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Research Article

Evaluation of Aqua-Crop Model using Onion Crop under Deficit Irrigation and Mulch in Semi-arid Nigeria

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ABSTRACT

The Aqua-Crop simulation model has been playing a crucial role in assessing the performance of the existing strategies for the management of irrigation schemes for improving agricultural water use efficiency. This study evaluated the Aqua-Crop model using Onion crops under deficit irrigation and mulch practices in semi-arid Nigeria. Measurements were taken from the experimental plots which consisted of irrigation and mulch each at 4 levels were used to evaluate the Aqua-Crop model using canopy cover, biomass, yield, actual crop ET, and water productivity of Onion during the 2021 irrigation season. The simulated results from the Aqua-Crop model were evaluated and statistically compared with the experimental results. The model simulated canopy cover with the highest degree of correlation coefficient ($0.74 \leq r \leq 0.94$). The model perfectly predicted Onion yield and biomass under full irrigation irrespective of the mulching. However, the model underestimated Onion yield and biomass at deficit irrigation. The model has perfectly estimated the seasonal actual crop evapotranspiration at different irrigation levels and mulch materials while underestimating water productivity in most of the treatments except at 100% irrigation under white synthetic mulch. However, both model and experimental water productivity were better at white synthetic mulch plots. Therefore, the Aqua-Crop model has proven to be a good Onion crop growth and yield predictor under different irrigation levels and mulch materials which can help improve Onion productivity in water-stressed areas like semi-arid Nigeria.

RESEARCH ARTICLE

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INTRODUCTION

Effective management of limited water in a water-stressed area like the semi-arid is a major challenge for irrigation water managers as agriculture consumes more than 70% of the total global freshwater (FAO, 2011; Shanono and Ndiritu, 2020). Therefore, effective and sustainable agricultural water management in such water-stressed areas is crucial. For example, managing water resources at both allocation and field levels in semi-arid Nigeria is very important and unavoidable (Tagar *et al.*, 2012; Heris *et al.*, 2014; Nasidi *et al.*, 2015; Shanono, 2019). Thus, on-farm strategy for irrigation water management should be conducted using irrigation techniques that conserve water such as deficit irrigation (DI) coupled with other on-farm management practices including mulching (Chukalla *et al.*, 2015). The concept of DI is a practice by which crops are deliberately exposed to a certain degree of water stress by irrigating below their crop water requirements. Although adopting DI practice, farmers might lose a certain proportion of yield. But, a considerable amount of water can be saved which could be used to develop and put additional land into cultivation thereby, increasing food production (Shanono *et al.*, 2014).

Mulching practices have been used all over the world to increase crop water use efficiency and yield, especially in water-stressed regions. The main aim was to protect the soil surface from solar radiation thereby, modifying the soil temperature, reduce the rate of evaporation and thus ensure more soil water availability for crops growth and hence, higher crop water use efficiency and yields. Mulching involves the placing of organic (e.g. crop residues and grasses) or inorganic material (e.g. polyethene sheets etc.) on the surface of soil under cultivation The effects of mulching on crop yield and water use efficiency have been reported by many studies (Igbadun *et al.*, 2012; Liu *et al.*, 2014). Khonok (2013) reported an improvement of about 33% in Bean yield when mulch was spread compared to no mulch Liu *et al.* (2014) reported a 20 to 35% increase in the yield of most grain crops and a 20 to 60% increase in the yield of most of the cash crops when the crops were planted under plastic mulch as compared to No mulch conditions.

Crop simulation models have been developed and applied in agricultural water management (Nazeer, 2009; Zakari *et al.*, 2015). Such crop models contributed immensely in testing and developing alternate strategies for obtaining maximum crop yield with less irrigation water particularly in water-stressed regions (Toumi *et al.*, 2016). Moreover, simulation models are mainly used as prediction tools to make the right decision for future scenarios (Shanono *et al.*, 2012). The models are tools used for gaining insights into the crop characteristics, growth, yield, physiological mechanisms and data extrapolation and prediction (Rauff and Bello, 2015). It simulates the behaviour of a plant including growth parameters such as roots, leaves, stems and yield, as well as other processes concerning the growth stages of a crop on a timely basis, climatic factors and management practices (Darko *et al.*, 2013). Thus crop modelling can provide powerful tools for investigating the dependence and nature of relationships among the variables of crop production. Many crop models have been developed and used to predict crop growth parameters and yield as a response to varying agro-climatological environments for different categories of crops. Some of these models include Crop Syst (Stöckle *et al.*, 2003), EPIC (Williams *et al.*, 1989), the APSIM models (Keating *et al.*, 2003), the DSSAT model (Jones *et al.*, 2003) etc. However, when large number of input parameters are demanded, advanced skill are needed before calibration and operation which render their application very difficult for the users and policy-makers for irrigation scheme planning, operation and management (Fereres, 2011).

