Original Research Article

Assessing impact of projected climate change on *Sali* rice in a representative district of Upper Brahmaputra Valley Zone of Assam

ABSRACT

Three years of field trial along with DSSAT v4.6 CERES-Rice model-based simulation experiment was carried out to study the impact of climate change on Sali rice yield under various Representative Concentration Pathways (RCPs) in the agro-climatic conditions of Jorhat, Assam. Field experiments were conducted during *kharif*, 2017, 2018 and 2019 at the Instructional-Cum-Research (ICR) farm of Assam Agricultural University, Jorhat with three varieties *viz.*, Mahsuri (150 days), Swarna Sub-1 (140-145 days) and TTB-404 (140-145 days); transplanted under three different micro-climatic regimes created by manipulating date of transplanting *i.e.*, 26th June (early), 11th July (mid) and 26th July (late) under split plot experimental design with four replications. The validated model showed a good agreement for estimation of days required to attain different phenological events with RMSE value 3.5, 2.9 and 2.9 days for Swarna sub-1; 2.4, 3.3 and 4.1 days for Mahsuri and 3.7, 2.6 and 2.4 days for TTB-404, respectively for panicle initiation, anthesis and physiological maturity. The overall d-stat value varied within 0.53 to 0.85 for phenology and 0.68 to 0.79 for grain yield. The ensemble weather data under four RCPs revealed an increase in mean maximum (0.3 to 3.0°C) and minimum (0.8 to 3.5°C) temperature along with rainfall (11.8 to 43.4%) during the crop growing period compared to experimentation period (*i.e*. 2017-19) in three projected years. The grain yield of *Sali* rice showed positive deviation in all four RCPs and projected years under successive transplanting dates. The overall results reveal an increase in mean temperature up to 3°C during the crop growing period has no substantial adverse impact on grain yield of *Sali* rice under the agro-climatic condition of Jorhat, Assam.

Keywords:Calibration, Validation, DSSAT, GCM, MarkSim, RCPs

1. INTRODUCTION

The climate change is a serious global environmental concern, primarily caused by building up of Green House Gases (GHGs) concentration, aerosols and other pollutants in the atmosphere. Intergovernmental Panel on Climate Change (IPCC) report stated that, anthropogenic activities induced global warming has been estimated to raise global mean surface temperature by approximately 1.0°C (with range 0.8 to 1.2°C) above pre-industrial levels and if it continues to increase at the current rate, it is predicted to reach 1.5°C between 2030 and 2052 [10]. Likewise, atmospheric Carbon dioxide concentration in 1750 has increased from 280 to 412 µmol/mol in 2019 [18] and is expected to escalate up to 540-970 µmol/mol by the end of the 21st century [11]. In view of the radiative forcing levels over the globe, IPCC has developed climate data sets for the past, present and the future representing different radiative forcing scenarios at global scale [24]. Climate projections in AR5 of the IPCC are made by using the newly developed Representative Concentration

Pathways (RCPs) under the Coupled Model Inter-comparison Project 5 (CMIP5) [4]. These scenarios include a stringent mitigation scenario (RCP2.6), two intermediate scenarios (RCP4.5 and RCP6.0) and one scenario representing very high Green House Gas emission (RCP8.5). Global Climate Models (GCMs) better known as IPCC climate models projected future climate change based on these emission pathways. MarkSim Decision Support System for Agrotechnology Transfer (DSSAT) Weather File Generator, a web tool not only downscales but also generates daily weather from GCMs [13]. Outputs from GCMs are available in this public domain, provides daily weather data for current as well as future climatology in DSSAT friendly format. Although, there is a considerable uncertainty exists about the spatial and temporal pattern in climatic variables due to enhanced radiative forcing, their impact on crop have been studied in different parts of the world using DSSAT CSM by different researchers [19, 20].

Rice (*Oryza sativa* L) is the principal crop, growing over 25.03 lakh ha area with a production of 51.93 lakh ton and accounts for 92.22 per cent of total food production of the state of Assam [3]. Assam is a rice surplus state with an appreciable productivity of 2090 kg/ha. Nevertheless, the state would require 130 lakh tons of rice to feed its escalating population as well as to maintain self-sufficiency and fulfill demands by 2050. The climate change studies have predicted as much as 10-40% loss in food grain production in India which might occur by 2080-2100 due to increase in temperature alone [1]. However, impact of climate change on rice production is location specific and with the increase in temperature, grain yields were less affected in western India, moderately affected in north India and severely affected in southern India; whereas yield projection was less affected and reveals an increasing trend over eastern India [2]. Within eastern India, considerable differences in yield predictions among different locations were reflected from the finding of Krishnan *et al.* [15], noted an increasing trend for rice yield in Jorhat but declining trend in Cuttack and Bhubaneshwar with an increase in temperature at current CO_2 level. Similarly, impact of temperature variability on yield projections using simulation model showed that grain yield will increase in a decreasing rate during 2020, 2050 and later during 2080s considerably for future scenarios given by IPCC RCP 4.5 and 8.5 [8]. The potential effect of climate change on rice crop has been critically analyzed by several researchers and a large effect on food security goals of the nation was foresighted by the end of 21st Century [7-8].

Rice is cultivated mainly as rainfed kharif crop over different agro-climatic regions of India.

