ZIBELINE INTERNATIONAL™ PUBLISHING

ISSN: 2521-294X (Online)
ISSN: 2521-2931 (Print)
CODEN: MJSAEJ

Malaysian Journal of Sustainable Agriculture (MJSA)

DOI: http://doi.org/10.26480/mjsa.02.2025.121.130

CrossMark

RESEARCH ARTICLE

OPTIMIZING RICE PRODUCTION UNDER CLIMATE STRESS: INSIGHTS FROM DSSAT SIMULATIONS IN EASTERN PLAINS NEPAL

Manoj Kumar Joshi[a,b*], Jawed Alam[b], Muktinath Jha[c], Aditya Dhakal[b], YK Rai[b], Tirtha Karki[b], Shukra Raj Shrestha[f] Sandeep Joshi[d] and Ravi Prasad Chaudhary[e]

[a] Nepal Agricultural Research Council, Directorate of Agricultural Research, Koshi Province, Tarahara, Nepal
[b] Institute of Engineering, Purwanchal Campus, Dharan, Nepal
[c] Nepal Agricultural Research Council, National Agricultural Engineering Research Center, Khulamtar, Lalitpur
[d] University of Hildesheim, Lower Saxony, Germany
[e] Agriculture Knowledge Center, Lumbini Province, Banke, Nepal
[f] Directorate of Agricultural Research, Gandaki Province, Lumle, Kaski
**Corresponding Author's Email: ma.kumarjoshi@gmail.com*

ARTICLE DETAILS

Article History:

Received 04 January 2025
Revised 19 February 2025
Accepted 29 March 2025
Available online 31 April 2025

ABSTRACT

Nepal's agricultural sector is crucial for employment generation and GDP, but it is vulnerable to adverse weather and climatic conditions, particularly affecting rice production. The Decision Support System for Agro Technology Transfer (DSSAT) uses the Cropping System Model (CSM)-CERES Rice to simulate rice growth and development. This study used the DSSAT rice growth simulation model to assess rice production in the Terai region of the eastern province, specifically Tarahara. Data was collected from 2013 to 2018, using the NR 1190 (Radha-13) rice variety under long-term soil fertility experiments. The study found that increased atmospheric temperature, solar radiation fluctuations, CO2 concentration variations, and rainfall fluctuations negatively affected rice yield. Maximum temperatures increased rice yield proportionally, while decreased minimum temperatures led to significant yield loss. Changes in solar radiation intensity also negatively affected yields. The model indicated a linear increase in rice yield up to 600vpm of CO2 concentration, but beyond which the yield plateaued. Precipitation changes exhibited decreasing trends in yield, and the combined effect exacerbated the negative impact. The study also assessed best management practices (BMPs) for rice production in the study region. The optimal conditions identified included planting ten days earlier, an NPK ratio of 120:40:50, and a plant density of 130 at transplanting, resulting in a 23.49% increase in yield on applying all best management practices.

KEYWORDS

Climate change, DSSAT/CERES rice growth model, Rice production, Best management practice

1. INTRODUCTION

Nepal's agricultural sector holds paramount significance in the nation's economy, providing substantial employment opportunities and contributing significantly to the Gross Domestic Product (GDP). In 2022, the agriculture sector's GDP contribution reached 23.95% %. A shift has occurred over the years, with approximately 75% of the population relying on agriculture in 2000, decreasing to 66% by 2022 % (Kaatya Mishra, 2023).

Rice (Oryza sativa L.) is a critical staple food globally, particularly in Asia, and plays a vital role in ensuring global food security. In Nepal, rice serves as the primary staple crop, contributing substantially to income generation for farmers. The Terai region of Nepal accounts for 73% of rice production, while the hills and high hills contribute 24% and 4%, respectively. Beyond its economic impact, rice plays a crucial role in food and nutrition security, constituting 67% of total cereal consumption and providing 23% of protein intake. It also contributes 20% to the Agricultural Gross Domestic Product and 7% to the overall GDP, accounting for 53% of total cereal food production (Joshi et al., 2020).

Rice consumption in Nepal averages around 120 kilograms of milled rice annually, constituting one-third of the total calorie intake. The country's predominantly rice-focused agriculture covers the largest land area, yet yields remain relatively low. Despite improvements in agriculture-related services, paddy farmers can only achieve 76% of their potential output (Choudhary et al., 2022). Improved management practices and the introduction of superior varieties can increase rice production. Modern varieties have been developed and released for general cultivation across production domains, with 45 varieties introduced after the establishment of the Nepal Agricultural Research Council (Gairhe, et al., 2022). Despite these efforts, rice imports in Nepal persist due to insufficient production, preferences for fine rice, and increased road access in hilly areas with rising income levels. The highest rice cultivation elevation is observed in Chumchaur of Jumla (3050 m), offering a diet suitable for people with diabetes due to its low carb content, high mineral content (iron, calcium, phosphorous), fiber richness, and protein content. However, cultivation of Jumli Marshi rice is decreasing due to low productivity and susceptibility to blast (Gautam et al., 2022).

The Decision Support System for Agrotechnology Transfer (DSSAT) is a powerful tool that incorporates crop simulation models and tools, including the CERES-Rice module of the Cropping System Model (CSM). Developed by an interdisciplinary team, DSSAT is crucial in stimulating growth, development, and yield in response to soil-plant-atmosphere dynamics (DSSAT Foundation, 2023). This makes it an invaluable tool in our research. Focusing on the Eastern Terai region of Nepal, particularly Tarahara, this study assesses the impact of climate change on rice production. The analysis model investigates climate factors, their

Quick Response Code	Access this article online	
	Website: www.mjsa.com.my	**DOI:** 10.26480/mjsa.02.2025.121.130

Cite The Article: Manoj Kumar Joshi, Jawed Alam , Muktinath Jha, Aditya Dhakal, YK Rai, Tirtha Karki, Shukra Raj Shrestha, Sandeep Joshi and Ravi Prasad Chaudhary (2025). Optimizing Rice Production Under Climate Stress: Insights from Dssat Simulations in Eastern Plains Nepal. *Malaysian Journal of Sustainable Agriculture (MJSA), 9(2): 121-130.*

variability, and associated consequences on rice production. The study also discusses adaptive strategies and recommends management practices for enhancing rice production efficiency amidst climate change. Identifying the impacts of climate change on rice yield is crucial for increasing the country's rice production through climate-smart agricultural practices (Ray and Ray, 2018; Amgain et al., 2022).

Against this backdrop, the primary objective of this study is to evaluate the influence of climate change on rice production within the rice-wheat cropping system in the Eastern Terai region achieved through the following objectives:

To evaluate the sensitivity of rice yields under various climate change scenarios using the DSSAT CERES Rice model.

To analyze adaptation strategies and propose optimal management practices for enhancing rice production in response to climate change.

2. Brief Overview of Climate of Study Area

2.1 Rainfall

As shown in Figure 1, the thirty years' annual average rainfall is 1945.28 m. The monthly average rainfall is 162mm, the maximum average rainfall is 494.52 in June and minimum is 3.95mm in November.

