Calibrating and validating AquaCrop model for maize crop in Northern zone of Nigeria

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Abstract: Farmers in the northern Guinea Savannah ecological zone of Nigeria have been experiencing declining crop yield due to erratic water supply. In recent times, research on better water management and interaction between effects of climate, soil and field management on crop production is fast gaining grounds with the use of models. Models can be used to predict the impact of long-term climate variability, thus providing an opportunity of better techniques compared with the traditional multi-location trials. This study presents the calibration and validation of AquaCrop model for drip irrigated maize (Zea mays). Calibration was done using data of 2013, while validation across seasons was done with data of 2014. The modelling efficiency of grain yield, biomass yield and crop water use were 81%, 90%, and 85% when calibration was done, while during the validation the modelling efficiency were 86%, 74% and 50%, respectively. This indicates a good fit between the simulated output and measured data. The model has a tendency to over-predict grain and biomass yield at harvest by 3%-4%, under-predict seasonal evapotranspiration by 2%, and over-predict grain water productivity by 3% and biomass water productivity by 24% according to the coefficient of residual mass. The AquaCrop model high reliability for the simulations indicates it can be useful for on-the-desk assessing of the impact of irrigation scheduling protocols when properly calibrated.

Keywords: growth stage, deficit irrigation, drip irrigation, water management, modelling

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1 Introduction

Management of irrigation water is necessary for agriculture sustainability. The Northern Guinea savannah ecological zone is characterized by erratic water supply, and some farmers irrigate until their fields are saturated, which leads to poor yields and increased production risks (Igbadun et al., 2012). The call to improve the efficiency and productivity of water use for crop production has never been more urgent than now because of the emerging threat to sustainability of agriculture (Kendall, 2011; Igbadun et al., 2012).

Deficit irrigation has been recognized as a viable practice to increase crop yield, reduce negative environmental impact and improve sustainability of irrigated agriculture (Igbadun, 2008; FAO, 2012). Evaluation of irrigation scheduling methods can be performed by conducting field trials. However, this approach is expensive, time consuming, subject to uncontrolled environmental condition and difficult for farmers to analyse long-term effects and large impact scenarios. An easier option is to use crop simulation models (Igbadun, 2008). Models cannot fully replace field studies; they do help researchers to describe the growth dynamics of a crop in relation to the environment, understand the interactions of various components and extend results beyond experimental sites and years (Kumar and Ahlamat, 2004; Oguntunde, 2004; Abedinpour et al., 2012).

There are several models to implement management strategies for limited available water. Most models are complicated, demanding advanced skills for their

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calibration, operation and need of large number of parameters. Several models have been tested in maize, such as the CROPSYST which is based on both water and solar radiation driven modules (Azam et al., 1994; Tanner and Sinclair, 1983; Steduto et al., 2007), WOFOST which simulates crop growth using a carbon-driven approach (Stockle et al., 2003), amongst others are Ceres, CERES-Maize (Jones and Kiniry,1986), Hybrid-Maize (Yang et al., 2004) and EPIC model (Heng et al., 2009; Cavero et al., 2000).

Many efforts have been made to develop a new model that is less complex with accuracy, simplicity and versatility with fewer inputs (Steduto et al., 2009). Morphology and phenology of a crop is a function of crop variety, extent of irrigation deficit, irrigation method, climate and other agronomic practices. A majority of farmers in Samaru have embraced the early maturity maize (*Zea mays*) var. SAMMAZ 14 (Premier Seeds, Zaria, Nigeria). This variety is yet to be tested with Aqua Crop model.

AquaCrop evolves from the previous Doorenbos and Kassam (1979) approach with the use of crop yield response factor (Ky) by separating ET into soil evaporation (E) and crop transpiration (Tr) and the final yield (Y) into biomass (BY) and harvest index (HI). The separation of ET into E and Tr avoids the confounding effect of the non-productive consumptive use of water (E). The separation of Y into B and HI allows the distinction of the basic functional relations between the environment and B from those between environment and HI. The changes described led to Equation 1 as the core of the AquaCrop growth engine.

$$B = WP \cdot \Sigma Tr \qquad (1)$$

Where

WP = water productivity (kg/m^3)

Tr = Transpiration (mm)

B = Biomass (t/ha)

AquaCrop allows simulating a range of viable field management practices; when well calibrated for a crop, the model is expected to be an effective tool even for novice users in aiding the development of water management strategies to improve production and save water (Hsiao et al., 2009). AquaCrop is described by Steduto et al. (2009), while the structural details and algorithms are reported by Raes et al. (2009). For a more detailed description of the AquaCrop model see Heng et al. (2009). The model strikes a balance between accuracy, simplicity, robustness, and ease of use, and is aimed at practical end users such as extension specialists, water managers, personnel of irrigation organizations, economists and policy specialists who use simple models for planning and scenario analysis (Hsiao et al., 2009).

