Research Journal of Agricultural Sciences
Volume 14; Issue 05 (Sep-Oct 2023); pp 1492–1496

Open Access
ISSN: 0976-1675 (P)
ISSN: 2249-4538 (E)

Full Length Research Article

# Projections of Rice Yield in the 21st Century: A Study on the Below Sea Level Farming Region of Kerala, India

P. Shajeesh Jan*[1] and K. Ajith[2]

[1] Regional Agricultural Research Station (Kerala Agricultural University), Ambalavayal - 673 593, Kerala, India
[2] Regional Agricultural Research Station (Kerala Agricultural University), Kumarakom - 686 563, Kerala, India

## Abstract

The study utilized dynamically downscaled climate projections from the Regional Climate Model (RCM), RegCM4.4, driven by two General Circulation Models (GCMs): HadGEM2-ES and GFDL-ESM2M. These projections covered the period from 1971 to 2100 and were employed to assess potential changes in future climate. To project plausible changes in future climate, the study considered two representative concentration pathways (RCPs), namely RCP 4.5 and RCP 8.5, as adopted by the IPCC Fifth Assessment Report (AR5). The main focus was to evaluate the impacts of these future climate changes on rice yield in the Kuttanad region of Kerala, for two leading rice varieties: Uma and Jyothi using DSSAT crop simulation model. The study found that the relative difference (R.D%) in rice yield for the Uma variety, under the RCP 4.5 scenario, increased steadily from the near (6.2%) to the end century (9.7%) across all models. However, the R.D% of rice productivity declined under the RCP 8.5 scenario. For the Jyothi variety, the percent relative difference of rice yield exhibited a positive trend across all models and scenarios, except for a slight decline (-2.15%) in yield observed at the end of the century in the HadGEM2-ES model.

***Key words***: Regional climate model, General circulation models, Representative concentration pathways, Assessment report, Percent relative difference

Projecting the effect of climate change on rice yield is indeed crucial, given the central role rice plays in global food security, especially in many Asian countries. Climate change can have both direct and indirect impacts on rice production. Global Climate Models (GCMs) serve as valuable tools for forecasting future climate changes within projected scenarios. However, due to the intricacies of smaller regions like Kerala, GCM projections are typically conducted at a coarse resolution. In this study, two GCM projections were utilized to fulfill our objectives. Regional Climate Models (RCMs) leverage GCM fields as boundary conditions to produce higher-resolution outputs based on atmospheric physics within specific areas. The uncertainty in climate models' ability to generate realistic results can be attributed to various factors, including the choice of scenario, model, time period, and the projected number of generations [1]. To estimate future climate change, the study employed the Representative Concentration Pathways (RCP) 4.5 (stabilization scenario) and RCP 8.5 (high emission scenario) radiative forcing scenarios, as recommended by the IPCC Fifth Assessment Report [2]. These scenarios were implemented in the Regional Climate Model (RCM), RegCM4.4. For assessing the impact of climate change on rice production, the DSSAT-CERES-Rice model was utilized, incorporating the RCM's output on a daily time scale for crop simulation modeling. The Kuttanad region is a unique area in India where rice cultivation takes place below sea-level conditions. [3] projected future rice yield under representative concentration pathways (RCPs) climate change scenarios using DSSAT crop simulation model and predicted changing rainfall patterns, rising temperature, and intensifying solar radiation under climate change can reduce the rice yield. [4] conducted a study using Hadley-coupled models to assess the impact of climate change on rice yield. The results revealed a significant decrease in summer rice harvests, with a decline of 14.5% projected for the year 2005 across nine experiment stations in India. [5] explored the consequences of climate change on rice production in a separate investigation focused on Kerala's tropical and humid environment. The findings established a noticeable increase in rainfall, approximately 2 mm per day$^{-1}$, and a rise of about 1.5°C in the mean surface temperature during the monsoon season in Kerala between 2040 and 2049 compared to the 1980s. The CERES-Rice crop simulation model was employed to assess the impact of climate changes on rice productivity in Kerala, a state known for its tropical humid climate. The study encompassed five locations: Pattambi, Kasaragod, Kayamkulam, Ollukara, and Kottayam stations.

