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Performance of The CSM-CERES-Rice Model in Evaluating Growth and Yield of Rice in the Farm Level

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Abstract Crop simulation model becomes a useful tool in agricultural research. Its performance has been validated mostly by the experiments conducted by researchers in experimental stations, and the information on the performance of the model under farm conditions is rare. The objective of this study was to test the performance of the CSM-CERES-Rice model for evaluation of growth and yield of rice using farmer's field data. The simulation was carried out using the management practices of the farmers as input data. The simulated values were in good agreement with observed values for days to flowering, days to physiological maturity and top dry weight of rice, whereas the associations between simulated values and observed values were rather poor for grain yield and harvest index. The poor associations between observed values and simulated values for grain yield and harvest index was due largely to high infestation of insect pests. CSM-CERES-Rice model can be used with some degree of accuracy to predict growth and yield of rice under growing conditions that are practiced by farmers in case of no severe infestation of insect pests and diseases. The model may be used for policy making by the government and decision making to produce rice by farmers.

Keywords: Crop management, Crop simulation model, DSSAT v4.5, *Oryza sativa* L.

Introduction

Crop simulation models, which have been proposed by crop growth model developers, currently becomes a useful tool in many disciplines of agricultural research. CSM-CERES-Rice model is one of the models used in the decision support system for agrotechnology transfer (DSSAT) cropping system model (Jones *et al.*, 2003; Hoogenboom *et al.*, 2010). Numerous studies reported useful applications of CSM-CERES-Rice model including the response to nitrogen application (Cheyslinted *et al.*, 2001; Ahmad *et al.*, 2012; Vilayvong *et al.*, 2012), the response to plant density and irrigation management (Ahmad *et al.*, 2013), the response to planting date (Buddhaboon *et al.*, 2011) and response to climate change (Aggarwal and Mall, 2002; Kim *et*

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al., 2013; Mishra *et al.*, 2013). However, these studies were undertaken by researchers in experimental stations. The information on evaluation of the model for growth and yield of lowland rice under farm conditions is still limited. To the best of the author's knowledge so far, the study on the efficacy of CSM-CERES-Rice model for lowland rice production by using data of farmer's practices in farmer's farm is very rare, and this information is very important for adoption of the model to predict rice yield under the real production environments.

Moreover, the model can be used to analyze the yield gap and identify factors limiting yield in the farmers' fields. This information would be more useful to develop the suitable strategies for improving the productivity of rice. There are two conceptual frameworks for yield gap i.e., 1) the difference between potential and attainable yield and 2) the difference between actual and attainable yield (Witt *et al.*, 2009). Normally, the actual yield in the farmers' field is often lower than the attainable yield as the actual yield is defined as the yield achieved from the field with poor crop and nutrient management that may enhance pest and disease pressure. Therefore, the objective of this study was to test the performance of the CSM-CERES-Rice model for evaluation of growth and yield of lowland rice using the actual farmers' field data.

Materials and methods

Fields survey and data collection

At initiation of the research project, the statistical data of rice (*Oryza sativa* L.) growing areas in the central plain of Thailand were collected and then survey of farmers' field was carried out during November to December, 2009. Thirteen farmers, who gave permission to do research in their paddy fields, were selected for this study. The farmers were observed for their agronomic practices in their paddy fields from planting to harvest, data for all agronomic practices were recorded such as planting date, plant density, fertilizer rate, fertilizer date and time of fertilizer and chemical applications. The rice variety Chai Nat 1 was planted using pre-germinated sowing method in all representative farms.

Actual development, growth and yield data were collected in all farmers' field. Crop development data including days to flowering and days to physiological maturity were recorded. Crop cut was carried out at harvest in the harvest area 1 x 1 m with 5 replications for each field in 13 paddy fields. For each sample area, two hills (with many stems that were generated from 1 seed) were randomly chosen to determine grain yield, top dry weight and harvest index (HI).

Soil samples at 0-15 cm soil depth were taken from each field, and analyzed for physical (bulk density and soil texture) and chemical (pH in water, organic matter (OM), cation exchange capacity (CEC) and total nitrogen (N)) properties. The corresponding weather data for entire growing season were collected from the nearest weather concluded daily solar radiation (MJ m^{-2} d^{-1}), daily rainfall (mm) and daily maximum and minimum temperatures, which solar radiation was calculated from maximum and minimum temperatures followed the procedure of Phakamas et al. (2013). Soil data, weather data and agronomic practices data were used as input data for simulation.

