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Calibration and evaluation of ORYZA2000 model under different N options in irrigated rice in Iran

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Key words: Rice, model, nitrogen, ORYZA2000, total biomass, nitrogen use efficiency.

Abstract

ORYZA2000 is a growth model for lowland rice (*Oryza sativa* L.) developed by the International Rice Research Institute and Wageningen University. This model has been evaluated extensively in a wide range of environments. The model ORYZA2000 simulates the growth and development of rice under conditions of potential production and nitrogen limitations. Crop simulation models could provide an alternative, less time-consuming and inexpensive means of determining the optimum crop nitrogen requirement under varied nitrogen conditions. In this study, ORYZA2000 was calibrated and evaluated using data from experiments carried out in the North area of Iran. These experiments were performed on three varieties rice cultivar (Hashemi, Kazemi, Khazar) at various N rates (0, 30, 60 and 90 kg $N.ha^{-1}$) in a RCBD in 2008, with 3 replications at Rice Research Institute of Iran, Rasht. ORYZA2000 was then applied to explore biomass of leaves, panicles, total above ground biomass and grain yield response to N fertilization by adjusted linear correlation coefficient between simulated and measured values (R^2), T test of means, absolute and normalized root mean square errors (RMSE). Results showed that the highest total biomass with a RMSE of 559 (less than 6%).However, the prediction of biomass of leaves at low level of nitrogen application was poor. The simulated crop N variables, such as grain N concentration and crop N uptake were slightly more accurate than those of crop biomass. Simulation accuracies might be increased by improving the simulation of soil N dynamics.

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Introduction

Rice plant weight mainly consists of organic matter like protein and carbohydrate. Carbohydrates are composed of cell wall substances such as cellulose and reserved substances like starch. The protein metabolism dominates in the vegetative growth stage and carbohydrate metabolism does in the reproductive growth stage.

Nitrogen is a constituent of numerous important compounds found in living cells, including amino acids, proteins (enzymes), nucleic acids, and chlorophyll (Traore *et al,* 1999). Nitrogen use efficiency by flooded rice is less than 50% (Fageria *et al*, 2001, 2003). The low N use efficiency of lowland rice is associated with its loss by several mechanisms in the soil-plant systems. The main N loss mechanisms are volatilization of ammonia (NH_3), leaching loss of nitrate (NO_3), loss through denitrification and soil erosion.

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 main objective of this study was: calibrate and evaluate the Oryza-2000 model under varying N levels, In order to this study, commercial varieties of rice response to N fertilization, and estimate grain yield, dry matter production, N uptake, N use efficiency and validation and performance evaluation of the ORYZA2000 model under varying N levels at two years and four N rates were carried out.

Materials and methods

Field experiment

The experiment was conducted at Rice Research Institute, Rasht, Guilan, Iran, during the growing season 2008. Physico-chemical properties of the soil were measured by the standard methods of soil chemical analysis (NIAST, 1988). 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 ha^{-1} N; N3- 60 kg ha^{-1} N; N4- 90 kg ha^{-1} N. Date of transplanting of seedling from nursery to the main field was 12th May in first year (2008) and 8th Jun in second year (2009). Three different varieties were examined (Hashemi: V1, Alikazemi: V2 and khazar: V3). The N fertilization was applied as single incorporated application of urea (46% N).

The ORYZA2000 model

ORYZA2000 is a crop model that simulates growth and development of lowland rice for potential, water- and N-limited production situations. The model simulates daily dry matter (DM) increases in plant organs and phonological development progress. By integrating these rates over time, DM production and development stage are simulated throughout the growing season. The development stage is tracked as a function of daily mean temperature and photoperiod. Net daily growth rate is obtained by subtracting maintenance and growth respiration requirements, and then is partitioned into roots, leaves, stems and panicles, using experimentally derived factors. (Bouman *et al.*, 2001; van Ittersum *et al.*, 2003; Bouman and van Laar, 2006; Jing *et al.*, 2007).

ORYZA2000 parameterization

In order to calibrating of plant parameter of model was used measured data of nitrogen management (0 and 30 kg N/ha) and for model validation was utilized measured data of nitrogen management (60 and 90 kg N/ha). Weather data on sun hour, maximum and minimum air temperature, vapor pressure, wind speed, and rainfall for the crop season was obtained from Rasht meteorological station.

