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Evaluation of the Rice Growth Model ORYZA2000 Under Water Management

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Abstract: The model ORYZA2000, which simulates the growth and development of rice under conditions of potential production, water and nitrogen limitations. The model was evaluated against a data set of field experiments. The study was laid out in RCBD with 3 replications for one popular traditional landrace Hashemi carried out in 2005 at Rice Research Institute of Iran, Rasht. The irrigation managements were I1 with continuous irrigation while I2, I3 and I4 were irrigation 1, 3 and 5 days after water disappearance of ponded water and I5, I6 were irrigation at 5 and 8 days intervals. In this study compared simulated and measured Leaf Area Index (LAI) and biomass of leaves, stems, panicles and total aboveground biomass by adjusted coefficient of correlation (R^2), absolute and normalized Root Mean Square Errors (RMSE). On average, RMSE of model were 532-871 kg ha^{-1} for total biomass, 82-246 kg ha^{-1} for leaf biomass, 280-456 kg ha^{-1} for stem biomass, 234-473 kg ha^{-1} for panicle biomass and 0.23-0.52 (-) for LAI. For these crop variables, normalized RMSE values were 14-24 for total biomass, 10-24 for panicle biomass, 14-55 for leaf, 16-27 for stem and 27-70 for LAI. The model Simulated LAI generally exceeded measured values.

Key words: Rice, model ORYZA2000, simulation, evaluation, biomass

INTRODUCTION

In the Netherlands, crop growth modelling was initiated and developed from the mid-sixties onwards by De Wit *et al.* (1970) in Wageningen. The origins of crop simulation models from the School of De Wit (Van Ittersum *et al*., 2003) were in the classical publication on modelling photosynthesis of leaf canopies (De Wit, 1965). One of the first dynamic crop growth simulators was ELCROS (Elementary Crop Simulator) (De Wit *et al*., 1970), the comprehensive model BACROS (Basic Crop Growth Simulator) was developed from ELCROS (De Wit *et al*., 1978; Penning de Vries and Van Laar, 1982). These early models were forerunners of several versions of the Simple and Universal Crop growth Simulator, or SUCROS (Van Keulen *et al*., 1982), which were aimed toward practical applications, such as studies of climate effects on production and water management. The MACROS (Modules of an Annual Crop Simulator, Penning de Vries *et al*., 1989) model was developed as part of the Simulation and Systems Analysis for Rice Production (SARP) project to facilitate the transfer of simulation and systems analysis methodologies to researchers in Southeast Asia (Ten Berge, 1993). MACROS provided users with a development tool for developing and applying models for different applications, including the management of water, nutrients and pests. The ORYZA rice production models (Kropff *et al*., 1994) evolved from MACROS and SUCROS in that project to serve specific applications.

ORYZA2000 is an ecophysiological crop model of the School of De Wit (Bouman *et al*., 2001). Since the mid-90s, the International Rice Research Institute (IRRI) and Wageningen University and Research Center (WUR) have been developing the ORYZA model series to simulate the dynamics of rice growth and development. The first model was ORYZA1 for potential production (Kropff *et al*., 1994), followed by ORYZA_W for water-limited production (Wopereis *et al*., 1996) and by ORYZA-N (Drenth *et al*., 1994) and ORYZA1N (Aggarwal *et al*., 1997) 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; Feng *et al*., 2007). The main objective of this study is to evaluate ORYZA2000 model in irrigation managements in paddy field, ORYZA2000 was parameterized and validated using the observations at different irrigation managements.

MATERIALS AND METHODS

The model ORYZA2000: A detailed description of the model is given by Bouman *et al*. (2001) and only a summary description follows here. The rice crop has four phenological phases, viz: Juvenile phase from emergence (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% flowering (DVS = 1.0) and grain-fill phase from DVS = 1.0 until physiological maturity (DVS = 2.0). Each of these four phases has variety-specific development rate constants.

The light profile within the canopy is calculated from the amount and vertical distribution of leaf surface area. When the canopy is not yet closed, leaf area development is calculated from mean daily temperature. When the canopy closes, the increase in leaf area is obtained from the increase in leaf weight using the specific leaf area. The daily canopy assimilation rate is calculated by integrating the instantaneous leaf photosynthesis rate over the height of the canopy and over the day. The daily dry matter accumulation is obtained after subtraction of maintenance and respiration requirements. The dry matter produced is partitioned among the various plant organs as a function of phonological development, which is tracked as a function of ambient mean air temperature.

