

Evaluation of CERES-Rice model (DSSAT 4.5) for simulating the response of rice (*Oryza sativa*) cultivars to age of seedlings in temperate Kashmir

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ABSTRACT

A field experiment was conducted at Agronomy Farm of Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Shalimar during the rainy season (*kharif*) 2010 and 2011 to simulate the effect of age of seedling on growth and yield of 3 rice (*Oryza sativa* L.) cultivars viz. 'Jhelum', 'SKUA 403' and 'SR 1'. The experimental data were used for CERES-Rice model calibration and development of the genetic coefficients of these rice cultivars. The predicted and observed dates of phenological events were in close agreement. Similarly, the predicted and observed grain, straw and biological yields were also very close. Among cultivars, 'Jhelum' recorded the highest grain yield and harvest index, whereas straw yield was highest in 'SKUA 403'. Setting in of different phenological stages occurred earlier in 'Jhelum' compared to other cultivars. Forty days old seedlings performed better than 30- and 20- days-old seedlings in all respects. Their growth and yield-attributing characters were significantly higher than young aged seedlings. The time taken by 40-days-old seedlings to different phenological stages was also lesser than that of 30- and 20-days-old seedlings. Grain, straw, biological yields and harvest index of 40-days-old seedlings were also significantly better than 30- and 20-days-old seedlings. Regarding simulation studies similar results were obtained with permissible deviations. Simulation studies with respect to age of seedling and sowing time showed better results in terms of crop growth and yield when the crop was sown earlier with 40-days-old seedlings. Sowing earlier with aged seedling gave better results in terms of growth and yield as compared with late sown with younger seedlings. Hence for realizing optimum rice yields, 40-days-old seedlings of rice cultivar 'Jhelum' should be transplanted in the field by 10–11 June.

Key words : CERES-Rice model, Harvesting schedule, Simulation, Seedling age, Temperate rice cultivars, Transplanting dates

Rice production is determined by the varietal and environmental parameters including genetic characteristics, soil, weather and crop management. Rice grain yield for a given cultivar is mainly dependent upon local climatic conditions, such as solar radiation and temperature, when plants are grown on the conditions of ample nutrients and water. Rice, a staple food in Kashmir valley, is planted on an area of 0.14 million ha. Low temperature during critical growth periods, lack of timely inputs, proper selection of variety and socio-economical conditions are main constraints resulting in low yield. Under temperate conditions of Kashmir, temperature plays a major role in crop production and, therefore, planting date assumes greater signifi-

cance (Summerfield *et al.*, 1992). Total biomass production of rice is determined by crop photosynthesis and respiration losses, both of which are sensitive to temperature (Horie *et al.*, 1994). For those regions where a rice–fallow system is predominant and there is more flexibility in the calendar, the determination of optimum planting time will be of great benefit in increasing grain yield per unit area. The optimal growing season for an already developed cultivar, for a long period, has been determined by changing planting dates with a certain time interval through experimentation that generally takes 2–3 years to complete. Due to variations in weather conditions between years, the results from these experiments cause great uncertainty, especially when the weather conditions during the growing season are far from normal. Moreover, such experiments usually cost a lot since these must be conducted over a wide range of cropping area.

Crop simulation models are a solution to such prob-

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lems. These are mathematical, computer-based representations of crop growth and environmental interaction. They provide output data to describe attributes of the crop at different points in time (Mathews *et al.*, 2002) and have several practical usages in agriculture. Since certain agricultural activities require advanced information of certain stages of crop development, output results from the crop models can be used to select the crop varieties specific to a region to minimize risk of damage due to unfavorable conditions, and estimate the magnitude of on-going and expected shifts in phenophase occurrence due to global warming.

The growth period of rice crop in Kashmir valley is limited by low temperature in spring and autumn and temperature fluctuation at flowering and grain-filling stages results in high spikelet sterility. Temperature cannot be manipulated easily under field conditions, but seeding time can be adjusted to meet the specific requirement for physiological stage of crop growth cycle. The adverse effect of sowing dates can also be minimized by selecting a suitable cultivar, as the magnitude of yield reduction varies with the cultivars.