To tackle these concerns and to achieve an optimal balance between accuracy, simplicity, and robustness, FAO's crop-water model Aqua-Crop has been developed to solve these limitations. This resulted from a series of scientific experiments designed to quantify and understand crop growth in relation to water. The model simulates the yield of several herbaceous crops under the following four conditions, rain-fed, deficit, supplemental, as well as full irrigation condition (Steduto *et al.*, 2009b; Steduto *et al.*, 2009a). Compared with other models, Aqua-Crop is easire to operate and allows the simulation of the performance of crops using many scenarios. Moreover, it is characterised with a higher level of accuracy and requires few input parameters (Steduto *et al.*, 2009a). The Aqua-Crop model has the capacity of predicting water requirements, water use efficiency and crop productivity under water-stressed conditions (Raes *et al.*, 2009). Thus, applying Aqua-Crop Model in semi-arid regions could improve crop water productivity and water use efficiency. The main objective of this research was to calibrate and validate Aqua-Crop Model for simulating Onion growth/yield and water used parameters under different irrigation levels and mulch materials in the semi-arid region of Nigeria.

MATERIALS and METHODS

Site Location and Experimental Design

This study was conducted at Dala Alamderi Irrigation Project, Maiduguri, Borno State, Nigeria. The Irrigation project is located between Latitudes 11°05' and 11°55' N, Longitudes 13°02' and 13°16' E and altitude 345 m above mean sea level. The mean annual rainfall of the study location is about 625 mm and the temperature range of 28.5°C-40.5°C (Adeniji *et al.*, 2013). The climate of Maiduguri is generally semi-arid with moderate variation in temperatures. The soils in the study location is predominantly sand to sandy-loam having low moisture retention and high permeability, and few places with clay to clay-loam.

The field experiments consisted of two factors (water application depth and mulch practice) each at four levels. The 4 levels of water applications are 100, 85, 70, and 55% of weekly reference evapotranspiration (WRET), while the 4 levels of mulch materials which include No Mulch (NM); Rice Straw Mulch (RM), Wood Shaving Mulch (WM) and White Synthetic Plastic Mulch (SM). The treatments were replicated 3 times making 4 × 4 × 3 = 48 experimental plots. The experiment was laid out using a split-plot design (SPD). The block was separated by 0.5 m and the basins in each block were also separated by a distance of 0.5 m. Such separation aims to minimize the water lateral movement from one plot to another.

Land Preparation, Agronomic Operations and Water Application

A land with an area of 36 m by 15 m was cleared and prepared into levelled basins of 2.0 m x 2.0 m and Onion seedlings were transplanted on 1st December 2020. The variety of Onion used was a red creole, which is commonly grown in the study area. The crop was transplanted with a spacing of 20 cm between plants and 25 cm between rows resulting in a crop density of 80 plants per plot. The mulch were placed two weeks after transplanting after which the transplanted Onion is fully established and recovered. All other operations were conducted using the standard agronomic procedure (Igbadun *et al.*, 2012, Sinnadurai, 1992; Sen *et al.*, 2006). The surface irrigation method which is not uncommon in the study location was used.

The surface irrigation method which is common in the study location was used. The major source of water in the study area are tube well. During the early growth stage, all experimental plots were irrigated at full irrigation to ensure proper plant establishment. Different irrigation water levels were applied to the developmental, mid and late growth stages. The water applied at every irrigation period was recorded during the entire croping season using the reference ET amount for the days of irrigation and for each experimental treatment plots. The average weekly reference ET for December, January, February and March were 25 mm, 37 mm, 53 mm and 58 mm, for treatment Irrigated at 100% respectively. The seasonal water applied for the treatments irrigated at 100%, 85%, 70%, 55% WRET were 577, 490, 404, and 317 mm respectively throughout the crop growing season. Reference ETo of the site was calculated using the FAO-Penman-Monteith method which is incorporated in the CROPWAT model (FAO, 1977). The weather data for the calculation of ETo was obtained from the Meteorological Station (NIMET) situated in Maiduguri International Airport, Maiduguri. The consumptive use of the crop (CWU) of the treatments irrigated at 100% WRET (I_{100}), was regarded as actual crop consumptive use (ACWU) while the crop CWU of the deficit irrigated treatments (I_{85}, I_{70}, I_{55}) was regarded as deficit consumptive use (DCWU).

