Evaluating ORYZA2000 model in shifting Irrigation conditions of Bahar variety rice

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ABSTRACT
In order to evaluate the ORYZA2000 model, an experiments was conducted on hybrid variety (Bahar) under the conditions of shifting irrigation management in crop year of 2008 at country's Rice Research Institute. The irrigation intervals were considered in 4 levels (continuously flooded, 5, 8 and 11 days interval). Evaluation of simulated and measured values of grain yield and biological yield was performed by using the parameters of coefficient of determination, t-test and the root mean square error (RMSE) and normalized root mean square error (RMSEn). The results showed that normalized root mean square error of grain yield and biological yield were determined 3% and 8%, respectively. The research results show that ORYZA2000 model has a good accuracy in simulation of grain yield and biological yield. The obtained results show that the ORYZA2000 model can be used to support the experiment results under the irrigation management conditions.

INTRODUCTION
Rice plant, in terms of importance is the second important edible cereal of country after wheat, with almost 600,000 hectares of area under cultivation and the capita consumption of 38 to 42 kg. Coastal areas of the Caspian Sea especially in Mazandaran province and Gilan were accounted for more than 70% of the area under cultivation of rice.

Modeling, at first was used to increase scientific knowledge on the way of elapsing the grow steps in plants, once the attempts at agricultural research shifted toward scientific uses rather than theoretical findings, the development of modeling, due to the strategic and tactical decisions, was driven to predict plants yield (Bouman et al, 1996). In the mid-90s, Research Center of Wageningen University and International Rice Research Institute introduced ORYZA model in order to simulate the growth of rice in the tropical lowlands. The first model of this series, is ORYZA1 model of the production in potential conditions (Kroppff et al, 1994), the second model is ORYZA-N for growth in the conditions of nitrogen limitation (Drenth et al, 1994), and then ORYZA-W model was introduced to produce in the conditions of water scarcity (Wopereis, 1996) and the latest model of this series is ORYZA2000 model (Bouman et al, 2001). The ORYZA2000 model simulates the growth of rice plant in favorable conditions, water and nitrogen limitations. The simulation begins in the shortest time interval, which is usually one day. In all these circumstances, it is assumed that the plant is protected against diseases and weeds, and no decline in performance of these factors is considered (Bouman et al, 1996).

Feng et al (2007) and Geo et al (2008) evaluated ORYZA2000 model for the mutual conditions of nitrogen fertilizer and irrigation management, their research results showed that the value of simulated grain yield has no significant different with measured value at the 95% probability level.

Several researchers have employed the ORYZA2000 model to simulate the growth of rice plants various managements such as irrigation. Arora (2006), Amiri (2008) and Belder et al (2007) assessed the model in flooded and non-flooded irrigation conditions.

Bannayan et al (2005) used ORYZA2000 model to study the interaction of increasing the air Carbon Dioxide and nitrogen fertilizer in northern Japan and concluded that by increasing the amount of carbon dioxide, ORYZA2000 model simulates the leaf area index more than to measure it, but simulates the amount of biological yield with some more estimation.

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Bowling et al. (2007) were able to calibrate the transplant and direct seeding of rice in upland conditions in ORYZA2000. Based on the information of 8 growing seasons, the coefficient of determination (R²) for grain yield and biological yield were, respectively, 0.95 and 0.89, and the normalized root mean square error of biological yield and grain yield were obtained, respectively, 25 and 16 percent.

Bouman and Laar (2006) evaluated rice growth under the conditions of nitrogen deficiency by using the ORYZA2000 model for information about five irrigated rice farms in the International Rice Research Institute (IRRI), between 1991 and 1993. Root Mean Square Error of biological yield was obtained 620-1250 kg per hectare. They also observed that the leaf area index of simulation is generally higher than measured values, especially when nitrogen is low. Plant growth models are useful tools for better understanding of production yield changes based on changes in inputs and environmental factors, the amount of product yield is a result of the interaction between water, soil, plant and atmosphere agents as a continuous system, in this context, simulation of plant growth stages and thus predict the product yield will lead to the better planning and more efficient management in the production process. In agronomic science, the crop plants simulation models of human knowledge about various aspects of science including agriculture, meteorology, soil physics, soil chemistry, crop and plants physiology, have make it possible to modify plants and crops by mathematical equations to predict the growth and yield of crop plants. Thus simulation models of crop plants are known as the main tool of agricultural science transmission to the information age.