Leaf area growth includes a source- and sink-limited phase. In the early phase of growth, leaves do not shade each other and leaf area growth is not limited by the amount of available assimilate. In this phase, leaf area grows exponentially as a function of temperature sum times a relative leaf growth rate. After LAI is larger than 1, leaf area growth is limited by the amount of carbohydrates available for leaf growth. In this linear phase of growth, the increase in leaf area is calculated from the increase in leaf weight times a specific leaf area that is a function of development stage. The transition from the exponential to linear growth phase is smoothened by taking weighted values of leaf area growth rates derived using the exponential equation and the linear equation.

Drought stress affects leaf expansion, leaf rolling, leaf senescence, photosynthesis, assimilate partitioning, root growth and spikelet sterility. For these processes, stress factors are calculated as a function of the soil water tension in the root zone. The water dynamics in the ORYZA2000 model is accounted by using a soil water balance module (PADDY) (Wopereis *et al*., 1996; Bouman *et al*., 2001). In PADDY, a lowland rice soil is modelled as a layer of muddy topsoil overlying a 3-5 cm plough sole and a nonpuddled subsoil. With ponded water on the surface, vertical water flow is either a fixed percolation rate. The water retention and conductivity characteristics are expressed by Van Genuchten parameters (Van Genuchten, 1980).

Parameterization: About 10% of the crop parameters are expected to be variety-specific and need empirical derivation. These parameters are development rates, assimilate partitioning factors, specific leaf area, relative leaf growth rate, leaf death rate, fraction of stem reserves and maximum grain weight. These parameters should be derived from well-designed field experiments under potential production conditions, that is, without any water or nutrient limitations and without disease, pest, or weed infestation. ORYZA2000 was parameterized for the rice cultivar, starting with the standard crop parameters for cultivar IR72 and following the procedures set out by (Bouman *et al*., 2001). First, development rates were calculated using observed dates of emergence, Transplanting, panicle initiation, flowering and physiological maturity. Next, 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. For parameterization, used data from the continuous irrigation to have sufficient variation in environmental conditions.

Input data: ORYZA2000 was parameterized for the rice cultivar used in this experiment, starting with the standard crop parameters for cultivar IR72 and following the procedures set out by Bouman *et al*. (2001). first, development rates were calculated using observed dates of emergence, panicle initiation, flowering and physiological maturity. Next, Specific Leaf Area (SLA) was calculated from the measured values of leaf surface area and leaf dry weight. The values of partitioning coefficients were derived by analyzing the fraction of dry mass increment allocated to the plant organs between successive samplings. Soil water content at specified metric potential was estimated in the pressure plate extractor (Table 1). The Van Genuchten parameters of different soil layers using Pedotransfer Functions (PTFs) (Van Genuchten *et al*., 1991; Aimrun *et al*., 2004). The

Table 1: Soil physical properties of the experiment field

Depth (cm)	Sand (%)	Loam (%)	Clay (%)	Bulk density (g cm $^{-1}$)	θ_{sat}	K_{sat}	θ_{FC}	θ_{PWP}
0-10	14	39	47	1.10	0.65	57.54	0.40	0.27
10-20	17	39	44	1.20	0.62	30.80	0.40	0.30
20-30	9	44	47	1.32	0.62	0.40	0.41	0.30
30-40	11	42	47	1.31	0.60	11.40	0.42	0.30

amount of irrigation water applied was monitored at each irrigation from transplanting till maturity, by using flow meters. weather data on total radiation, maximum and minimum air temperature, vapor pressure, wind speed and rainfall for the crop season was obtained from Rasht meteorological station.

Model evaluation: Several statistical methods were used to compare the simulated and observed results. In this study, used a combination of graphical analyses and statistical measures, graphically compared the simulated and measured aboveground biomass and LAI. For the same variables and computed coefficient of determination R^2 of the linear regression between simulated (P_i) and measured (O_i) values. In this study, evaluated model performance using the absolute Root Mean Square Error (RMSE) and root mean square error normalized ($RMSE_n$). RMSE and $RMSE_n$ characteristics are common tools to test the goodness of fit of simulation models, also evaluated model performance using the Student's t-test of means assuming unequal variance (P(t*)), (Bouman and Van Laar, 2006):

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

$$RMSE_n = 100(\sum_{I=1}^{n} (P_i - O_i)^2 / n)^{0.5} / O_{mean} \quad (2)$$

where, P_i is the simulated value, O_i is the measured value and n is the number of measurements.

