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Evaluation of CSM-CERES-Rice in simulating the response of lowland rice cultivars to nitrogen application

Saythong Vilayvong[1], Poramate Banterng[1,2*], Aran Patanothai[1], Krirk Pannangpetch[1]

[1]Department of Plant Science and Agricultural Resources, Faculty of Agriculture, Khon Kaen University, Khon Kaen 40002, Thailand
[2]Plant Breeding Research Center for Sustainable Agriculture, Faculty of Agriculture, Khon Kaen University, Khon Kaen 40002, Thailand

[*]Corresponding author: bporam@kku.ac.th

Abstract

The objective of this study was to evaluate the ability of CSM-CERES-Rice to simulate responses of lowland rice cultivars to different N-fertilizer applications in a tropical area. Experiments on 4 planting dates (July 6, August 5, and September 9, 2010 and January 14, 2011) were conducted in Khon Kaen province, Thailand. A split-plot randomized complete block design with 3 replications was used. Three N-fertilizer application rates (0, 60 and 120 kg N ha^{-1}) and 2 rice cultivars (TDK8 and TDK11) were assigned to the main-plots and sub-plots, respectively. Soil, plant, management and climatic data were collected from 4 experimental fields. The data from crops planted on July 6, 2010 and January 14, 2011 with application of 120 kg N ha^{-1} were used for model calibration. The remaining experimental data were used for model evaluation. The results for model calibration showed that the derived genetic coefficients provide simulated values of phenological events, biomass accumulation and grain yields that were in good agreement with their corresponding observed values. The model evaluation results indicated that for 2 rice cultivars grown under 3 rates of N-fertilizer application, the differences between observed and simulated values for time between transplantation and anthesis varied from 0-6 days, and for time between transplantation and maturity varied from 0-14 days. The normalized root mean square error ($RMSE_n$) values for biomass accumulation ranged from 0-34% and for grain yield ranged from 2-354%. In general, however, these results indicate that CSM-CERES-Rice can be used as a tool to support decision-making for rice production in tropical area.

Keywords: Fertilizer, Lao's rice cultivar, Nitrogen management, *Oryza sativa* L., Simulation model.
Abbreviations: ^{0}Cday_Celsius degree days; CSM-CERES-Maize_Cropping system model-Crop Environment Resource Synthesis-Maize; CSM-CERES-Rice_Cropping system model-Crop Environment Resource Synthesis-Rice; CSM-CROPGRO-Soybean_The generic cropping system model for soybean; DAT_Days after transplantation; DSSAT_Decision Support System for Agrotechnology Transfer; GDD_Growing degree day; h_Hour; KDML_Khao Dok Mali; N_Nitrogen; O_Observed value; RD_Rice Department; RMSE_Root mean square error; $RMSE_n$_Normalize root mean square error; S_Simulated value; SD_Standard deviation of the mean; TDK_Tha Dok Kham.

