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Assessment of CERES-Rice model for rice production and climatic variability on rice model in temperate Kashmir

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Abstract
CERES-Rice model was calibrated and validated for rice cultivars (K-39,Jhelum,Shalimar-ice1, Chenab,CH-1039,CH-1007,Kohsaar,K-332) and sowing dates (25^{th} May,10^{th} June and 25^{th} June)the data was collected from the field experiment conducted at Shere- Kashmir University of \Agricultural Sciences in the year 2010 and 2011.Prediction capabilities of the model were tested by judging the performance of crop in terms of phenology, leaf area index, grain yield and biological yield. Days to anthesis ranged between 53 to 109 days and 54 to 120 days for observed and predicted values respectively. The observed and the predicted days to maturity ranged between 82 to 165 days and 83 to 167 days respectively. Grain yield ranged between 34.15 to 99.28 and 34.0 to 104.6 q/ha for simulated and observed data respectively. The observed and predicted LAI and biological yield did not match. Sensitivity analysis was done in which the maximum and minimum temperature was increased by 3^0c resulted in decrease in the yield by 1.7% and decreases days to maturity by 33 days. The effects of elevated CO_2 (350ppm) of the base value 330ppm showed increase of grain yield by 8.1% with no effect on crop maturity.

Keywords: CERES-Rice model, calibration, validation, sensitivity analysis

Introduction
Rice is the most important staple food crop for more than half of the world's population, provides 21% of the total caloric intake(Singh *et al*.,2017) [7]. In India it occupies an area of 43.8 million ha and a production of 105 million tonnes with average productivity of 2.21 t/ha(Kumar *et al*., 2016). Jammu and Kashmir is the sixth largest State in India and covers a geographical area of about 2, 22,236 square kilometres with varied topographical features. Agriculture is an important occupation, because 73% of population resides in rural areas and 70% of the total workers are directly or indirectly involved in cultivation. Agriculture is the main source of income for thousands of families with 1.14 m ha of cultivated land covering just 0.05% of total geographical area for the reason that major percentage of it is under mountain terrains. The irrigated area is over 0.32 m ha. The climate is typically temperate in Kashmir valley and some upper reaches of Jammu Division, while as, subtropical to intermediate kind of climate is generally found in Jammu division. The climate of Ladakh region is cold arid. There is a wide variability in the annual precipitation which ranges between 80-1500 mm. It is less than 80 mm in Ladakh and more than 1400 mm in some parts of Jammu region; however, in Kashmir region average annual occurrence of precipitation is 680-750 mm including snowfall during the winter months. Rice cultivation is an integral component of rich cultural heritage of the state. The crop is grown on 100% irrigated ecology in Kashmir valley and melting snow is the source of irrigation. The crop is grown in all districts of Kashmir valley on an area of 0.159 m ha. Crop simulation models can be used as a tool for agricultural risk analysis. They allow researchers to explore potential cropping location and appropriate farm management strategies. Over the last two decades, crop models have evolved considerably which have reasonably good approximations of reality and are used for applications after careful calibration and validation in the target environment (Ritcher and Sondgerdth, 1990) [1]. The crop growth model developed can be useful in crop management, if phenological stages are accurately simulated in necessary detail needed for practical applications (Miller *et al.*, 1993) [5]. Some of the crop management decisions which can be linked to phenology are: [1] irrigation application which should be made

at strategic phenophases to achieve maximum water use efficiency, [2] fertilizer application at early, mid & maximum tillering and at panicle initiation, [3] herbicide application, which can be based on the leaf stage of the crop as well as the target weeds, [4] invertebrate pest control, which must take place prior to a given leaf stage and [5] harvest.

2. Materials and Method

The CERES- rice model was calibrated and validated with the data sets generated during kharif season of 2010 and 2011 through the field experiment carried out at Shalimar Station of Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir with the objective to study the growth and yield of different varieties of rice at varying sowing dates. The treatment consisted of three dates of transplanting *viz.* 25 May, 10 June and 25 June and eight cultivars *viz.* K-39, Jhelum, Shalimar-ice1, Chenab, CH-1039, CH-1007, Kohsaar, K-332. The experiment was laid out in split plot design with four replications, assigning transplanting dates in main plot and cultivars in sub-plots. Treatments were allotted in each experimental plot randomly.

