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Comparative evaluation of WOFOST and ORYZA2000 models in simulating growth and development of rice (*Oryza sativa* L.*)* in Punjab

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ABSTRACT

Two simulation models, viz. WOFOST and ORYZA2000 were validated and compared to predict growth and productivity of 2 rice varieties (PR 116 and PR 118), under central plain regions of Punjab, India, during 2006-2008. The simulated values of dry weight of leaves, dry weight of stem, above ground biomass, leaf area index and grain yield did not differ significantly with observed values. Based on statistical evaluation of performance of crop simulation models, ORYZA2000 showed an advantage over WOFOST model in simulating crop growth parameters and grain yield of rice.

Key words*:* WOFOST, ORYZA2000, crop models, simulation, rice

Rice (*Oryza sativa* L.) is the most important cereal crop in Asia, grown under varying hydrological conditions. Rice grows in Asia on an area of 90 per cent of total world's rice area. It is the main staple food crop of India, covering an area of about 43.8 million hectares with total production of 96.4 million tonnes of rice during 2008-09 (Anonymous, 2009).

Simulation modelling is one of the most powerful tools for analysing interactions in the soil, plant and atmosphere systems. The growth and development of a plant at any time can be described as the net result of the biochemical, physiological processes of the plant with the growing environment. The qualification of such an interaction of weather in terms of growth and yield of a crop is called crop modelling. Crop models are simplified representations of the complex relationship between variables, comprises crop environment and crop performance using established mathematical or statistical technique or both (Baier, 1989). Simulation would be an essential step in defining the yield gap between farmers yield and potential yields, assisting efforts to bridge the gaps. The problem is associated with the selection of simulation model as variety of rice based models like IRRI MOD, GRORYZA, RICE MOD, ORYZA, CERES - RICE, WOFOST, SIMRIW, ORYZA 2000, DSRICE1 are being used in different parts of the world for analysis of crop and yield. In Punjab, rice is grown under irrigated conditions where water is not a limiting factor. Hence calibration and validation of rice based models under potential production conditions 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. WOFOST and ORYZA 2000, to simulate the growth and yield of two popular varieties of rice crop under potential production conditions of Northern India.

MATERIALS AND METHODS

To evaluate WOFOST 7.1 and ORYZA2000 models, field experiments were conducted at Punjab Agricultural University Research Farm, Ludhiana, India (30°54 N, 75°48 E, 247m above mean sea level) on a deep alluvial sandy loam soil (USDA: *Typic ustocherpt*, FAO: *Dystric cambisol*) during 2006 to 2008. This area is representative of the central plains of Punjab and is characterized by subtropical, semi-arid climate with 25.5°C average temperature and 550mm rainfall during crop season (May-Oct). Two varieties PR 116 and PR 118 of rice were transplanted after 30 days of sowing at 20 cm x 15 cm hill to hill spacing and with 2 seedlings per hill. The crop was fertilized @ 125:30:30 kg ha^{-1} of N: P_2O_5: K_2O. The optimum soil moisture was maintained by applying 7.5cm irrigation water 2 days after disappearance of ponded water in addition to rain water received during crop season. All the recommended agronomic practices from package and practices were adopted to raise the crop.

Model calibration

Input parameters for WOFOST (ver. 7.1) and ORYZA2000 were derived from the data sets of the field experiments during the wet season of 2006, 2007 and 2008 for model calibration and validation.

