



# Simulating upland rice yield at diverse temperatures using DSSAT4.7-CERES-Rice crop model under changing climatic conditions

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## Abstract

Declaration of climate emergency reminds that the main source of variations in worldwide food production sourced from developing countries and is of utmost concern. Process-based models use simplified functions to express the interactions between upland rice growth and the major environmental factors (i.e., climate, soils, and management) that affect crops yield. This research was conducted to investigate the DSSAT-CERES-Rice model for simulating the impact of different temperature (28°C, 30°C and 32°C) on upland grain yield (Dawk Payawm, Mai Tahk, Bow Leb Nahng, Dawk Kha 50 and Dawk Kahm). The results showed that the temperature significantly affected the grain yield, flowering, and maturity date. The highest grain yield bearing genotype was Bow leb Nahng (6235.80 kg ha<sup>-1</sup>) with the highest variation between the genotypes. At maximum temperature 32°C simulated grain yield varied from (3194-6669) kg ha<sup>-1</sup>, at high temperature 30°C it varied from 3252-6667 kg ha<sup>-1</sup> while at moderate temperature 28°C 3189-6711 kg ha<sup>-1</sup> was the observed range. However, results indicated that moderate temperature i.e., 28°C gave the highest simulated grain yield. Thus, it was demonstrated that the CERES-Rice model was more useful as a tool for simulating grain yield under the changing different temperature conditions.

**Key words:** DSSAT; CERES-Rice model; temperature effect; upland rice; grain yield; phenological traits

## 1. Introduction

Model simulation, one of the important tools in agriculture. It has increased the utility of parameters related to meteorological, soil and plant aspects to predict the crop yield and growth features (Lone *et al.*, 2016). Upland rice (*Oryza sativa* L.) is an essential cereal crop nourishing more than half of the world's population and contributing 50 to 80% of regular caloric consumption (FAO, 2019; Nayak *et al.*, 2019). Upland rice suffers severely from irregular environmental factors, e.g., air temperature, drought, and precipitation (Jalota *et al.*, 2009). As rice originated in tropical or subtropical areas and is a low-temperature

sensitive crop. Rice crop growth and development are severely damaged below 15° C. But extreme temperatures are also destructive to plant growth. High temperature causes heat stress and ultimately negatively affects the rice crop yield (Cruz *et al.*, 2007). At different times during the life cycle, rice plant is differentially sensitive to temperature stress. Hence, the critically low and high temperatures, normally below 20°C and above 30°C vary from one growth stage to another (P. Krishnan *et al.*, 2011). It has been observed that the mean temperature, temperature sum, range, distribution pattern and diurnal changes or a



combination of these, are highly correlated with grain yields and had significant issues (Araus *et al.*, 2011).

According to the Intergovernmental Panel on Climate Change (IPCC, 2013) the increase in global mean surface temperatures for 1986-2005 and 2081-2100 are in the range of 0.3°C to 4.8°C. Similar changes are also expected in Thailand, where the average day temperature increase is likely to be 2.0°C to 4.0°C by 2100 (IPCC, 2013). The simulation impacts of climate change reveal that rice production is expected to decrease by 4.56 to 33.77% in response to the future climate scenarios for 2030 to 2090 in Thailand reported by Tazhibayeva *et al.*, (2009). Thus, assessment of relation between variability in climate changing and yield help in decision making regarding the management of agricultural crops (Abbas *et al.*, 2017).

Several crop models have been used for a long time to assist in crop management practices and in exploring physiological mechanisms under different environments (Reidsma *et al.*, 2010). DSSAT (Decision Support System for Agrotechnology Transfer) is a software combining of several dynamic crop simulation models, and with the help of soil, daily weather (historical or future), and management data it can predict accurately growth, development, and yield of crops to assist farmers in developing long-term plans (Lizaso *et al.*, 2011). CERES (Crop Environment Resource Synthesis)-Rice model in DSSAT software has adjustments for different temperatures, and it can be used to evaluate the risks for upland rice production system (Soler *et al.*, 2007). This study focused to simulate the effect of temperatures on yield performance for phenology, grain yield, tops weight, leaf area index, harvest index, and tillers number. The DSSAT-CERES-Rice model simulated upland rice yield, above ground biomass and growth durations at harvest and the valued were compared with the observed valued during calibration processes. Climate change induced global warming is a serious threat to the prevailing rice production systems in Thailand. Therefore, an attempt was made to predict the upland rice yield under different temperature regimes by simulating different temperature changes on yield contributing characters using the DSSAT v 4.7 CERES simulation model.

