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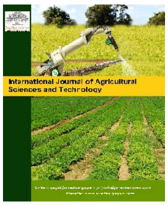

Research Paper **Open Access**

Rice phenology and growth simulation using DSSAT- CERES-Rice crop model under the different temperatures changing with climatic condition

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Abstract

This research paper aims to evaluate the performance of DSSAT CERES-Rice model in simulating the impact of different (28 °C, 30 °C and 32 °C) increased temperatures change with the relations of five upland rice genotypes (Dawk Pa-yawm, Mai Tahk, Bow Leb Nahng, Dawk Kha 50 and Dawk Kahm) on grain yield for future crop management. Results showed that temperature significantly affected grain yields, harvest index, flowering and maturity date which indicate that medium temperature (30 °C) gave highest grain yield bearing genotype Dawk Kahm (6,700 kg/ ha) whereas at maximum temperature (32 °C), simulated grain yields varied from 3094 to 6460 kg/ ha. Root Mean Square Error (RMSE) values of simulated and observed data less than 10% indicated that grain weight, leaf area index, tillers number and harvest index had more consistency agreement with the yield. Thus, it was proved that the CERES-Rice crop simulation model was more useful as a tool for different phenological traits under changing temperature conditions. And the model approximated grain yields at different temperatures with reasonable accuracy.

Keywords: *DSSAT-CERES-Rice model, Grain yield, Phenological traits, Temperature effect, Upland rice*

1. Introduction

Model simulation is one of the most imperative tools in the current world for analyzing the utility of parameters related to meteorological, soil and plant aspects, to predict the crop yield and growth features (Lone *et al.*, 2016). Rice (*Oryza sativa* L.) is an essential cereal crop nourishing near about half of the world's populations by contributing 50 to 80% of regular caloric consumption (Amirjani, 2011; FAO, 2012). It is mentioned that Japonica, Javanica and Indica subspecies have different types of ecosystems namely, irrigated, rainfed lowland, deep water and upland rice (Bridhikitti and Overcamp, 2011; Nayak *et al.*, 2019).

Upland rice suffers severely from irregular environmental factors, e.g., air temperature, drought, and precipitation (Jalota, 2010). Temperature is credited by its impact on crop yield, due to production expansion under heat stress conditions that greatly influences the growth duration and pattern of the rice plant (Fahad *et al.*, 2017). During the

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** Corresponding author: Shams Shaila Islam, Department of Agronomy, faculty of Agriculture, Hajee Mohammad Danesh Science and Technology University, Dinajpur-5200, Bangladesh. Email: shaila.hmdstu@gmail.com* growing season the mean temperature, temperature sum, ranges, distribution pattern and diurnal changes or a combination of these, highly correlated with grain yields had a significant issue (Araus and Slafer, 2011).

Depending on different Representative Concentrate Pathways, increase global mean surface temperatures for 1986-2005 and 2081-2100 is projected to be in the range of 0.3 °C to 4.8 °C (IPCC, 2016). Same changes will also be found in Thailand where average day temperature increase is likely to be 2.0 °C to 4.0 °C by 2100 (IPCC, 2013). In developing countries, several studies have recently examined the economic effects of climate change on agricultural production and showed susceptibility of crop agriculture to this change reported by Fazal and Wahab (2013).

Several crop models used from long time to assist crop management practices with explore physiological mechanisms under different environments (Reidsma *et al.*, 2010). The crop models are Decision Support Systems for Agrotechnology Transfer (DSSAT), (ICASA, 2011); Chen *et al.* (2010) used Agricultural Production System Simulator (APSIM) model for winter wheat and summer corn rotation in simulation of climate and water management (Goyal *et al.*, 2012) used (Hydrus-2D) model for simulation of subsurface drip irrigation for onion and ground nut; Crop System Model (CSM) was used by Jat *et al.* (2017) to simulate grain yield, biomass and water balance of rice crop.

Lizaso *et al.* (2011) stated DSSAT is a software combination of several dynamic crop simulation models, with the help of soil, daily weather (historical or future), input different management data can predict accurately growth, development and yield of crops to assist farmers in developing long-term plans. CERES (Crop Environment Resource Synthesis)-Rice model in DSSAT software with adjustment of different temperatures can be used to evaluate risk associated uncertainties for upland rice production system (Soler *et al.*, 2017). Due to global warming and climatic risk, the current rice production in Thailand have danger. Because, to fulfill the increase rice demand of ever-growing population pressures, an estimation of likely impact is vital for planning strategies. So, the objectives of the research study were (1) to determine the best temperature schedule with high yielding genotypes and (2) using DSSAT-CSM-Rice model to simulate the impact of different temperatures change on upland rice yield, yield contributing traits and production.