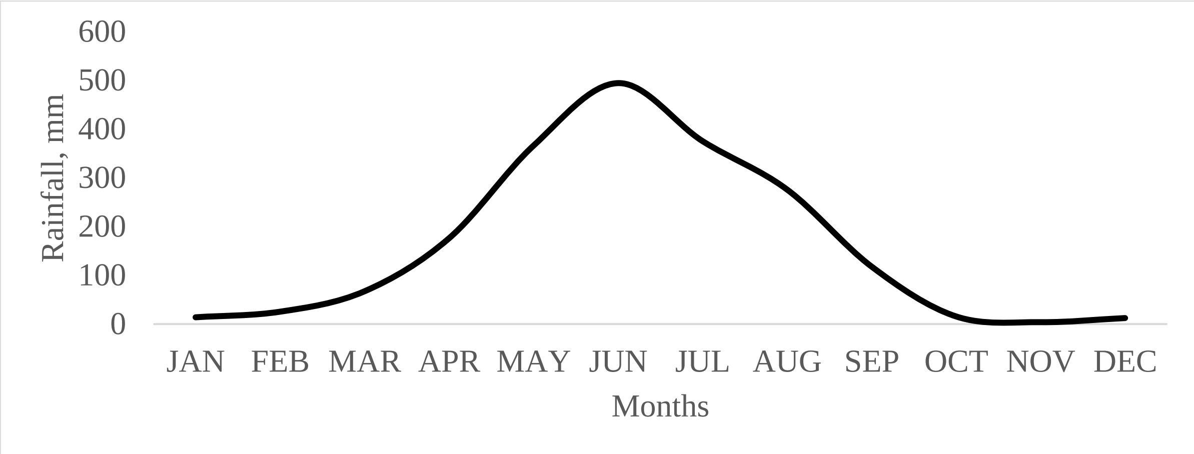

Figure 1: Variation of monthly precipitation at Tarahara from 1993 to 2022.

2.2 Temperature

Figure 2 illustrates that the average maximum monthly temperature in Tarahara from 1993 to 2022 was 30.02°C, while the average minimum monthly temperature was 18.4°C.

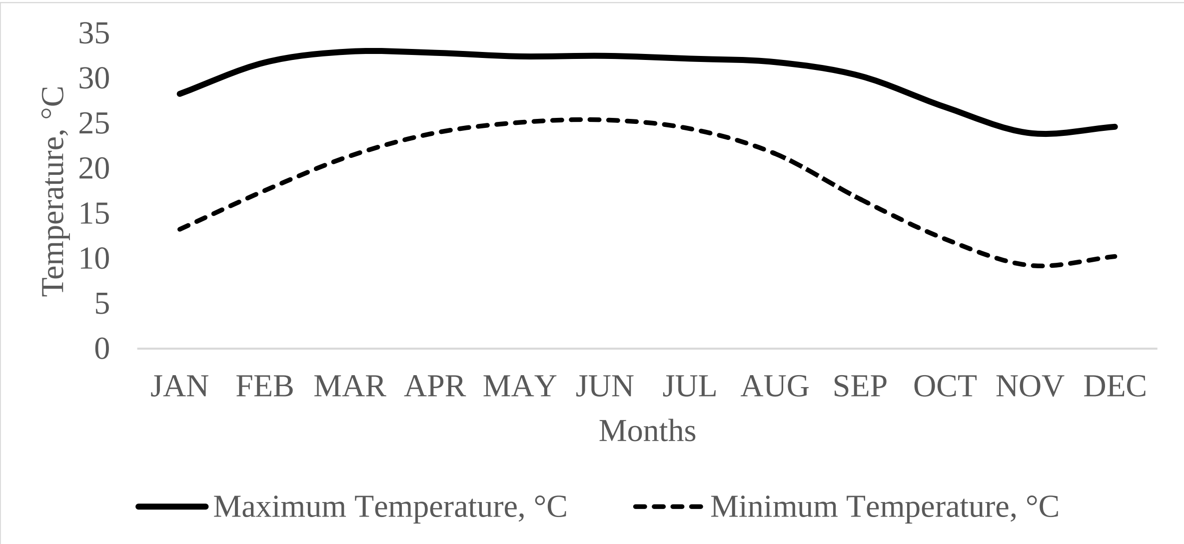

Figure 2: Variation of monthly minimum and maximum temperature at Tarahara from 1993 to 2022. (DHM)

2.3 Solar Radiation

Figure 3 indicates that in Tarahara, the maximum average solar radiation occurs in April at 21.53 $MJ/m^2/day$, while the minimum is in January at 12.62 $MJ/m^2/day$.

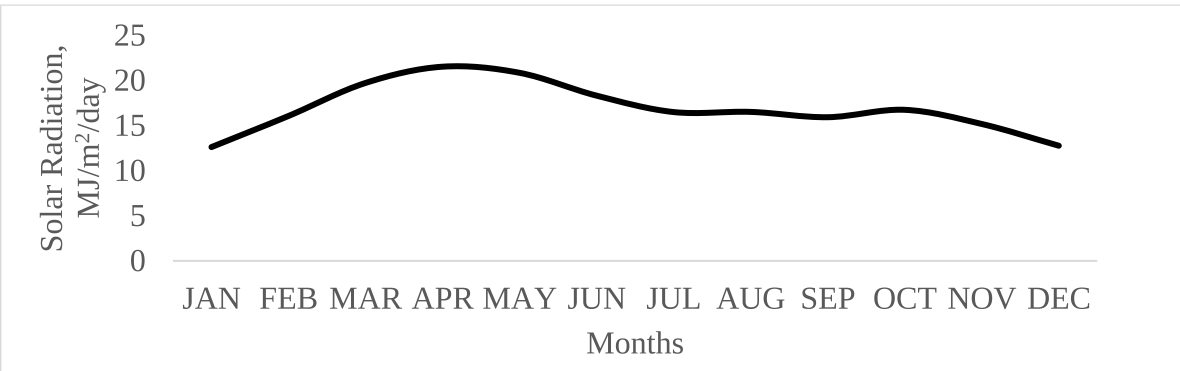

Figure 3: Variation of Monthly Mean solar radiation at Tarahara from 1993 to 2022.

3. METHODOLOGY

3.1 Research Design

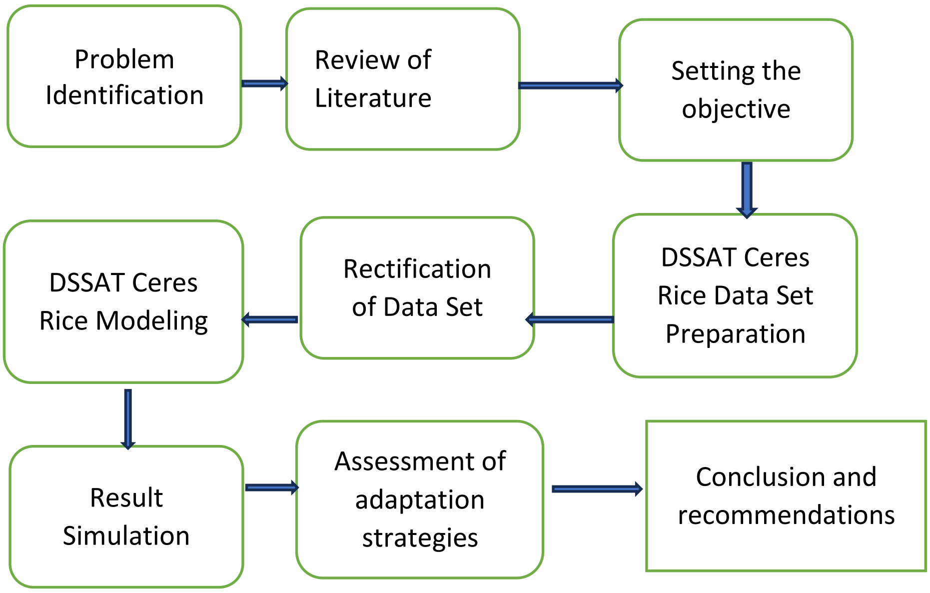

Figure 4: Flowchart of research methodology.

3.2 Study Area

Nepal is a landlocked country in South Asia, bordered by China to the north and India to the south, east, and west. It covers 147,516 square kilometers, situated between approximately 28°N latitude and 84°E longitude, within the temperate zone north of the Tropic of Cancer. The country spans about 800 km from east to west and 150-250 km from north to south, with extensive water systems draining south into India.