The CERES-Rice crop model was used, which is embedded in the DSSAT v4.5 software (Hoogenboom *et al.*, 2010) [2]. The DSSAT software consists of Minimum Data Set (MDS), suite of Crop models and Analysis package.

2.2. Input requirements

The model requires a set of minimum data pertaining to weather, soil, genotype characteristics and crop management details to run. These data are provided to the model through data files. In addition to these, the experiment performance data is also used as input, if the simulated results are to be compared with data recorded in a particular experiment. To run the model, a file containing information about all the available experiments is provided to the model.

Weather data: Daily weather data on maximum temperature, minimum temperature, total solar radiation and rainfall for the crop period are required for simulation.

Soil data: Soil properties, including single value of drainage, runoff, evaporation and radiation reflection coefficients; values of several depth increments of rooting preference factors; soil water contents at the drained upper limit, lower limit, and saturation; N and organic matter details; initial conditions of soil water content; texture, bulk density, pH, NO3 and NH4 at several depth increments (Jones *et al*., 2003) are the essential parameters needed for running the model.

Cultivar data file: Eight cultivar specific genetic coefficients are required for describing the various aspects of performance of a particular genotype in the model (Table 1).

Experiment details file: This contains the details of all inputs (observed field data) to the models for each simulation.

Experiment performance file: This contains observed values of experimental performance of the crop, which can be used for comparison with the simulated outputs of the model runs. The information provided includes anthesis date, physical maturity, yield, grain weight, grain number, panicle number, maximum LAI and dry matter.

After validation of model question arises how sensitive is model to variation in parameter or data? In other words sensitivity means rate of change in output variable per unit change in input variable or parameter. Therefore, the weather parameters selected for sensitivity analysis were ambient temperature (±3ºC) and concentration of carbon dioxide (350-700 ppm). Detailed treatment combinations are given in table

Table 1

Genetic coefficients of rice S. No.	Parameter definition
1.	Time period (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. This period is referred to as the basic vegetative phase of the plant (P1)
2.	Critical photoperiod or the longest day length (in hours) at which the development occurs at a maximum rate. At values higher than P2O developmental rate is slowed, hence there is delay due to longer day lengths (P2O)
3.	Extent to which phasic development leading to panicle initiation is delayed (expressed as GDD in °C) for each hour increase in photoperiod above P2O (P2R)
4.	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 (P5)
5.	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. A typical value is 55 (G1)
6.	Single grain weight (g) under ideal growing conditions, *i.e.*, non limiting light, water, nutrients, and absence of pests and diseases (G2)
7.	Tillering coefficient (scaler value) relative to IR-64 cultivar under ideal conditions. A higher tillering cultivar would have coefficient greater than 1.0 (G3)
8.	Temperature tolerance coefficient. 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 (G4)

Table 2: Combination of weather parameters selected for sensitivity analysis

Treatment	Max. Temperature (ºC)	Min. Temperature (ºC)	Carbon-dioxide Concentration (ppm)
C_1	Normal (Ambient)	Normal (Ambient)	Normal (330 ppm)
C_2	+3	+3	Normal
C_3	Normal	Normal	350l
C_4	+3	+3	450
C_5	Normal	Normal	700
C_6	+3	+3	700

Results and Discussion

Calibration of CERES-Rice model

Model calibration or parameterization is the adjustment of parameters to the local conditions so that simulated values compare well with the observed ones (Timsina and Humphreys, 2006). Calculating the genetic coefficient of cultivars is the first step in the conventional use of the CERES models. Data from field experiments conducted in *kharif* seasons of 2011 for eight rice cultivars in conjunction with requisite soil and weather parameters were used to derive its genetic coefficients. To begin with, the genetic coefficients of rice cv. IR-36 available in the list provided with DSSAT package were used and further these coefficients were modified following an iterative procedure (Hunt *et al.*, 1993) to match the simulated values with the observed values mainly flowering duration, maturity duration, grain yield, grain weight and harvest index. The order of priority in which the coefficients were modified, was phenolgical coefficients (P1, P2O, P2R and P5) followed by growth coefficients (G1, G2, G3 and G4) following Hunt and Boote (1998). Genetic coefficients, along with their definition, derived for eight rice cultivars are given in Table 3.