Degree-days are in degree Celsius. For the rice heat unit (degree days) calculations, base temperature (T_{base}) was 8 ^{0}C, optimum temperature (T_{opt}) was 30 ^{0}C and maximum

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Table 1: Calibrated genotype coefficients of different rice varieties for WOFOST model

S No	Genetic coefficient*	PR116	PR118
1.	TSUM1	2150	2150
2.	TSUM2	860	840
3.	LAIEM	0.0200	0.0230
4.	RGRLAI	0.0035	0.0039
5.	CVL	0.7300	0.7590
6.	CVO	0.6500	0.7000
7.	CVR	0.7040	0.7040
8.	CVS	0.7000	0.7450
9.	RML	0.0180	0.0180
10.	RMO	0.0140	0.0120
11.	RMR	0.0100	0.0100
12.	RMS	0.0090	0.0090

*TSUM1-temperature sum from emergence to anthesis, TSUM2-temperature sum from anthesis to maturity, LAIEM-leaf area at emergence, RGRLAI-maximum relative increase in LAI, CVL-efficiency of conversion into leaves, CVO- efficiency of conversion into storage organ, CVR- efficiency of conversion into roots, CVS-efficiency of conversion into stem, RML-maintenance Resp. rate leaves, RMO-maint. Resp. rate storage org., RMR-maint. Resp. rate roots, RMS-maint. Resp. rate stems

Table 2: Genotype coefficients for different rice varieties computed through ORYZA2000 model

Development rate constants (DRC)(°C day-1) for rice cultivar: PR116					
DRCJ = 0.000450	Development rate in juvenile Phase				
DRCI = 0.000750	Development rate in photoperiod-sensitive phase				
DRCP = 0.000758	Development rate in panicle development phase				
DRCR = 0.00166	Development rate in reproductive phase				
Development rate constants (DRC)(°C day-1) for rice cultivar: PR118					
DRCJ = 0.000400	Development rate in juvenile Phase				
DRCI = 0.000745	Development rate in photoperiod-sensitive phase				
DRCP = 0.000745	Development rate in panicle development phase				
DRCR = 0.00156	Development rate in reproductive phase				
Partitioning coefficient For rice cultivars PR116 and PR118					
DS	0	0.5	0.75	1.0	2.0
FLT	0.50	0.50	0.35	0.07	0.0
FST	0.50	0.50	0.65	0.48	0.0
FSO	0.0	0.0	0.0	0.45	1.0
SLA	0.0030	0.0030	0.0023	0.0017	0.017

Where DS in development stage : FLT is Leaves as a fraction of shoot increment; FST is Stem as a fraction of shoot increment; FSO is Shoot organ as a fraction of shoot increment; SLA is Specific leaf area

temperature was 42 °C. For temperature below the base temperature or above the maximum temperature, the rate of development is zero. The heat units for a day (°C day^{-1}) are calculated from the mean daily temperature (T_d).

Parameterization

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 presented in the Table 1 and 2 for WOFOST and ORYZA2000, respectively.

RESULTS AND DISCUSSION

Phenological stages

The duration of important phenological stages of two popular rice varieties of the region were recorded (Table 3). Both the varieties were transplanted in second fortnight of July at 30 days after sowing (DAS). Study revealed that active tillering period was within 60 days after sowing in both the selected varieties. Among the varieties studied PR 116 had the shorter duration (144 days) as compared to PR 118 (158 days) to attain maturity. The flowering stage varied from 102 in PR 116 to 113 in PR 118.

Leaf area index

Simulated LAI for both the rice cultivars (PR 116 and PR 118) was in good agreement with observed LAI. The only exception was with ORYZA2000 at tillering stage, where

