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Research Paper

Impact of climate change on rice yield under projected scenarios in central zone of Kerala

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ABSTRACT

The future climate for central zone of Kerala was estimated with climate change projections generated using ECHAM model and GFDL-CM3 model based on RCP 4.5 and RCP 8.5. The CERES Rice model was used to evaluate the influence of climate change on the rice variety Jyothi during near (2030), mid (2050) and end of the century (2080) under 5 dates of planting. Results showed that the performance of rice variety Jyothi was better on October 1st planting under projected climate. Under RCP 4.5 the decrease in yield was 13.2, 21.3 and 31.9 per cent and under RCP 8.5 scenario, the decrease was 12.7, 24.8 and 36.0 per cent respectively during near, mid and end centuries. The yield reduction in almost all the planting dates in RCP 4.5 and RCP 8.5 scenarios may be due to increased minimum and maximum temperature and increased rainfall during anthesis.

Keywords: Climate change, rice, CERES -Rice, climate projection, representative concentration pathway (RCP)

Earth as a whole is facing large impulses as a result of climate change. According to the sixth assessment report of IPCC, in the next 20 years, global warming is expected to reach or exceed 1.5 ^{0}C above the 1800s (IPCC, 2021). The expected effect of climate change includes increase in temperature and uncertainties in rainfall. Goswami *et al.* (2016) examined the precise effects of climate change on rice yield variability for the Jorhat district of Assam under various Representative Concentration Pathways (RCPs), and found that the projected grain yield variances over the observed mean yield from 2009 to 2013 ranged from -12.7 to -43.4 percent under all the scenarios and dates of transplanting under study. Bhuvaneswari *et al.* (2014) investigated the impact of climate change on rice in the western zone of Tamil Nadu using DSSAT-CERES crop simulation model and stated that the yield is anticipated to decrease under future warmer climatic circumstances and that the rice crop would be significantly impacted by the changing climate.. Ding *et al.* (2020) reported that changing sowing date is a better tactic that deals the climate change effect in China. Rice is the staple food of the state of Kerala and increased temperature and erratic rainfall as a result of climate change is reported to have adverse effects on rice yield under projected climate change scenarios threatening states food security. The temperature sensitivity experiments on rice undertaken by Saseendran *et al.* (2000) for Kerala have demonstrated that there is a yield reduction of 6% with every degree increase in temperature, with the pattern being evident up to a rise of 5 ^{0}C. Jan *et al.* (2017) reported that rainfall during January, March and June showed significant decreasing trend and the decrease in June rainfall adversely affects paddy cultivation in Kerala. The present investigation was carried to understand the influence of plausible climate change on rice production over Kerala under two future climate change scenarios.

MATERIALS AND METHODS

An experiment was conducted during 2019-20 at the Regional Agricultural Research Station, Pattambi, with rice variety Jyothi in a completely randomized design with five planting dates: June 1st (D1), June 30th (D2), October 1st (D3), October 30th (D4), and January 1st (D5) with four replications. The planting dates were chosen to coincide with the sowing windows in Kerala's three main rice growing seasons: *virippu* (April-May to September-October), *mundakan* (September-October to November-December), and *punja* (December -January to March- April) (KAU, 2016). Jyothi is one of the most cultivated varieties of rice in Kerala with 110-115

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Table 1: Genetic coefficients used in DSSAT-CERES-rice model

Genetic coefficients	Varities
P1	558
P2R	25.6
P5	460.8
P2O	10.8
G1	53
G2	0.028
G3	1.1
G4	1.1
PHINT	81

Source: Vysakh *et al*. (2016)

days duration and due to its wider adaptability it is cultivated during all the three seasons and in a wide range of field conditions.