Received: 24 Jul 2023; Revised accepted: 01 Oct 2023; Published online: 06 Oct 2023

**Correspondence to:** P. Shajeesh Jan, Regional Agricultural Research Station (Kerala Agricultural University), Ambalavayal - 673 593, Kerala, India, Tel: +91 9495175114; E-mail: shajeesh.jan@kau.in

**Citation:** Jan PS, Ajith K. 2023. Projections of rice yield in the 21st century: A study on the below sea level farming region of Kerala, India. *Res. Jr. Agril. Sci.* 14(5): 1492-1496.

The findings provided compelling evidence of increased rice yield, and the projected climate change scenario indicated a higher likelihood of achieving enhanced rice output by the middle of the next century.

Examining data from 1992 to 2003 at the research farm of the International Rice Research Institute, Philippines, [6] observed a decline of 10% in rice grain yield for every 1°C increase in the minimum temperature during the growing season. Conversely, the effect of maximum temperature on crop yield was deemed insignificant. However, [7] argued that the impact of minimum temperature on rice output was overestimated, as they discovered a substantial negative correlation between solar radiation and minimum temperature in the datasets used [6]. Rice yield and light and heat resource utilization indicators showed a significant negative correlation with temperature. [8] hypothesized that the recent warming trend contributed to increased rice yield in Northeastern China and soybean yield in Northern and Northeastern China. However, it had a negative effect on maize yield in seven provinces (autonomous regions or municipalities) and wheat yield in three provinces, based on provincial-scale analyses throughout China. Additionally, [9] found a positive association between solar radiation and rice yields, with solar radiation being a key factor influencing yield variance. Understanding how projected climate change scenarios may affect rice productivity is vital for developing adaptation methods to increase rice output and ensure food security.

## MATERIALS AND METHODS

An investigation was conducted to study the impact of climate change on rice productivity in the Kuttanad region of Kerala. This region, spanning three districts (Alappuzha, Kottayam, and Pathanamthitta), consists of ten taluks and 69 panchayats (Fig 1). It is located between 9.08° and 9.78°N latitude and 76.30° and 76.60°E longitude and is characterized by being below sea level, with marshes covering over two-thirds of its land area. The fertile loamy soil from the Meenachil, Pamba, Manimala River systems, and Achencoil enriches the region, making it ideal for paddy cultivation.

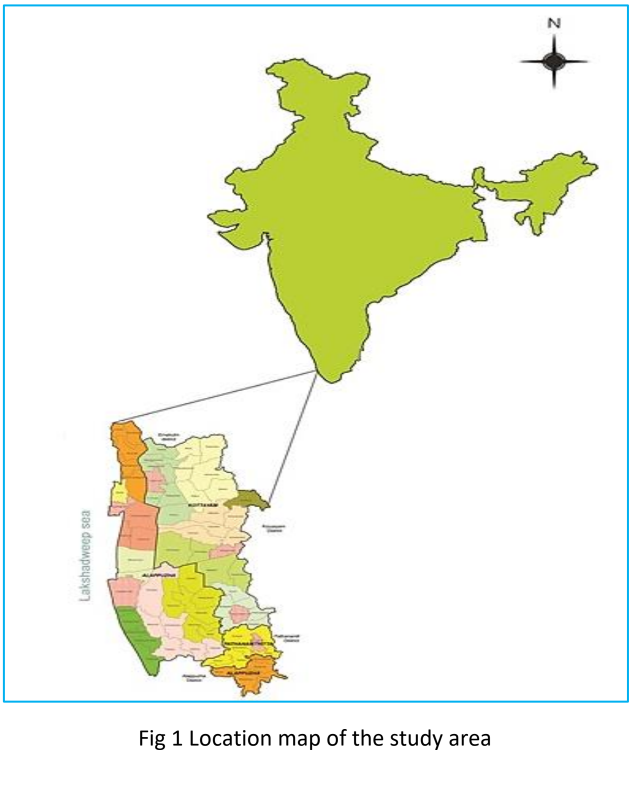


Fig 1 Location map of the study area

For the study, the Kuttanad region had 6 grid points at 0.22-degree resolution from the RegCM 4.4 run, achieved through dynamical downscaling at the Agro Climate Research Centre, Tamil Nadu Agricultural University, Coimbatore, using the Regional Climate Model (RCM) RegCM4.4. This model, version 4.4, was developed at the Abdus Salam International Centre for Theoretical Physics (ICTP) and is widely used globally for regional climate and seasonal prediction research.