Crop Data Collection

To ascertain the Onion response to the deficit irrigation and mulch conditions, number of leaves per plant and plant height were measured at 2, 4, 6, 8 and 10 weeks after transplanting. The canopy cover, leaf area, crop biomass, and harvest index were computed at 2, 4, 6, 8 and 10 weeks after transplanting using equations 1, 2, 3 and 4 respectively (Hsiao *et al.*, 2009; Corcoles *et al.*, 2015).

$$CC = \frac{LA_m N}{A} \times 100 \quad (1)$$

$$LA = 0.000199 + 1.277L \times \mathrm{A}_{25} \quad (2)$$

$$CB = BB + LB \quad (3)$$

$$HI = \frac{Y}{B} x100\% \quad (4)$$

Where; CC = canopy cover in %, LA_m = average leaf area in m^2, N = number of leaves and A = area occupied by crop in m^2. L = total leaf length and A_{25} is leaf width taken from the distance of 25% from the base of the leaf. HI = harvest index, Y = Onion yield in kg ha^{-1}, CB = crop biomass, BB = bulb biomass, LB = leaves biomass and B is the total onion biomass in kg ha^{-1}.

The Onion yield and crop water use efficiency were calculated for each of the experimental plots using equations 5 and 6 expressed by Igbadun *et al.* (2012) and Bagg and Turner (1976) respectively.

$$Y = \frac{W}{A} \quad (5)$$

$$CWUE = \frac{Y_a}{ET_a} \quad (6)$$

Where; Y = Onion bulb yield in kg ha^{-1}, W = crop weight in kg and A = experimental plot in ha. $CWUE$ = Crop Water Use efficiency, ET_a = Actual crop evapotranspiration (m^3) and Y_a is the crop yield (kg m^{-2})

Model Description and Input data

Aqua-Crop crop was developed by Food and Agriculture Organization. The aim of the model was to predict water use efficiency, water requirement and crop productivity under water-stressed conditions (Hsiao *et al.*, 2009; Raes *et al.*, 2009). Aqua-Crop originates from the Doorenbos and Kassam (1979) method using crop yield response factor (*Ky*) by separating evapotranspiration (*ET*) into crop transpiration (*Tr*), soil evaporation (*E*) and the final yield (*Y*) into the harvest index (*HI*) and biomass (*B*). This led to equation 7 as the basis for the Aqua-Crop growth engine. The biomass can also be divided into the yield (*Y*), while the ratio of yield to biomass is known as harvest index (HI), thus, the yield can be obtained using Equation 8.

$$B = WP \times \Sigma \mathrm{Tr} \quad (7)$$

$$Y = B \times HI \quad (8)$$

Where: WP = water productivity (kgm^{-3}), Tr = Transpiration (mm) and B = Biomass (t ha^{-1})

The aqua-Crop model input parameters include crop with its growth, soil with its water balance, development, and yield. Others include the atmosphere with its thermal conditions, evaporative demand, rainfall and CO_2 concentration (Hsiao *et al.*, 2009; Raes *et al.*, 2009; Steduto *et al.*, 2012). The climate components involves daily weather data on maximum and minimum rainfall, air temperature, CO_2 concentration and ETo. These data were obtained from an agrometeorological station at the Maiduguri International Airport. While the daily ETo was calculated using the FAO Penman-Monteith equation installed in the model. The soil file incolves soil characteristics including field capacity, permanent wilting point, volumetric water content at saturation and saturated hydraulic conductivity of the different soil profile depths. These parameters were obtained following standard international procedures.

The crop input component of Aqua-Crop contains both conservative and user-specific parameters. Some of the user-specific ones involve emergence time, plant density, maturity time, canopy senescence, yield formation duration, flowering period rooting depth, and reference HI. Some of the conservative parameters include canopy growth, soil water extraction pattern, crop coefficient for transpiration at full canopy; and water stress response coefficients for canopy expansion, water productivity for biomass; stomatal closure, and early canopy senescence. Groundwater effects due to capillary were not simulated because in the study location the watertable is below effective root zone (typically > 7 m). The input data also include information relating to field management and irrigation. These input variables are management and location-specific.