Introduction

Rice is the most important staple food for half of the world's population, especially in Asia. It is the most important grain with regard to human nutrition and caloric intake, providing more than one-fifth of the calories consumed by humans worldwide. Rice is the third highest grain produced after maize and wheat with approximately 158 million ha harvested, 88.9% in Asia (Food and Agriculture Organization, 2010). Today, the need for information to aid decision-making about suitable management practices and rice production improvement is rapidly increasing. The generation of new data through agronomic research methods is insufficient to meet these needs. Conducting experiments at particular points in time and space is time consuming and expensive due to the many years of data collection that are required. In recent years, several dynamic crop growth simulation models have been developed as tools to support decision-making for agronomic research, land-use planning and crop production. These models have been contained within the Decision Support System for Agrotechnology Transfer (DSSAT) (Hoogenboom et al., 2010). Use of the models to determine suitable crop management practices has been studied. For example, Soler et al. (2007a, b) applied the Cropping System Model-Crop Environment Resource Synthesis-Maize (CSM-CERES-Maize) to optimize maize planting dates in Brazil. Banterng et al. (2010) used the generic cropping system model for soybean (CSM-CROPGRO-Soybean) to determine the optimal management practices for soybean in Thailand. In addition, Ahmad et al. (2012) used CSM-CERES-Rice for identifying the optimal combination of plant density and N levels for rice production in Pakistan. CSM-CERES-Rice is widely used as a technological tool to support strategic decision-making (Sarkar and Kar, 2006). This model has been evaluated in a variety of rice-growing areas. For example, in India, Timsina et al. (2004) showed that the model performed satisfactorily in terms of grain yield and N uptake when simulated results were compared to data from field experiments from 3 locations in northwest India. In the temperate Kashmir valley in India, Singh et al. (2007) noted that the model could be used to estimate crop productivity and optimize management practices. Yao et al. (2005) showed that the model could simulate days to anthesis, grain number, yield and biomass in diverse agro-environments of China. In Thailand, Cheyglinted et al. (2001) found that the model reasonably simulated the phenology and yields of the RD23 and KDML105 cultivars. CSM-CERES-Rice was also used to simulate the influence of the rate and timing of N-fertilizer application in acid sulphate soils on yields of KDML105. Another study by Kerdsuk (2002) found that the model was able to simulate suitable planting time and yield potential of KDML105 under natural rainfall and irrigation in Tung Samrit area, Nakhon Rachasima province, Thailand. In a recent study, Ahmad et al. (2012) concluded that the model was able to simulate growth and yield of irrigated rice in the semiarid climate of Pakistan. However, studies on the use of CSM-CERES-Rice have not covered all commercial rice cultivars in tropical areas, including Laos's lowland rice cultivar. Thus, application of CSM-CERES-Rice to Laos's rice cultivar is necessary to increase the potential of widely using this model in tropical areas. Currently, there are 2 improved Lao glutinous rice cultivars (TDK8 and TKD11) that are commonly used by farmers in the Vientiane plain. TDK8 and TKD11 account for 73% and 15% of the total rice seed distribution, respectively (Rice and Cash Crops Research Center, 2010). The objective of this study was to evaluate the performance of CSM-CERES-Rice in simulating responses of 2 lowland rice cultivars (TDK8 and TDK11) to different N-fertilizer applications in a tropical area.

Results

Model calibration

The genetic coefficients that determine the duration of vegetative and reproductive growth are shown in Table 1. These genetic coefficients are the first new sets of genetic coefficients for TDK8 and TDK11 cultivars in Laos. The growing degree days for the basic vegetative phase to panicle initiation, the photoperiod sensitivity coefficient, and growing degree days from beginning of grain filling to physiological maturity were 415, 195, and 520 Celsius degree days (^{0}Cday), respectively for TDK8 and 409, 199, and 400 ^{0}Cday, respectively for TDK11. The critical day lengths of TDK8 and TDK11 were 10.6 and 11.2 hours, respectively. The potential spikelet number coefficient was 40 for TDK8 and 42 for TDK11, while the single grain weight was 0.025 g for both cultivars. The tillering coefficient for both cultivars was very similar (0.8 for TDK8 and 0.9 for TDK11). The temperature tolerance was 0.8 for both cultivars. A perfect agreement between simulated and observed values was obtained for phenology of both cultivars planted on July 6, 2010 and January 14, 2011 (Table 2). There was a difference of only 1 day for the number of days from transplantation to anthesis and the number of days from transplantation to maturity for TDK8. For TDK11, the model perfectly simulated the number of days from transplantation to anthesis and the number of days from transplantation to maturity for plants planted on January 14, 2011. There was a difference of 1 day for the number of days from transplantation to anthesis of TDK11 planted on July 6, 2010. Simulated and observed values of above ground biomass dry weights at 4 different growth stages of 2 rice cultivars grown under treatment with 120 kg N ha^{-1} planted on July 6, 2010 and January 14, 2011 are shown in Fig 1. The model underestimated and overestimated total above ground dry biomass of both cultivars planted on July 6, 2010 and January 14, 2011, respectively. For plantings on July 6, 2010, the RMSE values for total above ground dry biomass of TDK8 were 27, 200, 1305 and 273 kg ha^{-1} for the 1st, 2nd, 3rd and 4th growth stages, respectively; the RMSE$_n$ values were 14, 17, 23 and 3% for the 1st, 2nd, 3rd and 4th growth stages, respectively (Table 3). The RMSE values for total above ground dry biomass of TDK11 were 20, 280, 1490 and 1330 kg ha^{-1} for the 1st, 2nd, 3rd and 4th growth stages, respectively; the RMSE$_n$ values were 7, 21, 24 and 13% for the 1st, 2nd, 3rd and 4th growth stages, respectively. For TDK8 planted on January 14, 2011, the RMSE values for total above ground dry biomass were 13, 28, 232, and 1017 kg ha^{-1} for the 1st, 2nd, 3rd and 4th growth stages, respectively; the RMSE$_n$ values were 6, 3, 6 and 11% for the 1st, 2nd, 3rd and 4th growth stages, respectively. The RMSE values for total above ground dry biomass of TDK11 were 16, 214, 178 and 1296 kg ha^{-1} for the 1st, 2nd, 3rd and 4th growth stages, respectively; the RMSE$_n$ values were 9, 30, 4 and 20% for the 1st, 2nd, 3rd and 4th growth stages, respectively. At harvest maturity, a good correlation was found between simulated and observed grain yield of 2 rice cultivars grown under treatment with120 kg N ha^{-1} and planted on July 6, 2010 and January 14, 2011 (Table 4). The model underestimated the grain yield of both cultivars planted on July 6, 2010 and overestimated the grain yield for plantings on January 14, 2011. The RMSE values over 2 planting dates varied from 38-203 kg ha^{-1} for TDK8 and 571-855 kg ha^{-1} for TDK11. The RMSE$_n$ values ranged from 1-7% and 23-27% for TDK8 and TDK11, respectively (Table 4).

