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Resource optimization for rice (*Oryza sativa* L.) under climate change scenario in *Terai* region of Uttarakhand

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Abstract

A field experiment was conducted at G. B. Pant University of Agriculture and Technology, Pantnagar in 2016 for optimizing date of transplanting, timing and rate of application of split doses of nitrogen fertilizer for rice under climate change scenario in the *terai* region of Uttarakhand. Crop Environment Resource Synthesis (CERES)-Rice model of Decision Support System for Agrotechnology Transfer (DSSAT) v4.6 software was used after calibration and validation for optimization of resources for rice varieties HKR-47 and Pant Basmati-1, against a rise of 1.7 °C in the mean temperature during the year 2050. The model performance in simulating LAI, biomass and grain yield was found satisfactory with values of R^2, nRMSE and d-index between 0.75-0.86, 5.90-13.37% and 0.85-0.95, respectively. Our results showed that early transplanting by 5 to 6 days along with optimising nitrogen fertilizer application date and rate of split doses of nitrogen application gives better yield of rice as compared to the existing practices. The recommendations after optimizing the resources increased the yield of HKR-47 and Pant Basmati-1 by 4.52% and 5.06%, respectively against the temperature rise in 2050. We conclude that the optimized practices suggested using the model output is more profitable as compared to existing standard practices and can be used for improving rice production in *terai* region of Uttarakhand under climate change scenario.

Keywords: Climate change, adaptation, DSSAT, CERES-rice

Introduction

Rice (*Oryza sativa* L.) is one of the most important cereal crops of India. It occupies about 23.3% of gross cropped area of the country and plays a vital role in the national food security (FAOSTAT, 2018) [5]. Rice being climatically the most adaptable cereals, it is grown over a large spatial domain and a broad range of landscape types. With such a huge variation in landscapes and climates in the rice-growing regions of the country, a great number of unique paddy farming methods have also been evolved, based on farming type (irrigated, rainfed, deepwater), crop management (single crop, multiple crops), and seasonality (wet season, dry season). However, production of rice, as for other crops, is beset by the constraints such as drought, flooding, salt stress and extreme temperatures, all of which are likely to worsen with climate change. Severe changes in the rainfall patterns coupled with the rising temperatures will introduce adverse growing conditions (due to drought, flooding etc.) into cropping calendars thereby modifying the growing seasons, which could consequently reduce crop productivity **(**Srivastava *et al*., 1999**)** [16].

According to IPCC (2014) [7], "Climate change refers to a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer". It refers to any change in climate over time, either due to natural variability or as a consequence of the human activity. It will directly affect future food availability and increase the difficulty of feeding the rapidly growing world's population (Singh *et al*., 2017) [13]. Long-term climatic variability influences the sowing date, crop duration, crop yield, and other management practices followed in rice production. Short-term weather episodes can also affect the yield by inducing changes in temperature, potential evapotranspiration, and moisture availability.

Crop simulation models are the principal tools needed to carry agronomic sciences into information sciences. With these crop models, it became possible to simulate a living plant through the mathematical and conceptual relationship which governs its growth in the Soil-Water-Plant-Atmosphere Continuum **(**Sah *et al*., 2019; Kumar and Sharma, 2004; Timsina *et al*., 2004) [15, 11, 17]. The simulation of crop development, growth and yield are accomplished through evaluating the stages of crop development, the growth rate and partitioning of the biomass into growing organs. One of the most important uses of models is to forecast the output of a given system in response to a given set of inputs. One very important upcoming use of models in agriculture is to forecast the effects of certain environmental condition and agricultural practices on crop performance. All of these processes are dynamic and are affected by environment and cultivar specific factors. The description of key processes in crops provides a means of quantifying how cultivars differ and help to offer a system of simulating grain yield production utilising crop models (Kiniry *et al.*, 2001) [10]. The mechanistic models simulating cropping systems at one level are best described by the processes at a subordinate level (Amthor and Loomis, 1996) [2]. Daily canopy photosynthesis, respiration, growth, biomass partitioning and crop development can be simulated by the CSM-CERES-Rice model as a function of input data such as daily weather conditions, soil properties, management practices and cultivar characteristics (Jones *et al*., 2003) [9]. It has also been applied to ascertain improved rice management systems under irrigated conditions (Ahmad *et al*., 2012) [1] and simulate rice yield under several agronomic management practices and varying climatic scenario (Lamsal and Amgain, 2010) [12].