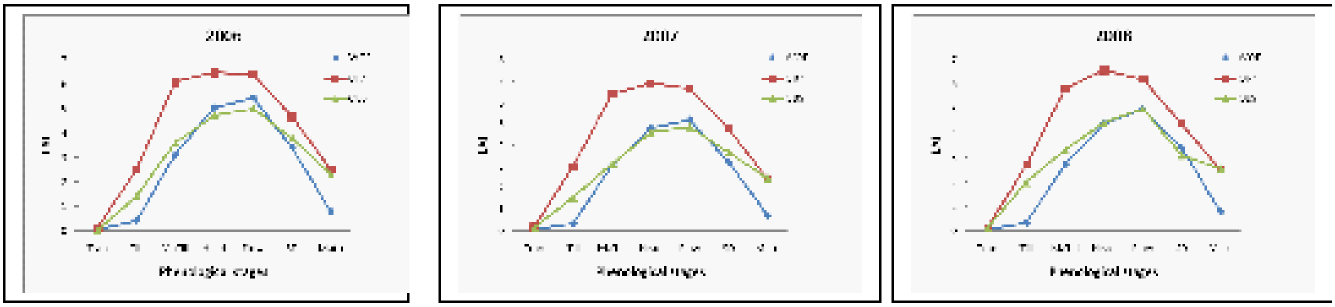

Fig 1: WOFOST, ORYZA 2000 simulated and observed (OBS) LAI of Rice variety PR 116

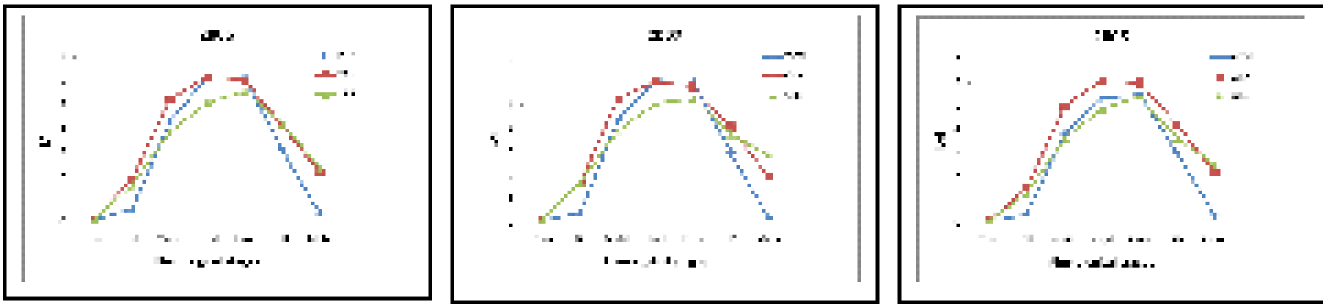

Fig 2: WOFOST, ORYZA 2000 simulated and observed (OBS) LAI of Rice variety PR 118

Table 3: Differences in plant characters of rice varieties used in the study

Plant characters	PR 116	PR 118
Height (cm)	108	104
Duration (days)	144	158
Tillering ability	High	High
Average yield (q ha^{-1})	69	73
Phenology (days after sowing)		
Transplanting	30	30
Active tillering	54	58
Panicle initiation	85	93
Flowering	102	113
Maturity	144	158

simulation overestimated the observed levels. It may be due to transplanting shock, as after transplanting rice plant takes time to develop new root system to recover the injuries occurred during transplanting. ORYZA2000 model assumed the quick recovery from transplanting shock and simulated the high LAI during tillering growth stage.

Observed and simulated values of LAI are represented in Fig. 1 and 2. Overall LAI was reasonably simulated by both the models as the coefficient of determination (r^2) for observed and simulated LAI were around 0.90 for all simulation years and for all the cultivars.

Biomass

Periodic dry matter accumulation (dry weight of leaves, dry weight of stem and total above ground biomass) of rice were simulated using WOFOST and ORYZA2000 models and comparative results of observed and simulated values are presented in Table 4. It was revealed that simulated values of dry weight of leaves, dry weight of stem and above ground biomass were in good agreement with field observations. Model simulated results were satisfactory for both varieties in all the three years, because most of the simulated values lie within their corresponding observed values and high degree of correlation was observed between them.

