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Response of maize (*Zea mays* L.) growth and yield to different fertilizer application in Rainforest agro-ecological zone of Nigeria: Evaluation of CERES-maize crop model

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ABSTRACT

Field trials were carried out in the rainforest agroecological zone of Nigeria to assess the usefulness of the CERES-maize model as a decision support tool for optimizing growth and yield production of maize crop through varying application of organic manure as well as recommended Nitrogen Phosphorus Potassium (NPK) 20:10:10 fertilizer rate. The experiment was laid in a Randomized Complete Block Design (RCBD) in three (3) replications. The trial was conducted in the 2016 growing season at the Teaching and Research Farm, Federal University of Technology, Akure to calibrate and evaluate the performance of three maize cultivars (Suwan-1-SR-Y, ART/98/SW1 and ART/98/SW6 respectively) using sunshine organic manure applied at the rate of 0, 60, 90 and 120 kg N ha^{-1} and NPK 20:10:10 applied at a recommended rate of 70 kg N ha^{-1}. Model performance across fertilizer management was evaluated using some statistical indicators such as Mean Square error (RMSE), Mean bias error (MBE), and R^2 to measure its efficacy. Results showed that the model predicts accurately maize grain yield and total biomass with NPK 20:10:10 at 70 kg N ha^{-1} better than different rates of sunshine organic manure application for all the maize cultivars. The result further showed good agreement between the model predicted and observed data with low RMSE of ≤ 1 day for anthesis and ≤ 5 days for physiological maturity while the total leaf number ranged from 1.9 to 2.7. Model accuracy for predicting grain yield and total biomass was also good, for both the calibration and validation with lowest RMSE and NRMSE of the observed mean values.

Keywords: CERES-maize model, crop simulation, sunshine organic manure, Nigeria.

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INTRODUCTION

Maize is an important cereal crop growing across all the agro-ecological zones in Nigeria as well as in the world. It is a major staple food for most communities as it contributes about 20% of calories to their diet (Braimoh and Vlek, 2006).The production of maize recorded a massive increase from 0.66 M tons to about 11.3 M tons (1978 – 2013) because of the increase in the land area that is subjected to maize production (FAOSTAT, FAO, 2014). However, despite the increased area under maize production, maize yieldshave remained quite low especially in the rainforest zone considered to have high inherent soil fertility. In 2013, the world average yield of maize was 5.5 tons ha^{-1}, Nigeria average yield of maize was 1.4 tons ha^{-1} while the USA produced 9.5 tons ha^{-1} (FAOSTAT, FAO, 2013). Many authors have identifieddifferent limiting factors of maize production in Nigeria; among which are, frequent droughts (Kamara et al., 2009), the inherently poor soils (Jibrin et al., 2012), lack of proper adherence to improved agronomic practices (especially planting densities and dates) coupled with low use of improved inputs such as fertilizers and seeds, especially in high rainfall belt (Badu-Apraku et al., 2009). The low soil fertility is due to increasing pressure on land because of an increase in the human population in Nigeria. This farming system results in soil nutrient deficiencies, particularly for the essential soil nutrients; nitrogen (N) and phosphorus (P) (Bationo et al., 2003).