To analyze the effects of climate change on rice productivity, the study utilized downscaled projections from GFDL-ESM2M [10-11]), HadGEM2-ES [12] using Regional Climate Model (RCM) RegCM4.4. GFDL has constructed NOAA’s first Earth System Models (ESMs) to advance the understanding of how the earth's biogeochemical cycles, including human actions, interact with the climate system. The model has 1°×1° horizontal grid resolution. ESMs incorporate interactive biogeochemistry, including the carbon cycle. ESM2M evolved from prototype model ESM2.1. HadGEM2-ES is a coupled AOGCM with atmospheric resolution of N 96 (1.875° ×1.25°) with 38 vertical levels and an ocean resolution of 1° (increasing to 1/3° at the equator) and 40 vertical levels. For the historical period (1971-2005), daily weather variables such as maximum and minimum temperatures, precipitation, and solar radiation were considered. We selected these GCM's because they appeared, on average, across the globe, to be the driest and wettest. For the future period, three time slices, near-century (2010-2039), mid-century (2040-2069), and end of the century (2070-2100), based on two RCP scenarios, were fed into crop simulation models proposed [13].

To assess the impact of climate change on rice productivity in the Kuttanad region, the crop simulation model used was the Decision Support System for Agrotechnology Transfer (DSSAT) model, which accounted for the genetic coefficients of the cultivated varieties in the investigation. In recent times, there has been widespread utilization of Decision Support System for Agrotechnology Transfer (DSSAT)-CERES-Rice in conjunction with integrated climate model for evaluating the effects of climate change on future rice production [14-18]. The CERES-Rice model, calibrated on the Uma and Jyothi cultivars in the Kuttanad region through an iterative process, was utilized. The percentage relative difference (R.D) in rice productivity from the base year (1971-2005) for the near century (2010-2039), mid-century (2040-2069), and end of century (2070-2100) was calculated using the following formula:

$$R.\text{D}.(\%) = \frac{\text{Mean of future yield} - \text{Mean of base period yield}}{\text{Mean of base period yield}} x100$$

## RESULTS AND DISCUSSION

*Simulating rice yield under projected climate change on the Uma rice variety*

The impacts of climate change on the Uma rice variety over the 21st century was assessed for the near, mid and the end century. It was observed that, under the representative concentration pathway (RCP) 4.5 scenario, rice productivity showed an increase (6.2 to 9.7%) compared to the base year (Fig 2).

This positive trend was attributed to the fertilization effect of $CO_2$ (423 to 532 ppm), which offset the negative impact of increased maximum temperatures (Fig 3) ranging from 0.48 °C to 2.7 °C.

Additionally, during these time periods, decreased minimum temperatures (Fig 4) and increased rainfall (Fig 5) seemed to favor higher productivity.

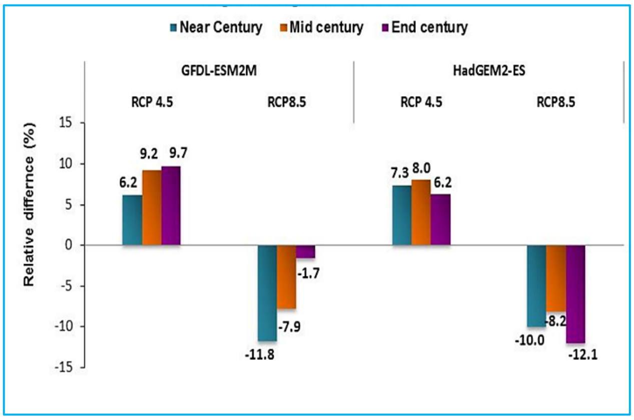


Fig 2 Percent relative difference of rice yield (Uma) during different time slices

