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Impact of climate change on rice yield at Jorhat, Assam

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ABSTRACT

Impact of climate change on rice yield variabilities under various Representative Concentration Pathways (RCPs) has been estimated for Jorhat district, under Upper Brahmaputra Valley Agroclimatic Zone of Assam. CERES-Rice module of DSSAT 4.5 was calibrated and validated for rice cultivar 'Mahsuri' under three different dates of transplanting between May and July. Increase in both maximum and minimum temperatures at Jorhat, under all the RCPs for 2020, 2050 and 2080, suggests increasing level of heat stress during crop growth period. The deviations in projected grain yield over observed mean yield of 2009-2013 was found ranging from -12.7 to -43.4 per cent under all the scenario and dates of transplanting. Among all the climate scenarios, the reduction in grain yield was highest (-43.4%) under RCP 8.5 and lowest (-12.7%) under RCP 2.6.The mean yield reduction, considering all scenarios together, was highest in second transplanting date(-38.5%), followed by third(-28.8%) and first one (-23.3%).

Key words: Climate change, RCP, rice yield variability, rainfed, CERES-Rice

The present rapid climate change and its adverse affects are mostly governed by the rapidly increasing concentration of green house gases (GHG's), aerosols and other pollutants. These emissions are regulated by various natural and anthropogenic factors. Anthropogenic GHG emissions are mainly driven by population size, economic activity, lifestyle, energy use, land use patterns, technology and climate policy. The Representative Concentration Pathways (RCPs), which are used for making future climatic projections, based on these factors. The RCPs describe four different 21st century pathways of GHG emissions and atmospheric concentrations, air pollutant emissions and land use (IPCC, 2014). The RCPs include a stringent mitigation scenario (RCP2.6), two intermediate scenarios (RCP4.5 and RCP6.0) and one scenario with very high GHG emissions (RCP8.5). Among different RCPs, RCP2.6 is representative of a scenario that aims to keep global warming likelybelow 2°C above pre-industrial temperatures. Though these emissions scenarios are highly uncertain but they serves as an important tool to analyze how various driving forces may influence future emission outcomes and possible impacts on the biological world. They also assist in the study of the location specific assessment of impacts of climate change and potential adaptation and mitigation measures (Anon, 2015).

Climate change is projected to reduce renewable surface water and groundwater resources in most dry subtropical regions, intensifying competition for water among various sectors, including agriculture (IPCC, 2014). In India, the sustainability of its agricultural production depends on performance of monsoon rainfall every year to a great extent. It is also widely apprehended that under projected severe completion for water, the poor and marginalized farmers may not be able to compete with water extraction by industries and large-scale agriculture and there by impacting overall production of crops. Going by the revelation of various researchers it has been found that though the Indian monsoon rainfall is projected to increase (IPCC, 2013), but in the recent years it has shown frequent weaker performance (Ramesh and Goswami, 2007), erratic distribution and increase in extreme rainfall events during the four months of monsoon (Dash *et al*., 2009) leading to poor yield realization. Climate change has evidently already negatively affected India's hundreds of millions of rice producers. Auffhammer *et al.* (2012) reported that affect of drought and extreme rainfall on rice yield is more prominent in predominantly rainfed areas and drought is having a much greater impact than extreme rainfall. They found that had there been no change in frequency of drought since 1960, India would have gained additional 1.7% of rice yield over its average. A drought during the summer of 2009 was one of the most severe in decades, where India's rice

Table 1: Soil physico-chemical properties of the experimental site

Sl. No.	Parameters	Description			
1	Soil colour	Grey			
2	Soil texture	Sandy clay loam			
3	Drainage	Moderately well			
4.	Soil series	Rowriah			
5	Soil classification	Fine, mixed, hyperthermic family of Humic Endoaquepts			
6	Slope (%)	Nearly level to very gently sloping			
		Soil layers (cm)			
		0-20	20-48	48-62	62-100
7	Clay (%)	24.4	35.4	41.4	35.2
8	Silt (%)	52.7	49.0	35.0	32.4
9	Sand (%)	22.9	15.6	23.6	32.4
10	pH	5.2	5.1	5.1	5.0
11	CEC (Cmol kg^{-1})	6.1	8.4	9.6	7.9
12	Organic C (%)	0.88	0.42	0.32	0.19
13	Soil moisture (%/v)	24.4	25.5	26.8	28.8

production was declined by 14% (Commission for Agricultural Costs and Prices, 2010).

