Evaluation of CERES –Rice Model for Simulating Rice yield and phenophases

ABSTRACT

In this study, the performance of the CERES-Rice model in simulating the growth and yield of the Rajeshwari variety in the Raipur district of Chhattisgarh, India, was evaluated. Utilizing observed data from 2021 and 2022, the model was calibrated and validated using key parameters such as days to anthesis, physiological maturity, and yield. Calibration involved adjusting genetic coefficients to improve simulation accuracy, with validation ensuring the model's reliability beyond the calibration period. The comparison between observed and simulated data for crop performance parameters showed that the model performed reasonably well. For days to Anthesis, the RMSE was 4.32 with a d-stat of 0.59, and an error of 5.4%. For Days to Panicle initiation, the RMSE was 1.83, the d-stat was 0.82, and the error was -4.7%. For days to PM, the RMSE was 6.7, the d-stat was 0.65, and the error was 3.0%. Yield showed an RMSE of 472.4, a d-stat of 0.81, and an error of 7.7%.FThe mean simulated values closely matched the observed means, indicating overall good model accuracy. In this study, fine tuning the genetic coefficients of CERES rice model for the variety Rjeshwariwas done and can be used for further studies and applications.

1. Introduction

Rice is a staple food crop, sustaining over 3.5 billion people globally, with more than 90% of its production and consumption centered in Asia (IRRI, 2012). Chhattisgarh is known as the rice bowl of central India. Nowadays, rice cultivation is susceptible to climatic fluctuations despite the advancements in technology.To mitigate these risks, crop growth simulation models emerge as indispensable tools, offering insights for both tactical and strategic agricultural decisions. Through accurate validation against field data, these models minimize the need for extensive and costly trials, facilitating analyses such as yield gaps across diverse crops, including rice. Specifically, the CERES-Rice model emerges as anidealtool for precision agriculture, guiding cultivar selection and optimal planting schedules (Nayak, 2022). As a process-based model, CERES-Rice is having versatile applications in various research areas. These include irrigation responses (Hussain *et al*., 2023), studies on cropping sequence (Chandran, *et al.,* 2021 and Gao et al., 2022), yield-gap analyses (Harithalekshmi, 2020 and Saberali*et al.,* 2024), yield forecasting (Kaeomuangmoon*et al.,* 2019), and climate change impact studies (Darikandeh*et al.,* 2020 and Darikandeh*et al*., 2024).The model's flexibility makes it a powerful tool for addressing a wide range of agricultural research questions and practical applications. However, the efficacy of these models depends on accurate genetic coefficients, which must be carefully calibrated and validated for each variety in its specific region (Vysakh *et al.,* 2016). Once validated, such models unlock the potential to tailor crop management strategies to individual varieties and locations, helping decision-making processes and enhancing resource utilization efficiency (Singh *et al*., 2015). Thus, this study was done to evaluate the performance ofCERES-Rice model in Raipur districts, focusing on the variety Rajeshwari.

2. Methodology

2.1 CERES DSSAT model

The CERES-Rice model is a component of the Cropping System Model (CSM) within the DSSAT (Decision Support System for Agrotechnology Transfer) framework (Singh *et al*., 1990; Buresh *et al*., 1991; Singh *et al*., 1993; Ritchie *et al.*, 1987, 1998). A minimum data set (MDS) is necessary to run the model. Like other crop modules in the CSM, CERES-Rice uses essential daily weather data, soil profile characteristics, crop management practices, and variety-specific genetic inputs. There are several steps that can be followed to perform the calibration of the crop model. The CERES-Rice model within DSSAT v 4.6 (Hoogenboom*et al.*, 2023) was utilized to examine rice grain yield and growth stages. All necessary input files, such as weather, soil, and crop data, were prepared using station records. To ensure precise simulation results, accurate genetic coefficients were essential, and can be determined using the 'Gencalc' tool in DSSAT. The genetic coefficient used in CERES DSSAT model was represented in Table 1.

