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Developing Genetic Coefficients of Sorghum Cultivars Using Gencalc and Glue Genetic Coefficient Estimators in DSSAT

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

DSSAT (Decision Support System for Agrotechnology Transfer) is a software system used for crop growth and development, soil and water balance, nutrient cycling, climate change impact simulations and precision agriculture. The objective of this study was to calibrate and validate the sorghum cultivars TNAU sorghum CO 30 and K12 under various sowing windows and fertilizer applications. CERES-Sorghum model (DSSAT v 4.7.5) was calibrated and validated using experimental field data obtained from Tamil Nadu Agricultural University, Coimbatore. The derived genotype co-efficients of sorghum cultivars simulated the phenology, growth and yield accurately well under various sowing windows and nitrogen levels. The nRMSE (Normalised Root Mean

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Square Error) values for simulations for grain yield were 2.4 per cent and 8.8 per cent for TNAU sorghum CO 30 and K12, respectively. The mean simulated grain yield was 3127 kg/ha against the observed grain yield of 3052 kg/ha in TNAU CO 30 sorghum. The mean observed grain yield was 3312 kg/ha against the observed grain yield of 3020 kg/ha K 12. The model satisfactorily simulated the phenology and yield of sorghum cultivars, and hence it can be used in undertaking suitable management practices and yield prediction under changing climatic conditions in the western region of Tamil Nadu.

Keywords: Sorghum; DSSAT; genetic co efficient; CERES; crop model.

1. INTRODUCTION

Sorghum is an important grain crop in semiarid regions of the world and grown for various uses like food, forage, and fuel. India holds fifth rank at global level in terms of sorghum in production [1]. In the early 1950s, sorghum was referred to as "great millet" because it was a significant cereal crop occupying an area of more than 16 million hectares [2]. In India, Maharashtra (1.76 MT) topped in sorghum production followed by Karnataka (0.88 MT), Rajasthan (0.59) and Tamil Nadu (0.45) in 2019-20. The cultivable sorghum area in Tamil Nadu had increased to about 4.50 lakh ha which constitutes about 7.6% of the total cropped area of the state. Sorghum is sown both under rainfed as well as in irrigated conditions.The distircts like Namakkal, Salem, Dindigul, Dharmapuri, Tiruchirapalli, Tiruppur, Coimbatore and Karur together constitute about 83% of the total area under this crop in the state during 2019-20. Crop Simulation models are computer-based models that tend to understand the basic principles of crop growth and physical, chemical, and biological processes and represent them as mathematical equations [3]. There are plenty of Crop Simulation Models or a combination of models to serve individual purposes.

Genetic coefficients are an important component of the crop simulation models especially in DSSAT. The genetic coefficients provides the critical information about the crop variety being simulated, including its potential yield and response to different management practices [4]. By incorporating this information into the DSSAT, the growth and yield of the different crop varieties under different environmental and management conditions can be accurately simulated. Thus DSSAT can help farmers and breeders to select the most suitable varieties for their specific agro-ecological zones and management practices. Climate change is expected to affect crop growth and yield in many regions of the world. By using genetic coefficients to simulate the response of different crop varieties to future climate scenarios, DSSAT can help identify varieties that are more resilient to climate change and facilitate adaptation. Genetic coefficients can be used to simulate the response of crops to different management practices, such as planting density, irrigation, and fertilizer application. By optimizing these practices based on the crop simulation models, farmers can increase their yield and profitability while minimizing environmental impact [5]. The use of genetic coefficients in these models allows researchers and educators to test hypotheses and explore different scenarios in a cost-effective and time-efficient manner.

2. MATERIALS AND METHODS

2.1 Description of the Study Area

The field experiment was conducted on the Eastern block farm (Field No 37 F) of TNAU, Coimbatore, during *rabi* 2019. The Geographical location of the site was latitude 11^0N & longitude 77 ^{0}E. The mean altitude of 426.7 m above the mean sea level (MSL). The soil is sandy clay loam in texture. The average annual rainfall of Coimbatore is 675 mm.

