

Evaluation of ORYZA2000 and CERES-Rice Models under Potential Growth Condition in the Central Plain of Thailand

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Abstract

This paper reports result of a comparison of two rice growth models, ORYZA2000 and CERES-Rice for cultivation in the Central Plain of Thailand. ORYZA2000 is relatively new research tool in Thailand, while CERES-Rice has been tested and applied for years. Since both models were developed from different approaches, comparison between the models under the same input condition is necessary, otherwise the assessment of impact might be biased. In order to calibrate crop parameters of ORYZA model and to compare performance of the two models, two field experiments had been undertaken under potential growth condition for direct-seeded during wet season in 2007 and 2008, at Mae Klong Yai Irrigation Research Station (13°57' N, 99°58' E, 7.8 m MSL) in Nakhon Pathom province, located in the Central Plain of Thailand. The first field trial was laid out in randomized complete block design (RCBD) with 3 replications for 3 rice cultivars. Those were 2 medium-duration cultivars and 1 long-duration cultivar. The second field trial was also laid out in RCBD with 4 replications for 4 medium-duration rice cultivars. Observed crop data set were collected from the first field trial for crop parameter estimation in ORYZA2000, and those from the second field for models comparison. The result showed that both models predicted satisfactorily leaf area, days to panicle initiation, days to flowering and grain yields. Simulated yields were within $\pm 12\%$ of the measurements in term of RMSE statistical index. It might be concluded that both models, are adequate to simulated rice growth and development, particularly ORYZA2000 can be use as an alternative research tool to assist management decision at field scale level in the Central Plain of Thailand.

Keywords: rice, crop model, ORYZA, CERES-Rice

Introduction

Rice is one of the most important staple crops in Asia. Modeling of rice growth and development began more than 30 years ago (Bouman and van Laar, 2006). CERES-Rice and ORYZA are two popular models that are widely used in several countries (Mall and Aggarwal, 2002). A considerable number of studies based on such models have been conducted in recent years in Asian regions, some of these works focused on the response of the whole country or continent to changing climate (Matthews et al., 1995), while

some focused on different managements of resources. Those researches include the following examples: ORYZA application in the Philippines (Bouman and Van Laar, 2006), India (Arora, 2006), Indonesia (Boling et al., 2007), China (Belder et al., 2007; Jing et al., 2007; Bouman et al., 2007; Feng et al., 2007), and Iran (Amiri, 2009; Amiri and Rezaei, 2009), CERES-Rice application in Australia (Timsina and Humphreys, 2003), China (Min and Zhi-ging, 2009), India (Sarkar and Kar, 2008), and South Korea (Yun, 2003).

ORYZA is lesser-known in Thailand in comparison with CERES-Rice that has been tested

at many locations across Thailand. The following examples are studies dealt with application and tests of CERES-Rice. Phenological stages of four Thai rice varieties including KorKhor7 (RD7), KorKhor25 (RD25), Niew Sanpatong and Kaow Dawk Mali105 (KDML105) were evaluated using the weather data of northern Thailand (Mankeb, 1993). In north and northeast Thailand, Jintrawet (1995) reported accurate predictions of phenology for both photoperiod sensitive and insensitive cultivars, but the heading dates were underestimated for a photo-sensitive cultivar, especially for early planting. Boonjung (2000) reported that CERES-Rice accurately predicted the days to maturity of a photoperiod sensitive cultivar, KDML 105, at six sites in northeast Thailand, though the number of days to panicle initiation and anthesis were overpredicted. Tongyai (1994) studied the impact of climate change on simulated rice production for four locations in Thailand (Chiang Mai, Phitsanulok, Nankhon Sawan, and Bangkok) using CERES Rice. Cheyglinted et al. (2001) evaluated CERES-Rice against data sets of 4 rice varieties: KorKhor23 (RD23), Hom-Supan Buri (HSP), Suphan Buri90 (SPR90), and KDML105, grown in the field experiments at various places in the Central Plain of Thailand, including Pathum Thani, Suphan Buri, Kamphaengsaen and Nakhon Pathom. Observed data were phenological events (panicle initiation, anthesis and maturity), growth and yield.

Due to their different approaches for simulating growth and yield, performance comparison of both models had been studied at various locations, for example, Mall and Aggarwal (2002) compared the performance of CERES-Rice and ORYZA1N at 11 locations from north to south India. Kropff et al. (1994) reported that ORYZA1 and CERES-Rice overestimated yields in the wet season at IRRI, and CERES-Rice predicted LAI inaccurately in the dry and wet season at IRRI, and at Kyoto, Japan and Yanco.

In quantifying impacts of climate change on crop growth and yield, implement of powerful simulation tool has been of a high concern. Reliable crop growth model is one of new technologies frequently used for analyzing climatic impact under changing environmental conditions in relation to resource management, since the results

obtained from evaluated crop models are accurate and precise for aggregating for regional and national studies.

In order to implement an alternative research tool that is readily available and to enhance the credibility of rice growth models the study objectives were thus aimed to determine ORYZA2000 parameters according to application location and to assess the performance of two crop growth models, ORYZA2000 and CERES-Rice, in simulating potential growth and yield of rice under the environment of the Central Plain of Thailand.