The aim of this paper was to calibrate and validate the AquaCrop model for deficit irrigated maize in the Northern Guinea savannah ecological zone of Nigeria.

2 Materials and methods

2.1 The study area

The field experiments used in calibrating and validating the AquaCrop model were located at the Institute for Agricultural Research (I.A.R) Irrigation farm, Ahmadu Bello University, Zaria, Nigeria (11^{o}11’N, 7^{o}38’E, and 686 m above sea level), within the Northern Guinea savannah ecological zone (Odunze, 1998). The weather data for the crop growing seasons were obtained from the meteorological station located in the irrigation farm (Table 1). Soil characteristics such as saturated hydraulic conductivity, water content at saturation, field capacity and wilting point of individual soil horizons were estimated from soil texture and organic carbon content using pedo-transfer functions available in the hydraulic properties calculator (Saxton et al., 2006) (Table 2).

Table 1 Average weather data for the 2013/2014 crop growing season

Months	Humidity, %	Min. temp, °C	Max. temp, °C	Sunshine hr	Wind speed, Km/h	ETo[a], mm/d	Total rainfall, mm
January	19.37	17.74	32.48	8.01	142.66	6.82	-
February	13.52	18.79	35.50	7.49	131.44	8.56	-
March	26.37	22.77	39.29	7.63	118.24	9.14	-
April	38.85	24.77	37.47	7.09	143.03	7.89	14.76

Table 2 Physical properties of soils at various depths at the Irrigation Research Farm, Samaru

Depth, mm	FC, %Vol	PWP, % Vol	Bulk density, g/cm^3	Hydraulic conductivity, mm/hr	TAW, mm/m	Ksat, mm/day	Clay%	Silt%	Sand%	Texture class[a]
0 -150	24.8	13.6	1.58	70	112	70	22	28	50	Loam
150-300	26.3	15.9	1.58	100	104	100	26	22	54	Loam
300-450	27.4	17.1	1.57	100	103	100	28	18	54	Loam
450-600	25.9	15.9	1.58	125	100	125	26	18	56	Sandy clay loam
600-800	29.5	18.2	1.55	125	113	125	30	22	48	Sandy clay loam

Note: Texture class[a] (Odunze, 1998)

2.2 Field trials

Two field experiments were carried out concurrently during 2013 (Field A and B) and 2014 cropping season, for the purpose of generating data for calibrating and validating the AquaCrop Model. Each field experiment consisted of eight treatments replicated for three times in a randomized complete block design, across the general slope of the field in order to ensure as much homogenous soil conditions as possible within the blocks. The treatments were based on water application regulated at selected crop growth stages. Water applied was based on the daily reference evapotranspiration computed from the current year climatic data of study area. The plots were irrigated every three and four days alternately of the daily reference evapotranspiration. The following growth-stages ranges were adopted in this research: Vegetative (15-42 DAP); Flowering-tasselling to silking (43-63 DAP) and grain filling to physiological maturity stages (64-95 DAP) based on the study by Igbadun (2012).

Table 3 Description of experimental treatments for 2013 season

Treatment Label.	Treatment Description
V_{100} $F_{100}G_{100A}$	Water applied was 100% of DRET in all the growth stages.
V_{100} F_{75} G_{100A}	Water applied was 75% of DRET at Flowering (F) Stage and 100% of DRET at Vegetative (V) and Grain filling (G) Stages
V_{100} F_{50} G_{100A}	Water applied was 50% of DRET at Flowering (F) Stage and 100% of DRET at Vegetative (V) and Grain filling (G) Stages
V_{100} F_{100} G_{75A}	Water applied was 75% of DRET at Grain filling (G) Stage 100% of DRET at Vegetative (V) and Stages Flowering (F)
V_{100} F_{100} G_{50A}	Water applied was 50% of DRET at Grain filling (G) Stage 100% of DRET at Vegetative (V) and Stages Flowering (F)
V_{75} F_{100} G_{100A}	Water applied was 75% of DRET at Vegetative (V) Stage and 100% of DRET for Flowering (F) and Grain filling (G) Stages.
V_{50} F_{100} G_{100A}	Water applied was 50% of DRET at Vegetative (V) Stage and 100% of DRET for Flowering (F) and Grain filling (G) Stages.
V_{50} F_{50} G_{50A}	Water applied was 50% of DRET in all the growth stages