In Nigeria, the use of both organic and inorganic fertilizer has been adopted to boost crop production. Arije et al. (2018) revealed that increasing rates of Sunshine organic manure positively influence maize grain yield.However, the use of robust and well-tested crop growth models can be an effective way to analyze the complex relationship between management options and crop productivity (Penning de Vries, 1993). In recent years, crop simulation models have been increasingly used in sub-Saharan Africa, though the bulk of the studies have been concentrated in the semi-arid and Sahelian regions. For example, Naab et al. (2004) used CROPGRO-Peanut to quantify yield gaps in peanut production in the Guinea Savannah region of Ghana. APSIM has also been used to aid decision making regarding N fertilization in Pearl millet in the Sahelian region (Akponikpe et al., 2010). There has been an assessment of the impact of contrasting nutrient and residue management practices on the yield of sorghum in semi-arid Ghana (MacCarthy et al., 2009). Recent studied by Adnan et al. (2017a, b) explore the use of CERES-Maize Model for determining the optimum planting dates and nitrogen fertilization rates of early maturing maize varieties in Northern, Nigeria. Despite the increasing interest for the use of crop simulation models across sub-Sahara West Africa, little information is available on the optimal N fertilizer needs, both from experimental and modelling, especially maize crop planted humid part of semi-arid because of the varying contradiction of the school of thought over the region with respect to rainfall pattern and soil fertility. While the rural farmers are battling with the problem of low soil fertility, change in climate presents an additional burden. This change translates into production risks because agriculture in Nigeria depends largely on rainfall resulting in uncertainty in the timing of field operations, and the probability of extreme events. Increase in temperature accelerates the physiological development of maize yield by hastening the maturation thereby reducing maize yield (Arije et al., 2018). Thus, with the use of crop simulation models such as Decision Support Systems for Agrotechnology Transfer (DSSAT), a better understanding can be obtained more quickly, thereby reducing the risk of total crop loss or drastically low yields which are associated with low N use efficiency and climate change. DSSAT has been proven to be a useful tool to simulate crop yields (Keating et al., 2003; Wu et al., 2006; Wang et al., 2009; Hoogenboom et al., 2010). This study, therefore, aims to evaluate the performance of CSM-CERES maize model in simulating maize growth and yield in response to organic and inorganic fertilization over rainforest agroecological zone, Nigeria.

MATERIALS AND METHODS

Experimental procedure for model calibration and evaluation

The experiment was conducted at the Teaching and Research Farm, Federal University of Technology, Akure (FUTA) (7°16' N, 5°12' E) located within the Rainforest agro-ecological zone of Nigeria. It was laid out in a Randomized Complete Block Design (RCBD) experiment with three replicates. The first experiment was carried out during the rainy season between March and July) and the second experiment was conducted dry season between September and December with supplementary irrigation in 2016 growing season. The site was disc-plowed to a depth of 15cm, and soil samples were taken from the following depth; 0-15, 15-30, and 30-45 cm prior to application of either organic or inorganic fertilizer. The field was sprayed with herbicide (Atrazine at the rate of 4 L/ha) using knapsack sprayer. The field size was 14 m by 14 m (Area: 196 m^2), and experimental units were 4 m by 2 m with 1 m alley. The two selected maize varieties are Suwan-1-SR-Y, ART/98/SW1 and ART/98/SW6 were obtained from the Institute of Agricultural Research and Training, Moor Plantation, Ibadan in Nigeria. The seeds used for this experiment were improved maize variety fortified with protein. After the land preparation (ploughing, harrowing and field layout), the seeds were sown two seeds per hole at a spacing of 75 cm × 25 cm and later thinned to one plant stands 2 weeks after planting. Weeding was carried out manually (hoeing and hand-pulling). The treatmentwas four levels of Nitrogen concentration of the Sunshine Organic Manure (S.O.M) (0, 60, 90, 120 kg ha^{-1}) with NPK 20:10:10 at 70 kg N ha^{-1}as a standard to compare the performance of both fertilizer types. The detailed agronomic results have been reported by Arije et al. (2018), only theagronomic parameters relevant to modeling purpose are reported in this study which includes days to anthesis, days to maturity, total leaf number, grain yield, total biomass,and harvest index respectively.