Model Calibration and Validation

The results obtained from the field experimental and meteorological data from Maiduguri International Airport were used to calibrate the Aqua-Crop model. The purpose of the calibration is to adjust some model parameters to make the model match the measured data at the specific location (Farahani *et al.*, 2009). Calibration was performed with the four different irrigation regimes and mulch materials treatments by first matching the ability of the parameters for the fully irrigated treatment with both no mulch and mulched experimental plots. Then, the water stress parameters were changed manually around the default value to reproduce the measured values, the process involved the comparison of simulated and observed values for canopy cover, biomass, actual evapotranspiration, water productivity and yield of Onion. The procedure is an iterative approach from ehich sensitive parameters are adjusted, mainly non-conservative parameters, and assessing both the absolute and relative differences. For each change in input parameters, simulations were run using the calibrated crop file and the corresponding irrigation file. Thus, continuous iterations of the parameters were done until satisfactory results for all the irrigation treatments in the calibrated experiment were achieved.

The Aqua-Crop model was calibrated using the measured data from the experimental field at the Dala Irrigation site during the 2020/2021 experimental season. Calibration was performed with the four irrigation regimes and two selected mulch materials for each irrigation treatment by first matching the ability of the fully irrigated treatment under no mulch condition in terms of the canopy cover *(CC)*, yield *(Y)*, biomass *(B)*, actual crop evapotranspiration and the evapotranspiration water productivity. While the remaining two mulch materials with the four irrigation regimes were used for the validation of the Aqua-Crop model. The conservative and non-conservative parameters used to calibrate the Aqua-Crop model for simulating the Onion growth, yield and water used efficiency parameters are presented in Table 1.

Table 1. Parameters used to calibrate the Aqua-Crop model for simulating onion crop.

		Values				
S/No	**Description**	**NM**	**SM**	**WM**	**RM**	**Units**
1	Base Temperature	10	10	10	10	°C
2	Cut- off Temp	30	30	30	30	°C
3	Initial canopy cover	1.65	1.65	1.65	1.65	%
4	Canopy size seedling	5.00	5.00	5.00	5.00	cm^2 $plant^{-1}$
5	Canopy growth co-eff.	0.94	1.02	0.99	0.98	% GDD
6	Canopy decline co-eff.	0.37	0.64	0.49	0.49	%GDD
7	Maximum canopy cover	62.8	69.5	64.8	63.9	%
8	Water productivity (*WP*)	18.5	18.0	18.0	17.5	g m^{-2}
9	Canopy expansion growth threshold P_{upper}	0.20	0.25	0.20	0.20	
10	Canopy expansion growth threshold P_{lower}	0.55	0.50	0.45	0.45	
11	Effect of canopy shelter on soil *ET* in late season (*Ke*)	60	65	65	65	%
12	Effect of crop transpiration (*KcTr*)	1.15	1.15	1.00	1.00	
13	Saturation	5.0	5.0	5.0	5.0	%
14	Early canopy senescence stress coefficient (P_{upper})	0.55	0.50	0.45	0.45	
15	Shape factor for soil-water stress	3.0	3.0	3.0	3.0	
16	Stomata closure threshold (P_{upper})	0.55	0.50	0.45	0.45	
17	Reference harvest index (*HIo*)	65	68	63	63	%
18	Time of transplanting to recover	18	16	17	17	Days
19	Time of transplanting to max. cc	77	75	72	72	Days
20	Time of transplanting to senescence	89	84	88	88	Days
21	Time of transplanting to harvest	100	100	100	100	Days
22	Irrigation regimes (100%)	403.8	348.9	378.2	383.6	mm
23	Irrigation regimes (85%)	376.0	334.0	354.3	362.2	mm
23	Irrigation regimes (70%)	344.5	315.5	331.5	332.8	mm
24	Irrigation regimes (55%)	284.6	252.6	269.7	275.7	mm

Aqua-Crop model performance was evaluated based on how simulated data are close to the observed data and was determined using the following statistical indicators; Root Mean Square Error (Heng *et al.*, 2009), Nash and Sutcliffe Efficiency Coefficient (Nash and Sutcliffe, 1970) and Coefficient of Residual Mass (Kahimba *et al.*, 2009) as expressed in Equations 9, 10 and 11 respectively.

