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Calibration and Validation of CERES-Maize model for spring maize under tarai region of Uttarakhand

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***Abstract*—Calibration in modeling is the process of adjusting the parameters of a model to improve its accuracy in predicting or simulating real-world data. After calibration validation was performed to check the accuracy of the data. Validation in modeling refers to the process of evaluating a model's performance to ensure that it accurately predicts. The purpose of validation is to check the model's accuracy. CERES-Maize model used for the present investigation. It is a crop simulation model that is part of the Decision Support System for Agrotechnology Transfer (DSSAT) suite of models. This model is specifically designed to stimulate growth, development and yield of rice crops under varying environmental conditions and management practices. Three-year data used for calibration and two-year data used for validation purpose. CERES-Maize model was able to validate and calibrate spring maize crop with good accuracy percent.**

***Index Terms*—calibration, validation, CERES (Crop Environment Resource Synthesis), Decision Support System for Agrotechnology Transfer (DSSAT), model**

I. INTRODUCTION

Spring maize also called as "queen of cereals," due to its high demand and broad adaptability. For year 2022-23 country's maize production reached an estimated 23.10 million tonnes with average production of 19.89 million tonnes by 3.21 million tonnes (MoA & FW, 2022). Maize serves as basic raw material for numerous industrial products such as starch, food sweeteners, pharmaceuticals, baby food, cosmetics, film, gum, textiles and the paper packaging industry. Optimum sowing time for spring maize is middle of February but some cultivator used to cultivate it first week of March.

Calibration is the process of adjusting parameters of model as it is crucial step in model development and application. After calibration there is an effective approach known as validation is performed to check the accuracy of the model. The DSSAT modeling system features the Crop Environment Resource Synthesis (CERES-Maize) model, designed to simulate maize growth and yield under various environmental conditions. This model has been employed for diverse applications, including devising strategies to manage limited weather and soil conditions (Malik and Dechmi, 2019) assessing the impact of climate change on crop production (Babel and Turyatunga, 2015; Jiang *et al*., 2021; Lin *et al*., 2015), optimizing agronomic practices to enhance production (Mubeen *et al*., 2016), and evaluating the performance and suitability of different cultivars across various environmental settings (Chisanga *et al*., 2021; Feleke *et al*., 2021).

The DSSAT modeling system features the Crop Environment Resource Synthesis (CERES-Maize) model, which precisely simulates maize (Zea mays L.) growth and yield under various environmental conditions. This model has been applied to numerous areas, including developing strategies to manage limited weather and soil conditions (Malik and Dechmi, 2019) and evaluating the performance and suitability of different cultivars in diverse environmental settings (Chisanga *et al*., 2021; Feleke *et al*., 2021).

II. MATERIAL AND METHODS

A. Experimental site

The field survey for this investigation took place from February to June in 2021 and 2022. The study was conducted in the Kankpur village under U.S. Nagar district, Uttarakhand. Latitude, longitude and altitude of study area is 28.97° N, 79.47° E and 208 m (MSL), respectively.

B. Climate

The weather conditions during the crop growing season were favorable for the growth and development of spring maize crop. The climate of the study region is humid subtropical.

C. Soil characteristics

The experimental site has sandy loam soil. The soil is highly productive, calcareous with dark greyish brown in colour.