Model evaluation

CSM-CERES-Rice was evaluated by using the genetic coefficients in Table 1 and independent data sets of TDK8 and TDK11 grown under N-fertilizer applications of 0 and 60 kg N ha^{-1} for plantings on July 6, 2010 and January 14, 2011 and 0, 60 and 120 kg N ha^{-1} for plantings on August 5 and September 9, 2010. For both rice cultivars grown under 0 and 60 kg N ha^{-1} applications and planted on July 6, 2010 and January 14, 2011, a good correlation was found for most comparisons between simulated and observed number of days from transplantation to anthesis and to maturity (Table 5). However, for TDK8 planted on August 5, 2010 and treated with 3 different N-fertilizer application rates, the model overestimated the time from transplantation to anthesis by 4-6 days and the time from transplantation to maturity by 11-14 days. For TDK11, the model overestimated the time from transplantation to anthesis by 2-3 days and the time from transplantation to maturity by 10-11 days (Table 5). For TDK8 grown under 3 different N-fertilizer application rates and planted on September 9, 2010, the model also overestimated the days from transplantation to anthesis and to maturity by 3 and 5 days, respectively. For TDK11, the model overestimated the time from transplantation to anthesis by 1-2 days and the time from transplantation to maturity by 7-8 days. The average deviations between simulated and observed anthesis dates under different N-fertilizer application rates were within 1-9% for TDK8 and 0-5% for TDK11, while the average deviations for maturity dates varied from 1-16% for TDK8 and 1-12% for TDK11. A comparison between simulated and observed values for total above ground dry weight at 4 different growth stages of 2 rice cultivars grown under different N-fertilizer application rates for plantings on July 6, August 5 and September 9, 2010 and January 14, 2011 are shown in Fig 2. Based on visual inspection, the trends indicate that the model can predict above ground dry biomass of 2 rice cultivars grown under 3 different N-fertilizer application rates quite well. The RMSE values for 2 rice cultivars grown under different N-fertilizer application rates in all 4 planting dates were in an acceptable range. The RMSE values for TDK8 for the 1st, 2nd, 3rd and the 4th growth stages varied from 10-115,

Table 1. The genetic coefficients for the TDK8 and TDK11 cultivars.

Genetic coefficient	Cultivar name	
	TDK8	TDK11
Phenology coefficient		
Growing degree day (GDD) for the basic vegetative phase (^{0}Cday)	415	409
Photoperiod sensitivity coefficient (^{0}Cday)	195	199
GDD from the beginning of grain filling to physiological maturity (^{0}Cday)	520	400
Critical day length (h)	10.6	11.2
Growth coefficient		
Potential spikelet number coefficient	40	42
Single grain weight (g)	0.025	0.025
Tillering coefficient	0.8	0.9
Temperature tolerance	0.8	0.8

