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Climate change impact assessment and developing adaptation strategies for rice crop in western zone of Tamil Nadu

K.BHUVANESWARI, V.GEETHALAKSHMI, A. LAKSHMANAN, R.ANBHAZHAGAN and D NAGOTHU UDAYA SEKHAR[1]

Agro Climate Research Centre, Tamil Nadu Agriculture University, Coimbatore -3

[1]Norwegian Institute for Agricultural and Environmental Research, Norway

Corresponding author email:bhuviagm@gmail.com

ABSTRACT

The CERES-Rice model in the Decision Support System for Agro-technology Transfer (DSSAT) was used for assessing the impact of climate change on rice and developing adaptation strategies to sustain rice production in western zone of Tamil Nadu. Model results showed that the rice yield reduction ranged from 4 -56 % with increase in temperature from 1 to 5°C respectively from the current climate under different dates of planting from 1st June to 15th July. The different sowing windows tested as adaptation strategy to climate change indicated that the change in yield from current condition under early, normal, late planting during kharif season was -21.2, -15.0 and -16.3 % respectively for 3°C increase in temperature and 650 ppm CO_2 enrichment, during rabi season, it was -9.2, +10.2 and +11.0 % respectively. To manage the water crisis under changing climatic conditions, different methods of cultivation viz., transplanted rice (TRC- conventional), direct sown rice (DSR), alternate wetting and drying method (AWD), system of rice intensification (SRI) and aerobic rice cultivation (ARC) was simulated. Higher grain yield was registered under SRI with water saving of 16 and 7.8% respectively during kharif and rabi seasons.

Key words: Climate change, Rice, CERES-Rice model

Increase in green house gas concentration and the resultant increase in temperature has led to notable changes in different sectors including water and agriculture which would impact food security (IPCC, 2007). Rice is the staple food crop for most of the people living in Asia and provides 23 per cent of the global human per capita energy and 16 per cent of the per capita protein (IRRI, 1997). India ranks first in area under rice (about 45 million ha) and ranks second in production next to China. Occurrences of climatic extremes especially at critical growth stages of rice significantly reduce the yield (Peng et al., 1996). Reduction in crop duration, average grain weight and increase in respiration, sterility and resultant decline in yield are expected as a result of temperature increase (Morita *etal*., 2002). Elevated temperature is expected to enhance the water requirement of the crops besides altering the phenological and physiological responses (Mahoo *etal.*, 2007). As rice is mainly grown under flooded condition, any change in climate that lead to reduction in water availability for agriculture might impact the production and productivity of rice to a greater extent. For precise assessment of direct and indirect impacts of climate change on rice crop weather models could be one among the cost effective and time saving tools, well calibrated and validated crop simulation models could be used for evaluating the impact of global climatic changes on agriculture and for developing adaptation strategies against climate change (Hundal and Kaur,1996; Fengmei Yao *etal.*, 2007). In this context, in the current study, crop modeling tool was employed for assessing the impact of climate change as well as developing adaptation strategies to manage the negative effect of climate change on rice.

MATERIALS AND METHODS

CERES-Rice model setup

The CERES-Rice model of DSSAT v 4.5 was used to assess the impact of climate change on rice productivity at Coimbatore. The DSSAT models require the input data files pertain to weather, soil, genotype characteristics (crop and cultivar) and experiment details (crop management). The daily weather data viz., maximum temperature (°C), minimum temperature (°C), solar radiation (MJ m^{-2} day^{-1}) and rainfall (mm) for the crop growing period (averaged over the period of 1980-2010) were used for creating weather file in the model. Soil file prepared with soil information obtained from soil sample analysis from the experimental fields. The details of the experimental conditions, field characteristics and management practices including cultivar were incorporated in the experimental file.

Calibration of CERES-Rice model

Data obtained from the experiments carried out with rice cultivar CORH2 under six dates of sowing (03.10.2002, 10.10.2002, 19.09.2002, 03.10.2003, 10.10.2003, 19.09.2003) 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 observations that were not used for the calibration (Jones et al., 2003). The experimental data collected (D1:1st June, D2:15th June, D3:1st July and D4:15th July in 2010) were used for independent model validation. Statistical index used for model validation is

RMSE (Root Mean Square Error) = $\left[\sqrt{\frac{\sum_{t=1}^{n}(\mathrm{Pi}-\mathrm{Oi})^2}{n}}\right]$

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. Normalized RMSE (RMSEn) gives a measure (%) of relative difference of simulated verses observed data.