2. Materials and methods

2.1. Plant materials and conduction of experiment

For simulating the crop growth and yield of upland rice, a field experiment was conducted during (July to December) of 2017 at the research area of Plant Science 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 high yielding upland rice genotypes namely, Dawk Pa-yawm, Mai Tahk, Bow Leb Nahng, Dawk Kha 50 and Dawk Kahm were selected. The experiment was conducted as a split plot using Complete Block Design (CRD) as main plots with three replications. The main plots were five Thai upland rice genotypes and sub plots three different temperatures (28 °C, 30 °C and 32 °C) recorded by using the data logger (UA–002–08 HOBO Pendant, for Temp/Light) and daily solar radiation (MJm-2 day-1) was calculated by using weatherman tools in DSSAT v4.7 software.

For this experiment used a limited number of genotypes because selected genotypes have retained 76 characteristics of survival under different temperatures condition. Another important point was that availability of upland condition tolerant genotypes are limited in Thailand. In 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 among the plots. 15:15:15 N-P-K fertilizers was applied at the rate of 15 kg of N, P and K ha-1 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. Direct rice seeded were done and each pot 2-3 seeded were placed. Irrigation and plant protection measures were followed uniformly in all the pots as per the requirement. Insect pests were controlled by the application of 10 ml per 1 L Cypermethrin 10% w/v EC and 2.5 ml per 1 L Benfuracarb 20% w/v EC with water. The crop management data (i.e., phenological data) required for the simulation of the model include planting date, 50% germination date, 100% germination date, flowering and maturity, tillers number, panicles number, leaf area index, grain yield, biomass and 1000 grain weight were recorded at the harvesting stage.

2.2. Description of the DSSAT - CERES-Rice model

DSSAT-CERES-Rice present in DSSAT v4.7 which is an advanced physiologically based model was used to calibrate and evaluate the crop simulation model. Genetic coefficients for the five upland rice genotypes were used to calibrate

CSM-CERES-Rice model. Soil analysis was done before started of the experiments to analyze soil fertility and to carryout proper fertilizer management. Weather parameters including maximum and minimum temperatures, rainfall with air intensity were recorded by using the data logger (UA–002–08 HOBO Pendant, for Temp/Light) and daily solar radiation (MJm-2 day-1) was calculated by using weatherman tools in DSSAT v4.7. Mai Tahk genotype was used as border crop to avoid the varietal errors.

To run the model, the following five input files were created:

1. Daily weather data: Maximum and minimum air temperatures, precipitation, rainfall, and solar radiation (derived from sunshine hour data) were collected from the weather station of Kho Hong Agro meteorological office, Hat Yai, Thailand.

2. Soil data: Collected input data on soil characteristics at 5, 10, and 20 cm depths before planting. Soil classes, organic carbon (%), sand, silt, clay (%), soil texture, soil pH in water, field capacity (%), organic carbon (%), cation exchange capacity, total nitrogen, potassium and phosphorus, potential root distribution and depth were taken.

3. Management practices: Planting density, planting date, irrigation, weeding, plant row spacing, sowing depth, amount and types of fertilizers, insecticide application was done whenever necessary.

4. Plant profile 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, tillers number, tops weight (grain weight), harvest index and grain yield per genotype, i.e., grain yield per area of production.

5. Genetic coefficients file: The genetic coefficients were determined in the CERES-Rice simulation model with the following 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).

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 Significant Difference (LSD) for split plot design to see the varietal differences. This study focused to simulate the effect of different temperatures on yield performed for phenology, grain yield, tops weight, leaf area index, harvest index, and tillers number. According to Kiniry *et al.* (1997) model evaluation was calculated by the Root Mean Square Error (RMSE) and d stat index (Willmott, 1982). The RMSEn gives the level of error associated with each evaluation between the observed and simulated values.

