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Simulation of growth and productivity of rice (*Oryza sativa*) under tropical monsoon climate

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ABSTRACT

Simulation models in the field of agriculture are mathematical equations that represent the reactions occurring within the plant and the interactions between the plant and its environment to assess growth and productivity. In this study two simulation models, viz. CERES-Rice and ORYZA1, were validated to predict growth and productivity of 5 rice varieties ('Lalat', 'Ranjit', 'Gayatri', 'Savitri' and 'Swarana') under tropical monsoon climate of eastern India (Jatni, Khurda in Orissa) during rainy (*kharif*) season of 2003-2005. On validation it was observed that the simulated values of dry weight of leaves, weight of stems, weight of panicles, above - ground biomass, grain yield and leaf-area index (LAI) were not significantly different from the observed values for both CERES-Rice and ORYZA1. Only simulated specific leaf weight (mg/dm^2) was found significantly different from the observed values. Based on the correlation between above-ground dry biomass at flowering stage and yield, grain yield of the rice can be predicted in advance, i.e. at least 30 days before harvesting the crop.

Key words : CERES-Rice, Crop growth, ORYZA1, Rice, Simulation model

Recently simulation modelling has become one of the most powerful tools for analysing interactions in the soil, plant and atmospheric system. With the advent of computer use in agriculture, utility of meteorological, soil and plant-physiological parameters has increased for predicting crop yield or dry matter. Rice (*Oryza sativa* L.) is main staple food of India, occupying 42 million ha land (23% of total cropped area), and any negative fluctuation in its production will have a direct impact on food security of the country, Hence assessment of crop-growth parameters of rice with simulation models using meteorological, soil and plant-physiological parameters and their interrelationship with final yield will be helpful to predict rice production in advance, so that precautionary measures may be taken by policy-makers of the country. Some of the rice-based models like IRRI MOD, GRORYZA, RICE MOD, ORYZA, CERES-Rice, WOFOST (van Diepen *et al.*, 1988), SIMRIW (Horie, 1987), INTERCOM (Kropff and Van Laar, 1993), LOWBALL (Bouman, 1993), ORYZA-2000 (Bouman *et al.*, 2001), DSRICE1 (Barney, 2002) are being used in different parts of the world for analysis of crop growth and yield. But in most of the places validation was done under irrigated condition and models were used in isolation. In eastern India, 78% rice is grown under rainfed condition. Hence calibration and validation of rice based models under rainfed field condition will be useful to predict crop growth and yield in the region. In this study, we attempted to perform comparative study of two rice-based models, viz. CERES-Rice and ORYZA1, to simulate the growth and yield of five popular varieties of rice crop under rainfed condition of eastern India.

MATERIALS AND METHODS

Two rice models, viz. CERES-Rice and ORYZA1, were calibrated and validated in the field from 2003-2005 to estimate the crop growth and yield of five popular rice varieties of the region under tropical monsoon climate of eastern India (Khurda in Orissa). The mean monthly maximum temperature ranges from 41.6^{0}C in May to 26.9^{0}C in January. On the contrary, mean minimum temperature varies from 27.7^{0}C in May to 17.7^{0}C in December. The mean total annual rainfall is 1,439 mm, 69.2 % of which occurs during rainy season or south-west monsoon period (June-September). On an average, pre-monsoon and south-west monsoon showers contribute 6.1 % and 69.2 % of the total annual rainfall respectively. During post monsoon period (October-November), 22 % of annual rainfall occurs, which can be helpful for lowland, long duration rice, because the crop is at reproductive stage during that period. The mean date of onset of effective monsoon (OEM) was found to be 14 June, and the south-west monsoon generally ended on 28 September. The earliest and latest prob-

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able dates of OEM were found to be 5 and 20 June respectively, whereas those of monsoon withdrawal were worked out to be 13 September and 2 October respectively. Total annual potential evapo-transpiration (PET) and actual evapo-transpiration (AET) in the region were computed as 1,531 mm and 795 mm respectively.