Root Mean Square Error (RMSE): This is the measure of the average magnitude of the difference between simulated (*S*) and observed (*O*) data. It ranges from 0 to positive infinity with the former showing good and the latter indicating poor performance.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(O_i - S_i)^2}{N}} \quad (9)$$

Nash-Sutcliffe Efficiency Coefficient (NSE): The aim of computing NSE was to determine how well the observed and simulated data are match. The NSE is calculated as one minus the ratio of the error variance of the modeled time-series divided by the variance of the observed time-series. In the situation of a perfect model with an estimation error variance equal to zero, the resulting Nash–Sutcliffe Efficiency equals 1 (NSE = 1). Thus, an NSE of 1 indicates an excellent match between the simulated and observed data.

$$EF = 1 - \frac{\sum_{i=0}^{N}(O_i - S_i)^2}{\sum_{i=0}^{N}(O_i - O_{av})^2} \quad (10)$$

Coefficient of residual mass (CRM): This describes the tendency of the crop model to either under-predict or over-predict, a positive indicates a tendency of under-prediction, whereas a negative value shows over-prediction as expressed in Equation 7 (Igbadun *et al.*, 2012; Kahimba *et al.*, 2009).

$$CRM = \frac{\sum S_i - \sum O_i}{S_i} \quad (11)$$

Where; S_i and O_i = simulated and observed values, N = number of observations and O_{av} = mean of the observed values

RESULTS AND DISCUSSION

Calibration for Canopy Cover (CC)

The development of a green canopy cover for the Onion under different irrigation and mulch materials treatment for 10 weeks after transplanting (WAT) is presented in Figure 1. The figure revealed how CC of Onion was underestimated by the Aqua-Crop model at the early growth stage (2WAT) throughout the treatments irrespective of irrigation levels or mulch materials. Whereas, at 4WAT, the simulated CC values at plots with white synthetic mulch (SM) and full irrigation slightly overestimated the observed values The simulated model values recorded at 6WAT and 8WAT has greatly overestimated the observed field values throughout the experiment as shown. However, the model simulated values recorded during the experiment were very close to the observed field values at 10WAT. This result shows that as the crop approaches the maturity stage, CC enters a declining phase due to leaf senescence as observed. Observation data confirmed that the treatments with extreme water stress condition have a shorter CC than those with no stress. Also, the observed and simulated CC growths were well fitted for treatment with 100 and 85% irrigation under both no-mulch and mulch conditions. This assertion has also been observed by Farahani *et al.* (2009) for cotton, Geertz and Raes (2010) for quinoa and Zeleke *et al.* (2011) for canola. Generally, the result indicates that Onion crop CC increases with an increase in the number of weeks after transplanting while decreasing with an increase in deficit irrigation irrespective of mulch conditions.

Figure 2 shows the result obtained from statistical tests and a strong agreement between the observed and simulated CC values for all treatments. The correlation coefficient values (r) ranging from 0.74 to 0.94 with the maximum value of r = 0.94 was recorded at 10WAT while the minimum value of 0.74 at 2WAT. The co-efficient values per treatment were closer to 1, indicating a positive linear relationship between observed and simulated CC development and similar findings were reported by Kiptum *et al.* (2013) with a good relationship of r = 0.95 between observed and simulated CC.