P Coefficient		**G Coefficient**	
P1	Juvenile phase coefficient (°C.d)	G1	Spikelet number coefficient
P20	Critical Photoperiod (h)	G2	Single Grain Weight (g)
P2R	Photoperiodism Coefficient (°C.d)	G3	Tillering Coefficient
P5	Grain filling duration coefficient	PHINT	Temperature tolerance coefficient

2.2 Calibration and Validation

Calibrating a crop model is a standard procedure that involves estimating crop parameters based on observed field data. This process entails determining unknown parameters done by adjusting the model's parameters. Calibration involves selecting the correct values for coefficients that significantly influence various factors, including soil nitrogen, soil organic carbon, soil phosphorus, crop growth, phenological development, biomass accumulation, dry-matter partitioning, nutrient uptake, yield and yield attribute.

During calibration, genetic coefficient values were adjusted based on how well the simulations matched observed values during 2021. Validation means checking if the simulated results matches with observed valueswhich was not used during calibration (values observed during 2022). Both during calibration and validation, the simulated data was compared with observed values using different skill scores like Root Mean Square Error (RMSE), index of agreement (d-stat) and error percentage (%).Around 2500 iterations were conducted to fine-tune these coefficients.

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

Where, Pi, Oi and n denotes predicted value, observed value and number of observations respectively (Wallach and Goffinet, 1987).

$$d - stat = 1 - \left[\frac{\sum (P_i - O_i)^2}{\sum (\left|P_i'\right| + \left|O_i'\right|)^2}\right]$$

Where, $P_i' = P_i - \overline{O}$ and $O_i' = O_i - \overline{O}$

It ranges from zero to 1, with 1 signifying the highest level of fit (Timsina and Humphreys, 2006 and Anothai*et al*., 2008).The d-statistic should tend towards one, while the RMSE should tend towards zero to indicate effective model performance (Willmott, 1982).

Error percentage (%)

$$Error(\%) = \frac{(simulated - observed)}{(observed)} \times 100$$

The observed data was collected from the experiment conducted by All India Coordinated Research Programme on Agrometeorology, Department of Agrometeorology for a period of 2021 to 2022. The variety used was Rajeshwari (IGVR 1), a short duration rice variety released by IGKV during 2021.

3. RESULTS AND DISCUSSION

In the study, the calibration and validation outcomes of the CERES model were assessed by analyzing phenological observations and yield data. The model's calibration involved comparing observed and simulated values of three key parameters: Anthesis day, physiological maturity day, and yield.

3.1 Model performance evaluation during calibration

The model calibration was done with the simulated values and observed values of days to anthesis, days to physiological maturity and yield during 2021.

Observed (Obs.) and simulated (Sim.) data for various parameters including days to Anthesis, days to Panicle initiation (PI), days to Physiological Maturity (PM), and Yield for three dates of planting labeled as D1, D2, and D3, along with their respective means were presented in Table 2.

For Days to Anthesis, Days to PI, and Days to PM, the mean observational values were 70, 42, and 100 days respectively, while the mean simulated values were 74, 40, and 103 days respectively. The Yield data showed observed yields ranging from 3537 to 4597 acrossdifferent dates of planting, with corresponding simulated yields ranging from 3004 to 4597. The mean observational yield was 4048, while the mean simulated yield was 3758. The RMSE values for days to Anthesis, days to PI, and days to PM were 4.32, 1.83, and 6.7 respectively. The d-Stat values for simulatingdays to Anthesis, days to PI, and days to PM were 0.59, 0.82, 0.65 and 0.81 respectively indicating better agreement between observed and simulated values.

Table 2: Performance evaluation of CERES rice model during calibration

Particulars	**Days to Anthesis**		**Days to PI**		**Days to PM**		**Yield**	
	Obs.	**Sim.**	**Obs.**	**Sim.**	**Obs.**	**Sim.**	**Obs.**	**Sim.**
D1	70	76	44	43	105	106	3938	3741
D2	73	75	41	41	98	104	4332	4597
D3	66	70	40	37	99	100	3004	3537
Mean	70	74	42	40	100	103	3758	4048
RMSE	4.32		1.83		6.7		472.4	
d- Stat	0.59		0.82		0.65		0.81	
Error (%)	5.4		-4.7		3.0		7.7	

3.2 Model performance evaluation during validation

The results of model evaluation during validation period (2022) was described in Table 3.For Days to Anthesis, Days to PI, and Days to PM, the mean observational values are 68, 45, and 99 days respectively, while the mean simulated values are 74, 41, and 105 days respectively.Yield data shows observational yields ranging from 3528 to 4278 across the different instances, with corresponding simulated yields ranging from 3831 to 4482. The mean observational yield is 3764, while the mean simulated yield is 4173.