Amiri and Rezaei (2010) evaluated the model for interaction conditions of nitrogen fertilizer and irrigation management in the Gilan province, their research results showed that model simulates the grain yield and biological yield value by normalized root mean square error of 5-11 and 9-28%, respectively, in calibration and validation conditions. Also the model estimates the value of leaf area index higher than the actual value.

Amiri et al. (2011) used the model for the conditions of irrigation management and planting spaces in the Gilan Province, their results showed that the model predicts grain yield to be 0.71 in conditions of calibration with coefficient of determination and be 0.63 in the validation conditions. Also they did not observe significant differences between the model and the grain yield measurement.

Amiri Larijani et al. (2011) calibrated and validated the model for rice varieties for 2 crop years in the Mazandaran province in conditions of 17, 24 and 33 days of transplant age, and reported the value of normalized root mean square error of grain yield and biological yield to be 16-12 and 9-6 percent, respectively.

The overall, objective of this research is to simulate grain yield and biological yield of Bahar variety rice under the conditions of irrigation management and nitrogen fertilizer in Gilan province, by using the ORYZA2000 model.

MATERIALS AND METHODS

In order to evaluate ORYZA2000 model in Gilan province, an experiment was done in the form of factorial and based on randomized complete block design with three replications in crop year of 2008 in the country's Rice Research Institute on the hybrid variety (Bahar). The irrigation intervals are in 4 levels of continuously flooded, 5, 8 and 11 days, each experimental unit consisted of 15 sowing line with 5 meters length and transplants planting space is 25 × 25 cm. All the cropping operations and required notes such as sowing date in the nursery, transplantation, flowering and harvesting was performed according to the agricultural standards of the International Rice Research Institute (IRRI). At ripening, the value of grain yield and biological yield was measured with harvesting 5 square meters from the center of each plot by removing the marginal effect.

In the ORYZA2000 model, the calculation of phenological development pace follows the daily calculation pattern, using the sum of these values over time; the developmental stages will be simulating throughout the growing season (Bouman et al., 2011). In the model, the growth period of rice based on time - heat is divided into four phenological stages:

- 1 - Basic vegetative phase;
- 2 - Photoperiod-sensitive phase;
- 3 - Panicle formation phase;
- 4 - Grain-filling phase.

In potential conditions (without the limitation of water and fertilizer) the growth of varieties characteristics in terms of phenology and physiological and morphological processes are considered as the major determinant factors of plant growth per day. The total daily value of plants' photosynthesis is calculated based on the amount of light, temperature and leaf area index. Based on the single-leaf photosynthetic characteristics and the value of leaf area index, photosynthesis of the whole canopy is calculated. The produced dry matter is divided between different parts of the plant. The specific coefficients are also included in the model based on the related functions which depends on plant phenology (Bouman et al., 2001).

All the parameters of ORYZA2000 model can be changed in data files which are with the presented model. About 10 percent of the vegetation parameters are for each variety and the other parameters are the same for all varieties (Bouman et al., 2011). These parameters are: the pace of phenological development, differentiation factors of dry matter, relative growth rate of leaf area, specific leaf area, leaf death rate and stem storage fraction. For calibration of ORYZA2000 vegetation parameters, the two DRATES and PARAM applications
were used which DRATES used to calibrate the phenological development pace and PARAM application used to calibrate other parameters that are specific to the varieties.