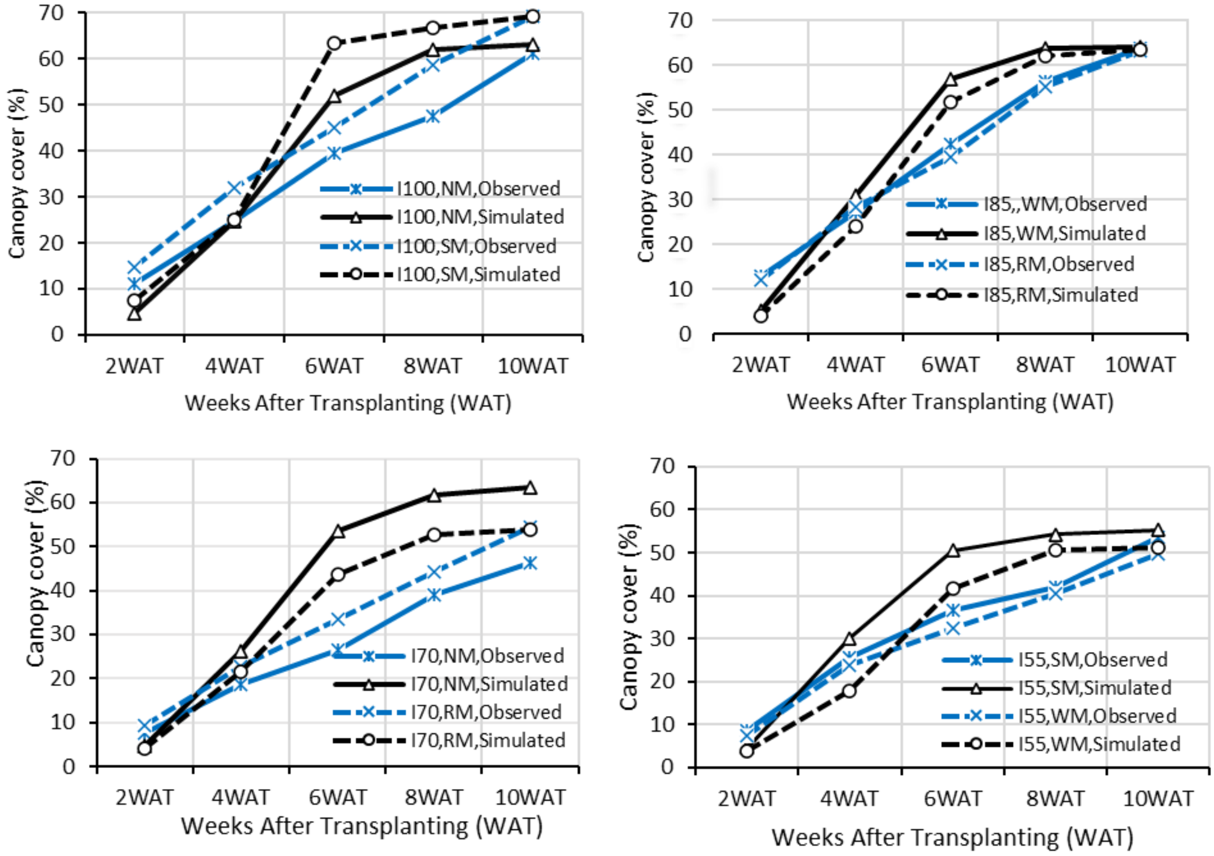

Figure 1. Simulated and observed canopy cover under different irrigation and mulch treatments.

While the EF and CRM values were recorded throughout the growing period ranged from -1.58 to 0.99 and 0.03 to 0.19 respectively. The model efficiency was better predicted at 6WAT and 10WAT with the efficiency values of 0.99 and 0.83 respectively. The CRM values indicated that the model has slightly underestimated the observed values. However, a significant difference in RMSE was observed with the increase in deficit irrigation levels in both no-mulched and mulched fields. The maximum and minimum values of RMSE obtained during CC development were 13.88 and 3.34% at 6WATand 10WAT respectively.

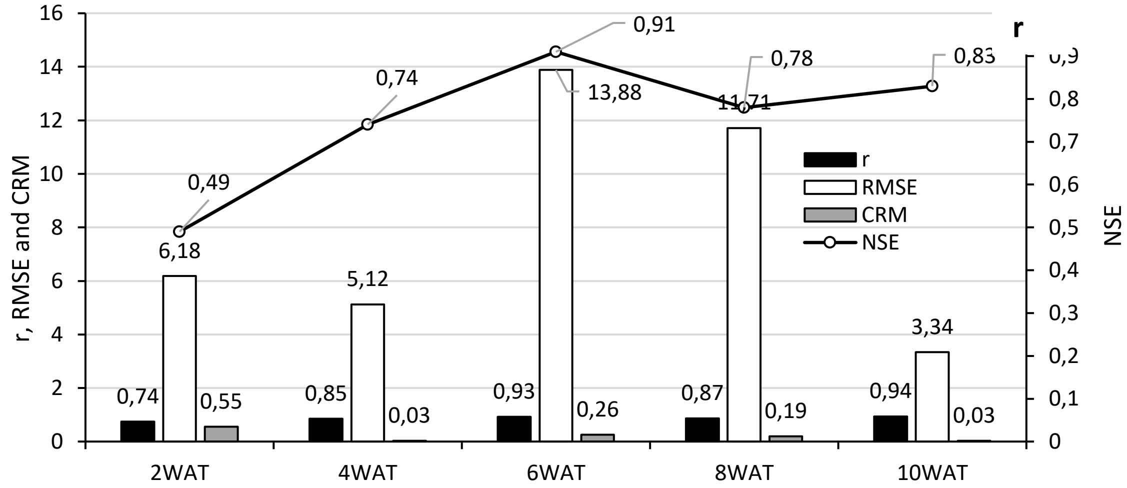

Figure 2. Statistical testing for results simulated and observed values of canopy cover.