Root Mean Square Error (RMSE) values for Days to Anthesis, Days to PI, Days to PM and yield are 6.46, 4.83, 7.77 and 697.3 respectively. The d-Stat values for the parameters range from 0.52 to 0.58, indicating a better agreement between observed and simulated values.

Table 3: Performance evaluation of CERES rice model during validation

Particulars	Days to Anthesis		Days to PI		Days to PM		Yield	
	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.
D1	72	77	49	43	105	106	4278	4205
D2	67	75	44	41	99	105	4034	4482
D3	65	71	43	38	92	104	3728	3831
Mean	68	74	45	41	99	105	3951	4173
RMSE	6.46		4.83		7.77		697.3	
d- Stat	0.54		0.57		0.52		0.58	
Error %	8.8		8.8		6.0		5.6	

The calibration and validation results of the CERES model using phenological observations and yield data, highlighting the agreement between observed and simulated values for the various parameters.For the selected parameters, model performance was good at calibration and validation.

As per Vysakh *et al.* (2016), a percentage deviation of less than 10% between observed and predicted values suggests effective model performance. The average error percentage for days to germination, anthesis, physiological maturity, and yield were below 10%. Therefore, the model exhibited good performance in predicting these variables. Notably, among the various phenophases, the model demonstrated particularly accurate predictions for days to panicle initiation. In case of yield all the error statistics showed good agreement with observed and simulated values.Hence it can be understood that the model was able to predict anthesis, panicle initiation, physiological maturity date and yield in an acceptable level of accuracy. Figure 1 represents the graphical representation of model performance. From the figure it was clear that observed data points closely align with the simulated data, exhibiting a tightly clustered distribution along the line of best fit. This indicates a high degree of agreement between the observed and simulated datasets.

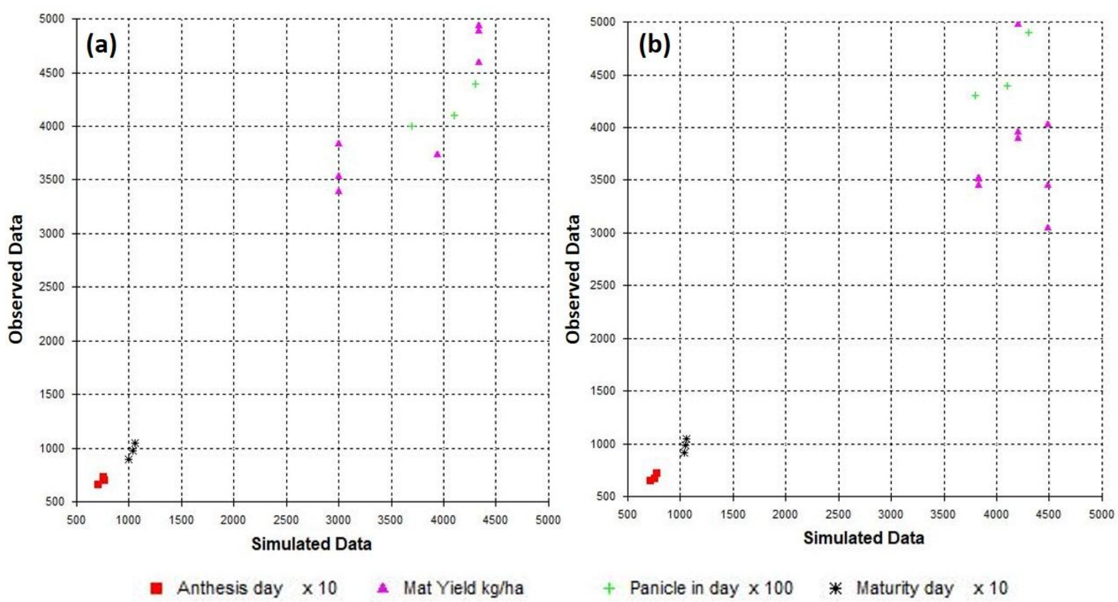

Figure 1: The scatterplot showing observed and simulated values of anthesis, panicle initiation, maturity day and yield during (a) calibration and (b) validation

The genetic coefficients specific to the Rajeshwari variety have been established and thefinal genetic coefficient used for simulation was in given in Table 4.