Note: DRET= Daily Reference Evapotranspiration

Table 4 Description of experimental treatments for 2014 season

Treatment Label.	Treatment Description
$V_{100}\ F_{100}G_{100B}$	Water applied was 100% of DRET in all the growth stages.
$V_{100}\ F_{60}\ G_{100B}$	Water applied was 80% of DRET at Flowering (F) Stage and 100% of DRET at Vegetative (V) and Grain filling (G) Stages
$V_{100}\ F_{60}\ G_{100B}$	Water applied was 60% of DRET at Flowering (F) Stage and 100% of DRET at Vegetative (V) and Grain filling (G) Stages
$V_{100}\ F_{100}\ G_{80B}$	Water applied was 80% of DRET at Grain filling (G) Stage 100% of DRET at Vegetative (V) and Stages Flowering (F)
$V_{100}\ F_{100}\ G_{60B}$	Water applied was 60% of DRET at Grain filling (G) Stage 100% of DRET at Vegetative (V) and Stages Flowering (F
$V_{80}\ F_{100}\ G_{100B}$	Water applied was 80% of DRET at Vegetative (V) Stage and 100% of DRET for Flowering (F) and Grain filling (G) Stages.
$V_{60}\ F_{100}\ G_{100B}$	Water applied was 60% of DRET at Vegetative (V) Stage and 100% of DRET for Flowering (F) and Grain filling (G) Stages.

Note: DRET= Daily Reference Evapotranspiration

Maize var. SAMMAZ 14 was planted on February 7th and 18th, 2013, respectively; while during the 2014 cropping season the crop was planted on February 5th, 2014. In both seasons, the planting was done along the drip lines, the fields were divided into plot sizes of 5 ×1.8 m each, a plant spacing of 30 cm between plants and 60 cm between rows was used giving a plant population of 55,556 plants/ha which is a deviation from the conventional spacing of 25 cm ×75 cm because the emitter spacing of the drip used in the experiment was 30 cm. In 2013 season, manual weeding was carried out three times for both fields at three, six and nine weeks after planting. In 2014 season, however, weeding was carried out at two, five and nine weeks after planting. Fertilizer (NPK 15-15-15) was applied as basal dose at the rate of 60 kg N/ha at three weeks after planting. Urea was used for topdressing at six weeks after planting at a rate of 60 kg N/ha as reported by Igbadun (2012); thus the total N applied was 120 kg/ha. The fertilizers were applied after weeding on each occasion. There was no incidence of pests or diseases during the 2013 cropping season. In 2014 there was attack of aphids during the 5th week, which was managed with the application of lambda cyhalothrin as active ingredient (Karate; Corvallis; US) at 0.8 L/ha using 40 mL in 15 L knapsack sprayer as recommended by Avav and Ayuba (2006). Date of sowing and date of emergence were recorded. Emergence date was considered when 90% of seedlings had emerged. Flowering and duration of flowering, maximum canopy cover, senescence and maturity observations were also made.

2.3 Computation of soil moisture content

Soil moisture content of the experimental plots was monitored throughout the crop growing season using calibrated gypsum blocks (227 Delmhorst; Campbell Scientific; Logan, Utah, U.S.A.) in both seasons. Four gypsum blocks were installed in each experimental plot at 12, 25, 45 and 70 cm soil profile depths to monitor soil moisture changes at 0-15, 0-30, 30-60, 60-90 cm depths. Soil moisture resistances were measured using Delmhorst soil moisture tester (FX-2000 model, Delmhorst, New York, U.S.A.), a day after every irrigation and just before the next irrigation. The resistance measured were related to gravimetric soil moisture content using gypsum-moisture content specific calibration curve as shown in Equation 2 ($R^2 = 0.87$).

$$GMC = 44.75 \cdot R^{-0.24} \qquad (2)$$

in which, GMC is the gravimetric moisture content (% dry weight basis) and R, the electrical resistance in ohm (Ω)

The actual crop evapotranspiration was calculated from the measured soil moisture content data using gypsum blocks as outlined by Michael (1978). Equation 3 was used to estimate the actual crop evapotranspiration (ETa). The evapotranspiration was obtained as the product of the daily crop evapotranspiration between successive soil moisture content sampling and the number of days used as irrigation intervals (three and four days), while the seasonal evapotranspiration was the summation of the daily ET (Equation 3).

$$ET_a = \sum_{i=1}^{n} \left[\frac{(M1-M2)D_i \times Bi}{t}\right] \quad (3)$$

where:

M_1 = gravimetric moisture content (g/g) at first sampling in the i-th layer;

M_2 = gravimetric moisture content (g/g) at the second sampling in the i-th layer;

D_i = depth of i-th layer, mm;

n = number of layers within the soil profile;

B_i = bulk density, g/cm^3;

t = number of days between successive soil moisture content sampling.

2.4 Aboveground biomass and final harvesting

The crop attained physiological maturity at 89 and 86 DAP in 2013 and 2014 season, respectively; irrigation was withdrawn thereafter to allow the crop to dry in both seasons. Harvest was done by cutting the above ground dry matter. Each plot had three rows with an area of 1.2 m × 5 m which constituted the plot for final yield assessment. They were conveyed to the laboratory for curing for three weeks until the biomass was fully dried and the maize grain had attained 13.5% moisture content. The dry matters were then weighed, the maize cobs threshed and weighed.