## **2. Materials and methods**

### *2.1 Experimental plant materials*

For simulating the crop growth and yield of upland rice field experiments were conducted from July to December

in 2017-2018 at the research area of Plant Sciences Department, Faculty of Natural Resources, Prince of Songkla University, Hat Yai campus (7.13 °N, 100.26 °E and 63 meters), Thailand. For this purpose, five popular upland rice genotypes namely, Dawk Pa-yawm, Mai Tahk, Bow Leb Nahng, Dawk Kha 50 and Dawk Kahm were selected. The experiments were conducted as a split plot using Complete Block Design (CRD) with three replications. The main plots were five Thai upland rice genotypes and sub plots with three temperatures (28°C, 30°C and 32°C) which were set up after one month of planting date up to harvesting by using the data logger (UA-002-08 HOB0 Pendant, for Temp/Light) and daily solar radiation ( $\text{MJm}^{-2} \text{day}^{-1}$ ) was calculated by using weatherman tools in DSSAT v4.7 simulation model.

Each treatment consisted of five rows (5 meters/row) with five genotypes, which were randomized and replicated within each block. Each genotype was planted 30 cm apart between rows and 25 cm within the rows. N-P-K was applied at the rate of 15 kgs of N, P and K/ha as urea, super phosphate, and muriate of potash to the plots before planting. Nitrogen was applied in four equal splits at basal, active tillering, panicle initiation and flowering stages to the individual replication as per the treatment schedule of fertilizer application. Agronomic operations e.g., weed and insect control were done manually. Insect pests were controlled by the application of 20 ml per 1 L Cypermethrin 10% w/v EC and 50 ml per 1 L Benfuracarb 20% w/v EC with water. At 30 days after planting, urea fertilizer (46-0-0) was applied.

### *2.2 Set up of temperature treatments (28°C, 30°C and 32°C)*

Three temperature treatments including weather parameters, maximum and minimum temperatures with air intensity, were recorded by using a data logger (UA-002-08 HOB0 Pendant, for Temp/Light), that was set up after one month from planting of the experiments and daily solar radiation ( $\text{MJm}^{-2} \text{day}^{-1}$ ) was calculated by using weatherman tools in DSSAT V4.7. Moreover, Dawk Pa-yawm genotype was used as border crop to avoid the varietal errors.

To run the DSSAT-CERES-Rice model, the following four input files were created.



*I. Daily weather data*

Maximum and minimum air temperatures, rainfall, and solar radiation (derived from sunshine hour data) were collected from the weather station of Kho Hong Agrometeorological office, Hat Yai, Thailand for the 2017/2018 cropping season.

*II. Soil data*

For generating the data on soil characteristics soil samples from 0-5, 5-15, 15-25, 25-35, 35-50 and 50-65 cm depths were taken before planting. Soil class, organic carbon (%), sand, silt, clay (%), soil texture, soil pH in water, field capacity (%), cation exchange capacity, total nitrogen, potassium and phosphorus, potential root distribution and depth were recorded as per Wilkens *et al.*, 2004.

*III. Agronomic traits data*

Sowing date, emergence date, flowering date, physiological maturity date, panicle initiation (when 50% and 100% of the crop had reached those stages) plant population, plant height, tiller number, tops weight (grain weight), harvest index and grain yield/genotype/production.

*IV. Genetic cultivar coefficients file*

The following genetic coefficients parameters [P1 (Time period or basic vegetative phase), P2O (Critical photoperiod), P2R (Photoperiodism coefficients), P5 (Grain filling duration coefficient), G1 (Spikelet number coefficient), G2 (Single grain weight), G3 (Tillering coefficients) and G4 (Temperature tolerance coefficient)] were calibrated and validated by Lone *et al.*, (2019) for same location were used to carry the simulation studies.