The Terai region of Nepal covers 33,998.8 square kilometers, about 23.1% of Nepal's land area, at elevations between 67 and 300 meters. This area includes over 50 wetlands and is bordered to the north by the Bhabar, a continuous forest belt 8–12 km wide. The southern part of Koshi Province, part of the Terai, features fertile agricultural plains with elevations ranging from 70 to 1,000 meters and comprises the districts of Jhapa, Morang, and Sunsari

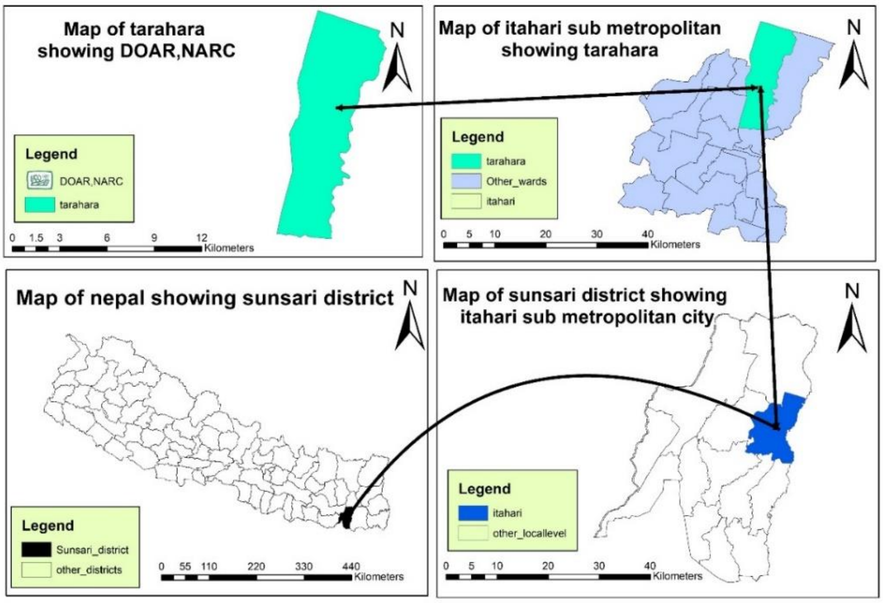

Figure 5: Study Location Map.

3.3 Experimental design and layout

The experiment employed a Randomized Complete Block Design (RCBD) with nine treatments and three replications. Conducted on-station by the Soil Science Unit at the Directorate of Agricultural Research (DoAR), Koshi Province, the study used fertilizer doses as treatments. Each plot measured 6m by 4m, with a spacing of 35 cm, as detailed in Table 1.

Table 1: Details of experimental layout

Rice variety	NR 1190(Radha-13)
Experimental Design	RCBD
Treatments	9
Replications	3
Plot Size	6m x 4m
Plot Spacing	35cm
Harvested Area	15m^2

Table 2: Treatments used in the study

S.N.	Treatments	N	P	K
1	T1	100	30	30
2	T2	100	30	0
3	T3	100	0	30
4	T4	0	0	0

The above-mentioned treatments in Table 2 were chosen to examine both the inclusion and exclusion of every single and all NPK components.

3.4 Data Acquisition

The data required for the modeling are as following.

- Long term Weather Data
- Soil data
- Experimental and crop management Data

Tarahara was selected as the study location due to the availability of long-term data (1993 to 2022) maintained by the Department of Hydrology and Meteorology (DHM), which can represent the eastern Terai of Nepal. DHM Dharan provided daily minimum and maximum temperatures, precipitation, and relative humidity. Since sunshine hours were unavailable for the study period, data were downloaded from the NASA Power website in MJ/m^2/day for 1993 to 2022. These climate data were then adjusted in Microsoft Excel 2016 to meet model requirements. Soil analysis data, along with experimental and crop management data, were collected from the Soil Science Unit at the Directorate of Agricultural Research, Nepal Agricultural Research Council, Koshi Province, Tarahara, Sunsari.

3.5 Calibration and Validation of CERES Rice

Given the availability of long-term crop management and experimental data for the rice variety Radha-13, this variety was selected to calibrate the model. Released by the Nepal Agricultural Research Council for rain-fed conditions in the Terai and inner Terai, as well as irrigated conditions up to 700m mean sea level, Radha-13's performance data were gathered from the Soil Science Section of DoAR Tarahara. Additional data were sourced from the Plant Breeding Unit and Annual reports.

From 2013 to 2018, Radha-13 was used by the Soil Science Unit of DoAR Tarahara for research. This variety was transplanted with a row spacing of 20 cm, maintaining a plant population density of 80 plants/m^2. The soil in research area was classified as silt loam. Fields were set up using a randomized complete block design (RCBD), with fertilizer dosages used as treatments: 1) 100:30:3 NPK kg/ha, 2) 100:30:0 NPK kg/ha, 3) 100:0:30 NPK kg/ha, and 4) 0:0:0 NPK kg/ha. These dosages were purposively selected to include and exclude all NPK and each nutrient individually.

Daily weather data, including maximum and minimum temperatures, rainfall, and relative humidity, were collected from DHM for DoAR Tarahara. For model calibration, average crop/management data from 2013 to 2015 were used, while data from 2016 to 2018 were used for validation.

3.6 Sensitivity Analysis and Adaptation Strategy

A widely accepted method for assessing the potential impacts of various climate changes on crop yields involves quantifying the incremental alterations in temperature, precipitation, CO_2 levels, and similar factors and then uniformly applying these changes to a reference climate, such as the daily climate data recorded at a weather station. (Islam et al., 2016; White et al., 2011).

Following model calibration and validation, the sensitivity of rice yield to variations in different climatic parameters was analyzed. The results were visualized and compared with findings from other researchers globally to standardize the outcomes of environmental modifications. Additionally, varying fertilizer doses, transplanting dates, and plant density per square meter were tested to determine the best management practices. The optimal adaptation strategy was then developed by applying all individual best options simultaneously.

4. Results and Discussion

4.1 Seasonal weather of the Study region

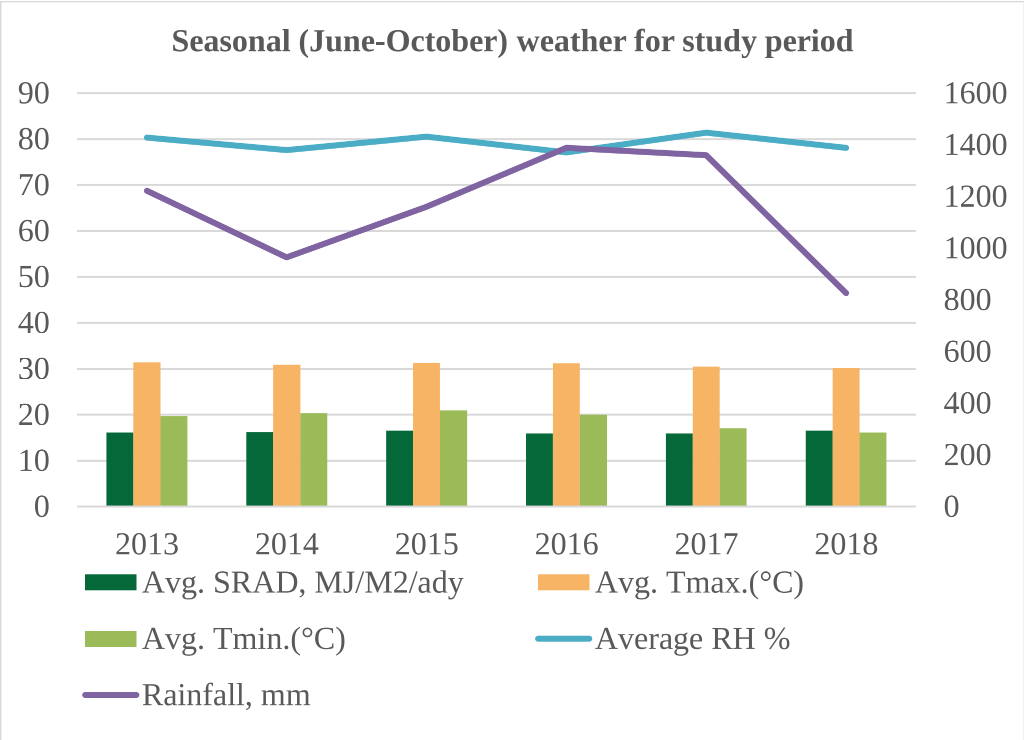

Figure 6: Weather detail for rice growing season within study period

The seasonal weather data presented in Figure 6 encompass six years (2013-2018) for the months of June to October, corresponding to the rice-growing season. Over this period, average solar radiation, maximum temperature, and minimum temperature remained relatively stable. However, there is a slight decreasing trend in average relative humidity from 2013 to 2018. Rainfall exhibited significant variability, peaking in

2016 and notably decreasing in 2018. This analysis indicates that while some weather parameters remain stable, others, such as rainfall and relative humidity, exhibit greater variability over the study period.