Materials and Methods

A large number of developed rice growth models include ORYZA1 (Kropff et al., 1994), CERES-Rice (Singh et al., 1993), TRYM (Williams et al., 1994), VSM (Kobayashi, 1994), SIMRIW (Horie et al., 1992), RICAM (Yin and Qi, 1994) and a rice-weed competition model (Graf et al., 1990) and ORYZA2000 (Bouman et al., 2001). Each model has its specific objective(s) and, hence, its own set of underlying assumptions and complexity. Scientific-based descriptions of plant development processes of ORYZA2000, the recent version of ORYZA series are different from CERES-Rice. A brief report of those differences is given below.

ORYZA Model

The ORYZA2000 model is an update of the previous models of ORYZA series, simulates growth, development, and water balance of rice under potential production, water-limited and nitrogen-limited environments. A detailed explanation of the model and program code is given in Bouman et al. (2001).

In ORYZA2000, the rice crop has four phenological 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). Each of these four phases has variety-specific development rate constants (DRC).

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 phenological 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 smoothed by taking weighted values of leaf area growth rates derived using the exponential equation and the linear equation.

The water dynamics in the ORYZA model is accounted by water balance in 3 soil types. Those are poorly- drained lowland soil, regular upland, and well-drained upland. The water gains through rain and/or irrigations are accounted by ET and percolation losses. Daily soil evaporation (E) and plant transpiration (T) from ET are met preferentially from ponded water layer, and then from top soil layer (for E) and all rooted layers (for T) in the absence of ponded water. The percolation from the puddled layers is calculated using an iterative procedure that makes use of hydraulic characteristics of plough sole and that of underlying non-puddled subsoil. The percolation rate can never be greater than the amount of ponded water after extraction of ET loss for the

day. When the depth of ponded water after accounting for ET and percolation loss exceeds bund height, the excess water is assumed lost as runoff. Even in the case of no percolation, there are inter-layer fluxes contributing towards drainage due to redistribution of water in the soil profile. All water input in excess of field capacity is drained from a layer with a maximum rate equal to saturated hydraulic conductivity (Ks) of the layer. If the rate is low, the water content may reach saturation and may develop a perched water table. If the soil profile is not freely draining, one or more layers in the profile restrict water flow. When the outflow flux for a given layer is too low, the excess water is redistributed upward, and may cause ponding at the soil surface. In the case of presence of ground water in the soil profile, soil layers in the subsoil may drain to their field capacity values. Capillary rise from the ground water to a soil layer is assumed to occur only if soil water tension is greater than field capacity.

The evapotranspiration (ET) module computes potential evaporation rates from soil and plant surfaces for the main field crop using one of the three methods, namely, Penman, Priestley and Taylor, and Makkink depending on the availability of meteorological data. The computed reference potential ET can also be modified to account for local effects. The effects of water limitations on crop growth and development are accounted by considering their effects on expansive growth, leaf rolling, spikelet sterility, assimilate partitioning, delayed flowering, and accelerated leaf death. The stress factors for each of these processes are defined as a function of soil water tension in the root zone.

CERES-Rice Model

CERES-Rice, a physiological-based rice (*Oryza sativa L.*) model is a crop model contained in the Decision Support System for Agro-technology Transfer (DSSAT) developed by International Benchmark Systems Network for Agrotechnology Transfer (IBSNAT). The model can estimate yield potential by combining the properties of crops, soil and weather. The model assumes complete control of growth limiting factors such as weeds, insects, diseases and other management variables (i.e., phosphorus, potassium, liming, etc.).

CERES-Rice calculates nine phenological events and stages including 5 above ground stages. The duration of each stage makes use of the concept of thermal time similar to ORYZA, with a base temperature of 9°C, optimal temperature of 33°C and a maximum temperature of 42°C. When the temperature is outside this range, thermal time is calculated by dividing a 24h-day into eight 3h sections, calculating a temperature correction factor for each section.

CERES-Rice does not calculate gross photosynthesis and respiration separately as done in ORYZA. Instead, it calculates net photosynthesis (CARBO) based on the constant radiation use efficiency (RUE), leaf area index (LAI), extinction coefficient (k) and light absorption (IPAR) by the canopy. Temperature between 14 and 32°C is considered in the model as optimal for photosynthesis; beyond this range, it has a decreasing effect. This greater sensitivity of photosynthesis in CERES-Rice as compared to ORYZA could possibly be due to separate consideration of gross photosynthesis and maintenance respiration in the latter model.

The effect of CO₂ on net assimilation is simulated by multiplying the net rate by a factor on CO₂ effects on C3 and C4 crops. The multiplier has a value of 1.0 at 330 ppm CO₂, linearly increasing to 1.25 as CO₂ increased to 660 ppm and to 1.43 until CO₂ level became 990 ppm. A comparison of this CO₂ effect on photosynthesis shows that the magnitude of effect is more in ORYZA as compared to CERES-Rice. At 550 and 660 ppm CO₂ level, the photosynthesis increases by 26 and 33%, respectively in ORYZA as compared to 16 and 25% response in CERES-Rice. The difference between two models, however, may not be explicit once the gross photosynthesis in ORYZA is converted to net photosynthesis after consideration of temperature dependent maintenance respiration. The effects of water, nitrogen and temperature stress on the net photosynthesis in increased CO₂ environments are mediated through their effects on leaf area growth and hence radiation absorption.