Field experiments: Field experiments were conducted in 2005 at Rice Research Institute of Iran, Rasht (37°12' N, 49°38' E) on a clay soil in a lowland rice area. The experiment was laid out in a RCBD design with 3 replicates for one popular traditional landrace Hashemi, the irrigation managements were I1 with continuous irrigation while I2, I3 and I4 were irrigation 1, 3 and 5 days after water disappearance of ponded water and I5, I6 were irrigation at 5 and 8 days intervals. The soil physical properties are shown in Table 1.

Thirty five days old seedlings were transplanted at a rate of 4 seedlings per hill and 25 hills m^{-2}. Transplanting and harvest dates were May 22 and August 15. 60 kg N ha^{-1}, 25 kg P_2O_5 ha^{-1} and 75 kg K_2O ha^{-1} were applied just before transplanting. For each treatment, the dates of emergence, transplanting, 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. The instruments of Quick method were used for determination of percolation and seepage during the rice growth season.

RESULTS

Calibration data set: In continuous irrigation, the dynamics in biomass of leaves, stems and panicles and LAI was simulated quite well throughout the growing season, simulated LAI was slightly overestimated around flowering day (Fig. 1).

Table 2 shows the R^2, RMSE and $RMSE_n$ for each treatment separatel. The $RMSE_n$ of LAI was consistently largest and that of biomass of panicle consistently (calibration) smallest. Moreover, except for LAI, the range in RMSE values for each crop variable was small. Using the whole calibration set, student's t-test indicates that simulated crop growth variables were similar to measured values (Table 2). The relatively low R^2 reflects the large spread in the data. Table 2 shows the goodness-of-fit parameters for the dynamic crop variables of the whole data set.

Validation data set: Figures 2-6 compare simulated and measured crop growth variables in time in water managements. Compared with the calibration set (Fig. 1), simulated total aboveground biomass values exceeded measured values, whereas simulated biomass of leaves, stems and panicles matched measured values well. Figure 2-6, suggest that the effect of water limitation during exponential Leaf area growth was simulated relatively accurately, but that, in the linear phase, water limitations may have reduced specific leaf area, which the model did not simulate.

In the validation set, simulated total aboveground biomass exceeded measured values, which was mainly caused by the oversimulation of stem biomass since the biomass of leaves and panicles was simulated quite well (Table 2). Like in the calibration set, simulated LAI generally exceeded measured LAI. Goodness-of-fit parameters were similar to those in the calibration set for the dynamic biomass of leaves, stems and panicles (Table 2). For LAI, absolute RMSE and normalized RMSE (%) values were smaller in the than calibration set in the

Table 2: Evaluation results for ORYZA2000 simulations of crop growth variables over the entire growing season, for the calibration and validation data sets

	Water regime^a					
	Calibration	Validation				
Parameters	I1	I2	I3	I4	I5	I6
RMSE						
Biomass of green leaves (kg ha^{-1})	83.00	82.00	90.00	141.00	217.00	246.00
Biomass of panicles (kg ha^{-1})	234.00	392.00	369.00	407.00	396.00	473.00
Biomass of stems (kg ha^{-1})	453.00	406.00	438.00	456.00	291.00	280.00
Total biomass (kg ha^{-1})	580.00	620.00	761.00	871.00	555.00	532.00
Leaf area index (-)	0.23	0.35	0.49	0.42	0.52	0.49
RMSE$_n$						
Biomass of green leaves (%)	14.00	15.00	18.00	30.00	43.00	55.00
Biomass of panicles (%)	10.00	21.00	20.00	24.00	20.00	24.00
Biomass of stems (%)	23.00	22.00	24.00	27.00	16.00	17.00
Total biomass (%)	14.00	16.00	20.00	24.00	15.00	14.00
Leaf area index (%)	27.00	47.00	67.00	69.00	70.00	70.00
R^2						
Biomass of green leaves (kg ha^{-1})	0.94	0.95	0.94	0.89	0.83	0.81
Biomass of panicles (kg ha^{-1})	0.98	0.97	0.96	0.95	0.95	0.94
Biomass of stems (kg ha^{-1})	0.93	0.95	0.94	0.92	0.97	0.98
Total biomass (kg ha^{-1})	0.97	0.97	0.94	0.96	0.97	0.98
Leaf area index (-)	0.92	0.77	0.70	0.72	0.67	0.64
P(t)						
Biomass of green leaves (kg ha^{-1})	0.58*	0.30*	0.15*	0.13*	0.19*	0.15*
Biomass of panicles (kg ha^{-1})	0.25*	0.10*	0.06*	0.07*	0.50*	0.50*
Biomass of stems (kg ha^{-1})	0.74*	0.35*	0.94*	0.45*	0.38*	0.07*
Total biomass (kg ha^{-1})	0.35*	0.12*	0.01	0.02	0.48*	0.37*
Leaf area index (-)	0.48*	0.19*	0.12*	0.09*	0.25*	0.27*

a: I1 with continuous irrigation, I2, I3 and I4 were irrigation 1, 3 and 5 days after water disappearance of ponded water and I5, I6 were irrigation at 5 and 8 days intervals