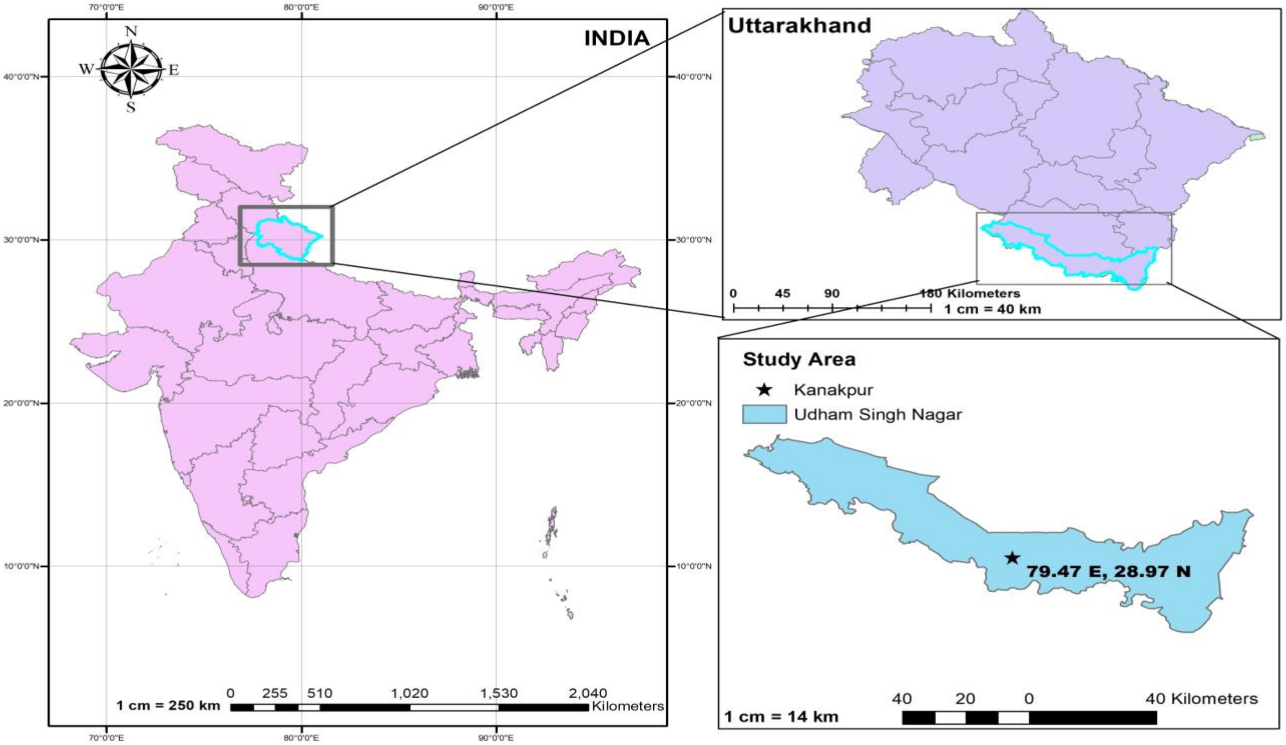


Fig1: Map of experimental site

The study was done in the farmer's fields. All the cultural practices were used to be taken on farmer's application.

Table 1: Details of Study during year 2021 and 2022

S. No.	Particulars	Details
1	Years of study	2021 and 2022
2	Target crop	Spring Maize
3	Duration of crop	February to May
4	Variety	Farmer's cultivated variety (DEKALB-1908)
5	Irrigation	Farmer's practice
6	Fertilizers	Farmer's practice
7	Plant protection chemicals	Farmer's practice
8	Crop simulation model used for study	DSSAT 4.7.5

III. METEOROLOGICAL OBSERVATIONS

Weather parameter necessary to run the model are maximum temperature, minimum temperature, rainfall and bright sunshine hours (BSS) collected from the Department of Agrometeorology, G. B. Pant University of Agriculture & Technology.

A. Model Description

Decision support system for Agrotechnology Transfer (DSSAT) is used to simulate growth, development and yield of a crop being grown on uniform area of land (Jones *et al*., 2003). The current version of DSSAT, Version 4.7.5.0 (Hoogenboom *et al*., 2019) is available from the DSSAT portal (www.DSSAT.net), while the source code of the CSM model can be obtained from GitHub under the 3-Clause BSD license (https://github.com/DSSAT/dssat-csm-os).