2.5 Running AquaCrop Model

The input data used for the running of the model include: weather, soil, crop and irrigation scheduling (timing of irrigation and amount of water applied). Maize crop simulation parameters used for calibrating AquaCrop Software are presented in Table 5.

Table 5 Crop input parameters for AquaCrop Model

Description	Value	Source
Base temperature	8 °C	Hsiao *et al.*, 2009
Cut-off temperature	35 °C	Hsiao *et al.*, 2009
Canopy cover per seedling at 90% emergence (CCo)	6.5 cm^2	Hsiao *et al.*, 2009
Canopy growth coefficient (CGC)	19.6%	Dirk *et al.*, 2010
Maximum canopy Cover (CCx)	60%	Function of plant density
Canopy decline Coefficient (CDC) at senescence	12.5%	Dirk *et al.*, 2010
Water productivity normalized for ETo and C0$_2$ during yield formation	85%	Dirk *et al.*, 2010
Leaf growth threshold p-upper	0.10	Hsiao *et al.*, 2009
Leaf growth threshold p-lower	0.45	Hsiao *et al.*, 2009
Leaf growth stress coefficient curve shape	2.9	Hsiao *et al.*, 2009
Stomata conductance thresh p-upper	0.45	Hsiao *et al.*, 2009
Stomata stress coefficient curve shape	6.0	Hsiao *et al.*, 2009
Senescence stress coefficient p-upper	0.45	Hsiao *et al.*, 2009
Senescence stress coefficient curve shape	1.5	Hsiao *et al.*, 2009
Coefficient, inhibition of leaf growth on HI	7	Dirk *et al.*, 2010
Coefficient, inhibition of stomata on HI	3.0	Dirk *et al.*, 2010
Maximum basal crop coefficient (K_{cb})	1.05	Allen *et al.*, 1998
Effective rooting depth	0.6m	Keller and Bliesner, 1990
Water productivity normalized for ETo and C0$_2$, g/m^2	31.7	a
Plant density	55,556 plants/ha	a
Time from sowing to emergence	8 days	a
Length of the flowering stage	10days	a
Time from sowing to maximum canopy cover	47days	a
Time from sowing to flowering	52 days	a
Time to maximum rooting depth	60 days	a
Time from sowing to start Senescence	65 days	a
Time from sowing to maturity	90 days	a

Note: a= data obtained from the field

2.6 Calibration procedure

Model calibration involves a systematic adjustment of the parameters that can describe more closely the system behaviour for site-specific application as reported by Igbadun (2012). During the calibration process, conservative parameters were adapted from the report of Hsiao et al. (2009). These parameters included canopy cover growth and canopy decline coefficient; crop coefficient for transpiration at full canopy; water productivity (WP); soil water depletion thresholds for inhibition of leaf growth, stomata conductance and acceleration of canopy senescence. These parameters are presumed to be applicable to a wide range of conditions and not specific for a given crop cultivar. The process of calibration was repeated several times to list out a set of parameters that produced results in line with the measured data (Abedinpour et al., 2012). The days to emergence, maximum canopy, senescence and maturity as observed from the field were 8, 47, 65 and 90 DAP, respectively. The calibrated maximum canopy cover was 60%, values of canopy growth coefficient (CGC) and canopy decline coefficient (CDC) for the experiment were 19.6% and 22.5%, respectively.

The controlled days to flowering, duration of flowering, length to building of yield were 52, 10 and 34 DAP, respectively. The effective rooting depth was set at 0.6 m, while the maximum basal crop coefficient (Kcb_x) value obtained was 1.05 which is in line with the crop coefficients for the midseason as giving by FAO-56 (Allen et al., 1998). The value of WP adopted was 31.7 g/m^2 which was in the range (31-34 g/m^2) suggested for the AquaCrop for C_4 (crops that produces the 4-carbon compound oxalocethanoic acid as the first stage of photosynthesis). The harvest index obtained was 32% and the soil set as clay loam with initial soil condition as wet dry.

The model output during the calibration process that was compared with the field-measured data include: biomass yield at harvest, grain yield, seasonal evapotranspiration and water productivity. The difference between the predicted and the experimental data was adjusted by using a trial and error approach until the closest match between the simulated and the observed value were obtained. The final values of the adjusted parameters at which the model simulated outputs had the highest correlation with the field-measured data were adopted as input data for the model as is shown in Table 5.

2.7 Validation of the AquaCrop Model

Model validation was carried out by two independent field data for 2013 and 2014 cropping season. Grain yield, biomass yield, Seasonal crop water use and irrigation water productivity for biomass and yield, were considered as the evaluation parameters for the AquaCrop model.

2.8 Statistical analysis

Since no single measure can determine how well a simulation model performs, a combination of statistical indices are generally used to evaluate the model (Anjum et al., 2014). The agreement between the measured and the simulated values can be assessed using the following statistical indices: Root Mean Squared Error (RMSE), Coefficient of Variation (CV), Modelling Efficiency (EF) and Coefficient of Residual Mass.