Padali (1980) reported that 'half of the success of rice cultivation depends upon the seedling' and as such the ideal age of seedling is of primary importance for uniform stand and seedling establishment. Transplanting shock is a setback to growth due to uprooting and replanting of seedlings. It increases with increased age of seedling. Although transplanting rice at optimum period is critical to achieve high grain yield, optimum planting dates are genotype and location specific (Bruns and Abbas, 2006). The ideal age of transplanting is governed by duration of varieties and field condition. Time of planting and age of seed-

ling are 2 cultural practices which influence the growth and yield of transplanted rice. Thus, it is important to select suitable seedling age contributing towards increased rice production and resolve the problem posed by non-optimal transplanting schedule, which otherwise leads to high seedling mortality after transplanting as well as low grain yield. Hence the present investigation was taken up for the study.

MATERIALS AND METHODS

To simulate growth and yield of rice under temperate Kashmir conditions CERES-Rice model (DSSAT 4.5) was used. Evaluation of the model was done and genetic coefficients determined as per the already laid criteria in the model (Table 1).

Observed weather data of SKUAST of Kashmir, Shalimar, for growing seasons 2010 and 2011 were used for calibrating the coefficients of 3 rice varieties using set of data of 1 treatment of field experiment (22 May sowing). The coefficients for cultivars were estimated from field experiment conducted at Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir during 2010 and 2011 by adjusting coefficients until close match were achieved between simulated and observed phenology and yield. Soil of the experimental field was silty clay loam with neutral pH (6.8), low available nitrogen (368 kg N/ha) and medium phosphorus and potassium (14.4 and 160 kg/ha respectively). The crop management was done as per the recommended package of practices and only age of seedlings (20-, 30- and 40-day-old) was altered. The data used included anthesis day, grain yield and above-ground crop biomass, grain number per unit of ground area, individual grain weight, maximum leaf-area

Table 1. Genetic coefficients for the DSSAT CERES-Rice model

P_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 also referred to as the basic vegetative phase of the plant.
P_2R	Extent to which phasic development leading to panicle initiation is delayed (expressed as GDD in °C) for each hour increase in photoperiod above P_{20} .
P_5	(Time period in GDD in —°C) from beginning of grain filling (3 to 4 days after flowering) to physiological maturity with the base temperature of 9-°C.
P_2O	Critical photoperiod or the longest day-length (in hours) at which the development occurs at a maximum rate. At values higher than P_{20} development rate is slowed, hence there is delay due to longer day lengths.
G_1	Potential spikelet number coefficient as estimated from the number of spikelets per g of main culm dry weight (less leaf blades and sheaths plus spikes) at anthesis. A typical value is 55.
G_2	Single grain weight (g) under ideal growing conditions, i.e. non-limiting light, water, nutrients and absence of pests and diseases.
G_3	Tillering coefficient (scalar value) relative to IR-64 cultivar under ideal conditions. A higher tillering cultivar would have coefficient greater than 1.0.
G_4	Temperature tolerance coefficient. Usually 1.0 for varieties grown in normal environments. G_4 for <i>japonica</i> type rice growing in a warmer environment would be 1.0 or greater. Likewise, the G_4 value for <i>indica</i> type rice in very cool environments or season would be less than 1.0.

index (LAI) and final grain yield. To assess the accuracy of the model simulation compared with the observations, data generated from 3 ages of seedlings and 3 cultivars of rice over 2 years (2010 and 2011) were used for validating the performance of CMS-CERES-Rice model. Prediction capabilities of the model were tested by judging the performance of the crop in terms of grain yield, phenology (days to anthesis), straw yield and top weight (biological weight). Weather parameters selected for sensitivity analysis included ambient temperature ($\pm 3^\circ\text{C}$) and concentration of carbondioxide (350–700 ppm). Detailed treatment combinations are given in Table 2. Yearly data base of Kashmir (Shalimar) from 2009–10 to 2010–11 was then run to simulate response of rice cultivars ‘Jhelum’ found most suitable under existing agro-climatic condition out of three cultivars tested in the field experiments, i.e. ‘Jhelum’, Shalimar ‘Rice 1’ and ‘SKUA 403’.