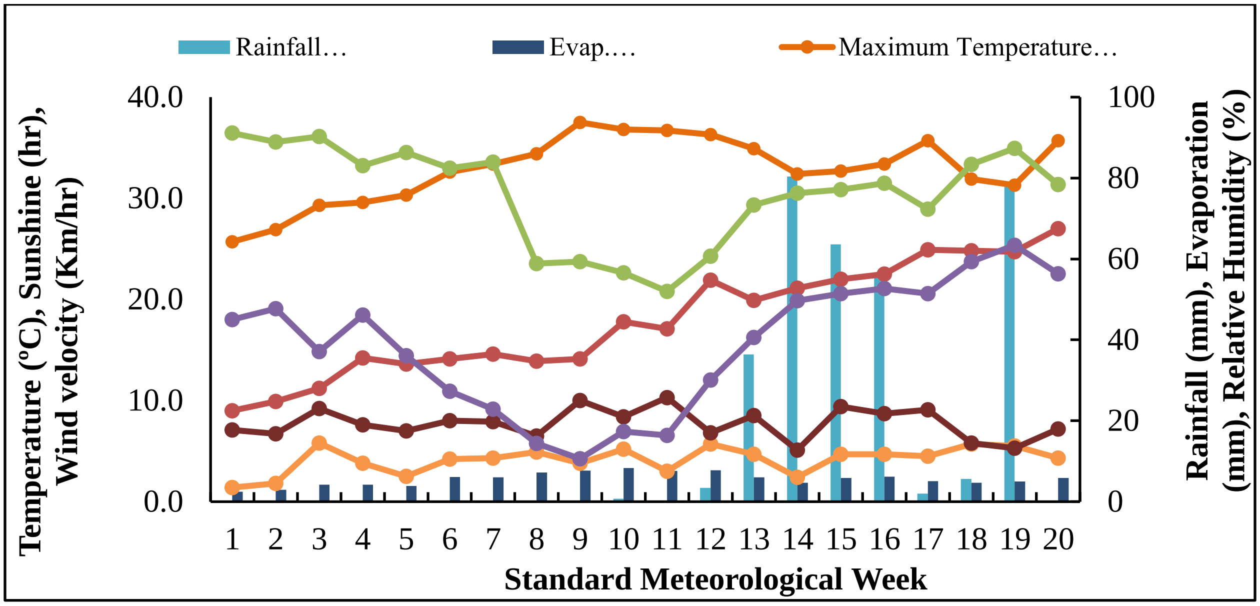


Fig 2: Weekly weather data of growing season 2021

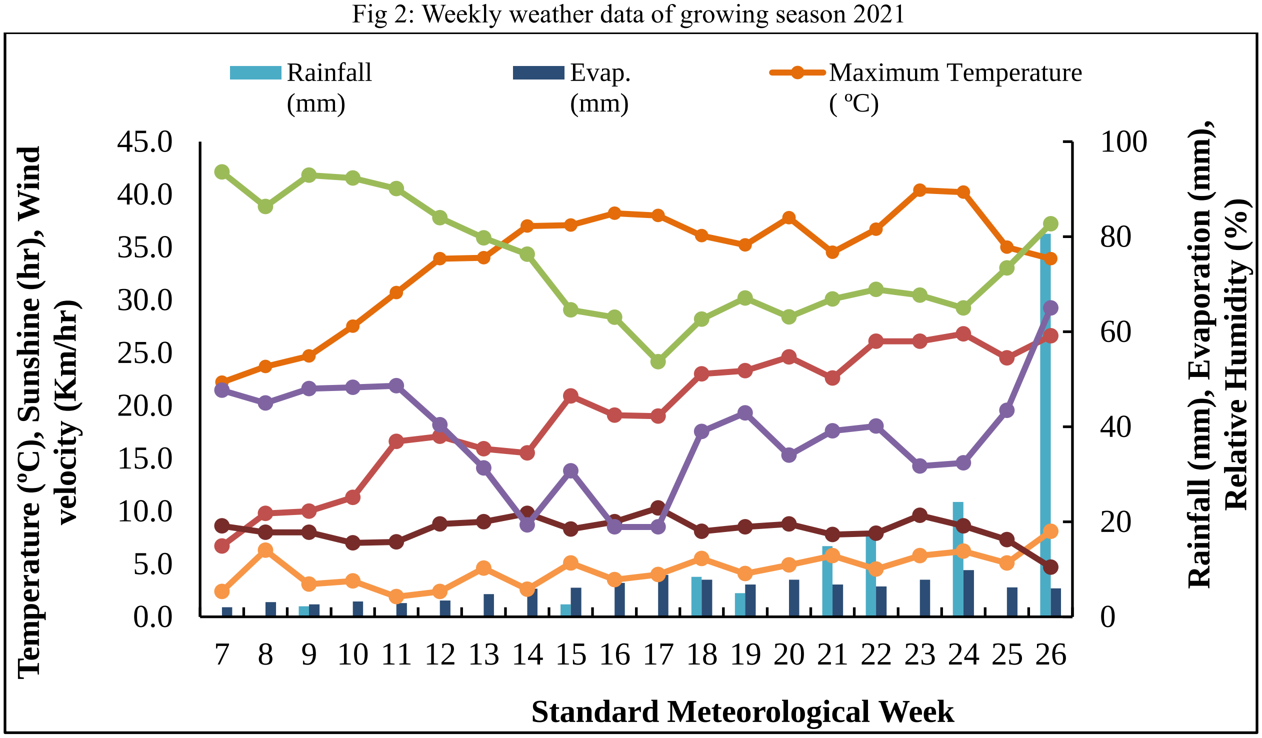


Fig 3: Weekly weather data of growing season 2022

B. CERES-Maize model

One of the primary models in DSSAT is the Cropping System Model (CSM). CSM-CERES-Maize serves as a tool for new approaches such as on-farm irrigation scheduling, utilizing long-term and multi-year simulations.