Consequently, any aberration in rainfall during this monsoon season considerably affects the grain yield at harvest. Since more than 80 percent crop area is under rainfed agriculture in Assam; climate change and climate variability may possess very high impact on the agricultural production system by virtue of acute soil moisture deficit, lack of other irrigation management and soil fertility management practices [21]. Hence, the question of uncertainties regarding rice production under climate change scenario needs to be answered as per the latest warming projections. Therefore, a comprehensive study on performance of promising rice cultivars under different climate change scenarios is very much important for undertaking several need-based measures for improvement in crop yield. Keeping in view of the importance of above facts, the present study was carried out to evaluate impact of climate change on phenology and grain yield of *Sali* rice under different RCP scenarios employing DSSAT Crop Simulation Modelling techniques.

2. MATERIALS AND METHODS

The optimum *Sali* rice cultivation season in the state of Assam lies within June/July to November/December coinciding the monsoon season. The state receives more than 60% of the total annual precipitation during this monsoon period, thereby promotes cultivation of semi aquatic hydrophytes like paddy over this region under rainfed situation. The area under investigation viz., Jorhat (26°47'N latitude, 94°12'E longitude and 87m above MSL) was considered as the representative region of Upper Brahmaputra Valley Zone (UBVZ) of Assam which receives a mean annual rainfall amount of 1870 mm (1989-2018) with CV 37%, of which south-west monsoon contributes an average amount of 1187 mm (63 percent of annual amount) with CV 54%. Monthly mean morning relative humidity of the station always remains above 85%, whereas monthly mean afternoon relative humidity varies from 61 to 76% throughout the year. The monthly average maximum and minimum temperatures varies from 22.6 to 32.7°C and 9.7 to 25.2°C, respectively.

A dynamic crop simulation module “CERES-Rice”, which is embedded in the DSSAT v4.6 software [9] was used in the present study to simulate growth, development and yield of rice crop. In order to generate minimum dataset pertaining to different input files of DSSAT CSM, field experiments were conducted consecutively for three years at the Instructional-Cum-Research (ICR) farm of Assam Agricultural University, Jorhat. The experiment was conducted in clay loam soil with 25% clay, 53% silt and 22% sand with pH, CEC and organic carbon value ranging from 5.0 to 5.2, 6.1-7.0 Cmol/kg and 0.60 to 0.80 percent, respectively. The experiment consists of three different micro-climatic regimes created by manipulating date of transplanting i.e., D1 as early (26th June), D2 as mid (11th July) and D3 as late (26th July) situation with three varieties viz., Mahsuri (140-150 days), Swarna sub-1 (150-155 days) and TTB-404 (140-145 days) cultivated in field following split plot design with four replications. For transplanting in the main field, thirty days old seedlings of all three cultivars were used. The recommended fertilizer doses of 60:20:40 kg/ha of N: P2O5: K2O were applied as per package of practices for Semi dwarf medium (120-140 days) and long duration (150 days) rice cultivars. In case of tall long duration cultivars (150 days), recommended fertilizer doses of N: P2O5: K2O in the ratio of 20:10:10 kg/ha were applied. The daily meteorological data was recorded in the agrometeorological observatory situated adjacent to the experimental plot and utilized for the present study. The whole objective of the experiment was grouped into two components- field experiment from 2017 to 2019 with three cultivars for initial calibration and validation of CERES-Rice module of DSSAT v4.6 followed by estimation of yield variability of the selected cultivars under projected climate change scenario during 2025, 2050 and 2080 for Jorhat condition. The performance of the model was checked based upon the number of days required to attain phenological events viz., panicle initiation, anthesis and physiological maturity along with the grain yield at harvest. Eight genetic coefficients that influence the occurrence of growth, development and yield in CERES-rice model for the selected varieties were derived iteratively following previous workers [6-7]. The coefficients were adjusted until there was a close match between observed and simulated days to panicle initiation, anthesis, physiological maturity and grain yield (Table 3).

To fulfill the second objective, the MarkSim DSSAT weather file generator web tool was used to acquire downscaled future climate data on a daily basis [13, 19]. MarkSim is a third-order Markov Chain based weather simulator which predicts the occurrence of a rainy day [14]. Because of its continuous development over the past 20 years the model was tested as a globally valid model [24]. The daily weather data (Solar radiation, rainfall, maximum and minimum temperatures) for the period of 2010-2080 were generated from MarkSim DSSAT weather generator for Jorhat region following the procedure mentioned by Jones and Thornton [13]. The data of 30 replications for 17 GCMs, with a spatial resolution of 26°47'N latitude and 94°12'E longitude was selected. The generated weather data under four RCP scenarios from 2010 to 2019 period; were chosen as a baseline weather scenario generated by individual GCMs and compared with the observed weather data for the same period in order to assess the performance of individual GCMs for Jorhat location. Similarly, mean of observed weather were calculated for experimentation period (2017 to 2019) and were chosen as baseline for relative assessment of climate change impact on rice crop during future years (2025, 2050 and 2080) under four different concentration pathways.

