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Calibration and validation of CERES-rice model using varied transplanting dates and seedling ages of RNR 15048 and assessing high temperature sensitivity in the North Eastern Ghat region of Odisha

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सार – RNR 15048 के लिए CERES - चावल मॉडल को जांचने और मान्य करने के लिए ओडिशा के उत्तर पूर्वी घाट क्षेत्र में PG प्रायोगिक फार्म, एम. एस. स्वामीनाथन स्कूल ऑफ एग्रीकल्चर, परलाकाहेमुंडी, गजपति जिले में प्रत्यारोपण की चार तारीखों (29 जुलाई, 7 अगस्त, 17 अगस्त और 27 अगस्त) और अंकुरों की तीन अवधि (15, 25 और 35 दिन पुरानी) के साथ एक क्षेत्रीय प्रयोग किया गया । एंथेसिस और शारीरिक परिपक्वता परघटना विज्ञान के अनुकरण के संबंध में मॉडल मूल्यांकन को क्रमशः 3% और 1% के RMSEn के साथ उत्कृष्ट माना जाता है, जो क्रमशः प्रत्यारोपणकी तारीखों और अंकुरों की अवधि दोनों से प्रभावित होता है। इसी प्रकार, अनुकरणीय अनाज की पैदावार भी कम RMSE और RMSEn मानों के साथ प्रेक्षित की गई पैदावार से निकटता से संबंधित थी।घटना विज्ञान और अनाज की पैदावार दोनों के अनुकरण से प्राप्त CRM मूल्य नकारात्मक थे, जो अनुमानों के अति-आकलनको रिपोर्ट कर रहे थे।इसके अलावा, अनुकरणीयमॉडल पैदावार का उपयोग अनाज की उपज पर अधिक तापमान +0.3 और +0.9 °C के प्रभाव का अध्ययन करने के लिए किया गया, जिसमें तापमान में वृद्धि के साथ अनाज की पैदावार में कमी देखी गई। इसलिए, मॉडल को आरएनआर 15048 के लिए उपयुक्त प्रबंधन प्रथाओं का सुझाव देने के लिए ओडिशा के पूर्वी घाट क्षेत्र के परिवर्तनशील कृषि-पर्यावरण में एक अनुसंधान उपकरण के रूप में उपयोग करने के लिए पर्याप्त संवेदनशील पाया गया।

ABSTRACT. A field experiment was carried out with four dates of transplanting (29^{th} July, 7^{th} August, 17^{th} August and 27^{th} August) and three age of seedlings (15, 25 and 35 days old) at PG Experimental farm, M. S. Swaminathan School of Agriculture, Parlakahemundi, Gajapati district to calibrate and validate the CERES-Rice model for RNR 15048 in the north eastern ghat region of Odisha. The model evaluation with respect to simulation of phenology at anthesis and physiological maturity is considered to be excellent with RMSEn of 3% and 1% as influenced by both dates of transplanting and age of seedlings, respectively. Similarly, the simulated grain yields were also closely related to observed yields with lower RMSE and RMSEn values. The CRM values obtained in simulating both phenology and grain yields were negative, reporting an over-estimation of predictions. Further, the model simulated yields were used to study the influence of elevated temperatures +0.3 and +0.9° C on grain yield which showed reduction in grain yields with an increase in temperatures. Therefore, the model was found to be enough sensitive to be used as a research tool in the variable agro-environments of eastenghat region of Odisha to suggest suitable management practices for RNR 15048.

Key words – CERES-Rice model, Elevated temperature, Genetic coefficients, RNR 15048, Sensitivity analysis.

1. Introduction

Rice stands as the predominant essential food source, providing sustenance for more than 60 percent of the global population (Spohrer *et al*., 2013). As the global population continues to grow at a rapid pace, the importance of ensuring a reliable food source becomes even more crucial (Shankar *et al.*,2022). A key objective within this context is to improve rice yields significantly. However, the production of rice crops remains highly vulnerable to unfavorable environmental conditions exacerbated by climate change, which presents a significant area of concern (Malhi *et al*., 2021). To effectively tackle this challenge, it becomes imperative to