The one-dimensional soil water balance model computes the daily changes in soil water content by soil layer. The changes are due to infiltration of rainfall and irrigation, vertical drainage,

unsaturated flow, soil evaporation, plant transpiration, and root water uptake. The soil requires parameters that describe its surface condition, water holding capacity and hydraulic conductivity. The model uses an overflow or “cascading bucket” approach for computing soil water drainage when a layer’s water content is above the drained upper limit. Drainage of water through the profile is first calculated based on an overall soil drainage parameter assumed to be constant with depth. The amount of water passing through any layer is then compared with the saturated hydraulic conductivity of that layer. If the saturated hydraulic conductivity of a layer is less than the computed vertical drainage, actual drainage is limited to the conductivity value, and water accumulates above the layer. This feature allows the model to simulate poorly drained soils and perched water tables. CERES-Rice can also simulate the effect of bund height. In addition, floodwater depth, runoff (when floodwater depth exceeds bund height) and evaporation from floodwater are simulated. The model also simulates the effect of puddling on percolation rate and bulk density, temporal changes in these properties, and the reversion to a non-puddled state.

Evapotranspiration in the CERES-Rice also responds to increased CO₂ by increasing stomata resistance. This effect is not likely to be important in the present study conducted for well-irrigated environments where water stress is insignificant. Soil and plant nitrogen (N) balance and the effects of N stress on crop growth and yield in CERES-Rice are similar to ORYZA, except that components of soil N balance are considered in much greater detail and the thresholds of the N deficit effect on crop growth and development are different in the latter model.

Field Experiment

Two direct-seeded field experiments were undertaken during wet season in 2007 and 2008 at Mae Klong Yai Irrigation Research Station (13°57' N, 99°58' E, 7.8 m MSL), in Nakhon Pathom province, located in the Central Plain of Thailand. Both paddy field trials had been conducted under potential production. The ground water depth at the experimental site was more than 10m, and did not influence water dynamics in the soil profile. Data

sets obtained from the first experiment were used for crop parameter estimation in ORYZA and those obtained from the second experiment was used for ORYZA and CERES-Rice simulation comparison. Weather data required for model simulation were obtained from weather station, located at 200 m from the field site. Those data were irradiance (KJ m^{-2}), minimum and maximum temperature ($^{\circ}\text{C}$), early morning vapor pressure (kPa), mean wind speed (m s^{-1}), and rainfall (mm d^{-1}).

Typically, ORYZA requires input data on crop and cultivar characteristics, soil water retention and drainage, irrigation management, water table depth, and weather conditions. As paddy fields were conducted under conditions of potential production without any water or nutrient limitations and without disease, pest or weed infestation, crop growth was then a function of weather (radiation and temperature) and the physiological characteristics of the cultivar (Bouman et al., 2001; Hoogenboom et al., 1999). Consequently, data sets required for calibration were crop and cultivar characteristics.

In this study, it was assumed that genetic coefficients that naturally induce different length of growth stages in different cultivars (Timsina and Humphreys, 2003) did not cause significant difference of growth, yield, and yield components among those cultivars within the same maturity group, in term of photoperiod and temperature response. So, one cultivar could be used as representative in simulation. In order to validate the assumption, two field experiments were conducted. In addition, information for models evaluation were supposed to get from both field experiments. The field works detail is explained in the following text.

First experiment was laid out in Randomized Completed Block Design (RCBD) (Gomez and Gomez, 1976) with 3 replications. Treatments comprised 2 medium-duration rice varieties (Chainat1 [CNT1], Suphan Buri1 [SPR1]) and 1 long-duration variety (Leung Pratew123 [LPT123]). Each subplot measured of 8 x 8 m with a bund height of 0.25 m to minimize run-off loss and run-on gain. A hundred kg ha^{-1} of Diammonium phosphate (DAP) $(\text{NH}_4)_2\text{HPO}_4$ and 68 kg ha^{-1} of Urea $\text{CO}(\text{NH}_2)_2$ were applied at 272 days after sowing, and additional 68 kg ha^{-1} of urea were applied at 298 days after sowing. Sequential crop samples had been taken during the growing season to determine LAI, biomass of green leaves, stems, and panicle. The rice samples were cleaned and kept cold in a portable refrigerator. A sub-sample was chosen and separated into different components: stems, green leaves, dead leaves and grains. Leaf blade area was determined with a LI-3100 electro area meter. Oven dry weight measurements ($65\text{--}70^{\circ}\text{C}$ during 24 h) were made independently for every component of the plant sample. A final harvest of 5 m^2 of crop of all replicates per plot was collected to get yield and yield components. Those included number of plants per square meter, panicles per square meter, spikelets per panicle, good grains per panicle, first branches per panicle, panicle length and individual grain weight. Observed phenological developments were dates of sowing, emergence, physiological maturity, and harvesting. Tables 1, 2 and 3 present insignificant differences of growth, yield, and yield components among rice cultivars of the same maturity group, in term of environmental response. The result ensures Chainat 1 cultivar choice of selection for model simulation.