Validation of CERES-Rice model

The data from field experiments conducted in each of the year 2010and 2011 were used to validate the calibrated CERES-Rice model (Table 4&5). The results indicated that simulation of main physiological events, *viz*., anthesis and physiological maturity dates were in close agreement with observed ones and RMSE ranged from 4.2 to 7.24 days respectively (Table 4). Grain yield ranged between 34.15 to 99.28 and34.0 to 04.6 q/ha for simulated and observed data, respectively. Predicted and simulated data match well (RMSE =6.16) except varieties Kohsaar and K-332 which under or overestimated predicted yield when transplanted late (25 june). Leaf area index and biological yield values (Table 5) for predicted values did not match with the observed values accurately. These results indicated that the CERES-Rice v4 model is capable enough in estimating growth and yield of rice with reasonable accuracy under the prevailing agro-climatic conditions of Kashmir valley and hence can be considered as a reasonably reliable model for use in climate risk assessment studies in the study area. Work by Singh *et al.* (2005) evaluated the performance of the CERES Rice v4.0 for the climatic conditions of the state of Kashmir and found that model can predict the growth and yield successfully. Accurate prediction of different stages may help farmers to take decisions on crop management operations linked to crop phenology.

Sensitivity analysis

Simulated yield as effected by elevation of amient maximum and minimum temperature by 3ºC (C_2) resulted in increased rice yield by 17.7 per cent over normal temperature (Table 6) and decreased days to maturity by 33 days. The effect of elevated CO_2 (350 ppm) of the base value 330 ppm on simulated grain yield of rice showed increase of 8.1 per cent and days to crop maturity was not affected. Increase in maximum and minimum temperature 3ºC under elevated CO_2 concentration of 450 ppm decreased yield by 5.6 per cent and crop maturity decreased by 33 days (C_4).Highest increased grain yield over normal climatic condition was 13.2 per cent when CO_2 level was increased up to 700 ppm (C_5).It was observed that seed yield decreased 2.7 per cent by increasing temperature by 3ºC even CO2 level was 700 ppm (C_6).
This indicates that model CERES-Rice can be used to predict the yield successfully under temperate conditions of Kashmir.

Table 3: Genetic coefficients of cultivars

Genetic parameter	Description*	K-39	Jhelum	Shalimar rice-1	Chenab	China 1039	China 1007	K-332	Kohsaar
P1	Time period (GDD) of basic vegetative phase	610.0	640.0	610.0	630.0	640.0	630.0	300.0	200.0
P2R	Extent phasic development (GDD)	5.0	10.0	10.0	10.0	10.0	10.0	05.0	10.0
P5	Time period (GDD) of grain filling phase	515.0	500.0	505.0	525.0	500.0	500.0	300.0	250.0
P20	Critical photo period (hour)	12.0	12.0	12.0	12.0	12.0	12.0	12.0	11.0
G1	Potential spikelet number	60.0	60.0	60.0	55.0	57.0	56.0	60.0	60.0
G2	Single grain weight	.0240	.0240	.0247	.0240	.0246	.0249	.0249	.0249
G3	Tillering coefficient	1.00	1.00	1.10	1.10	1.10	1.10	1.10	1.00
G4	Temperature tolerance coefficient	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table 4: Validation results of rice cultivars for, days to anthesis and maturity and Grain yield (q/ha^{-1}) under differen transplanting dates at Shalimar