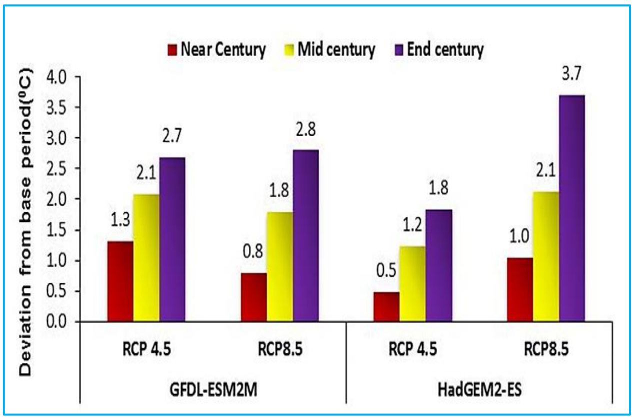


Fig 3 Deviation of projected maximum temperature from the base during different time

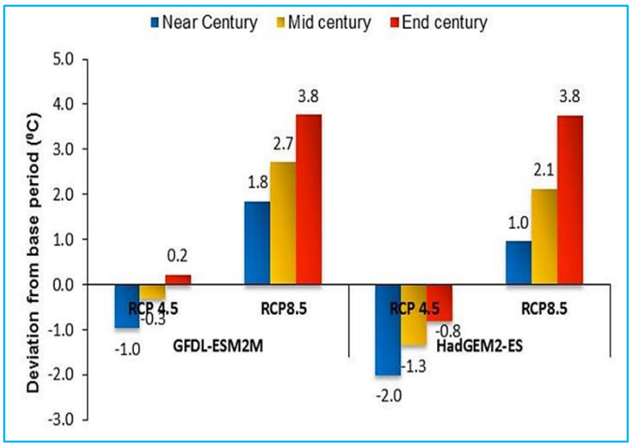


Fig 4 Deviation of projected minimum temperature from the base during different time slices

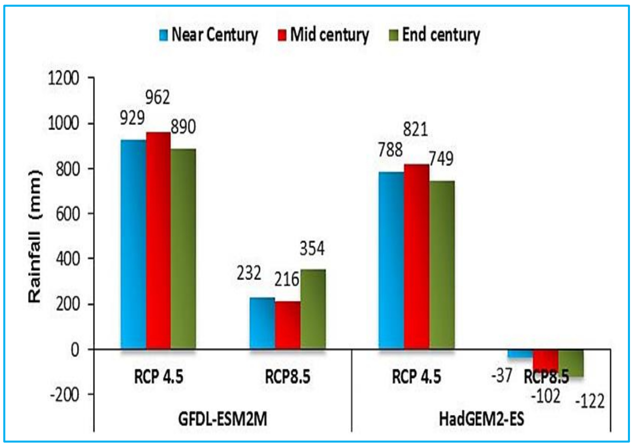


Fig 5 Deviation of projected rainfall from base during different time slices

The analysis revealed that the productivity (kg/ha) of rice in the Kottayam and Pathanamthitta districts surpassed that of the Alappuzha district (Fig 6-9). These findings align with Saseendran *et al*.'s [4] study, which also reported a 12% increase in rice productivity during 2040-2049 in Kottayam district, situated within the Kuttanad region.