The future climate was estimated by climate change projections generated using ECHAM model and GFDL-CM3 model based on Representative Concentration Pathway 4.5 (RCP 4.5) and Representative Concentration Pathway 8.5 (RCP 8.5) for near (2030), mid (2050) and end (2080) centuries. The climate projection data generated using Marksim DSSAT weather file generator was used in DSSAT-CERES rice crop simulation model to determine the influence of climate change on rice growth and yield. Soil data and management data were obtained from the Department of Agronomy, Regional Agricultural Research Station, Pattambi. The genetic coefficient for variety Jyothi generated by Vysakh *et al*. (2016) was used for the study. Calibration of DSSAT-CERES-rice crop simulation model was done based on crop data for 5 years (2011 to 2015) obtained from the field experiments at Regional Agricultural Research Station, Pattambi. The calibrated genetic coefficient is presented in Table 1. Furthermore the model was validated using experimental data for a period of 4 years (2016 to 2019) obtained from above station. Data collected by field experiment conducted during 2019-2020 for five different planting dates representing *virippu, mundakan and punja* seasons in Kerala was used for assessing the performance of model. In this study, crop performance obtained from historic runs for 20 years (baseline period) during different planting dates, was compared with simulation results obtained under anticipated climate change scenarios in RCP 4.5 and RCP 8.5 during 2030, 2050 and 2080. The base years were selected from 1986 to 2005 as suggested by Liersch *et al.* (2020).

RESULT AND DISCUSSION

Results showed that the observed grain yield of rice varied from 4131 kg ha^{-1} (January 1) to 7039 kg ha^{-1} (October 30) for different planting dates (Table 2). The root mean square error (RMSE), d-stat index and mean absolute percentage error (MAPE) indicated in good agreement with observed yield (Table 2) with RMSE (418.94), d-stat index (0.599), and MAPE (11.9).

The simulated grain yields for the baseline (1986-2005) period and for near (2030), mid (2050) and end of century (2080) under two climate change scenarios along with the percent change over base yield are presented in Table 3. Results show that the grain yield was found to decrease under both the projected climate change scenario in almost all the plantings dates except in October 1st, wherein the yield was least influenced by the climate change projection. In year 2030, the change in yield was observed to vary from +5.6% to -38.8% under RCP 4.5 and from +9.6% to -41.0% under RCP 8.5. In year 2050, it varied from +0.6% to -43.7% under RCP 4.5 and from -2.5% to -47.3% under RCP 8.5 and in year 2080, it was found to vary from -5.0% to -46.8% under RCP 4.5 and from -2.0% to -49.0% under RCP 8.5. In October 1 planted rice the yield slightly increased (5-9 %) in 2030 and decreased marginally (-2 to -5%) at the end of the century (2080) under both climate change scenario, while the maximum reduction in yield was observed under early (June 1) planted rice.

Table 2: Observed and predicted grain yield of rice with their percentage error

Planting dates	Grain yield(kg ha^{-1})		Error %
	Observed	Simulated	
June 1	5345.0	5811.0	8.7
June 30	6150.0	6297.0	2.4
October 1	5687.0	5890.0	3.6
October 30	7039.0	6378.0	-9.4
January 1	4131.0	4532.0	9.7
Average	5670.4	5781.6	6.7
RMSE	418.94		
d-Stat	0.699		
MAPE	11.9		