Model simulation

The CSM-CERES-Rice model in the DSSAT v4.5 was used to simulate growth and yield of lowland rice, and the input data were similar to those for experimental field in research stations except that the data were collected from farmers' fields. Crop management practices such as planting date, harvesting date, plant density, fertilizer rate, fertilizer and chemical application, organic application and weed control were different among fields. After simulation was carried out, the output data for growth and yield of rice including days to flowering, physiological maturity, grain yield, top dry weight and harvest index were obtained for statically analysis.

Data analysis

The accuracy CSM-CERES-Rice model to simulate growth and yield of lowland rice was determined by the agreement of the simulated data and observed data as indicated by the values of root mean square error (RMSE), normalized root mean square error (RMSEn) and d-stat or “index of agreement” (Willmott, 1982). The RMSE and RMSEn were computed using the following equation:

$$\text{RMSE} = \sqrt{\frac{\sum_{i-1}^{n} (P_i - O_i)^2}{n}}$$

where n is the number of observations, P_i is the simulated value for the *i*th measurement and O_i is the observed value for the *i*th measurement.

$$\text{RMSEn} = \frac{RMSE \times 100}{\bar{O}}$$

where RMSE is the root mean square error and $\bar{O}$ is the mean of the observed values.

The d-stat or “index of agreement” value (Willmott, 1982) was computed using the following equation:

$$d - stat = 1 - \left[\frac{\sum_{i=1}^{N} (P_i - O_i)^2}{\sum_{i=1}^{N} \left[\left|P_i^{'}\right| + \left|O_i^{'}\right| \right]^2} \right]$$

where N is the number of observations, P_i is the simulated value for the ith measurement and O_i is the observed value for the i th measurement. The d-stat value of a 'good' model should approach unity.

Low values RMSEn (expressed in percent) indicated that the data were well associated (Jamieson et al., 1991). The agreement of simulated values and observed values is considered to be excellent if RMSEn values is lower than 10 %, good if the values were in the range of 10-20 %, fair if the values were in the range of 20-30 % and poor if the values greater than 30 %. The d-stat parameter has values between zero to one, and value one shows the best fit of the data.

Results

Farmer Managements

A survey of farmer’s fields was conducted in Chai Nat (CN) province (3 fields), Nakhon Sawan (NS) province (5 fields) and Uthai Thani (UT) province (5 fields), and there were 13 fields altogether. All fields used pre-germinated sowing method and rice variety Chai Nat 1 (non-photoperiod sensitive rice variety). However, planting date, planting density, time of fertilizer application and time of chemical application varied among fields. Rice was planted from 21 November 2009 to 18 December 2009, and pre-germinated seed was used. Planting densities varied between 16 and 45 plants/m^2. Time of fertilizer application varied between 1 and 3 times, and Time of chemical application varied between 2 and 6 times (Table 1).

Soil properties

Seven types of soil texture consisting of clay (3 fields), silty clay (1 field), silty clay loam (3 fields), clay loam (1 field), loam (2 fields), loamy sand (1 field) and sand (1 field) were found among 13 farmer's fields. Bulk density varied from 1.39 to 1.83 g/cm^3 (Table 1). The analysis of chemical properties showed that most fields were moderately fertile except for field UT 1 that showed the lowest soil fertility. Values of organic matter (OM) were in the range from 0.43-4.46 % and pH values were in a range between 5.21 and 6.54, indicating strongly acidic soil. Total nitrogen values and cations exchange capacity values (CEC) was varied from 0.08 to 0.35 % and 1.88 to 23.52 me/100g, respectively (Table 2).

Table 1. Basic data and crop management practices in each farmer's field

				Time of Application	
Field	**Planting date**	**Planting method***	**Plant /m^2**	**Fertilizer**	**Chemical**
CN 1	5 December 09	Pre-germinated	21	2	4
CN 2	9 December 09	Pre-germinated	30	3	3
CN 3	18 December 09	Pre-germinated	22	3	3
NS 1	3 December 09	Pre-germinated	24	2	4
NS 2	2 December 09	Pre-germinated	23	3	4
NS 3	27 November 09	Pre-germinated	16	3	4
NS 4	6 December 09	Pre-germinated	25	3	6
NS 5	10 December 09	Pre-germinated	23	3	5
UT 1	21 November 09	Pre-germinated	18	2	4
UT 2	1 December 09	Pre-germinated	45	3	5
UT 3	30 November 09	Pre-germinated	42	2	4
UT 4	6 December 09	Pre-germinated	20	2	4
UT 5	30 November 09	Pre-germinated	29	3	4

* = The variety Chai Nat 1 (non-photoperiod sensitive rice variety) was planted in all fields.