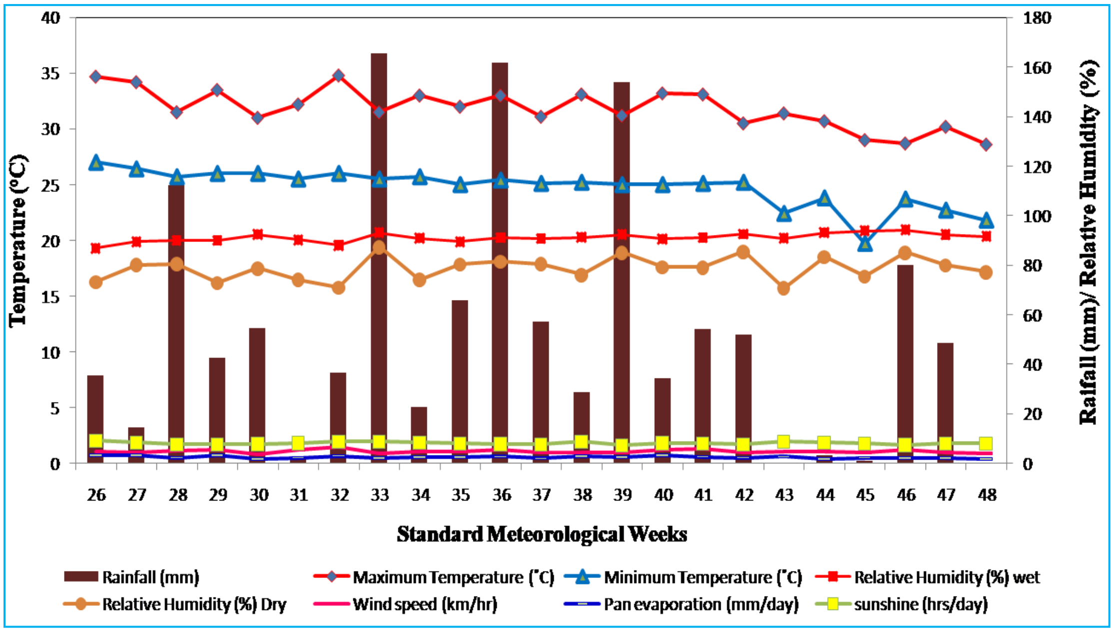

Fig. 1. Weekly weather parameters during crop growing season (June to November)

predict the impact of climate change on both soil and crops (Raza *et al.*, 2019). At this critical juncture, crop simulation models have emerged as indispensable tools. These models offer convenience, affordability, and time efficiency, while also holding the potential to predict the outcomes of climate change on crop productivity (Bindi *et al.*, 2015). They additionally play a pivotal role in facilitating diverse decisions surrounding rice crop management. The CERES-Rice model, available within the DSSAT framework, is a computer-based package that quantifies how climate, soil and management practices impact the suitability and performance of rice cultivars. However, for these models to be reliable and applicable, they need to be trained using region-specific data (Hussain *et al.*,2023).

The RNR 15048 (Telangana Sona) rice variety developed by Professor Jayashankar Telangana State Agricultural University (PJTSAU), Hyderabad, with a growth cycle of 120-125 days, was introduced in South Odisha. Yet, standardized management practices for this specific agroclimatic region have not been established (Sindhu *et al.*, 2022a). In light of this, generating new data to formulate suitable crop management strategies through long-term agronomic research proves to be time-intensive and costly. Hence, developing a calibrated and validated CERES-Rice model tailored to RNR-15048 in southern Odisha holds the potential to serve as a valuable tool.

Rice producers in north eastern ghat zone of Odisha frequently face challenges such as delayed monsoon onset during the *kharif* season (Sindhu *et al.*, 2022b). To effectively address this concern, a field experiment was conducted involving different transplanting dates and seedling ages which was used to fine-tune and validate the CERES-Rice model. Additionally, the study endeavors to predict the yield response of RNR-15048 using the validated model through sensitivity analysis.

2. Materials and methods

To validate the CERES-Rice model for RNR-15048 in north eastern ghat region of Odisha a field experiment was carried out during *kharif* season 2021 at Post Graduation Research Farm, M. S. Swaminathan School of Agriculture, Parlakahemundi, Gajapati district, situated at 18° 48" N latitude, 84° 10" E longitude and an altitude of 64 m above mean sea level. The climate of the experimental area is tropical with hot and dry summer, cool winter and erratic rainfall. During the crop growing season (June to November), the crop received a total rainfall of 1223 mm and the average maximum temperature varied from 28.7 to 34.7 °C, while the minimum temperature ranged from 19.7 to 27 °C. Moreover, the relative humidity recorded during this period by wet bulb and dry bulb averaged at 91.1% and 78.7%, respectively (Fig. 1). The soil of the experimental site was sandy clay in texture, well drained, having pH 5.4, electrical conductivity 0.4 dS/m, organic carbon

0.75%, low in available N (225 kg/ha), medium in available P (14.2 kg/ha) and exchangeable K (110 kg/ha). The experiment was carried out in split plot design with four transplanting dates (29th July, 7th August, 17th August and 27th August) in main plot and three age of seedlings (35, 25 and 15 days) in sub plot factor, replicated thrice. The data collected during 2019 from the experiment was used to calibrate the genetic co-efficients for RNR-15048 and these calibrated coefficients were validated with experimental findings of 2021.

