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Climate Change Impact on *Kharif* Rice Production in Central Agro-Climatic Zone of Kerala under Different Representative Concentration Pathways

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Abstract A field experiment was conducted during 2014-15 at the RARS, Pattambi, Palakkad district, Kerala. Two popular varieties of Kerala Aathira and Vaisakh were selected for this study. DSSAT model was calibrated and validated against the field data. Model showed good agreement between observed and predicted yields. RMSE for Aathira prediction is 515.6 kg and R^2 value is 0.64 RMSE for Vaisakh prediction is 377.75 kg and R^2 value is 0.82. The ensemble data of seventeen climate models was used in the study under different Representative Concentration Pathways (RCPs) of IPCC (Intergovernmental Panel on Climate change) 5th Assessment Report (AR5). The yield projections were made upto the years 2030s, 2050s and 2080s. Under RCP 4.5 the yield of Aathira will not change by 2030s. But by 2050s it will decrease by 7% and it will be reduced by 22% in 2080s. The yield of Vaisakh will be reduced by 16, 20 and 20% by 2030s, 2050s and 2080s respectively. The yield of Aathira will remain 5.7 t ha^{-1} for the period 2030s and 2050s. Whereas for the 2080s, there will decline in the yield by 24%. Yield of Vaisakh will be reduced by 20, 22 and 25% for the periods 2030s, 2050s and 2080s respectively. Yield of Aathira in will not be changed 5.7 t ha^{-1} for the periods 2030s. Whereas a reduction of 20 and 28% is forecasted for the periods 2050s and 2080s. Yield of Vaisakh will be reduced by 20, 29 and 38% in the periods 2030s, 2050s and 2080s respectively. The results of the simulation study showing a clear evidence for a decrease of rice yield with projected climate change.

Keywords Assessment report 5 (AR5), IPCC, Representative concentration pathways (RCPs), DSSAT, CERES-Rice.

Introduction

Agriculture is always vulnerable to vagaries due to weather events and climate conditions. Despite technological advances such as improved crop varieties and irrigation systems, weather and climate are important factors, which play a significant role in agriculture. The impacts of climate change on agriculture are global concerns and for that matter India, where agriculture sector alone represents 23% of India's Gross National Product (GNP) and the livelihood of nearly 70% of the population is exposed to a great danger, as the country is one of the most vulnerable countries to climate change (Houghton 2004). The most remarkable characteristic of climate change is the increase in temperature which has been attribut-

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Table 1. Genetic coefficients for the CERES-Rice model.

P1	Basic vegetative phase of the plant.
P2R	Extent to which phasic development leading to panicle initiation is delayed (expressed as GDD in °C) for each hour increase in photoperiod above P20.
P2O	Critical photoperiod or longest day length (in hours) at which the development occurs at maximum rate. At values higher than P2O the development rate is slowed (depending on P2R), there is delay due to longer day length.
P5	Time period in GDD in °C from beginning of grain-filling (3-4 days after flowering) to physiological maturity with base temperature of 9°C.
G1	Potential spikelet number coefficient as estimated from number of spikelets per g of main culm dry weight (less leaf blades and sheaths plus spikes at anthesis). A typical value is 55.
G2	Single dry grain weight (g) under ideal growing conditions. i.e., non-limiting light, water, nutrients, and absence of pests and diseases.
G3	Tillering coefficient (scalar value) relative to IR64 cultivars under ideal conditions. A higher tillering cultivar would have coefficient greater than 1.
G4	Temperature tolerance coefficient. Usually 1.0 for cultivars grown in normal environment. G4 for japonica type rice grown in warmer environments would be ≥ 1.0. Tropical rice grown in cooler environments or season will have G4<1.0.

ed to the enhanced greenhouse effect. Agricultural production, and thus global food security, is directly affected by the increasing temperatures (Ainsworth and Ort 2010). The agriculture sector is already under pressure for increasing food demand, problems associated with agricultural land and water resource depletion. The issues of climate change make the pressure more acute for the sector.