Dry weight of leaves best simulated at panicle initiation stage (r = 0.83 (WOF), 0.89 (ORY) for PR 116, and at flowering stage (r = 0.71 (WOF), 0.74 (ORY) for PR 118 by both the models. As the crop leads to maturity, leaf sensation was precisely predicted by both the models, depicted by the high degree of correlation of coefficient (r = 0.91 (WOF), 0.88 (ORY)), at physiological maturity stage. Although dry weight of stem reasonably simulated throughout the crop growth, yet simulation at physiological maturity stage made the difference by high degree of correlation between observed and simulated values for both the rice cultivars (PR 116, r = 0.89 (WOF), 0.90 (ORY), PR 118, r = 0.92 (WOF), 0.96 (ORY)). Total above ground biomass substantially simulated

Table 4: Comparison between observed and simulated crop-growth parameters at different stages.

Cultivar	Year	Active Tillering			Panicle Initiation			Flowering			P. Maturity		
		OBS	WOF	ORY	OBS	WOF	ORY	OBS	WOF	ORY	OBS	WOF	ORY
Dry weight of leaves (t ha^{-1})													
	2006	1.15	1.87	0.97	2.60	2.73	2.95	3.06	2.63	3.22	1.15	1.06	0.77
PR 116	2007	1.35	2.03	0.95	2.62	2.80	2.81	3.11	2.69	3.57	0.78	1.00	0.64
	2008	0.95	1.92	0.89	2.40	2.69	2.59	2.90	2.63	3.05	1.56	1.07	0.78
r^1			0.45	0.52		0.69	0.79		0.46	0.77		0.83	0.77
	2006	1.19	1.61	1.12	2.87	2.48	3.22	2.92	2.46	3.18	1.56	0.88	0.81
PR 118	2007	1.23	1.51	1.10	2.65	2.41	3.17	2.32	2.39	3.11	0.70	0.82	0.79
	2008	1.15	1.40	0.98	2.61	2.46	2.92	2.48	2.46	3.05	1.01	0.91	0.78
r^1			0.27	0.62		0.37	0.53		0.50	0.55		0.28	0.59
Dry weight of stem (t ha^{-1})													
PR 116	2006	1.40	2.04	1.00	4.01	4.24	4.15	5.14	4.97	5.21	4.45	4.36	3.96
	2007	1.64	2.18	0.97	3.71	4.21	3.88	4.69	4.94	4.93	4.20	4.30	3.42
	2008	1.21	2.10	0.91	3.80	4.26	3.51	5.02	5.02	4.95	4.52	4.47	3.82
r^1			0.38	0.36		0.16	0.37		0.36	0.56		0.79	0.81
PR 118	2006	1.68	1.83	1.42	4.82	4.04	4.83	5.92	5.00	6.03	4.13	4.30	4.46
	2007	1.19	1.67	1.39	4.58	3.88	4.70	5.00	4.66	5.76	4.04	4.08	4.00
	2008	0.99	1.54	1.25	4.59	4.09	4.26	5.41	5.15	5.74	4.14	4.50	4.36
r^1			0.96	0.69		0.10	0.42		0.40	0.76		0.85	0.92
Total above-ground biomass (t ha^{-1})													
PR 116	2006	2.55	3.91	1.98	7.22	7.54	7.96	9.36	8.96	10.37	15.78	14.38	16.24
	2007	2.99	4.22	1.93	6.80	6.98	7.44	9.15	8.98	9.76	15.95	14.74	16.12
	2008	2.16	4.03	1.81	6.58	7.09	6.72	9.46	9.07	9.96	15.21	14.50	16.04
r^1			0.63	0.66		0.86	0.96		0.62	0.51		0.40	0.65
PR 118	2006	2.87	3.45	2.56	8.02	7.08	8.35	11.26	8.94	12.14	16.95	14.85	17.29
	2007	2.42	3.19	2.5	7.19	6.90	7.97	10.56	8.31	11.5	16.09	14.89	17.09
	2008	2.14	2.94	2.23	7.61	7.15	8.25	11.02	9.19	11.7	17.62	14.98	17.25
r^1			0.98	0.77		0.49	0.94		0.66	0.85		0.38	0.41

Table 5: Comparison between observed and simulated grain yield (t ha^{-1}) of different rice varieties.