Table 4: The calibrated genetic coefficient of Rice variety *Rajeshwari*

P Coefficient		G Coefficient	
P1	408.0	G1	73.8
P20	12	G2	0.0275
P2R	200	G3	1.10
P5	340	PHINT	83.0

CONCLUSION

The performance evaluation during calibration and validation of the CERES model were conducted using observed and simulated data for various parameters, including days to anthesis, days to physiological maturity, and yield, for the years 2021 and 2022. The agreement between observed and simulated values was evaluated through measures RMSE), d-Stat values and error (%), indicating satisfactory performance of the model in both calibration and validation phases. The model exhibited good performance in predicting key variables, indicating its reliability in simulating the growth and yield of the Rajeshwari variety. In this study, the genetic coefficients specific to this variety have been established and incorporated into the simulation process, further enhancing the accuracy of the model's predictions.

REFERENCE

Anothai J, Patanothai A, Jogloy S, Pannangpetch K, Boote KJ and Hoogenboom G (2008). A sequential approach for determining the cultivar coefficients of peanut lines using end-of-season data of crop performance trials. *Field Crops Research*,108, 169–178.

Buresh, R.J., Singh, U., Godwin, D.C., Ritchie, J.T. and De Datta, S.K., 1991. Simulating soil nitrogen transformations and crop response to nitrogen using the CERES-RICE model. IRRI research paper series-International Rice Research Institute.

Chandran, M. S., Banerjee, S., Mukherjee, A., Nanda, M. K., Mondal, S., & Kumari, V. V. (2021). Evaluating the impact of projected climate on rice–wheat-groundnut cropping sequence in lower Gangetic plains of India: A study using multiple GCMs, DSSAT model, and long-term sequence analysis. Theoretical and Applied Climatology, 145(3), 1243-1258.

Darikandeh, D., Shahnazari, A., Khoshravesh, M., & Hoogenboom, G. (2023). Evaluating rice yield and adaptation strategies under climate change based on the CSM-CERES-Rice model: a case study for northern Iran. Theoretical and Applied Climatology, 151(3), 967-986.

Darikandeh, D., Shahnazari, A., Khoshravesh, M., & Hoogenboom, G. (2023). Evaluating rice yield and adaptation strategies under climate change based on the CSM-CERES-Rice model: a case study for northern Iran. Theoretical and Applied Climatology, 151(3), 967-986.

Gao, F., Luan, X., Yin, Y., Sun, S., Li, Y., Mo, F., & Wang, J. (2022). Exploring long-term impacts of different crop rotation systems on sustainable use of groundwater resources using DSSAT model. Journal of Cleaner Production, 336, 130377.

Harithalekshmi, V. (2020). Analysis of potential yield and yield gap of rice (Oryza sativa L.) using CERES rice model (Doctoral dissertation, Department of Agricultural Meteorology, College of Horticulture, Vellanikkara).

Hoogenboom, G., C.H. Porter, V. Shelia, K.J. Boote, U. Singh, W. Pavan, F.A.A. Oliveira, L.P. Moreno-Cadena, T.B. Ferreira, J.W. White, J.I. Lizaso, D.N.L. Pequeno, B.A. Kimball, P.D. Alderman, K.R. Thorp, S.V. Cuadra, M.S. Vianna, F.J. Villalobos, W.D. Batchelor, S. Asseng, M.R. Jones, A. Hopf, H.B. Dias, L.A. Hunt, and J.W. Jones. 2023. Decision Support System for Agrotechnology Transfer (DSSAT) Version 4.8.2 (www.DSSAT.net). DSSAT Foundation, Gainesville, Florida, USA.