Rice (*Oryza sativa* L.) is the major staple food for more than half of the worlds population (FAO 2013), accounting for approximately 30% of the total dietary intake, globally and in South Asia (Lobell et al. 2008). The fact that climate impacts often exceed 10% of the rate of yield change indicates that climate changes are already exerting a considerable drag on yield growth (Lobell et al. 2011). Climate change has already negatively affected India's millions of rice producers and consumers. Harvest could have been 5.67% higher in the absence of climate change. Impacts of these changes in future on rice yield in India would likely be larger than the historical ones (Auffhammer et al. 2012).

(We are thankful for CGIAR for providing us the downscaled climate data under different RCPs in an user friendly manner).

Materials and Methods

Field experiments were conducted during 2014-15 to study the climate change impact on rice production and crop weather relationships in rice. The field experiments were conducted during January 2014 to March 2015 at the Regional Agricultural Research Station of the Kerala Agricultural University at Pattambi, Palakkad district, Kerala. The station is located at 10°48′ N latitude and 76°12′ E longitude at an altitude of 25.36 m above mean sea level. The experiments were conducted in *kharif* season of 2014-15 by planting at fortnightly intervals. Two popular varieties of Kerala Aathira and Vaisakh were selected for this study. Aathira and Vaisakh are photo insensitive varieties with the duration of 117–125 days and 113–120 days respectively.

Crop weather model

CERES-Rice has been used in this study to model the effect of weather parameters on crop growth and yield. The CERES models have been extensively used for assessment of the impact of climatic change on

Table 2. Genetic coefficients of Aathira and Vaisakh.

	Genetic coefficients							
Variety	P1	P2R	P5	P20	G1	G2	G3	G4
Aathira	895.0	5.0	270.0	10.8	46.0	0.0222	0.98	0.90
Vaisakh	630.0	1.0	270.0	10.8	54.0	0.0200	1.00	1.00

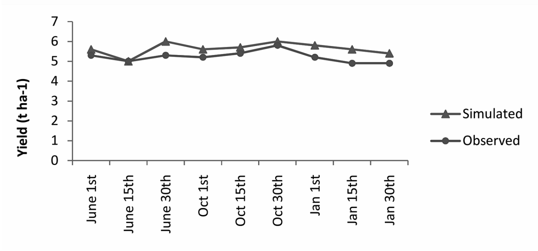

Fig. 1. Observed and simulated yields of Aathira.

agricultural crop production. CERES -Rice model is physiologically oriented and simulates rice response to climate variables. The simulation of rice growth was performed with the CERES-Rice. Model developed by the International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT). The IBSNAT models were employed for the simulation of crop response to climate change because they have been already validated for a wide range of climates all over the world and are independent of location or soil type encountered.√

Calibration of model

Data obtained from the experiments carried out with rice cultivars Aathira and Vaisakh were used for estimating the genetic parameters. The genetic coefficients that influence the occurrence of developmental stages in the CERES–Rice model were derived iteratively, by manipulating the relevant coefficients to achieve the best possible match between the simulated and observed phenological events as well as the model was calibrated for yield parameters and grain yield. The genetic coefficients required for CERES-Rice mentioned in Table 1.

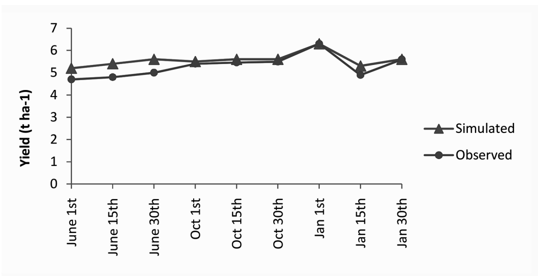

Fig. 2. Observed and simulated yields of Vaisakh.