NRMSE (Normalized Root Mean Square Error)

$$= \left[\frac{\mathrm{RMSE\ x\ 100}}{\overline{O}}\right]$$

Where O ¯ is mean of observed data

The simulation is considered excellent with a normalized RMSE less than 10 per cent, good if the normalized RMSE is greater than 10 and less than 20 per cent, fair if the normalized RMSE is greater than 20 per cent and less than 30 per cent and poor, if the normalized RMSE is greater than 30 per cent (Loague and Green 1991).

Impact of elevated temperature on rice productivity

The calibrated and validated CERES-Rice model was used for assessing the effect of elevated temperature (1°C to 5°C) on rice yield. Temperature of current climate data using environmental modification sub module of CERES –Rice model and the model simulation was performed with modified weather files for each 1°C increase in temperature up to 5°C.

Development of adaptation strategies

DSSAT model was employed to identify the possible adaptation measures to cope the adverse effect of elevated temperature. The best management practices considered in this study were shifting planting window, different rice cultivation systems such as System of Rice Intensification (SRI), Alternate Wetting and Drying (AWD), direct sown rice (DSR) and aerobic rice cultivation (ARC). The simulation runs were performed with different experiment files created for selected management options.

Shifting planting window

Future climate scenarios derived from 16 Global Climate Models at a resolution of 50 x 50 km is available for the whole globe from the source www.climatewizard.org and extracted only to the study region. The 16 Global Climate Models projection indicated that in western zone, an increase of 1.9°C and 3.0°C is expected for mid and end century respectively. The CO_2 levels are expected to increase continuously and by the end of the century, most of the predictions report doubling of CO_2 in most part of the world (Keeling etal.(1995); Prinn (1998); Morison and Lawler (1999). Based on these research outcomes, in the current study, 3°C increase in temperature with 650 ppm CO_2 levels were considered for testing the appropriate sowing window as climate change adaptation option. Normal planting for the *kharif* season rice is 1st June and it is 15th September for rabi season. Fifteen days earlier and 15 days delayed planting from the normal dates of planting were simulated using the DSSAT model and the results were compared for the future climatic condition (With 3°C increased temperature + 650 ppm CO_2).

Rice cultivation systems

Rice is traditionally grown under flooded condition. As the availability of water for irrigation is shrinking under changing climate, research on maximising water use efficiency in order to minimize the impact of climate change on rice productivity is of prime importance. Hence,

Table 1: Genetic co-efficient of Rice- CORH2

Genetic co-efficient	P1	P2O	P2R	P5	G1	G2	G3	G4
Rice – CORH 2	590	160	337	12.5	59.5	0.249	1	1

Table 2. Observed and CERES-Rice model simulated panicle initiation (PI), flowering date, physiological maturity date (in days) and grain yield (kg ha^{-1}) of rice for different dates of planting

Date of planting	Days to flowering			Days to physiological maturity			Grain yield		
	Oi	Pi	D*	Oi	Pi	D*	Oi	Pi	D*
D1:1stJune	66	68	2	110	108	-2	6687	6144	543
D2:15thJune	65	65	0	104	106	2	5808	5313	495
D3:1stJuly	62	64	2	99	105	6	5200	4864	336
D4:15thJuly	61	62	1	101	104	3	4653	4188	465
RMSE		1.5			3.6			233	
NRMSE		2.34			3.50			4.54	

D* = Deviation, Pi = Predicted, Oi = Observed, D=(Pi-Oi)

Table 3: Impact of elevated temperature on rice productivity (kg ha^{-1}) under different dates of planting

Date of planting	Current climate	Increase in temperature				
		1°C	2°C	3°C	4°C	5°C
D1:1stJune	6687	-4	-15	-22	-37	-53
D2:15thJune	5808	-4	-13	-23	-39	-53
D3:1stJuly	5200	-4	-12	-24	-40	-54
D4:15thJuly	4653	-6	-15	-25	-40	-56

Table 4: Effect of different dates of planting on rice yield (kg ha^{-1}) under current climate and elevated temperature (3°C) with CO2 enrichment (650ppm)

Simulation	Kharif season planting			Rabi season planting		
	Early-15thMay	Normal-1st Jun.	Late-15thJun.	Early-1stSep.	Normal-15thSep.	Late-1stOct.
T1:Current climate	4972	6687	5808	4533	4393	5405
T1+3°C increase in temperature+650 ppmCO_2 enrichment	4056	5670	4862	4115	4839	5997
Change in yield (%)	-18.4	-15.0	-16.3	-9.2	10.2	11.0

in the current study the performance of various rice cultivation methods.