3. Results and discussion

3.1. Soil analysis and discuss of the soil properties

Soil physio-chemical and morphological properties were analyzed by using standard methods. Result (Table 1) indicated that by using Hydrometer method soil was medium sandy loam with sandy clay loam textured containing sand 72.60%,

Table 1: Soil physical and chemical properties determined for net house soil

Sample detail	Percent			Total P (mg kg^{-1})	Avail-able P (mg kg^{-1})	Field Capa-city	NH40Ac extract (mg kg^{-1})		DTPA extract (mg kg^{-1})	CEC (meq 100 g soil)	1:5 H_2O		Particle size			Texture
	Total N	OM	OC				K	Ca	Fe		pH	Ec (μS cm^{-1})	% Clay	% Silt	% Sand	
0-5 cm	0.07	1.92	0.79	422.13	131.49	14.80	242.12	178.44	136.34	4.00	5.15	130.3	28.10	12.33	70.90	Sandy clay loam
6-10cm	0.08	1.90	0.81	440.30	120.35	13.70	185.59	192.52	137.92	4.00	5.24	119.1	27.20	11.36	67.97	Sandy clay loam
11-20cm	0.06	1.65	0.76	425.32	107.32	12.80	176.00	198.52	130.34	400	5.15	120.7	27.40	15.57	78.92	Sandy clay loam
Average	0.07	1.82	0.79	429.25	119.72	13.77	201.24	189.83	134.89	4.00	5.18	123.37	27.57	13.10	72.60	

clay 27.57%, silt 13.10%. By using Gravimetric method field capacity of soil was measured 13.77%. Soil containing average organic carbon was 0.79%, organic matter 1.82%, total nitrogen 0.07%, total phosphorus 429.25%, available phosphorus 119.72%, available potassium 201.24%, available calcium 189.83%, available Fe 134.89%, cation exchange capacity 4.00%, exchangeable cation 123.37% and pH in water 5.18. Optimum dose of NPK fertilizer was applied at three splits with 35.50 gm N_2, 35.50 gm P_2O_5 and 35.50 gm of K_2O @ 15-15-15 kg ha^{-1}. Various agronomic practices, e.g., weed and insect control were done manually. Insect pests were controlled by the application of 20 ml/1 L Cypermethrin 10% w/v EC and 50 ml/1 L Benfuracarb 20% w/v EC with water. Urea fertilizer (46-0-0) was applied at 30 days after planting.

3.2. Weather condition analysis

Impact of primary atmospheric variables on crop growth, development and grain production were rainfall, solar radiation, air temperatures, humidity, and precipitation. Reported by Kumari *et al.* (2017). Figure 1 showed that weather conditions had no visible variations. Here, the maximum and minimum temperatures ranged between 25 to 38 °C and 20 to 22 °C. Solar radiation ranged (10.2 to 20) MJ m^{-2} d^{-1} hence appropriate solar radiation is useful especially during specific crop stages, crops' grain filling and maturity period in case adequate water supply (Villegas *et al.*, 2016). Average rainfall ranged (20-980 mm) where highest was shown in the month of November to mid-December. After that January 151 month was second highest rainfall month near about 700 mm rainfall, respectively. Hatfield and Prueger (2015) noted 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 and flood having impact to rice yields. Optimum temperature required for rice growth is 25 °C to 35 °C and anthesis period is between 30 °C to 33 °C (Choudhury *et al.*, 2018). Extreme high temperature beyond the average temperature hampered during experiment might have negative influence on crop growth and development have high risk for yield decrease (Hatfield and Prueger, 2015).

