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Testing the modeling capability of ORYZA2000 under nitrogen limit conditions in Northern Iran

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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 leaf area index (LAI), 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 grain yield was simulated with a root mean squared error (RMSE) of 388 (less than 15%) and total biomass with a RMSE of 782 (less than 15%).However, the prediction of leaf area index (LAI) at low level of nitrogen application was poor. Results specified too, model can use as an applied mean for estimate of rice grain yield at nitrogen levels management in a paddy soil of Guilan.

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Introduction

Rice is a major food crop in South America, Asia, and Africa (Fageria *et al*, 2009). Nitrogen (N) is essential for rice, and usually it is the most yield-limiting nutrient in irrigated rice production around the world (Ladha *et al*, 2003). Rice plants require N during vegetative stage to promote growth and tillering, which in turn, determines potential number of panicles. Nitrogen contributes to spikelet production during early panicle formation stage, and contributes to sink size during the late panicle formation stage. Nitrogen also plays a role in grain filling, improving the photosynthetic capacity, and promoting carbohydrate accumulation in culms and leaf sheaths (Mae *et al*, 1997).

In the 1980s a wide range of scientists in Wageningen became involved in the development and application of crop models. The first model was ORYZA1 for potential production (Kropff *et al*, 1994), followed by ORYZA_W for water-limited production (Wopereis *et al*, 1996),for nitrogen-limited production. For all production situations, optimal control of diseases, pests, and weeds is assumed. In 2001, a new version in the ORYZA model series was released that improved and integrated all previous versions into one model called ORYZA2000 (Bouman *et al*, 2001).The ORYZA2000 was evaluated under potential, water-limited, and/or nitrogen (N)-limited conditions in the Philippines (Bouman and Van Laar, 2006), India (Arora, 2006), Indonesia (Boling *et al*, 2007), and China (Belder *et al*, 2007; Jing *et al*, 2007; Bouman *et al*, 2007; Xue *et al*, 2008).

In this study, we combined the use of field experiments and ORYZA2000 to asses the effect of N fertilizer content ond to explore options to combine high yield and rice grow in irrigated rice system in north of Iran.

Materials and methods

Field experiments was conducted in 2008 at Rice Research Institute of Iran, Guilan province, located in the north of Iran (37°12′ N, 49°38′ E), at the rice cultivation season. Physico-chemical properties of the soil were measured by the standard methods of soil chemical analysis. Soil initial chemical characteristics are presented in Table 1. The experimental design was RCBD at three replicates. 4 N-levels involved N1: no N application, N2: total N rate of 30 kg/ha, N3: total N rate of 60 kg/ha and N4: total N rate of 90 kg/ha.Three varieties used were Hashemi, Kazemi, Khazar. Seedlings were grown in wet beds for approximately 25 days and transplanting was done at 3 plants per hill with a spacing of 20×20 cm. A mixed commercial fertilizer was applied at the rate of 25 kg P ha^{-1} and 75 kg K ha^{-1}: all of phosphorous, potassium, (N1 and N2 nitrogen level) and half of nitrogen fertilizer (N3 and N4-level) were applied at basal and other 50% nitrogen fertilizer has applied as a top dressing at maximum tillering. For each treatment, the dates of emergence, panicle initiation, flowering, and physiological maturity were recorded. Measurements from samples collected at the beginning of transplanting in all treatments, Crop samples were taken at regular intervals of 10-15 days to determine leaf area index (LAI) and biomass of green leaves, yellow/dead leaves, stems and panicles. At each sampling 12 hills were harvested from plot, LAI was measured using a Licor LI3100 area meter, The dry weights were obtained after oven-drying at 70°C to constant weight, and are reported here as dry biomass. Grain yield was measured from a central 5 m^2 and is reported at 14% moisture.

ORYZA 2000 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. On the basis of single leaf photosynthetic characteristics, instantaneous rates of CO_2 assimilation are calculated at three moments during the day and at three depths in the canopy. Integration over total leaf area and over the day, yields gross daily assimilation rates. 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. Leaf area grows exponentially as a function of temperature sum when the canopy is not yet closed. Then, leaf area grows linearly and is calculate d from the increase in leaf weight times a specific leaf area (Bouman *et al.*, 2001; van Ittersum *et al.*, 2003; Bouman and van Laar, 2006; Jing *et al.*, 2007).

ORYZA2000 was calibrated according to Bouman *et al.* (2001). The crop parameters calibrated were: development rates (DVR); assimilate partitioning factors to leaves, stems and storage organs (FLV, FST and FSO, respectively); specific leaf area (SLA); leaf death rate (DRLV); and fraction of stem reserves (FSTR) and maximum grain weight. Development rates were calculated using observed dates of emergence, Transplanting, panicle initiation, flowering, and physiological maturity. Specific leaf area was calculated from the measured values of leaf area and leaf dry weight. The partitioning of assimilates was derived from measured data on the biomass of leaf, stem, and panicles. 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.