The RMSE gives the weighted variations in errors (residual) between the modelled and observed values and is calculated from Equation 4 (Nash and Sutcliff, 1970).

$$\text{RMSE} = \sqrt{\frac{1}{n}\sum(M_i - S_i)^2} \qquad (4)$$

The coefficient of Variation is a measure of variability expressed by Equation 5 (Willmout and Matsuura, 2005).

$$\text{CV} = 100\cdot \sqrt{\frac{1}{n}\frac{\sum(M_i - S_i)^2}{S_i}} \qquad (5)$$

in which S_i is simulated, M_i, measured value and n, the number of measurements.

Modelling efficiency is a measure of the degree of fit between simulated and measured data, similar to the coefficient of determination (R^2), and varies from negative infinity for total lack of fit to 1 for an exact fit. The expression is given in Equation 6 (Willmott, 1982).

$$EF = \frac{\left[\sum(S_i - S_m)^2 - \sum(M_i - S_i)^2\right]}{\sum(S_i - S_m)^2} \qquad (6)$$

Where S_m is the measured average

The coefficient of residual mass is an indicator of the tendency of the model to either over-or under-predict measured values, a positive value indicates a tendency of under-prediction, while a negative value indicates a tendency of over-prediction as is shown in Equation 7 (Igbadun, 2012; Kahimba et al., 2009).

$$CRM = \frac{\sum S_i - \sum M_i}{\sum S_i} \qquad (7)$$

The model performance was further evaluated using prediction error. The expression is given in Equation 8 (Nash and Sutcliff, 1970).

$$Pe = \frac{Si - Mi}{Mi} \times 100 \qquad (8)$$

3 Results and discussion

3.1 Field results for 2013 and 2014 cropping season

The vegetative stage was subjected to deficit at 25% (V_{75} F_{100} G_{100A}) and 50% (V_{50} F_{100} G_{100A}) for Field A (Table 6). The grain and biomass yields were 12.7%, 30.4% and 13.7% and 31.2% less than when 100% water was applied to all the crop growth stages. Also, when deficit was imposed at the flowering stage 25% (V_{100} F_{75} G_{100A}) and 50% ($V_{100}F_{50}$ G_{100A}), the reduction in grain and biomass yield were 8.8%, 26.8% and 9.4, 36.7%, respectively, with respect to the control. Furthermore, when deficit was imposed at grain filling stage at 25% (V_{100} F_{100} G_{75A}) and 50% (V_{100} F_{100} G_{50A}) the corresponding grain and biomass yield reduction were 0.9%, 4.7% and 2%, 5.9 %.

Table 6 Grain yield, biomass yield and harvest index of the maize crop used for calibration

	Field A 2013 cropping season			**2014 cropping season**		
Treatments	GY, t/ha	BY, t/ha	HI, %	GY, t/ha	BY, t/ha	HI, %
$V_{100}F_{100}G_{100A}$	3.39a	11.12a	31	3.43a	11.38a	31
$V_{75}F_{100}G_{100A}$	2.96bc	9.6bc	30	3.12bc	10.74bc	32
$V_{50}F_{100}G_{100A}$	2.36de	7.65de	30	2.80bc	10.00bc	32
$V_{100}F_{75}G_{100A}$	3.09bc	10.07bc	31	3.50bc	11.17ab	31
$V_{100}F_{50}G_{100A}$	2.48dc	7.04dc	27	2.96bc	10.37bc	32
$V_{100}F_{100}G_{75A}$	3.36ab	10.9ab	29	3.35ab	10.17ab	32
$V_{100}F_{100}G_{50A}$	3.23bc	10.46bc	31	3.22bc	11.21ab	31
$V_{50}F_{50}G_{50A}$	1.56e	5.63e	31	1.77c	7.21c	31
Field B 2013 cropping season						
$V_{100}F_{100}G_{100B}$	3.52a	11.53a	31			
$V_{80}F_{100}G_{100B}$	3.17cd	10.37cd	31			
$V_{60}F_{100}G_{100B}$	2.83cd	9.16cd	31			
$V_{100}F_{80}G_{100B}$	3.24b	10.51b	31			
$V_{100}F_{60}G_{100B}$	2.69d	8.72d	31			
$V_{100}F_{100}G_{80B}$	3.28a	10.64a	31			
$V_{100}F_{100}G_{60B}$	3.19c	10.33c	31			
$V_{60}F_{60}G_{60B}$	2.08e	6.75e	31			

Note: Treatment means followed by the same letter(s) in any column are not significantly different at 5% level of significance. GY = Grain yield; BY = Biomass Yield; HI = Harvest Index (%)