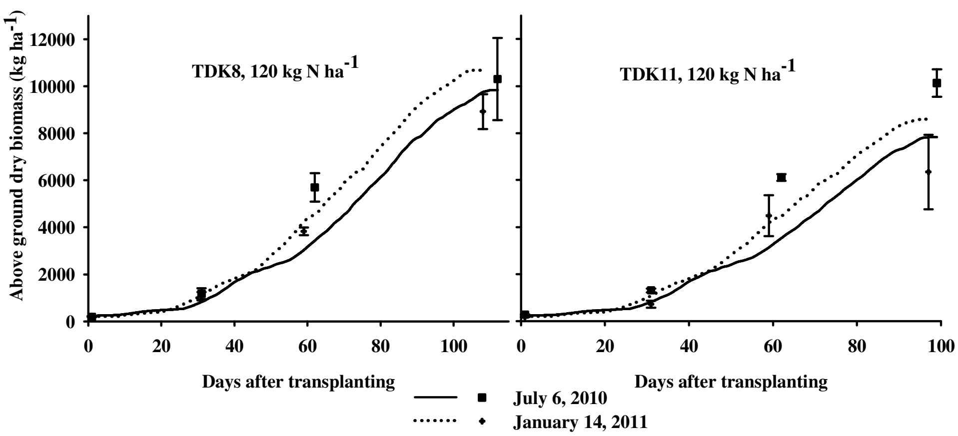

Fig 1. Simulated (lines) and observed (symbols) values for total above ground dry biomass (kg ha^{-1}) at different growing stages of 2 rice cultivars grown with 120 kg N ha^{-1} applications in plantings on July 6, 2010 and January 14, 2011 in Khon Kaen, Thailand.

33-667, 138-1417 and 23-1653 kg ha^{-1}, respectively. For TDK11, the RMSE values ranged from 1-119, 5-697, 57-1715 and 209-1516 kg ha^{-1} for the 1st, 2nd, 3rd and the 4th growth stages, respectively (Table 6). In addition, the $RMSE_n$ values for both rice cultivars grown under different N-fertilizer application rates in all 4 planting dates were generally low. The $RMSE_n$ values for TDK8 varied from 4-30, 4-33, 3-26 and 0-23% for the 1st, 2nd, 3rd and the 4th growth stages, respectively. For TDK11, the $RMSE_n$ values for the 1st, 2nd, 3rd and the 4th growth stages ranged from 1-28, 1-34, 1-30 and 2-29%, respectively. By comparing simulated and observed grain yield of both rice cultivars grown under different N-fertilizer application rates, good correlations were found for plantings on July 6 and August 5, 2010 and January 14, 2011 (Table 7). The RMSE values were generally in an acceptable range and varied from 42-390 kg ha^{-1} for TDK8 and 98-420 kg ha^{-1} for TDK11. The $RMSE_n$ values were generally lower and between 2-15% for TDK8 and 4-18% for TDK11 (Table 7). However, the model provided a very high overestimation of grain yield for plantings on September 9, 2010.

Discussion

This study is an attempt to evaluate the applicability of CSM-CERES-Rice for simulating responses of 2 lowland rice cultivars to different N-fertilizer applications in a tropical area. The results from model calibration based on the data collected from the experiments on 2 planting dates indicated that the derived genetic coefficients related to growth and development of individual rice cultivar were sensitive enough to capture the differences among TDK8 and TDK11 cultivars. The model simulated most of phenological events total above ground dry biomass and grain yield of TDK8 and TDK11 reasonably well with the derived genetic coefficients. The differences between observed and simulated values for total above ground dry biomass and grain yield as indicated by the $RMSE_n$ values are in an acceptable range found in the other studies, which vary from 1 to 27% (Saseendran et al., 1998; Cheyglinted et al., 2001; Ahmad et al., 2012). For model evaluation with independent data sets, the results indicated that the model performed fairly well in simulating phenological development. The deviation between simulated and observed timing for anthesis and maturity of both rice cultivars was similar to a study by Yao et al. (2005) who found that the simulation deviated 10% from the observed anthesis duration. The overestimation occurred because the life cycle of the rice crop in the 2 planting dates used for model calibration (Table 2) was longer than the life cycle of plants used for model evaluation (Table 5). The simulated and observed values for total above ground dry biomass and grain yield of 2 rice cultivars are acceptable when compared to previous studies. Ahmad et al. (2012) reported that the difference between simulated and observed values ranged from 2-15% for total above ground dry biomass and 2-3% for grain yield. Yao et al. (2005) also found that the simulation deviated from observed yield by 15%. In addition, Timsina and Humphreys (2006) reported that the difference between simulated and observed values for biomass and grain yield was approximately 23%. However, we found an overestimation of grain yield for plantings on September 9,

Table 2. Simulated (S) and observed (O) values for days after transplantation to anthesis and maturity of 2 rice cultivars grown under 120 kg N ha^{-1} application and planted on July 6, 2010 and January 14, 2011 in Khon Kaen, Thailand.