4.2 Calibration of CERES-Rice model

The model was calibrated using averages of the experimental data of the years 2013, 2014 and 2015 and validated for years 2016, 2017 and 2018. Using these data, genetic coefficients were calculated using Genotype coefficients calculator. The calibrated genetic coefficients are presented in Table 3.

Table 3: Genetic coefficients for Radha-13 rice variety

Genetic coefficients	P1	P2R	P5	P20	G1	G2	G3	PHINT	THOT	TCLDP	TCLDF
Value	209.2	36.3	779.8	11.3	65.7	0.023	0.81	83	29.7	15	15.5

The genetic coefficients were calculated using GenSelect Wizard Version 4.8.0.0, which uses data reported for an array of experiments.

After calculating the genetic coefficients for the variety, the simulated and observed yields were plotted, and the correlation coefficient was determined to assess the model's efficiency, resulting in a value of approximately 84%, as shown in Figure 7.

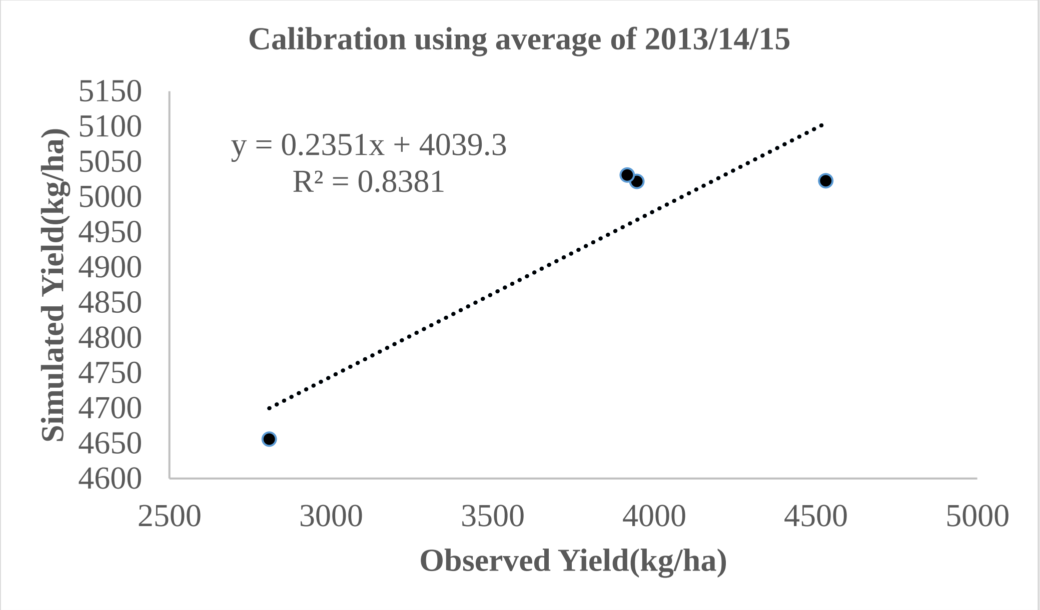

Figure 7: Calibration of CERES Rice model.

4.3 Validation of CERES-Rice model

Validation of the model was performed for the years 2016, 2017, and 2018, following its calibration. The model's predictive accuracy was assessed by plotting simulated versus observed yields in scatter plots and calculating the correlation coefficient. The validation results obtained are as follows:

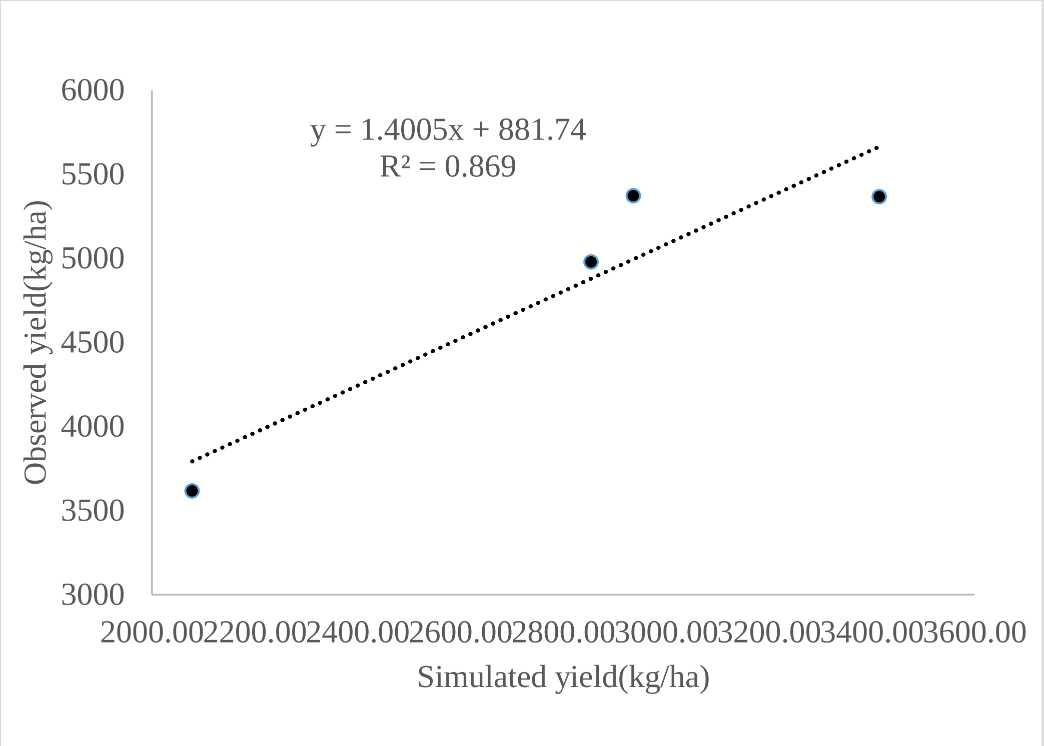

Figure 8: validation of CERES Rice model for 2016

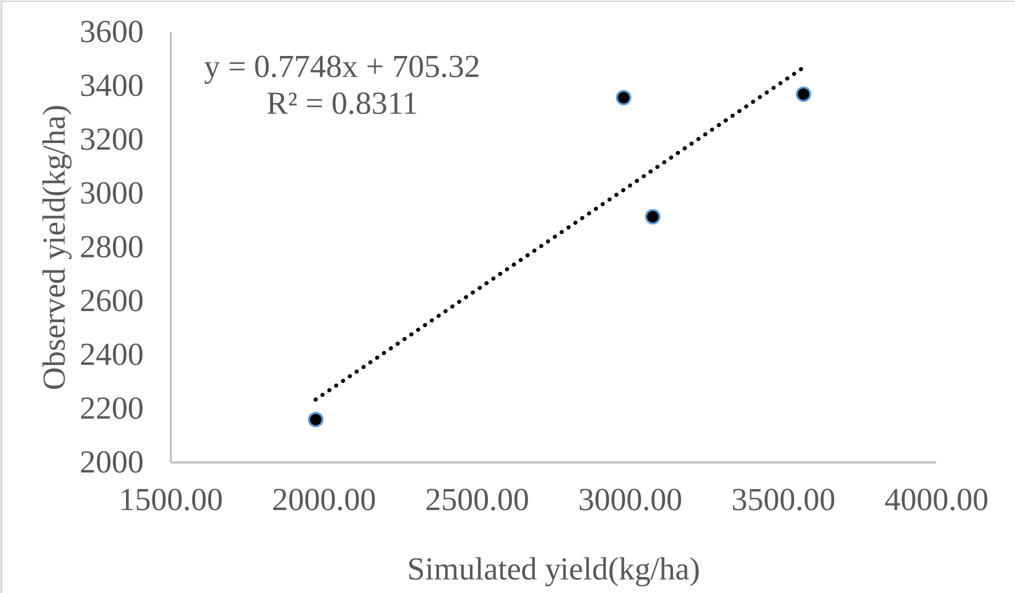

Figure 9: Validation of CERES Rice model for 2017

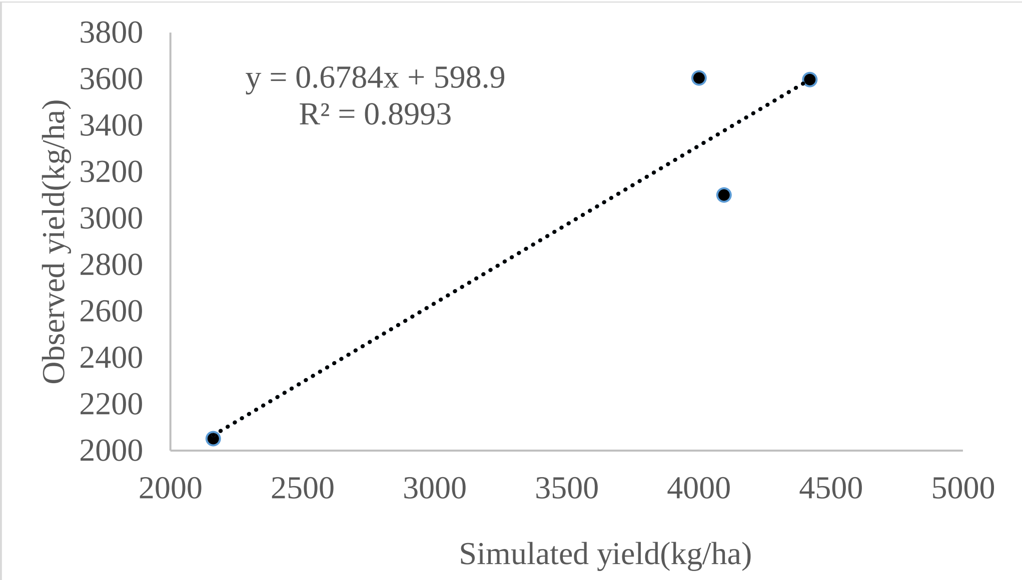

Figure 10: Validation of CERES Rice model for 2018.

The scatter plots presented in Figures 8, 9, and 10 demonstrate that the CERES Rice model achieved good validation efficiency, with correlation coefficients ranging from 86% to 90%. Thus, the model is reliable for simulating rice yield and can be used to assess the impact of climate change on rice production also found the same (Alejo, 2021; Ansari et al., 2021).

4.4 Sensitivity of rice yield to weather parameters

To develop resilient agricultural practices and adapt to shifting climatic conditions, it is crucial to understand the sensitivity of rice production to various weather factors. To quantify yield variations resulting from changes in these factors, the following combinations of parameters and their associated yield impacts are analyzed.

4.4.1 Effect of temperature on yield of Rice

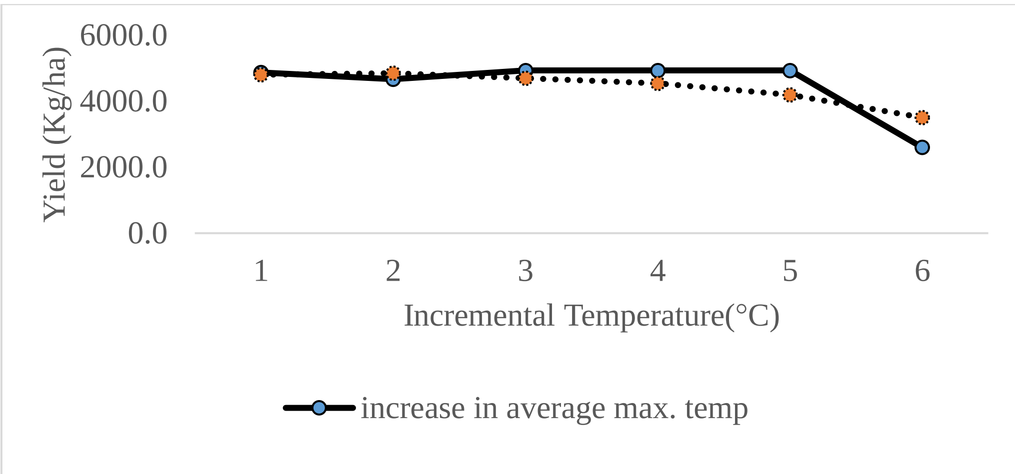

Figure 11: Response of rice to change in maximum and minimum temperature.

Figure 11 shows that an increase in temperature up to 5°C has a mild effect on yield, but a further increase of 1°C results in a yield reduction of approximately 47%. These findings align with previous studies, which have linked elevated temperatures to reductions in grain weight and quality (Krishnan et al., 2011; Song et al., 2022; Pasuquin et al., 2023). Specifically, it reported decreased spikelet fertility, grain number, and grain yield under higher daytime temperatures(Pasuquin et al., 2023).

4.4.2 Effect of solar radiation on yield of Rice

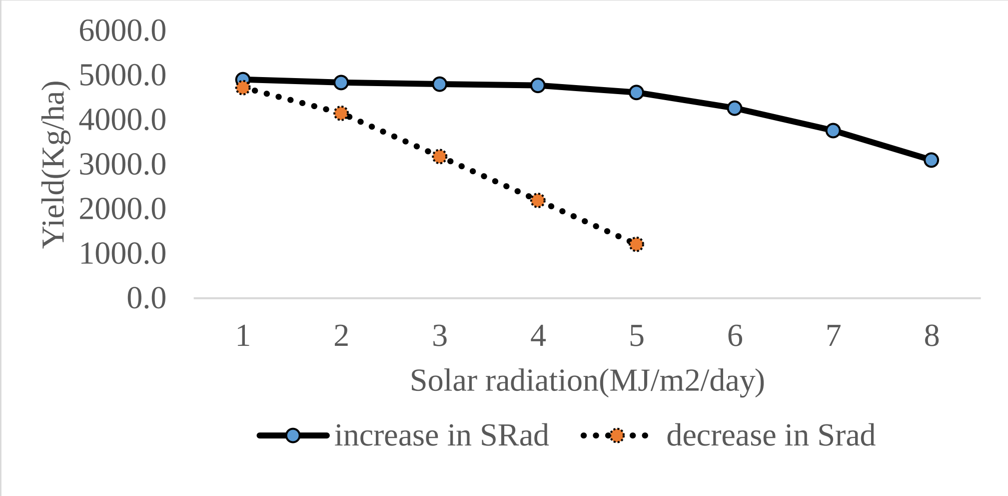

Figure 12: Effect of change of solar radiation in rice yield.

Figure 12 illustrates that both increases and decreases in solar radiation adversely affect rice yield, with decreases having a more severe impact. For instance, a 2 MJ/m^2/day increase in solar radiation results in a 3.6% yield reduction, whereas a decrease of the same magnitude causes approximately 6% yield reduction, which is twice as high. Similarly, a 4 MJ/m^2/day increase in solar radiation leads to a 4.4% yield reduction, while a 4 MJ/m^2/day decrease results in a 17.5% yield reduction. This indicates that greater variations in solar radiation amplify yield losses exponentially.