The soils of the study fields were sandy loam to sandy clay-loam. The soil pH was slightly acidic to normal. The available soil-moisture content at field capacity ranged from 0.252 m^3/m^3 to 0.281 m^3/m^3. No salt problem was detected in the soil profile. Organic carbon content was low to medium in different study fields.

Description of rice models

CERES-Rice is the DSSAT (Decision Support System for Agro-technology Transfer) group of model, which works on daily time step basis and requires weather, soils and management-related data. Model calibration or parameterization is the adjustment of parameters so that simulated values compare well with the observed values.

In our experiment CERES-Rice model was calibrated with the help of 2003 rainy season (*kharif*) experimental data for all the 5 varieties separately. Calibration of the models was based on genetic coefficients [P1 = time period (GDD) of basic vegetative phase; P5 = time period (GDD) of grain filling phase; P2O = critical photo period (hour); G1 = potential spikelet number; G2 = single grain weight; G3 = tillering coefficient, G4 = temperature tolerance coefficient and P2R = extent phasic development (GDD)] generated through GENCALC software, on field-measured values of leaf-area index (LAI) grain yield, and soil. The model was run under non-stress nitrogen condition.

ORYZA1, an eco-physiological model for irrigated rice production, was developed in the SARP project (Simulation and System Analysis for Rice Production), which was co-ordinated by IRRI (International Rice Research Institute). It is based on INTERCOM (Kropff *et al*., 1993) and MACROS-L1D (Penning de Vries *et al*., 1989). The model describes crop growth and development as affected by solar radiation and temperature. The model follows the daily calculation scheme for the rates of dry-matter production of the plant organs and the rate of phenological development. By integrating these rates over time, dry-matter production of the crop is simulated throughout the growing season.

Input parameters for calibration of ORYZA 1 model were derived from the data sets of the field experiments during the *kharif* season of 2002 and 2003. The model performance was validated with the experimental data of 2004 and 2005 *kharif* seasons. The five variety specific genetic coefficients were calculated for calibrating ORYZA1 model and the variation among these genetic coefficients were noted. Other variety-specific input parameters [RGRL = relative growth rate of leaf area development 1/^{0}Cd; FSTR = fraction of stem reserves; SPGF = spikelet growth factor [no./kg]; WGRMX = maximum individual grain weight [mg/grain]; SLA = specific leaf area (ha leaf/kg leaf); FLV = fraction of shoot-dry matter allocated to leaves; FST = fraction of short-dry matter allocated to stems; FSO = fraction of shoot-dry matter allocated to storage organ; FSTR- fraction of stem reserves] were also calculated.

Crop management and experimental procedures

For simulating the crop growth and yield of rice, the experiments were conducted with 5 rice varieties, viz. 'Lalat', 'Ranjit', 'Gayatri', 'Savitri' and 'Swarna', during rainy season of 2002 to 2005. The differences in plant characteristics of 5 rice variables are mentioned in Table 1. The individual gross plot size was 8 m x 6 m with 5 replications. In each year rice was transplanted during the last week of July. The plant - to - plant and row – to - row distances were kept 0.15 m and 0.20 m respectively. The fertilizer doses (N: P: K) in the ratio of 80: 21.8**:** 41.6 were applied to the crop. Full dose of P and K and one-third of N were applied basal. The remaining N fertilizer was applied at tillering and panicle-initiation stages in two equal splits. Other crop-management practices like weeding and intercultural operations were performed using standard agronomic package of practices.

Plant samples were collected at transplanting, active tillering, panicle initiation, flowering and maturity stages of all the varieties for of plant growth. After collection the plant samples were cleaned to remove surface contamination and then separated into stems (leaf sheath + stem), leaves and panicles, and the leaf area was determined. To determine dry-biomass production, the samples were oven dried in order to stop enzymatic reactions and to remove moisture. The dry weight of the samples of different plant parts was recorded. The total dry-matter production at important phenological stages of the crop was also determined.