Table 1 Agronomic characteristics of Suphan Buri 1 (SPR1), Chainat 1 (CNT1) and Luengpratew123 (LPT123) grown at the Mae Klong Yai Irrigation Research Station under direct-seeding cultivation in wet season of 2007.

Cultivar	Plant height (cm)	Number of leaf (number plant ⁻¹)	Panicle length (cm)	Number of 1 st branch (number panicle ⁻¹)
SPR1	86.97	5.47	20.59	8.13
CNT1	84.84	5.30	20.95	7.33
LPT123	129.30	5.57	24.12	10.33
LSD (*p<0.05) ^{1/}	3.381	ns	2.721	1.184
CV (%)	1.49	5.44	5.48	6.08

^{1/} ns = non significant

Table 2 Yields and yield components of Suphan Buri 1 (SPR1), Chainat1 (CNT1) and Luengpratew123 (LPT123) grown at the Mae Klong Yai Irrigation Research Station under direct-seeding cultivation in wet season of 2007.

Cultivar	Yield (kg rai ⁻¹)	Number of					1000 grain wt. (g)
		Stem (--- number m ⁻² ---)	Panicle	Spikelet (number panicle ⁻¹)	Filled (--- spikelet panicle ⁻¹ ---)	Sterile	
SPR1	917	258	270	89.33	80.67	8.67	28.90
CNT1	896	253	259	84.33	75.67	8.33	29.87
LPT123	928	248	256	122.66	115.67	9.33	28.4
LSD (*p<0.05) ^{1/}	24.18	ns	ns	14.06	12.69	ns	1.09
CV (%)	1.17	2.89	2.00	6.28	6.17	7.59	1.66

^{1/} ns = non significant**Table 3** Agronomic characteristics of Chinat 1 (CNT1), Suphan Buri 90 (SPR90), Hom-Suphan Buri (HSP), and Pathum Thani 1 (PTT1), grown at the Mae Klong Yai Irrigation Research Station in wet season of 2008.

Cultivar	Height (cm)	Stem (number m ⁻²)	Panicle length (cm)	Yield (kg rai ⁻¹)	Good seed (number panicle ⁻¹)	1000 grain wt. (g)
CNT1	83.7	260	19.94	844	52.72	29.30
SPR90	76.05	254	20.01	872	50.52	29.30
HSP	76.83	254	21.38	860	56.32	29.05
PTT1	78.46	260	20.97	860	56.28	29.75
LSD (*p<0.05) ^{1/}	4.106	ns	ns	ns	ns	ns
CV (%)	2.4	6.9	3.04	2.7	9.7	2.86

^{1/} ns = non significant

Second direct-seeded field experiment also under potential production, laid out in RCBD design with 4 replications for 4 treatments of medium-duration rice varieties: CNT1, Suphan Buri90 (SPR90), Hom-Suphan Buri (HSP), and Pathum Thani1 (PTT1). Rice was grown in 16 subplots of the same size and bund height as in the first experiment. Similar sets of crop data had been recorded during the growing season.

Estimation of Crop Parameters

ORYZA model calibration in this study was the adjustment of crop parameters regarding location in which the model was applied. The data used to determine crop parameters was collected from the first experiment during wet season in 2007. Since the process was done under potential situation, soil data file was not included in the model execution.

The data needed in estimation of crop parameters were data of experimentation that had been changed in accordance with the actual conditions of the first field trial and the default crop parameters data of IR72 cultivar in the ORYZA model.

The procedure started with the values of default crop parameters (IR72) and then followed the procedures set out by Bouman et al. (2001). Development rates were firstly calculated using observed data from the first field experiment (Table 4). Those were dates of sowing, 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. Finally, partitioning of assimilates was derived from measured data on the biomass of leaf, stem and panicles.

Table 4 Fraction of plant parts and LAI of Chainat 1 cultivar, derived from the first experiment in 2007 at the Mae Klong Yai Irrigation Research Station.

Day after sowing	Plant part					LAI
	WAGT	WLVG	WST	WLVD	WSO	
0	0	0	0	0	0	0
14	12	5	8	0	0	0.71
28	586	460	126	0	0	1.6
42	2630	1233	1377	20	0	3.1
56	3761	1656	2060	45	0	3.1
70	7110	1757	2887	532	1934	3.1
84	9225	1414	2680	886	4245	2.4
98	10162	853	2545	1264	5500	1.7
112	10292	456	2478	1758	5600	1.1

Note: WAGT= weight of above ground total biomass, WLVG=weight of leaves biomass, WST= weight of stems biomass, WLVD= weight of dead leaves biomass, WSO=weight of storage organ (grain) biomass, LAI=leaf area index.

Comparison of Model Performance

Simulation of ORYZA and CERES-Rice was done under the same input initial conditions in the situation of potential production that required daily weather data, agronomic management, crop characteristics. Water table depth was set to 10m from the soil surface. Weather data required for simulation was obtained from the weather station, located 200 m from the experiment site. Those data were irradiance, minimum and maximum temperature, early morning vapor pressure, mean wind speed, and rainfall.