2.1 *Model description*

Decision Support System for Agrotechnology Transfer (DSSAT) is a software package developed by IBSNAT group that helps users to simulate phonological stages, growth, yield, water and nitrogen balance by providing input related to soil, weather and crop management practices. Presently, the DSSAT package is inclusive of CERES models for cereals (rice, maize, wheat, sorghum, pearl millet and barely), CROPGRO models for legumes (beans, peanuts, soybean *etc*.) and SUBSTOR models for root crops (cassava, aroid and potato). In the present study, CERES rice model version 4.7.5.0 of the DSSAT modeling system was used to simulate the grain yield of RNR 15048 at different transplanting dates with different seedling ages. Further, it helped to assess the impact of temperature extremes on grain yield.

2.2. *Input requirements*

The input data required to execute the DSSAT models include daily weather data, soil data and crop management information

2.3. *Weather data*

The daily meteorological data of minimum data set, *viz.*, maximum temperature, minimum temperature, solar radiation and rainfall during the period of simulation at the given location was obtained from automatic weather station (AWS), M. S. Swaminathan School of Agriculture, Centurion University of Technology and Management.

2.4. *Soil data*

The soil in the experimental area was sampled from different soil depths and determined the clay (%), silt (%), organic carbon (%), pH of water and other soil parameters, *viz.*, lower limit, drained upper limit, saturated water content, bulk density, saturated hydraulic conductivity and root growth factor were estimated by using the inbuilt Build tool .

2.5. *Crop management data*

The crop management data includes information related to cultivar selection, date of planting, row spacing, row direction, planting depth, age of seedlings, method and period of scheduling irrigation, nutrient management, tillage and harvest.

TABLE 1

Genetic coefficients of RNR 15048 calibrated for the North Eastern Ghat Region of Odisha

Genetic Coefficients	Value
P1	489
P20	11
P2R	95.1
P5	330
G1	55
G2	0.023
G3	1
G4	1
PHINT	82

TABLE 2

Planting information used to run the model

Parameters	Value
Date of planting	As per the treatment
Method of planting	Transplants
Planting distribution	Hills
Plant population at seeding, plants m^{-2}	33
Plant population at emergence, plants m^{-2}	33
Row spacing, cm	20
Row direction, degrees from north	0
Planting depth, cm	5
Age of seedlings	As per treatment

2.6. *Cultivar*

The calibrated genetic coefficients of RNR 15048 (Telangana Sona) rice variety has been used in the present investigation (Table 1). It is a medium duration fine variety with low glycemic index. The varietal coefficients were determined by thermal time from emergence to the end of juvenile stage (P1), rate of photo induction (P2R), optimum photoperiod (P2), thermal time for grain filling (P5), conversion efficiency from sunlight to assimilates (G1), tillering rate (TR), and grain size (G2).

2.7. *Planting*

In planting management, detailed information on date of planting, method of planting, plant population both at seeding and emergence, row spacing, row direction, planting depth, age of seedlings and temperature during transplanting adopted during the cropping season were provided (Table 2).

2.8. *Irrigation*

The total amount of water supplied during each irrigation schedule was provided along with the stage and method of application.

2.9. *Nutrient management*

In the present study, RNR 15048 was supplied with 100 kg N, 60 kg P_2O_5 and 50 kg K_2O per hectare through urea, SSP and MOP, respectively. The entire recommended dose of phosphorus and potassium and 50 per cent dose of nitrogen were applied as basal application while, the remaining nitrogen dose was applied in two equal splits. No organic amendments were applied during this experiment.

