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Assessment examine of the modeling ability of ORYZA2000 for rice cultivars in Guilan province (Iran)

Ebrahim Azarpour[1], Maral Moraditochaee[2]*, Hamid Reza Bozorgi[1]

[1] *Young Researchers and Elite Club, Rasht Branch, Islamic Azad University, Rasht, Iran*

[2] *Department of Agriculture, College of Agricultural Science, Takestan Branch, Islamic Azad University, Takestan, Iran*

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Abstract

Various crop growth simulation models exist for rice but thorough validation and evaluation reports are scarce. We present the model ORYZA2000, which simulates the growth and development of rice under conditions of potential production and water and nitrogen limitations. In order to evaluated model, an experiment as factorial in RCBD with three replications was conducted during 2009 year in the Rice Research Institute, Iran, and Roudsar, East of Guilan. Factors were cultivar (Khazar, Ali Kazemi and Hashemi), and nitrogen fertilizer levels (0, 30, 60, and 90 Kg N/ha). Two programs DRATES and PARAM provided by ORYZA2000 are performed for the calibration using the experimental. Evaluation assimilate and measured partitioning factors to leaves, stems, storage and above ground total (FLV, FST, FSO and FAGT respectively); leaf area index (LAI); total biomass and grain yield for each cultivar with determination R2, p(t), α, β, CRM, RMSE and RMSEn. With respect to in both locations the difference between simulated and measured total biomass of the varieties was +2 to +13% and the difference between simulated and measured grain yield was +3 to +12% (Tables 2, 3, 4), it can be concluded that the model has a high capability to simulate total biomass and grain yield of the cultivars in Guilan climate condition.

***Corresponding Author:** Maral Moraditochaee ✉ Maral_Moraditochaee@yahoo.com

Introduction

Rice is an important food crop for a large proportion of the world's population. It is staple food in the diet of the population of Asia, Latin America, and Africa. Rice provides 35-60% of the dietary calories consumed by more than 3 billion people (Fageria *et al.,* 2003). Globally, it is also the second most cultivated cereal after wheat. Unlike wheat, 95% of the world's rice is grown in less developed nations, primarily in Asia, Africa, and Latin America. China and India are the largest rice producing and consuming countries in the world. By the year 2025, it is estimated that it will be necessary to produce about 60% more rice than what is currently produced to meet the food needs of a growing world population. In addition, the land available for crop production is decreasing steadily due to urban growth and land degradation. Hence, increases in rice production will have to come from the same or an even less amount of land. This means appropriate rice production practices should be adopted to improve rice yield per unit area (Fageria, 2007). Guilan province has allocated more 35 and 42 percent of paddy production and cultivation land area cultivation area of Iran, respectively. In this province more than 181 exploiters on productive and talented areas with more than 230000 hectares, are busy rice farming (Peykani *et al.,* 2006). Indeed, rice cultivation is considered the most important agricultural activity in this province and the economy of the province is also based on agriculture, with rice cultivation in top. Most of the under cultivation area of local varieties in Guilan are including Hashemi and Alikazemi. Most of the under cultivation area of breed varieties in Guilan are including Khazar, Hybrid and Gohar (azarpour and moradi, 2013).