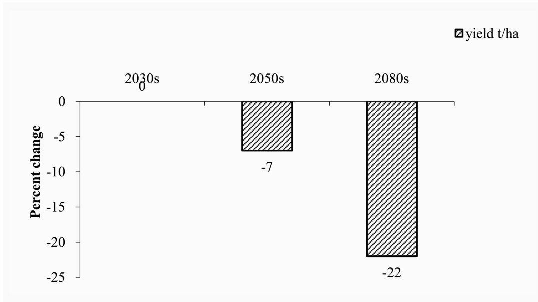

Fig. 3. Percent change in yield of Aathira in RCP 4.5 compared to present yields.

Validation of CERES-Rice

Validation is the comparison of the results of model simulations with observations that were not used for the calibration. The experimental data collected were used for independent model index used for model validation is

$$\text{RMSE (Root Mean Square Error)} = \sqrt{\frac{\sum_{t=1}^{n} (Pi - Oi)^2}{n}}$$

Where Pi and Oi refer to the predicted and observed values for the studied variables (e.g. grain yield and total biomass) respectively and n is the mean of the observed variables.

Climate change scenarios

Impacts of climate change will depend not only on the response of the earth system but also on how humankind responds. These responses are uncertain, so future scenarios are used to explore the consequences of different options. The scenarios provide a range of options for the worlds governments and other institutions for decision making. Policy decisions based on risk and values will help determine the pathway to be followed.

Table 3. RMSE and R^2 for DSSAT prediction.

Variety	RMSE	R^2
Asthira	515.60	0.64
Vaisakh	377.75	0.82

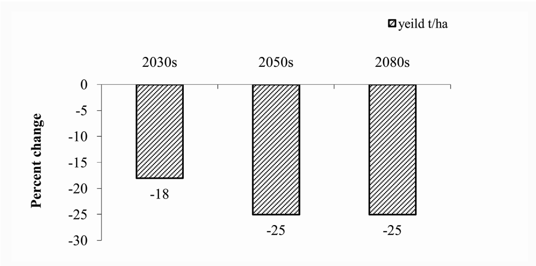

Fig. 4. Percent change in yield of Vaisakh in RCP 4.5 compared to present yields.

The Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) (IPCC 2013) has introduced a new way of developing scenarios. These scenarios span the range of plausible radiative forcing scenarios, and are called representative concentration pathways (RCPs) (Moss et al. 2010). They are prescribed pathways for greenhouse gas and aerosol concentrations, together with land use change, that are consistent with a set of broad climate outcomes used by the climate modelling community. The pathways are characterized by the radiative forcing produced by the end of the 21st century.

General circulation models used for the study

The ensemble data of seventeen climate models was used in the study. The data were downloaded from http://-gisweb.ciat.cgiar.org/MarkSimGCM/. The models are BCC-CSM, BCC-CSM 1. 1 (m), CSIRO-Mk3.6.0, FIO-ESM, GFDL-CM3, GFDL-ESM2G, GFDL-ESM2M, GISS-E2-H, GISS-E2R, HadGEM2-ES, IPSL-CM5A-LR, IPSL-CM5A-MR, MIROC-ESM, MIROC-ESM-CHEM, MIROC5,

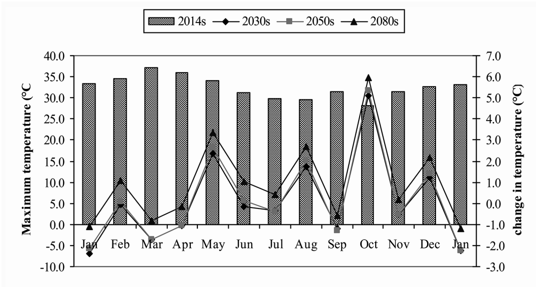

Fig. 6. Projected changes in monthly mean maximum temperature as per RCP 4.5 scenario.

MRI-CGCM3 and NorESM1-M.