Treatment	Days to anthesis			Days to maturity Grain Yield					
	Obs	Sim	Devi%	Obs	Sim	Devi	Obs	Sim	Devi
25th May K-39	100	97	3.0	144	144	0	84.4	85.2	-1.1
25th May Jhelum	110	106	3.6	146	144	1.4	75.8	84.3	-11.1
25th May SR-1	101	98	3.0	143	144	-0.7	62.3	85.9	-10.8
25th May Chenab	106	104	1.9	146	146	0	69.1	78.3	-11.0
25thth June CH-1039	110	111	-0.9	146	144	1.4	77.6	79.6	-6.6
25th June CH-1007	100	107	-7.0	144	145	-0.7	72.5	82.6	-14.0
25th June Kohsaar	98	100	-2.0	107	109	-1.9	52.5	55.4	5.3
25th June K-332	89	81	9.0	110	112	-1.8	55.9	58.5	6.2
10th June K-39	98	101	-3.1	134	132	1.5	71.9	81.6	-13.5
10th June Jhelum	105	106	-1.0	135	134	0.7	79.2	83.3	-5.2
10th June SR-1	87	86	1.1	133	132	0.8	78.5	83.1	6.8
10th June Chenab	99	102	-3.0	138	135	2.2	72.5	76.4	-27.3
10th May CH-1039	101	89	11.9	132	134	-1.5	67.6	78.6	-12.3
10th May CH-1007	90	97	-7.8	140	137	2.1	62.8	82.7	0
10th May Kohsaar	82	85	-3.7	99	95	0. 4	36.5	49.7	-9.9
10th May K-332	84	89	-6.0	105	103	1.9	43.3	61.9	8.4
25th June K-39	90	88	2.2	132	131	0.8	67.7	70.1	-5.2

25th June Jhelum	101	104	-3.0	132	134	-1.5	70.3	70.3	0.1
25th June SR-1	99	102	-3.0	126	130	-3.2	51.4	70.9	-0.2
25th June Chenab	98	95	3.1	134	135	-0.7	55.7	64.1	-11.1
25th June CH-1039	100	95	5.0	134	134	0	60.8	66.4	-8.3
25th June CH-1007	90	93	-3.3	145	145	0	48.2	62.2	-8.4
25th June Kohsaar	84	80	4.8	82	82	0	38.4	45.4	-18.4
25th June K-332	80	75	6.3	86	86	0	39.7	47.6	--14.9
					Conti…………….table 4				

Obs=observed ; sim=simulated; devi=deviation; RMSE=Root mean square error;

Table 5: Validation results of rice cultivars for, days to anthesis and maturity and yield (q/ha^{-1}) under differenttransplanting dates at Shalimar

Treatment	Days to anthesis				Days to maturity Yield				
	Obs	Sim	Devi%	Obs	Sim	Devi	Obs	Sim	Devi%
25th May K-39	103	106	-2.9	145	158	-9	104.6	92.7	6.5
25th May Jhelum	113	109	-5.8	145	159	-9.7	104.5	90.8	7.2
25th May SR-1	107	106	0.9	149	155	-4	91.9	93.2	2.5
25th May Chenab	105	109	-3.8	148	161	-8.8	96.2	83.8	-9.3
25thth June CH-1039	104	109	-4.8	147	159	-8.2	101.8	85.8	2.7
25th June CH-1007	102	110	-7.8	149	165	-10.7	92.3	77.4	5.3
25th June Kohsaar	83	87	-4.8	128	125	2.3	67.5	63.1	-3.8
25th June K-332	88	87	1.1	126	129	-2.4	67.7	66.6	-5.1
10th June K-39	96	97	-1.0	141	151	-7.1	92.5	80.8	2.6
10th June Jhelum	96	100	-4.2	141	152	-7.8	93.8	80.3	3.8
10th June SR-1	102	97	4.9	147	148	-0.7	90.6	80.9	-1.2
10th June Chenab	98	99	-1.0	145	152	-4.8	81.9	73.9	-10.5
10th May CH-1039	97	100	-3.1	142	152	-7	89.9	75.9	-3
10th May CH-1007	97	101	-4.1	148	157	-6.1	80.9	73.9	8.6
10th May Kohsaar	82	81	1.2	125	109	12.8	57.9	60.3	26.4
10th May K-332	78	81	-3.8	121	113	6.6	44.6	64.9	-4.8
25th June K-39	89	86	-3.4	138	145	-5.1	48.8	61.8	-6.1
25th June Jhelum	89	88	1.1	138	148	-7.2	44.4	59.7	-11.9
25th June SR-1	94	90	4.3	141	141	0	44.7	63.1	-1.1
25th June Chenab	93	87	6.5	140	150	-7.1	34.0	56.2	-9.6
25th June CH-1039	90	88	2.2	139	148	-6.5	42.6	56.3	2.8
25th June CH-1007	90	95	-5.6	143	160	-11.9	43.6	48.4	-3.9
25th June Kohsaar	58	61	-5.2	126	89	29.2	51.3	42.7	-25.5
25th June K-332	62	61	1.2	123	92	25.2	57.9	45.7	-2.2
RMSE	4.2				7.24 6.16				