Crop modeling and systems analysis have become important tools in modern agricultural research. A crop model synthesizes our insights into the physiological and ecological processes that govern crop growth into mathematical equations. Our understanding of crop performance is tested by comparing simulation results with experimental observations, thus making the gaps in our knowledge explicit. Experiments can then be designed to fill these gaps. Once a model is validated, it can be used to help analyses and interpret field experiments. It can also be used in application-oriented research such as the design of crop ideotypes, the analysis of yield gaps, the optimization of crop management, the ex ante analysis of the effects of climate change on crop growth, and agro ecological zonation. RYZA2000 model was developed under the system analysis for rice production project jointly by Wageningen University, Netherlands, and International Rice Research Institute, Philippines (Bouman *et al,* 2001). The model simulates plant physiology, phenology, nutrients and water requirement and a few options are available to estimate irrigation requirements by hydrological modules. ORYZA2000 follows a daily calculation scheme for the rate of dry matter production of the plant organs and for the rate of phenological development. By integrating these rates over time, dry matter production and development stage are simulated throughout the growing season. The calculation procedures for dry matter production are well documented. Crop growth simulation models in combination with field experiments are powerful tools to explore such management options. Simulation models synthesize current insights in physiological and ecological crop growth processes, and can help in increasing insight in relationships between indigenous soil N supply, fertilizer N rates, and crop performance. Once a model has been parameterized and validated, it can be used in support of analysis and interpretation of field experiments, for extrapolation of experimental results over a wider range of management practices and weather conditions, and to derive efficient N management strategies (Bouman *et al.,* 1996). The schematic diagram in ORYZA model under nitrogen limited production conditions as shown in Figure 1 (Boxes: state variable; Valves: rate variables; Circles: intermediate variables; Solid lines: flow of material; Dotted lines: flows of information). The objectives of this study was to calibrate and evaluate ORYZA2000 performance for current rice cultivars growing different levels of nitrogen fertilizer in north of Iran.

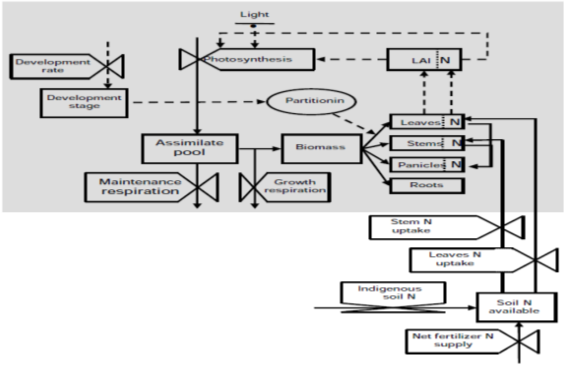

Fig. 1. The structure of model ORYZA under nitrogen limited production conditions.

Materials and methods

Field experiment

The experiment was conducted at Rice Research Institute, Rasht, Guilan, Iran, and Roudsar, East of Guilan; during the growing season 2009. The experiment was laid out factorial in randomized complete block design with three replications of four nitrogen fertilizers levels (N1-control (no N fertilizer); N2- 30 kg N/ha; N3- 60 kg N/ha; N4- 90 kg N/ha. Three different cultivars were examined (V1-Hashemi, V2- Alikazemi and V3-khazar). The N fertilization was applied as single incorporated application of urea (46% N). Tillage operations were done according to typical practices of the region and needed notes such as sowing time, transplanting, flowering, harvesting, the amount and the date of nitrogen fertilizer application, the number of seedling per hill and the number of hill per square meter were recorded at two locations. In order to establish of weather file of two locations, daily data related to the minimum and maximum of temperature, rainfall, sundial and relative humid of the Rasht and Roudsar weather station was used.

For the studying of growth analysis, sampling of each plot was done with 15 days intervals, after removing border rows as marginal effect with selection of 4 plants, randomly. Leaf area was measured with leaf meter (GA-5 model produced by Japan OSK Company). After that different parts of rice dried in an oven at 70°C for 48 h to weight dry matter.

ORYZA2000 model

ORYZA2000 model uses a daily computed plot for simulating the production of plant parts dry matter and physiological growth rate and with the completion of this process over time dry matter production is simulated during the season.

Data required running the ORYZA2000 model:

1- Location: latitude, longitude and altitude

2- Meteorological data: sun hour, maximum and minimum air temperature, vapor pressure, wind speed, and rainfall for the crop season.

3- Soil data: native soil nitrogen.

4- Plant information: sowing time, transplanting, flowering, harvesting, the amount and the date of nitrogen fertilizer application, the number of seedling per hill and the number of hill per square meter, leaf area index sampling during the growth season, dry matter sampling of plant parts (leaf, stem and panicle) during the growth season and grain yield.