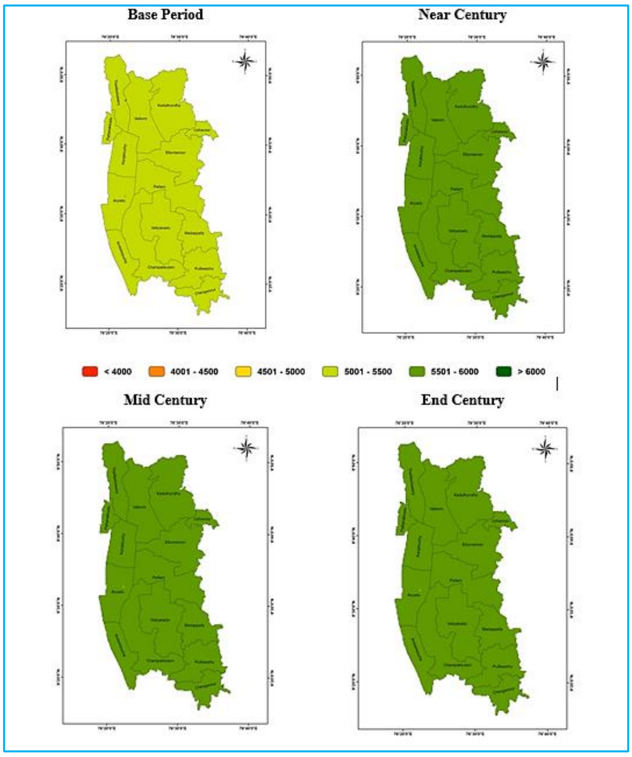


Fig 6 Spatial and temporal variation of rice yield (Uma) under RCP4.5 of GFDL-ESM-2M

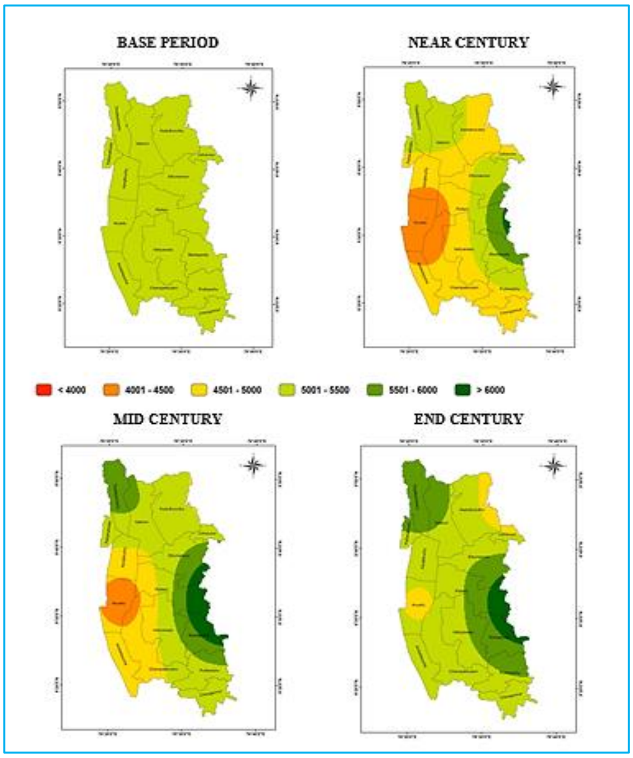


Fig 7 Spatial and temporal variation of rice yield (Uma) under RCP8.5 of GFDL-ESM-2M

However, contrasting results emerged under the RCP 8.5 scenario, where a decline in rice productivity of up to 12% was projected. This scenario experienced pronounced increases in maximum and minimum temperatures, along with decreased rainfall, contributing to the yield decline. Our study's findings align with other pertinent research, which demonstrates that rising temperatures, and changes in rainfall patterns in terms of frequency and intensity, have adverse effects on rice production, [19]. Furthermore, our results reinforce the conclusions of prior studies, highlighting that under the Representative Concentration Pathways (RCP) 8.5 scenario, the most substantial reduction in rice production is anticipated. Such negative impacts of high temperature on rice yield were previously studied [20-23].