Obs=observed; sim=simulated; devi=deviation; RMSE=Root mean square error;

Table 6: Validation results of rice cultivars for, biological yield (q/ha^{-1}) and LAI under different Transplanting dates at Shalimar

Treatment	Biological yield				LAI	
	Obs	Sim	Devi%	Obs	Sim	Devi
25th May K-39	188.9	180.0	4.7	4.3	3.0	30.2
25th May Jhelum	182.2	180.3	1.1	4.4	3.0	31.1
25th May SR-1	148.4	177.5	-19.6	4.6	3.0	35.0
25th May Chenab	161.9	180.6	-11.5	4.4	3.0	32.3
25thth June CH-1039	180.5	180.9	-0.3	4.2	3.0	27.9
25th June CH-1007	185.5	171.1	7.8	6.0	3.0	50.0
25th June Kohsaar	101.9	115.3	-13.1	3.0	2.3	22.3
25th June K-332	104.3	121.3	-16.2	2.4	2.4	1.7
10th June K-39	159.6	177.6	-11.2	6.2	3.5	43.4
10th June Jhelum	182.6	175.9	3.6	5.4	3.5	36.1
10th June SR-1	196.1	175.4	10.6	5.9	3.3	43.4
10th June Chenab	170.4	179.1	-5.1	5.2	3.5	33.5
10th May CH-1039	158.2	177.2	-12	5.2	3.5	33.7
10th May CH-1007	163.4	173.1	-5.9	5.6	3.7	33.9
10th May Kohsaar	73.05	106.8	-46.2	3.3	2.3	31.5
10th May K-332	84.41	124.5	-47.5	1.9	2.5	-32.1
25th June K-39	108.2	148.9	-37.6	4.2	3.4	20.2
25th June Jhelum	129.8	150.2	-15.7	4.9	3.5	29.0
25th June SR-1	150.1	145.5	3	5.5	3.3	39.6
25th June Chenab	116.3	154.6	-32.9	5.9	3.5	41.5
25th June CH-1039	124.4	152.6	-22.6	4.6	3.5	24.3
25th June CH-1007	135.2	138.1	-2.1	6.2	3.8	39.5
25th June Kohsaar	86.58	99.1	-15.4	1.3	2.0	-50.8
25th June K-332	83.87	108.4	-29.3	1.5	2.3	-51.3
	Conti……….table5					

Conclusions

Genetic coefficients required for the CERES-Rice v4 model for simulation of the growth and development of rice crop have been derived for rice cultivars under the agro-climatic conditions Kashmir valley. The model was validated using the field data of 2010 and 2011. The model was found to be able to predict the phenological occurrence of the crop well enough to help the farmers to make broad scale decisions on the crop management operations which can be directly linked to crop phenology. The better ability of the model in simulating total grain yield of the crop would enable the policy makers and planners on taking agriculture based economic decisions in the kashmir valley. It is envisaged that the validated model would provide insights for rice crop physiologists and agronomists about the response mechanisms to various weather/climate conditions. Also, it can be concluded that the modelling of rice crop yield using CERES-Rice v4.5 is accurate enough to be considered a reasonably reliable tool for use in climate risk assessment studies in agriculture.

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