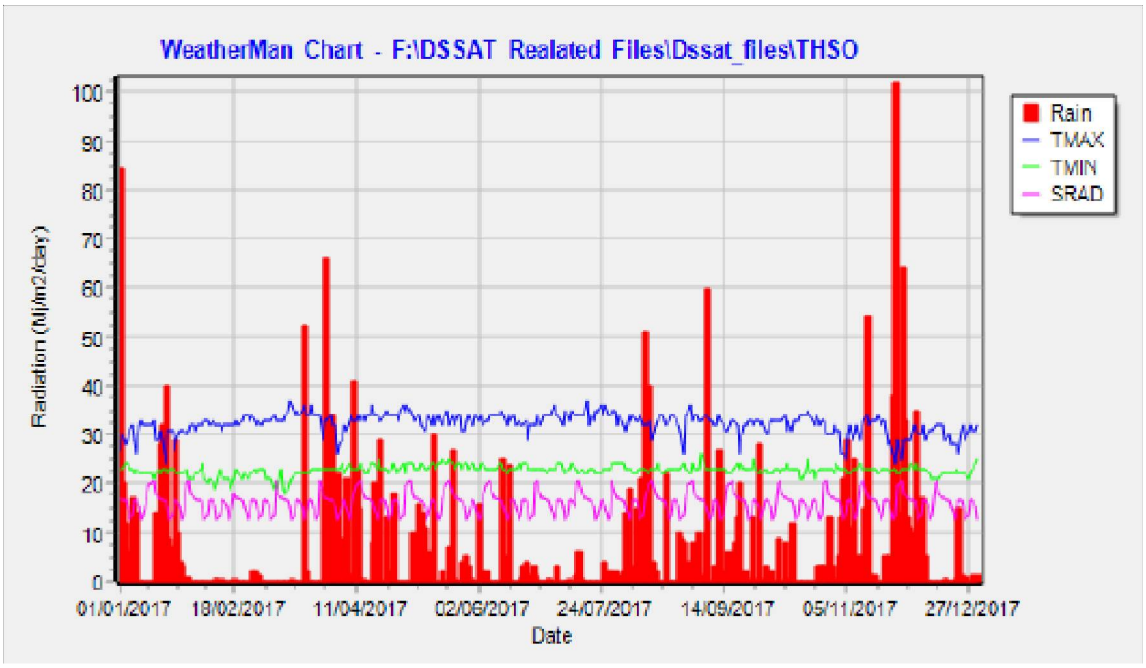


Figure 1: Mean daily maximum and minimum temperature, rainfall and solar radiation determined in 2017

3.3. Calibration and evaluation of the model

According to Jones *et al.* (2010), model calibration is the adjustment of genotype specific parameters so that simulated values compared well with observed field data. The genetic coefficients of CERES-Rice model were calibrated through time series observations collected from the experiment at three different temperatures (28 °C, 30 °C and 32 °C) stages. Accuracy in simulation of yield, phenology and growth requires the appropriate coefficient (Choudhury *et al.*, 2018). The genetic coefficients varied due to variation in their developmental rate at different phases (Lone *et al.*, 2016). Based on experiments by repeated iterations until a close match between simulated and observed phenology and yield was obtained.

Time series grain yield, tops weight, leaf area index, biomass and tillers number collected for genotypes Dawk Pa-yawm, Mai Tahk, Bow Leb Nahng, Dawk Kha 50 and Dawk Kahm. There was a good agreement between simulated and observed grain yield. Results showed juvenile or basic vegetative stage (P1 = 128), critical photoperiod (P2O = 10.8), phasic development phase (P2R = 230) and time period (P5 = 400) for grain filling were same for all the genotypes. But Potential spikelet number of coefficient (G1) was higher for most of the genotypes namely Dawk Kahm (82.9), Bow Leb Nahng (82.1), MaiTahk (80.8), Dawk Kha 50 (78.8) and Dawk Pa-yawm (68.3) very low for compared to others. Highest single grain weight (G2) was observed from the both genotypes Dawk Kahm (0.0300) and Dawk Kha 50 (0.0300) while lowest value from Dawk Pa-yawm (0.020). Highest tillering coefficient (G3) was noted for Dawk Kahm (0.89) and the lowest was for Bow Leb Nahng (0.33). Consequently, highest temperature tolerance coefficient (G4) was observed from genotype Dawk Kahm (1.09) and the lowest one from Dawk Pa-yawm (0.78). So, Dawk Kahm genotype was the most temperature tolerant among the others. All the calibrated genetic coefficients were shown in Table 2.

Table 2: Calibrated Genetic coefficient values for 5 upland rice genotypes

	Genetic coefficient values							
Genotypes	**P1**	**P2O**	**P2R**	**P5**	**G1**	**G2**	**G3**	**G4**
Bow Leb Nahng	128.0	10.8	230.0	400.0	82.1	0.024	0.33	0.98
Dawk Kahm	128.0	10.8	230.0	400.0	82.9	0.030	0.89	1.09
Dawk Kha-50	128.0	10.8	230.0	400.0	78.8	0.030	0.61	0.90
Mai Tahk	128.0	10.8	230.0	400.0	80.8	0.029	0.61	0.95
Dawk Pa-yawm	128.0	10.8	230.0	400.0	68.3	0.020	0.37	0.78

Note: [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)

3.4. Analysis the result of yield and yield attributes

3.4.1. Analysis of variance

ANOVA results (Table 3) for phenological traits using LSD test ($p < 0.05$ and $p < 0.01$) revealed that some traits showed highly significant differences with temperatures and genotypes. Grain yield, tops weight, harvest index, flowering date,

Table 3: Results of mean squares from analysis of variance for 5 upland rice genotypes

Source	Mean Squares							
	df	**TN**	**TW**	**LAI**	**HI**	**GY**	**FD**	**MD**
Replication	2	3.82	6897576	0.00054	0.00037	1123827	287.20	37.70
Temperature (T)	2	8.96	7714899**	0.0017	0.00050**	21101974**	1488.40**	4.29**
Error (a)	4	3.46	1909466**	0.0003	0.00034**	895471**	248.000**	19.00**
Genotypes (G)	4	26360**	1412628**	0.0310**	0.17674**	8577099**	2.00**	9.48**
T × G	8	2.20	275655	0.0017	0.00008	210410**	5.01**	1.844**
Error (b)	24	5.99	123482	0.0019	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