RESULTS AND DISCUSSION

The genetic coefficients of the 3 cultivars were estimated using crop data of the these cultivars including phenological dates, yield and yield components. The genetic coefficients varied due to variation in their developmental rate at different phases. The genetic coefficients which are an important input parameter of the CERES-Rice model to simulate crop growth parameters are presented in the Table 3. As can be depicted from the table, the time period (GDD) of basic vegetative phase P_1 ranged from 440 in ‘Jhelum’ to 510 in ‘Shalimar Rice 1’, critical photoperiod hour was same in the 3 varieties, single grain weight ranged from 0.024 to 0.025, tillering coefficient was 1.0 for ‘Jhelum’ and ‘SKUA-403’ and it increased to 1.1 in ‘Shalimar Rice’. The CERES-Rice model was validated for 3 rice varieties, viz. ‘Jhelum’, ‘SKUA 403’ and ‘Shalimar Rice’, with 3 ages of seedlings i.e. 20-, 30- and 40-day during 2010 and 2011 in terms of grain yield, bio-

Table 3. Genetic coefficient of test varieties of rice

Genetic parameters	‘Jhelum’	‘Shalimar Rice 1’	‘SKUA 403’
P_1	440	510	500
P_2R	10	10	8.9
P_5	400	405	392
P_2O	12	12	12
G_1	60	60	60
G_2	0.024	0.025	0.024
G_3	1.0	1.1	1.0
G_4	1.0	1.0	1.0

Details of genetic parameters are given in Table 1

logical yield, straw yield and anthesis day and the data were plotted against observed.

Grain yield

Validation results revealed that the grain yield could be predicted well. The predicted yield was plotted against the observed yield (Fig. 1). Simulated grain yield was comparable with the observed grain yield with a variation ranging between 0.27 and 22%. The yield equation thus obtained was $Y = 0.9789 X - 0.7101$ with $R^2 = 0.9381$ and $RMSE = 4.05$, which indicated that a similar trend was followed by both observed and simulated values. The observed yield of all the treatments ranged between 3.93 and 8.23 tonnes/ha compared to simulated yield lying between 4.12 and 7.93 tonnes/ha. Twenty-day-old seedlings of age variety ‘Jhelum’ recorded the lowest grain yield, while the same variety when planted as 40 days old seedling recorded the highest grain yield during both the years. Validation of different rice varieties under temperate conditions of Kashmir was also done by Singh and Singh (2006) at Shalimar to predict whether grain, straw and biological yields were in agreement with the observed values. In *Tarai* belt of Uttarakhand state yield and maturity dates of 2 rice cultivars (‘Hybrid 6444’ and ‘Pantdhan 4’) pre-

Table 2. Combination of weather parameters selected for sensitivity analysis

Treatment	Max. temperature ($^\circ\text{C}$)	Min. temperature ($^\circ\text{C}$)	Carbon dioxide concentration
C_1	Normal (Ambient)	Normal (Ambient)	(ppm)
C_2	+3	+3	Normal
C_3	-3	-3	Normal
C_4	Normal	Normal	350
C_5	+3	+3	450
C_6	Normal	Normal	700
C_7	+3	+3	700
C_8	-3	-3	700

Note: C_1 - C_8 are combinations of weather parameters

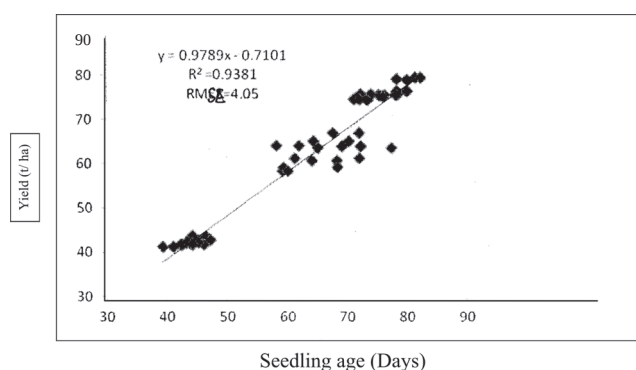


Fig. 1. Validation results for grain yield (tonnes/ha) as influenced by rice varieties and seedling age

dicted by CERES-Rice model were similar to the observed yield and maturity (Dass *et al.*, 2012)

Straw yield

Like grain yield, straw yield could also be predicted well. Simulated straw yield was comparable to observed straw yield with variation percentage ranging between 1.8 and 9.8. The R^2 value of 0.779 and RMSE value of 6.79 also indicated the closeness of predicted yield with simu-

lated yield. The observed straw yield ranged between 6.17 and 8.70 tonnes/ha, while the simulated straw yield ranged between 5.95 and 9.12 t/ha. Forty-day old seedlings of 'SR 1' gave the highest observed straw yield which varied from the simulated straw yield by 16.3%, while 20-day-old seedlings of 'SR 1' recorded the lowest observed straw yield which varied from simulated straw yield by 1.44% (Table 5) indicating that more biomass production leads to more grain yield subsequently.

Table 4. Observed and simulated grain yield (tonnes/ha) under different age of seedlings.