3. RESULTS AND DISCUSSION

3.1 Evaluation of performance of MarkSim DSSAT weather generator

The performance of 17 individual models of MarkSim DSSAT weather generator were tested based on d-Stat and RMSE value by comparing model generated monthly mean maximum and mean minimum temperature and monthly cumulative rainfall with the observed data over the period of 2010-2019 exclusively for four different RCPs (Fig. 1). Relative to other scenarios RCP 6.0 found with least d-Stat value of 0.91 with high RMSE value 2.04°C in MIROC-ESM-CHEM model. Unlike maximum temperature, no significant variation in d-Stat and RMSE values were observed in a particular model tested for minimum temperature prediction under four different RCPs. In case of rainfall prediction, higher value of RMSE is mainly attributed to variation in the temporal as well as spatial distribution of rainfall within the day, month and the season over this location. Similarly, higher RMSE (6.67 to 7.65 MJ/ m2 /month) and very poor d-Stat (0.31 to 0.39) value were observed for solar radiation. The unevenness among observed and model simulated solar radiation values were mainly attributed to transformation of bright sunshine hours into solar radiation using Angstrom equation rather than actual measurement of the parameter. Analogous to temperature; no substantial results were obtained in support of unsuitability of a particular model for rainfall and solar radiation projection in four different scenarios over the location under investigation. Henceforth, the ensemble product of 17 GCMs were utilized for studying the future weather scenario under four RCPs during three different years viz., 2025, 2050 and 2080 for assessing its impact on phenology and grain yield of three rice cultivars. Chaturvedi et. al. [4] validated the new CMIP5-based climate projections (i.e., temperature and rainfall) for India by comparing CMIP5-based model simulated climate for the period of 1971-2000 with that of Climate Research Unit (CRU) based observed climate data over the same period using Taylor diagram. The study revealed that model ensemble performs better than any of the individual model.

Fig. 1 (a-d). Individual performance of GCMs based on comparison between monthly value of observed and generated weather data of Jorhat station (2010-2019)

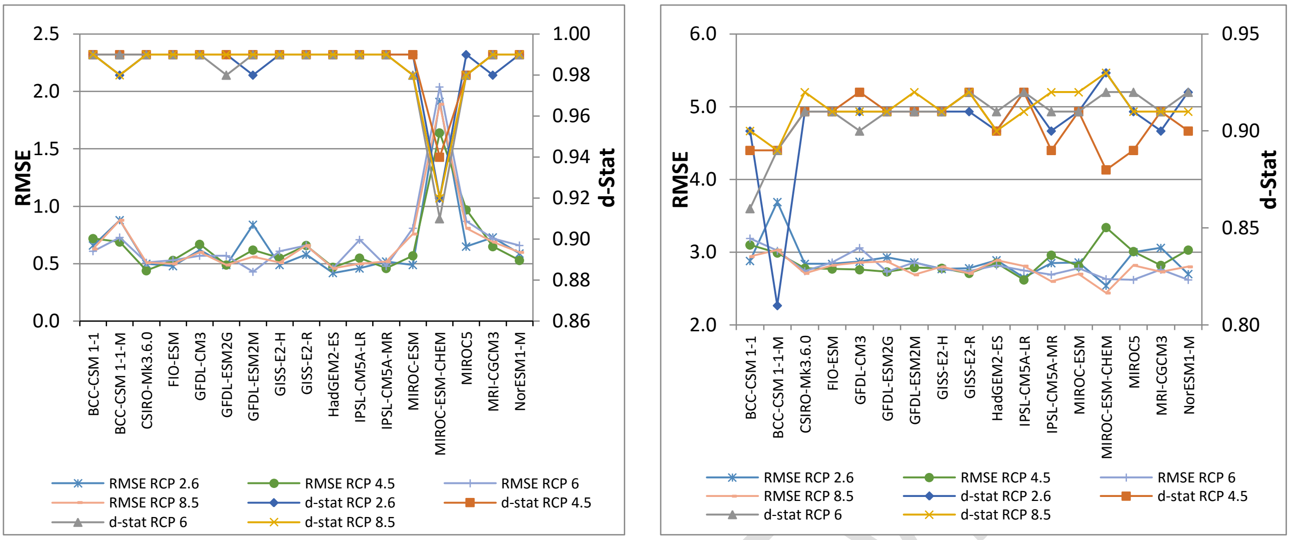

Fig. 1(a): Monthly mean Maximum temperature (^{0}C month^{-1})

Fig. 1(b): Monthly mean Minimum temperature (^{0}C month^{-1})

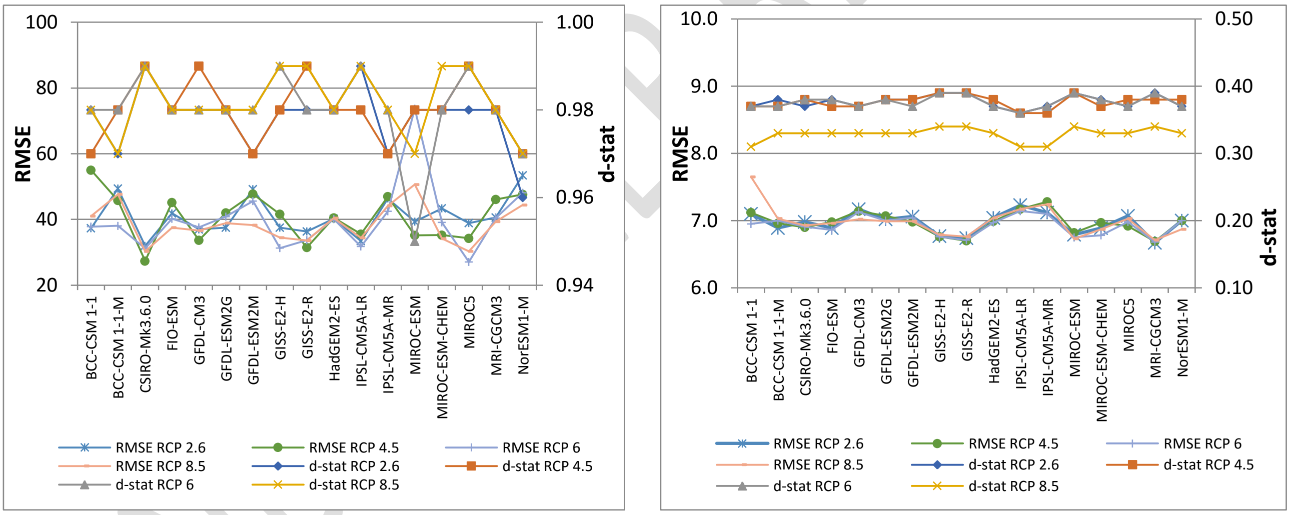

Fig. 1(c): Monthly accumulated Rainfall (mm month^{-1})