Note: 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; and ** = significant at 1% level.

and maturity date was highly significantly affected by temperatures. Non-significant difference for tillers number, and leaf area index occurred possibly due to the optimum input of temperatures at the early stage. Result showed that grain yield at each treatment reduced with delay in planting date, i.e., flowering and maturity date. Whereas all the phenological traits such as tillers number, tops weight, leaf area index, harvest index, grain yield, flowering and maturity date had highly significant variation by the different genotypes. Grain yield, flowering date and maturity date had interaction effects between temperature and genotype.

3.5. Analysis of mean comparison for phenotypic parameters

Tables 4 showed mean comparison for the phenotypic traits of the genotypes. Results showed that Mai Tahk genotype had highest tiller number 78.00 no, with low tops weight 7610.10 gm, leaf area index 1.60, and grain yield 3991.00 k/g ha. It seemed that this genotype was highly affected for all the temperature stages and highly temperature sensitive genotype. On the other hand, Dawk Kahm genotype had lowest tillers number 65.00 no, with highest tops weight 8404.00 gm, leaf area index 1.83, harvest index 0.69, highest maturity date 115 days and grain yield 6231.00 kg/ ha. And Dawk Kha genotype had second lowest tillers number 77.00 no, with second highest tops weight 8313.40 gm, leaf area index 1.73, highest maturity date 109 days and highest grain yield 6133.20 kg/ ha. The finding was very much similar with (Singh *et al.,* 2014). The simulated phenology and yield were found in agreement with observed data suggesting that calibrated model can be used suitably with observed soil, crop management and weather parameters.

Table 4: Results of mean comparison for 5 upland rice genotypes

	Triats						
Genotypes	**TN (no)**	**TW (gm)**	**LAI**	**HI**	**GY (kgha^{-1})**	**FD (day)**	**MD (day)**
Bow Leb Nahng	73.00	8289.30	1.69	0.65	5535.00	91	109
Dawk Kahm	65.00	8404.00	1.83	0.69	6231.00	95	115
Dawk Kha	77.00	8313.40	1.73	0.42	6133.20	91	109
Mai Tahk	78.00	7610.10	1.60	0.62	3991.00	92	109
Dawk Pa-yawm	76.00	8189.30	1.81	0.69	6067.80	91	112
LSD$_{0.05}$	2.38	327.75	0.03	0.010	240.79	–	1.35
LSD$_{0.01}$	3.23	444.16	0.04	0.014	326.31	–	1.84

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

3.6. Simulated effect of temperature on grain yield

After calibration the model, comparison was made between simulated and observed grain yield at 28 °C, 30 °C and 32 °C temperature stages with time (Table 5).The close agreement between observed and simulated values of grain yield for all the genotypes shown in this study. Results showed Dawk kahm and Dawk Kha were the best genotypes due to increasing simulated grain yield and best performed with the moderate temperature at 30 °C (Dawk Kahm 6700 kg ha^{-1} and Dawk Kha 6300 kg ha^{-1}). Whereas at 32 °C temperature stage, a large variation for all the genotypes decreased in yield with the maximum temperature increased. Highest reduction in simulated yield was recorded for Bow Leb Nahng genotype (3180 kg/ha at 28 °C, 3250 kg/ ha at 30 °C and 3094 kg/ ha at 32 °C) compared to others with best performed while minimum temperature increased at high temperature (30 °C) stage. Similar finding was shown by Shamin *et al.* (2010), Singh *et al.* (2014).

The simulated yield of upland rice ranged were (3094 to 6700) kg/ha respectively. Maniruzzaman *et al.* (2018) reported grain yield deceased with increase in temperatures at 28 °C, 30 °C and 32 °C. This indicated that rice production will be decreasing trends in 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 increasing respiration and shortened vegetative and grain filling period reported by Jerry L Hatfield, (2016). All though major rice models using DSSAT indicated about 5% yield reduction for every degree rise in mean temperature (Dias *et al.,* 2016) estimated 25%-35% yield reduction.