Treatment	2010			2011		
	Observed	Simulated	Deviation (%)	Observed	Simulated	Deviation (%)
V ₁ A ₁	4.52	4.27	5.82	4.73	4.28	10.60
V ₁ A ₂	6.92	6.38	8.40	7.23	6.38	13.17
V ₁ A ₃	8.14	7.93	2.65	8.23	7.93	3.72
V ₂ A ₁	4.43	4.36	1.44	4.65	4.35	6.74
V ₂ A ₂	6.77	6.69	1.21	7.21	6.68	7.84
V ₂ A ₃	7.84	7.64	2.63	8.01	7.64	4.81
V ₃ A ₁	4.43	4.16	6.43	4.62	4.19	10.62
V ₃ A ₂	6.52	6.34	2.75	7.75	6.35	22.07
V ₃ A ₃	7.55	7.55	0.27	7.61	7.52	1.11

V₁, 'Jhelum'; V₂, 'SKUA 403'; V₃, 'SR 1'; A₁, 20 Days old seedling; A₂, 30 Days old seedling; A₃, 40 Days old seedling

Table 5. Validation results for straw yield (tonnes/ha) of rice varieties under different age of seedlings

Treatment	2010			2011		
	Observed	Simulated	Deviation (%)	Observed	Simulated	Deviation (%)
V ₁ A ₁	6.52	5.95	9.48	6.13	5.96	2.78
V ₁ A ₂	7.61	6.95	9.54	6.64	6.95	-4.51
V ₁ A ₃	8.06	7.92	1.79	7.80	7.94	-1.73
V ₂ A ₁	6.52	6.08	7.11	6.57	6.45	1.90
V ₂ A ₂	8.04	7.60	5.82	7.95	8.29	-4.14
V ₂ A ₃	8.67	8.24	5.22	9.01	8.44	6.74
V ₃ A ₁	6.43	6.48	-2.24	6.12	6.30	-2.91
V ₃ A ₂	8.32	8.70	-4.30	7.18	7.98	-9.97
V ₃ A ₃	9.28	8.57	8.25	9.41	9.12	3.12

V₁, 'Jhelum'; V₂, 'SKUA 403'; V₃, 'SR 1'; A₁, 20 Days old seedling; A₂, 30 Days old seedling; A₃, 40 Days old seedling

Table 6. Validation results for biological yield (tonnes/ha) of rice varieties under different age of seedlings

Treatment	2010			2011		
	Observed	Simulated	Deviation (%)	Observed	Simulated	Deviation (%)
V ₁ A ₁	11.04	10.22	7.96	10.86	10.24	6.05
V ₁ A ₂	14.54	13.34	9.00	13.87	13.34	3.96
V ₁ A ₃	16.21	15.85	2.23	16.04	15.88	0.99
V ₂ A ₁	10.95	10.45	4.74	11.23	10.81	3.86
V ₂ A ₂	14.82	14.29	3.67	15.16	14.98	1.21
V ₂ A ₃	16.52	15.88	3.98	17.03	16.09	5.83
V ₃ A ₁	10.86	10.74	1.12	10.73	10.47	2.47
V ₃ A ₂	14.85	15.05	-1.33	14.94	14.33	4.22
V ₃ A ₃	16.84	16.11	4.52	17.02	16.65	2.22

V₁, 'Jhelum'; V₂, 'SKUA 403'; V₃, 'SR 1'; A₁, 20 Days old seedling; A₂, 30 Days old seedling; A₃, 40 Days old seedling

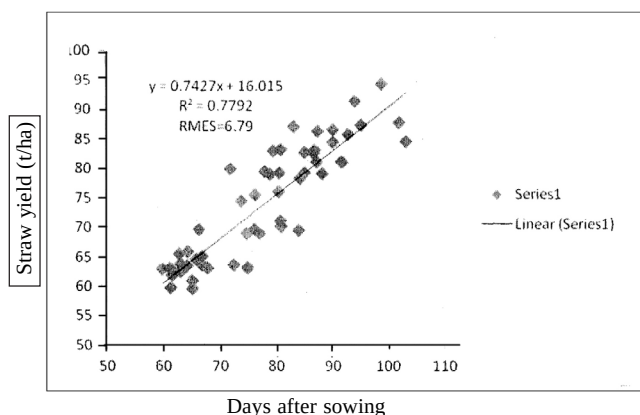


Fig. 2. Validation results for straw yield (tonnes/ha) of rice varieties under different age of seedlings