2.10. *Model calibration and validation*

The genetic coefficients were estimated for RNR 15048 using GENCALC (Genotype Coefficient Calculator) as per standard procedure of iteration for the models and the calibration of the DSSAT-CERES-Rice model for RNR 15048 was done with the help of observed experimental data during the *kharif* season 2019 (Islam *et al*., 2021). Further, it was validated with experimental findings recorded for four dates of transplanting and three age of seedlings during the year 2021. This was done by comparing the observed results with simulated yield using absolute root mean square error (RMSE), normalized root mean square error (RMSEn) and coefficient of residual mass (CRM).

2.11. *Statistical analysis*

Model performance evaluation was statistically presented by the absolute Root Mean Square Error (RMSE), normalized root mean square error (RMSEn) and coefficient of residual mass (CRM). Where Oi and Pi are the observed and predicted values respectively for the i^{th} data point of n observations. The RMSE and RMSEn elucidate the magnitude of the average error but do not provide information about the relative size of the average difference between the observed and predicted. But, CRM indicates the direction of the error magnitude. The root mean square error (RMSE) was calculated using the following equation (Wallach and Goffinet, 1989).

$$\text{Root Mean Square Error (RMSE)} = \sqrt{\sum_{i=1}^{n} \frac{(pi - oi)^2}{n}} \quad (1)$$

TABLE 3

Comparison between observed and simulated days to attain anthesis of RNR 15048 after transplanting at different dates of transplanting with varying age of seedlings

Treatments	Days to Anthesis		
	Observed	Simulated	Error (%)
Dates of transplanting			
29th July	69	71	2.90
7th August	67	67	0.00
17th August	64	65	1.56
27th August	63	66	4.76
RMSE		2	
RMSEn (%)		3	
CRM		-0.02	
Age of seedlings			
35 Days	60	62	3.33
25 Days	65	68	4.62
15 Days	72	73	1.39
RMSE		2	
RMSEn (%)		3	
CRM		-0.03	

The simulation is considered excellent with a normalized RMSE less than 10 %, good if the normalized RMSE is greater than 10 and less than 20%, fair if the normalized RMSE is greater than 20% and less than 30%, and poor if the normalized RMSE is greater than 30%. The RMSEn was calculated using the following Equation (Kumar *et al*., 2017).

$$\text{Normaliszed Root Mean Square Error (RMSE)} = \left[\frac{\text{RMSE}}{\text{Mean of observed values}}\right] \times 100 \quad (2)$$

The Coefficient of Residual Mass (CRM) was also used to measure the tendency of the model to overestimate or under estimate the measured values. A negative CRM indicates over prediction and positive CRM indicates under prediction (Vijayalaxmi *et al*., 2016).The CRM was calculated using the following Equation.

$$\text{Coefficentor ResidualMass(CRM)} = \frac{\sum_{i-1}^{n} oi - \sum_{i-1}^{n} pi}{\sum_{i-1}^{n} oi} \quad (3)$$

TABLE 4

Comparison between observed and simulated days to attain physiological maturity of RNR 15048 after transplanting at different dates of transplanting with varying age of seedlings

Treatments	Days to physiological maturity		
	Observed	Simulated	Error (%)
Dates of transplanting			
29th July	96	97	1.04
7th August	96	96	0.00
17th August	94	96	2.13
27th August	91	94	3.30
RMSE		1	
RMSEn		1	
CRM		-0.02	
Age of seedlings			
35 Days	88	91	3.41
25 Days	96	97	1.04
15 Days	98	99	1.02
RMSE		1	
RMSEn		1	
CRM		-0.02	

2.12. *Sensitivity analysis*

The sensitivity of the validated CERES-Rice model to different elevated temperatures was studied in terms of grain yield of RNR 15048 by considering the simulated yields under optimum conditions as a reference.

3. Results and discussion

Model simulation efficiency was evaluated with the data obtained from four dates of transplanting and three ages of seedlings during the year 2021. During this process the collected data on grain yield was compared with the simulated values using statistical indices.

3.1. *Days to anthesis*

Simulated values of days to anthesis obtained by the model as influenced by different dates of transplanting were closely related to the observed data with RMSE, RMSEn and CRM values of 2.0 days, 3 per cent and -0.02, respectively (Table 3). The negative CRM values indicates that the CERES-Rice model over estimated days to anthesis to an extent of 0.02 per cent and prediction was considered excellent as the RMSEn values were less than 10 per cent.

The simulated values of days to anthesis with different age of seedlings was considered good with lower RMSE and RMSEn values of 2.0 days and 3 per cent, respectively. In addition, the negative CRM values indicated that the model over predicted the simulations by 0.03 percent. However, the days to anthesis simulated on 7th of August was 100% in agreement with the observed. This could be attributed to the fact that the calibrated genetic coefficients have strong agreement with the actual thermal time required for anthesis.