2.2 Edapic Characteristics

The mechanical and physio-chemical properties of the soil are presented in Table 1. The soil sample was collected 15 days before the sowing and analyzed in the Department of Soil Science and Agriculture Chemistry, TNAU, Coimbatore. The soil of the experimental site was sandy clay. The chemical composition analysis indicated that the soil was low in available nitrogen (176 kg/ha), medium in available phosphorous (10 kg/ha) and very high in potassium (716 kg/ha). The soil was slightly alkaline in reaction (pH 7.9), and electrical conductivity was 0.14 dSm^{-1}.

2.3 Field Experiment Details

The field experiment was laid out in a split-plot design with the treatments involving three date of sowing and three nitrogen levels with three replications. The rainfed farmers generally chooses 38th SMW to 39th SMW as a highly suitable sowing window for sorghum. Hence, the first sowing was taken on 15th September, the second sowing on 30th September, and the third date of sowing on 15th October 2019. The level of fertilizer was fixed based on the Soil Test Crop Response (STCR) reports. The main plot were with different sowing windows (D_1 - 15th September 2019, D_2 - 30th September 2019, and D_3 - 15th October 2019) and the Subplots were with different nitrogen levels (N_1 - 75 % of the Recommended dose of fertilizer(RDF), N_2 - 100 % RDF and N_3 - 125 % RDF).

2.3.1 Crop and variety details

Sorghum varieties CO 30 and K 12 released by Tamil Nadu Agricultural University (TNAU) were used for the study. Seeds were obtained from the Department of Millets, TNAU, Coimbatore. The characteristics of TNAU Sorghum CO 30 and K 12 varieties are furnished in Table 2.

Table 1. Mechanical and chemical properties of experimental field

S. No.	Mechanical properties	Percentage (%)
1.	Clay	32.6
2.	Coarse sand	39.4
3.	Fine sand	15.1
4.	Silt	11.8
Chemical properties		
5.	pH	7.9
6.	Organic carbon (%)	0.52
7.	Electrical conductivity (dS m^{-1})	0.14
8.	Available N (kg/ha)	176
9.	Available P_2O_5 (kg/ha)	10
10.	Available K_2O (kg/ha)	716

2.4 Model Description

DSSAT model is process-oriented and designed to simulate the growth and development daily. The model requires inputs that include environmental conditions, management practices, and characteristics of crop genotype or cultivar-specific genetic coefficients. The model is sensitive to planting date, fertilizer application, irrigation management, row spacing, and cultivar choice. Before applying a crop simulation model, it is necessary to determine the genetic coefficients and evaluate model performance for the cultivars that have not been previously used in the model [6]. There are two tools present in DSSAT for estimating cultivar coefficients for the different crops. The first tool, GENCALC, was developed by L. A. Hunt. This tool computerized and organized a quest of parameters that lessened RMSE between simulated and observed variables; the principles for choosing parameter values depended on the parameter being estimated in a consecutive search procedure. The second tool is GLUE (Generalized Likelihood Uncertainty Estimation). The integration of GLUE CSP estimation method was done with the help of the R language. It is a Bayesian estimation method that uses Monte Carlo sampling from prior distributions of the coefficients and a Gaussian likelihood function to determine the best coefficients based on the data that were used in the estimation process.

2.4.1 Weather parameters

The Weatherman tool is an important feature of DSSAT that helps users generate weather data files for crop simulation models. The weatherman tool was effective in generating weather data that accurately represented the local climate, and that the crop simulation models performed well in predicting yield under different environmental and management conditions [7]. The daily weather data on rainfall (mm), solar radiation (MJ m^{-2} day^{-1}), minimum temperature (°C), and maximum temperature (°C) for the crop period was collected from Agro Climate Research Centre, Coimbatore, and converted into DSSAT weather file format using Weatherman tool available in DSSAT for running CERES – sorghum experiments. The soil profile was used in ‘S Build’ as an input database file to create a soil file in DSSAT. At the same time, the initial soil condition was collected from the experimental field and analyzed for soil characteristics on pH of the soil, EC, during cropping seasons. The crop management data were collected from a field experiment. It includes date of sowing, emergence and anthesis day, plant height, leaf area index, plants per row, spacing, irrigation, fertilizer application, weeding, grain weight, grain yield per unit of production and harvest date and output options are given through ‘X Build’ tool in DSSAT in order to stimulate the yield.