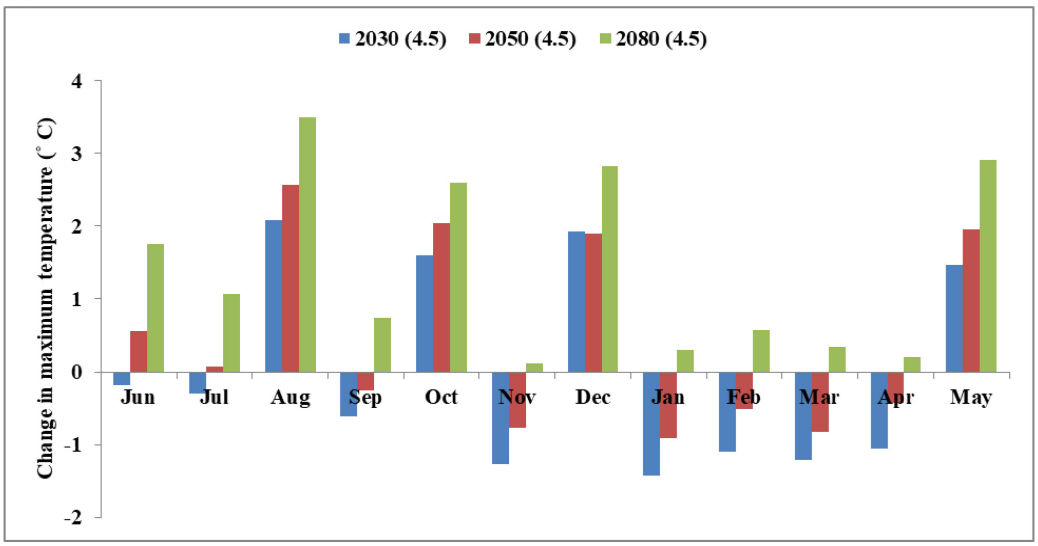
Change in maximum temperature from baseline under RCP 4.5 and RCP 8.5 scenario for different months are given in Fig. 1. During near century, maximum temperature is increasing during August, October, December and May only. During mid century maximum temperature is increasing from the baseline during June, July, August, October, December and May months. But as we approach end of the century, maximum temperature is increasing during all the months. The trends shows those days in August, October, December and May will be warmer in coming years. August and December coincides with the reproductive stage of rice crop during the *viruppu* and early sown *mundakan* season crop in Kerala respectively. Fu *et al*. (2008) reported that duration of grain filling period increases with maximum temperature and this will reduce seed setting rate in rice. Hence, high maximum temperature which experience in future may result in rice yield reduction during *virippu* and early sown *mundakan* season and the crop is at risk during this period. Since summer season is coinciding with the reproductive stage the yield reduction is already experienced by farmers for crop grown during *punja* season.

Fig. 2 represents variation in minimum temperature from baseline under RCP 4.5 and RCP 8.5 scenario for different months. In all the months minimum temperature is showing an increasing trend from the base line during projected years. This shows that irrespective of the scenarios and time line the night temperature may increase in future. Mohammed and Tarpley (2009) reported that as the minimum temperatures increases, there will be a reduction in the pollen grain germination percentage and this will induce spikelet infertility. So high minimum temperature prevailing during *virippu, mundakan* and *punja* seasons in coming years will have negative

Table 3: Grain yield during baseline and projected under RCP 4.5 and RCP 8.5 scenario

Date of planting	Base line yield (kg ha^{-1})	2030		2050		2080	
		Simulated yield (kg ha^{-1})	(Error %)	Simulated yield (kg ha^{-1})	(Error %)	Simulated yield (kg ha^{-1})	(Error %)
RCP 4.5 scenario							
June 1	5902	3610	-38.8	3324	-43.7	3311	-43.9
June 30	5995	5485	-8.5	5038	-16.0	4025	-32.9
October 1	5810	6138	5.6	5845	0.6	5520	-5.0
October 30	5809	4385	-24.5	3618	-37.7	3092	-46.8
January 1	5380	5400	0.4	4846	-9.9	3734	-30.6
Mean	5779.2	5003.6	-13.2	4534.2	-21.3	3936.4	-31.9
RCP 8.5 scenario							
June 1	5902	3480	-41.0	3111	-47.3	3105	-47.4
June 30	5995	5498	-8.3	4612	-23.1	3056	-49.0
October 1	5810	6365	9.6	5666	-2.5	5692	-2.0
October 30	5809	4389	-24.4	3544	-39.0	2999	-48.4
January 1	5380	5410	0.6	4810	-10.6	3590	-33.3
Mean	5779.2	5028.4	-12.7	4348.6	-24.8	3688.4	-36.0

(a)



(b)

