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G Subramanyam
M.Sc (Ag.) student, Dept. of Agricultural Meteorology, KAU, Thrissur, Kerala, India

KM Sunil
Assistant Professor, KVK, Palakkad, KAU, Thrissur, Kerala, India

B Ajithkumar
Head of the Department, Dept. of Agricultural Meteorology, KAU, Thrissur, Kerala, India

Correspondence
G Subramanyam
M.Sc (Ag.) student, Dept. of Agricultural Meteorology, KAU, Thrissur, Kerala, India

Climate change impact on summer rice production in central agro-climatic zone of Kerala under different RCP's

G Subramanyam, KM Sunil and B Ajithkumar

Abstract
Agriculture is always vulnerable to unfavorable weather events and climate conditions. Despite technological advances such as improved crop varieties and irrigation systems, weather and climate are still key factors in agriculture productivity. Field experiments were conducted during 2014-15 to study the climate change impact on rice production by validating DSSATV4.5 model and crop weather relationships in rice. The field experiments were conducted at the Regional Agricultural Research Station of the Kerala Agricultural University at Pattambi, Kerala. Two popular varieties of Kerala Aathira and Vaisakh were selected for this study. Model was validated against the field data. It has showed good agreement between observed and predicted values. The 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 yield projections were made upto the years 2030s, 2050s and 2080s. The yield of Aathira will be reduced by 28 per cent, 14 per cent and 12 per cent for the periods 2030s, 2050s and 2080s respectively in RCP 2.6. Vaisakh yield will be reduced by 12 per cent by 2030's, 21 per cent by 2050s and 10 per cent by 2080s in RCP2.6. Aathira yields will be reduced by 35 per cent, 37 per cent and 42 per cent in the periods 2030s, 2050s and 2080s respectively in RCP8.5. Vaisakh yields will be reduced by 28 per cent, 35 per cent and 38 per cent in the periods 2030s, 2050s and 2080s respectivelyin RCP 8.5.

Keywords: Crop models, Climate change, DSSAT, RCP's

Introduction
Agriculture is always vulnerable to unfavorable weather events and climate conditions. Despite technological advances such as improved crop varieties and irrigation systems, weather and climate are still key factors in agriculture productivity. The greenhouse gases (GHGs) are presently increasing at the rate of 1 percent for CH_4, 0.4-0.5 percent CO_2 and 0.2-0.3 percent for N_2O (Baker 1989) [2]. The increased level of CO_2 from 340 to 680 ppm could increase the yield of major crops by 10-15 percent especially in C_3 plants like rice (Allen, 1990) [1] but the beneficial effects can be negated as the incidence photosynthetically Active Radiation (PAR) is likely to decline by 1 percent (Hume and Cattle, 1990) [5]. The rising temperatures and carbon dioxide and uncertainties in rainfall associated with climate change may have serious direct and indirect consequences on crop production and hence food security. There is an urgent need to document the temperature sensitivities of major crop varieties to changes in temperature. The present study is for assessing the impact of climate change on rice production.

Materials and Methods
Location and varieties
Field experiments were conducted during 2014-15 to study the climate change impact on rice production by validating DSSAT model and crop weather relationships in rice. The field experiments were conducted at the Regional Agricultural Research Station of the Kerala Agricultural University at Pattambi, Kerala. The station is located at 10° 48' N and 76° 12' E at an altitude of 25.36 m above MSL. The experiments were conducted in summer 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. The experiment was laid out in Split plot Design with three replications. The Main plot treatments consist of three dates of planting and two varieties i.e. Aathira and Vaisakh as subplot treatments. The plot size was 40 m^2 and the spacing adopted was 20 cm x 15 cm.

Leaf area index (LAI)

Leaf area index was computed at weekly intervals. Two sample hills were randomly selected in each plot and number of tillers was counted in each hill. The length and maximum width of leaves in the middle tiller of the sample hills were measured separately and leaf area was computed based on length- width method.

Leaf area = $L \times W \times K$, where

K is the Adjustment factor (0.75), L is the length and W is the width (Gomez, 1972). The leaf area index was calculated using the following formulae.

$$\text{Leaf area per hill} = \text{Total area of middle tiller} \times \text{Total number of tillers}$$

$$\text{LAI} = \frac{\text{Sum of leaf area per hill of "n" sample hill } (cm^2)}{\text{Area of land covered by "n" hills } (cm^2)}$$

Crop weather model

A climate-crop coupled model, in which a crop growth model is coupled to a climate model, is one tool to assess the influence of the climate-crop interaction. CERES-rice crop growth model 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 worldwide for assessment of the climatic change impact on agricultural crop production. CERES-rice model simulates rice response to climate variables (Singh *et al.* 1994) [9]. The CERES model developed by the International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT). The CERES-Rice (Crop Estimation through Resource and Environment Synthesis) model (Ritchie, 1986 and Godwin *et al*., 1990) [8, 3] was adopted as the basis to simulate the effects of cultivar, planting density, weather, soil water and nitrogen on crop growth, development and yield. CERES- Rice model shared a common input and output data format, which had been developed and embodied in a software package called Decision Support System for Agro-technology Transfer (DSSAT).