ORYZA2000 Calibration

In ORYZA2000 model, rice life cycle based on time-temperature is divided on four phonological stages:1-basic vegetative phase (DVRJ), 2- photoperiod-sensitive phase (DVRI), 3- panicle formation phases (DVRP) and 4- grain filling phase (DVRR). In ORYZA2000, the rice crop has four phonological phases, viz., juvenile phase from emergence (development stage [DVS]=0) to start of photoperiod-sensitive phase (DVS=0.4), photoperiod-sensitive phase from DVS = 0.4 until panicle initiation (DVS=0.65), panicle development phase from DVS = 0.65 until 50 % of flowering (DVS=1.0), and grain-fill phase from DVS = 1.0 until physiological maturity (DVS=2.0). (Bouman *et al.*, 2001). For the calibration of ORYZA2000 plant parameters, two different programs (DRATES and PARAM) were applied. The result of DRATES was computing the rate of phonological development at four deferent basic vegetative phases (DVRJ), photoperiod-sensitive phase (DVRI), panicle formation phases (DVRP) and grain filling phase (DVRR). With running the PARAM program and other parameters such as maximum relative growth rate of leaf area (RGRLMX), fraction of stem reserves (FSTR), Relative death rate of the leaves as a function of development stage (DRLVT), specific leaf area (SLA), assimilate partitioning factors to leaves, stems, storage and above ground total (FLV, FST, FSO and FAGT respectively) were calculated (Bouman *et al.,* 2001).

ORYZA2000 evaluation

Since any particular criteria did not show the accuracy of models simulation, statistical and graphical values combination was used (Gauch *et al.,* 2003). In graphical form, comparing of measured and simulated value for each cultivar with determination of R^2, α and β was done. For statistical evaluation of simulation results, t-test P (t) and below statistic parameter were used (Bouman and Van Laar, 2006; Rinaldi *et al.,* 2003).

(1) Root Mean of Square Error (RMSE)

$$RMSE = (\sum_{I=1}^{n} (P_i - O_i)^2 / n)^{0.5}$$

(2) Normalized Root Mean Square Error ($NRMSE_n$)

$$NRMSE = 100(\sum_{I=1}^{n} (P_i - O_i)^2 / n)^{0.5} / \overline{O}$$

(3) Coefficient of residual mass (CRM)

$$CRM = (\sum_{i=1}^{n} O_i - \sum_{i=1}^{n} P_i) / \sum_{i=1}^{n} O_i$$

p_i = simulated values, O_i = measured values, n = samples no. and $\overline{O}$ = mean of measured values.

RMSE, NRMSE and CRM values at optimum condition or the state of equality between simulated and measured values are 0. The negative value of CRM shows that the mode had more estimated simulated values than measured ones and the positive value means that it had less estimated simulated values compared to measured values. If the t-test result is greater than 0.05, it reveals that the simulated and measure values of parameter has not significant difference at 95% level of possibility. RMSE indicates the amount of overestimation or less of model compared to observations (measurements) and it should be less than or equal to the value of standard error. If the NRMSE value is less than 10, 10-20, 20-30 and more than 30 it shows excellent, good, fair and weak form of simulation, respectively. In computed functions of the parameters, the best condition is that the values of R^2 and α coefficients are equal to 1.

Results and discussion

Leaf Area Index (LAI)

The trends of cultivars LAI in Rasht and Roudsar is indicated in figures 2 and 3. Among the rice cultivars, Khazar late-maturity cultivar had the highest simulated and measured of LAI and after that Ali-Kazemi and Hashemi early-maturity varieties. Caton (2003) claimed that more length of vegetative growth, more LAI. The maximum difference between the simulated and measured values of LAI in Rasht was belong to the Ali-Kazemi cultivar (+34 percent) and in Roudsar, Khazar variety (+29 percent) had the maximum one (Tables 1, 2 and 3). According to the t-test (Tables 1, 2 and 3), it was revealed that simulated values of cultivars LAI had not significant difference with measured values at 95% level of possibility. In the cultivars at Rasht and Roudsar, the model had more estimated the simulated values of LAI than measured ones. For this reason, the negative value of CRM in all the conditions is negative (Tables 1, 2 and 3). $RMSE_n$ of Hashemi LAI in Rasht and Roudsar (28 and 22) shows more appropriate simulation of Hashemi LAI compared to the other cultivars (Tables 1, 2 and 3). Bouman and Van Laar (2006) demonstrated that NRMSE value at model calibration (IR58 variety) and model validation (IR72 variety) were 90 and 50, respectively. Feng et al (2007) showed that NRMSE of LAI at model calibration (XD90247 variety) and model validation (HD297 variety) were 29 and 59. α, β, R^2 coefficients and RMSE of rice cultivars simulated LAI were fair (Tables 1, 2 and 3).