Fig. 1(d): Monthly accumulated Solar radiation (MJ m^{-2} month^{-1})

3.2 Pattern of change in temperature and rainfall over experimentation period

In Jorhat, the mean maximum temperature during crop growing period was higher by 0.50°C during field experimentation period (2017-19) over normal period (1986-2015) (Table 1). The degree of increase in maximum temperature is likely to be 0.3, 0.3, 0.1 and 0.3°C during 2025 and 0.7, 1.0, 0.7 and 1.4°C during 2050 for RCP 2.6, 4.5, 6.0 and 8.5 scenarios, respectively during crop growing period. Projections for 2080 suggest a further increase of maximum temperature in all scenarios by 0.6, 1.5, 1.6 and 3.0°C for RCP 2.6, 4.5, 6.0 and 8.5, respectively. Similarly, the minimum temperature has also shown a likely increasing trend at Jorhat. Considering change in projections together, the likely increase in minimum temperature varied from 0.8°C in RCP 6.0 to 1.1°C in RCP 8.5 scenario for 2025; 1.3°C in RCP 2.6 to 2.1°C in RCP 8.5 scenario for 2050 and 1.2°C in RCP 2.6 to 3.5°C in RCP 8.5 scenario for 2080 over 2017-19 (Table 1).

Rainfall under different projections in future years were compared with the rainfall received during the experimentation period especially confined to crop growing period only (Table 1). Rainfall during the crop growing period may be higher at Jorhat by 37.2, 36.9, 38.3, and 36.8% in 2025; 36.0, 43.4, 37.2 and 34.1% in 2050 and 37.6, 41.0, 34.4 and 11.8% in 2080 for RCP 2.6, 4.5, 6.0, 8.5, respectively relative to experimentation period. The end part of the 21st century i.e., 2080 highlight a relatively less increase in percent change in rainfall amount over the experimentation period. Thus, the increase in absolute value of maximum and minimum temperature beyond 3°C with drop in percent change in rainfall (from 41.0% in RCP 4.5 to 11.8% in RCP 8.5) may leads to higher atmospheric vapour pressure deficit causing higher rate of evapotranspiration demand from crop field. The result is in corroboration with the findings of Chaturvedi *et al.* [4] which represents 2.9 to 3.3°C increase in mean temperature during projected years (2070-2099) over the period of 1861-1900 for RCP 4.5 and RCP 6.0, respectively. It was also evident that by 2099 CMIP5 model's projects rise in all-India ensemble mean annual precipitation by 7%, 9.4%, 9.4% and 18.7% for RCP2.6, RCP4.5, RCP6.0 and RCP8.5, respectively.

Table 1: Projected variation in maximum and minimum temperature and rainfall under different RCPs over baseline period (2017-2019)

Scenarios	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Maximum temperature (°C)				
Normal value (1986-2015)		30.9		
Actual mean during expt. Period (2017-19)		31.4 (0.5)		

Mean of scenario (2025)	31.7 (0.3)	31.7 (0.3)	31.5 (0.1)	31.7 (0.3)
Mean of scenario (2050)	32.1 (0.7)	32.4 (1.0)	32.1 (0.7)	32.8 (1.4)
Mean of scenario (2080)	32.0 (0.6)	32.9 (1.5)	33.0 (1.6)	34.4 (3.0)
Minimum temperature (°C)				
Normal value (1986-2015)	23.1			
Actual mean during expt. Period (2017-19)	23.0 (-0.1)			
Mean of scenario (2025)	24.0 (1.0)	24.0 (1.0)	23.8 (0.8)	24.1 (1.1)
Mean of scenario (2050)	24.3 (1.3)	24.6 (1.6)	24.5 (1.5)	25.1 (2.1)
Mean of scenario (2080)	24.2 (1.2)	25.2 (2.2)	25.2 (2.2)	26.5 (3.5)
Rainfall (mm)				
Normal value (1986-2015)	1180.0			
Actual mean during expt. Period (2017-19)	1425.0 (20.7)			
Mean of scenario (2025)	1955.5 (37.2)	1950.2 (36.9)	1970.5 (38.3)	1949.6 (36.8)
Mean of scenario (2050)	1937.7 (36.0)	2043.2 (43.4)	1954.5 (37.2)	1911.4 (34.1)
Mean of scenario (2080)	1960.3 (37.6)	2009.9 (41.0)	1915.6 (34.4)	1592.7 (11.8)

** Figures in the parenthesis represent absolute change for temperature and per cent change for rainfall over experiment period*