C. Data input described by IBSNAT

There are three basic input data used in CSM model such as soil data, management data and weather data

Table:2 Basic input data for CERES-Maize model

Basic Input data for Crop Simulation Model					
Models	Soil data	Management data	Weather data	Site data	Plant data
CERES-Maize	Bulk density, layer wise sand (%), silt (%) and clay (%), soil texture, soil organic carbon (%)	Cultivar, row spacing, sowing depth, amount and time of fertilizer application, irrigation date, plant protection measures, date and method of harvesting	Solar radiation (MJ/m2), maximum and minimum temperature (oC), rainfall (mm)	Longitude (E-W), Latitude (N-S) and altitude (m)	Phenological stages eg. Emergence, flower initiation, anthesis date, days attain to physiological maturity,

In weather data all meteorological parameters other than solar radiation were directly measured at the agro-meteorological observatory. The solar radiation values were calculated from the recorded bright sunshine hours using a program created by Nain (2002), which is based on the Angstrom model (Angstrom, 1924). The coefficients 'a' and 'b' used in the equation were determined according to the daily temperature range as specified by Mani and Rangarajan (1982). The following steps were followed the procedure for estimating solar radiation.

Table:3 Angstrom coefficients (a and b) for calculating solar radiation (Mani and Rangarajan, 1982)

Station	Latitude	Longitude	Coefficient 'a'	Coefficient 'b'
Pantnagar	$29^{0}02'$ N	$79^{0}28'$ E	0.256	0.446

D. Genetic coefficient

The crop development depends upon genetic character of plant, which is defined as Genetic Coefficients (GCs) of the plants.

Table 4: Statistical parameters for model evaluation

S.N.	Statistical Parameter	Formula	Value range	Remarks
1.	Coefficient of determination (R2)	$\left(\frac{\frac{1}{n}\sum_{i=1}^{n}(y_i-\bar{y}_i)(\hat{y}_i -}{\sigma_y\sigma_{\hat{y}}}\right.$	0 to 1	Evaluation of linear relationship present between the observed and predicted datasets
2.	Root means square error (RMSE)	$\sqrt{\frac{\sum_{i=1}^{n}(y_i-\hat{y}_i)^2}{n}}$	Difference between the observed values from the environment and predicted values by the model.	The lower value of RMSE shows better model performance and higher value shows poor model performance.

3.	Normalized root means square error (nRMSE)	$\frac{RMSE}{\bar{y}_i}$	scatter index	The unit of nRMSE is percentage
4.	Correlation coefficient (CC)	$\frac{n\sum_{i=1}^{n} y_i\hat{y}_i \ldots}{\sqrt{n(\sum_{i=1}^{n} y_i^2) - (\sum_{i=1}^{n} \ldots}}$	-1 to + 1	The -1 and +1 value show strong negative and strong positive relationship, respectively

IV. RESULT AND DISCUSSION

In CERES-Maize model three-year data used for calibration and two-year data used for validation.

Table 5: Genetic coefficients used in calibration of DEKALB 9108 by CERES- Maize model in DSSAT v.4.7.5

S.N.	Parameters	Genetic Coefficients
1.	P1	150.0
2.	P2	0.400
3.	P5	682.0
4.	G2	906.9
5.	G3	10.13
6.	PHINT	37.90

Comparison between observed and simulated value

Grain yield

Table 6: Simulated and observed value of grain yield (kg/ha)

Year	Date of sowing	Observed yield (kg/ha)	Simulated yield (kg/ha)
2018	D1	7658	7268
	D2	7432	7110
	D3	7189	7089
2019	D1	7656	7886
	D2	7432	7591
	D3	7002	7432
2020	D1	7256	7142
	D2	7031	6933
	D3	6948	6411
RMS E (kg/ha)	305.24		
RMSE %	4.18		

From the table simulated yield was 7089 to 7268 kg/ha for year 2018 and observed yield was 7189 to 7658 kg/ha. Simulated and observed yield was obtained for year 2018 was 7432 to 7886 kg/ha and 7002 to 7656 kg/ha. The range of yield range between 6411 to 7142 kg/ha for simulation and 6948 to 7256 kg/ha for observed data set.