2.4.2 Genotype data file

The genotype data file is an important component of the DSSAT modeling framework, as it provides the genetic information necessary to accurately simulate the growth and yield of specific crop cultivars. In DSSAT, the genotype data file is used to provide information about the genetic characteristics of the crop cultivars being simulated [8]. The genotype data file can be created using a text editor or spreadsheet program and saved in a specific format that is recognized by DSSAT. The format of the genotype data file can vary depending on the crop being simulated and the specific simulation model being used. Cultivars were defined by a particular collection of genetic coefficients for each crop simulation model. These coefficients express the genetic potential of each genotype regardless of all environmental constraints, such as soil and temperature. By modifying the appropriate coefficient parameters, the genetic coefficient parameters affecting the occurrence of phenological phases, growth parameters, yield parameters, and yields in the CERES were obtained to achieve the best possible match between the simulated [9].

2.4.3 Calibration and validation

Calibration and validation are important steps in the application of DSSAT models for crop simulation. These processes help to improve the accuracy and reliability of model outputs. Calibrating the model for the specific cultivar and validating its ability to stimulate the yield is essential for application in impact assessments [10]. Accurate calibration and validation of DSSAT models can enhance their usefulness for decision-making in agricultural production, and help to promote sustainable and efficient use of agricultural resources [11]. The DSSAT crop model framework simulates the yield of the respective cultivar for which genetic coefficients are available. In DSSAT, the CERES module, sorghum crop CO 30, and K 12 were not available in the existing module. Hence, the data observed from the field trials were used in the GENCALC tool for deriving the cultivar-specific parameter for those varieties.

2.4.4 Evaluation of derived CSP

The model was tested for the observed and simulated data using statistical analysis such as agreement index (d), normalized root means square error (nRMSE), modelling efficiency (EF), and determination coefficient (r^2).

2.4.5 Root Mean Square Error (RMSE)

With the help of the following equation [8].

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

Normalized root means square error (RMSE) is calculated. It is a good measure of how accurately the model predicts the response. The value of the RMSE should be minimum.

Where,

n = Number of observations,
Pi = Predicted values
Oi = Observed Value
M = Observed mean value

2.4.6 Wilmott index of agreement

Index of agreement (d), as described by Willmott [12] was calculated as given in the following equation:

$$d = 1 - \left[\frac{\sum_{i=1}^{n} (P_i - O_i)^2}{\sum_{i=1}^{n} (|P_i - \bar{O}| - |O_i - \bar{O}|)^2}\right]$$

Where n - Number of observations Pi - predicted observation O_i - measured observation, A value of one for the index of agreement (d) shows a good relationship between the observed and simulated values while values closer to 1 indicate the good prediction. A d value of zero indicates no predictability.

2.4.7 Coefficient of determination (r^2)

To assess the ability of the model to predict or explain an outcome in the linear regression analysis, the coefficient of determination between observed and predicted data was calculated.

Table 2. Particulars of sorghum varieties

S. No.	Characters	CO 30	K 12
1.	Parentage	Derivative of APK 1 x TNS 291	Derivative of SPV 772 × S 35-29
2.	Duration (Days)	95 - 105	95 - 100
3.	Plant height (cm)	220 to 240	225 to 240
4.	Grain colour	White	Creamy white
5.	Fodder yield (kg/ha)	11900	7000
6.	Grain yield (kg/ha)	3213	2400

2.4.8 Easy grapher

Easy Grapher (EG) is a software package for the graphical and statistical evaluation of DSSAT outputs [13]. EG calculates several statistics, such as Mean Error (E or ME), Root Mean Square Error (RMSE), index of agreement (d) (EF) and Modelling Efficiency to evaluate the simulated results with observed values that are provided in the T file (Time series).

$$E = \sqrt{\sum (P_i - O_i)^2 / n}$$

$$EF = 1 - \sum (P_i - O_i)^2 / \sum (P_i - \bar{P})^2$$

3. RESULTS AND DISCUSSION

Genetic co-efficient was developed for different sorghum varieties for DSSAT model validation, presented in Table 3. The model was validated for phenology and yield.