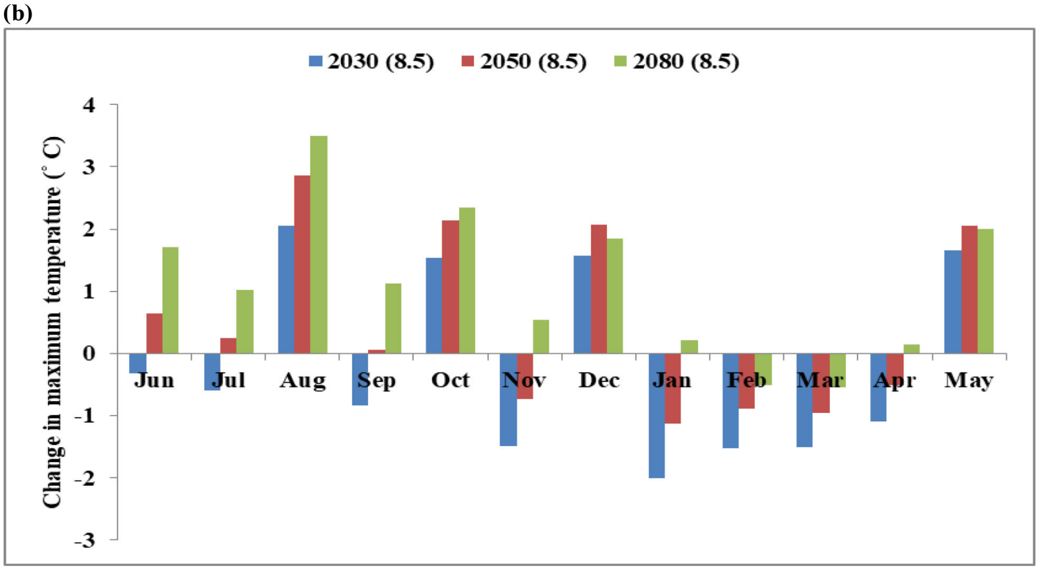


Fig. 1: Change in maximum temperature from baseline under (a) RCP 4.5 and (b) RCP 8.5 scenario for different months