Cultivar	Planting date	Anthesis date (DAT)			Maturity date (DAT)		
		S	O±SD	S-O	S	O±SD	S-O
TDK8	July 6, 2010	77	78±1	-1	112	112±2	0
	January 14, 2011	75	74±1	+1	107	108±2	-1
TDK11	July 6, 2010	70	71±1	-1	99	99±2	0
	January 14, 2011	65	65±1	0	97	97±3	0

DAT is days after transplantation. SD is the standard deviation of the mean.

2010. This was the result of a severe flood during anthesis stage (November 3-15, 2010), and the grain yield was reduced by at least 45-101% for TDK8 and 36-91% for TDK11 when compared to the normal observed grain yield from plantings on August 5, 2010. The variation between simulated and observed values for grain yield was largely due to uncontrolled factors that affected rice plants in the experimental fields such as flood, crabs and diseases, which were not accounted for by the model. In addition, the observed data from the experimental fields were variable. Therefore, future experiments for model evaluation should be performed in research stations with good management practices to avoid these undesirable factors. The results from both model calibration and evaluation in this study illustrated the potential of CSM-CERES-Rice for simulating the response of 2 lowland rice cultivars to different rates of N-fertilizer application. In addition, the genetic coefficients of TDK8 and TDK11 cultivars derived from experimental data sets from 2 different planting dates are also sufficiently accurate for further application of CSM-CERES-Rice to support decision-making. Therefore, the information of this study would support creditability of the model applicable as a viable information technology tool in assisting to determine alternate N-fertilizer management strategies for lowland rice production in tropical areas such as choosing suitable rate and time for N-fertilizer application in specific production area.

Materials and methods

Four experiments were conducted in a farmer's rice field in the Khon Kaen province, Thailand (16° 28' N, 102° 48' E, 200 m above mean sea level) during June 2010 to May 2011. Each experiment was laid out in a split-plot design with 3 replications. The experimental sub-plot size was 5 x 4.5 m. The three N-fertilizer treatments were randomized in the main-plots. The rates of fertilizer used in this study were no N-fertilizer application (control), N-fertilizer application at a rate of 60 kg N ha^{-1} (the rate recommended by Linquist and Sengxua (1999) for lowland rice in central Laos), and N-fertilizer application at a rate of 120 kg ha^{-1} (2 times of the recommended rate). Two Lao's rice cultivars (TDK8 and TDK11) were randomly assigned to the sub-plots. Before rice transplantation, N, P_2O_5 and K_2O were applied as basal fertilization at the recommended rate of 37.5 kg ha^{-1} (Douangsila et al., 2010). The first three experiments were conducted under rain-fed conditions, and approximately 30-day-old rice seedlings were transplanted on July 6, 2010, August 5, 2010 and September 9, 2010. The forth experiment was irrigated condition, and 30-day-old rice was transplanted on January 15, 2011. The plant spacing was 25 x 25 cm and 3 seedlings $hill^{-1}$. Urea fertilizer was applied to the plots corresponding to the designated fertilizer treatment in 3 split applications; 30% was applied at 20 days after transplantation, 40% applied at 35 days after transplantation, and 30% more applied at 60 days after transplantation (Vergana,1979). After completion of rice transplantation, the insecticide Abamectin (1.8% W/VEC) was applied at a rate of 40 cc/20 litre of water