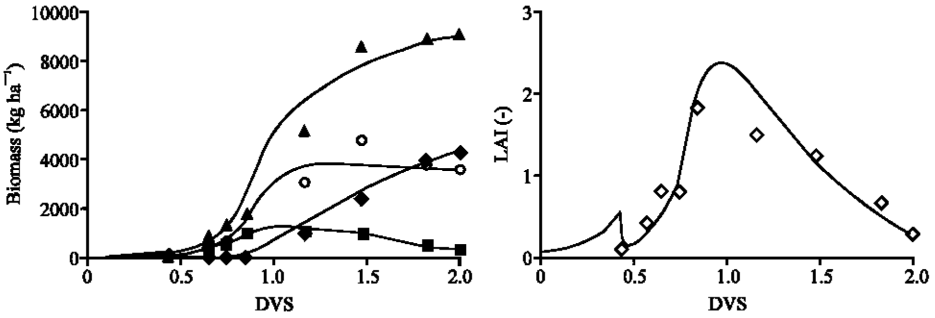

Fig. 1: Simulated and measured biomass of total aboveground dry matter (Δ), leaves (□), stems (○) and panicles (♦) and LAI (◊) in irrigation treatment I1

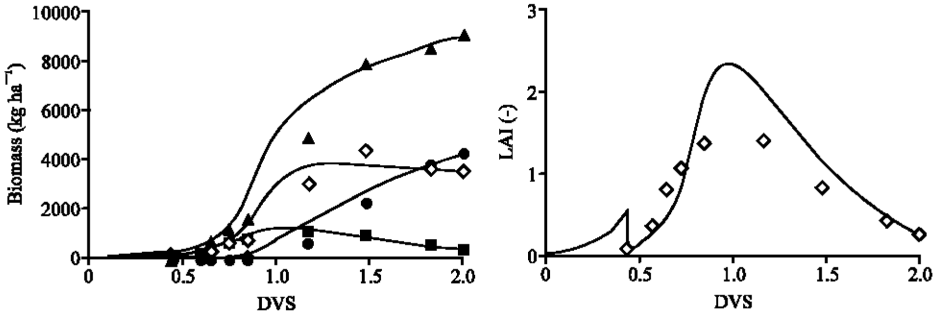

Fig. 2: Simulated and measured biomass of total aboveground dry matter (Δ), leaves (□), stems (○) and panicles (♦) and LAI (◊) in irrigation treatment I2

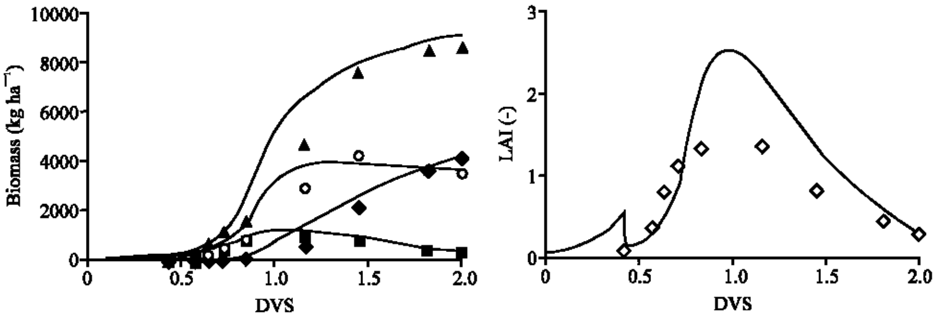

Fig. 3: Simulated and measured biomass of total aboveground dry matter (Δ), leaves (□), stems (○) and panicles (♦) and LAI (◊) in irrigation treatment I3