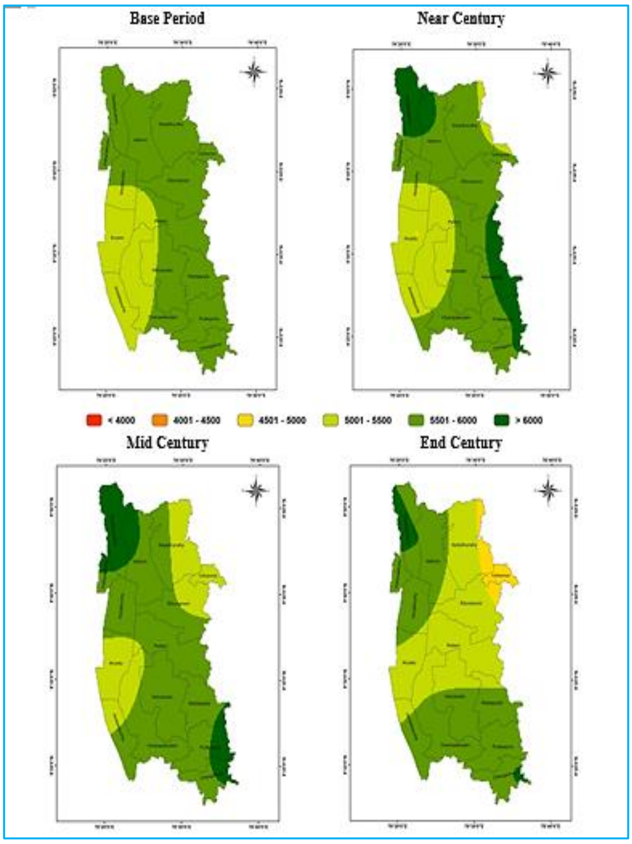


Fig 8 Spatial and temporal variation of rice yield (Uma) under RCP4.5 of HadGEM2-ES

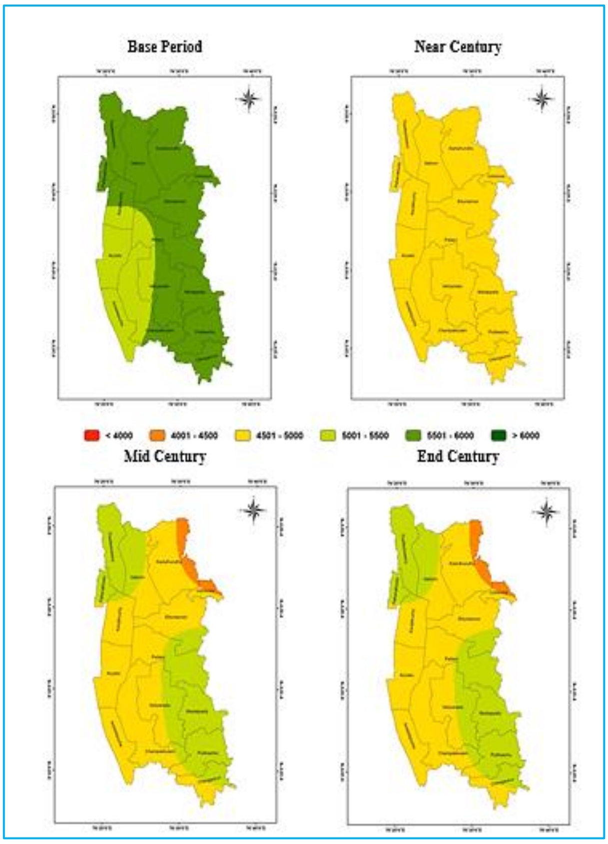


Fig 9 Spatial and temporal variation of rice yield (Uma) under RCP8.5 of HadGEM2-ES

*Simulating rice yield under projected climate change for the Jyothi rice variety*

The study also examined the impacts of climate change on the Jyothi rice variety over the 21st century, considering near, mid, and end-century scenarios (Fig 10). The simulation results indicated a significant increase in rice productivity, reaching up to 15%, for both scenarios and the model, except for the end century under the high emission scenario of the HadGEM2 model. This slight decline in rice yield, as projected by the HadGEM2 model, could be attributed to the decrease in rainfall during the end of the century under the RCP 8.5 scenario.