Calibration for onion bulb yield and biomass

The comparison between the simulated and observed values of Onion bulb yield and biomass and their percentage deviation are presented in Table 2. The result revealed that irrespective of the level of irrigation and mulch, the observed values for both Onion bulb yield and biomass recorded were underestimated by the Aqua-Crop model except at 100% irrigation with white synthetic mulch with a % deviation of 0.7. The result was in line with a report by Agbemabiese *et al.* (2017) which suggested that crop yields were overestimated at 10% irrigation level and underestimated at deficit levels. The highest model values of 6.09 ton ha^{-1} and 8.24 ton ha^{-1} of bulb yield and biomass respectively were recorded at 100% irrigation under white synthetic mulch. While the corresponding minimum values of 3.77 ton ha^{-1} and 5.94 ton ha^{-1} were obtained at 55% irrigation with wood shave mulch. The % deviation of the model simulated values from the observed values in these fields were ranged between −14.6 to 0.7% for Onion bulb yield and -17.6 to −7.4% for biomass which shows a satisfactory prediction. The deviations recorded in this study were also in line with work by Nazeer and Hussein (2012) who reported that the performance of the model to estimate Onion biomass and bulb yield was satisfactory.

Table 2. Observed and simulated Onion bulb yield and total biomass and their % deviations.

Treatment		Yield (ton ha^{-1})			Biomass (ton ha^{-1})		
Irrigation	**Mulch**	**Observed**	**Simulated**	**% dev.**	**Observed**	**Simulated**	**% dev**
100%	**NM**	5.06	5.02	-0.8%	8.87	7.46	-15.9%
	SM	6.05	6.09	0.7%	10.00	8.24	-17.6%
85%	**WM**	5.52	4.94	-10.5%	9.24	8.24	-10.8%
	RM	5.37	4.81	-10.4%	8.29	7.41	-10.6%
70%	**NM**	4.72	4.13	-12.5%	7.71	6.78	-12.1%
	RM	4.58	4.19	-8.5%	7.18	6.65	-7.4%
55%	**SM**	4.71	4.02	-14.6%	7.84	6.49	-17.2%
	WM	3.77	3.58	-5.0%	6.62	5.94	-10.3%

Table 3 presents the validation results of Aqua-Crop model performance for onion biomass, bulb yield, water productivity and actual crop evapotranspiration under different irrigation levels and mulch materials. From the table, the Aqua-Crop model has perfectly predicted both the bulb yield and biomass at both full and deficit irrigation irrespective of the mulching conditions. This was proved by the correlation coefficient (r) values between simulated and observed Onion bulb yield and biomass of 0.91 and 0.94 respectively. The average value of RMSE obtained was 0.59 ton ha-1 and 0.10 ton ha-1 for bulb yield and biomass respectively. The EF and CRM values for the yield were respectively recorded as 0.35 and 0.04, thus the model has slightly underestimated the observed values. The corresponding values of EF and CRM values of biomass obtained were 0.27 and 0.10 respectively which also indicates a slight underestimation of the observed values. Generally, the RMSE, EF and correclation (r) values obtained indicated that the Aqua-Crop simulation model has satisfactorily simulated Onion yields in the study area. This result contradicts the finding by Hussain (2012) that performance indicators of RMSE and Nash Coefficient of efficiency on simulated onion biomass and yield under deficit irrigation gave overestimated results and declared the model's performance as unsatisfactory.

Table 3. Statistical index validation for simulated and observed values of onion yield and biomass.

Parameters	Corrrelation (r)	RMSE	EF	CRM
Onion Crop Biomass (B)	0.94	0.91	0.27	0.10
Onion Bulb Yield (Y)	0.91	0.59	0.35	0.04

Actual crop evapotranspiration (ETa) and water productivity (ET_{wp})

The differences in the seasonal ETa and ET_{wp} between the simulated and observed values for different irrigation levels and mulch are presented in Table 4. The simulated ETa has generally achieved an acceptable performance under different irrigation levels and mulch conditions. However, the Aqua-Crop model underestimated the observed ETa at 100% irrigation level under white synthetic mulch materials. Aqua-Crop model was able to predict ETa for all the treatments with acceptable % deviations ranging between -7.3 to 23.5%, the highest % deviation was recorded at 55% irrigation under wood mulch and the lowest deviation was observed at experimental plots with white synthetic mulch. However, a larger % deviation was noted under severe water stress treatments. Thus, the performance of the Aqua-Crop model reduces as water-stress increases. For the ET_{wp}, the simulated values underestimated the observed values in almost all the treatments except at 100% irrigation under white synthetic mulch. This could be as a result of a larger % deviation of ETa that was observed at water-stressed plots. This result was in line with the findings by Agbemabiese *et al.* (2017) which states that the Aqua-Crop model underestimated ET_{wp}. The % deviation observed between the observed and simulated ET_{wp} values were fairly estimated for most of the treatments as shown in Table 4. Results indicate that the % deviations in ET_{wp} values are a function of the level of plant water stress. However, both simulated and observed ET_{wp} was seemingly better at irrigation treatments with white synthetic mulch materials, indicating a potential for water saving.