*2.3 Statistical analysis*

The analysis of variance (ANOVA) was performed by R/ agricolae program (Mendiburu and Simon 2007). Mean separation was done by Least Square Difference (LSD) for split plot design to see the varietal differences.

**3. Results and discussions**

*3.1 Soil analysis*

The detailed soil profile data showed that higher yield was highly correlated with higher soil organic carbon, organic matter, available (Phosphorus, Potassium and Calcium), and exchangeable cation percentages which helped reach a higher yield (Table 1).

**Table 1a:** Soil Physical and chemical properties determined in study

Sample	percent			Field capacity (%)	Available P (mg kg <sup>-1</sup> )	NH <sub>4</sub> OAc extract (mg kg <sup>-1</sup> )		DTPA extract (mg kg <sup>-1</sup> )	1:5 H <sub>2</sub> O pH	Soil Texture
	OM	OC	CEC			K	Ca			
0-5 cm	1.88	0.78	3.40	14.80	131.49	182.12	161.44	119.34	5.05	Sandy clay loam
5-15 cm	1.85	0.81	3.00	14.60	120.35	165.59	181.52	137.92	5.24	Sandy clay loam
15-25 cm	1.70	0.77	3.00	12.80	107.32	156.00	198.52	124.34	5.00	Sandy clay loam
25-35 cm	1.69	0.77	3.00	12.40	105.23	152.20	195.57	134.20	5.11	Sandy clay loam
35-50 cm	1.69	0.76	3.00	12.00	103.45	150.10	188.80	130.00	5.01	Sandy clay loam
50- 65 cm	1.69	0.76	2.98	12.00	102.20	150.00	190.90	128.23	5.00	Sandy clay loam
Average	1.75	0.78	3.06	13.01	111.67	159.34	186.13	129.00	5.06	

*3.2 Weather conditions*

The detailed weather data showed that weather conditions had no visible variations across the cropping season 2017-2018. The maximum and minimum temperatures ranged between 25 and 38°C and from 20 to 22°C. Solar radiation

ranged from 10.2 to 20 MJ m<sup>-2</sup> d<sup>-1</sup>. Rainfall range was 20-980 mm from July to December months and the highest rainfall was in November to mid-December. After that, January was the second most rainfall month having about



700 mm of rainfall. Linquist *et al.* (2005) noted that in some cases, although the total annual amount of rainfall shows not much difference, the differences in its distribution can lead to risk of drought or flood, having impact on upland rice yields. Optimum temperature required for upland rice

growth is 25°C to 35°C (Yoshida, 1978) and for anthesis period it is between 30°C-33°C (Surajit *et al.*, 1981). A schematic representation of these critical parameters is presented in Fig. 1a and 1b.