The evaluation statistics developed with the Crop Specific Parameters affirmed that the model was efficient in simulating the crop variables like anthesis day, by product kg/ha, top weight at anthesis and maturity stage, grain yield, and maturity days. Where the d-statistics are found to be more than 0.8 in anthesis day, tops weight kg/ha, grain number per unit, grain yield kg/ha and maturity day except by-product kg/ha (0.62) and tops weight at anthesis stage (0.66). The values of evaluation statistics of K 12 variety (RMSE, d-stat, r-square) confirmed that the model was effective in simulating the crop variables like anthesis day, by product kg/ha, tops weight at anthesis and maturity stage, grain yield and maturity days. Where the d-statistics is found to be more than 0.8 in anthesis day, tops weight kg/ha, grain number per unit, by product kg/ha, tops weight at anthesis stage, and maturity day except grain yield (0.74).

3.1 Model Calibration

Calibration and validation are considered essential steps in using crop simulation models for yield prediction. CERES model was calibrated and validated for preferred cultivars of sorghum CO 30 and K 12. CERES sorghum DSSAT V4.7.5 model requires genetic coefficients for model simulation, and this coefficient for sorghum varieties CO 30 and K 12 were not available in the DSSAT crop module. Hence, the genetic coefficients of these varieties were estimated by taking the initial value of sorghum varieties CSH 5 and CSH 6, respectively, which already existed in the genotype file of the DSSAT CERES – Sorghum model. The genetic coefficients were determined by iteration multiple runs simulation data from field experiments. The derived genotype coefficients of sorghum cultivars simulated the phenology, growth, and yield accurately well under various sowing windows, and nitrogen levels are presented in Figs. 1 and 2.

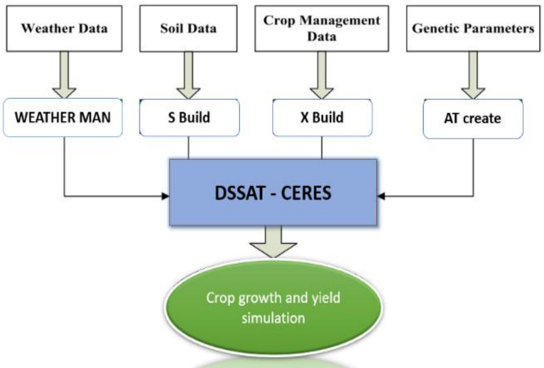


Fig. 1. Methodology of DSSAT-CERES module

The actual anthesis day was found to be in close agreement with the simulated values. The r-square value of 0.74 and 0.76 was observed for CO 30 and K 12 varieties, respectively. This finding was corroborated with the findings of Vieira et al. [14] and Tesfaye et al. [15] who reported r square (r^2) values of 0.87 and 0.71 for the anthesis day of sorghum and maize, respectively. The difference between simulated and observed values was meagre for grain and fodder yields of both the sorghum varieties. of 0.69 The r-square and 0.88 for CO 30 and 0.85 and 0.77 for K 12, respectively for grain and fodder yield. Akinseye et al. [16] and Srinivasarao et al. [17] calibrated the DSSAT CERES model for sorghum varieties of western Africa, and reported r square values of 0.6 and 0.85 for grain and fodder yield, respectively.

Similarly, the maturity day was well simulated by the CERES-Sorghum model and found very close to the observed value for both sorghum varieties. The observed r-square values were 0.63 and 0.61 for CO 30 and K 12 varieties, respectively. A similar relationship was reported by Zewdu et al. [18], Amede et al. [19] and Kassie et al. [20], where they found good agreement between the observed and simulated maturity days with r square values is 0.82.

3.2 Model Validation

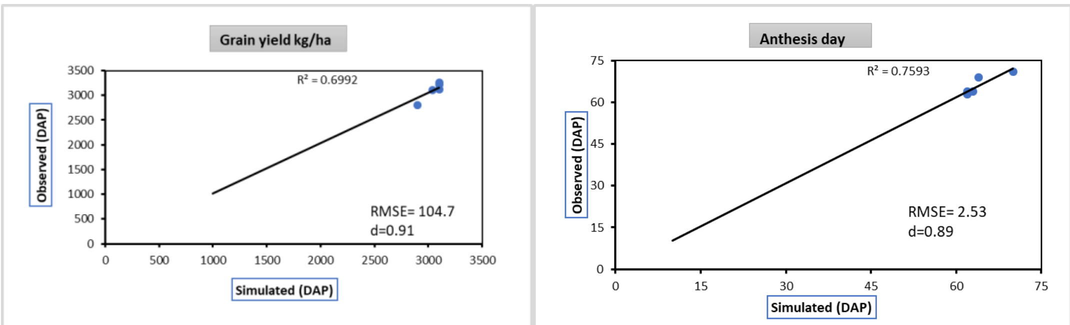
The efficiency of the calibrated model was assessed with the help of another data set obtained through field experimentation for the two sorghum varieties (CO 30 & K 12). The model validation was carried out for sorghum growth, and yield attributes to test the model applicability under various sowing windows and nitrogen levels. The simulated results matched the acceptable limits compared with field experiment data. Validation was done with the two-variety data of the crop seasons from 2019 to 2020.