4.4.3 Effect of incremental CO2 level on yield of Rice

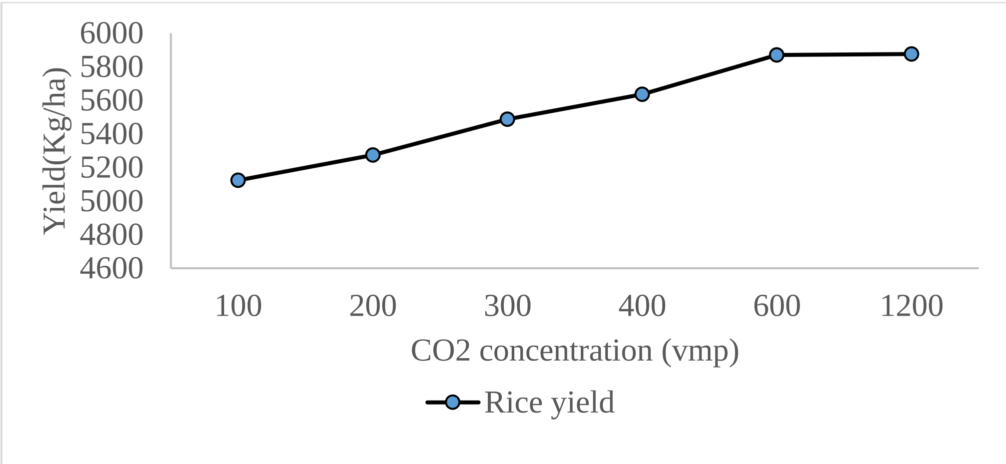

Figure 13: Impact of increased CO_2 level on rice yield

Figure 13 shows that doubling CO_2 levels from 380 ppm to 780 ppm results in an average yield increase of 14%. This finding is consistent with previous studies by (Krishnan et al., 2007 and Hu et al., 2021). Additionally, while higher nutrient levels show a yield response to elevated CO_2 that aligns with previous estimates, lower nutrient levels initially exhibit a positive response to CO_2, but this effect diminishes at a rate inversely related to the CO_2 responsiveness observed under high nutrient conditions.

4.4.4 Effect of precipitation (rainfall) on yield of Rice

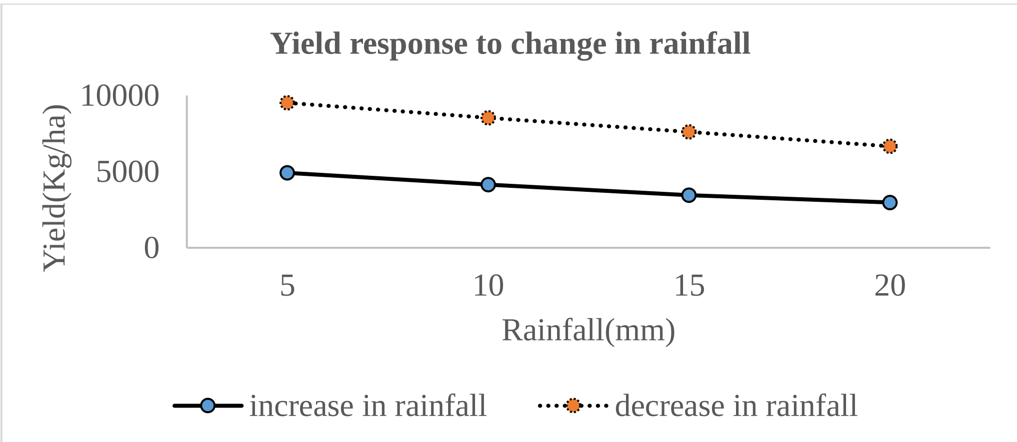

Figure 14: Variation of yield with change in rainfall.

Figure 14 shows that both increases and decreases in rainfall adversely affect yield, contrary to some literature suggesting that increased rainfall boosts yield. This result may be attributed to the specific genetic characteristics of the rice variety under study and the optimal water management conditions in the current research trial. In contrast, other studies indicate that decreased rainfall leads to yield loss at a rate of approximately 8% per 2 mm/day reduction, up to about 16 mm/day (Saseendran et al., 2000). Additionally, they reported an average yield increase of 0.4% for every 10% increase in rainfall, while it noted that both excessive rainfall and drought contribute to yield decline (Levine and Yang, 2014; Shrestha et al., 2022).

4.4.5 Combined effect of change in maximum, minimum temperature, and solar radiation

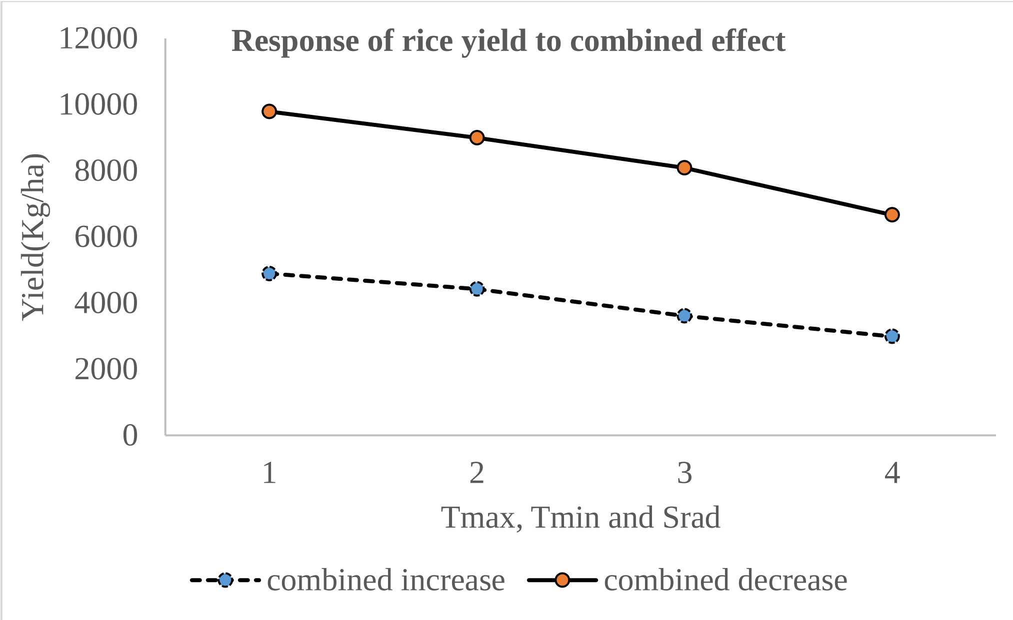

Figure 15: Variation of rice yield in response to combined changes in weather parameters.

Figure 15 illustrates the variation in rice yield in response to combined changes in weather parameters. This represents the impact of climate change, which, as shown, has a negative effect on yield. Both incremental and detrimental scenarios lead to decreased rice yield. Therefore, it can be concluded that climate change adversely affects rice yield and threatens food security. For adaption, climate resilient management practices(shifting of planting date and adjustments in cropping pattern as well as climate forecasting by using remote sensing and modeling can be used to sought out the issues related to climate change (Anwar, 2020).

4.5 Evaluation of Adaptation Measures

It is crucial to assess adaptation techniques in climate change studies to determine their efficacy, identify hurdles, and guide future responses. Assessing the effectiveness and results of certain adaptation measures is part of the assessment process.

In this study, adaptation strategies to changing climate conditions involved varying aspects of rice cultivation, including transplantation dates, plant population density at transplanting, and fertilizer doses. The optimal combinations of these factors were applied simultaneously, and the resulting yield was assessed.