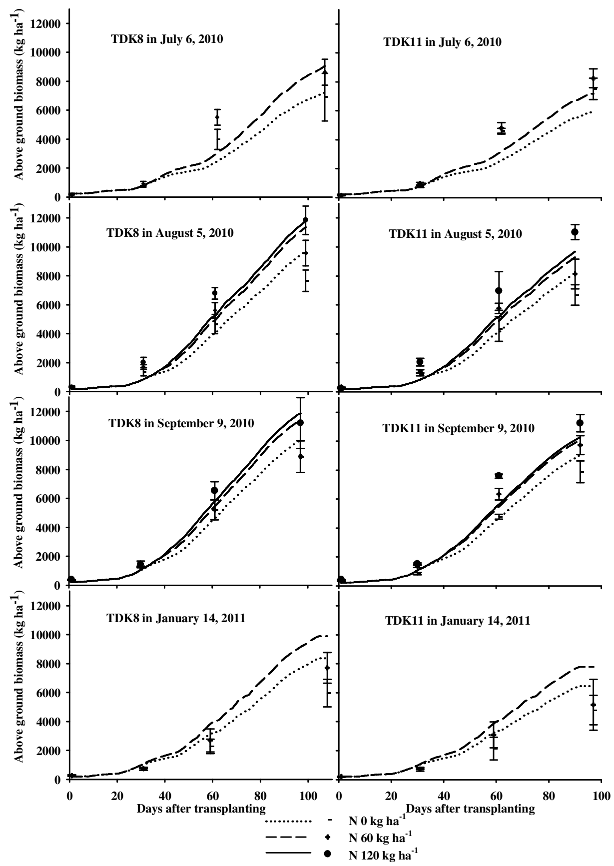

Fig 2. Simulated (lines) and observed (symbols) above ground dry biomass of 2 rice cultivars grown under 3 N-fertilizer application rates in plantings on July 6, August 5 and September 9, 2010 and January 14, 2011 in Khon Kaen, Thailand.

for prevention of golden snails and crabs for the first month after transplantation. 2,3-dihydro-2,2-dimethylbenzofuran-7-y (dibutylaminothio) methylcarba-mate (20% W/V EC) and methyl benzimidazol-2-ylcarbamate (50% WP) were often sprayed at rates of 110 cc and 10 g in 20 litres of water, respectively, to prevent the rice pests and diseases. Weeding was often performed by hand, and irrigation was well managed to minimize water stress on the rice crop. For data collection, soil samples were collected before conducting the experiment at 3 spots in the experimental site at different depths from the soil horizon (0-15, 15-30, 30-45, 45-60, 60-75, 75-90, and 90-105 cm). The soil samples were then analysed for soil bulk density and soil texture (percentage of sand, silt and clay) by the hydrometer method (Ashworth et al., 2001) and for chemical properties including pH, electric conductivity, organic matter, total nitrogen, available

Table 3. Root mean square error (RMSE) and normalize RMSE ($RMSE_n$) for total above ground dry biomass at different growing stages of 2 rice cultivars grown under 120 kg N ha^{-1} application and planted on July 6, 2010 and January 14, 2011 in Khon Kaen, Thailand.

Cultivar	Planting date	RMSE (kg ha^{-1})				$RMSE_n$ (%)			
		Time of sampling				Time of sampling			
		1st	2nd	3rd	4th	1st	2nd	3rd	4th
TDK8	July 6, 2010	27	200	1305	273	14	17	23	3
	January 14, 2011	13	28	232	1017	6	3	6	11
TDK 11	July 6, 2010	20	280	1490	1330	7	21	24	13
	January 14, 2011	16	214	178	1296	9	30	4	20

Table 4. Observed and simulated values, root mean square error (RMSE) and normalize RMSE ($RMSE_n$) for grain yield of 2 rice cultivars grown under 120 kg N ha^{-1} application and planted on July 6, 2010 and January 14, 2011 in Khon Kaen, Thailand.

Planting date	Crop traits	Cultivar	
		TDK8	TDK11
July 6, 2010	Observed yield±SD (kg ha^{-1})	2958±106	3741±585
	Simulated yield (kg ha^{-1})	2904	2532
	RMSE (kg ha^{-1})	38	855
	$RMSE_n$ (%)	1	23
January 14, 2011	Observed yield±SD (kg ha^{-1})	2776±441	2121±295
	Simulated yield (kg ha^{-1})	3063	2928
	RMSE (kg ha^{-1})	203	571
	$RMSE_n$ (%)	7	27

SD is the standard deviation of the mean.

phosphorus, exchangeable potassium, exchangeable calcium, and cation exchange capacity by using soil analysis procedures (Pansu and Gautheyrou, 2006). Daily rainfall, maximum and minimum air temperature, and solar radiation for 2010 and 2011 were obtained from the Khon Kaen Field Crop Center, Khon Kaen province, Thailand. Crop phenological events included anthesis and maturity dates were recorded when 70% of the rice plants in each plot had reached those stages (Yin and Kropff, 1998; Anzoua et al., 2010). Above ground plant biomass was assayed by a monthly destructive harvest from 4 hills starting from the transplantation day to the final harvesting day, a total of 4 sampling times. For each sample, plants were oven dried at 80°C degree for 4 days until a constant weight was obtained and the above ground dry biomasses were then recorded. Grain yield was measured by harvesting plants in the yield sampling area of each sub-plot. Additionally, all management information of the experiment was recorded.