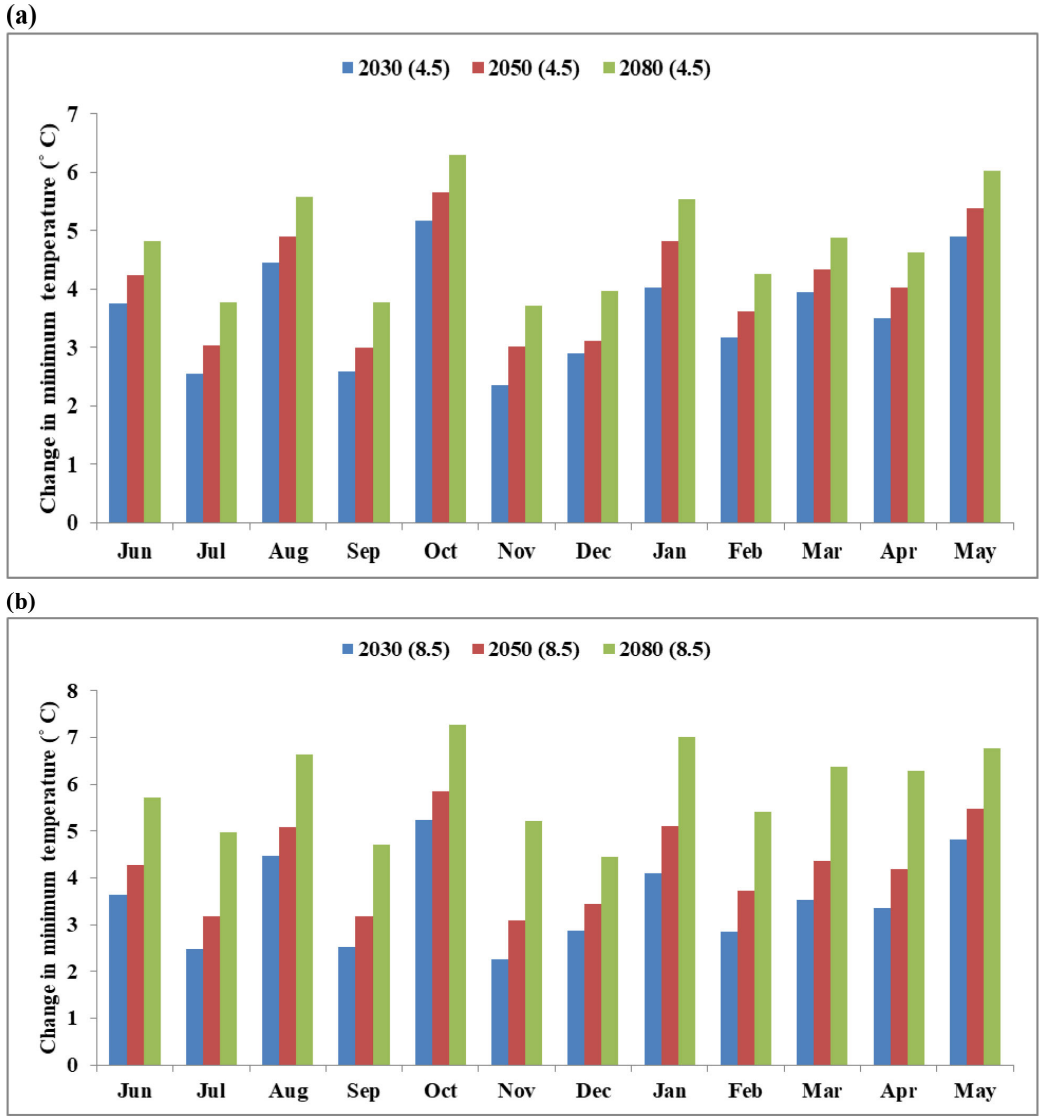


Fig. 2: Change in minimum temperature from baseline under (a) RCP 4.5 and (b) RCP 8.5 scenario for different months

effect on rice yields

Change in rainfall from baseline under RCP 4.5 and RCP 8.5 scenario for different months is given in Fig. 3. In June, July and May months there may be a considerable increase in rainfall from the baseline. Whereas, in August, September and October months, there will be a decrease in rainfall from the baseline in future. This shows that rainfall during southwest monsoon period shows an increasing trend which may be detrimental for the crops as this season contributes major share to annual rainfall and it may lead to high water table and flooding. The crop is at risk of flooding during *virippu* season as it falls during the southwest monsoon period. Rainfall during northeast monsoon may decrease causing water deficit in succeeding winter and summer months. Generally, the wetter months tends to be more wet and drier months to be drier. This may cause flood as well as drought in the same year in future. Goswami *et al*. (2006) reported that in recent years heavy to very heavy rainfall events are becoming more frequent and intense in India. The severe flood events experienced in Kerala during the past years complying to this finding.

In almost all the cases, reduced yield may be due to increased temperature during different growth stages of rice. A study in southern Japan conducted by Oh-e *et al*. (2007) found that maximum air temperature of about 31.8 °C during the entire growth period of rice speed up leaf senescence reduces photosynthetic rate and lowers grain yield, mainly due to increased spikelet sterility. It is found that there is an increase in minimum temperature from the baseline in all dates of planting in the year 2030, 2050 and 2080 under the projected climate change scenarios RCP 4.5 and RCP 8.5. Yield reduction may be mainly due to increase in minimum temperature.

Increased yield from baseline in October 1st planting under RCP 4.5 and 8.5 scenarios may be due to decreased maximum temperature from the baseline in the month of November. Grain filling period increases with maximum temperature and this will