Assimilate partitioning factors to leaves, stems, storage and above ground total

Among the rice cultivars, Khazar late-maturity cultivar had the maximum assimilate partitioning factors to leaves, stems, storage and consequently assimilate partitioning factors to above ground total and after that Ali-Kazemi and Hashemi early-maturity cultivars (Figures 2 and 3). Khazar cultivar had the maximum vegetative growth length and leaf dry weight. More vegetative growth length causes more leaf area index and leaf dry weight, absorbs more light radiation and photosynthesis (Caton, 2003). It sounds that in Khazar cultivar the difference of total photosynthesis from total respiration is more than other cultivars and as a result it causes further increases in total dry weight than the others (Graphius, 1959; welbank *et al.*, 1996).

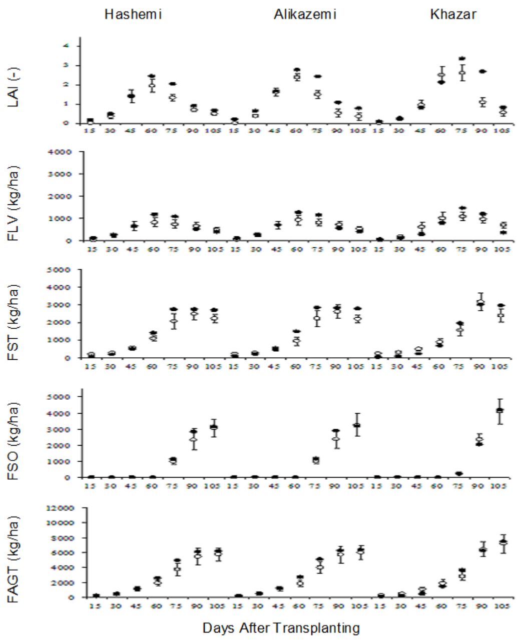

Fig. 2. Simulated (●) and measured (○) LAI, FLVG, FST, FSO and FAGT of rice cultivars in Rasht.

Note: assimilate partitioning factors to leaves, stems, storage and above ground total (FLV, FST, FSO and FAGT respectively), LAI= Leaf Area Index.

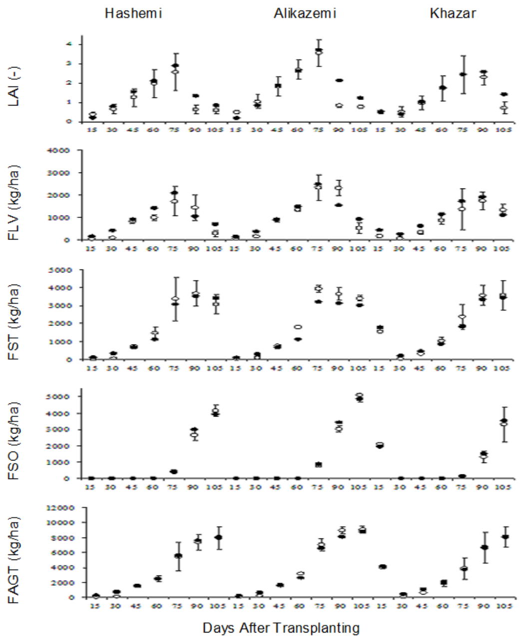

Fig. 3. Simulated (●) and measured (○) LAI, FLVG, FST, FSO and FAGT of rice cultivars in Roudsar.

Note: assimilate partitioning factors to leaves, stems, storage and above ground total (FLV, FST, FSO and FAGT respectively), LAI= Leaf Area Index.