Evaluation of ORYZA2000 model

ORYZA2000 was run under conditions observed in field experiments. Then, graphical analysis and statistical measures were carried out, following Bouman and van Laar (2006) and Jing *et al.* (2007). Simulated and measured total biomasses, grain yield, total crop-N, and grain N concentration were compared graphically. In this result, evaluating of growing process simulation was done by coefficient between simulated and measured values (R^2), T test of means.

For the same variables, ORYZA2000 performance was evaluated by looking at the absolute and normalized root mean squared error (RMSE) between simulated and measured values, calculated as:

$$RMSEa = (1/n\,\Sigma\,(Oi - Xi)^2)^{0.5}$$

$$RMSEn = \frac{100 \times (1/n\,\Sigma\,(Oi - Xi)^2)^{0.5}}{\Sigma\,Oi/Xi}$$

Where n is the number of observations, and O is the mean value of measured parameters from three replicates of the field trials. Additionally, a Student's *t*-test of means (P (*t*)) assuming unequal variance was applied for end-of-season variables. A model reproduces experimental data best when α is close to 1, β close to 0, $R2$ close to 1, $P(t^*)$ larger than 0.05, RMSEa less than 20.

Table 1. Evaluation results of ORYZA2000 simulations of crop growth variables over the entire growing season, for the evaluation data sets.

Crop variable	N[a]	X_{sim} (SD)	X_{obs} (SD)	R^2	α	β	P(t)	RMSE	$RMSE_n$
Calibration set									
Total biomass (kg.ha-1)	42	2411	2636	0.96	0.90	44	0.32	537	22
Biomass of panicle (kg. ha-1)	18	1877	1693	0.92	0.95	6.93	0.40	198	10
Validation set									
Total biomass (kg.ha-1)	42	3173	3419	0.97	0.81	194	0.35	644	20
Biomass of panicle (kg. ha-1)	18	2515	2676	0.96	0.96	66	0.37	216	8

*X*mea, mean of measured values in whole population; *X*sim, mean of simulated values in whole population; S.D., standard deviation of whole population; *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; *R*2, adjusted linear correlation coefficient between simulated and measured values; RMSEn (%), normalized root mean square error between simulated and measured values (%); RMSEa, absolute root mean square error between simulated and measured values. In a column, * means simulated and measured values are the same at 95% confidence level. a *N*, number of measured/simulated data pairs.

Table 2. Evaluation results of ORYZA2000 simulations of crop growth variables at harvest time, for the evaluation data sets.

Crop variable	N[a]	X_{sim} (SD)	X_{obs} (SD)	R^2	*α*	*β*	P(t)	RMSE	$RMSE_n$
Amount of final N in crop (kg.ha^{-1})	12	14.5	18.5	0.65	1.036	4.1	0.17	12	18
Amount of final N in grain(kg.ha^{-1})	12	10.26	12.63	0.77	1.08	-0.13	0.21	7	15

*X*mea, mean of measured values in whole population; *X*sim, mean of simulated values in whole population; S.D., standard deviation of whole population; *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; *R*2, adjusted linear correlation coefficient between simulated and measured values; RMSEn (%), normalized root mean square error between simulated and measured values (%); RMSEa, absolute root mean square error between simulated and measured values. In a column, * means simulated and measured values are the same at 95% confidence level. a *N*, number of measured/simulated data pairs.

Results and discussion

Model calibration

Total biomass and panicle biomass

The statistical outputs used evaluate the model performance are in Table 1. The biomass of crop organs was simulated quite accurately. Goodness-of-fit parameters for the dynamic crop variables are given in Table 1. The Student's test indicated that all simulated values were similar to measured values with 95% confidence in both data sets. Slopes (*α*) of the biomass variables are close to 1 and the intercept (*β*) values small, indicating a close fit between simulated and measured data. Also the *t*-test indicated no significant differences between simulated and measured values (total biomass: p (t) =0.32, panicle biomass: p (t) =0.4).