Hoogenboom, G., C.H. Porter, V. Shelia, K.J. Boote, U. Singh, W. Pavan, F.A.A. Oliveira, L.P. Moreno-Cadena, T.B. Ferreira, J.W. White, J.I. Lizaso, D.N.L. Pequeno, B.A. Kimball, P.D. Alderman, K.R. Thorp, S.V. Cuadra, M.S. Vianna, F.J. Villalobos, W.D. Batchelor, S. Asseng, M.R. Jones, A. Hopf, H.B. Dias, L.A. Hunt, and J.W. Jones. 2023. Decision Support System for Agrotechnology Transfer (DSSAT) Version 4.8.2 (www.DSSAT.net). DSSAT Foundation, Gainesville, Florida, USA.

Hussain, T., Mulla, D. J., Hussain, N., Qin, R., Tahir, M., Liu, K., ... &Duangpan, S. (2023). Optimizing nitrogen fertilization to enhance productivity and profitability of upland rice using CSM–CERES–Rice. Plants, 12(21), 3685.

IRRI (International Rice Research Institute) (2012). IRRI Annual Report, Los Banos, the Philippines.

Kaeomuangmoon, T., Jintrawet, A., Chotamonsak, C., Singh, U., Buddhaboon, C., Naoujanon, P., ... & Hoogenboom, G. (2019). Estimating seasonal fragrant rice production in Thailand using a spatial crop modelling and weather forecasting approach. The Journal of Agricultural Science, 157(7-8), 566-577.

Nayak, A. K. (2022). Advanced Techniques for Precision Farming in Rice. *Climate Resilient Technologies for Rice based Production Systems in Eastern India*.

Ritchie, J. T., E. C. Alocilja, U. Singh, and G. Uehara. 1987. IBSNAT and the CERES-RICE model, IN Weatherand Rice, Proceedings of the International Workshop on ‘The Impact of Weather Parameters on Growth and Yield of Rice,” IRRI, Philippines, pp. 271-283.

Ritchie, J.T. , Singh, U., Godwin, D.C., Bowen, W.T. 1998. Cereal growth, development, and yield. Pages 79-98 in Tsuji G.Y., G. Hoogenboom, and P.K. Thornton (Eds) Understanding options for agricultural production. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Saberali, S. F., &Darzi□Naftchali, A. (2024). Yield gap analysis and the relative importance of factors explaining yield variability in paddy fields. European Journal of Agronomy, 156, 127172.

Singh, P. K., Singh, K. K., Bhan, S. C., Baxla, A. K., Gupta, A., Balasubramanian, R. and Rathore, L. S. (2015). Potential yield and yield gap analysis of rice (*Oryza sativa* L.) in eastern and north eastern regions of India using CERESrice model. *Journal of Agrometeorology,*, 17(2): 194-198.

Singh, U., Ritchie, J.T., Godwin, D.C. 1993. A user’s guide to CERES Rice – V2.10.Simulation Manual IFDC-SM-4. IFDC, Muscle Shoals, Alabama, USA.

Singh, U., Tsuji, G.Y., Godwin, D.C. 1990. Planting new ideas in DSSAT: the CERES-Rice model. Agrotechnology Transfer, 10:1-7. University of Hawaii, Honolulu, Hawaii, USA.

Timsina J and Humphreys E (2006). Performance of CERES-Rice and CERES-Wheat models in rice–wheat systems: a review. *Agricultural Systems,*90, 5–31.

Vysakh, A., Ajithkumar, B., and Rao, A. S. (2016). Evaluation of CERES-Rice model for the selected rice varieties of Kerala. *Journal of Agrometeorology*, *18*(1), 120-123.

Wallach D and Goffinet B (1987). Mean squared error of prediction in model for studying ecological and agronomic systems. Biometrics 43, 561–573.

Willmott, C. J. (1982).Some comments on the evaluation of model performance. *American Meteorological Society*, Bull.,63:1309- 1313.

Bhanusree D, Srinivasachary D, Nirmala B, Supriya K, Naik BB, Rathod S, Brajendra ., Reddy BNK, Bellamkonda J. Application of the CERES-Rice Model for Rice Yield Gap Analysis. Int. J.Environ. Clim. Change. [Internet]. 2022 Nov. 1 [cited 2024 May 17];12(11):3471-8. Available from: https://journalijecc.com/index.php/IJECC/article/view/1396

Timsina J, Humphreys EJ. Performance of CERES-Rice and CERES-Wheat models in rice–wheat systems: A review. Agricultural systems. 2006 Oct 1;90(1-3):5-31.