The highest yield reduction value of 54% and 49.4% for grain and biomass yield was observed when 50% (V_{50} F_{50} G_{50A}) depth of water was applied throughout the crop growth season for 2013. The highest and lowest grain yield reduction values of 48.4% and 2% were obtained for treatment $V_{50}F_{50}$ G_{50A} and V_{100} $F_{75}G_{100A}$, respectively, during 2014 cropping season. When 20% (V_{80} F_{100} G_{100B}) and 40% (V_{60} F_{100} G_{100B}) deficit with respect to daily ETo was applied at Vegetative stage, the grain and biomass yield reduction with respect to the control were 9.9% and 19.6% and 10% and 21%, respectively for Field B during 2013 cropping season, deficit of at the flowering stage at 20% (V_{100} F_{80} G_{100B}) and 40% ($V_{100}F_{60}$ G_{100B}), led to grain and biomass yield reduction value of 8% and 24%, respectively. Furthermore, when 20% (V_{100} F_{100} G_{80B}) and 40% (V_{100} F_{100} G_{60B}) deficit was imposed at grain filling stage, the grain and biomass yield reduction were 6.8%, 9.4% and 7.7%, 10.4%, respectively as is shown in Table 6.

The results obtained showed that the vegetative and flowering stages seem to be very sensitive to yield reduction, which suggests that imposing deficit irrigation on the maize crop may be advantageous, if such is done at grain-filling and maturity at the study area; but if imposed at vegetative and flowering stage, it will drastically affect the grain and biomass yield, which is in consistent with the findings of Igbadun (2012) who reported that when rain is observed during the grain filling stage, its will overturn the impact of stress.

This was contrary to the report of Angela (2012), in which the deficit suffered at a more critical stage such as flowering and grain formation stage may dramatically affect yield because they are more sensitive to water shortage, which is not the case reported herein.

3.2 AquaCrop Model calibrations

3.2.1 Grain yield

The simulated grain yield during the model calibration ranged from 2.01 to 3.19 t/ha (Figure 1). The P_e in grain yield prediction was recorded in treatments V_{60} F_{100} G_{100B} and V_{80} F_{100} G_{100B} amounting to 10.95% and 0.32%, respectively. There was a remarkable match between the simulated and measured grain yield with EF of 0.82, RMSE of 0.32, CV of 10.7 and CRM of 0.02. The minimum P_e recorded in this research was lower than the results reported by Abedinpour et al., (2012) that the maximum and minimum prediction error observed was 16% and 0.84% when maize was planted in a semi-arid environment.

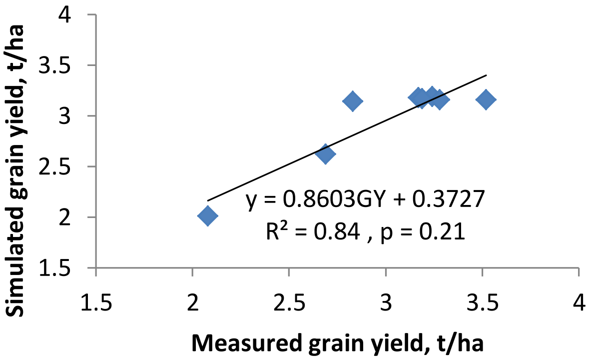

Figure 1 Simulated and measured grain yield during model calibration for field B 2013 cropping season

Evaluation of the measured and predicted value of the grain yield for field B was not significant (NS) at $p > 0.05$. Stricevic et al. (2011) reported R^2 values greater than 0.84 when simulating yield of maize, sun flower (*Helian annuus*) and sugar beet (*Beta vulgaris altissima*) under both rain-fed and irrigated conditions when Aquacrop was calibrated. Araya et al., (2010a) reported R^2 values > 0.80 when simulating barley grain yield using Aquacrop; while Karunaratne et al. (2011) reported R^2 values > 0.72 when simulating Bambara groundnut yield using Aquacrop model. Abedinpour et al. (2012) reported a grain yield of maize and obtained R^2 value of 0.90, which are in agreement with the outcome of this research.

3.2.2 Biomass yield

The fit between the measured and predicted values of the biomass yield for field B was not significant (NS) at $p > 0.05$ (Figure 2). The simulated biomass yields varied from 6.08 to 10.87 t/ha. The maximum and minimum error in biomass yield prediction for treatments V_{60} F_{100} $G_{100\ B}$ and V_{100} $F_{60}G_{60B}$ amounted to 13.8% and 0.95%, respectively. The Pe for biomass yield obtained in this research is 15% lower compared to biomass yield prediction error as reported by Abedinpour et al. (2012), that the maximum and minimum prediction error observed was 30.6% and 1.82%. The simulated and measured biomass yield with EF of 0.73, RMSE of 0.31, CV of 3.17 and CRM of -0.02. The CRM shows that the model has a tendency to over-predict grain and biomass yield at harvest by 2%.