3.3 Calibration and validation of CERES-Rice

The observed and simulated days to panicle initiation, anthesis and days to physiological maturity along with grain yield were found in good agreement with RMSE value 3.4, 1.2 and 2.3 days and 123 kg/ha, respectively with d-stat value in the range of 0.61 to 0.96 for Swarna sub-1 cultivar (Fig. 2. (a-l)). Similarly, observed and simulated days to panicle initiation, anthesis and days to maturity as well as grain yield were found in good agreement with RMSE 3.5, 2.1 and 3.1 days and 177 kg/ha for Mahsuri; 4.5, 1.3 and 1.7 days and 159 kg/ha, respectively for TTB-404 with d-stat value in the range of 0.55 to 0.94, respectively. In case of validation, the percent deviation of simulated yield from observed yield varied within 10% with an RMSE and d-stat value of 111 kg/ha and 0.79 for Mahsuri, 158 kg/ha and 0.76 for Swarna Sub-1 and 112 kg/ha and 0.68 for TTB-404, respectively (Table 2). Irrespective of cultivar, percent variation among simulated and observed yield was relatively low (less than 1%) when crop was transplanted on 11 July, 2019; whereas it was in between 1 to 3% and 4 to 6.5% for crop transplanted under earlier (26 June, 2019) and delayed (26 July, 2019) situations, respectively. The overall results of the model are satisfactory and the standardized genetic coefficients of three cultivars are presented in the Table 3. Low RMSE and d-stat > 0.5 was observed in both calibration and validation process; henceforth eight genetic coefficients were standardized for three different varieties [6, 8, 17].

Table 2. Results of validation of CERES-Rice model for rice cultivar Mahsuri, Swarna Sub-1 and TTB-404 for *kharif*, 2019

Date of transplanting	Days to Panicle initiation		Days to anthesis		Days to Physiological Maturity		Grain yield (kg ha^{-1})	
	Observed	Simulated	Observed	Simulated	Observed	Simulated	Observed	Simulated
	Mahsuri							
26 June, 2019	59	59	91	95	122	123	3972	3870
11 July, 2019	57	56	89	93	118	123	3828	3812
26 July, 2019	54	50	86	87	116	121	3546	3708
RMSE	2.4		3.3		4.1		111	
d-stat	0.85		0.72		0.53		0.79	
	Swarna Sub-1							
26 June, 2019	62	62	95	99	126	127	4091	4210
11 July, 2019	60	59	93	96	123	127	3974	4011
26 July, 2019	59	53	90	91	121	124	3670	3914
RMSE	3.5		2.9		2.9		158	
d-stat	0.58		0.76		0.60		0.76	
	TTB-404							
26 June, 2019	59	58	90	94	120	122	4006	3854
11 July, 2019	57	55	89	91	119	122	3928	3868
26 July, 2019	55	49	86	86	117	119	3664	3768
RMSE	3.7		2.6		2.38		112	
d-stat	0.64		0.78		0.57		0.68	

Table 3. Calibrated and validated genetic coefficients of *Sali* rice cultivars *viz*., Mahsuri, Swarna Sub-1 and TTB-404 using three years of experiment data

Genetic coefficient	Description	calibrated genetic coefficient		
		Mahsuri	Swarna Sub-1	TTB-404
P1	Juvenile phase coefficient (°C)	712.1	677.2	511.2
P2R	Photoperiodism coefficient (°C)	259.7	293.1	277.3
P5	Grain filling duration coefficient (°C)	315.0	292.9	318.9
P2O	Critical photoperiod (hr)	11.75	11.66	11.35
G1	Potential spikelet number per panicle	31.33	31.35	31.66
G2	Single grain weight (g)	0.0205	0.0205	0.0200
G3	Tillering coefficients.	1.00	1.00	1.0
G4	Temperature tolerance coefficient	1.00	1.00	1.0

Fig. 2 (a-l). CERES-Rice Model performance for simulating phenological events and grain yield for rice cultivar Mahsuri, Swarna Sub-1 and TTB-404 grown during *kharif* 2017 and 2018.