Data needed to evaluate the model include meteorological data (daily data of maximum and minimum temperature, amount of rainfall, sunny hours, relative humidity) and management information (nursery day, number of days in nursery, the number of transplant in pile, the number of pile in square meter, the transplant day, date of panicle emergence, 50% of flowering and ripening date, the amount and timing of irrigation water) and plant information (seed yield and biological yield).

Evaluation criteria of model results:

In order to evaluate the results of ORYZA2000 model simulation, the combination of Graphical and statistical methods, comparison of the simulated and measured value of grain yield and biological yield in terms of irrigation interval were used, the scatter plot of simulated and measured data and 1:1 lines was also used to demonstrate the total proportionality of model, as well as the determination coefficient (R²) of linear regression between simulated (P) and measured (O) values was calculated.

In order to statistical evaluation of the model simulation results, t test and the following statistical variables were used:

\[ RMSE = \sqrt[5]{\frac{1}{n} \sum_{i=1}^{n} (P_i - O_i)^5} \]  

\[ RMSE_n = 100 \sqrt[5]{\frac{1}{n} \sum_{i=1}^{n} (P_i - O_i)^5} / \bar{O} \]

Which in these relations:
- \( P_i \) = the amount of model simulation of plant components,
- \( O_i \) = value of true measurement of plant components
- \( n \) = number of actual measurement of plant components,
- \( \bar{O} \) = the average of measured values of plant components,
- \( RMSE \) = root mean square error,
- \( RMSE_n \) = Root Mean Square Error- Normalized.

Values of root mean square error and normalized root mean square error in optimum condition or state in which the simulated and measured values are equal, are equal to zero, obviously, the closer to zero the value of this these two parameters, the more accurate the model is. If the normalized root mean square error is less than 10 it shows the good state of simulation, between 30-10 shows the excellent state of simulation, between 30-20 shows the medium state and over 30 shows the low state of simulation (Rinaldi et al., 2003).

For calibration of model plant parameters, the measured data under the terms of potential generation was used. DRATES program was first implemented, resulting the calculation of phenological development pace values. The pace of phenological development is in four phase including basic vegetative phase (DVRJ), photoperiod-sensitive phase (DVRI), panicle formation phase (DVRP), and grain-filling phase (DVRR):

- DVRI = 0.000576 (day⁻²°C)⁻¹
- DVRP = 0.000795
- DVRR = 0.001900

Then the PARAM program will be implemented that other desired parameters will be calculated for the calibration of vegetation parameters such as the maximum relative growth rate of leaf area (RGRLMX) and stem storage fraction (FSTR):

- (Day⁻²°C)⁻¹
- RGRLMX = 0.0070
- FSTR = 0.20

The death rate during the leaf growth (DRLVT, (day⁻¹))

Specific leaf area during the growth period (SLA, ha/kg)

The separation factor of biomass between leaf (-) FLV, stem (-) FST and cluster (-) FSO during the growth period

<table>
<thead>
<tr>
<th>The death rate during the period of leaf growth</th>
<th>Specific leaf area during the growth period</th>
<th>The separation factor of biomass between leaf</th>
</tr>
</thead>
<tbody>
<tr>
<td>DRLVT(day⁻¹)</td>
<td>DVS</td>
<td>SLA(ha/kg)</td>
</tr>
<tr>
<td>0.00</td>
<td>0.00</td>
<td>0.0045</td>
</tr>
<tr>
<td>0.00</td>
<td>0.60</td>
<td>0.0045</td>
</tr>
<tr>
<td>0.015</td>
<td>1.00</td>
<td>0.0033</td>
</tr>
<tr>
<td>0.025</td>
<td>1.60</td>
<td>0.0030</td>
</tr>
<tr>
<td>0.050</td>
<td>2.10</td>
<td>0.0025</td>
</tr>
<tr>
<td>0.050</td>
<td>2.50</td>
<td>0.0023</td>
</tr>
</tbody>
</table>
RESULTS AND DISCUSSION

Grain yield:
Evaluation of Model: statistical variables which was considered to assess the model ability to simulate the rice grain yield, is shown given in Table 1; the results show that the root mean square error of grain yield is 200 kg per hectare. The value of normalized root mean square error of grain yield was obtained 3%.