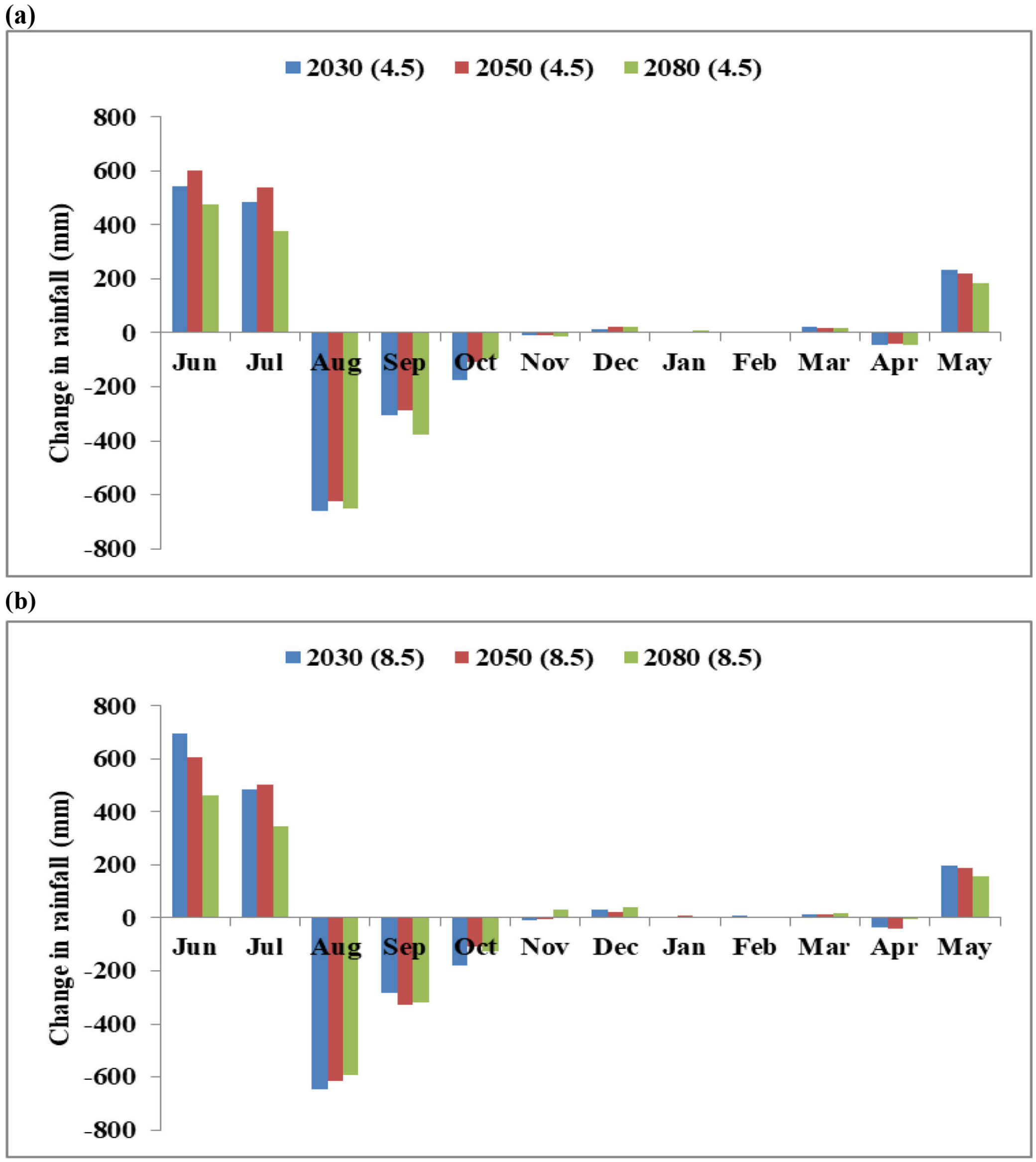


Fig. 3: Change in rainfall from baseline under (a) RCP 4.5 and (b) RCP 8.5 scenario for different months

reduce seed setting rate in rice. Less pollen production and repression of stamen dehiscence may be the reason for yield reduction under high temperature (Matsui *et al*., 2005). Vijayakumar *et al*. (1996) observed that increased morning rainfall will reduce the pollination of flowers. This will lead to unfertilized ovaries and chaffy grains and thereby decreasing yield. Yield reduction was observed in June 1st (*virippu*) planting under all the projected climate change scenarios may be due to increase in rainfall from baseline which coincides with the flowering period under both the scenarios. This confirms that an increase in temperature during different growth phases and increase in rainfall during reproductive stage causes a reduction in productivity of Jyothi variety of rice in the central zone of Kerala. The study reiterates the need of adaptation strategies like adjusting the planting time and ensuring standing water in the field during vulnerable stages of the crop to ensure higher productivity.

CONCLUSION

The increase in temperature under future climate will result in drastic temperature increase during critical growth phases such as flowering and grain filling and it may speed up the growth progression in rice, resulting in rapid biomass accumulation and severe yield loss. Similarly, rainfall during reproductive stages has negative effect on yield. Rice crop showed a continuous decrease in yield during near, mid and end centuries in climate change scenarios RCP 4.5 as well as RCP 8.5. Suitable adaptation methods have to be followed to reduce future yield loss due to climate change.

Conflict of Interest Statement: The author (s) declares (s) that there is no conflict of interest.

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