A. Maximum Leaf Area Index

leaf area index for year 2018 and 2019 was 4.39 to 4.71 and 4.98 to 5.21, respectively. Observed value was 4.65 to 5.9 whereas simulated value was 5.2 to 5.8. For year 2020, LAI was obtained between 4.46 to 4.89 and for observed data it was 5.21 to 5.74.

Table 7: Simulated and observed value of Leaf Area Index (LAI)
Emergence from DAS

Year	Date of sowing	Observed LAI	Simulated LAI
2018	D1	5.21	4.71
	D2	5.1	4.68
	D3	4.98	4.39
2019	D1	5.6	5.19
	D2	5.2	4.65
	D3	5.8	5.9
2020	D1	5.74	4.89
	D2	5.21	4.46
	D3	5.31	4.84
RMSE	0.53		
RMSE %	9.63		

For year 2018 simulation emergence was found between 10 to 13 and observed data it was found between 10 to 15. For year 2020 emergence date was obtained for simulated data 8 to 10 to 14 and 11 to 14 for observed data set.

Table 8: Simulated and observed emergence DAS

Year	Date of sowing	Observed emergence DAS	Simulated emergence DAS
2018	D1	15	13
	D2	12	11
	D3	10	10
2019	D1	11	10
	D2	10	9
	D3	8	9
2020	D1	14	14
	D2	11	12
	D3	10	11
RMSE	0.97		
RMSE %	0.75		

Comparison between observed and simulated emergence DAS

Anthesis

For year 2018 simulated anthesis DAS ranged between 52 to 58 and 58 to 60 for observed data. For year 2019, the simulated range between 56 to 57 and observed range between 60 to 63. For 2020-year anthesis ranged from 65 to 67 for simulated data and observed range between 69 to 73.

Table 9: Simulated and observed value of anthesis DAS

Year	Date of sowing	Observed anthesis DAS	Simulated anthesis DAS
2018	D1	60	58
	D2	58	54
	D3	58	52
2019	D1	62	56
	D2	63	57
	D3	60	56
2020	D1	69	65
	D2	73	67

	D3	73	66
RMSE	5.20		
RMSE %	8.05		

Comparison between observed and simulated anthesis day from DAS

Physiological maturity

For year 2018 physiological maturity reach 91 to 98 days for simulated and 108 to 112 for observed data. It was 102 to 106 for simulated data year 2020 and 112 to 115 for observed data

Table 10: Simulated and observed value of physiological maturity DAS

Year	Date of sowing	Observed physiological maturity	Simulated physiological maturity
2018	D1	112	95
	D2	110	91
	D3	108	98
2019	D1	106	91
	D2	108	92
	D3	107	91
2020	D1	115	106
	D2	114	104
	D3	112	102
RMSC	11.54		
RMSC %	10.47		

Validation of CERES-Maize for spring maize

After calibrating the model and setting the genetic coefficient, model validation process was done. Model validation was done using the data of year 2021 and 2022. Validation is the process to check the truthfulness of the model. Validation of model was done for some parameters *viz.* grain yield, leaf area index, emergence, anthesis and physiological maturity.

Grain yield

The data pertaining of validation to comparison between measured and simulated value of crop emergence during 2021 to 2022 (two year) have been presented in Table

Table 11: Simulated and observed value of grain yield (kg/ha)

Year	Date of sowing	Observed yield (kg/ha)	Simulated yield (kg/ha)
2021	D1	7456	7066
	D2	7342	6965
	D3	6795	6543
2022	D1	7564	7086
	D2	7432	7056
	D3	7214	6684
RMSC (kg/ha)	405.52		
RMSC %	5.54		

The yield for year 2021 was ranged from 6543 to 7066 kg/ha and 6795 to 7456 kg/ha was observed yield. The simulated yield was 6684 to 7086 kg/ha and 7214 to 7564 kg/ha for observed data.

The range of leaf area index for simulated data was 4.82 to 4.93 and 5.4 to 5.6 for observed data sets. LAI for simulated found to be ranged in 4.52 to 4.75 and 5.1 to 5.27 for year 2022.