In ORYZA, initial condition of experiment was set to potential production environment without water and nitrogen stresses, using timer data on sowing date of the second field experiment and management parameters were set to the default of direct-seed cultivation. In the crop data file, some parameters derived from Chainat 1 cultivar were used instead of the default value of IR72 cultivar. Those were four development rates (DVR [Cd⁻¹]), leaf and stem growth parameters and growth parameters. Without adverse effect of soil properties, soil initial condition was set to default of potential production in experiment condition without PADDY soil water balance model.

In CERES-Rice, initial condition in experiment data file were soil profile with 100% of water availability in the presence of 35 kg ha⁻¹ of nitrogen availability in default medium silty loam texture. Irrigation was set at full application with fix rate of deep percolation at 1 mm d⁻¹. Planting condition of

Chainat 1 cultivar was initialized at 200 plant m⁻² of plant population during seeding and emergence times with planting depth of 5 cm. Most of specific crop characteristics of Chainat 1 cultivar were already included in CERES-Rice, only those of crop management mentioned above was required in the simulation process.

In the process of model evaluation, 4 statistical methods were selected to compare the results from simulation and observation. In this study, combination of graphical, tabular, and statistical analysis were applied. Model performance evaluation was presented by the absolute Root Mean Square Error (*RMSE*) and Root Mean Square Error normalized (*RMSE_n*). Both characteristics are common tools to test the goodness of fit of simulation models. The *RMSE* (equation 1) between the simulated and observed values for a data set with *n* measured points, and the *RMSE_n* (equation 2) are defined as:

$$RMSE = \left[\sum_{i=1}^n (S_i - Ob_i)^2 / n \right]^{0.5} \quad (1)$$

$$RMSE_n = 100 \left[\sum_{i=1}^n (S_i - Ob_i)^2 / n \right]^{0.5} / Ob_{avg} \quad (2)$$

where *S_i* and *Ob_i* are the model simulated and experimental measured points, respectively. The *n* observed data points may be from one treatment or multiple treatments (Ma and Selim, 1994). The

next two statistical indices to compare simulation with measured ones was the D-index, and a normalized objective function (*NOF*) proposed by Ahuja et al. (2002). The D-index (equation 3) is defined as:

$$D = 1 - \frac{\sum_{i=1}^n (S_i - Ob_i)^2}{\sum_{i=1}^n (|S_i - Ob_{avg}| + |Ob_i - Ob_{avg}|)^2} \quad (3)$$

where Ob_{avg} = average of observed values that could be from one treatment or multiple treatments (Ahuja et al., 2002); S_i and Ob_i are simulated and observed values respectively. D-index is a measure of the deviation between model prediction and measurement in relationship to the scattering of the observed data. It has a values ranging from 0 to 1, where =1 means perfect simulation. The normalized objective function (equation 4) is defined as:

$$NOF = RMSE / Ob_{avg} \quad (4)$$

$NOF = 0$ indicates a perfect match between experiment and modeling results. $NOF < 1$ may be interpreted as simulation error of less than one standard deviation around the experiment mean.

Results and Discussion

Crop Parameters

The results from ORYZA model in calibration phase, including biomass of leaves, biomass of stem, biomass of panicle, and leaf area index (LAI), are in good agreement with those from observation throughout the growing season (Figure 1). The simulated LAI in Figure 1a of observed values are lower than simulated LAI, while values of observed stems biomass (d) are fluctuate through the growing season. Both yield and leaves parameters show good agreement of simulated and observed values.

Table 5 shows RMSE, $RMSE_n$, and D-index for biomass of green leaves, biomass of panicles, biomass of stem, total biomass and LAI. The

$RMSE_n$ of stems is the largest and that of panicle smallest, while RMSE of total biomass is the largest and that of LAI smallest. Figure 1d confirms that statistical analysis of simulated stem is higher than observed values during anthesis towards the end of growing season. Consequently, total above-ground biomass exceeded measured which was mainly caused by the over-simulation of stem biomass since the simulated biomass of leaves and panicles are close to observed values. Values D-index of leaves, panicles and LAI were interpreted as good agreement between simulations and observations, while biomass of stem expressed lower D-index than other parameters.

Comparison of harvest-time measured and simulated grain yield (14% moisture) for CNT1 shows the root mean square of deviations (RMSE) was 8.16 kg ha⁻¹, $RMSE_n$ was 0.85 kg ha⁻¹, and D-index was 0.99, while comparison of measured and simulated LAI shows the RMSE, $RMSE_n$ and the D-index with 0.32, 12.92 and 0.99 respectively.

Model Performance

Observed panicle initiation and flowering durations of CNT1 in Table 6 are 48 and 64 days in ORYZA2000, whereas simulated periods of CERES-Rice are 45 and 77 days. It is obviously seen that development was earlier in ORYZA2000 than that in CERES-Rice. Time period between panicle initiation (PI) and anthesis (flowering) is shorter in ORYZA, while duration from flowering to physiological maturity day was longer which indicates that ORYZA spent longer time for grain-fill phase. Harvest-time grain yield is slightly under-predicted in CERES-Rice with RMSE 11.68 kg ha⁻¹, and over-predicted in ORYZA2000 with a RMSE 7.04 kg ha⁻¹. It is evident from low RMSE that both models predicted grain yields close to measured yields, indicating their ability to simulate crop growth under optimal condition. Table 7 reveals that simulated values obtained from ORYZA2000 were closer to the observed values than those obtained from CERES-Rice, except anthesis date. *NOF* showed lesser error in ORYZA2000 than in that in CERES-Rice, except anthesis date, accordingly.