Description of model calibration and evaluation

The Decision Support Systems for Agrotechnology Transfer DSSAT-CSM crop simulation model, which comprises a suite of modules that are process-based, mechanistic and crop management oriented (Jones et al., 2003), was used in the present study. The model utilizes data on daily weather (rainfall, minimum,and maximum temperature, and solar radiation), soil profile information and crop genetic coefficients to simulate crop growth and yield. The phasic and morphological developments of the crop are simulated using daily temperature, day length and genetic characteristics (Jones and Thornton, 2003). Whereas optimal plant growth and development is influenced by photosynthetic capacity, radiation capture, thermal time and photoperiod sensitivity, actual growth and development are constrained by water and nutrient stress as well as suboptimal temperatures (Soler et al., 2008). Details on the CERES-Maize module of DSSAT are available in Jones and Kiniry (1986). The water and nutrient balance submodules reduce growth via stress factors. Nitrogen availability emanates from either organic matter mineralisation or fertiliser/manure application. Soil organic matter

(SOM) mineralisation and nutrient release are simulated using the Century model embedded in DSSAT (Gijsman et al., 2002). In the application of DSSAT cultivar,genetic coefficients were generated for each variety during parameterization. These coefficients include;

P1: Thermal time from seedling emergence to the end of the juvenile phase.
P2: Extent to which development (expressed as days) is delayed for each hour increase in photoperiod above the most extended photoperiod at which development proceeds at a maximum rate,
P5: Thermal time from silking to physiological maturity.
G2: Maximum possible number of kernels per plant.
G3: Kernel filling rate during the linear grain filling stage and under optimum conditions.
PHINT: Phylochron interval; the interval in thermal time (degree days) between successive leaf tip appearances.

Thereafter, further evaluation of the maize model was carried out usingdata collected from second experiment conducted between September and December.While statistical evaluation was done by comparing observed and simulated results for the two growing seasons using mean bias errors (MBE), root mean square error (RMSE), normalized root mean square error (NRMSE), and R^2, measuring its efficiency and suitability for specific predictions (Anothai et al., 2008).The crop data evaluated include; phenology (anthesis, and days to maturity) grain yield and total biomass respectively.

RESULTS AND DISCUSSION

Model calibration and evaluations

Cultivar-specific parameters generated from the calibration experiments of the three maize varieties are presented in Table 1. The observed thermal time from seedling emergence to the end of juvenile phase (P1) for Suwan-1-SR-Y and ART/98/SW6 was 140°C day while that of ART/98/SW1 was 120°C day. The calculated value for P2 (Delay in development for each hour that day-length is above 12.5 h) was set at 0.5, since all the varieties are photo-insensitive.

Similarly, yields determining parameters (P5, G2 and G3) were also higher for Suwan-1-SR-Y and ART/98/SW6 than ART/98/SW1, this makes Suwan-1-SR-Y and ART/98/SW6 had potentially have higher yields and slightly longer maturity period than ART/98/SW1. Phyllochron interval (PHINT) for the cultivars ranged from 40°C days for ART/98/SW6 and ART/98/SW1 to 44°C days for Suwan-1-SR-Y. While yield information may exist, there are no records on general crop growth conditions such as planting dates, maturity dates, or total final biomass or initial field conditions; this is one of the setbacks to compare the estimated cultivar coefficients for modelling application or improvement of maize crop in rainforest agroecological zone of Nigeria.

Thereafter, the model was evaluated for its ability to simulate days to anthesis, days to physiological maturity, leaf number, grain yield and total biomass at harvest maturity respectively for the three maize varieties used. Thiswas done by comparing simulated model variables to actual observed variables across the fertilizer application rates using statistical indicators. Themodel closely reproducedthe observed values for all the parameters across the treatmentswithin the acceptable range of statistical error (Table 2a, b). Table 2a shows that the mean observed and model simulated for days to anthesis reproduced closely for all the cultivars across the fertilizer treatments with low MBE and RMSE of less or equal to a full day while model over predicts the physiological maturity with the estimated MBE and RMSE was ≤ 5days across the cultivars. Also, model over predicted against observed values for total leaf number indicates RMSE of 2.4, 1.9 and 2.7 leaf per plant for Suwan-1-SR-Y, ART/98/SW1 and ART/98/SW6 respectively. As shown in Table 2b, both the grain yield and total biomass were reasonably simulated across the fertilizer application treatment for all the cultivars. The RMSE varied from 121 kg to 211 kg ha^{-1} while NRMSE ranged from good (15.2%) to fairly (21.9%) estimate of the mean observed value for grain yield.