Material and Methods

A field experiment was conducted for resource optimization under climate change scenario for rice (*Oryza sativa* L.) in *terai* region of Uttarakhand using CERES-Rice simulation model during *Kharif* season of 2016 at plot number C5 of Norman E. Borlaug Crop Research Centre of Govind Ballabh Pant University of Agriculture and Technology, Pantnagar. Pantnagar is situated at latitude of 29.02°N, 79.28°E longitude and at an altitude of 217.80 m above the mean sea level and lies in the narrow belt to the south from the foothills of Shivalik range of the Himalayas, known as “*Terai*” region. The climate of Pantnagar comprises of sub-humid to sub-tropical with hot dry summers and cool winters with mean annual rainfall of 1400 mm. The meteorological data used for the study (i.e. minimum and maximum temperature, bright sunshine hours, relative humidity, rainfall) was taken from the agrometeorological observatory located at Norman E. Borlaug Crop Research Centre Pantnagar, which is located few meters away from the experimental site. Soils of *Terai* region are young and of alluvial origin (Deshpande *et al*., 1971) [3]. The soil of the experimental site is sandy loam and belongs to the Haldi series. The chemical analysis of soil showed that it was medium in organic carbon, low in available nitrogen, medium in available phosphorus, potassium and slightly alkaline in reaction. Important physico-chemical properties of the study area are given in Table1.

Table 1: Physico-chemical properties of the soil of experimental field during 2016

S. No.	Parameters	0-15 cm	15-30 cm
1.	Organic carbon (%)	0.68	0.52
2.	Available nitrogen (kg/ha)	216.32	197.51
3.	**Soil texture**		
	Clay (%)	17.3	18.9
	Silt (%)	47.2	46.2
	Sand (%)	35.5	34.9
4.	Textural class	Sandy loam	
5.	Field capacity (%)	22.5	23.1
6.	Wilting point (%)	7.4	8.5
7.	Bulk density, moist (g/cm^3)	1.48	1.52
8.	Available Phosphorus(kg/ha)	21.5	18.6
9.	Available Potassium (kg/ha)	258.7	243.8

There were a total of 18 experimental plots having combinations of 6 treatments. The variety of rice selected for the experiment was HKR-47 and Pant Basmati-1. The crop was transplanted at three different transplanting dates i.e. 25 June, 5 July and 15 July 2016 with three replications in a factorial 2x3 randomised block design. The crop was grown with all the standard recommended agronomic practices under irrigated situations. Five plants in each block were tagged to monitor the different crop parameters and their development. The observations were taken at weekly intervals for the various crop characteristics. The different weather parameters were recorded daily for the same corresponding crop period from the agrometeorological observatory. The model used for the study was CERES-Rice (Singh *et al*., 1993) [14] which is embedded in the DSSAT v4.6 software (Hoogenboom *et al*., 2010) [6]. The model was calibrated using the early transplanted crop (i.e. 25th June) data collected during 2016. Crop phenology, leaf area index, biomass, and yield data were used to calibrate the model and the genetic coefficients were calculated for HKR-47 and Pant Basmati-1 using 6000+ iterations of Generalized Likelihood Uncertainty Estimation (GLUE) module available in DSSAT and further manually tuning the relevant coefficients to achieve the best possible match between the simulated and observed set of data. Prior to the derivation of coefficients, weather file (WTH) was created using data of agrometeorological observatory near the experimental field and the soil file (.SOL) was created by conducting lab analysis and literature search. The CERES-Rice model was validated with the normal and late sown crop (i.e. 5th July and 15th July) which created different growing environments. To assess the accuracy of the CERES-Rice model, results were validated with the data generated from all the treatments. The prediction capability of the model was testing the model’s capability to simulate maximum leaf area index, total above ground biomass (t/ha) and grain weight (t/ha). Model accuracy evaluation was done using deviation statistics *viz*. index of agreement (d), root mean square error (RMSE), normalised root mean square error (nRMSE) and one test statistic (coefficient of determination, R^2) for evaluating the performance of the model. The validated model was used for optimizing the transplanting dates, timing and split doses of nitrogen fertilizer for rice against a rise of 1.7 °C in the mean temperature during the year 2050 as suggested by IPCC (2007) [8].

Results and Discussion

Adaptation to climate change consists of initiatives and measures to lower the vulnerability of natural and human systems against actual or expected climate change effects (IPCC, 2014) [7]. Adaptation has the potential to reduce the adverse impacts of climate change and to enhance beneficial impacts, without incurring additional costs and by preventing damage due to increased temperature. Because of the current and the projected climate disruption supported by a rise in temperature (°C), adaptation is a necessary strategy at all scales to complement climate change mitigation efforts.

Calibration and validation of CERES-Rice model

Model calibration is the adjustment of genetic parameters or coefficients in a functional relationship so that the model behaviour matches with one set of the real world. In its simplest form, model validation is a comparison between simulated and observed values. A model can be considered valid if the simulated values remain within the predicted confluence level band. Thus, validation is used as an assessment of the model for its usefulness. The CERES-Rice model was calibrated using the field trial data of 2016 for two varieties and three dates of transplanting combination and validated with the remaining data for different treatments in the same year for the rice cultivar HKR-47 & Pant Basmati-1.