Table 5 ORYZA2000 calibration against calibration data set from field experiment in 2007 under situation of potential production showing crop growth variables over the entire growing season.

ORYZA2000 Calibration	Statistical indices		
	RMSE	RMSEn	D-index
Biomass of green leaves (kg ha ⁻¹)	13.02	7.50	0.99
Biomass of panicles (yield) (kg ha ⁻¹)	8.16	0.85	0.99
Biomass of stem (kg ha ⁻¹)	46.83	15.82	0.98
Total biomass (kg ha ⁻¹)	69.36	8.68	0.99
Leaf area index (LAI) (ha leaf ha soil ⁻¹)	0.32	12.92	0.99

Table 6 Main growth and development variables of CNT1 variety, obtained from observation, and simulation of ORYZA2000 and CERES-Rice.

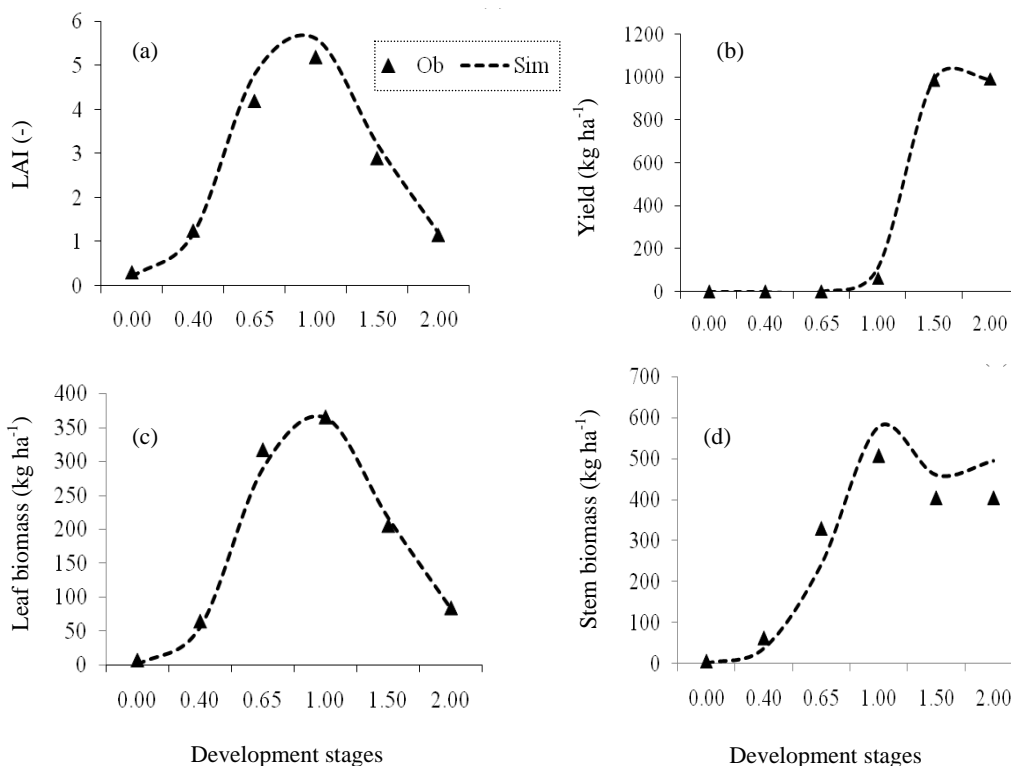
Variable	Observed	ORYZA	CERES
Panicle Initiation day (das)	53	48	45
Anthesis day (das)	72	64	77
Physiological maturity day (das)	124	120	103
Yield at harvest maturity (kg [dm] ha ⁻¹)	5275	5319	5202
Leaf area index, maximum	2.57	3.45	2.33

Table 7 Evaluation of ORYZA2000 and CERES-Rice against crop data set in 2008, under situation of potential production.

Variable	RMSE	RMSEn	NOF
ORYZA2000 simulation			
Yield (kg ha ⁻¹)	44	0.83	0.008
LAI	0.88	34	0.34
Panicle initiation (PI)	5.0	9.43	0.09
Anthesis	8	11	0.11
Physiological maturity day	4	3.22	0.03
CERES-Rice simulation			
Yield (kg ha ⁻¹)	73	1.38	0.014
LAI	0.64	25	0.25
PI	8	15	0.15
Anthesis	5	6.99	0.07
Physiological maturity day	21	16	0.17

In general, there was a good agreement between the measured and simulated values. Figure 2 (a) reveals LAI values obtained from 8 measurements are between those higher ORYZA and lower CERES-Rice with maximum value of 2.57, 3.45 and 2.33 presented in Table 5. Both models could attain the peak yield recorded in the experiment as shown in Figure 1.

Comparison of scatter plots (Figures 2 and 3) present similar outputs of yield and above-ground total biomass with coefficient of determination (R^2) of 0.97 in both models. Simulated leaves biomass of CERES-Rice in Figure 2c shows higher value of R^2 at 0.86 than that of ORYZA in Figure 2d at 0.64, while simulated stem biomass of ORYZA in Figure 3d displays higher R^2 at 0.73 than the value obtained from CERES-Rice in Figure 3c with R^2 at 0.69.