Table 3. Genotypic coefficients for sorghum cultivars

Parameters	P1	P2	P2O	P2R	PANTH	P3	P4	P5	PHINT	G1	G2
TNAU sorghum CO 30	410	92	12	90	513	133.5	83	410	54	4	6.062
K 12	390	88	11.7	88	480.5	130	75.5	380	60	4.3	5.2

Table 4. Description of genetic coefficients of sorghum cultivars

Co-efficient code	Description
P_1	Thermal time from seedling emergence to the end of the juvenile phase (expressed in degree days above TBASE during which the plant is not responsive to changes in photoperiod
P_2	Thermal time from the end of the juvenile stage to tassel initiation under short days (degree days above TBASE)
P_2O	Critical photoperiod or the longest day length (in hours) at which development occurs at a maximum rate. At values higher than P2O, the rate of development is reduced
P_2R	Extent to which phasic development leading to panicle initiation (expressed in degree days) is delayed for each hour increase in photoperiod above P_2O
PANTH	Thermal time from the end of tassel initiation to anthesis (degree days above TBASE)
P_3	Thermal time from to end of flag leaf expansion to anthesis (degree days above TBASE)
P_4	Thermal time from anthesis to beginning grain filling (degree days above TBASE)
P_5	Thermal time from beginning of grain filling to physiological maturity (degree days above TBASE)
PHINT	Phyllochron interval: the interval in thermal time between successive leaf tip appearances (degree days)
G_1	Scaler for relative leaf size
G_2	Scaler for partitioning of assimilates to the panicle (head).