Genetic coefficients: The key process of the model calibration was adjusting eight variety specific genetic parameters of the cultivars. Four of these are related to developmental aspects and the other four are related to the growth of the crop. These genetic coefficients were generated for both of the rice cultivars. Modified genetic coefficients for rice cultivars HKR-47 & Pant Basmati-1 have been presented in Table 2.

Table 2: Modified genotype coefficients for rice varieties under study

Parameter	Description of parameter	Genetic coefficient	
		HKR-47	Pant Basmati-1
P1	(Expressed as growing degree days GDD in °C above a base temperature of 9 °C) from seedling emergence during which the rice plant is not responsive to changes in photoperiod.	550.0	560.0
P2O	The longest day length (in hours) at which the development occurs at a maximum rate. At values higher than P2O, the developmental rate is slowed; hence there is a delay due to longer day lengths.	400.0	300.0
P2R	Extent to which phasic development leading to panicle initiation is delayed (expressed as GDD in °C) for each hour increase in photoperiod above P2O.	110.0	200.5
P5	Time period (in GDD °C) from beginning of grain filling (3 to 4 days after flowering) to physiological maturity with a base temperature of 9 °C.	12.5	12.1
G1	Potential spikelet number coefficient as estimated from the number of spikelets per g of main culm dry weight (less lead blades and sheaths plus spikes) at anthesis.	47.0	42.5
G2	Single grain weight (g) under ideal growing conditions, i.e., non-limiting light, water, nutrients, and absence of pests and diseases.	0.025	0.023
G3	Tillering coefficient (scalar value) relative to IR-64 cultivar under ideal conditions. A higher tillering cultivar would have coefficient greater than 1.0.	0.70	0.80
G4	Usually 1.0 for varieties grown in normal environments. G4 for japonica type rice growing in a warmer environment would be 1.0 or greater. Likewise, the G4 value for indica type rice in very cool environments or season would be less than 1.0.	1.00	1.00
PHINT	Phylochron interval; the interval in thermal time between successive leaf tip appearances.	83.0	83.0

The statistical analysis for comparison of observed and simulated values of different crop parameters for both the varieties are given below:

Leaf Area Index

The simulated and observed values of maximum LAI were presented in Table 3. In case of HKR-47, the maximum leaf area index ranged between 3.2 to 3.7 and 3.0 to 3.4 for observed and simulated data, respectively. The model underestimated the values of maximum LAI for all the transplanting dates during the experimental year. In case of Pant Basmati-1, the maximum leaf area index ranged between 3.0 to 3.8 and 3.1 to 3.9 for observed and simulated data respectively. The model overestimated the values of LAI for all the transplanting dates during the experimental year. The difference between the simulated and observed values was small with a percentage error between 3.03-8.11%. RMSE and nRMSE values of LAI were found to be 0.24 and 7.07%, respectively. The coefficient of determination and the d-index have shown good model performance with the values of 0.75 and 0.89, respectively.

Table 3: Simulated and observed values of maximum LAI

Date of transplanting	HKR-47			Pant Basmati-1		
	Observed	Simulated	% Error	Observed	Simulated	% Error
25th June	3.7	3.4	8.11	3.8	3.9	2.63
5th July	3.3	3.2	3.03	3.2	3.3	3.12
15th July	3.2	3.0	6.25	3.0	3.1	3.33

Total above ground biomass

The value for biomass (t/ha) ranged from 10.79 to 11.98 and 11.38 to 12.47 for observed and simulated values respectively during different date of transplanting for HKR-47. Similar trend was observed for Pant Basmati-1 where biomass (t/ha) ranged from 9.44 to 11.63 and 10.46 to 13.12 for observed and simulated values respectively during different date of transplanting (Table 4). The % error were fairly below 15% and ranged between 4.09 and 12.81%. The model overestimated the values of total above ground biomass for both the varieties within acceptable limits with lower values of RMSE (1.45), nRMSE (13.4%) and high values of R^2 (0.83) and d-index (0.85).

Table 4: Simulated and observed values of total above ground biomass (t/ha)

Date of transplanting	HKR-47			Pant Basmati-1		
	Observed	Simulated	% Error	Observed	Simulated	% Error
25th June	11.98	12.47	4.09	11.63	13.12	12.81
5th July	10.89	11.87	9.00	10.44	11.67	11.78
15th July	10.79	11.38	5.47	9.44	10.46	10.81

Grain yield

The simulated and observed values of grain yield for both varieties were presented in Table 5. The observed and simulated data for grain yield (t/ha) of HKR-47 ranged between 3.82 to 4.76 and 3.92 to 4.65, respectively. The simulated values were found to be close to the observed data in the experimental year with % errors ranging from 0.29 to 6%. In case of Pant Basmati-1, the observed and simulated values of grain yield (t/ha) vary between 3.43 to 4.27 and 3.44 to 4.04, respectively. The model performance to simulate grain yield was good with RMSE of 0.24, nRMSE of 5.9%, R^2 of 0.86 and d-index of 0.95.