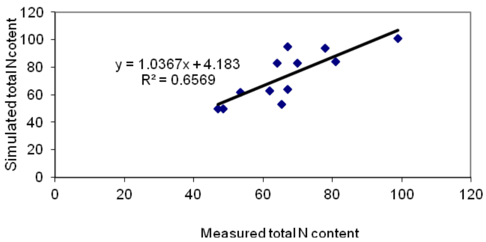

Fig. 1. Simulated versus measured N content of grain (A) crop biomass (kg N/ha) (B) from data set.

Model validation

Total biomass and panicle biomass

The simulation of total crop biomass and grain biomass at harvest was generally in the same order of accuracy as that of the dynamic crop variables (Table 1). The root mean square error (RMSE) was 644 kg ha^{-1} and normalized RMSE was 20% for measured harvest time total biomass. Harvest-time panicle biomass was slightly under predicted with a RMSE of 216 kg ha^{-1} and normalized RMSE 8 for measured panicle biomass. Paired t-test showed no significant differences between the measured and simulated panicle and total final biomass values (at *P* = 0.05 confidence level).

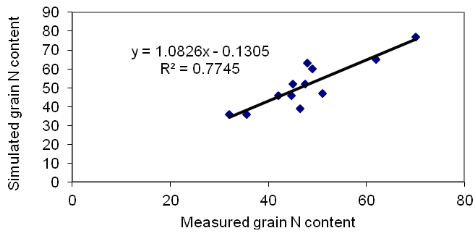

Fig. 2. Using the validation sets, Student's t-test indicates that simulated crop growth variables were similar to measured values. The linear regression between simulated and measured values had a slope α close to 1 and R^2 larger than 0.9 for panicle and crop biomass variables, indicating a close correlation between the simulations and the measurements.

Crop N-uptake and grain N concentration

The model provided very satisfactory estimate for the N content of grain too, almost all parameters indicated a close association between simulated and observed N content of grain.

The results of graphical evaluation for simulating the N content of crop biomass and grain at harvest are shown in Figure-1. The statistical outputs used evaluate the model performance are in Table 2.

Fig. 1 compared simulated with measured N content of crop biomass and grain at harvest for all data of the calibration and validation set. The root mean square error (RMSE) was 7 kg ha^{-1} and normalized RMSE was 15 % for measured N content of grain (A). N content of crop biomass was with a RMSE of 12 kg ha^{-1} and normalized RMSE 18 % for measured N content of crop biomass (B).

The linear regression between simulated and measured N values had a slope α close to 1, an intercept β that was relatively small, and an R2 larger than 0.65 for all variables, indicating a close correlation between the simulations and the measurements (Table 2). Godwin *et al.* (1990) and Buresh *et al.* (1991) reported predicted crop N uptake of 40–145 vs. observed uptake of 35–150 kg N /ha in the Philippines. Timsina *et al.* (1998) reported that both observed and simulated total crop N uptake by two rice cultivars ranged from 48–175 kg/ha, with absolute RMSE of 17 kg/ha in northern Bangladesh. The simulated crop N variables, such as grain N concentration and crop N uptake were slightly more accurate than those of crop biomass. Simulation accuracies might be increased by improving the simulation of soil N dynamics, which in ORYZA2000 is relatively simple. Total N availability is determined by a constant indigenous soil N supply rate and a maximum recovery of applied fertilizer N, defined as a function of crop development stage (Bouman *et al.*, 2001). In reality, indigenous soil N supply rate can vary substantially in the course of the growing season (Thiyagarajan *et al.*, 1997; Dobermann *et al.*, 2003a, b).

Conclusion

There are no absolute criteria to classify a model as "good" or "bad". Strictly speaking, models cannot be validated; only invalidation is possible on the basis of empirical evidence.

However, repeated and well-documented comparisons between model simulations and experimental measurements increase the confidence in the suitability of a model for a specific purpose (Bouman and Van Laar, 2006). For our purpose, and from our evaluation, we conclude that ORYZA2000 satisfactorily reproduced measured crop variables in both the calibration and the validation experimental data set.

The recovery of fertilizer N depends not only on crop development, but also on management (e.g., depth of placement, fertilizer type) and environmental conditions that affect volatilization and leaching losses. Simulation accuracies might be increased by improving the simulation of soil N dynamics, which in ORYZA2000 is relatively simple.

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