Year	Observed	WOFOST	ORYZA	% Deviation WOFOST	% Deviation ORYZA
PR 116					
2006	6.58	6.31	6.75	-4.11	+2.63
2007	6.86	6.65	7.09	-3.05	+3.37
2008	6.42	6.56	6.84	+2.23	+6.64
PR 118					
2006	7.56	6.93	7.50	-8.25	-0.69
2007	7.36	6.99	7.87	-5.00	+6.96
2008	7.22	7.35	7.43	+1.84	+2.91

at panicle initiation by WOFOST and ORYZA2000 crop simulation models for both the rice varieties, which is evident from aloft magnitude of correlation coefficient. The probabilities of estimates (r) for this stage were in the range of 0.70 - 0.96 for both the crop growth simulation models. Also, total above ground biomass best simulated flowering stage by WOFOST (r = 0.81) and ORYZA2000 (r = 0.92) simulation models.

Grain yield

The simulated rice yield for two rice cultivars are shown in Table 5. Both the models performed well in predicting grain yield for both the cultivars and the association between simulated and observed values was significant. The average

Table 6: Values of statistical parameters used in model comparison for simulated grain yield of rice

MODEL	Cultivar	ME (q ha^{-1})	RMSE%	CD	EF	CRM	Mean Rank
ORYZA2000	PR116	1.5 (1)*	2.9 (1)	0.05 (1)	-24.7 (1)	-0.01 (1)	1
	PR118	2.1(1)	3.5 (1)	0.12 (1)	-37.5 (1)	-0.01 (1)	1
WOFOST	PR116	3.0(2)	5.2 (2)	0.01 (2)	-78.8 (2)	0.04 (2)	2
	PR118	4.3(2)	6.3 (2)	0.02 (2)	-125.7(2)	0.05 (2)	2

*Values in parenthesis represent model rank

grain yield for PR 116 simulated by WOFOST model (6.50t ha^{-1}) and ORYZA2000 (6.89 t ha^{-1}) is quite close to observed average yield of rice (6.65 t ha^{-1}). WOFOST model under estimated the grain yield by 4.1% and 3.0% in 2006 and 2007 and overestimated by 2.2% in 2008. Whereas, ORYZA2000 model overestimated the grain yield in 2006, 2007 and 2008 by 2.6%, 3.3% and 6.6%, respectively. Almost similar trend was found in another but genetically similar cultivar of rice .i.e. PR 118. Overall performance of both the models was quite good as average simulated yield falls under ±8% deviation of average grain yield for both the cultivars in all the years.

The analysis revealed that both the models could be used for simulating major growth parameters and yield of rice in central plain regions of Punjab.

Evaluation of WOFOST and ORYZA 2000 models

The crop growth parameters and grain yield simulated by the models and observed from the field was subjected to mean analysis. The corresponding standard deviations were computed and compared with estimates of grain yield simulated by models WOFOST and ORYZA 2000 (Table 6).

CD statistic gives the ratio between the scatter of simulated values and scatter of measurements. The EF value compares the simulated values. The CRM is a measure of tendency of the model to overestimate or under estimate the measurements. A negative CRM shows a tendency to overestimate. The two models were ranked in order of performance for example the model produce greater EF values received a rank of one. The model produced minimum over all rank for a variable (yield) is chosen as best model with respect to that variable.

CONCLUSION

Thus the study revealed that simulated values of dry weight of leaves, dry weight of stem, above ground biomass, leaf area index and grain yield were not differ significantly for both WOFOST and ORYZA2000 with observed values. Both the models can be used for simulating major crop growth parameters and yield of rice under central plain region of Punjab with equal importance. But based on statistical evaluation of performance of WOFOST and ORYZA2000 crop simulation models, ORYZA2000 Showed an advantage over WOFOST model in simulating crop growth parameters and grain yield of rice. Hence ORYZA2000, which is a generic model, is more reliable in simulating rice crop growth as compared to WOFOST model.

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