Difference between measured and simulated values of assimilate partitioning factors to leaves, stems, storage and above ground total of all the cultivars at Rasht was between -7 to 16% and at Roudsar was between -16 to 33% (Tables 1, 2 and 3). With respect to t-test (Tables 1, 2 and 3), it was observed that the simulated values of assimilate partitioning factors to leaves, stems, storage and above ground total had not significant difference with measured values at 95% level of possibility. In the studied cultivars at Rasht and Roudsar, in most parameters, the model has estimated simulation values of assimilate partitioning factors to leaves, stems, storage and above ground total more than measured ones and for this reason CRM in all the parameters were negative (Tables 1, 2 and 3).

According to the $RMSE_n$ of assimilate partitioning factors to leaves, stems, storage and above ground total under weather conditions of Rasht and Roudsar, it was found that $RMSE_n$ value is in the appropriate range in the most parameters (Rinaldi *et al.*, 2003).

Therefore, based on $RMSE_n$ it can be concluded that the model has a fair efficiency to simulation of assimilate partitioning factors to leaves, stems, storage and above ground total (FLV, FST, FSO and FAGT respectively) of all the cultivars.

Bouman and Van Laar (2006) computed NRMSE of leaf, stem, raceme and total dry matter accumulation in model calibration (IR58) was 36, 17, 18, 11 and model validation (IR72) was 34, 38, 20, and 26, respectively. Feng et al (2007) showed that in model calibration (XD90247 variety) NRMSE of leaf, stem, panicle and total dry matter accumulation was 18, 36, 19, and 27 also in model validation (HD297 variety) it was 59, 41, 30, 41 and 27, respectively. α, β, R^2 coefficients and RMSE of simulated assimilate partitioning factors to leaves, stems, storage and above ground total (FLV, FST, FSO and FAGT respectively) in rice cultivars different were fair (Tables 1, 2 and 3).

Table 1. Evaluation results of ORYZA2000 simulations of crop parameters of Hashemi cultivar.

Crop parameters	$RMSE_n$	RMSE	CRM	$P(t^*)$	β	α	R^2	Variance (%)	X_{obs} (SD)	X_{sim} (SD)	N
(Rasht)											
FLV Kg/ha	23	120	-0.16	0.20	114	0.66	0.81	+16	587 (418)	505 (309)	28
FST Kg/ha	17	228	-0.15	0.25	169	0.75	0.95	+15	1472 (1227)	1277 (939)	28
FSO kg/ha	5	123	-0.11	0.29	51	0.92	0.95	+11	2373 (1073)	2136 (1013)	12
FAGT kg/ha	13	369	-0.14	0.28	76	0.85	0.97	+14	3076 (2620)	2697 (2260)	28
LAI -	28	0.25	-0.27	0.11	0.04	0.75	0.79	+27	1.13 (0.8)	0.89 (0.67)	28
Yield Kg/ha	13	415	-0.12	0.19	359	0.78	0.96	+12	3384 (816)	3015 (654)	4
Biomass Kg/ha	5	411	-0.04	0.37	404	1.09	0.97	+4	7364 (1686)	7058 (1738)	4
Roudsar											
FLV Kg/ha	33	242	-0.33	0.08	131	0.88	0.74	+33	975 (650)	730 (668)	28
FST Kg/ha	13	236	-0.01	0.47	70	1.02	0.93	+1	1768 (1462)	1738 (1552)	28
FSO kg/ha	4	109	-0.01	0.47	109	1.02	0.97	+1	2421 (1561)	2376 (1630)	12
FAGT kg/ha	10	374	-0.08	0.36	349	1.10	0.96	+8	3780 (3107)	3487 (3208)	28
LAI -	22	0.25	-0.25	0.12	0.09	0.86	0.86	+25	1.36 (0.91)	1.08 (0.84)	28
Yield Kg/ha	5	194	-0.03	0.29	1032	0.70	0.98	+3	3901 (515)	3765 (364)	4
Biomass Kg/ha	9	791	-0.08	0.17	1511	1.07	0.98	+8	9544 (1337)	8782 (1459)	4

Note1: Note: assimilate partitioning factors to leaves, stems, storage and above ground total (FLV, FST, FSO and FAGT respectively), LAI= Leaf Area Index.