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 co-efficients required for CERES-Rice mentioned in Table 1.

Calibration of CERES-Rice model

Data obtained from the experiments carried out with rice cultivars Aathira and Vaisakh under nine dates of sowing 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.

Validation of CERES Rice

Validation is the comparison of the results of model simulations with field observations The field data collected was used for the model validation. Formula used for model validation is

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

Where Pi and Oi refer to the predicted and observed values for the studied variables respectively and n is the mean of the observed variables.

Climate Change Scenarios

Impacts of climate change will depend on the response of the Earth systems and 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 world's governments and other institutions for decision making. Policy decisions based on risk and values will help determine the pathway to be followed.

The Intergovernmental Panel on Climate Change (IPCC 2013) [6] has used a new way of scenarios in their Fifth Assessment Report (AR5). These scenarios are called representative concentration pathways (RCPs) (Moss *et al* 2010) [7]. They are prescribed pathways for greenhouse gas and aerosol concentrations that are consistent with a set of broad climate outcomes used by the climate modelling community throughout the world.

General Circulation Models used for the study

The ensemble data of seventeen climate models was used in the study. The data was 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-E2-R, HadGEM2-ES, IPSL-CM5A-LR, IPSL-CM5A-MR, MIROC-ESM, MIROC-ESM-CHEM, MIROC5, MRI-CGCM3 and NorESM1-M.

Results and Discussion

DSSAT Model Validation

The Genetic coefficients for both the varieties were developed and presented in the Table 1.

Table 1: Genetic coefficients of Aathira and Vaisakh

Variety	Genetic co-efficients							
	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

The RMSE for Aathira prediction is 515.6 kg and R^2 value is 0.64 and the RMSE for Vaisakh prediction is 377.75 kg and and R^2 value is 0.82 (Table. 2).

Table 2: RMSE and R^2 for DSSAT prediction

Variety	RMSE	R^2
Aathira	515.60	0.64
Vaisakh	377.75	0.82

Yield changes in RCP 2.6

The yield of Aathira will be reduced by 28 per cent, 14 per cent and 12 per cent for the periods 2030s, 2050s and 2080s respectively (Fig.1). Vaisakh yield will be reduced by 12 per cent by 2030's, 21 per cent by 2050s and 10 per cent by 2080s (Fig.2).

Yield changes in RCP 4.5

The Aathira yield may be reduced by 26 per cent by 2030s and 2050s. Whereas, by 2080s yield reduction will be 23 per cent (Fig.3). The Vaisakh yield reduction will be 21 per cent for the periods 2030s, 2050s and 2080s (Fig.4)

Yield changes in RCP 6.0

Aathira yield will be reduced by 16 per cent, 24 per cent and 29 per cent for the periods 2030s, 2050s and 2080s respectively (Fig.5). Vaisakh Yield will be reduced by 12 per cent, 24 per cent and 22 per cent for the periods 2030s, 2050s and 2080s respectively during summer season (Fig.6).

Yield changes in RCP 8.5

Aathira yields will be reduced by 35 per cent, 37 per cent and 42 per cent in the periods 2030s, 2050s and 2080s respectively during summer season (Fig.7). Vaisakh yields will be reduced by 28 per cent, 35 per cent and 38 per cent in the periods 2030s, 2050s and 2080s respectively during the summer season (Fig.8).