Similarly, lower RMSE ranged from 207 kg ha^{-1} to 448 kg ha^{-1}, and also an excellent estimated NRMSE (13.2 to 19.4%) were recorded for total biomass across the cultivars. The result further showed that fertilizer treatment of SOM-120 kg ha^{-1} and NPK 20:10:10 at 70 kg N ha^{-1} better reproduced closely than other treatments. The failure of the model to accurately simulate the grain yield of maizeunder different rates of SOM and control treatments could be attributed to low inherent nitrogen concentration in the soil parameterized. Thismay require further experimentation in different locations within the zone to ascertain further because little or no information is available in the literature from the region.

Model evaluation with an independent dataset

The evaluation of the CERES-Maize model performance in simulating days to anthesis, physiological maturity and total leaf number across the fertilizer application rate with an independent data setis presented in Table 3. The results showed that thedegree of error between the observed and simulated mean value was very low. This was responsible for the low MBE and RMSE value that was recordedacross the cultivars. Suwan-1-SR-Y had MBE and RMSE value of (0.34; 0.45) and (5.34; 5.34) for anthesis and physiological maturity. ART/98/SW1 also gave a low MBE and RMSE value of (0.1; 1) and (5.7; 5.8)for anthesis and physiological maturity. The MBE and RMSE were also low for ART/98/SW6 cultivar with estimated values of (-0.2; 1.0) and (4.5; 4.5) for anthesis and physiological maturity respectively.

Furthermore, model performance for ART/98/SW6 cultivar was good with low NRMSE values for grain and total biomass of 17.4 and 17.1% of the observed mean respectively (Figure 1a, b). Also, with the exception of grain yield for ART/98/SW1, the accuracy of the model in predicting grain yield and total biomass of ART/98/SW1 and Suwan-1-SR-Ywas overall fair, indicated by relatively

Table 1. Calibrated cultivar genetic coefficients for the three maize varieties used in rainforest agro-ecological zone.

Cultivar name	P1 (°C day)	P2 (day)	P5 (°C day)	G2 (grains/ear)	G3 (mg/day)	PHINT (°C day)
Suwan-1-SR-Y	140.0	0.50	520.0	990.0	18.50	44.00
ART/98/SW6	140.0	0.50	520.0	900.0	11.50	40.00
ART/98/SW1	120.0	0.50	500.0	850.0	9.74	40.00

Table 2a. Comparison between the observed and simulated for phenology and total leaf number for ART/98/SW1, ART/98/SW6 and SWAN-1 maize varieties after calibration.

Fertilizer treatment	Days to anthesis		Days to maturity		Total leaf number	
	Observed	Simulated	Observed	Simulated	Observed	Simulated
Suwan-1-SR-Y						
Control	52.3	53	82.3	88	13	15.9
SOM 60	52.3	53	82.3	88	13	15.9
SOM 90	52.7	53	82.7	88	15	15.9
SOM 120	53	53	83	88	12.67	15.9
NPK 70	53	53	83	88	15.17	15.9
Mean	52.7	53	82.7	88	13.8	15.9
MBE	0.34		5.34		2.1	
RMSE	0.45		5.34		2.4	
ART/98/SW1						
Control	48.0	49.0	78.0	85.0	16.0	15.4
SOM 60	48.0	49.0	78.0	85.0	12.7	15.4
SOM 90	49.0	49.0	79.3	85.0	13.5	15.4
SOM 120	49.7	50.0	80.3	85.0	14.5	15.4
NPK 70	50.7	49.0	80.7	85.0	13.0	15.4
Mean	49.1	49.2	79.3	85.0	13.9	15.4
MBE	0.1		5.7		1.4	
RMSE	1.0		5.8		1.9	
ART/98/SW6						
Control	50.7	51.0	81.0	86.0	13.0	16.1
SOM 60	51.3	51.0	81.3	86.0	13.7	16.1
SOM 90	51.7	52.0	81.7	86.0	12.7	16.1
SOM 120	51.7	51.0	81.7	86.0	14.0	16.1
NPK 70	51.7	51.0	81.7	86.0	14.3	16.1
Mean	51.4	51.2	81.5	86.0	13.5	16.1
MBE	-0.2		4.5		2.5	
RMSE	1.0		4.5		2.7	