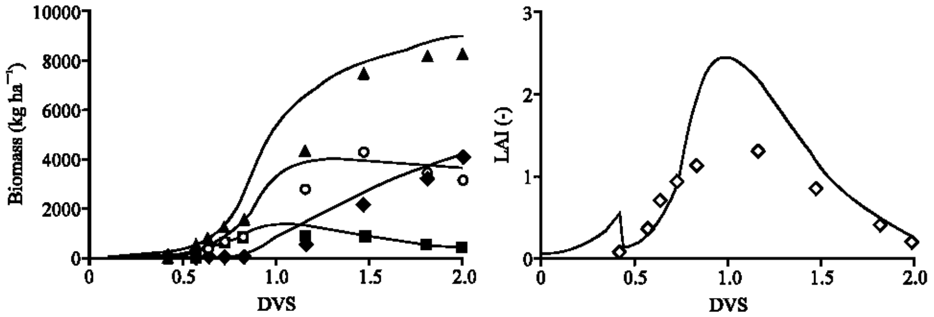

Fig. 4: Simulated and measured biomass of total aboveground dry matter (Δ), leaves (□), stems (○) and panicles (♦) and LAI (◊) in irrigation treatment I4

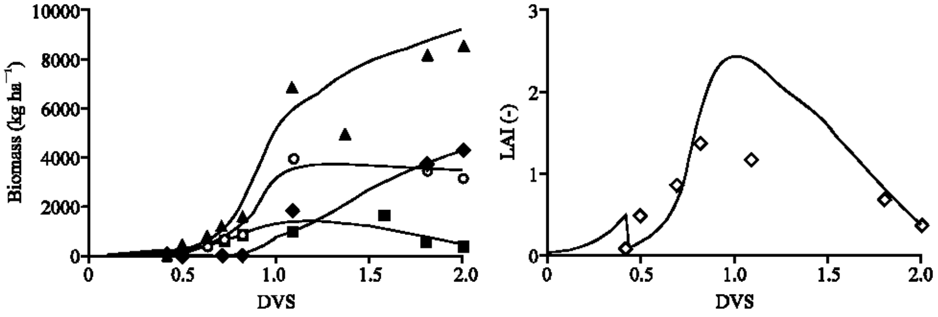

Fig. 5: Simulated and measured biomass of total aboveground dry matter (Δ), leaves (□), stems (○) and panicles (♦) and LAI (◊) in irrigation treatment I5

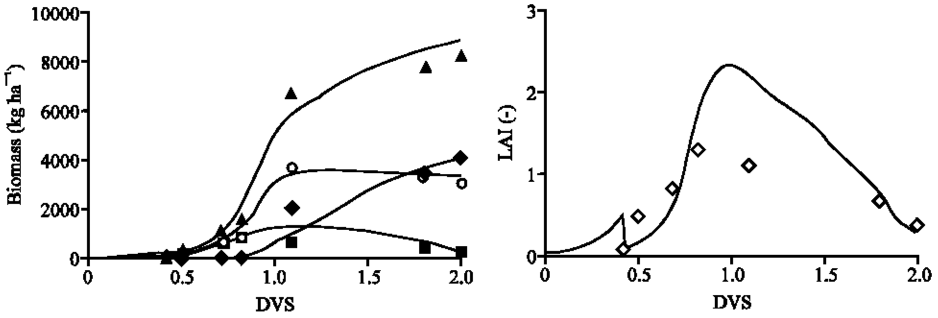

Fig. 6: Simulated and measured biomass of total aboveground dry matter (Δ), leaves (□), stems (○) and panicles (♦) and LAI (◊) in irrigation treatment I6

validation set. However, student's t-test indicated that simulated and measured dynamic biomass of aboveground biomass were not the same at the 95% confidence level in I3 and I4 water managements.

DISCUSSION

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). On average, RMSE of model were 532-871 kg ha^{-1} for total biomass, 82-246 kg ha^{-1} for leaf biomass, 280-456 kg ha^{-1} for stem biomass, 234-473 kg ha^{-1} for panicle biomass and 0.23-0.52 (-) for LAI. For these crop variables, normalized RMSE values were 14-24 for total biomass, 10-24 for panicle biomass, 14-55 for leaf, 16-27 for stem and 27-70 for LAI. The model Simulated LAI generally exceeded measured values. The relative difficulty of modelling LAI is well known and simulation errors have been reported as well, for example, for ORYZA2000 model (overestimation of LAI by the model, Bouman and Van Laar, 2006) and WOFOST model (overestimation of LAI by the model, Roetter *et al*., 1998). This 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 This data suggest that the specific leaf area may vary among water managements.

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