Table 1: Evaluation of the simulation results of plant parameters of ORYZA2000 model for the year 2008

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Number of samples</th>
<th>$\Omega_{\text{mean}}$</th>
<th>$P_{\text{mean}}$</th>
<th>$R^2$</th>
<th>$P(t)$</th>
<th>RMSE</th>
<th>RMSE, (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grain yield (kg/ha)</td>
<td>4</td>
<td>6289</td>
<td>6152</td>
<td>0.95</td>
<td>0.39</td>
<td>200</td>
<td>3</td>
</tr>
<tr>
<td>Biological yield (kg/ha)</td>
<td>4</td>
<td>14320</td>
<td>13688</td>
<td>0.89</td>
<td>0.24</td>
<td>1074</td>
<td>8</td>
</tr>
<tr>
<td>Leaf area index (-)</td>
<td>4</td>
<td>3.72</td>
<td>4.86</td>
<td>0.0078</td>
<td>0.02</td>
<td>1.35</td>
<td>36</td>
</tr>
</tbody>
</table>

Various researchers have shown that the ORYZA2000 model simulates grain yield value with a good accuracy: Amiri et al (2011), Jing et al (2007) and Bouman and Laar (2006) obtained the normalized root mean square error of grain yield value for the calibration conditions, respectively, 7, 13 and 11%. Also in conditions of model validation, the results of Amiri et al (2011), Geo et al (2008), Feng et al (2007), Bowling et al (2007), Belder et al (2007) and Bouman and Laar (2006) showed that normalized root mean square error of grain yield are 6, 19.11, 16, 13 and 11 percent, respectively. T-test results show that the model simulated grain yield values in irrigation management conditions, due to being higher than 0.05, at the 95% probability level are similar to the measured values (Table 1).

Results of linear regression between simulated and measured grain yield values indicate that the coefficient of determination ($R^2$) for all model data are 0.95, which indicates the suitability of the model in simulate the grain yield. Also the relatively high $R^2$ indicates a low dispersion of the data (Figure 1).

![Fig. 1: Comparison of simulated and measured grain yield compared to the 1:1 line](image)

Table 2: Values of the observed and simulated grain yield of rice plant and the percentage of simulated relative error by the model

<table>
<thead>
<tr>
<th>Treatment</th>
<th>2008</th>
<th>Observed (kg/ha)</th>
<th>Simulated (kg/ha)</th>
<th>Relative error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I1N4</td>
<td>2008</td>
<td>7093</td>
<td>6816</td>
<td>4</td>
</tr>
<tr>
<td>I2N4</td>
<td>2008</td>
<td>6487</td>
<td>6830</td>
<td>-5</td>
</tr>
<tr>
<td>I3N4</td>
<td>2008</td>
<td>7124</td>
<td>6827</td>
<td>4</td>
</tr>
<tr>
<td>I4N4</td>
<td>2008</td>
<td>5800</td>
<td>5172</td>
<td>11</td>
</tr>
</tbody>
</table>

Biological yield:

The evaluation results of model ability in simulation of rice biological yield show that the root mean square error of the biological yield is 1074 kg per hectare. Normalized root mean square error of biological yield is 8% (Table 1). Various researchers have shown that ORYZA2000 model simulates the biological yield with a good accuracy: In reports, Amiri and Rezaee (2010) showed that the root mean square error-normalized of biological yield varies 9%. T-test results indicate that the simulated biological yield values of model in conditions of irrigation interval and nitrogen fertilizer in probability level of 95% are not significantly different from the measured values (Table 1).