To evaluate the performance of different systems of rice cultivation, different cultivation strategies were incorporated in CERES-Rice under different climate change scenario. Rice cultivation systems such as transplanted rice cultivation (TRC), direct sown rice (DSR) alternate wetting and drying method (AWD), system of rice intensification (SRI) and aerobic rice cultivation (ARC) were evaluated for its future suitability. While creating the management file the aspects considered were transplanting 24 days old seedlings with a spacing of 20 x15 cm and water level maintained at 5 cm from transplanting to 10 days before harvest in transplanted

Table 5. Influence of different rice cultivation systems on water usage and rice yield

Cultivation systems	Total water used (m3 ha-1)		Water saving (%) over TRC		Yield (kg ha^{-1})		Yield (% change over TRC)	
	Kharif	Rabi	Kharif	Rabi	Kharif	Rabi	Kharif	Rabi
Traditional Rice Cultivation (TRC)	15784	13238	0	0	6687	6193	0	0
System of Rice Cultivation (SRI)	13261	12200	16	7.8	8901	8365	33.1	25.1
Alternate wetting and drying (AWD)	13773	11977	12.7	9.5	7675	7178	14.8	7.3
Direct seeded rice (DSR)	14074	12868	10.8	2.8	5484	5917	-18.0	-11.5
Aerobic rice (AR)	9032	8247	42.8	37.7	3984	4330	-40.4	-35.2

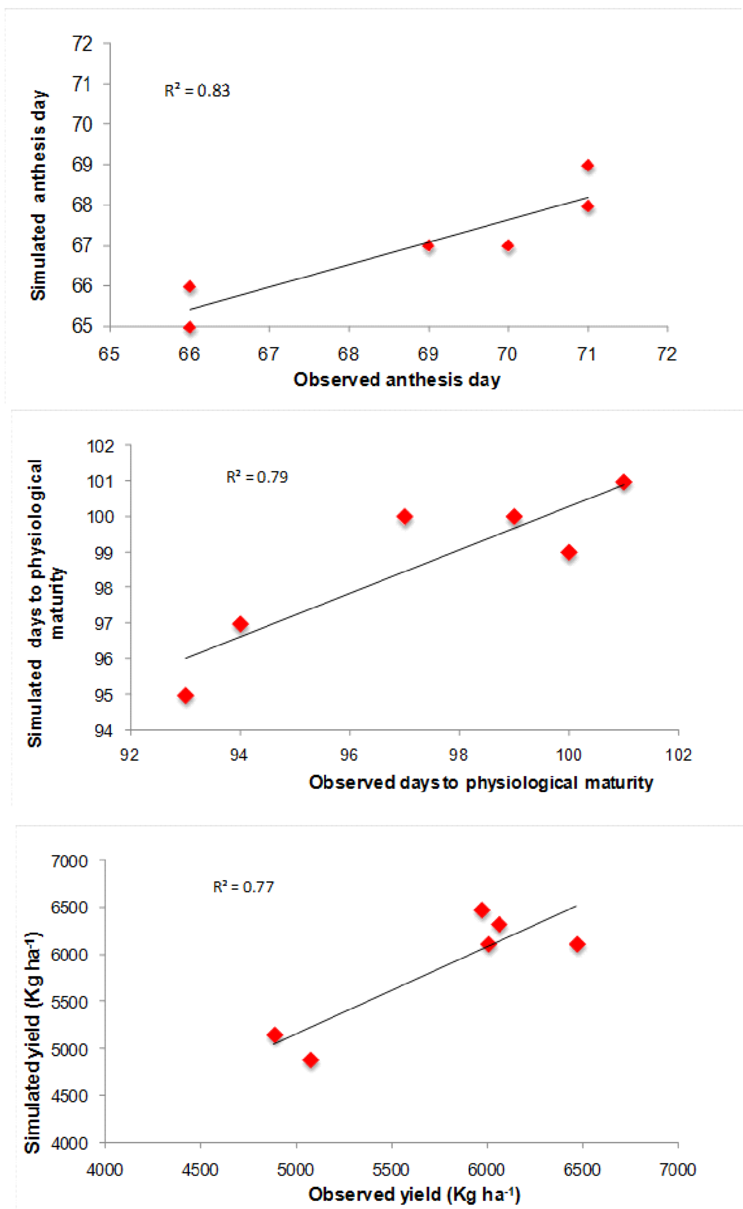

Fig.1. Comparison of observed and CERES –Rice simulated (a) days to flowering, (b) physiological maturity and (c) grain yield during calibration

rice. In SRI, fourteen days old seedlings were transplanted with a spacing of 22.5 x 22.5 cm and irrigation was done immediately after the disappearance of water. In AWD method, 24 days old seedlings were planted with a spacing of 20 x 15 cm, water was impounded to 5 cm depth and subsequent irrigations were given 3 days after complete disappearance of water. In aerobic rice cultivation, seeds were sown with 20 x 10 cm spacing and irrigations were given once in 5 days without impounding water. In DSR cultivation method, seeds were sown with 20 x 10 cm spacing. A thin film of water was maintained till seedling establishment and gradually the water level was raised to maintain 5 cm in the field just like TRC.