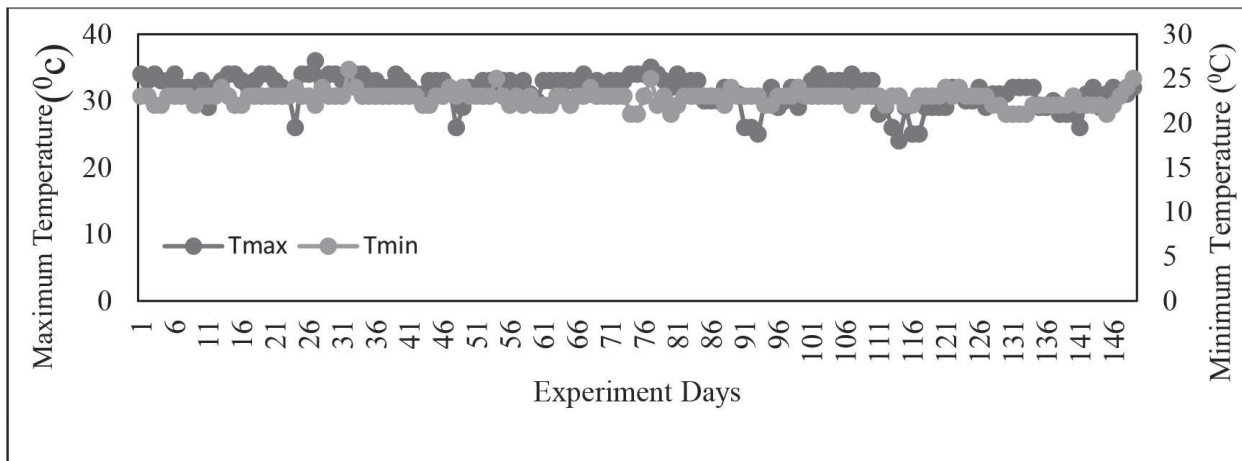


Fig. 1 (a): Mean daily maximum and minimum temperatures used in DSSAT

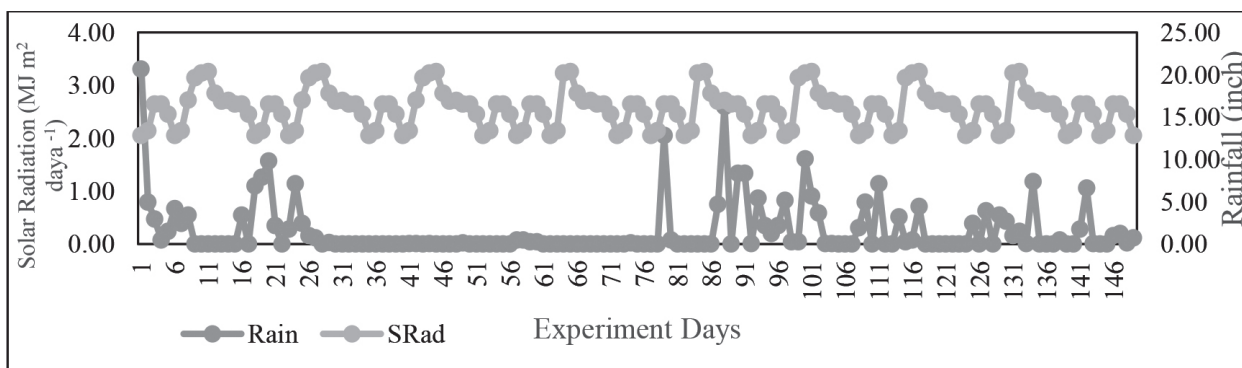


Fig. 1 (b): Mean daily solar radiation and rainfall used in DSSAT

### 3.3 Model calibration for estimating genetic coefficients

Based on experiments, the parameter calibration was done iteratively until a close match between simulated and observed phenology and yield was obtained. Out of 25 genotypes from DSSAT model, four were found to be similar to the genotypes under investigation. Dawk Pa-yawm, Mai Tahk comparatively matched with Basmati 385, Bow Leb Nahng, Dawk Kha-50 with CL448, Nahng Kian with Basmati-515 Rice and Dawk Kahm matched with KS-282 Rice. Results showed juvenile or basic vegetative stage (P1), critical photoperiod (P2O), phasic development phase (P2R) and time period (P5) for grain filling were the same for all the genotypes. But Potential spikelet number of coefficient (G1) was higher for most

of the genotypes namely Dawk Pa-yawm (79.9), Mai Tahk (79.8), Bow Leb Nahng (79.1), Dawk Kha 50 (78.8) and very low for Dawk Kahm (52.3) compared to others. Highest single grain weight (G2) was observed from the genotypes Dawk Pa-yawm and Dawk Kha 50 (0.0300) and lowest for Dawk Kahm (0.0200). The highest tillering coefficient (G3) was noted for Dawk Kahm (0.89) and the lowest was for Bow Leb Nahng (0.33). Moreover, the highest temperature tolerance coefficient (G4) was observed for Bow Leb Nahng (1.09) and the lowest for Dawk Pa-yawm (0.82). All the calibrated genetic coefficients are shown in Table 2.