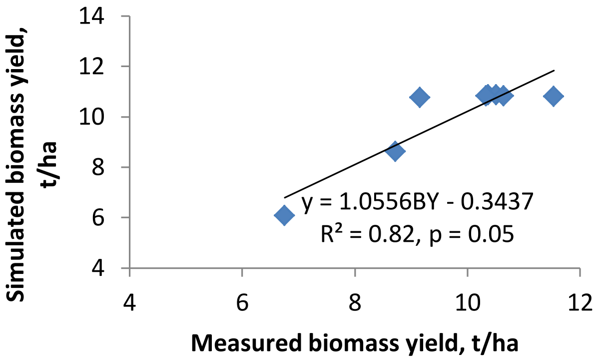

Figure 2 Simulated and measured biomass yield during model calibration for field B 2013 cropping season

3.2.3 Crop water use

The calibrated values varied from 357 to 435 mm while the field measured values varied from 329 to 458 mm (Figure 3). A t-test comparison of the measured and predicted value of the seasonal evapotranspiration field B was not significant ($p > 0.05$).

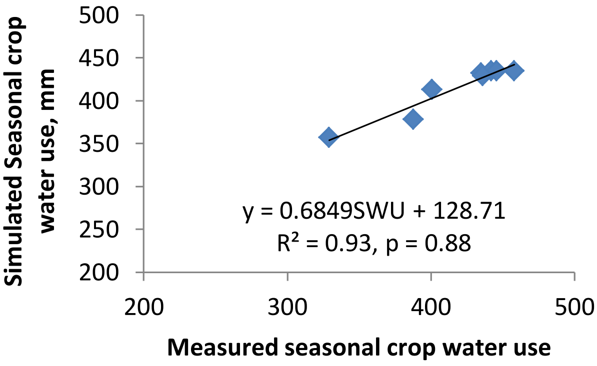

Figure 3 Comparison of simulated and field measured crop water use during model calibration

The simulated and measured biomass yield with EF of 0.86, RMSE of 0.32, CV of 0.08 and CRM of 0.03. The CRM shows that the model under-predict seasonal evapotranspiration by 3%, which is an indication that the model can predict seasonal evapotranspiration.

3.3 Crop water productivity

The simulated and field measured crop water productivity with respect to grain and biomass yield of maize for field B during 2013 cropping season is presented in Table 6, which are indicators of the quantity of crop yield produced per cubic meter of water applied used in evapotranspiration. They reflect the water utilization efficiencies, the rate at which the water supplied is converted to harvestable produce.

Table 6 Comparison of Simulated and field measured crop water productivity during model calibration for field B

Treatment	Grain water productivity, GWP, kg/m^3		Biomass water productivity, BWP, kg/m^3	
	Sim.	Obs.	Sim.	Obs.
$V_{100} F_{100} G_{100B}$	2.68	2.52	0.75	0.77
$V_{80} F_{100} G_{100B}$	2.51	2.38	0.75	0.73
$V_{60} F_{100} G_{100B}$	2.39	2.28	0.74	0.71
$V_{100} F_{80} G_{100B}$	2.40	2.38	0.75	0.73
$V_{100} F_{60} G_{100B}$	2.38	2.25	0.76	0.69
$V_{100} F_{100} G_{80B}$	2.48	2.39	0.75	0.74
$V_{100} F_{100} G_{60B}$	2.50	2.37	0.75	0.73
$V_{60} F_{60} G_{60B}$	2.42	2.05	0.74	0.63

The modelling efficiencies for grain water productivity and biomass water productivity were 73% and 92%. The CRM shows that the model has a tendency to over-predict grain water productivity by 6% and biomass water productivity by 5%. The close relationship between the simulated and measured data was considered as a good performance of the model ability to predict grain and biomass water productivity.

3.4 Model validation

3.4.1 Simulated grain and biomass yield

The data for 2013 cropping season was used for validation of the model, while 2014 cropping season field data was used for the validation of the model across seasons and fields. The maximum and minimum error of grain yield prediction during model validation with 2013 for treatments $V_{50}F_{100}G_{100A}$ and $V_{100}F_{100}G_{50A}$ amounted to 29.6% and 0.9%, respectively. Furthermore, the maximum and minimum error for biomass was observed to be in treatments $V_{50}F_{100}G_{100A}$ and $V_{100}F_{100}$ G_{50A} with 19.6% and 0.3%. Similarly, the maximum and minimum error of grain yield prediction error during the model validation across the season 2014 was obtained for treatments $V_{50}F_{100}G_{100A}$ and $V_{100}F_{100}G_{50A}$ amounting to 14.6% and 0.6%, while the maximum and minimum error value for biomass was observed to be recorded in treatment $V_{100}F_{100}$ G_{100A} and $V_{75}F_{100}$ G_{100A} amounting to 8.4% and 1.2%.