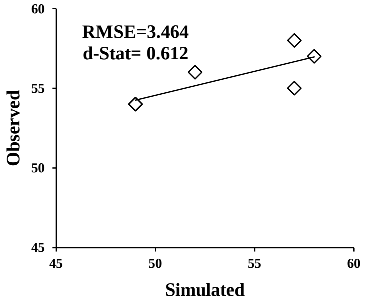

Fig. 2(a): Observed and simulated PI stage of Mahsuri

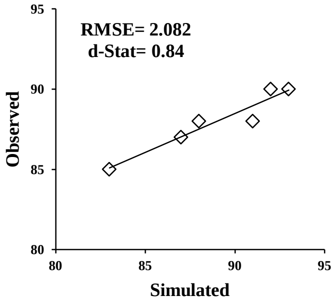

Fig. 2(b): Observed and simulated anthesis stage of Mahsuri

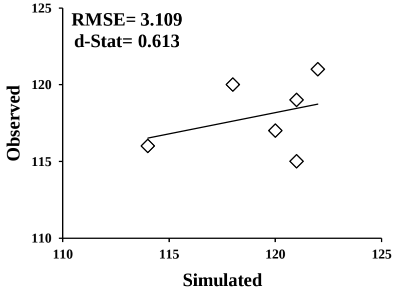

Fig. 2(c): Observed and simulated Maturity stage of Mahsuri

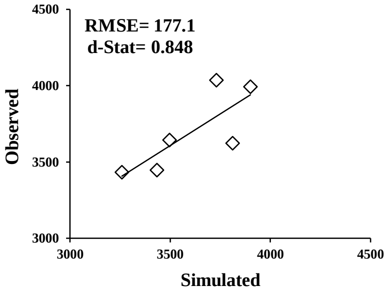

Fig. 2(d): Observed and simulated Grain yield of Mahsuri

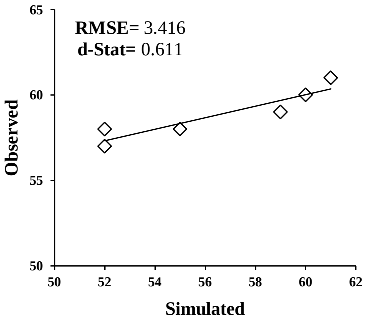

Fig. 2(e): Observed and simulated PI stage of Swarna Sub-1

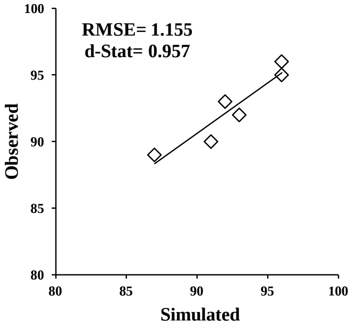

Fig. 2(f): Observed and simulated anthesis stage of Swarna Sub-1

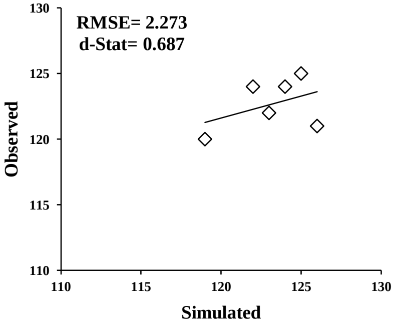

Fig. 2(g): Observed and simulated Maturity stage of Swarna Sub-1

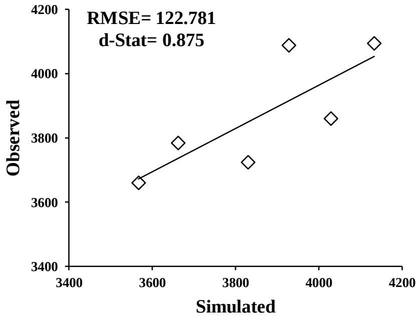

Fig. 2(h): Observed and simulated Grain yield of Swarna Sub-1

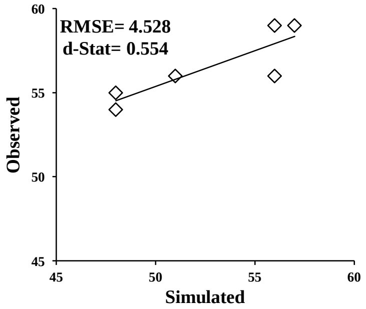

Fig. 2(i): Observed and

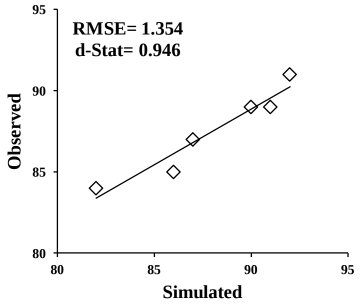

Fig. 2(j): Observed and

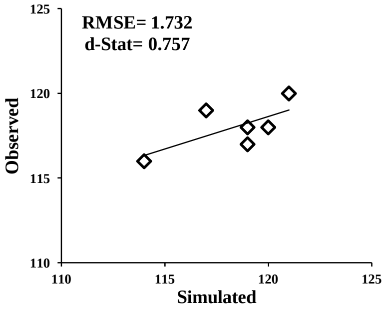

Fig. 2(k): Observed and

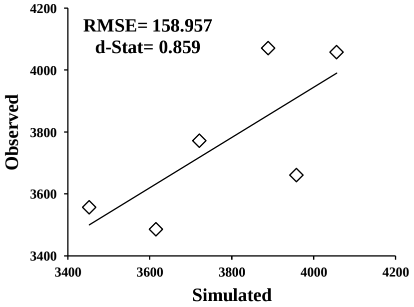

Fig. 2(l): Observed and simulated

simulated PI stage of TTB-404

simulated anthesis stage of TTB-404

simulated Maturity stage of TTB-404

Grain yield of TTB-404

3.4 Impact of Climate change on rice phenology

Overall, average number of days required to complete entire crop growing period would be decreased by 3 to 4 days, 1 to 3 days and 1 to 5 days when transplanted on 26th June, 11th July and 26th July, respectively during early part of the century. Similar type of decrease in mean number of days required to complete vegetative and ripening phases of the crop were observed during mid (2050) and end (2080) part of the century. Irrespective of varieties; analogous with vegetative phase, reduction in mean number of days required to complete ripening phase would vary within 4 to 6 days, 3 to 4 days and 2 to 5 days during mid and end part of the century when transplanted under D1, D2 and D3, respectively. Relative to the experimentation period, mean total crop duration was observed to be decreased by 5 to 6 days, 3 to 6 days and 5 to 7 days during mid-century and it decreased by 7 to 8 days, 5 to 8 days and 7 to 10 days during end-century when transplanted under D1, D2 and D3, respectively. Although deviations in mean duration taken among different phenophases were ambiguous among varieties; overall reduction in mean total crop duration was observed in all three cultivars during the projected years under different RCPs with delay in transplanting dates. Decrease in mean total crop duration was observed relatively higher in Swarna Sub-1 and TTB-404 (4 to 10 days) and least in Mahsuri (1 to 7 days) when transplanting was delayed (Table 4). Not taking into consideration of varieties; mean maximum and minimum temperature would be relatively higher during entire crop growing period under all four RCPs and varied from 26.8 to 40.1°C and 19.1 to 29.8°C (in D1); 26.4 to 39.7°C and 21.5 to 37.3°C (in D2) and 21.5 to 37.3°C and 15.3 to 29.6°C (in D3), respectively during the year 2025. The magnitude of variation in temperature enhances with gradual progress in the year i.e., from 2050 to 2080 due to increase in the radiative forcing effect (Table 1). Increase in CO_2 and other GHGs concentration became an anticipated climate change forcing in the atmosphere, which likely leads to an increase in temperature causing accumulation of required phase specific thermal unit within a shorter period. Thus, relatively a smaller number of days would be required to complete entire crop growing period in all three cultivars. Similar types of findings associated to decrease in total crop duration of rice by 3-5 days under elevated CO_2 and temperature condition in sub-tropical region of Kharagpur, India were also reported by Satapathy *et al.* [23].