This included seeding date, transplantation date, row spacing, crop varieties, time and amount of fertilizer applied, weeding, and pest and disease controls. For model calibration, the data from plantings on July 6, 2010 and January 14, 2011 that included soil, management and climatic data in addition to plant data for 2 rice cultivars grown under an N-fertilizer application rate of 120 kg N ha^{-1} were entered into the DSSAT v4.5. The soil profile information was created and estimated in the DSSAT v4.5 shell by using the soil data that were collected before conducting the experiments. There are 8 genetic coefficients that define developmental and growth characteristics of rice cultivars (Table 1). The phenology coefficients enable the model to simulate phenological events such as anthesis and maturity, and the growth coefficients simulate biomass accumulation and potential grain yield of a specific variety (Hoogenboom et al., 2010). In calibrating the genetic coefficients, the model was first run by using the genetic rice coefficients contained in the DSSAT v4.5. The values of the 8 genetic coefficients were adjusted until close matches were achieved between simulation and observation for phenology, above ground biomass and yield for 2 planting dates.

The accuracy of the procedure used to estimate the genetic coefficients was determined by comparing the simulated values of development and growth characteristics with their corresponding observed values. The RMSE value (Wallach and Goffinet, 1987) was used to test the agreement between simulated and observed data; a low RMSE value is desirable. The $RMSE_n$ value gives a measure (%) of the relative difference of simulated versus observed data. The simulation is considered excellent if the $RMSE_n$ value is less than 10%, good if the $RMSE_n$ is greater than 10% and less than 20%, and fair if the $RMSE_n$ is greater than 20% and less than 30% (Loague and Green, 1991). For model evaluation, the soil, management, climatic and plant data for 0 and 60 kg N ha^{-1} treatments for plantings on July 6, 2010 and January 14, 2011 and for 0, 60 and 120 kg N ha^{-1} treatments for plantings on August 5 and September 9, 2010 were entered in to the DSSAT v4.5. CSM-CERES-Rice was run with the calibrated genetic coefficients. Model evaluation was also performed by comparing the simulated values with their corresponding observed values with RMSE and $RMSE_n$ analyses.

Conclusion

The results from this study showed an acceptable agreement between simulated and observed values for phenological events, total above ground dry biomass and grain yield of 2 rice cultivars for both model calibration and evaluation. Some differences between observation and simulation were due to flood, crabs and diseases which were not accounted for by simulation as well as a deviation of observed values. Therefore, in order to increase an accuracy of model simulation, further experiment should be performed in the research stations with well managements. However, this is an initial evidence to show the potential of CSM-CERES-Rice in simulating development, growth and yield of Laos's rice cultivars under different N-fertilizer application and in various planting dates, and this also indicated the possibility in using CSM-CERES-Rice as a decision-supporting tool for rice

Table 5. Simulated (S) and observed (O) values for days after transplantation to anthesis and to maturity of 2 rice cultivars grown under different N-fertilizer application and planted on July 6, August 5 and September 9, 2010 and January 14, 2011 in Khon Kaen, Thailand.

Planting date	Cultivar/N rate	Anthesis date (DAT)			Maturity date (DAT)		
		S	O±SD	S-O	S	O±SD	S-O
July 6, 2010	TDK8/ 0 kg N ha^{-1}	77	77±1	0	111	110±1	+1
	TDK8/ 60 kg N ha^{-1}	77	78±1	-1	111	111±1	0
	TDK11/ 0 kg N ha^{-1}	70	72±1	-2	98	99±2	-1
	TDK11/ 60 kg N ha^{-1}	70	71±1	-1	98	98±1	0
August 5, 2010	TDK8/ 0 kg N ha^{-1}	74	68±1	+6	113	99±2	+13
	TDK8/ 60 kg N ha^{-1}	74	68±1	+6	113	98±2	+14
	TDK8/ 120 kg N ha^{-1}	74	68±1	+4	113	99±2	+11
	TDK11/ 0 kg N ha^{-1}	67	64±1	+3	100	89±2	+11
	TDK11/ 60 kg N ha^{-1}	67	65±1	+2	100	90±1	+10
	TDK11/ 120 kg N ha^{-1}	67	64±1	+3	100	90±2	+10
September 9, 2010	TDK8/ 0 kg N ha^{-1}	70	67±1	+3	111	96±1	+5
	TDK8/ 60 kg N ha^{-1}	70	67±1	+3	110	95±2	+5
	TDK8/ 120 kg N ha^{-1}	70	67±1	+3	111	96±2	+5
	TDK11/ 0 kg N ha^{-1}	64	62±1	+2	98	91±2	+7
	TDK11/ 60 kg N ha^{-1}	64	62±1	+2	98	91±1	+7
	TDK11/ 120 kg N ha^{-1}	64	63±1	+1	98	90±2	+8
January 14, 2011	TDK8/ 0 kg N ha^{-1}	75	74±1	+1	107	108±2	-1
	TDK8/ 60 kg N ha^{-1}	75	75±1	0	107	108±2	-1
	TDK11/ 0 kg N ha^{-1}	65	65±1	0	94	97±2	-3
	TDK11/ 60 kg N ha^{-1}	65	65±1	0	94	97±2	-3

