig.)**

Figure-3 here shows 1:1 alignment of both simulated and observed data for above ground biomass. Above ground biomass of sorghum perfectly matched after calibration (2011 data) as well as for 2012 data, which showed that model could simulate above ground biomass with high accuracy as it showed minimum RMSE of 387.67 for the year 2011 (calibration) and 234.13 for the year 2012 (evaluation).

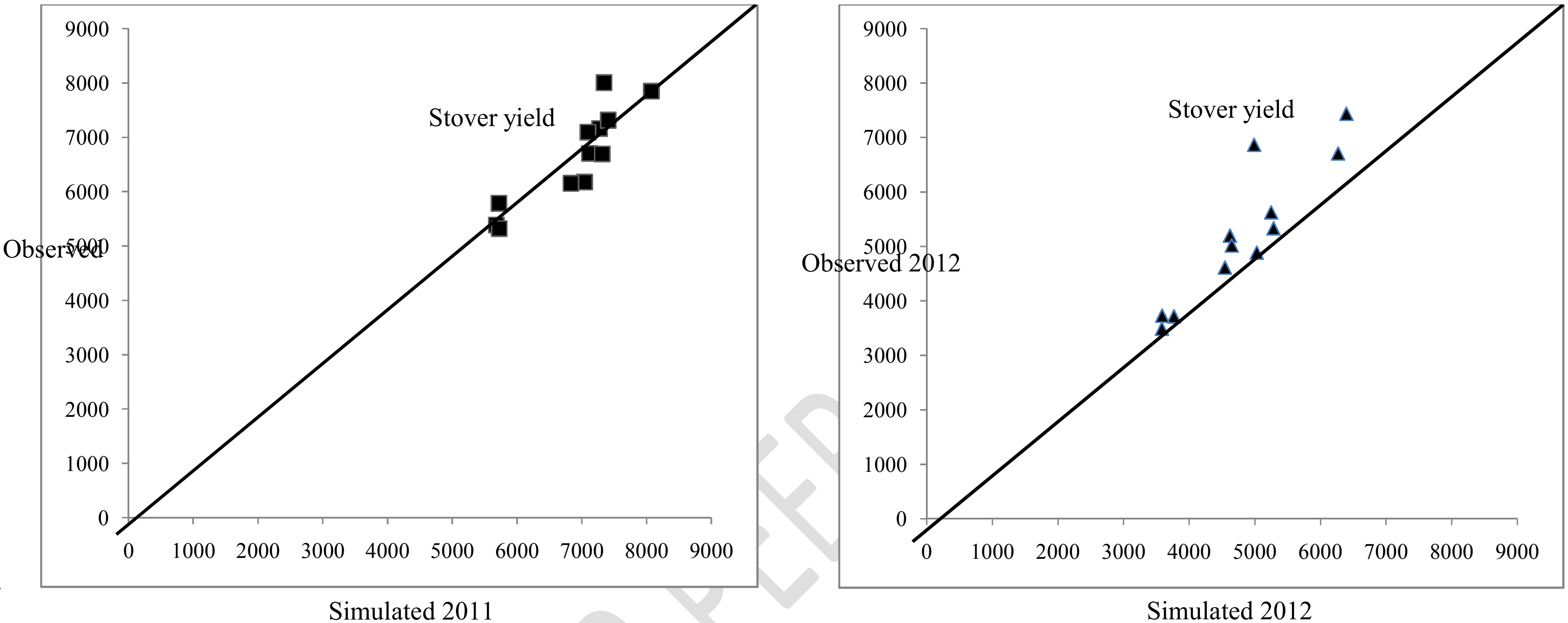



**Figure 4: Simulated and observed stover yield of kharif sorghum on 1:1 scale for the year 2011 (Calibration, left fig.) and 2012 (Validation, right fig.)**

Figure-4 here shows 1:1 alignment of both simulated and observed data for stover yield. Stover yield of sorghum perfectly matched after calibration (2011 data) as well as for 2012 data, which showed that model could simulate stover yield with high accuracy as it showed minimum RMSE of 289.79 for the year 2011 (calibration) and 105.12 for the year 2012 (evaluation).

## CONCLUSION

This exercise of calibration of crop specific parameters of four kharif sorghum genotypes using DSSAT-CERES-Sorghum model followed by evaluation of model using another independent set of data showed that DSSAT-CERES-Sorghum performed well and the model could be used as decision support tool for all those optimized four genotypes for various applications *viz.,* optimizing dates of sowing, population, spacing and inputs.

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