Note2: N, number of data pairs; Xmea, mean of measured values; Xsim, mean of simulated values; SD, standard deviation; P(t*), significance of paired t test; α, slope of linear relation between simulated and measured values; β, intercept of linear relation between simulated and measured values; R2, adjusted linear correlation coefficient between simulated and measured values; RMSE (%) normalized, normalized root mean square error (%); RMSE absolute, absolute root mean square error; CRM, Coefficient of Residual Mass.

* In a column, * means simulated and measured values are the same at 95% confidence level.

Table 2. Evaluation results of ORYZA2000 simulations of crop parameters of Alikazemi cultivar.

Crop parameters	$RMSE_n$	RMSE	CRM	$P(t^*)$	β	α	R^2	Variance (%)	X_{obs} (SD)	X_{sim} (SD)	N
(Rasht)											
FLV Kg/ha	22	124	-0.12	0.24	133	0.67	0.78	+12	629 (429)	557 (326)	28
FST Kg/ha	18	240	-0.19	0.2	73	0.78	0.96	+19	1534 (1241)	1281 (998)	28
FSO kg/ha	6	138	-0.08	0.33	164	0.99	0.91	+8	2416 (1059)	2242 (1097)	12
FAGT kg/ha	13	367	-0.14	0.27	35	0.88	0.97	+14	3199 (2636)	2791 (2361)	28
LAI -	34	0.33	-0.34	0.08	0.04	0.78	0.73	+34	1.30 (0.83)	0.97 (0.91)	28
Yield Kg/ha	12	406	-0.06	0.27	1178	0.59	0.73	+6	3445 (731)	3228 (509)	4
Biomass Kg/ha	12	933	-0.05	0.30	370	0.89	0.63	+5	7605 (1576)	7182 (1404)	4
Roudsar											
FLV Kg/ha	29	257	-0.23	0.15	114	0.91	0.73	+23	1075 (724)	869 (772)	28
FST Kg/ha	15	292	0.15	0.22	122	1.26	0.97	-16	1595 (1262)	1893 (1614)	28
FSO kg/ha	3	96	-0.03	0.44	247	1.05	0.98	+3	2790 (1585)	2692 (1686)	12
FAGT kg/ha	7	289	0.01	0.47	297	1.08	0.98	-1	3866 (3175)	3916 (3486)	28
LAI -	25	0.32	-0.23	0.13	0.01	0.81	0.77	+23	1.58 (1.02)	1.28 (0.94)	28
Yield Kg/ha	10	409	-0.09	0.08	608	0.77	0.98	+9	4393 (542)	4001 (422)	4
Biomass Kg/ha	3	337	-0.02	0.30	157	0.95	0.95	+2	9784 (984)	9503 (965)	4

Note1: Note: assimilate partitioning factors to leaves, stems, storage and above ground total (FLV, FST, FSO and FAGT respectively), LAI= Leaf Area Index.

Note2: N, number of data pairs; Xmea, mean of measured values; Xsim, mean of simulated values; SD, standard deviation; P(t*), significance of paired t test; α, slope of linear relation between simulated and measured values; β, intercept of linear relation between simulated and measured values; R2, adjusted linear correlation coefficient between simulated and measured values; RMSE (%) normalized, normalized root mean square error (%); RMSE absolute, absolute root mean square error; CRM, Coefficient of Residual Mass.

* In a column, * means simulated and measured values are the same at 95% confidence level.

Table 3. Evaluation results of ORYZA2000 simulations of crop parameters of Khazar cultivar.