RESULTS AND DISCUSSION

Observed phenological stages

The durations of important phenological stages of 5 popular rice varieties of the region were recorded (Table 2). All these varieties were transplanted at 30 days after sowing (DAS). Study revealed that active tillering period was within 48-59 days after sowing in different selected varieties. Among the varieties studied 'Lalat' had the shortest duration (124 days) and 'Savitri' the longest (149 days) to attain maturity. The flowering stage of the crop

Table 1. Differences in plant characters of rice varieties used

Variety	Height (cm)	Duration (days)	Tillering ability	Lodging* (0-10 scale)
Lalat	111±22	120-125	High	5
Savitri	111±28	145-150	High	5
Ranjit	122±24	145-150	High	10
Gayatri	122±28	145-150	High	10
Swarna	101±20	135-140	High	5

Table 2. Observed duration of different phenological stages (pooled data of 2004 and 2005)

Variety	Phenological developments (days after sowing)				
	TP	AT	PI	FL	MT
Gayatri	30	58	84	116	147
Lalat	30	48	75	95	124
Ranjit	30	54	83	114	145
Savitri	30	59	85	118	149
Swarna	30	55	81	112	142

varied from 95 days in 'Lalat' to 118 days in 'Savitri'. The active tillering period of varieties ranged between 48 and 59 days.

Derivation of genetic coefficients of rice

The genetic coefficients of these varieties vary due to variation in their development rate at different phases. As an important input parameter of the models to simulate crop-growth parameters, genetic coefficients of these varieties were derived and are presented in Tables 3 and 4 for ORYZA1 and CERES-Rice, respectively.

For ORYZA1 model, the crop coefficients are: (i) DVRJ = Crop-development rate during the juvenile phase $(^0Cd)^{-1}$; (ii) DVRI = crop-development rate during photoperiod-sensitive phase $(^0Cd)^{-1}$; (iii) DVRR = crop-development rate during the grain filling phase $(^0Cd)^{-1}$ and (iv) DVRP = crop-development rate during panicle development phase $(^0Cd)^{-1}$. The mean values of DVRJ, DVRI, DVRR, DVRP were derived as 0.00048, 0.00076, 0.00069 and 0.00192 respectively.

For genetic coefficients of CERES-Rice model, time period growing degree days of basic vegetative phase (P1) ranged from 580 in 'Lalat' to 808 in 'Savitri'. Critical photoperiod hour (P2O) was 10.5 in 'Lalat' to 13.5 in 'Savitri'. Tillering coefficient (G3) and temperature-tolerence coefficient (G4) were taken 1 for all the varieties. Single-grain weight of different varieties ranged from 0.21 g in 'Swarna' to 0.28 g in 'Lalat', and P5 parameter ranged from 430 in 'Lalat' to 450 in 'Ranjit'.

Observed crop-growth parameters

The parameters of crop-growth analysis like dry weight of leaves, dry weight of stem, specific leaf weight, above-ground biomass and leaf-area index were observed at different growth stages (Table 5) for comparison with simulated values. Study revealed that dry weight of the leaves at active tillering stage ranged from 0.64 t/ha in 'Swarna' to 1.18 t/ha in 'Lalat'. The dry weight of stem at active tillering stage was 0.82-1.10 t/ha, and its highest dry weight was recorded at flowering stage, being 7.96 t/ha in

Table 3. Developed genotype coefficients of different rice varieties for ORYZA1 model

Variety	Gayatri	Lalat	Ranjit	Savitri	Swarna	Mean	SD
DVRJ $(^0Cd)^{-1}$	0.00042	0.00055	0.00060	0.00040	0.00042	0.00048	0.00009
DVRI $(^0Cd)^{-1}$	0.00076	0.00076	0.00076	0.00076	0.00076	0.00076	0.00000
DVRP $(^0Cd)^{-1}$	0.00057	0.00084	0.00090	0.00051	0.00063	0.00069	0.00017
DVRR $(^0Cd)^{-1}$	0.00194	0.00189	0.00176	0.00195	0.00206	0.00192	0.00011

Table 4. Genotype coefficients for different rice varieties computed through CERES-Rice model