Results from linear regression analysis (Figure 2) of simulated and measured biological yield show that the coefficient of determination ($R^2$) is equal to 0.89, which indicates the suitability of the model in simulate the biological yield. Amiri Larijani et al (2011) reported the coefficient of determination ($R^2$) for estimating the biological yield to be 0.78 per cent. Amiri and Rezaei (2010) calculated coefficient of determination ($R^2$) for the estimation of biological yield in the range of 0.93.
**Fig. 2:** Comparison of measured and simulated biological yield compared to the 1:1 line

**Table 3:** Values of the observed and simulated grain yield of rice and the percentage of simulated relative error by the model

<table>
<thead>
<tr>
<th>Treatment</th>
<th>2008 Observed (kg/ha)</th>
<th>Simulated (kg/ha)</th>
<th>Relative error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I1N4</td>
<td>15472</td>
<td>14407</td>
<td>7</td>
</tr>
<tr>
<td>I2N4</td>
<td>15100</td>
<td>14420</td>
<td>5</td>
</tr>
<tr>
<td>I3N4</td>
<td>14985</td>
<td>14375</td>
<td>4</td>
</tr>
<tr>
<td>I4N4</td>
<td>12968</td>
<td>12937</td>
<td>0</td>
</tr>
</tbody>
</table>

Leaf Area Index maximum (LAImax):

Statistical parameters were calculated for the model evaluation in simulation of maximum rice leaf area index, and are given in Table 1; the results indicate that the root mean square error of maximum leaf area index is 1.35 square meter of leaf area per square meter of land surface. The value of normalized root mean square error of maximum leaf area index and validation were obtained 36%. The results do not indicate the acceptability of model accuracy in order to simulate the maximum leaf area index.

Amiri et al. (2009), Geo et al. (2008), Jing et al. (2007) and Bouman and Laar (2006) obtained the normalized root mean square error value of leaf area index, 32, 32, 64 and 44%, respectively. In Table (4), the comparison of measured and simulated maximum leaf area index is presented. The results show that with increasing nitrogen fertilizer, the actual maximum leaf area index will have an increasing trend; also model shows increment of simulated maximum leaf area index (Table 4). Results from linear regression analysis (Fig. 3) of simulated and measured Maximum leaf area index show that the coefficient of determination (R2) is equal to 0.0078. The results do not indicate the acceptability of model accuracy in order to simulate the maximum leaf area index.

**Fig. 3:** Comparison of simulated and measured maximum leaf area index compared to the 1:1 line
Table 4: Values of the observed and simulated yield of rice leaf area index and the percentage of simulated relative error

<table>
<thead>
<tr>
<th>Treatment</th>
<th>2008</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Observed (-)</td>
<td>Simulated (-)</td>
<td>Relative error (%)</td>
</tr>
<tr>
<td>I1N4</td>
<td>4.69</td>
<td>4.69</td>
<td>-18</td>
</tr>
<tr>
<td>I2N4</td>
<td>4.90</td>
<td>5.67</td>
<td>-16</td>
</tr>
<tr>
<td>I3N4</td>
<td>4.5</td>
<td>5.63</td>
<td>2</td>
</tr>
<tr>
<td>I4N4</td>
<td>3.90</td>
<td>5.36</td>
<td>-37</td>
</tr>
</tbody>
</table>

Conclusion:

Based on the results statistical and graphical evaluation of model in order to simulate grain yield and biological yield and maximum leaf area index, it can be concluded that the ORYZA2000 model, with respect to normalized root mean square error of 3 and 8% and coefficient of determination of 0.95 and 0.89, has a high accuracy in simulation of grain yield and biological yield, respectively, and in irrigation interval conditions simulates as well. However, does not simulate the maximum leaf area index very well with respect to the normalized root mean square error of 36% and coefficient of determination 0.0078 in the irrigation interval conditions. In general, this model can be recommended for managerial decision making of Bahar variety rice, such as irrigation interval, but to achieve more complete results and develop the model for rice varieties, long-term experiments in the field of irrigation interval and nitrogen fertilizer is needed.

REFERENCES