4.5.1 Impact of change in transplanting date on Rice yield.

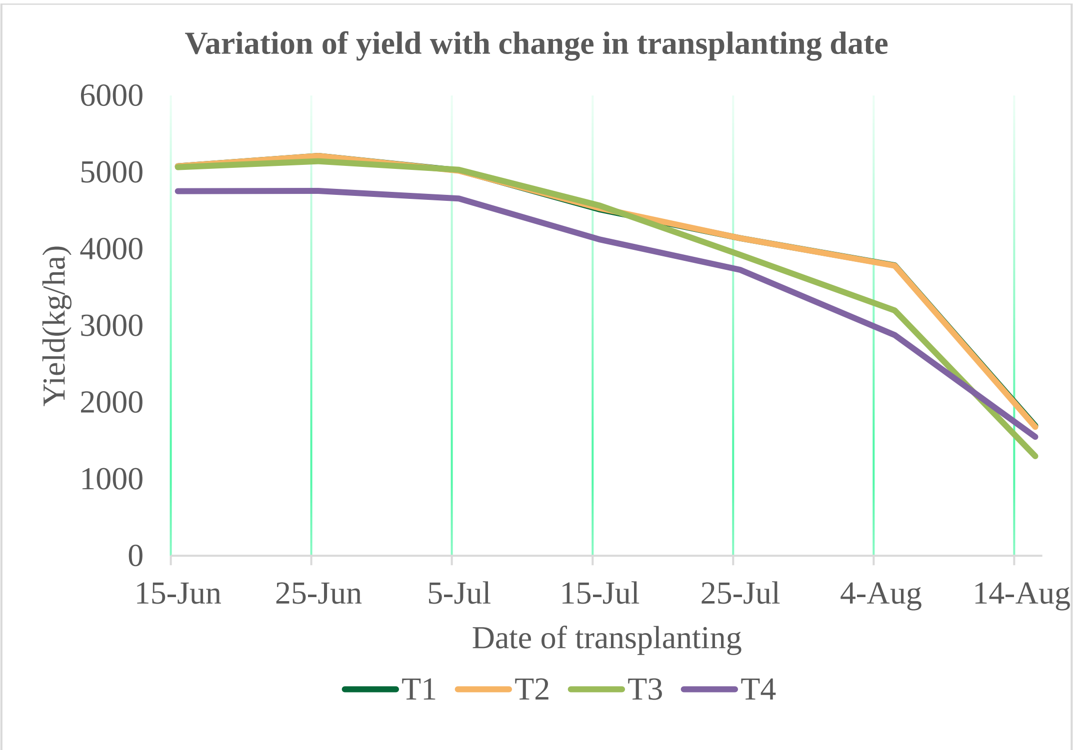

Figure 16: Variation of rice yield with change in transplanting date.

Figure 16 indicates that shifting the transplanting date from July 5 to June 25 results in a yield increase of approximately 3%. Therefore, the optimal transplanting date, according to the simulated yields, is June 25.

4.5.2 Impact of plant density on the yield of Rice

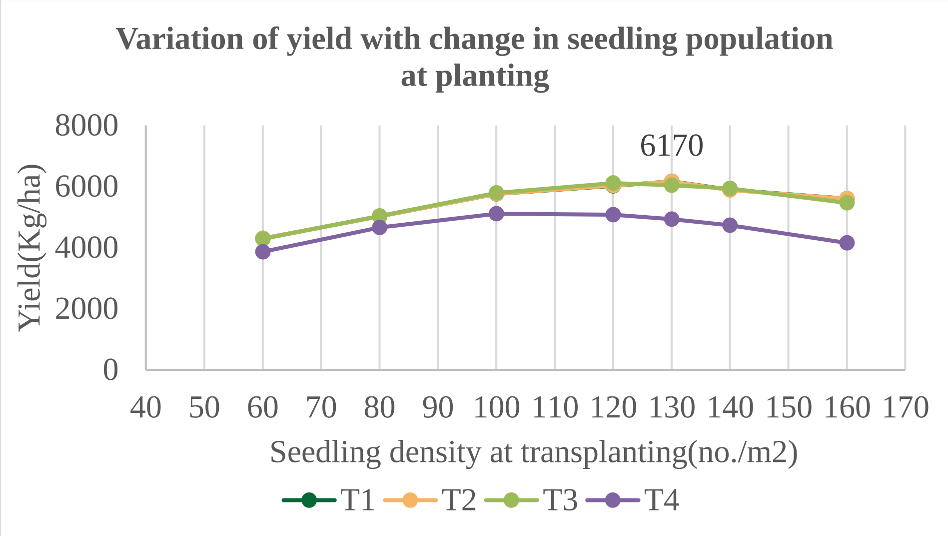

Figure 17: Variation of rice yield with change in plant density at transplanting.

Plant density at transplanting is critical for optimizing rice yield, particularly for low tillering varieties (source). For the variety Radha-13, increasing the number of plants per square meter from 80 to 130 results in an approximate 18% yield increase. Thus, the optimal plant density for transplanting is 130 plants per square meter, as illustrated in Figure 17.

4.5.3 Impact of fertilizer (NPK) dose in Rice Production

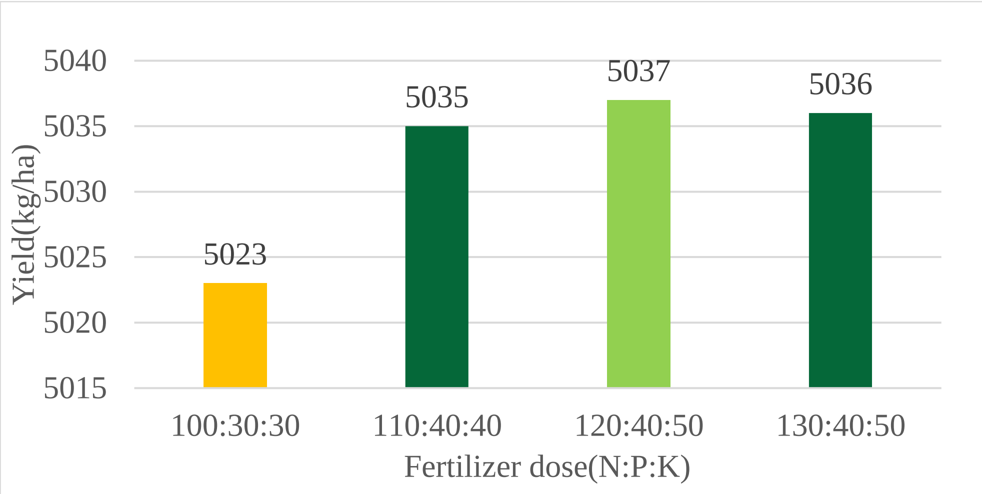

Figure 18: Variation of yield with fertilizer doses.

Figure 18 shows that, based on simulations of varying fertilizer doses, the optimal fertilizer mix is 140:40:50 N:P:K, which results in a yield increase of less than 1%. However, in low-fertility regions, this increase can be substantial. Notably, the recommended fertilizer dose by NARC for irrigated transplanted rice in the eastern Terai region aligns with the optimal dose identified in this study.

4.5.4 Variation of yield with best management practices

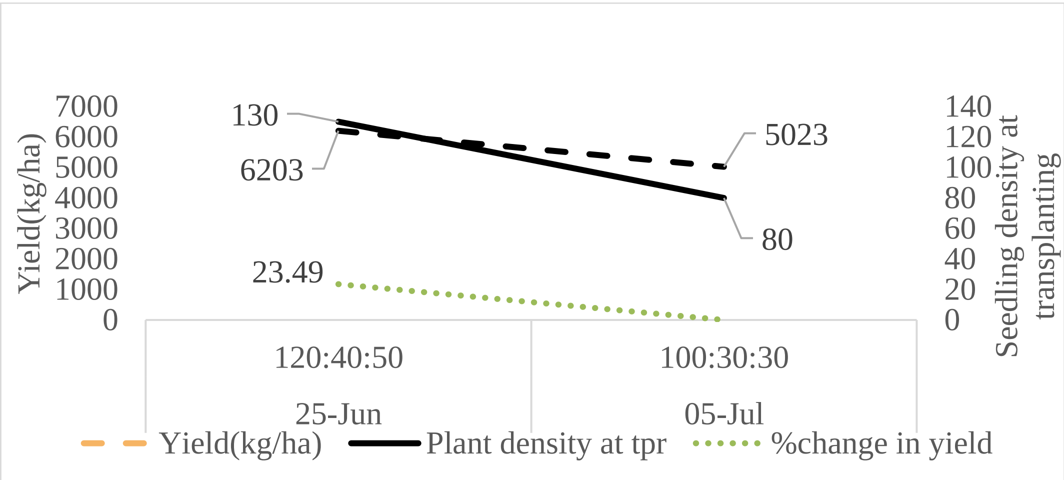

Figure 19: Variation of yield with best management practice.