Table 5: Results of comparison between measured and simulated grain yield of five upland rice genotypes at varying temperature levels with the DSSAT CERES-Rice model

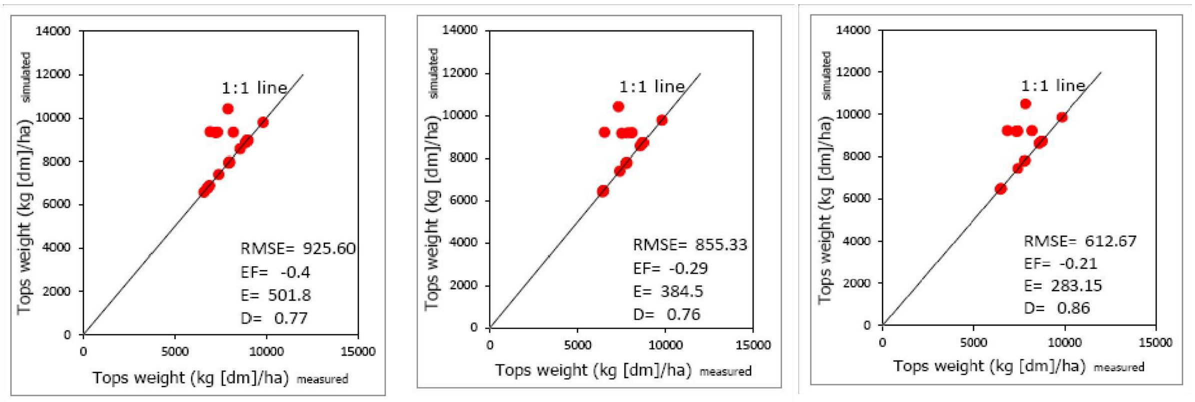
	Triats					
Genotypes	**28 °C**		**30 °C**		**32 °C**	
	Measured	**Simulated**	**Measured**	**Simulated**	**Measured**	**Simulated**
Bow Leb Nahng	4829	3180	3808	3250	3335	3094
Dawk Kahm	5857	6667	7762	6700	5074	6460
Dawk Kha	5947	6230	7431	6300	5021	5230
Mai Tahk	7532	5804	5920	5667	5055	5600
Dawk Pa-yawm	7323	6303	5983	6234	4897	4239

3.7. Calibration results of DSSAT model

Model calibration is an important step for the adjustment of simulations results that can be well compared with observations for the ensuring of crop growth and yield parameters. Collected data from experiment was used for calibration. Simulation results showed superior performance for top weight (kg [dm]/ ha), grain weight (kg [dm]/ ha), leaf area index, tiller number (no/m^2), harvest index (grain/top) and there was a strong agreement between simulated and observed values for phenology and yield parameters (Figures 2, 3, 4, 5 and 6).

3.8. Simulated effect of temperatures on tops weight (CWAD)

Simulation result revealed that tops weight (kg [dm]/ ha) could be predict well. Predict yield was plotted against observed yields (Figure 2). Top weight (kg [dm]/ ha) simulate with less accuracy as indicate by the values of RMSE were 925.60, 855.33, and 612.67 with d-stat 0.77, 0.76, and 0.86, respectively. The yield equation thus obtained measured mean tops weight 7618.53 (kg [dm]/ ha), nRMSE =14.28 indicated that had a poorest agreement by both observed and simulated values. Adjustment with 30 °C had a better agreement for tops weight with lower d-stat value among the three temperature stages for the genotypes. So, model performance was poor for tops weight. Pooled of tops weight indicated that the forecasting efficiency.

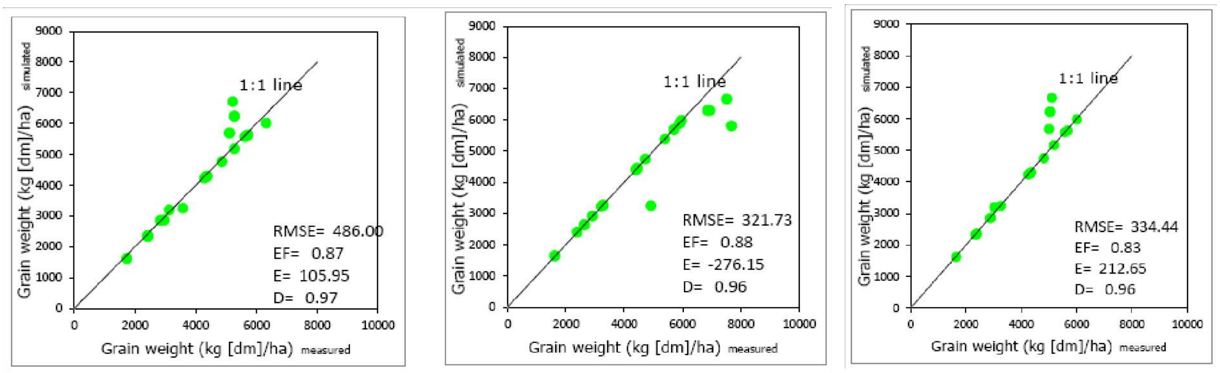


(a) **(b)** **(c)**

Figure 2: Simulated versus measured tops weight (2a at 28 °C), (2b at 30 °C), (2c at 32 °C).