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 leaf area index (LAI), total biomasses, biomass of individual organs, grain yield 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 equetion1:

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

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

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.

Results and discussion

Model evaluation

LAI

Graphical examples of simulated and measured LAI in time are given in fig. 1 for the calibration and validation set. As regards fig. 1, LAI, during growing season increased, as maximum observed at flowering stage and then decreased. Reason of this is related to falling leaves. In the other hand with decreasing levels of N, simulated and measured LAI values in lower rate of nitrogen fertilizer is less . Because nitrogen effected on jiberlin activity indirectly, so plant leaves growing increased. ORYZA2000 can simulate LAI variation. It is seen that the model simulates the LAI more than the observation in nitrogen rate fertilizer (fig. 1). Basis of results, the highest difference between measured and simulated values was observed in 0 and 30 kg N. ha^{-1} (+69% and +48%) and also the lowest difference value was related to 60 and 90 kg N. ha^{-1}(+5% and +7%). Because in the real condition, low fertilizer causes the falling of the specific leaf area and the decrease of the LAI while the model doesn't have the power of creating this falling. In this model, the amount of the specific leaf area has been considered stable during the vegetation period, but in the higher nitrogen rate fertilizer (60 and 90 kg N/ha), change of the specific leaf area is done well by means of this model and this results in suitable simulation of the LAI. Bouman and Van Laar (2006) and Jing *et al* (2007) found the same results in case of the simulation of LAI in low nitrogen fertilizer. In addition between varieties, the highest LAI value was allocated to Khazar variety (fig. 1). Caton *et al* (2003) stated that a variety with long vegetative duration produced the higher leaf area index.

In Fig. 1, at 0 kg N ha^{-1}, the transition between exponential and linear leaf area growth phases is clear. This graph suggests that the effect of N limitation during exponential growth was simulated relatively accurately, but that, in the linear phase, N limitations may have reduced specific leaf area, which the model did not simulate.

Table 1. Soil chemical characteristics (top 20 cm).

kind	Absorbent k(ppm)	Absorbent p(ppm)	N total (%)	pH (1:2.5 soil:water)	Electrical conductivity (dS m−1)	SP%
Si-Ci	280	17.8	0.189	7.4	1.12	75

Total biomass

Evaluation of change procedure of measured and simulated dry matter values showed that at first dry matter accumulation was higher in leaves and stems (because of storage of Photosynthetic products in leaves and stems), but during generation process, Photosynthetic products accumulated in panicles (fig. 3).

Regarding figure 2, the highest dry matter accumulation in leaves, stem and panicle was observed at higher level of nitrogen fertilizer. In regarding to increasing of nitrogen fertilizer usage, Photosynthesis rate increased. In addition high application of nitrogen, with stimulating vegetative duration, decreased storage of carbohydrate and increased dry matter production in leaves (Daniel *et al*, 2003).

Table 2. Evaluation results for ORYZA-2000 simulations of N content in above ground biomass and grain, for the valuation conditions.

Crop variables	N	X_{obs}	X_{sim}	α	B	R^2	P(t)	$RMSE_a$ (kg/ha)	$RMSE_n$ (%)
Final biomass (Kg ha^{-1})	12	7738	7546	0.99	157.8	0.75	0.38	782	10.1
Yield (Kg ha^{-1})	12	3560	3413	0.94	61.87	0.76	0.32	388	10.9

With increasing of nitrogen fertilizer, the total biomass procedure is simulated well during growth period. Simulated values matched measured values quite well until flowering, but afterwards, simulated values of total biomass was higher than measured values. This could have been caused by lodging of the crop from flowering onward which reduced the accumulation of biomass. Difference between simulated and measured values due to total biomass under nitrogen management varied between -0.08% and +13%. Bouman and Van Laar (2006) and Jing *et al* (2007) confirmed this result in their study.

Also Khazar variety mentioned the longest vegetative duration and the highest leaves dry matter. Caton *et al* (2003) believed the longest vegetative stage caused the highest LAI and leaves dry matter.