Table 12: Simulated and observed value of Leaf Area Index (LAI)

Year	Date of sowing	Observed LAI	Simulated LAI
2021	D1	5.6	4.93
	D2	5.4	4.69
	D3	5.4	4.82
2022	D1	5.27	4.75
	D2	5.1	4.52
	D3	5.25	4.72
RMSE	5.09		
RMSE%	10.04		

Emergence from DAS

The range of emergence was found to be between 10 to 12 and 11 to 12 for observed data set. Whereas for year 2022 emergence value for simulated was 8 to 12 and 9 to 11 for observed data set. Table 13: Simulated and observed value of emergence DAS

Year	Date of sowing	Observed emergence DAS	Simulated emergence DAS
2021	D1	12	12
	D2	11	11
	D3	11	10
2022	D1	11	12
	D2	10	9
	D3	9	8
RMSE	4.24		
RMSE %	6.16		

Anthesis

The data revealed that anthesis occur at 61 to 67 and 62 to 68 for observed data. For year 2022, the simulated value for anthesis in different date of sowing was in range between 53 to 59 and observed anthesis value in range between 55 to 61.

Table 14: Simulated and observed value of emergence DAS

Year	Date of sowing	Observed anthesis DAS	Simulated anthesis DAS
2021	D1	68	67
	D2	69	62
	D3	62	61
2022	D1	60	59
	D2	61	54
	D3	55	53
Avg. RMSE	4.16		
RMSE %	7.21		

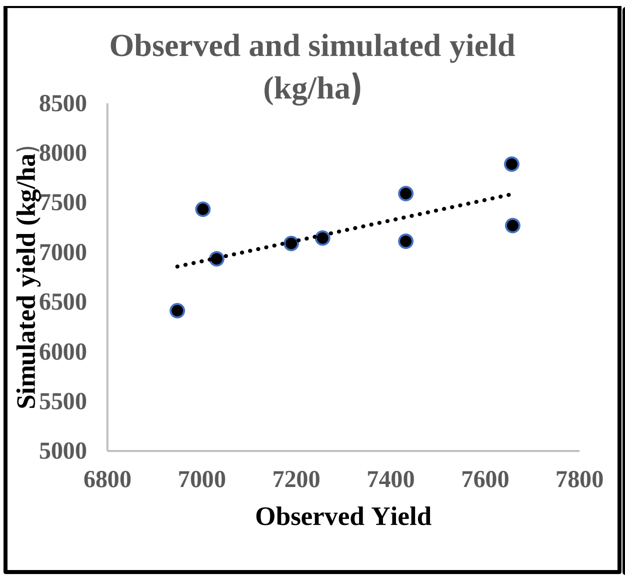
Physiological maturity

From the table physiological maturity was attained in 97 to 103 and 109 to 111 days for year 2020 and 2021. Physiological maturity was 85 to 91 and 98 to 100 days for observed data. The simulated values were obtained in accordance with observed value with 10.8 % RMSE.

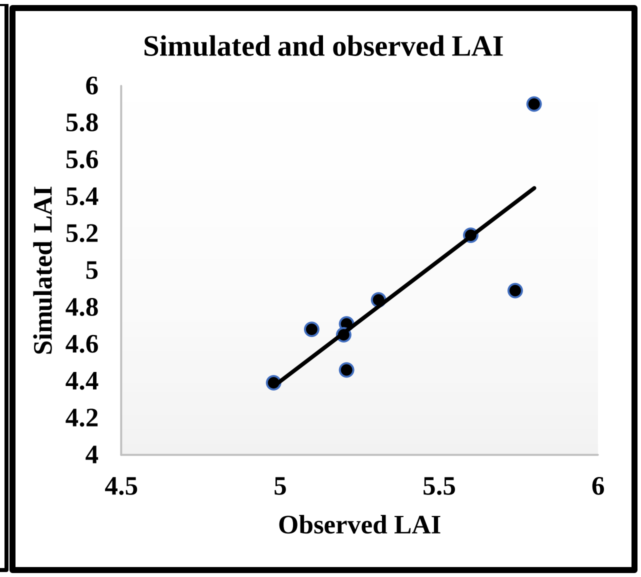
Table 15: Simulated and observed value of physiological maturity DAS

Year	Date of sowing	Observed physiological maturity	Simulated physiological maturity
2021	D1	109	103
	D2	111	99