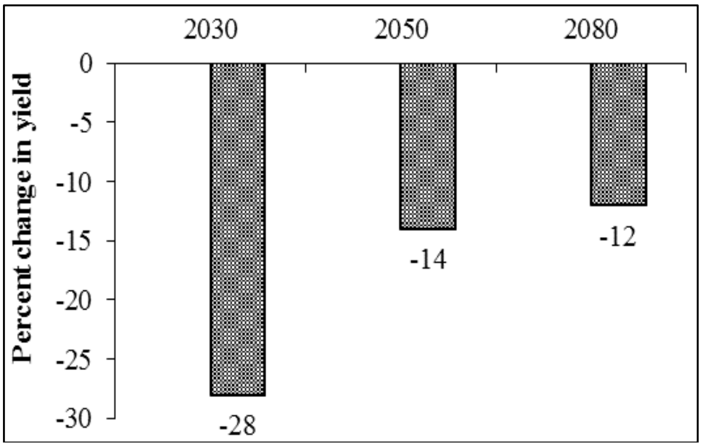

Fig 1: Percent change in Yield of Aathira in RCP 2.6

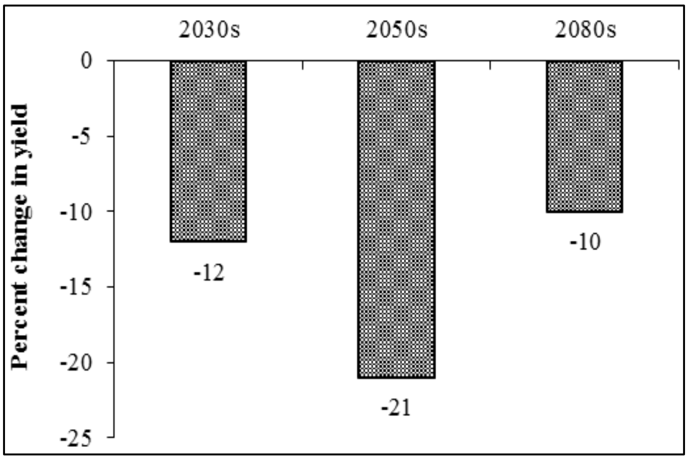

Fig 2: Percent change in Yield of Vaisakh in RCP 2.6

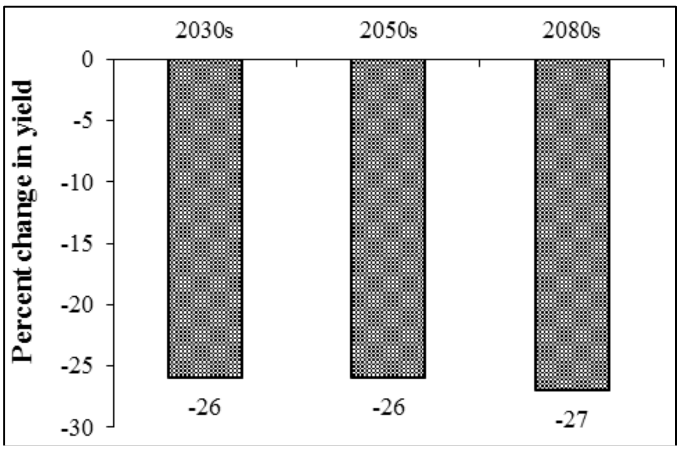

Fig 3: Percent change in Yield of Aathira in RCP 4.5

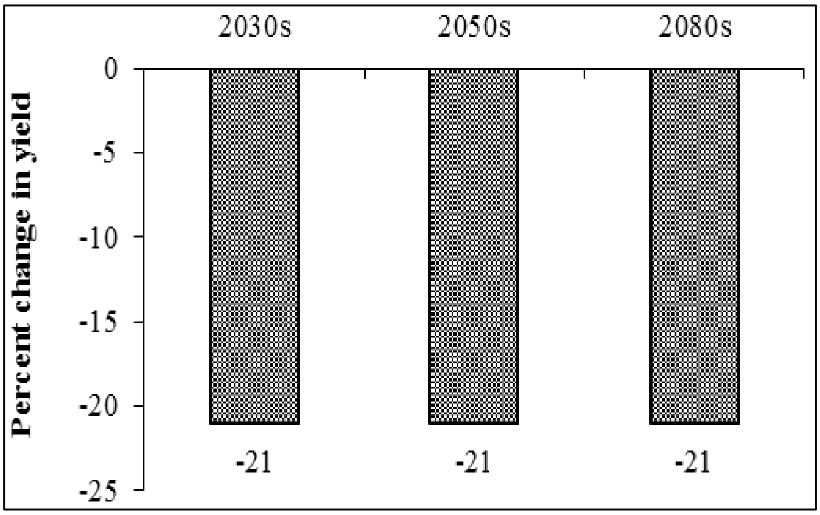

Fig 5: Percent change in Yield of Vaisakh in RCP 4.5

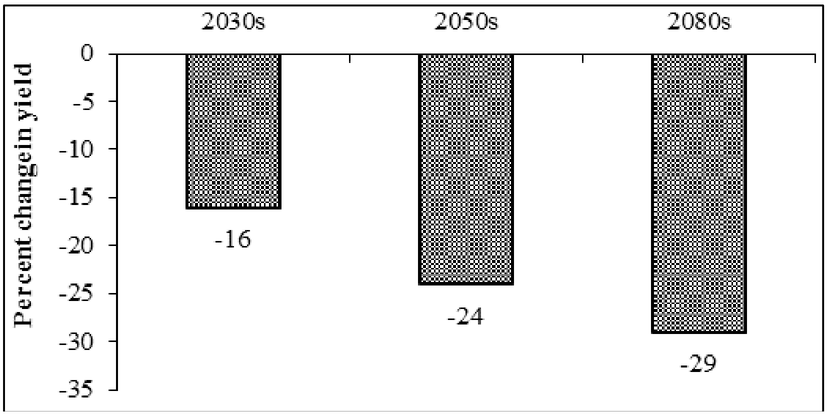

Fig 6: Percent change in Yield of Aathira in RCP 6.0

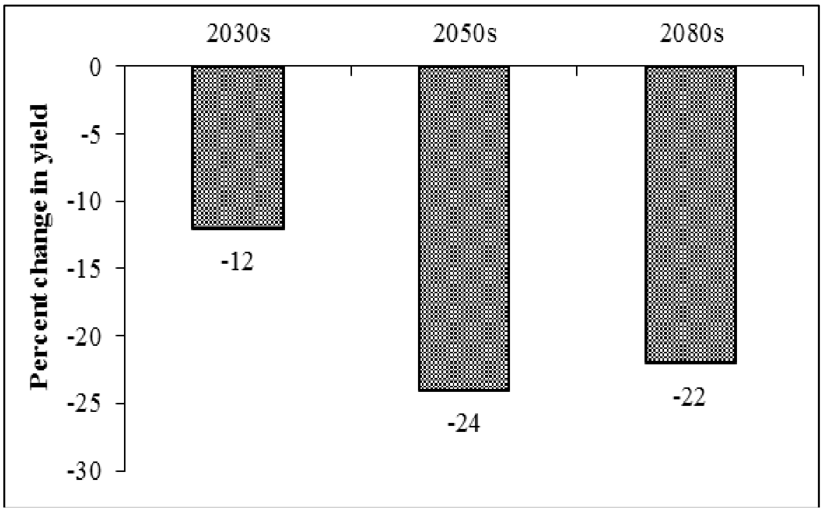

Fig 7: Percent change in Yield of Vaisakh in RCP 6.0

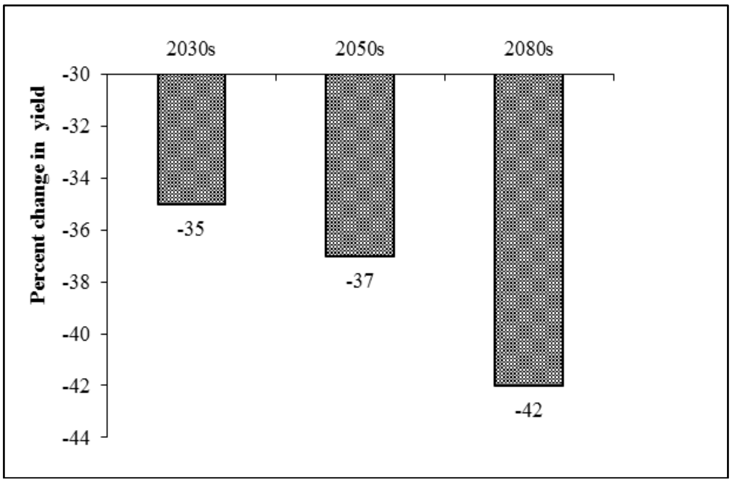

Fig 8: Percent change in Yield of Aathira in RCP 8.5

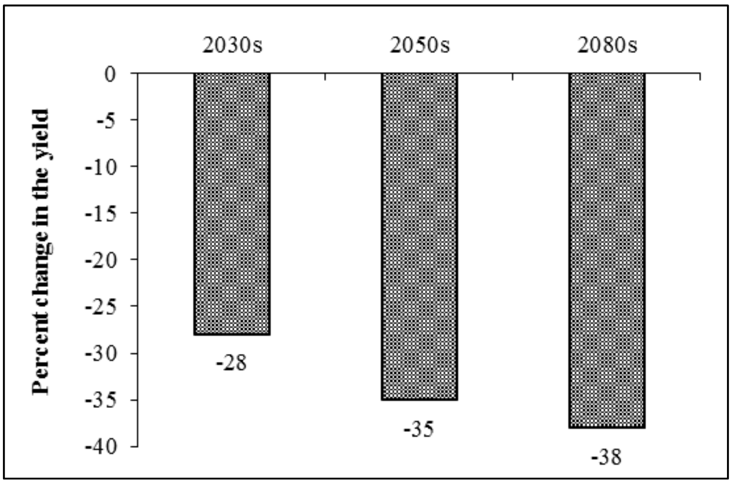

Fig 9: Percent change in Yield of Vaisakh in RCP 8.5

Conclusions

The results of study showing a clear decrease of rice yield with projected climate change under all the scenarios. The results also showing that the effect of minimum temperature rise would drastically reduce the yield. The future research should be directed towards creating varieties which can tolerate the heavy rainfall events and intermittent drought during the critical crop growth periods. There should be farmer and public awareness programs to create a consensus and responsibility in the citizens and the governments. Further area based studies should be conducted to understand the impacts of the climate change at regional levels.

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