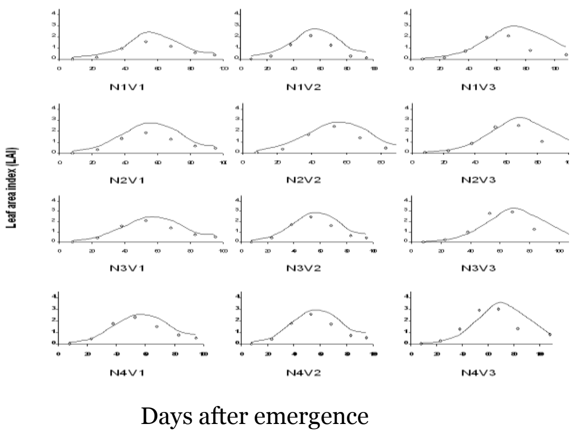
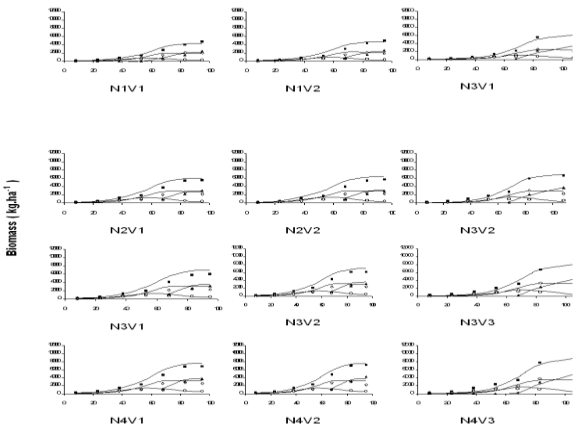


Fig. 1. Simulated (lines) and measured LAI (◊) under nitrogen management.

Crop biomass and yield at harvest

Figure 4 showed simulated and measured values of crop biomass at the end of the season, for the independent validation data set. Simulated and measured final crop biomass matched quite well, with the majority of data points close to the 1:1 line. The *t*-test showed that the simulated values were similar to measured values within a 95% confidence interval (P (*t*) =0.38).



Days after emergence

Fig. 2. Simulated (lines) and measured leaves(○) , stem (◊), panicle (▲) and total (■) under nitrogen management.

The *t*-test showed that the simulated values of grain yield were similar to measured values within a 95% confidence interval. This result and studying of P (t) value at various nitrogen fertilizers verified the ability of ORYZA 2000 model for grain yield simulating in all varieties.

Also basis on figure 3 was observed that R^2 larger than 0.75, indicating a close correlation between the simulations and the measurements. So ORYZA2000 model can use as an applied tool for approximate estimate of grain yield in paddy soil of Guilan.

Fig. 3 compared simulated with measured yield for harvest time data of valuation sets. For reference, the 1:1 line of the measured variables is also shown. The linear regression between simulated and measured values had a slope α close to 1, an intercept β that was relatively small, and an R^2 larger than 0.7 for all variables at harvest time, indicating a close correlation between the simulations and the measurements.

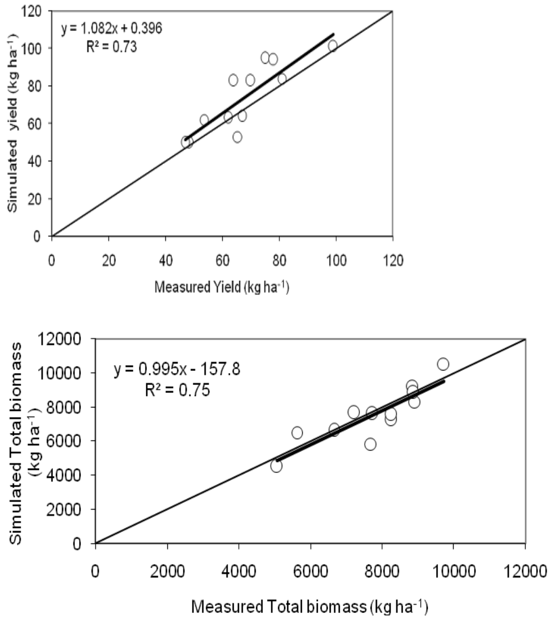


Fig. 3. Evaluation of ORYZA-2000 model for grain yield and total biomass under different N rates regimes.

Suitability of model for grain yield value simulation confirmed by Bannayan *et al* (2005), Boling *et al* (2010), Bouman *et al* (2006), Jing *et al* (2010) and Tung *et al* (2009) too.

Conclusions

We conclude that ORYZA2000 was sufficiently accurate to simulate leaf area index, grain yield and biomass at the end of the season for three rice cultivar growing under N-limited conditions in a paddy soil in Guilan. Additional comparisons between model simulations and experimental measurements are required to increase the confidence in the model predictions. Model ORYZA2000 was sufficiently accurate in the simulation of leaf area index (LAI) and biomass of leaves, panicles, and total above ground biomass yield under nitrogen limit conditions at our test site. Our evaluation results suggest that weak points in the simulation of LAI are the transition from the exponential to the linear phase of leaf area growth and the use of fixed values of specific leaf area as a function of development stage. Our data suggest that the specific leaf area may be influenced by N availability. Furthermore, a yield response to N fertilization was predicted. In this study, The

ORYZA2000 model could also support potential production and yield forecasting studies.

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