Table 2. Soil physical properties in each farmer's field

Field	Sand (%)	Silt (%)	Clay (%)	Soil texture	Bulk density (g/cm3)
CN 1	38.34	27.69	33.96	Loam	1.46
CN 2	31.98	44.45	23.57	Loam	1.55
CN 3	11.30	49.54	39.16	Silty Clay Loam	1.43
NS 1	12.71	55.83	31.46	Silty Clay Loam	1.39
NS 2	30.14	32.96	36.89	Clay loam	1.43
NS 3	6.02	31.02	62.96	Clay	1.60
NS 4	40.52	16.32	43.16	Clay	1.49
NS 5	28.11	15.28	56.61	Clay	1.42
UT 1	90.78	7.49	1.73	Sand	1.83
UT 2	16.73	54.38	28.88	Silty Clay Loam	1.45
UT 3	-	-	-	-	-
UT 4	7.20	41.16	51.64	Silty Clay	1.41
UT 5	81.64	13.93	4.43	Loamy Sand	1.78

* = use the soil data of the filed Uthai Thani 2 because they are adjacent plots.
OM = Organic matter, CEC= Cation exchange capacity, N = Nitrogen

Table 3. Soil chemical properties in each farmer's field

Field	pH (1:1)	OM (%)	CEC (me/100g)	Total N (%)
CN 1	5.61	2.51	15.37	0.22
CN 2	5.68	2.58	14.43	0.19
CN 3	5.47	3.50	20.39	0.22
NS 1	5.65	4.46	19.13	0.35
NS 2	5.52	2.89	23.21	0.18
NS 3	5.38	2.25	23.52	0.16
NS 4	5.50	2.56	13.80	0.20
NS 5	5.21	3.23	15.68	0.21
UT 1	6.54	0.43	1.88	0.08
UT 2	5.48	2.26	13.80	0.18
UT 3	-	-	-	-
UT 4	5.37	3.09	20.07	0.21
UT 5	5.72	0.43	2.19	0.08

* = use the soil data of the filed Uthai Thani 2 because they are adjacent plots.
OM = Organic matter, CEC= Cation exchange capacity, N = Nitrogen

Simulation of development stage

Observed values and simulated values were compared for days to flowering and days to physiological maturity (Table 3). Simulated value for days to flowering generated by CSM-CERES-Rice model on average was 4 days longer than observed value, and simulated values for most fields were higher than their corresponding observed values except for field NS 3. The results showed good agreement of observed data and simulated data for days to flowering as indicated by the values of RMSE (6.07 days), RMSEn (9.03 %) and d-stat (0.53). Means of simulated data and observed data for days to flowering were 71 and 67 days, respectively.

In contrast to days to flowering, simulated values for days to physiological maturity were lower than observed values, and means for simulated values and observed values for days to physiological maturity were 94 and 99 days, respectively. The RMSE, RMSEn and d-stat values were 6.13 days, 6.19 % and 0.50, respectively, indicating good agreement between simulated and observed values (Table 3).

Table 3. Comparison between observed (Obs.) data and simulated (Sim.) data for days to flowering and days to physiological maturity of rice in the 13 farmer's fields

	Days to flowering (days)		Days to physiological maturity (days)	
Field	Obs.	Sim.	Obs.	Sim.
CN 1	65	70	97	93
CN 2	68	69	97	92
CN 3	61	69	99	92
NS 1	64	71	96	93
NS 2	69	72	96	95
NS 3	75	74	95	96
NS 4	62	72	100	94
NS 5	61	71	92	93
UT 1	70	74	106	97
UT 2	70	72	103	95
UT 3	73	72	104	95
UT 4	61	71	99	94
UT 5	75	72	105	95
Mean	67	71	99	94
RMSE	6.07		6.13	
RMSEn (%)	9.03		6.19	
d-stat	0.57		0.50	

Simulation of growth and yield

The values of RMSE, RMESn and d-stat for top dry weight were 0.82 t/ha, 19.11 % and 0.85, respectively (Table 4). The results showed good agreement of observed values and simulated values and indicated that CSM-CERES-Rice model can be used to simulated top dry weight with acceptable accuracy. However, CSM-CERES-Rice model simulated grain yield higher than their corresponding observed values, which mean yield was 2.37 t/ha for simulated value and 1.58 t/ha for observed value. The RMSE, RMESn and d-stat values for grain yield were 0.82 t/ha, 51.72 % and 0.90, respectively. The results indicated that the model could poorly simulate grain yield by using available field data in this study. Simulation for harvest index showed the results that were similar to those for grain yield, and the values of RMSE, RMSEn and d-stat were 0.19, 51.20 % and 0.38, respectively. The results indicated that CSM-CERES-Rice model could simulate harvest index poorly.