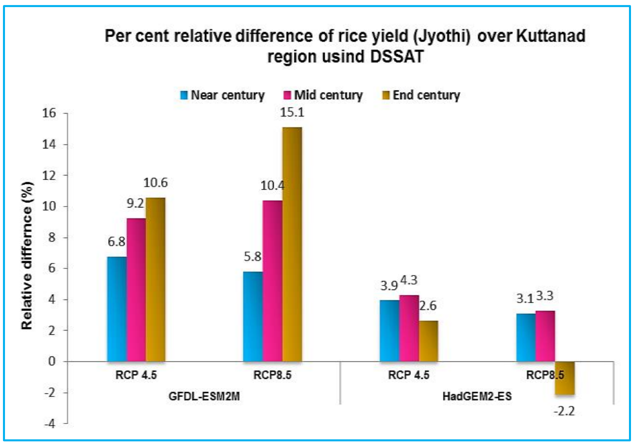


Fig 1 Location map of the study area

The higher yield of the Jyothi variety compared to the Uma variety could be attributed to its shorter duration, which is approximately 10-15 days less than the Uma. This difference in duration allowed the Jyothi crop to escape the high-temperature period coinciding with its critical stage, i.e., anthesis, resulting in improved yield. Furthermore, during the end century, the Jyothi variety also benefited from the $CO_2$ fertilization effect, with $CO_2$ levels reaching up to 801 ppm. A similar assessment was made [24], indicating that short-duration rice varieties are likely to be less affected by climate change compared to long-duration varieties.

## CONCLUSION

The projected changes in rice yield exhibited variability across different time slices, models, and scenarios used, leading to significant variations in the impact of climate change on rice yield in the Kuttanad region of Kerala. For the medium-duration rice variety (Uma) under the RCP4.5 scenario, the study revealed a consistent increase in rice productivity from the near century (6.2%) to the end century (9.7%) regardless of the models employed. However, under the Representative Concentration Pathways (RCP) 8.5 scenario, the percent relative difference in rice productivity showed a declining trend, irrespective of the model used. On the other hand, for the Jyothi rice variety, the percent relative difference in rice yield demonstrated a positive increase regardless of the model and scenario, except for the end century of the HadGEM2-ES model, where a slight decline (-2.15%) in yield was noticed. The investigation also highlighted that the magnitude of yield reduction was more pronounced for long/medium duration rice varieties compared to short-duration varieties, emphasizing the greater vulnerability of long/medium duration varieties to the impact of climate change.