Biological yield

The simulated biological yield was also similar to the observed biological yield with variation between the 2 ranging from 0.99 to 11.23%. The yield equation obtained was $Y = 0.9533x + 0.4126$ with R^2 value equal 0.9678 and RMSE 7.5 indicating that the biological yield could be well predicted by the CERES-Rice model (Table 6). The observed biological yield ranged between 10.73 for 20-day-old seedlings of 'SR 1' in 2011 and 17.02 tonnes/ha for 40-day-old seedling. However, the simulated biological

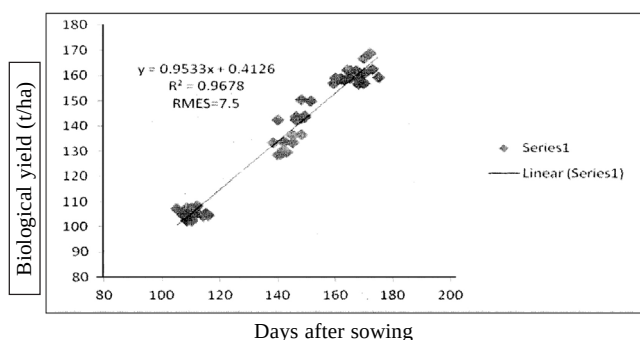


Fig. 3. Validation results for biological yield (t/ha) of rice varieties under different age of seedlings.

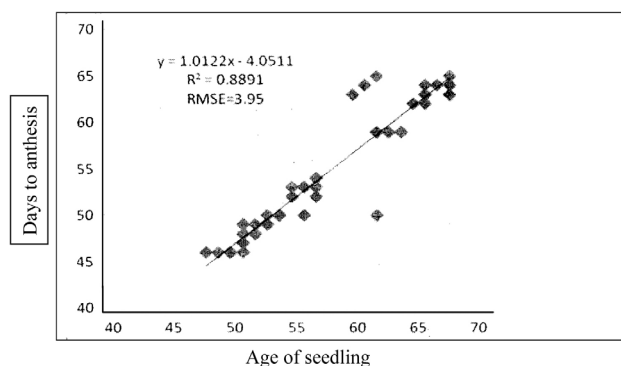


Fig. 4. Validation results for days to anthesis of rice varieties under different age of seedlings

yield ranged 10.22–16.65 tonnes/ha (Fig. 3).

Anthesis day

Simulation studies in most of the treatments revealed that lesser number of days were taken to anthesis than the observed days except for treatment 20-day-old seedlings of 'SR 1' and same variety when sown as 30-day-old seedling in which lesser days were taken to anthesis on field than were revealed by the simulation studies ranged between 4.08 and 24%. The obtained equation was $Y = 1.0122x - 4.0511$ with $R^2 = 0.8891$ and RMSE = 3.95. (Fig.4). From observed data, it could be concluded that 20-day-old 'SR 1' seedlings took least number of days to anthesis during both the years, i.e. 48 and 51 days on field, while simulation studies revealed that 40-day-old 'Jhelum' seedlings and 20-day-old seedlings of 'SR 1' took the lowest number of days to anthesis during the 1 and 2 years (Table 7).

Thus 2 year study revealed that transplanting 40-days old seedling of 'Jhelum' variety improved both growth and yield-contributing characters of rice. The said treatment combination also realized significantly higher grain yield

Table 7. Validation results for anthesis day of rice varieties under different age of seedlings

Treatment	2010			2011		
	Observed	Simulated	Deviation (%)	Observed	Simulated	Deviation (%)
V ₁ A ₁	60	59	1.69	66	59	11.86
V ₁ A ₂	64	47	36.17	61	47	29.78
V ₁ A ₃	54	46	17.39	60	46	30.43
V ₂ A ₁	62	63	-1.58	68	63	7.93
V ₂ A ₂	65	53	22.64	64	53	20.75
V ₂ A ₃	58	49	18.36	63	49	28.57
V ₃ A ₁	68	62	9.67	67	62	8.06
V ₃ A ₂	65	52	25.00	64	52	23.07
V ₃ A ₃	62	48	29.16	63	48	31.25

V₁, 'Jhelum'; V₂, 'SKUA 403'; V₃, 'SR 1'; A₁, 20 Days old seedling; A₂, 30 Days old seedling; A₃, 40 Days old seedling

and fitted well in the CERES-Rice model. Hence for realizing optimum rice yields, 40-day old seedlings of rice cultivar 'Jhelum' should be transplanted in the rice field by second week of June.

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