Table 4. Comparison between observed and projected mean numbers of days required to attain different phenological events of rice (irrespective of four RCP scenarios) for Jorhat condition during 2025, 2050 and 2080

Crop phenophases	Mahsuri				Swarna sub-1				TTB-404			
	2017-19	2025	2050	2080	2017-19	2025	2050	2080	2017-19	2025	2050	2080
26th June (D1)												
Vegetative (T-PI)	58	57 (-1)	57 (-1)	56 (-2)	61	60 (-1)	60 (-1)	59 (-2)	61	56 (-5)	56 (-5)	55 (-6)
Reproductive (PI-Anthesis)	32	34 (+2)	34 (+2)	34 (+2)	34	35 (+1)	35 (+1)	34 (0)	29	34 (+5)	34 (+5)	33 (+4)
Ripening (Anthesis-PM)	31	27 (-4)	25 (-6)	25 (-6)	30	26 (-4)	25 (-5)	24 (-6)	30	26 (-4)	26 (-4)	25 (-5)
Total (DAT)	121	119 (-3)	116 (-5)	114 (-7)	125	121 (-4)	119 (-6)	117 (-8)	120	117 (-4)	115 (-5)	113 (-7)
11th July (D2)												
Vegetative (T-PI)	56	55 (-1)	54 (-2)	54 (-2)	59	58 (-1)	57 (-2)	56 (-3)	59	54 (-5)	54 (-5)	53 (-6)
Reproductive (PI-Anthesis)	32	34 (+2)	34 (+2)	33 (+1)	34	35 (+1)	34 (0)	33 (-1)	29	34 (+5)	34 (+5)	33 (+4)
Ripening (Anthesis-PM)	30	28 (-2)	27 (-3)	26 (-4)	30	27 (-3)	27 (-3)	26 (-4)	30	28 (-2)	27 (-3)	26 (-4)
Total (DAT)	118	117 (-1)	115 (-3)	113 (-5)	123	120 (-3)	117 (-6)	115 (-8)	118	116 (-2)	114 (-4)	112 (-6)
26th July (D3)												
Vegetative (T-PI)	54	51 (-3)	50 (-4)	49 (-5)	58	53 (-5)	53 (-5)	52 (-6)	58	50 (-8)	49 (-9)	48 (-10)
Reproductive (PI-Anthesis)	32	34 (+2)	33 (+1)	33 (+1)	32	35 (+3)	34 (+2)	33 (+1)	27	34 (+7)	33 (+6)	32 (+5)
Ripening (Anthesis-PM)	30	30 (0)	28 (-2)	27 (-3)	31	28 (-4)	27 (-4)	26 (-5)	32	29 (-4)	28 (-4)	27 (-5)
Total (DAT)	116	115 (-1)	111 (-5)	109 (-7)	121	116 (-5)	114 (-7)	111 (-10)	117	113 (-5)	110 (-7)	107 (-10)

** Where, T: Transplanting; PI: Panicle Initiation, PM: Physiological Maturity and DAT: Days after Transplanting*
*** Figures in the parenthesis represents duration between two successive stages*

3.5 Impact of Climate change on rice yield

Irrespective of the RCPs, the mean percent change in projected grain yield compared to mean observed yield of Mahsuri during early (2025) and mid-part (2050) of the century varied from 9.4 to 11.5 and 8.1 to 9.2 percent, respectively (Table 5) and is expected to be declining under RCP8.5. Similar types of observations were also reported for TTB-404 cultivar. The mean projected grain yield of TTB-404 varied from 10.8 to 12.6%, 7.6 to 11.1% and 4.6 to 8.3% under early, mid and later part of the century under different climate change scenarios (Table 7). The mean percent change in yield of Swarna Sub-1 also noted to increase substantially over experimentation period under different climate change scenarios and varied from 8.4 to 13.6%, 6.5 to 11.7% and 5.6 to 6.3% under successive transplanting dates during 2025, 2050 and 2080s, respectively (Table 6). However, grain yield was predicted to be less (-10%) under RCP 8.5 during 2080 when transplanted earlier (D1) while further increase in yield was observed when transplanting was delayed up to 26th July. The optimum temperature for the normal development of rice ranges from 27 to 32°C [25] with threshold temperature of 33.7 and 35.0°C during anthesis and flowering in rice, respectively [12, 22]. The reduction in grain yield during 2080s may be attributed to an increase in mean maximum and minimum temperature by 3.50°C and 3.87°C, respectively and also the enhanced CO_2 levels in the atmosphere which aggravate the spikelet sterility possibly because of reduced transpirational cooling. A similar type of statement was also reported by Matsui *et al.* [16]. However, the effect of high temperature on spikelet sterility is difficult to model, as its effect seems to be limited only to time of flowering, which takes place during the morning hours.