Results and Discussion

DSSAT model validation

Three dates of transplanting in three seasons (*Virippu*, *Mundakan* and *Puncha*) has been raised for both the varieties for validating CERES–Rice (DSSAT 4.5). The genetic coefficients for both the varieties were developed and presented in the Table 2.

The observed and simulated yields of Aathira were presented in the Fig. 1. Maximum yield observed was 5.8 t ha^{-1} during the October 30th planting. Lowest yield observed was 4.9 t ha^{-1} on January 30th planting. RMSE for Aathira prediction is 515.6 kg and R^2 value is 0.64 (Table 3).

The observed and simulated yields of Vaisakh has presented in the Fig. 2. Maximum yield observed is 6.3 t ha^{-1} on January 1st planting. Lowest yield ob-

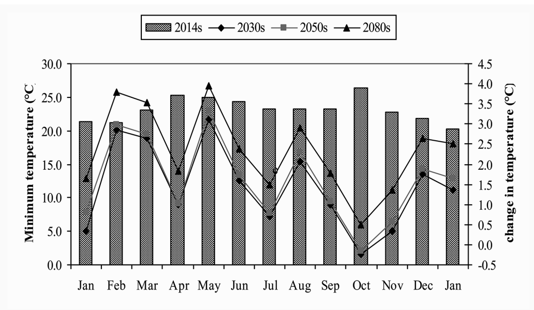

Fig. 5. Projected changes in monthly mean minimum temperature as per RCP 4.5 scenario.

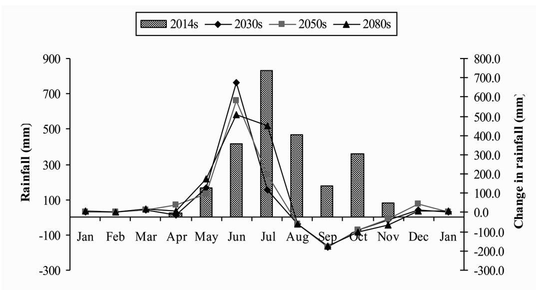

Fig. 7. Projected changes in monthly mean rainfall as per RCP 4.5 scenario.

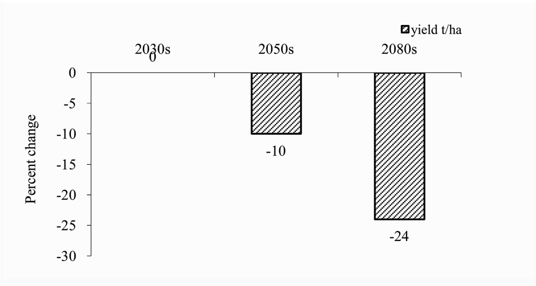

Fig. 8. Percent change in yield of Aathira in RCP 6.0 compared to present yields.

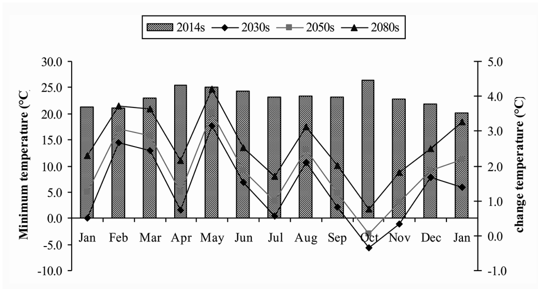

Fig. 10. Projected changes in monthly mean minimum temperature as per RCP 6.0 scenario.

served is 4.7 t ha^{-1} on January 15th planting. RMSE for Vaisakh prediction is 377.75 kg and R^2 value is 0.82 (Table 3).

Yield changes in scenario RCP 4.5

The yield of Aathira as per the RCP 4.5 will not change by 2030s (Figs. 3, 4). But by 2050s it will decrease by 7% and it will further reduce by 22% in 2080s. By 2030s the maximum temperature is decreasing 0.4°C and minimum temperature (Figs. 5, 6) will increase 0.7°C and this little increase will be compensated by increase in the rainfall (674 mm) (Fig. 7.). During the 2050s the yield will decrease by 7% and by 2080s it will decrease by 22%. This is due to increase in the minimum temperature (1.5°C) beyond the optimum temperature (24°C) during the flowering period (Fig. 5).