Simulated and observed grain yield of *rabi* sorghum (calibration) CO 30

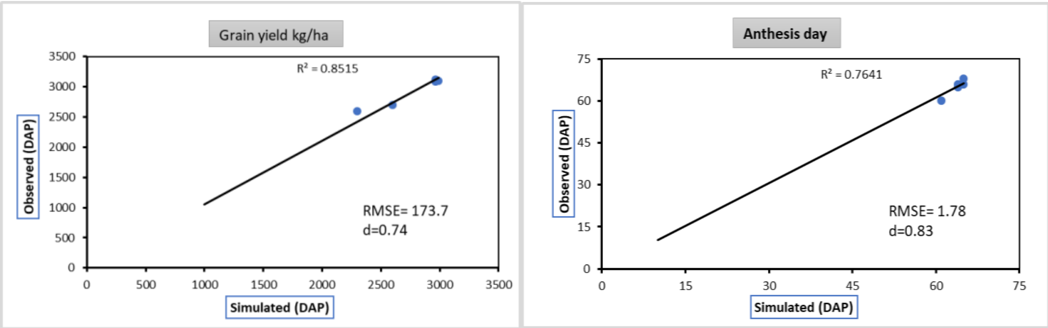


Fig. 2. Simulated and observed grain yield of *rabi* sorghum (calibration) K 12

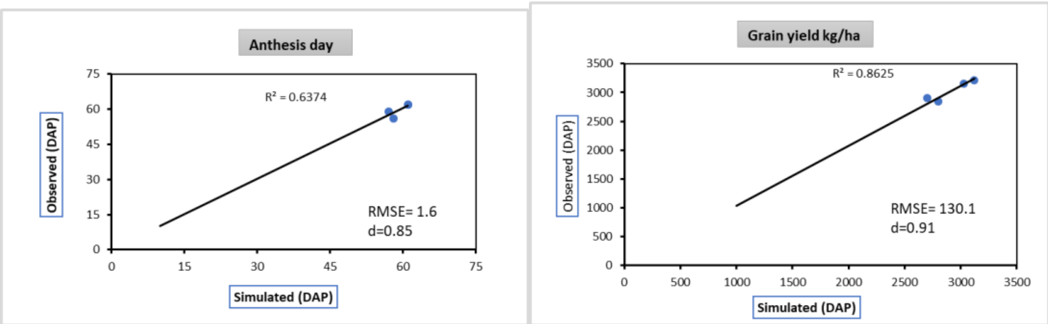


Fig. 3. Simulated and observed grain yield of *rabi* sorghum (validation) CO 30

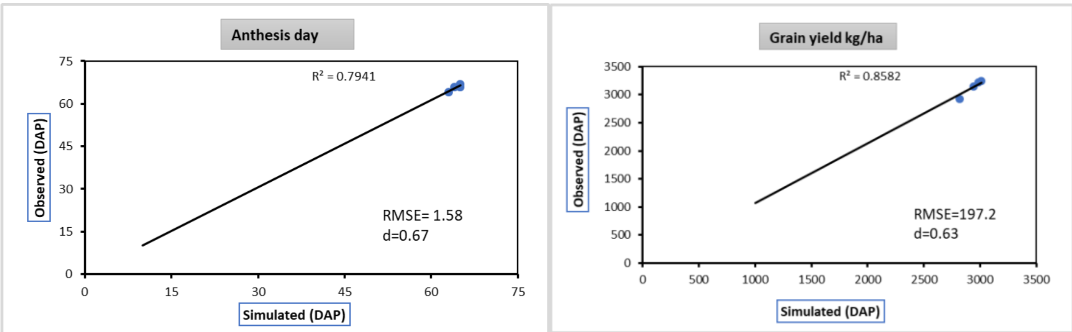


Fig. 4. Simulated and observed grain yield of *rabi* sorghum (validation) K 12

A close relationship was found between the observed and simulated values of anthesis and maturity days. The r square value of anthesis and maturity days were 0.64, 0.61 and 0.79, 0.78 for sorghum varieties of CO 30 and K 12, respectively. These findings were corroborated with the findings of Rani et al. [21], Bihon et al. [22], and Deressa et al. [23], where the r square values of 0.81 and 0.7 for anthesis and maturity days, respectively. The simulated grain and fodder yield of two sorghum varieties was in good agreement with the observed yields. The r square value for grain and fodder yield was 0.85, 0.86 (CO 30), and 0.73, 0.86 (K12). Asadi and Clemente [24] validated the CERES - Maize in the Asian Institute of Technology. They found a good agreement between the observed and simulated grain yield, with an r square value of 0.87.