3.9. Simulated effect of temperatures on grain weight (GWAD)

Simulation result showed that grain weight (kg [dm]/ ha) could be predict well. Predict yield was plotted in 1:1 graph (Figure 3). Grain weights simulate with less accuracy at 28 °C, 30 °C and 32 °C temperature stages. Hence, RMSE values



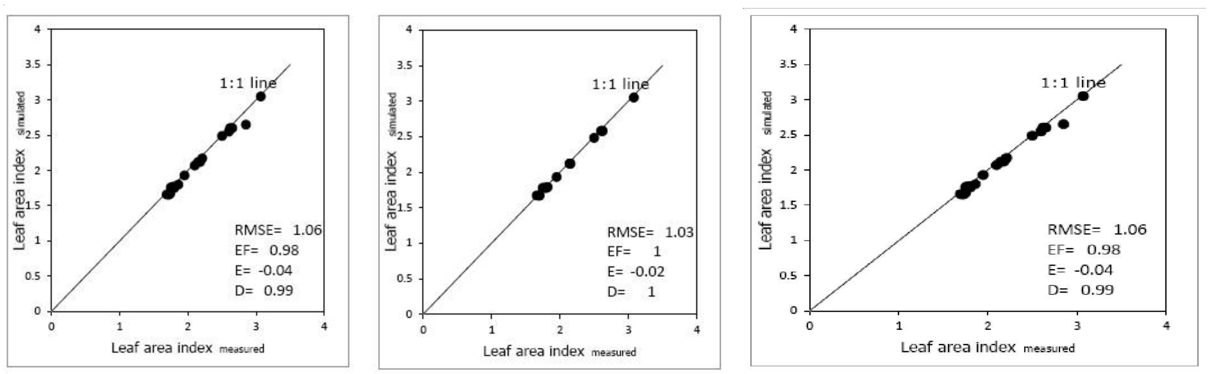
(a) **(b)** **(c)**

Figure 3: Simulated versus measured grain weight (3a at 28 °C), (3b at 30 °C), (3c at 32 °C)

were 321.73 334.44 and 486.00 with observed d-index 0.96, 0.96, 0.97, respectively. Measured mean grain weight 4289.83(kg [dm]/ ha) with nRMSE=14.80 which showed that very poorest agreement for simulated and observed values. Adjustment with 28 °C and 30 °C both had a better agreement for grains weight with lower d-stat value among the three temperature stages for the genotypes So, model performance was good for grain weight supported by Lone *et al.* (2016).

3.10. Simulated effect of temperatures on leaf area index (LAID)

Simulation results revealed that the leaf area index could be predicted well as well as excellent (Figure 4). 1:1 graph showed that the predicted leaf areas index was plotted against the observed data. Simulated LAI was comparable with the observed values. RMSE data 1.06, 1.03, and 1.04. The d-index values thus obtained 0.99, 1 and 1, respectively. Measured mean leaf area index = 2.14 with nRMSE =2.04 indicated that very excellent agreement for simulated and observed values where similar trend was followed by both the observed and simulated values. Hence, 28 °C had an adjustment excellent agreement for leaf area index with lower d-stat values among the three temperature stages for the genotypes. The result similar with the findings of Hussain *et al*. (2018).