RESULTS AND DISCUSSION

Calibration of CERES-Rice model

The CERES-Rice model was calibrated for CORH2 rice hybrid by iteration method comparing the results of field experiment with an objective to validate the model for assessing the effect of climate change on rice. The genetic coefficients estimated are listed in the Table 1. Comparison between observed and simulated data on phenological stages and grain yield is presented in Fig.1. The high R^2 value (>0.7) indicates good agreement between observed and model simulated data.

alidation of CERES-Rice model

The validation of CERES-Rice model was done by comparing the model simulated values with the observed values from the field experiments. The values on physiological events like date of flowering, date of physiological maturity and rice grain yield simulated using CERES-Rice model was validated. The simulated values were compared with the corresponding actual observed values obtained from the field experimentation, through statistical tool called NRMSE (Normalized Root Mean Square Error).

Comparisons of predicted and simulated values of days to flowering, physiological maturity and grain yield under different dates of planting (D1 - 1st June; D2 -15th June; D3 -1st July and D4-15th July) are presented in Table. 2. The NRMSE values less than 10 per cent for validation of days to flowering (2.34%), physiological maturity (3.50%) and grain yield (4.54%) revealed that the simulated data matches well with the observed data.

Impact of elevated temperature on rice productivity

Rice productivity was negatively impacted for elevated temperatures. The yield reduction ranged from 4-6%, 12-15%, 22-25%, 37-40% and 53-56% for 1°C, 2°C, 3°C, 4°C and 5°C respectively (Table 3).

Shifting planting window

The simulated yields were higher during Kharif compared to Rabi season. However, reduction in yield for increase in temperature and CO_2 was more during Kharif than Rabi season. Change in yield under early, normal, late planting of Kharif season was -18.4 -15.0 and -16.3 per cent respectively for increase in temperature and CO_2 enrichment, while for rabi season, it was -9.2, +10.2 and +11.0 per cent respectively (Table 4). From the analysis, it is clear that, the best time of planting is June 1st (Normal planting date) for kharif rice in the current as well as future climate indicating the favourable environmental condition for growth and development of the plant throughout the season. In contrast, the sowing window need to be delayed by 15 days (1st October) during Rabi season from the normal planting time (15th September) under future warmer climatic conditions. This might be due to the favourable environment that prevails during the grain filling stage in the changing climatic conditions.

Different systems of rice cultivation

The data simulated on water usage and rice yield under different rice cultivation systems is presented in Table 5. Total amount of water used was maximum under TRC, followed by DSR, alternate wetting and drying method (AWD) and SRI. The lower amount of water was used in ARC and recorded maximum water saving, followed by AWD. Rice grain yield was significantly influenced by different rice cultivation systems. Significantly higher grain yield was produced under SRI followed by TRC during both kharif and rabi seasons. Increased grain yield under SRI is mainly due to the synergistic effects of modification in the cultivation practices such as use of young seedlings, irrigating the field immediately after disappearance of water and frequent loosening of the top soil to stimulate aerobic soil conditions (Uphoff, 2001 and Stoop et al., 2002). During Kharif season, the total amount of water used under TRC, DSR, AWD, SRI and ARC was 15784, 14074, 13773, 13261 and 9032 $m^3 ha^{-1}$ respectively and among all the rice cultivation methods, SRI produced higher yield by 33.1 per cent with water saving of 16 per cent over TRC. In rabi season, the total amount of water used under TRC, DSR, AWD, SRI and ARC was 13238, 12868, 11977, 12200 and 8247 m^3 ha^{-1} respectively. Compared to all the methods SRI proved to be the best method in terms of water saving (7.8 %) with higher (25.1 %) grain yield.

CONCLUSION

Well calibrated and validated DSSAT- CERES-Rice model employed to assess the temperature impact on rice crop and frame the possible range of adaptation strategies to sustain rice productivity. Rice crop would be greatly affected due to changing climate and the yield is expected to go down under future warmer climatic conditions. Some of the adaptation technologies like timely planting and practicing system of rice intensification (SRI) would help in sustaining the rice yields under changing climatic conditions.

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