DAT is days after transplantation. SD is the standard deviation of the mean.

Table 6. Root mean square error (RMSE) and normalize RMSE ($RMSE_n$) for total above ground dry biomass at different growth stages of 2 rice cultivars grown under 3 N-fertilizer application rates and planted on July 6, August 5 and September 9, 2010 and January 14, 2011 in Khon Kaen, Thailand.

Cultivar	Fertilizer (kg N ha^{-1})	July 6, 2010				August 5, 2010				September 9, 2011				January 14, 2011			
		Time of sampling															
		1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th
TDK8																	
RMSE (kg ha^{-1})	0	10	33	867	192	110	307	370	1189	115	117	420	1653	30	168	490	1396
	60	42	64	1417	252	84	488	383	1040	68	119	138	1460	36	145	663	1266
	120	-	-	-	-	65	667	889	23	92	203	432	397	-	-	-	-
$RMSE_n$ (%)	0	4	4	22	3	29	22	8	16	27	14	11	23	12	30	22	23
	60	30	7	26	3	25	29	7	11	20	9	3	16	13	27	25	16
	120	-	-	-	-	22	33	13	0	24	14	7	4	-	-	-	-
TDK11																	
RMSE (kg ha^{-1})	0	4	5	1182	936	53	205	133	881	68	128	57	666	1	188	636	957
	60	44	82	920	614	79	330	501	669	65	157	491	209	3	202	455	1516
	120	-	-	-	-	20	697	1715	767	119	246	1134	553	-	-	-	-
$RMSE_n$ (%)	0	2	1	26	12	19	17	3	13	20	15	1	8	1	26	30	20
	60	27	8	19	7	25	23	9	8	19	12	8	2	1	28	15	29
	120	-	-	-	-	9	34	21	7	28	16	15	5	-	-	-	-

Table 7. Observed and simulated values, root mean square error (RMSE) and normalized RMSE ($RMSE_n$) for grain yield of 2 rice cultivars grown under 3 N-fertilizer application rates and planted on July 6, August 5 and September 9, 2010 and January 14, 2011 in Khon Kaen, Thailand.

Planting date	Cultivar					
	TDK8			TDK11		
	kg N ha^{-1}					
	0	60	120	0	60	120
July 6, 2010						
Observed yield±SD (kg ha^{-1})	2285±142	2697±291	-	2191±202	2451±212	-
Simulated yield (kg ha^{-1})	2142	2624	-	1881	2281	-
RMSE (kg ha^{-1})	83	42	-	179	98	-
$RMSE_n$ (%)	4	2	-	8	4	-
August 5, 2010						
Observed yield±SD (kg ha^{-1})	2558±230	4218±1003	3962±382	2092±162	2880±554	2858±552
Simulated yield (kg ha^{-1})	3234	3678	3801	2746	3459	3585
RMSE (kg ha^{-1})	390	312	93	378	334	420
$RMSE_n$ (%)	15	7	2	18	12	15
September 9, 2010						
Observed yield±SD (kg ha^{-1})	466±201	748±162	734±129	946±230	1023±186	1186±66
Simulated yield (kg ha^{-1})	3323	3679	3875	2787	3185	3250
RMSE (kg ha^{-1})	1649	1692	1808	1063	1248	1192
$RMSE_n$ (%)	354	226	243	112	122	100
January 14, 2011						
Observed yield±SD (kg ha^{-1})	2050±145	2323±231	-	1481±103	2544±502	-
Simulated yield (kg ha^{-1})	2349	2816	-	1923	1893	-
RMSE (kg ha^{-1})	173	285	-	255	376	-
$RMSE_n$ (%)	8	12	-	17	15	-

SD is the standard deviation of the mean. Blanks were used for model calibration.

production in tropical countries such as Thailand and Lao People's Democratic Republic.

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