Genetic parameter		**'Gayatri'**	**'Lalat'**	**'Ranjit'**	**'Savitri'**	**'Swarna'**	**Mean**	**SD ±**
P1:		790	580	748	808	755	736.3	93.11
P2R:		176	120	160	170	140	153.2	23.048
P5:		450	430	450	448	445	444.6	8.414
P2O:	Critical photoperiod (hr)	12.5	10.5	11.7	13.5	12.8	12.2	1.15
G1:		62	65	68	60	38	58.6	11.91
G2:	Single-dry grain weight(g)	0.026	0.028	0.023	0.025	0.021	0.025	0.00
G3:	Tillering coefficient	1	1	1	1	1	1.00	0.00
G4:	Temperature-tolerance coefficient	1	1	1	1	1	1.00	0.00

P1: Time period in growing degree days (base 9 ^{0}C) from emergence to end of juvenile phase; P2R: Photoperiod sensitivity (degree day delay per hr increase in daylength); P5: Degree days (base 9 ^{0}C) from beginning of grain-filling (3-4 d after flowering) to physiological maturity; G1:Potential spikelet number coefficient as estimated from number of spikelets/g main culm + spike dry weight at anthesis (g)

Table 5. Comparison between observed and simulated crop-growth parameters at different stages

Variety	Active tillering			Panicle initiation			Flowering			Maturity		
	OBS	CER	ORY	OBS	CER	ORY	OBS	CER	ORY	OBS	CER	ORY
Dry weight of leaves (t/ha)												
'Gayatri'	0.99	0.96	0.99	2.40	2.30	2.32	2.25	2.21	2.23	1.15	1.22	1.13
'Lalat'	1.18	1.26	1.15	2.55	2.68	2.69	2.45	2.67	2.42	1.25	1.20	1.36
'Ranjit'	0.95	1.01	1.01	3.10	3.26	3.04	1.92	2.09	1.90	0.81	0.78	0.81
'Savitri'	0.77	0.83	0.83	2.83	2.70	2.75	1.97	1.95	1.94	1.00	0.96	0.96
'Swarna'	0.68	0.65	0.67	2.44	2.44	2.36	2.25	2.24	2.40	0.89	0.87	0.85
Dry weight of stem (t/ha)												
'Gayatri'	0.91	0.89	0.83	4.10	3.62	3.96	7.50	6.09	7.14	5.45	5.31	5.43
'Lalat'	1.03	0.87	0.98	3.81	3.77	3.33	4.83	4.56	4.28	3.99	3.22	3.44
'Ranjit'	1.10	0.97	1.04	3.44	3.30	2.78	6.94	6.66	6.43	4.81	4.53	3.88
'Savitri'	0.83	0.81	0.71	4.29	4.22	4.27	7.96	7.61	7.22	5.63	5.40	4.93
'Swarna'	0.82	0.81	0.72	3.69	2.98	3.08	5.17	5.07	4.20	3.46	3.07	3.30
Total above-ground biomass (t/ha)												
'Gayatri'	1.90	1.86	1.82	6.50	5.92	6.28	11.04	9.57	10.75	13.66	13.43	13.38
'Lalat'	2.21	2.13	2.13	6.36	6.46	6.02	9.40	9.25	8.80	11.54	10.71	11.50
'Ranjit'	2.05	1.98	2.05	6.54	6.56	5.82	11.83	11.96	11.17	12.90	13.12	12.68
'Savitri'	1.60	1.64	1.54	7.12	6.91	7.02	12.45	11.97	11.86	14.58	13.96	14.46
'Swarna'	1.50	1.45	1.39	6.13	5.42	5.43	9.22	9.28	8.49	12.03	11.56	11.61
Specific leaf weight (mg/dm^2)												
'Gayatri'	372	356	358	588	628	632	444	466	485	752	822	822
'Lalat'	410	395	401	515	499	510	529	573	573	704	700	766
'Ranjit'	386	381	413	524	570	563	442	424	423	532	517	584
'Savitri'	448	441	435	508	496	489	467	460	452	592	571	581
'Swarna'	418	403	411	503	503	500	526	559	514	581	570	560
Leaf-area index												
'Gayatri'	1.90	1.21	1.29	4.25	2.92	2.53	4.09	2.14	2.08	1.63	1.16	1.15
'Lalat'	2.28	1.48	1.35	3.97	2.71	2.98	3.69	2.16	2.57	1.41	1.57	1.31
'Ranjit'	1.97	1.13	1.32	4.39	2.39	2.84	2.65	2.43	2.23	1.62	1.32	1.24
'Savitri'	1.48	1.79	1.61	4.46	3.78	3.42	3.31	2.81	2.78	1.81	1.67	1.39
'Swarna'	1.30	1.46	1.38	3.46	2.98	3.01	3.40	2.20	2.52	1.73	1.20	1.39