Overall, the yield projections of three rice cultivars showed that grain yield will increase subsequently in a decreasing rate during 2025, 2050 and 2080s with delay in transplanting for Jorhat region of Assam. The results also revealed that the crop yield would increases with rising temperature and rainfall regimes as depicted under different climate change scenarios during the projected years; however, intensification beyond the optimal range acts negatively towards crop phenology and grain yield. Das *et al.* [5] also reported similar findings where rise of CO_2 concentration up to 600 ppm and temperature up to 2°C have no substantial negative influence on growth and yield of rice crop under the agro-climatic condition of Jorhat. In similar way, Halder *et al.* [8] studied the effect of temperature and CO_2 on productivity of rice under sub-humid and sub-tropical condition of Eastern India using CERES-Rice model. The study revealed that rising temperature has negative effect on growth and development phases of crop and positive effect on grain yield.

Table 5. Projected rice (*cv*. Mahsuri) yield variability in Jorhat under different RCP scenarios and dates of transplanting over observed grain yield

Periods	**Mean Observed grain yield (kg/ha) (2017-19)**	**%Change in projected yield over mean observed yield**				
		RCP2.6	**RCP4.5**	**RCP6.0**	**RCP8.5**	**Mean**
2025D1	3999.7	9.3	8.4	12.76	9.3	9.9
2050D1		10.8	7.7	9.91	8.4	9.2
2080D1		10.6	5.0	5.71	2.4	5.9
2025D2	3697.7	9.1	8.2	11.12	9.1	9.4
2050D2		9.1	10.2	10.48	5.4	8.8
2080D2		9.9	3.3	2.50	2.0	4.4
2025D3	3474.7	11.8	11.3	11.09	11.8	11.5
2050D3		8.7	7.8	8.53	7.5	8.1
2080D3		8.3	6.6	6.97	7.5	7.3

(Where, D1: 26th June, D2: 11th July and D3: 26th July)

Table 6. Projected rice (*cv*. Swarna sub-1) yield variability in Jorhat under different RCP scenarios and dates of transplanting over observed grain yield

Periods	Mean Observed grain yield (kg/ha) (2017-19)	%Change in projected yield over mean observed yield				
		RCP2.6	RCP4.5	RCP6.0	RCP8.5	Mean
2025D1	4091.0	13.1	12.2	13.42	15.8	13.6
2050D1		13.6	10.3	12.66	10.3	11.7
2080D1		13.3	10.2	9.02	-10.0	5.6
2025D2	3872.7	12.6	11.7	8.61	12.6	11.3
2050D2		8.0	8.6	7.11	6.6	7.6
2080D2		7.7	7.0	5.61	4.9	6.3
2025D3	3684.7	6.7	6.2	14.47	6.1	8.4
2050D3		9.9	5.4	6.63	3.9	6.5
2080D3		9.2	3.1	4.70	7.3	6.1

(Where, D1: 26th June, D2: 11th July and D3: 26th July)

Table 7. Projected rice (*cv.* TTB-404) yield variability in Jorhat under different RCP scenarios and dates of transplanting over observed yield

Periods	Mean Observed grain yield (kg/ha) (2017-19)	%Change in projected yield over mean observed yield				
		RCP2.6	RCP4.5	RCP6.0	RCP8.5	Mean
2025D1	4045.0	11.7	10.7	12.01	11.7	11.5
2050D1		12.2	12.0	11.10	7.7	10.7
2080D1		11.6	3.3	3.46	0.1	4.6
2025D2	3787.0	13.0	12.0	12.73	12.9	12.6
2050D2		15.3	8.2	13.57	7.4	11.1
2080D2		16.3	5.2	4.57	7.2	8.3
2025D3	3569.0	11.3	10.0	10.42	11.5	10.8
2050D3		10.6	8.3	6.92	4.7	7.6
2080D3		10.4	4.3	3.59	6.9	6.3

(Where, D1: 26th June, D2: 11th July and D3: 26th July)

4. CONCLUSION

The study revealed that date of transplanting causes a noticeable variation in occurrence of different phenological events, crop duration and grain yield which can be considered as a simple technique for achieving higher crop performance under climate resilient agriculture scenario. For climate change study, MarkSim Ensembled GCM was found to be reliable enough for generating daily temperature, rainfall and solar radiation data in a DSSAT friendly format. The probable impact of climate change on weather parameters revealed a gradual increase in percent change in rainfall during crop growing period. The likely increase in rainfall was observed highest under RCP4.5 (36.9 to 43.4%) and RCP6.0 (34.4 to 38.3%) and least under RCP8.5 (11.8 to 36.8%) during projected years. Similarly, the degree of increase in mean minimum and maximum temperature was projected highest under RCP8.5 and least under RCP2.0 and RCP6.0. Furthermore, climate change impact on

Sali rice was assessed in CERES-Rice model, which revealed a good agreement between observed and simulated occurrence of different phenological events and grain yield. The simulation study indicated an advance in total crop growing period by 1 to 7 days in Mahsuri, 3 to 10 days in Swarna Sub-1 and 1 to 10 days in TTB-404 under different RCPs during the period under investigation. Comparatively maximum reduction in total duration was observed under RCP 6.0 and 8.5 during later part of the century mainly due to distinct reduction in vegetative and maturity period. The grain yield also gets markedly influenced by varying levels of radiative forcing effects represented by four different RCP scenarios. The percent change in projected grain yield over mean observed yield showed positive deviation for all three-cultivars almost in all four RCPs. Overall grain yield under the projected RCP scenarios were found to be increases in a decreasing rate when transplanting gets delayed from 26th June to 26th July. Furthermore, increase in mean maximum and minimum temperature not beyond 3°C compared to the baseline period (2017-19) has no substantial negative impact on rice yield during the projected climate change scenarios.

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