Remarks: development stages were defined by ORYZA2000 as followed 0.0 = emergence; 0.4 = end of basic vegetative phase (start of photoperiod-sensitive phase); 0.65 = panicle initiation; 1.0 = 50 % flowering; 2.0 = physiological maturity

Figure 1 ORYZA2000 calibration result showing simulated and measured (a) LAI, (b) yield, (c) leaf and (d) stems.

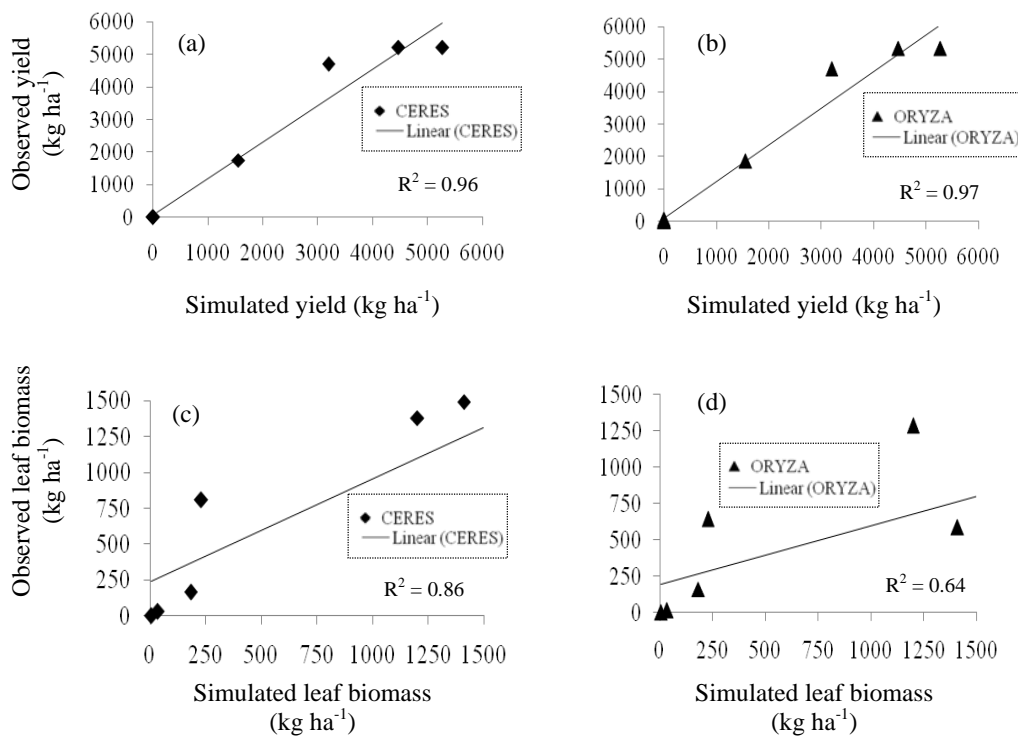


Figure 2 Comparison of (a) Obs vs CERES_Rice yield (b) Obs vs ORYZA2000 yield (c) Obs vs CERES_Rice leaf biomass (d) Obs vs ORYZA2000 leaf biomass, using data from the second field experiment in 2008.