Table 5: Simulated and observed values of grain yield (t/ha)

Date of transplanting	**HKR-47**			**Pant Basmati-1**		
	Observed	**Simulated**	**% Error**	**Observed**	**Simulated**	**% Error**
25th June	4.76	4.65	2.31	4.27	4.04	5.39
5th July	4.17	3.92	6.00	3.84	3.96	3.13
15th July	3.82	3.99	4.45	3.43	3.44	0.29

Optimization of inputs in climate change scenario for rice varieties under study

Among different transplanting dates, maximum yield was found with crop transplanted on 25th June, thus the crop transplanted on 25th June was taken as the base for the improved package of practices under the changed climatic scenarios for the year 2050. Package of practices was optimized so that it may avert the adverse effect of climate change by 2050. The optimised package of practices was presented in Table 6. As the first intervention, the transplanting date was adjusted. After suitable adjustment of transplanting date, the timings and rates of split doses of nitrogen fertilizer were adjusted in order to optimise the LAI, biomass and yield of rice in changed climatic scenario of 2050 for varieties HKR-47 and Pant Basmati-1.

Table 6: Optimized package of practices for HKR-47 & Pant Basmati-1

Transplanting date		**HKR-47**		**Pant Basmati-1**	
		Existing	**Optimized**	**Existing**	**Optimized**
		25 June	**19 June**	**25 June**	**20 June**
N Fertilizer recommendations					
I dose (Basal)	Date	25 June	19 June	25 June	20 June
	Amount	50%	40%	50%	40%
II dose	Date	20 July	15 July	20 July	15 July
	Amount	25%	30%	25%	30%
III dose	Date	19 August	25 August	19 August	25 August
	Amount	25%	30%	25%	30%

With the optimized package of practices for HKR-47 in climate change scenario during the year 2050, if the crop was transplanted 6 days in advance from 25th June with fertilizer amount being 40% as basal dose instead of 50% earlier and remaining as spilt doses of 30% (earlier 25%) each on 15th July and 25th August instead of 20th July and 19th August gives higher yield as compared to the existing recommendations. The maximum LAI also increased to 3.5, which was 3.3 earlier, total above ground biomass increased from 12.47 to 13.54 t/ha (+8.58%) and grain yield increased to 4.86 from 4.65 t/ha (+4.52%) with the optimized package of practices as compared to the existing recommendations.

Similar results were also observed for Pant Basmati-1 (Table 7). Advancement of transplanting by almost five days from 25th June transplanting for Pant Basmati-1 along with changes in the date and rate of nitrogen fertilizer application resulted in higher yield under changed climatic scenario as compared to the existing recommendations. As a result of new interventions, maximum leaf area index increased from 3.2 to 3.5, above ground dry biomass increased from 12.42 to 13.16 t/ha (+ 5.96%) and grain yield increased from 4.15 to 4.36 t/ha (+ 5.06%).

Our adaptation measures to mitigate the potential impact of climate change included possible changes in transplanting dates and fertilizer application dates and amount. The optimized package of practices recommended using the model output nullified the impact of rise in temperature during the year 2050 and have potential to increase the total above ground biomass and yield of rice as compared to the present package of practices.

Table 7: Outputs with optimized package of practices for HKR-47 & Pant Basmati-1

Crop characters	**HKR-47**		**Pant Basmati-1**	
	Existing	**Optimized**	**Existing**	**Optimized**
Maximum LAI	3.3	3.5	3.2	3.5
Total above ground biomass (t/ha)	12.47	13.54	12.42	13.16
Grain yield (t/ha)	4.65	4.86	4.15	4.36

Conclusion

The study calibrated and validated CERES-Rice model of DSSAT v4.6 and used it for resource optimization in *terai* region of Uttarakhand. The CERES-Rice model very well simulated LAI, biomass and grain yield of rice for the *terai* region. The suggested optimized package of practices is obtained from model output for resource optimization. The optimised dates of transplanting, nitrogen fertilizer application date and rate of its split application in rice under the changing climate scenario resulted in higher grain yield and above ground biomass for both HKR-47 and Pant Basmati-1 as compared to existing recommendations. Our study concludes that the DSSAT v4.6 embedded CERES-Rice model is a useful decision support tool for resource optimization and it can be used to increase the rice productivity under the changing climatic scenario to improve the profitability of rice farmers in *terai* region of Uttarakhand.

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