Many studies showed a strong agreement between predicted and observed days to anthesis through the utilization of the CERES-Rice model. This might be due to strong correlation between adjusted thermal time to physiological thermal time primarily governed by temperature and photoperiod factors (Vijayalaxmi *et al.*, 2016; Deka *et al.*, 2016).

3.2. *Days to Physiological Maturity*

The observed values of days to physiological maturity as influenced by different dates of transplanting were closer to the simulated values with RMSE values of 1 day and RMSEn values of 1 per cent (Table 4). The negative CRM showed the tendency of the model to over predict this parameter by 0.02 per cent.

The simulations of days to physiological maturity as influenced different age of seedlings with observed data was similar to the influence by different dates of transplanting with RMSE, RMSEn and CRM value of 1.0 day, 1 per cent and -0.02, respectively.

The durations of thermal time intervals, spanning from the appearance of the flag leaf ligule to anthesis and from sowing to emergence, demonstrate a notably consistent pattern across various genotypes and environmental conditions, in contrast to the period between emergence and flowering. The primary factor responsible for significant deviations in the duration between emergence and flowering has been identified as the main contributor to these pronounced variations (McMaster *et al.*, 2008). The close correspondence observed between the actual thermal time needed to attain physiological maturity and the calibrated genetic coefficients, particularly during the period from emergence to flowering, could potentially explain the strong concurrence found in the outcomes of Deka *et al.* (2016) and Satpute *et al.* (2018).

3.3. *Grain yield (kg/ha)*

Simulated grain yields obtained by the model as influenced by different dates of transplanting were closely related to the observed data with RMSE, RMSEn and CRM values of 152 kg, 4.83 and -0.046 respectively (Table 5, Fig. 2 and Fig. 3). A negative CRM indicates a tendency of the model towards over estimation of grain yield. Similarly, the lower value for RMSE and RMSEn reflected that the model predicted grain yield quite well. Similarly, upon assessing the Kanchana rice variety using the CERES-Rice model across diverse transplanting dates in Kerala found that the model over estimated the yield. This overestimation could likely be due to shortcomings in the inputs utilized for modeling, the recorded experimental data, and the incorporation of non modelled factors in model validation (Vysakh *et al*., 2016).

TABLE 5

Comparative analysis between observed and simulated grain yields of RNR 15048 at different dates of transplanting with varying age of seedlings

Treatments	Grain Yield (kg/ha)		
	Observed	Simulated	Error (%)
Dates of transplanting			
29th July	3607	3693	2.35
7th August	3225	3377	4.51
17th August	2997	3140	4.53
27th August	2758	2961	6.85
RMSE		152	
RMSEn		4.83	
CRM		-0.046	
Age of seedlings			
35 Days	3128	3317	5.67
25 Days	3322	3493	4.90
15 Days	2990	3069	2.57
RMSE		154	
RMSEn		4.89	
CRM		-0.047	

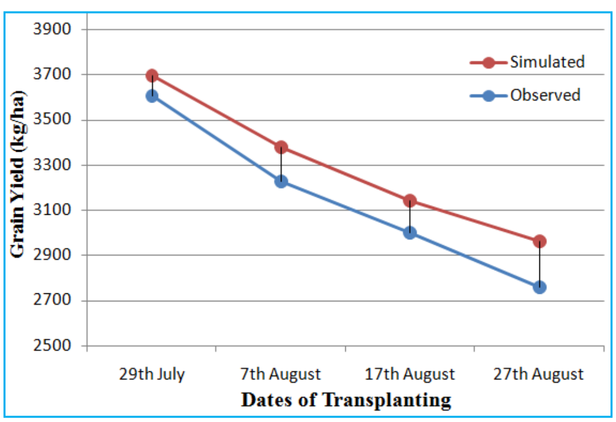

Fig. 2. Effect of dates of transplanting of RNR 15048 variety on simulated and observed grain yield (kg/ha)