## LITERATURE CITED


1. IPCC. 2013. Summary for policymakers. *In:* The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report. *Intergovernmental Panel on Climate Change*. (Eds) Stocker, T.F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V., Midgley, P.M. (Eds.), Climate Change 2013: Cambridge United Kingdom and New York, NY, USA. pp 1535.
2. Zhai P, Zhou B, Chen Y. 2018**.** A review of climate change attribution studies. *Jr. Meteorol. Research* 32: 671-692.
3. Ansari A, Lin YP, Lur HS. 2021. Evaluating and adapting climate change impacts on rice production in Indonesia: A case study of the Keduang Subwatershed, Central Java. *Environments* 117(8): 1-17.
4. Mohandrass S, Kareem AA, Ranganathan TB, Jeyaraman S. 1995. Rice production in India under the current and future climate. *In:* Modeling the impact of climate change on rice production in Asia. (Eds) R.B. Mathews, M.J. Kroff, D. Bachelet & H.H. van Laar. pp 165-181.
5. Saseendran SA, Singh KK, Rathore LS, Singh SV, Sinha SK. 2000. Effects of climate change on rice production in the tropical humid climate of Kerala, India. *Climate Change* 44: 495-514.
6. Peng S, Huang J, Sheehy J E, Laza RC, Visperas R M, Zhong X, Centeno CS, Khush GS, Cassman KG. 2004. Rice yields decline with higher night temperature from global warming. *Proc. Natl. Acad. Sci.* 101: 9971-9975.
7. Sheehy JE, Mitchell PL, Ferrer AB. 2006. Decline in rice grain yields with temperature: Models and correlations can give different estimates. *Field Crops Research* 98: 151-156.
8. Tao FL, Hayashi Y, Zhang Z, Sakamoto T, Yokozawa M. 2008. Global warming, rice production, and water use+ in China: developing a probabilistic assessment. *Agric. For Meteorology* 148(1): 94-110.
9. Zhang H, Zhou G, Liu DL, Wang B, Xiao D, He L. 2019. Climate-associated rice yield change in the Northeast China Plain: A simulation analysis based on CMIP5 multi-model ensemble projection. *Sci. Total Environ*. 666: 126-138.
10. Dunne P, John JG, Adcroft AJ, Griffies SM, Hallberg RW, Shevliakova E, Stouffer RJ, Cooke W, Dunne KA, Harrison MJ, Krasting JP, Malyshev SL, Milly PCD, Phillipps PJ, Sentman LT, Samuels BL, Spelman MJ, Winton M, Wittenberg AT, Zadeh N. 2012. GFDL's ESM2 global coupled climate–carbon earth system models. Part I: Physical formulation and baseline simulation characteristics. *Jr. Climate* 25: 6646-6665.
11. Dunne JP, John JG, Shevliakova E. 2012. GFDL's ESM2 global coupled climate carbon earth system models. Part II: carbon system formulation and baseline simulation characteristics. *Jr. Climate* 26: 2247-2267.
12. Martin GM, Bellouin N, Collins WJ. 2011. The HadGEM2 family of met office unified model climate configurations. *Geosci. Model Dev*. 4: 723-757.
13. Rosenzweig C, Jones JW, Hatfield J, Antle JM, Ruane AC, Boote KJ, Thorburn P, Valdivia RO, Descheemaeker K, Porter CH, Janssen S, Bartels W, Sulivan A, Mutter CZ. 2016. *Protocols for AgMIP Regional Integrated Assessments Version* 6.1. pp 65.
14. Shrestha S, Chapagain R, Babel MS. 2017. Quantifying the impact of climate change on crop yield and water footprint of rice in the Nam Oon Irrigation Project, Thailand. *Sci. Total Environ*. 599: 689-699.
15. Boonwichai S, Shrestha S, Babel MS, Weesakul S, Datta. 2019. Evaluation of climate change impacts and adaptation strategies on rainfed rice production in Songkhram River Basin, Thailand. *Sci. Total Environ*. 652: 189-201.
16. Alejo LA. 2021. Assessing the impacts of climate change on aerobic rice production using the DSSAT-CERES-Rice model. *Jr. Water Clim. Chang*. 12: 696-708.
17. Hoogenboom G, Porter CH, Shelia V, Boote KJ, Singh U, White JW, Hunt LA, Ogoshi R, Lizaso JI, Koo J. 2019. Decision Support System for Agrotechnology Transfer (DSSAT); Version 4.7.5; DSSAT Foundation: Gainesville, FL, USA.
18. Jones JW, Hoogenboom G, Porter CH, Boote KJ, Batchelor WD, Hunt LA, Wilkens PW, Singh U, Gijsman AJ, Ritchie JT. 2003. The DSSAT cropping system model. *Eur. Jr. Agron*. 18: 235-265.
19. Yuliawan T, Handoko I. 2016. Th e effect of temperature rise to rice crop yield in Indonesia uses Shierary Rice Model with Geographical Information System (GIS) feature. *Procedia Environ. Science* 33: 214-220.
20. Yoshida S, Hara T. 1977. Effects of air temperature and light on grain tilling of an indica and a japonica rice (*Oryza sativa* L) under controlled environmental conditions. *Soil Sci. Plant Nutrition* 23: 93-107.
21. Prasad PVV, Boote KJ, Allen LH, Jr., Sheehy JE, Thomas JMG. 2006. Species, ecotype and cultivar differences in spikelet fertility and harvest index of rice in response to high temperature stress. *Field Crops Research* 95: 398-411.
22. Prabnakorn S, Maskey S, Suryadi FX, de Fraiture C. 2018. Rice yield in response to climate trends and drought index in the Mun River Basin, Thailand. *Sci. Total Environ*. 62: 108-119.
23. Jagadish S, Craufurd P, Wheeler T. 2007. High temperature stress and spikelet fertility in rice (*Oryza sativa* L.). *Jr. Exp. Botany* 58: 1627-1635.
24. Haris AA, Chhabra BPBV. 2013. Climate change impacts on yields of phenologically different rice varieties over a sub-humid climatic environment. *Agriculture Research* 2: 319-329.