The yield of Vaisakh will be reduced by 16, 20 and 20% by 2030s, 2050s and 2080s respectively (Fig. 4). This can be because of the excess rainfall during the crop growth period reduced the grain yield in variety Vaisakh. Due to increase in the minimum temperature, by 1.9°C in 2030s and 2050s and 2.7°C in 2080s (Fig. 6) during the flowering and grain filling period, the yield will be reduced (Chaturvedi et al. 2017).

Yield changes under RCP 6.0

The yield of Aathira will remain 5.7 t ha^{-1} for the period 2030s and 2050s. Whereas for the 2080s, there will decline in the yield by 24% (Figs. 8, 9). This is mainly because of slight increase in the minimum temperature (0.6°C) (Fig. 10). By 2050s the yield will be decreased by 10% because of increase in the minimum temperature by 1.0°C, during critical crop growth stages. In 2080s, yield will be decreased by 24%. This can be due to increase in the minimum temperature (1.7°C) during the critical growth stages (Chaturvedi et al. 2017).

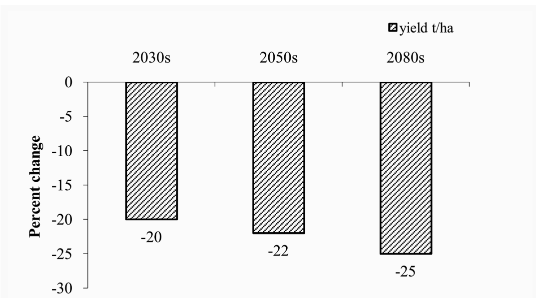

Fig. 9. Percent change in yield of Vaisakh in RCP 6.0 compared to present yields.

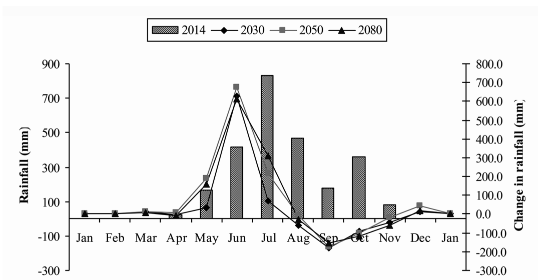

Fig. 11. Projected changes in monthly mean rainfall as per RCP 6.0 scenario.

Yield of Vaisakh will be reduced by 20, 22 and 25% for the periods 2030s, 2050s and 2080s respectively. This is mainly due to high rainfall (Fig. 11) (612 mm increase) and increase in the minimum temperature (Fig. 10).

Yield changes under RCP 8.5

Yield of Aathira in will not be changed (5.7 t ha^{-1}) for the periods 2030s. Whereas a reduction of 20 and 28% is forecasted for the periods 2050s and 2080s. Due to the slight increase in the minimum temperature during 2030s in the first crop season, Aathira yield will remains at 5.7 t ha^{-1}.

Yield of Vaisakh will be reduced by 20, 29 and 38% in the periods 2030s, 2050s and 2080s respectively. This can be due to increase in the rainfall by 78 1 mm during the first crop season.

Conclusion

The results of the simulation study showing a clear evidence for a decrease of rice yield with projected climate change. The results also show that the effect of minimum temperature would drastically reduce the yield. The increasing atmospheric CO_2 concentration is likely to have some positive effect on yield, but the effect is not significant compared to the negative impact of rise in temperature. The research should be directed towards creating varieties which can tolerate the heavy rainfall events and prolonged dry spells during the crop growth periods. There should be more frequent awareness programs to create a consensus and responsibility in the citizens. Further studies should be conducted area specifically to understand the impacts of the climate change in finer scale.

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