**Table 2:** Calibrated Genetic coefficient values [P1 (Time period or basic vegetative phase), P2O (Critical photoperiod), P2R (Photoperiodism coefficients), P5 (Grain filling duration coefficient), G1 (Spikelet number coefficient), G2 (Single grain weight), G3 (Tillering coefficients), and G4 (Temperature tolerance coefficient) for 5 Thai upland rice genotypes

Genotypes	Chosen genotypes	Genetic coefficient values							
		P1	P2O	P2R	P5	G1	G2	G3	G4
Bow Leb Nahng	CL448	126.0	10.9	250.0	500.0	79.1	0.029	0.33	1.09
Nahng Kian	Basmati-515	126.0	10.9	250.0	500.0	52.3	0.020	0.89	0.95
Dawk Kha-50	CL448	126.0	10.9	250.0	500.0	78.8	0.030	0.61	0.90
Mai Tahk	Basmati 385	126.0	10.9	250.0	500.0	79.8	0.024	0.37	0.98
Dawk Pa-yawm	Basmati 385	126.0	10.9	250.0	500.0	79.9	0.030	0.61	0.82

### 3.4 Yield performance

ANOVA result (Table 3) for phenological traits using least significant differences (LSD) test (with thresholds  $P < 0.05$  and  $P < 0.01$ ) revealed that some traits *i.e.*, grain yield, tops weight, flowering, and maturity date were affected by temperatures and had highly significant difference with temperatures for both cropping years. Non-significant

difference for tiller number, leaf area index with harvest index occurred possibly due to the optimum input at the early stage. It was also found that grain yield at each treatment reduced with delay in planting date, whereas some of the phenological traits had highly significant variation by genotype.

**Table 3:** Mean squares from analysis of variance for 5 Thai upland rice genotypes

Source	df	Mean Squares						
		TN	TW	LAI	HI	GY	FD	MD
Replication	2	3.82	6897576	0.00054	0.00033	1123827	279.20	33.76
Temperature (T)	2	8.96	7514889**	0.0017	0.00050	21101974**	1483.40**	3.29**
Error (a)	4	3.46	1909466**	0.0003	0.00034	895471**	247.000**	18.00**
Genotypes (G)	4	26360**	1412618**	0.0310**	0.17674**	8567099**	2.00	9.48**
T × G	8	2.20	265645	0.0017	0.00008	210410**	5.01**	1.844**
Error (b)	24	5.99	113482	0.0009	0.00012	61252	0.82	1.94
CV% (a)		3.41	16.67	1.04	3.06	16.51	17.28	3.87
CV% (b)		4.49	4.06	1.71	1.80	4.32	0.99	1.27

Here, TN= Tillers Number, TW= Tops Weight, LAI= Leaf Area Index, HI= Harvest Index, GY= Grain Yield, FD= Flowering Date and MD= Maturity Date.

\* = significant at 5% level; \*\* = significant at 1% level

### 3.5 Mean comparison for phenotypic parameters

Dawk Kahm genotype had highest tiller number, with very low leaf area index, harvest index and grain yield both cropping seasons (Table 4). It seems that Dawk kahm was highly affected for all the temperature stages and showed temperature sensitive genotype. Besides, Bow Leb Nahng genotype had lowest tiller number, with highest

tops weight, leaf area index, highest maturity days and grain yield in 2017/2018 cropping season. The finding was very much similar with (Kumar *et al.*, 2014). The simulated phenology and yield were found in agreement with observed data suggesting that calibrated CERES rice crop model can be used suitably with observed soil, crop management and weather parameters.