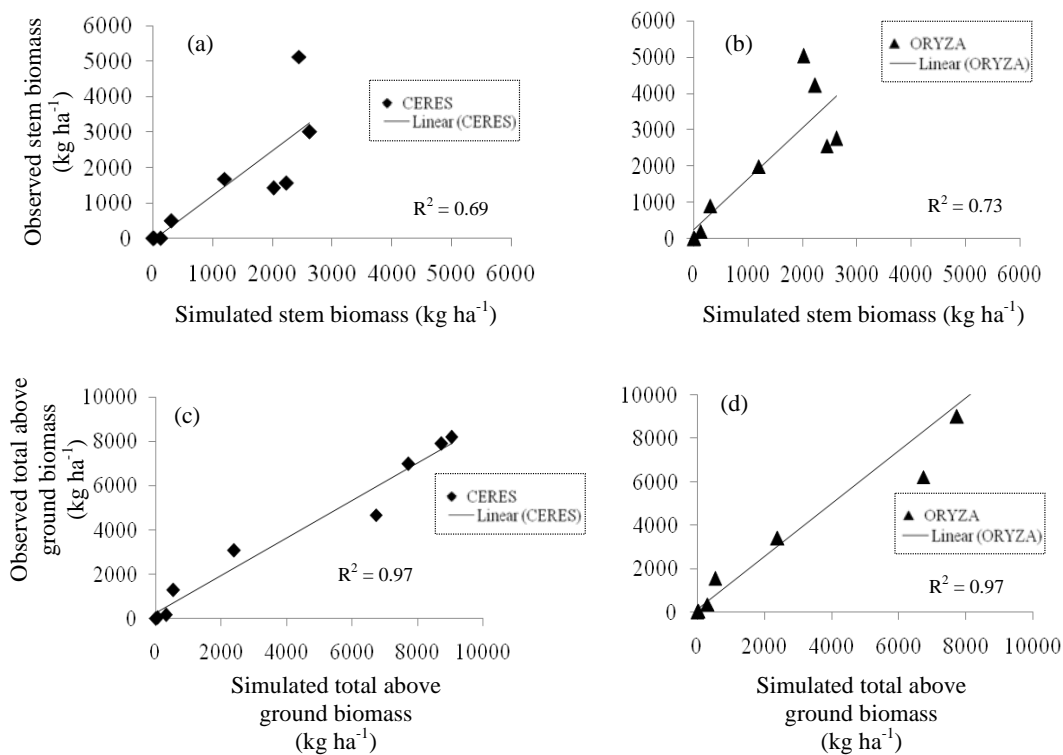


Figure 3 Simulated values of (a) CERES_Rice stem biomass (b) ORYZA2000 stem biomass (c) CERES_Rice above-ground biomass and (d) ORYZA2000 above-ground biomass, on a 1:1 line compared with observed values, using data from the second field experiment in 2008.

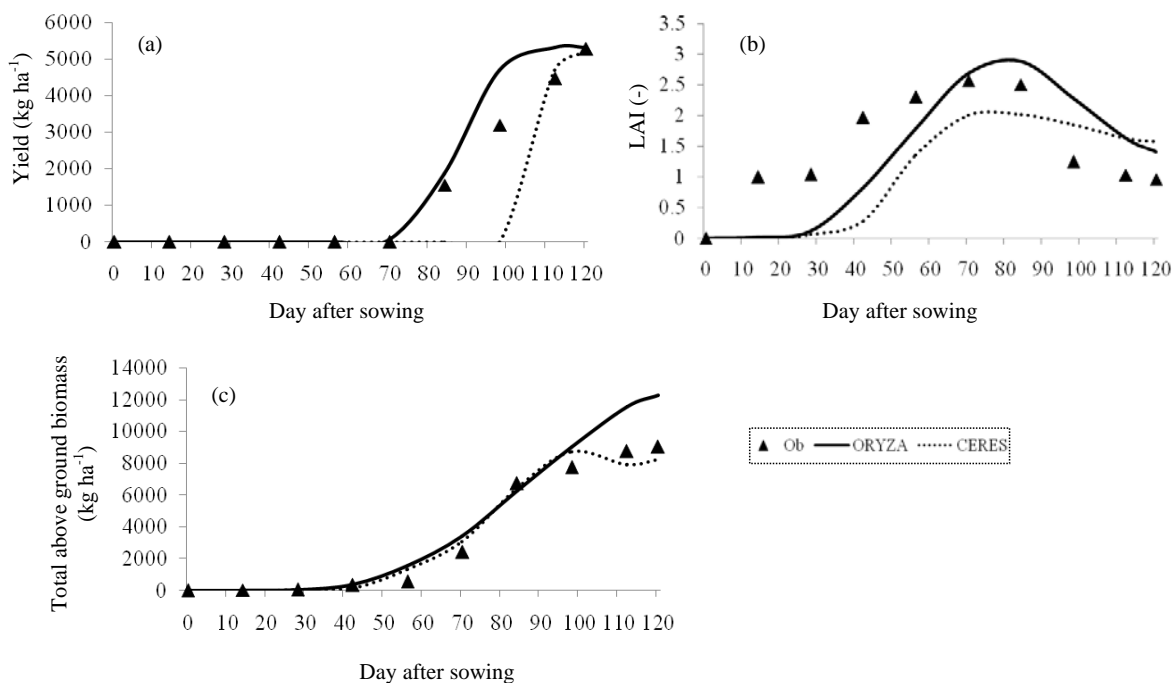


Figure 4 Simulated values of (a) yield (b) LAI and (c) total above ground biomass, from ORYZA2000 and CERES-Rice compared with Observed values, using data from the second field experiment in 2008.

Observed yield in Figure 4a and observed above-ground total biomass in Figure 4c are in between simulated values obtained from CERES-Rice and ORYZA, while observed LAI is fluctuated above and below simulated values obtained from both models.

Conclusions

ORYZA2000 model was calibrated against one field experiments conducted in wet season in 2007 under the situation of potential production to obtain crop growth and development specific coefficients. From iterative process to obtain matching between observed and simulated values, it might be said that model calibration is more likely to be a kind of art than a science. The most important thing to support the accuracy of calibration is the precise field measurement and observation, particular development events of the crop. Unless field data is measured with less error, the calibration output will be with more error.

Based on the simulation comparison, the results show that both models perform satisfactorily, with overall RMSE of crop growth and development less than 12 %. It can be concluded that both models are adequate to simulate rice growth and development under optimal growth condition.

Finally, there are no absolute criteria to distinguish the quality of model. 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. Particularly in this study, ORYZA2000 could be acceptable to use as a research tool for choosing the most appropriate strategy before real field experiments are conducted.

Acknowledgments

This research was funded by the Graduate School of Kasetsart University. The authors are grateful to Faculty of Engineering at Kamphaeng Saen for research facilities and financial support. Also equipments and tools as well as workers, kindly provided by the Mae Klong Yai Irrigation Research Station were highly appreciated. Finally, the authors thank to anonymous reviewers for comments and suggestions to improve their manuscript.

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Manuscript received 2 December 2009, accepted 8 July 2010