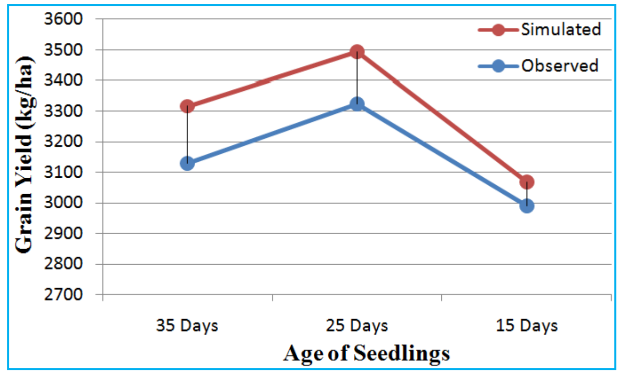

Fig. 3. Effect of age of seedlings of RNR 15048 variety on simulated and observed grain yield (kg/ha)

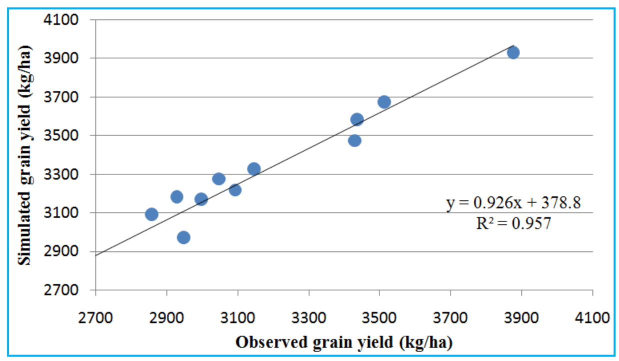

Fig. 4. Linear regression curve between observed and simulated grain yield of RNR 15048 as influenced by dates of transplanting and age of seedlings

The simulated grain yield with different age of seedlings were also closely related to the observed data with RMSE, RMSEn and CRM value of 154 kg, 4.89 and -0.047 respectively. The lower values of RMSE and RMSEn revealed that the grain yield predicted by model are closer to the real time situation and a negative CRM value indicates that the model tend to overestimate the grain yield of RNR 15048 in this experiment. The strong agreement observed between the validated model's simulated grain yields and the actual yields could be ascribed to the accurate prediction of critical growth stages like the duration to anthesis and physiological maturity. This discussion was in alignment with the findings of Vijayalaxmi *et al.* (2016) and Deka *et al.* (2016).

TABLE 6

Effect of elevated temperatures on simulated grain yield of RNR 15048

Treatments	Grain Yield (kg/ha)		
	Elevated Temperatures (°C)		
	Normal	+0.3	+0.9
Dates of transplanting			
29th July	3693	3659	3596
7th August	3377	3369	3275
17th August	3140	3093	3060
27th August	2961	2904	2833
Age of seedlings			
35 Days	3317	3235	3129
25 Days	3493	3468	3349
15 Days	3069	3067	3031

3.4. *Regression analysis*

There was a strong agreement between the simulated and observed grain yields of RNR 15048 with a regression coefficient of 0.957 as influenced by both dates of transplanting and age of seedlings of rice (Fig. 4).

3.5. *Sensitivity analysis*

Temperature regime has a marked influence on both growth duration and growing pattern of the rice plant. The grain yield of rice is highly correlated with the change in weather parameters. The sensitivity of RNR 15048 in terms of grain yield under elevated temperatures was assessed by increasing the mean temperature by 0.3 and 0.9 ˚C. The simulation results showed that temperature elevation above the normal led to a decrease in grain yield (Table 6). This might be due to curtailed phenophasic duration of a crop with rapid accumulation of heat units thus, reducing yield (Lamsal *et al.*, 2013 and Shamim *et al*., 2010).

4. Limitations

CERES-Rice model has the capability to substitute traditional research in devising typical rice cultivation methods for RNR-15048 in the northeastern ghat region of Odisha. However, its inability in evaluating risks linked to pests, diseases and various nutrients apart from nitrogen, phosphorus, potassium, and calcium could potentially result in erroneous conclusions, particularly in regions where these constraints are prevalent.

5. Conclusion

In conclusion, due to close simulation of phenology and grain yield as influenced by different transplanting dates and age of seedlings CERES-Rice model was found to be enough sensitive to be used as a research tool in the variable agro-environments of north eastern ghat zone of Odisha to suggest suitable management practices in RNR 15048. Further, in sensitivity analysis yield reduction of 1.12% and 3.18% was reported with the increase in mean temperature above normal by 0.3 ˚C and 0.9 ˚C respectively. This indicates a warning to the researchers to devise climate resilient strategies to tackle the adverse impact of climate change.

Disclaimer: The contents and views expressed in this research paper/article are the views of the authors and do not necessarily reflect the views of the organizations they belong to.

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