Crop parameters	$RMSE_n$	RMSE	CRM	$P(t^*)$	β	α	R^2	Variance (%)	X_{obs} (SD)	X_{sim} (SD)	N
(Rasht)											
FLV Kg/ha	25	160	0.06	0.36	242	0.67	0.73	-7	598 (538)	642 (419)	28
FST Kg/ha	4	189	0	0.48	233	0.82	0.95	-1	1280 (1285)	1292 (1090)	28
FSO kg/ha	4	91	0.02	0.46	115	0.97	0.99	-3	2168 (1751)	2227 (1723)	12
FAGT kg/ha	9	283	0.02	0.45	310	0.92	0.97	-3	2808 (2946)	2883 (2739)	28
LAI -	38	0.44	-0.27	0.15	0.14	0.68	0.66	+27	1.46 (1.21)	1.15 (1.01)	28
Yield Kg/ha	6	226	-0.05	0.31	77	0.97	0.95	+5	3849 (688)	3662 (684)	4
Biomass Kg/ha	3	244	-0.02	0.41	761	0.89	0.98	+2	8244 (1335)	8082 (1195)	4
Roudsar											
FLV Kg/ha	31	305	-0.27	0.15	177	0.93	0.77	+27	1222 (924)	962 (979)	28
FST Kg/ha	19	373	0.01	0.47	456	1.25	0.93	-2	1932 (1588)	1964 (2056)	28
FSO kg/ha	6	187	-0.10	0.34	87	0.92	0.96	+10	3180 (1998)	2868 (1895)	12
FAGT kg/ha	13	571	-0.08	0.36	673	1.06	0.95	+8	4517 (3867)	4155 (4231)	28
LAI -	28	0.37	-0.29	0.10	0.06	0.81	0.80	+29	1.70 (1.18)	1.31 (1.07)	28
Yield Kg/ha	12	542	-0.03	0.37	4957	2.08	0.98	+3	4429 (534)	4265 (1122)	4
Biomass Kg/ha	15	1457	-0.13	0.07	3983	1.25	0.74	+13	10742 (1127)	9505 (1643)	4

Note1: Note: assimilate partitioning factors to leaves, stems, storage and above ground total (FLV, FST, FSO and FAGT respectively), LAI= Leaf Area Index.

Note2: N, number of data pairs; Xmea, mean of measured values; Xsim, mean of simulated values; SD, standard deviation; P(t*), significance of paired t test; α, slope of linear relation between simulated and measured values; β, intercept of linear relation between simulated and measured values; R2, adjusted linear correlation coefficient between simulated and measured values; RMSE (%) normalized, normalized root mean square error (%); RMSE absolute, absolute root mean square error; CRM, Coefficient of Residual Mass.

* In a column, * means simulated and measured values are the same at 95% confidence level.

Total Biomass and Grain Yield

Among the cultivars, Khazar cultivar had the highest simulated and measured total biomass and grain yield at two locations. The high amount of total biomass and grain yield of Khazar cultivar was possibly due to the difference of total photosynthesis from total respiration is more than other cultivars and as a result it causes further increases in total dry weight and grain yield than the others (Graphius, 1959; welbank *et al.,* 1996). With respect to in both locations the difference between simulated and measured total biomass of the cultivars was +2 to

+13% and the difference between simulated and measured grain yield was +3 to +12% (Tables 1, 2 and 3), it can be concluded that the model has a high capability to simulate total biomass and grain yield of the cultivars. Since the model has estimated simulated grain yield and total biomass more than measured values, CRM was negative (Tables 1, 2 and 3). Also, grain yield and total biomass simulated values of the cultivars had not significant deference with the measured values at 95% possibility level. Total biomass NRMSE of the cultivars at Rasht and Roodsar was +3 to +15% and grain yield NRMSE of the cultivars in two locations was +5 to +13% (Tables 1, 2 and 3) which is indicative of good and excellent simulation (Rinaldi *et al.,* 2003). Bouman and Van Laar (2006) obtained grain yield and total biomass of NRMSE at model calibration (IR58 variety) and at model validation (IR72 variety) were 7, 13, 9 and 11, respectively. Feng et al (2007) showed that grain yield and total biomass of RMNSE at model calibration (XD90247 variety) and at model validation (HD297variety) were 21, 19, 12 and 11. α, β, R^2 coefficients and RMSE of simulated total biomass and grain yield in rice varieties were fair (Tables 1, 2 and 3).

Conclusions

We conclude that ORYZA2000 was sufficiently accurate to simulate grain yield and crop N uptake at the end of the season for a rice cultivars growing under nitrogen management conditions in north of Iran. Additional comparisons between model simulations and experimental measurements are required to increase the confidence in the model predictions, particularly for biomass production of individual organs. In this regard, the use of the ORYZA2000 model, calibrated and evaluated with regard to the production conditions of the major rice producing area in Iran can support experiments for the evaluation and adjustment of nitrogen fertilizer management practices. The ORYZA2000 model could also support potential production and yield forecasting studies.

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