The high rainfall North Eastern (NE) region of India, observes very frequent occurrence of dry spells in recent times, and decline in annual as well as monsoon rainfall may be attributed to rapid climate change (Manoj-Kumar, 2011). A study, based on standardized precipitation index, comprehensively shown changes in overall seasonal proneness to meteorological drying or wetting, and most of the North East India lost their degree of monsoon wetness during 1991-2007 (Saikia *et al.,* 2013). Ravindranath*et al.* (2011) assessed the effects of climate change in the districts of NE India with multiple socio-economic consequences and defined the vulnerability of the districts with respect to agriculture and water availability. He opined that since 80% of the crop area is under rainfed agriculture in the region, present and future climate change and variability potentially affect agriculture production here by virtue of acute soil moisture deficit and lack of irrigation/water harvesting infrastructure. Hence, comprehensive studies on selection of suitable crop/cultivars with multi-stress tolerance ability, crop diversification and intensification are required in the context of present and future scenarios. Under these circumstances, this study was taken up to evaluate the impact of climate change on present and future kharif rice production scenarios in Jorhat, Assam, which is a major rice growing area in the state.

MATERIALS AND METHODS

The rice soils of Assam are alluvial in nature and *kharif* (Sali) is the main rice growing season (June/July to November/December). The State gets more than 60% of the total annual precipitation during four months of monsoon season. Jorhat, the study area (26°44′N latitude, 94°10′E longitude and 91 m above mean sea level), is located in the Upper Brahmaputra Valley (UBV) agro-climatic zone, which receives 1500-2500 mm rainfall annually. The ranges of maximum and minimum temperatures at Jorhat are 23.6-31.7 and 10.0-24.2°C, respectively. On an average, the relative humidity remains above 70% throughout the year.

The experiment had two components: (a) field experiment from 2009-2013 with rice cultivar Mahsuri (normal duration: 150-160 days) for calibration (2009-2011) and validation (2012-2013) of the CERES-Rice module of DSSAT 4.5 and (b) estimation of rice (cv. Mahsuri) yield variability for 2020, 2050 and 2080 at Jorhat, Assam. The field experiments were conducted in randomized block design (RBD), with three replications, at the Instructional cum Research Farm of Assam Agricultural University, Jorhat. The soil physic-chemical status of the experimental site is presented in Table 1. Three transplanting windows were selected for transplanting of rice and they were maintained in the 3rd week of May, 2nd week of June and 1st week of July with near about 15 days interval between each transplanting.

Table 2 : Seasonal change in maximum and minimum temperatures and rainfall in 2020, 2050 and 2080 RCP projections at Jorhat over 2009-2013

Scenarios	Summer	Monsoon	Post monsoon	Winter
Maximum temperature (°C)				
2009-2013 Actual mean	28.8	32.3	27.3	24.5
Mean of all scenarios (2020)	31.6	33.5	28.6	23.5
Absolute change over 2009-2013	2.7	1.2	1.3	-1.0
Mean of all scenarios (2050)	32.0	33.8	28.8	23.9
Absolute change over 2009-2013	3.1	1.5	1.5	-0.7
Mean of all scenarios (2080)	32.9	34.7	29.8	24.9
Absolute change over 2009-2013	4.0	2.4	2.5	0.4
Minimum temperature (°C)				
2009-2013 Actual mean	19.6	25.5	16.2	11.1
Mean of all scenarios (2020)	21.5	26.6	17.4	11.0
Absolute change over 2009-2013	1.9	1.1	1.2	-0.1
Mean of all scenarios (2050)	21.9	26.9	17.7	11.4
Absolute change over 2009-2013	2.3	1.4	1.4	0.2
Mean of all scenarios (2080)	22.9	27.7	18.7	12.6
Absolute change over 2009-2013	3.3	2.2	2.5	1.5
Rainfall (mm)				
2009-2013 Actual mean	537.7	1187.2	106.6	23.5
Mean of all scenarios (2020)	786.5	1416.8	135.8	51.2
Absolute change over 2009-2013	248.8	229.6	29.2	27.7
% change over 2009-2013	46.3	19.3	27.4	118.0
Mean of all scenarios (2050)	883.1	1496.6	137.1	41.7
Absolute change over 2009-2013	345.4	309.4	30.5	18.3
% change over 2009-2013	64.2	26.1	28.6	77.9
Mean of all scenarios (2080)	701.9	1175.2	133.7	57.6
Absolute change over 2009-2013	164.3	-12.1	27.1	34.1
% change over 2009-2013	30.6	-1.0	25.4	145.3

Normal doses of fertilizer recommended for UBV agroclimatic zone were followed.