**Table 4:** Mean comparison of traits for the selected Thai upland rice genotypes

Genotypes	Traits						
	TN (no)	TW (gm)	LAI	HI	GY (kg $ha^{-1}$ )	FD (day)	MD (day)
Bow Leb Nahng	23.33	8589.30	1.83	0.65	6231.80	91	111
Dawk Kahm	150.74	7610.10	1.69	0.35	3991.00	92	109
Dawk Kha	37.89	8313.40	1.73	0.69	6133.20	91	109
Mai Tahk	24.67	8404.00	1.69	0.62	6235.00	91	109
Dawk Pa-yawm	36.33	8589.30	1.69	0.69	6067.80	91	109
LSD <sub>0.05</sub>	2.38	327.75	0.03	0.010	240.79	-	1.35
LSD <sub>0.01</sub>	3.23	444.16	0.04	0.014	326.31	-	1.84

Tiller Number (TN), Top Weight (TW), Leaf Area Index (LAI), Harvest Index (HI), Grain Yield (GY), Flowering Date (FD) and Maturity Date (MD)

### 3.6 Simulated effect of temperature on GY

After calibration of the model, a comparison was made between simulated and observed grain yield at 28°C, 30°C and 32°C temperature stages (Table 5). Results showed in 2017-2018, Bow Leb Nahng was the high yielding genotype due to increasing simulated grain yield and performed best at the moderate 28°C temperature. At 32°C temperature, a large variation for all the genotypes by decreasing grain yield as the maximum temperature increased. Highest reduction in simulated grain yield was recorded for Dawk Kahm genotype (3189 kg $ha^{-1}$  at 28°C, 3252 kg $ha^{-1}$  at 30°C and 3194 kg $ha^{-1}$  at 32°C) with best performance

at the high temperature 30°C stage in 2017-2018 cropping season. Similar finding was reported by Shamim *et al.*, 2010 and Singh *et al.*, 2014. Paradoxically Bow Leb Nahng (6669 kg $ha^{-1}$ ) and Dawk Pa-yawm (6239 kg $ha^{-1}$ ) showed increased simulated grain yield while they were the best performing genotypes with the high temperature 32°C. As these two genotypes performed highest maturity in their life cycle. Similar finding was shown by Peng *et al.* (2004). The simulated grain yield of upland rice ranged between 3189-6711 kg $ha^{-1}$  respectively. The finding was very much like that of Singh *et al.* (2014).

**Table 5:** Measured and simulated grain yield of Thai upland rice genotypes at varying temperature levels with the DSSAT-CERES-Rice model

Genotypes	28°C		30°C		32°C	
	Measured	Simulated	Measured	Simulated	Measured	Simulated
Bow Leb Nahng	7762	6711	5857	6667	5074	6669
Dawk Kahm	4829	3189	3808	3252	3335	3194
Dawk Kha	7431	6303	5947	6224	5021	6239
Mai Tahk	7732	5804	5920	5677	5055	5696
Dawk Pa -yawm	7323	6303	5983	6224	4897	6239

Grain yield decreased with increase in temperature at 28°C, 30°C and 32°C (Maniruzzaman *et al.*, 2018). This indicated that upland rice production might decrease in the future if climate smart practices are not adopted. Grain yield reduction was higher with short and medium growth duration rice genotypes compared to long duration Bow Leb Nahng, Mai Tahk and Dawk Pa-yawm. In general, the effect of increased temperature would be negative because of increased respiration (Penning de Vries *et al.*, 1993) and shortened vegetative and grain filling period.

In Sri Lanka by using the DSSAT-CERES-Rice model estimated for every degree rise in temperature near about 5% yield reduction occurred reported by Dias *et al.*, (2016).

### 4. Conclusion

The DSSAT-CERES-Rice crop simulation model was well validated and showed reliability of simulations with different temperatures for phenology and yield attributes of selected upland rice genotypes. Our study assessed the DSSAT-CERES-Rice model in a split plot experiment



including two factors; viz the genotypes (5 Thai upland rice genotypes) and another one of different temperatures (3 levels) to identify the variations of grain yield in southern Thailand under changing climatic conditions. The findings revealed that increase in temperature had negative effect on most of the genotypes. Thus, CERES-Rice model could be effectively used as a tool to simulate the grain yield of upland rice genotypes with the climate changing parameters like temperature stages.

### Conflict of Interest

Authors declare that they have no conflict of interest.

### Ethical Compliance Statement

NA

### Author Contribution

Conceptualization & Initial Draft: SSI, AKH; Critical review and finalization: SSI, AKH

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