The CRM shows that the model over-predicted grain yield by 3% and under-predicted yield at harvest by 6% for 2014 season, and over-predict grain and biomass yield by 3% and 4%, respectively, for 2013 season. The modelling efficiencies (EF) were between 74% and 90% biomass and grain yield. The close relationship between the simulated and the measured data was considered as good performance of the model ability to predict biomass and grain yields (Table 7).

Table 7 Simulated and measured dry matter and grain yields at harvest for 2013/2014 cropping season

Treatments	2013 cropping season				2014 cropping season			
	Grain yield, t/ha		Biomass yield, t/ha		Grain yield, t/ha		Biomass yield, t/ha	
	Sim.	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.	Obs.
V_{100} $F_{100}G_{100A}$	3.36	3.39	10.85	11.12	3.23	3.43	10.42	11.38
V_{75} F_{100} G_{100A}	3.13	2.96	9.94	9.60	3.29	3.12	10.61	10.74
V_{50} F_{100} G_{100A}	3.06	2.36	9.15	7.65	3.21	2.80	10.37	10.00
V_{100} F_{75} G_{100A}	3.06	3.09	10.99	10.9	3.34	3.17	10.71	11.67
$V_{100}F_{50}$ G_{100A}	2.37	2.48	7.85	7.04	3.03	2.96	9.59	10.37
V_{100} F_{100} G_{75A}	3.40	3.36	10.95	10.9	3.24	3.35	10.44	10.17
V_{100} F_{100} G_{50A}	3.20	3.23	10.32	10.46	3.24	3.22	10.46	11.21
V_{50} F_{50} G_{50A}	1.53	1.56	6.03	5.63	1.97	1.77	6.67	7.21

The simulated biomass production tended to be higher than the measured values in some treatments while in others they were low just as observed by Hsiao et al. (2009). This could have been the result of using a constant WP throughout the simulation exercise without alteration for different seasons (Table 5), since the WP was not adjusted given that it was considered as a conservative parameter of AquaCrop. The decision was also informed by Hsiao et al. (2009) and Heng et al. (2009) who handled the WP parameter in a similar way. There is also a chance of variation in WP among maize varieties used. Besides the use of constant WP* throughout the simulation, initial HI was set constant. Given the fact that the grain yields are derived directly from the total biomass yields, there is likely to be a compromise between over-prediction or under-prediction of either grain yields or total biomass depending on the objective of simulation exercise. In this study, the focus leaned more on grain yields given its importance especially as staple food in Nigeria.

3.4.2 Simulated seasonal evapotranspiration

The simulated and the field measured seasonal evapotranspiration for 2013 and 2014 cropping seasons is presented in Table 8. The maximum and minimum prediction error of crop water use for treatments $V_{100}F_{75}$ G_{100A} and $V_{75}F_{100}$ G_{100A} amounting to 8.6% and 0.7%, respectively, for 2013, while the maximum and minimum prediction error of crop water use for treatments $V_{50}F_{50}$ G_{50A} and $V_{75}F_{100}$ G_{100A} amounted to 24.9% and 0.2% for 2014.

Table 8 Simulated and measured Seasonal evapotranspiration

Treatment	Crop water use, mm 2013 field A		Crop water use, mm 2014	
	Sim.	Obs.	Sim.	Obs.
$V_{100}F_{100}G_{100A}$	492	483	442	453
$V_{75}F_{100}G_{100A}$	444	441	413	412
$V_{50}F_{100}G_{100A}$	412	417	408	368
$V_{100}F_{75}G_{100A}$	492	453	419	421
$V_{100}F_{50}G_{100A}$	402	428	400	399
$V_{100}F_{100}G_{75A}$	492	470	412	433
$V_{100}F_{100}G_{50A}$	486	464	412	414
$V_{50}F_{50}G_{50A}$	309	320	361	289
Mean	441	435	408	398
Standard Error	65.1	51.2	22.7	50.7

There was a tendency of over-prediction of the seasonal evapotranspiration by 1% in 2014 season and under-prediction of seasonal evapotranspiration by 2% in the 2013 season as indicated by the CRM. The modelling efficiency was low for 2014 cropping season (49%) and quite high for 2012/2013 cropping season (85%) which may be as a result of the low sensitivity of the gypsum blocks used to measure the crop during 2014 cropping season which in turn affected the model performance. The RMSE value for validation of the seasonal evapotranspiration obtained in this research were 0.19 and 0.21 mm for 2013 and 2014 season, respectively.

4 Conclusions

AquaCrop model was able to simulate grain and biomass yield, seasonal crop water use, biomass and grain water productivity accurately. The simplicity of AquaCrop input data, which are readily available, has made it user-friendly. The model can be useful for on-the-desk assessing of the impact of irrigation scheduling protocols. The possible consequences of a developed irrigation scheduling on the crop and its environment can be analysed without going to the field. AquaCrop model can be a great tool for policy makers, researchers and extension agents. AquaCrop can be recommended for applications under different agro-climatic conditions in northern guinea savannah ecological zone of Nigeria.

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