Table 4. Comparison between simulated and observed ETa and ET_{wp} and their % deviation.

Treatment		ET water productivity, ET_{wp} (kg m^{-1})			Actual crop ET,		ETa (mm)
Irrigation	Mulch	Observed	Simulated	% dev	Observed	Simulated	% dev
100%	NM	1.25	1.22	-2.4%	403.80	415.90	0.20
	SM	1.73	2.01	16.2%	348.90	303.20	-4.40
85%	WM	1.56	1.29	-17.3%	354.30	384.20	8.40
	RM	1.48	1.32	-10.8%	362.20	365.30	0.90
70%	NM	1.37	1.05	-23.4%	344.50	394.10	14.40
	RM	1.38	1.12	-18.8%	332.80	374.90	2.70
55%	SM	1.86	1.59	-14.5%	252.60	252.60	0.00
	WM	1.38	1.07	-22.5%	269.70	333.20	23.50

The validation of Aqua-Crop model performance for seasonal ETa and ET_{wp} of onion under different irrigation levels and mulching materials is presented in Table 5. From the table, the model performance of seasonal ETa under different irrigation and mulching were satisfactory with the correlation coefficient value (r) of 0.74. The RMSE value was 33.23, while the EF and CRM values were 0.29 and -0.05 respectively. The negative CRM value is an indication that the simulated values slightly overestimates the observed values at ETa. However, the model performance at seasonal ET_{wp} of Onion was excellent with the correlation coefficient (r) as 0.90. The RMSE value was low 0.32 kg m^{-3}. Similarly, the CRM and EF values recorded were 0.08 and -3.32 respectively, which shows that the model underestimates the observed values. However, the negative EF values indicate that the average observed field values is a better prediction of the model. The result obtained from this research is in line with a report by Atefeh and Ali (2013) which suggested that the amount of water required by crop and water use efficiency simulated by the Aqua-Crop model had well adapted and correlated with field measures.

Table 5. Statistical index validation for simulated and observed values of ETa and ET_{wp}.

Parameters	Corrrelation (r)	RMSE	EF	CRM
Actual Crop ET (ETa)	0.73	33.23	0.29	-0.05
Water Productivity (ET_{wp})	0.90	0.32	-3.32	0.08

CONCLUSION

Aqua-Crop model was calibrated and validated for its ability to predict canopy cover development, biomass, yield, actual ET and ET water productivity of Onion grown under different irrigation levels and mulch conditions in semi-arid Nigeria. The model tends to underestimate canopy cover during early growth stages irrespective of irrigation levels and mulch conditions. However, at the developmental and middle crop growth stage, the model has greatly overestimated the observed values. Nevertheless, the model simulated values were close to the observed field values at the late growing stage. Therefore, treatments with severe water stress have a shorter crop canopy cover than treatments with no stress. The statistical indicators used (RMSE, EF and CRM) indicates that Aqua-Crop was able to simulate canopy cover development with a high degree of accuracy, although the model's performance decreases as deficit irrigation intensifies. Generally, the model underestimated the observed field values for both Onion bulb yield, biomass, ETa and E_{wp} recorded at the deficit irrigation levels, except the observed values of Onion bulb yield recorded at 100% irrigation with white synthetic mulch. The correlation coefficient recorded for both bulb yield, biomass, ETa and E_{wp} was very good with a coefficient of correlation (r) as 0.91, 0.94, 0.73 and 0.90 respectively. Hence, the results of this study suggest that the Aqua-Crop model can be used to predict the Onion growth and yield parameters with a high degree of reliability under different irrigation and mulch management strategies in the semi-arid region, but it is important to note that the prediction accuracy reduces as water-stress conditions increases.

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DECLARATION OF COMPETING INTEREST

The authors declare that there have no conflict of interest.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Nura Jafar Shanono: Investigation, methodology, conceptualization, formal analysis, data curation, writing - original draft, review, and editing, visualization.
Baba Saleh Abba: Investigation, methodology, formal analysis, formal analysis, validation, review, and editing, visualization.
Nuraddeen Mukhtar Nasidi: Investigation, validation, review, and editing, visualization.

ETHICS COMMITTEE DECISION

This article does not require any ethical committee decision.

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