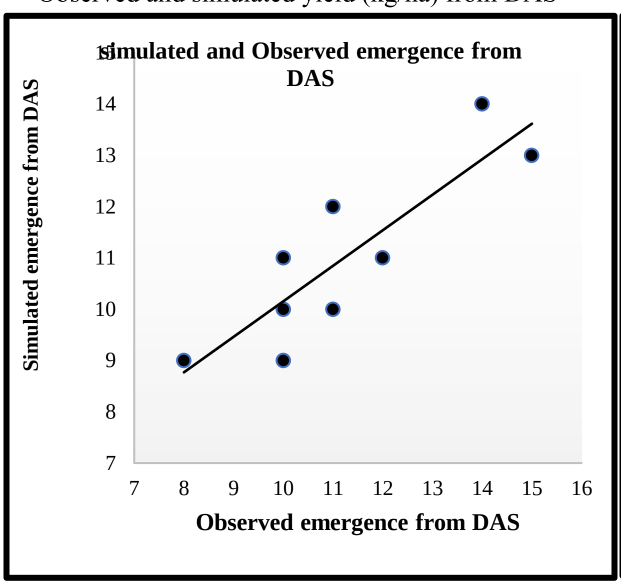
	D3	110	97
2022	D1	100	91
	D2	98	86
	D3	99	85
RMSE	11.31		
RMSC %	10.8		



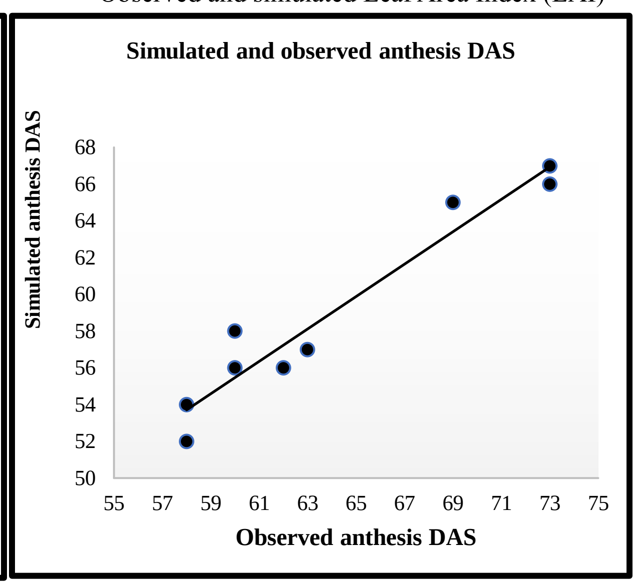
Observed and simulated yield (kg/ha) from DAS



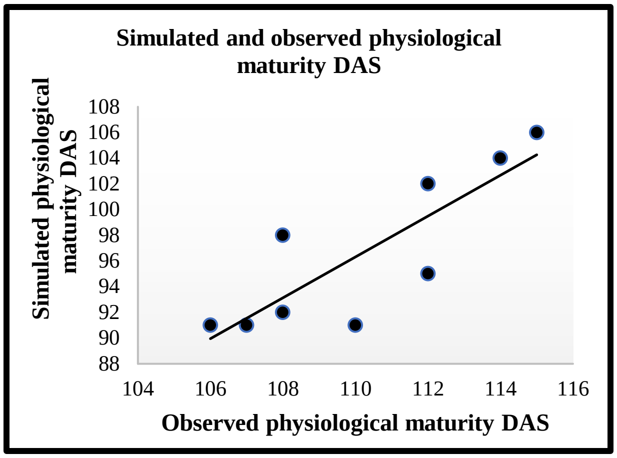
Observed and simulated Leaf Area Index (LAI)