low RMSE values ranging from 24.6 to 25.8% of the observed mean (Figure 1a, b). The coefficient of determination (R^2) values for grain yield and total biomass across the maize cultivars was generally positive, ranged from 0.58 - 0.83 between the observed and simulated values.

CONCLUSION

The study showed that maize yield is positively influenced byincreasing rates of Sunshine organic manure (SOM), but the yields were higher in the inorganic fertilizer NPK 20:10:10 at the recommended rateof 70 kgNha^{-1} compared to other levels and control. There was a good agreement between the model predicted,and field observed values which suggest that the CERES-Maize modelis capable of predicting the growth and yield response of maize crop over rainforest agroecological zone as it has been demonstrated in other agro-ecological zones of Nigeria. However, model response for grain yield and total biomass of maize

Table 2b. Comparison between the observed and simulated for yield parameters for ART/98/SW1, ART/98/SW6 and SWAN-1 maize varieties after calibration.

Fertilizer treatment	Grain yield ($kgha^{-1}$)		Total biomass($kgha^{-1}$)	
	Observed	Simulated	Observed	Simulated
Suwan-1-SR-Y				
Control	1026	686	1949	1619
SOM 60	1046	980	2179	2619
SOM 90	1077	986	2219	2619
SOM 120	1133	976	2419	2719
NPK 70	1191	1382	2770	3442
Mean	1094	1002	2307	2604
MBE	-92.3		296.5	
RMSE	194.6		448.2	
NRMSE (%)	17.8		19.4	
ART/98/SW1				
Control	683	692	977	1416
SOM 60	764	692	1336	1416
SOM 90	816	992	1383	1416
SOM 120	834	969	1510	1416
NPK 70	875	1011	1628	1555
Mean	794	716	1367	1444
MBE	76.8		76.9	
RMSE	120.9		207.1	
NRMSE (%)	15.2		15.2	
ART/98/SW6				
Control	893	680	1672	1523
SOM 60	951	680	1711	1523
SOM 90	992	680	1808	1523
SOM 120	996	980	1862	1523
NPK 70	1006	917	1925	1753
Mean	967	787	1795	1569
MBE	-179.9		-226.4	
RMSE	211.6		237.8	
NRMSE (%)	21.9		13.2	

Table 3. Evaluation of the CERES-Maize model performance in simulating days to Anthesis, physiological maturity and total leaf number across the fertilizer application rate against an independent dataset.

Cultivar parameters	Unit	N	MBE	RMSE		Observed range	Observed mean
				Absolute value	% of mean observed		
Suwan-1-SR-Y							
Anthesis	DAP	5	0.5	0.5	1.0	52.3 – 53	52.7
Phy. Maturity	DAP	5	5.3	5.3	6.5	82.3 – 83	82.7
ART/98/SW1							
Anthesis	DAP	5	0.1	1.0	2.1	48.0 – 50.7	49.1
Phy. Maturity	DAP	5	5.7	5.8	7.3	78.0 – 80.7	79.3
ART/98/SW6							
Anthesis	DAP	5	-0.2	1.0	2.0	50.7 – 51.7	51.4
Phy. Maturity	DAP	5	4.5	4.5	5.5	81.0 – 81.7	81.5

DAP- Days after planting; N-number of observations; MBE-mean bias error; RMSE-root mean square error.