The genetic coefficients of rice Cv. Mahsuri were generated (2009-2011) using inbuilt 'Genotype Coefficient Calculator' and RMSE and D-stat analysis were done to test the levels of agreement during the calibration runs. Four RCPs (RCP 2.6, 4.5, 6.0 and 8.5) were used, which were generated using Hadley Global Environment Model 2-Earth System (HadGEM2-es) (Collins *et al.*, 2011). RCP projected climatic data on daily maximum and minimum temperature, rainfall and solar radiation for 2020, 2050 and 2080 were collected from CRIDA, Hyderabad. Pattern of change of seasonal maximum and minimum temperatures and rainfall were compared among pre-experiment period (1991-2008), experiment period (2009-2013) and RCP projected data sets for 2020, 2050 and 2080. The simulated yields of different scenarios were compared with observed mean yield of 2009-2013 for their respective transplanting windows.

RESULTS AND DISCUSSION

Pattern of maximum and minimum temperatures and rainfall

Pattern of maximum and minimum temperatures and

Table 3: Calibration (2009-11) and validation (2012-13) results for rice Cv. Mahsuri at Jorhat

Variable	Observed	Simulated	RMSE	D-stat
Calibration (2009-11)				
Anthesis day	122	123	3.3	0.92
Grain yield (kg ha^{-1})	3128	3291	1651.9	0.50
Maturity day	164	150	19.1	0.51
Validation (2012-13)				
D1* (3rd week of May)				
Anthesis day	125	121		
Grain yield (kg ha^{-1})	2569	2337		
Maturity day	152	165		
D2 (2nd week of June)				
Anthesis day	117	119		
Grain yield (kg ha^{-1})	4553	4145		
Maturity day	161	158		
D3 (1st week of July)				
Anthesis day	103	107		
Grain yield (kg ha^{-1})	3134	3417		
Maturity day	135	141		

*D1 (3rd week of May), D2 (2nd week of June) and D3 (1st week of July) are the dates of transplanting

Table 4: Genotype coefficients for rice Cv. Mahsuri (model: CERES-Rice) at Jorhat

Genotype coefficients	Values
P1	763.1
P20	335.1
P2R	273.7
P5	10.9
G1	37.8
G2	0.260
G3	1.0
G4	1.0

rainfall during various seasons in the past, current and future RCP projected scenarios for 2020, 2050 and 2080 are presented in Tables 2 (a,b,c). At Jorhat the average maximum temperature was higher by 0.4°C during summer and monsoon and 1.2°C during winter in 2009-2013 (field experimentation period) over 1991-2007. The maximum and minimum temperatures for different RCP projections were compared with temperature conditions prevailed during the experimentation period. The various RCPs taken together, maximum temperature is likely to go up by 2.7, 1.2 and 1.3°C during summer, monsoon and post monsoon, respectively, and decrease by 1.0°C during winter of 2020 over average temperatures of the same seasons for the period of 2009-2013. By 2050 the magnitude of increase in maximum temperature is likely to be 3.1, 1.5 and 1.5°C during summer, monsoon and post monsoon, respectively, with decrease in winter by 0.7°C. Projections for 2080 suggest a further increase of maximum temperature in all the seasons by 4.0, 2.4, 2.5 and 0.4°C during summer, monsoon, post monsoon and winter, respectively. Like maximum temperature, the minimum temperature has also shown increasing trend at Jorhat. Considering all the RCP projections together, the ranges of increase in minimum temperature are 1.2°C in post monsoon to 1.9°C in summer (2020); 1.4°C in monsoon and post monsoon to 2.3°C in summer (2050) and 1.5°C in winter to 3.3°C in summer (2080) over 2009-2013.

With respect to seasonal rainfall, during 2009-2013, Jorhat experienced 14.6 and 4.3% higher rainfall during summer and monsoon seasons, respectively, where as drastic reduction in post monsoon and winter by 51 and 171.9%, respectively, over average values of 1991-2008. The rainfall for different RCP projections were compared with the rainfall received during the experimentation period. In 2020, 2050 and 2080, Jorhat is likely to receive higher amount of rainfall

Table 5: Projected rice (Cv. Mahsuri) yield variability at Jorhat under different RCP scenarios and dates of sowing over current condition (2009-2013)