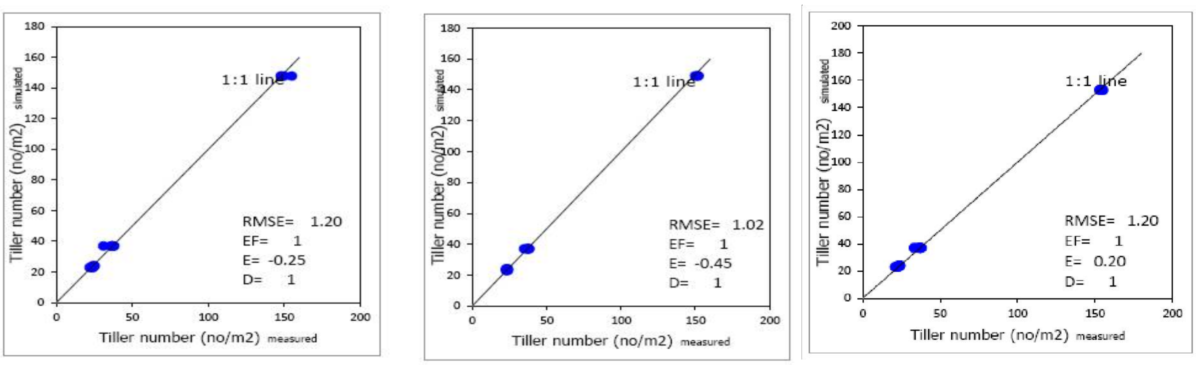


(a) **(b)** **(c)**

Figure 4: Simulated versus measured leaf area index (4a at 28 °C), (4b at 30 °C), (4c at 32 °C)

3.11. Simulated effect of temperatures on tillers number (T#AD)

Fiure 5 showed that tillers number (no/m^2) could be predicted excellently with 1:1 graph where predicted 258 tillers number plotted against observed data. With three temperature stages RMSE values were 1.20, 1.02, and 1.20 with d-index =1, 1, and 1, respectively. Measured mean tillers number = 56.45 (no/m^2) with nRMSE= 3.07 indicated that very excellent agreement with all the temperatures schedule and similar trend was followed by both the observed and simulated values for tillers number. This result is supported by Hussain *et al.* (2018) representing tillers number response to grain yield, i.e., important yield contributing environmental factors.

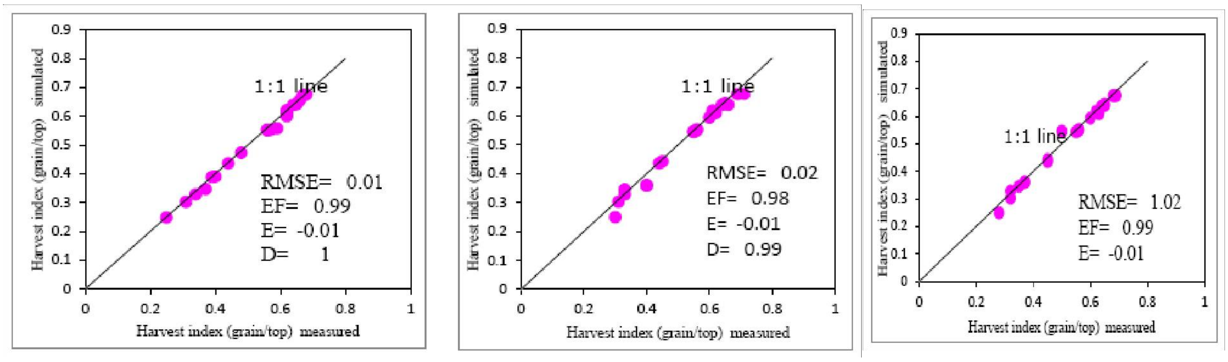


(a) **(b)** **(c)**

Figure 5: Simulated versus measured tillers number (5a at 28 °C), (5b at 30 °C), (5c at 32 °C)

3.12. Simulated effect of temperatures on harvest index (HIAD)

Figure 6 showed that harvest index (grain/top) could be well with 1:1 graph where predicted tillers number plotted against observed data. Whereas, excellent agreement was observed for harvest index, for the temperature stage 28 °C with lower RMSE value was 0.01 and maximum d-index 1 observed, respectively compared to 30 °C and 32 °C with RMSE value 0.02 and 1.02. Measured mean harvest index 269 = 0.52 (grain/top) with nRMSE= 3.22 indicated that poor agreement for simulated and observed values where similar trend was followed by both the observed and simulated values for harvest index and supported by Hussain *et al.* (2018).



(a) **(b)** **(c)**

Figure 6: Simulated versus measured harvest index (6a at 28 °C), (6b at 30 °C), (6c at 32 °C)

4. Conclusion

Evaluation of model showed their level of reliability of simulations with different temperatures for phenology and yield attributes of upland rice genotypes. It showed that grain weight, tillers number, leaf area index and harvest index had an excellent agreement with the observed value. Result revealed that highest simulated grain yield bearing genotype was Dawk Kahm 6700 kg/ha with 30 °C. Simulation result indicated that phenological traits like grain weight, leaf area index, tiller number and harvest index very well predicted by CSM-CERES-Rice model and have an excellent agreement. The simulated yield of aromatic rice ranges (2160-4770) kg/ha. Overall, it concludes that CSM-CERES-Rice model can be safely more used as a tool for simulating effect of temperatures on the growth and yield of aromatic rice under different agronomic and changing climatic conditions.

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