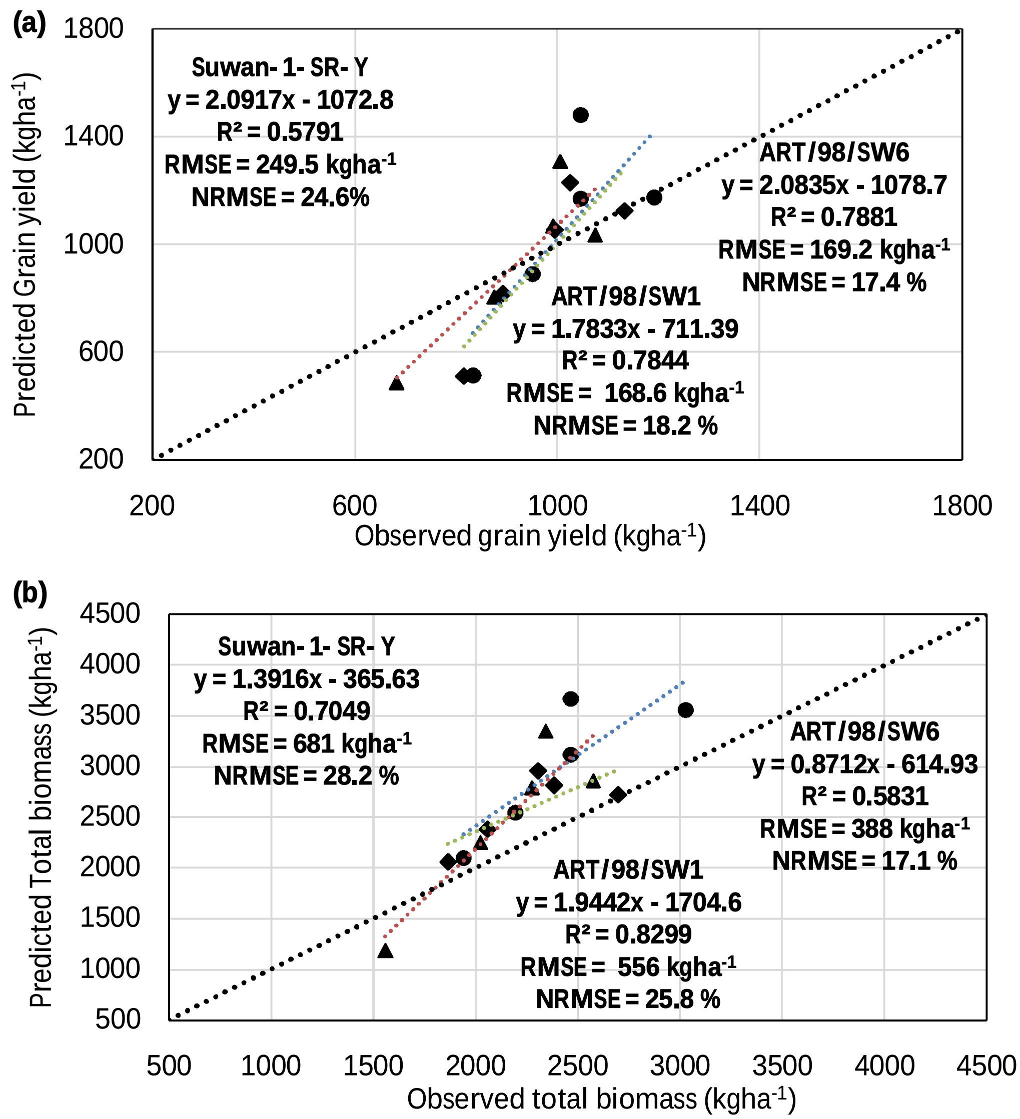

Figure 1. Model performance for (a) grain yield (b) total biomass.

cultivars under NPK 20:10:10 at 70 kgNha^{-1} treatmentwas better captured than different rates of SOM and control treatments. The study, therefore, conclude that the CERES-Maize model could successfully be used to predict the future crop yields under different management practices if well calibrated. It can also serve as a tool to know the appropriate fertilizer rate in a site-specific fertlizer recommendation experiment for improved maize production in the zone and other agro-ecological zones in Nigeria.

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