4. CONCLUSION

This exercise of calibration of the DSSAT CERES Sorghum model by optimizing crop-specific parameters of *rabi* sorghum CO 30 and K 12 followed by evaluation of the model using data from another independent data set DSSAT-CERES-Sorghum performed well to simulate phenology and yield. This indicates that the DSSAT CERES-Sorghum model can be used as a decision support tool for planting date, fertilizer application, irrigation management, row spacing, cultivar choice and climate impact studies.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. FAOSTAT. "FAO statistical year book." 2019:110–116.
2. Kumara Charyulu D, Bantilan MCS, Rajalaxmi A, Reddy BVS, Borikar ST, Ashok Kumar A, Singh NP, Shyam DM. Development and Diffusion of sorghum improved cultivars in India: Impact on growth and stability in yield; 2014.
3. Hunt LA, Pararajasingham S, Jones JW, Hoogenboom G, Imamura DT, Ogoshi RM. GENCALC-software to facilitate the use of crop models for analysing field experiments. Agron. J. 1993;85:1090–1094.
4. Loague Keith, Richard E Green. "Statistical and graphical methods for evaluating solute transport models: Overview and application." Journal of Contaminant Hydrology. 1991;7(1-2):51-73.
5. Singh VK, Khanna M, Prasad PVV, Rajashekar K, Bhatia VS, Goyal H, et al. Calibration and validation of maize models for climate change impact assessments in South Asia. Field Crops Research. 2017; 202:88-98.
6. Guerra P, Santos A, Darambara DG. "Development of a simplified simulation model for performance characterization of a pixellated CdZnTe multimodality imaging system." Physics in Medicine & Biology. 2008;53(4):1099.
7. Kim SH, Park SJ, Lee JW, Hong SY, Lee BH. Generating weather data for crop simulation models using the weatherman tool in DSSAT. Agronomy Journal. 2015;107(1):261-270.
DOI: 10.2134/agronj14.0546
8. Loague K, Green RE. Statistical and graphical methods for evaluating solute transport models: Overview and application. Journal of Contaminant Hydrology. 1991;7(1-2):51-73.
9. Wu L, Li Y, Chen X, Zhang W, Zhang F, Cui Z, Chen X. Improving the simulation of wheat growth and yield with cultivar-specific parameters in the CERES-Wheat model. Field Crops Research. 2016;199: 57-68.
10. Ibrahim Y, Awodun MA, Jibrin JM, Ali AM, Babalola SO. Calibration and validation of the CERES-maize model in DSSAT for maize yield prediction in sub-Saharan Africa. Agricultural Systems. 2021;193: 103140.
11. Dong T, Zhang L, Lu X, Xie Y, Chen Q. Calibration and validation of the DSSAT model for potato production in China. Computers and Electronics in Agriculture. 2021;184:106012.
12. Willmott, Cort J, Steven G Ackleson, Robert E Davis, Johannes J Feddema, et al. "Statistics for the evaluation and comparison of models." Journal of Geophysical Research: Oceans. 1985;90 (C5):8995-9005.
13. Yang-Huffman, Siew-Hong. Enhanced system and method for network usage monitoring. Google Patents; 2003.
14. Vieira, Paulo Vinicius Demeneck, Paulo Sérgio Lourenço de Freitas, Roberto Rezende, Rivanildo Dallacort, João Danilo Barbieri, Diego Fernando Daniel. "Calibration and simulation of the CERES-sorghum and CERES-maize models for crops in the Central-West region of Paraná state." Journal of Agricultural Science. 2019;11(18).
15. Tesfaye K, Dagmawi M, Bihon W, Blummel M, Sogbedji JM. Calibration and validation of the DSSAT sorghum model using the rainfed cropping system of Ethiopia. Agricultural Systems, 2016;143:132-142.
16. Akinseye, Folorunso M, Myriam Adam, Samuel O Agele, Munir P Hoffmann, PCS Traore, Anthony M Whitbread. "Assessing crop model improvements through comparison of sorghum (*Sorghum bicolor* L. moench) simulation models: a case study of West African varieties." Field Crops Research. 2017;201:19-31.
17. Srinivasarao C, Venkateswarlu B, Lal R. Validation of DSSAT model for simulating sorghum growth and yield under diverse agro-ecological conditions of India. Agricultural Systems. 2018;165:194-207.
18. Zewdu Eshetu, Gebre Hadgu, Lisanework Nigatu. "Impacts of climate change on sorghum production in North Eastern Ethiopia." African Journal of Environmental Science and Technology. 2020;14(2):49-63.
19. Amede T, Stroosnijder L, Kessler A, Haefele SM. Calibration and testing of the crop growth model SSM-Wheat for wheat under semi-arid conditions. European Journal of Agronomy. 2003;19(3-4):411-425.

20. Kassie BT, Dile YT, Singh P, Tesfaye K, Blummel M. Calibration and validation of DSSAT model for sorghum under rain-fed conditions of Ethiopia. Agriculture. 2019;9 (1):24.
21. Rani, Leela P, Sreenivas G, Raji Reddy D. "Calibration and validation of CERES-maize model for hybrid maize under variable plant densities and nitrogen levels in Southern Telangana zone of Telangana state, India." International Journal of Bio-resource and Stress Management. 2016;7(2):212-217.
22. Bihon W, Dagmawi M, Tesfaye K, Sogbedji JM. Calibration and validation of the DSSAT sorghum model for the Northwestern Ethiopian highlands. Agricultural Systems. 2017;157:208-220.
23. Deressa TT, Fadda C, Tengberg A. Calibration and validation of the DSSAT model for simulating crop yield and soil moisture in the lowland ecosystems of Ethiopia. Journal of Agricultural Science. 2017;155(2):229-244.
24. Asadi Mohammad E, Roberto S Clemente. "Evaluation of CERES-Maize of DSSAT model to simulate nitrate leaching, yield and soil moisture content under tropical conditions." Journal of Food Agriculture and Environment. 2003;1:270-276.

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