OBS = Observed, CER = Simulated result of CERES - Rice; ORY = Simulated result of ORYZA1

'Savitri' and of 4.83 t/ha the lowest in 'Lalat'. At maturity the dry weight of stem ranged from 3.46 to 5.63 t/ha among the varieties. The highest dry weight of leaves was observed at panicle-initiation stage of the crop, which varied from 2.4 to 3.1 t/ha in different varieties, but at maturity their dry weight ranged from 0.81 to 1.25 t/ha. At active tillering stage the observed peak leaf area index (LAI) varied from 1.30 in 'Swarna' to 2.28 in 'Lalat'; the highest (4.46) being in 'Savitri' at panicle initiation stage. At flowering stage the LAI was 2.46 - 4.09. The total above-ground biomass production was the highest at maturity stage and varied from 11.54 to 13.66 t/ha, but at flowering stage it varied from 9.22 t/ha in 'Swarna' to 12.45 t/ha in 'Savitri'.

Validation of simulated crop-growth parameters with observed values

The different crop growth parameters (dry weight of leaves, dry weight of stem, total above-ground biomass, leaf-area index and, specific leaf weight) of rice were simulated using ORYZA1 and CERES-rice models and comparative results of observed (mean of 2004 and 2005 results) and simulated values are presented in Table 7. The validated panicle weight and grain yield are mentioned in Table 6 and 7 respectively. A detailed statistical analysis was carried out through chi-square test (for observed and simulated data) with test for significance at 5% level. Different crop-growth stages were taken in columns and varieties in rows for statistical analysis (Table 8). The probabilities of estimates (simulation results) were also tabulated. It was revealed that simulated values of dry weight of leaves, dry weight of stem, panicle weight, above-ground biomass, LAI and grain yield were not significantly (5% level) different for both CERES-Rice and ORYZA1 simulation models with observed values. The probabilities of estimates for these parameters were in the range of 0.72-1.0 and 0.82-1.0 for CERES-Rice and ORYZA1 respectively. Only simulated specific leaf weight was found significant from the observed values with probability values, being 0.02 and 0.0005 for CERES-Rice and ORYZA1 models respectively. The analysis revealed that both the models can be used for simulating major crop-growth parameters and yield of rice in tropical monsoon climate of eastern India with equal importance.

Table 6. Comparison between observed and simulated panicle weight t/ha at different crop growth stages

Variety	Flowering			Maturity		
	OBS	CER	ORY	OBS	CER	ORY
'Gayatri'	1.29	1.36	1.61	5.42	5.35	5.21
'Lalat'	1.08	1.47	1.35	5.21	5.50	5.19
'Samrat'	1.27	1.79	1.88	6.30	6.61	6.47
'Savitri'	1.10	1.45	1.60	6.82	6.91	6.58
'Swarna'	1.80	1.81	2.19	5.54	5.39	5.38

OBS = Observed; CER = Simulated result of CERES Rice; ORY = Simulated result of ORYZA1

Prediction of yield with crop-growth parameters

The interrelationship between maximum above-ground biomass production and grain yield was established at active tillering, panicle-initiation, flowering and maturity. Study revealed that at flowering stages total biomass production was better correlated with grain yield (Fig. 1). Hence total biomass of that stage may be used for yield prediction.