Periods	Observed grain yield(kg ha^{-1}) (2009-2013)	%Change in grain yield over 2009-2013				
		RCP2.6	RCP4.5	RCP6.0	RCP8.5	Mean
2020D1*		-14.4	-14.8	-27.5	-27.5	-21.0
2050D1		-14.5	-34.3	-17.1	-35.3	-25.0
2080D1		-9.3	-33.8	-27.0	-23.7	-23.0
Mean	2600	-12.7	-27.6	-23.9	-28.8	-23.3
2020D2		-27.6	-29.5	-36.7	-36.7	-33.0
2050D2		-43.9	-43.5	-44.1	-44.8	-44.0
2080D2		-31.1	-38.9	-35.9	-48.8	-39.0
Mean	4594	-34.2	-37.3	-38.9	-43.4	-38.5
2020D3		-21.1	-26.8	-14.0	-14.0	-19.0
2050D3		-56.6	-58.9	-64.0	-61.9	-60.0
2080D3		-14.9	-5.5	-12.2	4.3	-7.0
Mean	3443	-30.9	-30.4	-30.1	-23.9	-28.8

*D1 (3rd week of May), D2 (2nd week of June) and D3 (1st week of July) are the dates of transplanting

in all the seasons compared to present mean rainfall. The various RCPs taken together, the rainfall will be higher at Jorhat by 46.3, 19.3, 27.4 and 118.0% during summer, monsoon, post monsoon and winter, respectively, in 2020; by 2050, magnitudes will be higher by 64.2, 26.1, 28.6 and 77.9%, respectively in the same order of the seasons. Projections for 2080 suggest a similar trend, but with reduced magnitude of rainfall compared to 2020 and 2050. There by impacting the production scenario, mostly in rainfed regions (Terink *et al.*, 2013).

Calibration and validation of CERES-Rice

The CERES-Rice model calibration (2009-11) and validation (2012-13) results along with the genotype coefficients developed for rice cv. Mahsuri are presented in Table 3and 4. The observed and simulated anthesis and maturity days and grain yield under calibration runs exhibited a very good agreement with acceptable D-stat values, which are above 0.5. During model validation, percent difference between observed and simulated grain yields were 9.0, 8.9 and 9.0%, for dates of transplanting *viz.* D1 (3rd week of May), D2 (2nd week of June) and D3 (1st week of July), respectively. Similarly, days for Anthesis and maturity also showed close agreement between observed and predicted values. The calibration and validation results suggest suitability of the model for further yield projections under futuristic scenarios.

Simulated rice yield variability under future RCP projections

The observed mean grain yield for first (D1), second (D2) and third (D3) dates of transplanting were 2600, 4594 and 3443 kg ha^{-1}, respectively, during 2009-2013 and rice yield under various RCP projections were compared with the present yield to estimate yield variability in future (Table 5). The results reveal that there is large negative deviation of projected rice yield in all scenarios compared to the mean observed grain yield. Under various scenarios, percent deviations in projected yield ranged from -12.7 (RCP 2.6) to -28.8% (RCP 8.5); -34.2 (RCP 2.6) to -43.4% (RCP 8.5) and -23.9 (RCP 8.5) to -30.9% (RCP 2.5) in first, second and third dates of transplanting, respectively, over observed mean yield of 2009-2013. Considering different transplanting dates, the maximum mean yield reduction is likely in second transplanting date (-38.5%), followed by third (-28.8%) and first one (-23.3%) under various RCP projections at Jorhat. There is likely increase in maximum and minimum temperature at Jorhat during the rice growing season (Monsoon and post monsoon). The projected magnitude of increase in maximum temperature is ranged from 1.2 (2020) to 2.4 (2080)

°C, during monsoon and 1.3 (2020) to 2.5 (2080) °C, during post monsoon seasons. The minimum temperature has also sown similar trend of increase. Though there is likely increase in seasonal rainfall in 2020 and 2050, but by 2080 the rainfall is likely to decrease compared to present mean rainfall. These factors, associated with temperature and rainfall, may definitely be attributedfor reduction in projected rice grain yield under various scenarios.

CONCLUSION

High magnitude in both maximum and minimum temperatures under all the RCPs at Jorhat suggests increasing levels of water and heat stresses during crop growth period. High minimum temperature during the reproductive stages may lead to minimization of economic yield. The long duration cultivars of rice which use to flower and ripen during the months of October and November are likely to face terminal season drought if not planted early. As summer has seen increase in rainfall at Jorhat, it may be wise to advance the sowing/transplanting of long duration rice from normal June-July to May-June. But considering the RCP projections, the rainfall at Jorhat is likely to increase by 2020, 2050 and 2080 in all the seasons. Excessive rain and flooding of matured paddy fields may cause further loss of yield in future scenarios. The above analysis suggests that the second date of transplanting (2nd week of June) is most vulnerable to possible climate change followed by third date of transplanting (1st week of July). As yield reduction is lowest in the first date of transplanting (3rd week of May), with this present cultivar, it will be appropriate to go for early season (3rd week of May) sowing/transplanting of rice at Jorhat to minimize climate induced yield loss considering the future scenarios.

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