Observed and simulated emergence DAS

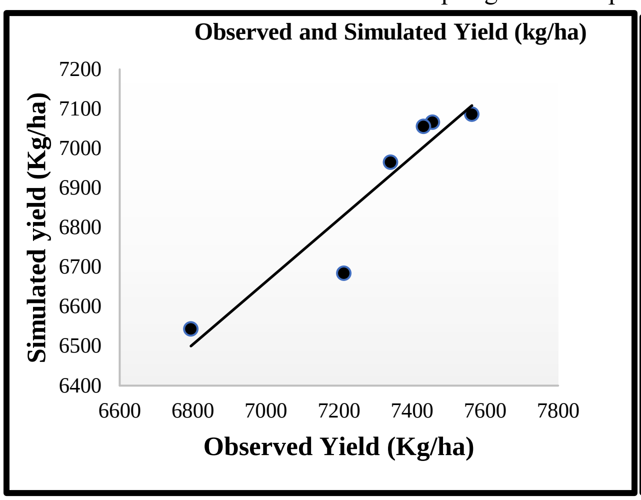


Observed and simulated anthesis day from DAS

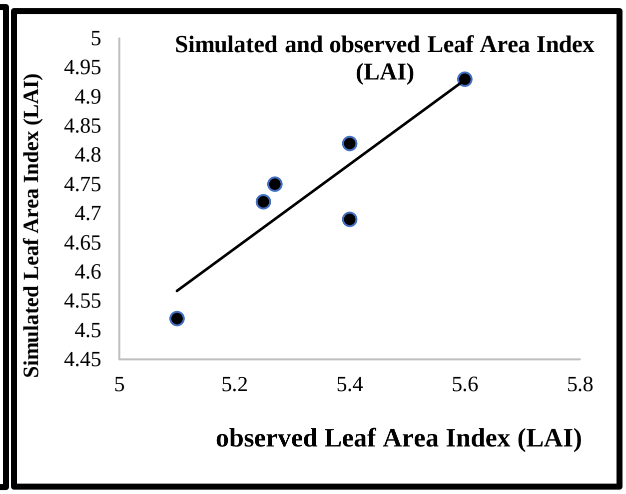


Observed and simulated physiological maturity from DAS

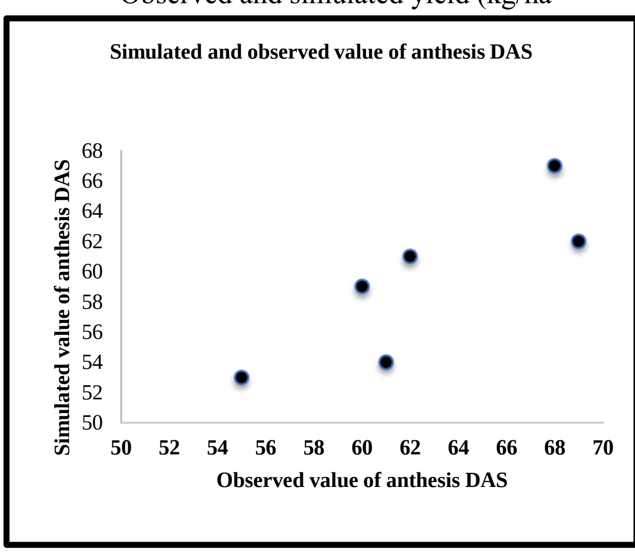
Validation of CERES -Maize model for spring maize crop



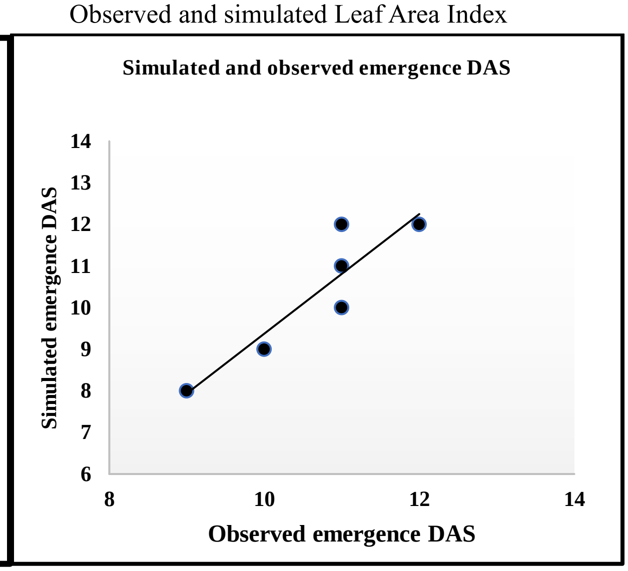
Observed and simulated yield (kg/ha



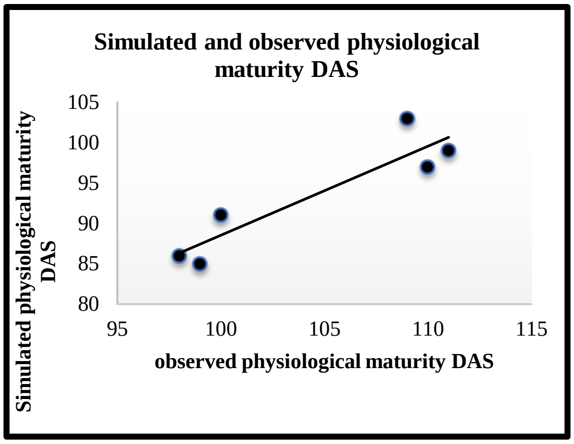
Observed and simulated Leaf Area Index



Observed and simulated anthesis



Observed and simulated emergence



Observed and simulated physiological maturity

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