Y (Yield) = a + b * X (Biomass at respective stage)

Yield = 5.08 - 3.00 *BM_{AT} (r = -0.14, R^2 = 0.02)

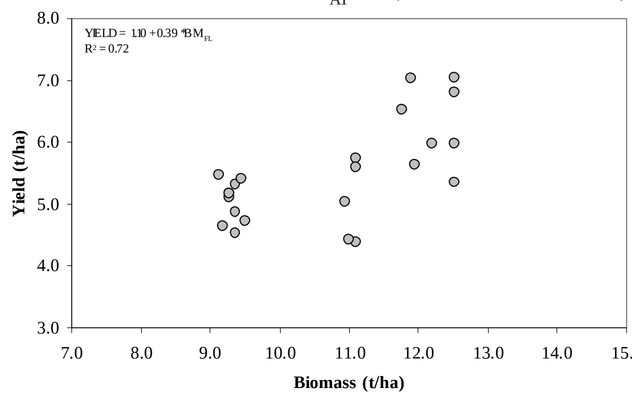

Fig. 1. Relationship between grain yield and biomass at flowering of different rice varieties

Table 7. Comparison between observed and simulated grain yields (t/ha) of different rice varieties

Data source	'Gayatri'	'Lalat'	'Ranjit'	'Savitri'	'Swarna'	Population, p(mean ± δ, n)
Observed	3.82	4.03	4.64	4.64	3.75	P (4.18, 0.44, 5)
CERES-Rice	4.38	4.54	5.50	5.75	4.93	P (5.02, 0.59, 5)
ORYZA1	4.00	4.29	5.14	5.22	4.29	P (4.49, 0.55, 5)

Table 8. Chi-square test between observed and simulated results

Crop parameter	Row	Column	Degrees of freedom	CERES-Rice				ORYZA1			
				Chi-square value		Prob- (chi-X, df)	Signi-ficance	Chi-square values		Prob- (chi-X, df)	Signi-ficance
				Actual	Tab- (5%,df)			Actual	Tab- (5%,df)		
Leaf weight	5-var	AT-PI-FL-MT	12	0.08238	21.02607	1.00000	NS.	0.04850	21.02607	1.00000	NS
Stem weight	5-var	AT-PI-FL-MT	12	0.92500	21.02607	0.99999	NS	1.24685	21.02607	0.99995	NS
Panicle weight	5-var	FL-MT	4	0.10155	9.48773	0.99875	NS	0.17807	9.48773	0.99626	NS
Above ground bio-mass	5-var	AT-PI-FL-MT	12	0.53474	21.02607	1.00000	NS	0.43106	21.02607	1.00000	NS
Leaf Area Index	5-var	AT-PI-FL-MT	12	8.73124	21.02607	0.72570	NS	7.44443	21.02607	0.82690	NS
Specific leaf weight (mg/dm^2)	5-var	AT-PI-FL-MT	12	23.72703	21.02607	0.02215	S	34.67380	21.02607	0.00053	S

AT = Active tillering, PI = panicle initiation, FL = flowering, MT = maturity, HR = harvest
S = significant, NS = non-significant; Weight in t/ha

Yield= -2.46 + 1.30 *BM_{PI} (r = 0.72, R^2 = 0.51)
Yield = 1.10 + 0.39 *BM_{FL} (r = 0.85, R^2 = 0.72)
Yield = 1.15 + 0.32*BM_{MAT} (r = 0.59, R^2 = 0.35)

where BM_{AT} = Above-ground dry biomass at active tillering stage; BM_{PI} = above-ground dry biomass at panicle-initiation stage; BM_{FL} = above-ground dry biomass at flowering stage; and BM_{MAT} = Above ground dry biomass at maturity stage.

Thus the study revealed that simulated values of dry weight of leaves, dry weight of stem, panicle weight, above-ground biomass, LAI and grain yield were not statistically significant (5% level) for both CERES-Rice and ORYZA1 with observed values. Only simulated specific leaf weight was found significantly different from the observed values. Both the models can be used for simulating major crop-growth parameters and yield of rice under tropical monsoon climate of India with equal importance. Based on correlation between above-ground dry biomass and yield at flowering stage, grain yield of the rice can be predicted in advance, i.e. at least 30 days before harvesting the crop.

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