Table 4. Comparison between observed (Obs.) values and simulated (Sim.) values for top dry weight, grain yield and harvest index of rice in farmer's fields

	Top dry weight (t/ha)		Grain yield (t/ha)		Harvest index	
Field	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.
CN 1	3.33	4.08	1.04	2.18	0.31	0.54
CN 2	4.92	4.32	1.87	2.63	0.43	0.54
CN 3	4.55	4.23	1.72	2.21	0.37	0.52
NS 1	3.60	4.32	1.40	2.38	0.39	0.55
NS 2	3.54	3.95	1.29	2.14	0.37	0.54
NS 3	2.20	3.40	0.73	1.90	0.33	0.56
NS 4	6.09	3.91	1.58	2.21	0.26	0.57
NS 5	4.08	3.72	1.36	2.04	0.33	0.55
UT 1	3.17	3.63	1.15	1.95	0.36	0.54
UT 2	6.75	6.26	3.02	3.45	0.45	0.55
UT 3	6.02	6.04	2.64	3.30	0.44	0.55
UT 4	3.13	3.54	0.97	1.84	0.31	0.52
UT 5	4.60	4.97	1.84	2.65	0.40	0.53
Mean	4.31	4.33	1.58	2.37	0.36	0.53
RMSE	0.82		0.82		0.19	
RMSEn (%)	19.11		51.72		51.20	
d-stat	0.85		0.90		0.38	

Discussion

The objective of this study was to test the performance of the CSM-CERES-Rice model in simulating the growth and yield of lowland rice under farmer's field conditions using limited information of agronomic practices from field survey. The model could acceptably simulated days to flowering, days to physiological maturity and top dry weight, but it could poorly simulated grain yield and harvest index as the values of RMSEn were greater than 30%. The results could be due to the fact that days to flowering, days to physiological maturity and top dry weight were more stable than grain yield and harvest index, which were effected greatly by environmental conditions and field management. The author simulated growth and yield by using the approximate rate of fertilizer application based on interviewing of the each owner’s field. Therefore, it might be one cause of yield variations.

The model simulated grain yield much higher than those of observed values, and it also simulated harvest index higher than those of observed values. The inability of then model to simulate these parameters correctly would be possible due to the important factors that were not included in the model such as fertilizer rates and infestation of pests and diseases, similar result was found in Vilayvong *et al.* (2012). For lowland rice, grain yield depends greatly on fertilizer application especially for nitrogen application.

Reductions in crop growth and grain yield were greatly affected by biotic factors (pests, diseases weed and abiotic factor (pollution) (Bhatia et al., 2008). In this study, most yielding fields were damaged by disease and insects, especially, *Nilaparvata lugens* (Stål) although the farmers applied chemicals for controlling pests. Higher simulated values than observed values for grain yield and harvest index was largely due to reductions in yield and harvest index caused by high infestation of insect pests. As insect pest parameters were not included in the model, the simulation of the model will be valid only if the crop is not affected by biotic stresses.

It is interesting to note here that the field UT 2 and UT 3 showed good association between observed grain yield and simulated grain yield. The reason for higher yield in these fields was because they were well managed as suggested by Department of Agricultural Extension, and the fields were used for production of foundation seeds. Gomez *et al.* (1979) reported if the rice plants are provided with all their biological needs and they are adequately protected from damage, they will give high yields.

Conclusion

Using farmer's practices instead of conducting research in the experimental station, CSM-CERES-Rice model could satisfactorily simulate days to flowering, days to physiological maturity and top dry weight of lowland rice, but the simulation of grain yield and harvest index was rather disappointing. The inability of the model to accurately simulate grain yield and harvest index was possibly due to high infestation of insect pest that caused high yield reductions in most fields. However, in case no severe pests and diseases, the model can be used as a convenient tool for prediction of yield of lowland rice under farmer's growing conditions. The CSM-CERES-Rice model is useful for decision making of farmers to produce rice and the government to decide about rice policy.

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