Figure 19 indicates that adopting optimal management practices can lead to a yield increase of approximately 23.5%. This significant boost could substantially reduce import volumes, enhance food security, and contribute to self-sufficiency in rice. Additionally, the use of newly released high-yielding, climate-resilient, and disease-free rice cultivars could further improve yields

5. Conclusion and Recommendation

The model calibration achieved an R-squared value of approximately 83%, and yield predictions were made with around 86% accuracy. Sensitivity analysis was conducted by varying several factors:

- **Air Temperature**: Increasing maximum temperature by 1°C results in a 1.33% yield reduction up to 4°C.
- **Minimum Temperature**: Each 1°C decrease in minimum temperature causes an 8% yield loss up to 4°C.
- **CO_2 Concentration**: Doubling CO_2 levels from 380 ppm to 780 ppm increases yield by 14%, after which the yield response plateaus.
- **Solar Radiation**: Both increases and decreases in solar radiation negatively impact yield, with decreases having nearly double the effect of increases. For instance, a decrease of 2 MJ/m^2/day results in a 5.9% yield reduction, whereas an increase of 2 MJ/m^2/day results in a 3.6% yield reduction.

The evaluation of best management practices (BMP) for rice production in the study region indicated that the highest yield was achieved by transplanting ten days earlier (shifting from July 5 to June 25), using an NPK ratio of 120:40:50, and a plant density of 130 plants per square meter. Implementing these practices can improve yield by 23.49%.

Based on the study's findings, the following BMPs are recommended:

- **Earlier Transplanting**: Shift transplanting to June 25.
- **Optimized Fertilization**: Use an NPK ratio of 120:40:50.
- **Increased Plant Density**: Maintain a density of 130 plants per square meter.

These adaptation practices are essential for achieving maximum yield potential in response to climate change and enhancing overall production and profitability.

Acknowledgements

I would like to express my sincere gratitude to the Department of Agricultural Engineering, Institute of Engineering, Dharan for allowing me to conduct this research. I would extend my heartfelt appreciation to Directorate of Agricultural Research, Koshi Province, NARC

Conflict of Interest

The author declares no conflict of interest

References

Alejo, L.A., 2021. Assessing the impacts of climate change on aerobic rice production using the DSSAT-CERES-Rice model. J. Water Clim. Change, 12(3), Pp. 696–708. https://doi.org/10.2166/wcc.2020.286

Amgain, L.P., Adhikari, S., Pandit, S., 2022. Multi-year Prediction of Rice Yield under the Changing Climatic Scenarios in Nepal Central Terai Using DSSAT Crop Model. J. Nepal Agric. Res. Council, 8, Pp. 88–100. https://doi.org/10.3126/jnarc.v8i.44868

Ansari, A., Lin, Y.-P., Lur, H.-S., 2021. Evaluating and Adapting Climate Change Impacts on Rice Production in Indonesia: A Case Study of the Keduang Subwatershed, Central Java. Environments, 8(11), Pp. 117. https://doi.org/10.3390/environments8110117

Anwar, S., 2020. Rice Production Under Climate Change: Adaptations and Mitigating Strategies.

Choudhary, D., Banskota, K., Khanal, N.P., McDonald, A.J., Krupnik, T.J., Erenstein, O., 2022. Rice subsector development and farmer efficiency in Nepal: Implications for further transformation and food security. Front. Sustain. Food Syst., 5, 740546.

Gairhe, S., Yadaw, R., Timsina, K., 2022. Status of Rice after NARC establishment in Nepal.

Gautam, R., Kandel, B.P., Chalaune, S., Koirala, B., 2022. Importance of world high altitude Jumli Marshi rice with cultivation practices. Heliyon, 8(2), e08885. https://doi.org/10.1016/j.heliyon.2022.e08885

Hu, S., Wang, Y., Yang, L., 2021. Response of rice yield traits to elevated atmospheric CO2 concentration and its interaction with cultivar, nitrogen application rate and temperature: A meta-analysis of 20 years FACE studies. Sci. Total Environ., Pp. 764, 142797. https://doi.org/10.1016/j.scitotenv.2020.142797

Islam, S., Cenacchi, N., Sulser, T.B., Gbegbelegbe, S., Hareau, G., Kleinwechter, U., Mason-D'Croz, D., Nedumaran, S., Robertson, R., Robinson, S., Wiebe, K., 2016. Structural approaches to modeling the impact of climate change and adaptation technologies on crop yields and food security. Global Food Security, 10, Pp. 63–70. https://doi.org/10.1016/j.gfs.2016.08.003

Joshi, K.D., Upadhyay, S., Chaudhary, P., Shrestha, S., Bhattarai, K., Tripathi, B.P., 2020. The Rice Processing Industry in Nepal: Constraints and Opportunities. Agric. Sci., 11(11), Article 11. https://doi.org/10.4236/as.2020.1111069

Kaatya Mishra, 2023. Impediments in the Agriculture Sector of Nepal [Online post]. Nepal Economic Forum. https://nepaleconomicforum.org/impediments-in-the-agriculture-sector-of-nepal/

Krishnan, P., Ramakrishnan, B., Reddy, K.R., Reddy, V.R., 2011. Chapter three—High-Temperature Effects on Rice Growth, Yield, and Grain Quality. In: D.L. Sparks (Ed.), Advances in Agronomy, Vol. 111, Pp. 87–206. Academic Press. https://doi.org/10.1016/B978-0-12-387689-8.00004-7

Krishnan, P., Swain, D.K., Chandra Bhaskar, B., Nayak, S.K., Dash, R.N., 2007. Impact of elevated CO2 and temperature on rice yield and methods of adaptation as evaluated by crop simulation studies. Agric. Ecosyst. Environ., 122(2), Pp. 233–242. https://doi.org/10.1016/j.agee.2007.01.019

Levine, D.I., Yang, D., 2014. The Impact of Rainfall on Rice Output in Indonesia (Working Paper 20302). National Bureau of Economic Research. https://doi.org/10.3386/w20302

Pasuquin, E.M., Eberbach, P.L., Hasegawa, T., Lafarge, T., Harnpichitvitaya, D., Wade, L.J., 2023. Responses to elevated daytime air and canopy temperature during panicle development in four rice genotypes under paddy conditions in large field chambers. Crop Environ., 2(3), Pp. 147–156. https://doi.org/10.1016/j.crope.2023.04.004

Ray, M., Ray, M., 2018. Application of DSSAT Crop Simulation Model to Estimate Rice Yield in Keonjhar District of Odisha (India) under Changing Climatic Conditions. Pp. 659–667.

Saseendran, S.A., Singh, K.K., Rathore, L.S., Singh, S.V., Sinha, S.K., 2000. Effects of Climate Change on Rice Production in the Tropical Humid Climate of Kerala, India. Climatic Change, 44(4), Pp. 495–514. https://doi.org/10.1023/A:1005542414134

Shrestha, B.B., Kawasaki, A., Inoue, T., Matsumoto, J., Shiroyama, T., 2022. Exploration of spatial and temporal variability of rainfall and their impact on rice production in Burma in 1901–1939 during the colonial period. Prog. Earth Planet. Sci., 9(1), Pp. 48. https://doi.org/10.1186/s40645-022-00506-2

Song, Y., Wang, C., Linderholm, H.W., Fu, Y., Cai, W., Xu, J., Zhuang, L., Wu, M., Shi, Y., Wang, G., Chen, D., 2022. The negative impact of increasing temperatures on rice yields in southern China. Sci. Total Environ., Pp. 820, 153262. https://doi.org/10.1016/j.scitotenv.2022.153262

White, J.W., Hoogenboom, G., Kimball, B.A., Wall, G.W., 2011. Methodologies for simulating impacts of climate change on crop production. Field Crops Res., 124(3), Pp. 357–368. https://doi.org/10.1016/j.fcr.2011.07.001