



# **Modeling Tomato Water Productivity Using Aquacrop Model in Njoro Sub County, Nakuru, Kenya**

**Hellen J. Sang<sup>1\*</sup>, Raphael M. Wambua<sup>1</sup> and James M. Raude<sup>2</sup>**

<sup>1</sup>Department of Agricultural Engineering, Egerton University, P.O.Box 536 – 20115, Egerton, Kenya.

<sup>2</sup>Department of Soil, Water and Environmental Engineering, Jomo Kenyatta University of Agriculture and Technology (JKUAT), P.O.Box 62000 – 00200 Nairobi, Kenya.

## **Authors' contributions**

*This work was carried out in collaboration among all authors. Author HJS designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors RMW and JMR managed the analyses of the study and the literature searches. All authors read and approved the final manuscript.*

## **Article Information**

DOI: 10.9734/JERR/2020/v10i317038

### Editor(s):

(1) Dr. Harekrushna Sutar, Assistant Professor, Department of Chemical Engineering, Indira Gandhi Institute of Technology, Sarang, India.

### Reviewers:

(1) Clement Kiptotich Kiptum, University of Eldoret, Kenya.

(2) Safaa Fakhir Yasir Al-Ghnamawi, Universiti Teknologi Mara, Malaysia.

Complete Peer review History: <http://www.sdiarticle4.com/review-history/54461>

**Original Research Article**

**Received 01 December 2019**

**Accepted 06 February 2020**

**Published 13 February 2020**

## **ABSTRACT**

**Aims:** To model tomato water productivity under deficit sub – surface drip irrigation and grass mulch densities using Aquacrop model.

**Study Design:** The study was factorial experimental with twelve treatments.

**Place and Duration of Study:** Tatton Agriculture Park, Egerton University, Nakuru, Kenya between January to May 2019.

**Methodology:** Tomato (*Lycopersicon esculentum* mill) crop (Tylka F1) was used to determine the effect of deficit irrigation and mulching on its productivity. Aquacrop model was calibrated to simulate the tomato yield, biomass and water productivity. Aquacrop model was used to estimate the tomato water requirements, water productivity, yield and biomass under deficit irrigation and mulching. The study was carried out on 36 experimental plots measuring 2 by 2 m with the total area under study being 144 m<sup>2</sup>.

\*Corresponding author: Email: [hellensang19@gmail.com](mailto:hellensang19@gmail.com);

**Results:** The results showed a good correlation between the actual and simulated water productivity as determined by the Nash and Sutcliffe efficiency (NSE) of 0.00, Root Mean Square Error (RMSE) (%) of 0.04 and Coefficient of determination ( $R^2$ ) of 0.72.

**Conclusion:** The study calibrated Aquacrop model for simulating tomato crop water productivity in Njoro Sub County and showed that the model is a good estimator of tomato water productivity.

*Keywords: Water productivity; deficit irrigation; calibrated.*

## 1. INTRODUCTION

### 1.1 Modeling

Sentence deleted. It is a method of simulating real life situations with mathematical equations to predict their future character [1]. Simulation is the process of imitating the character of a situation or a process by means of similar things. Simulation is the application of a model with the objective to derive strategies that help solve a problem or answer a question pertaining to a system [2]. Model validation is defined as the process of determining the degree to which a model is an accurate representation of the real world from the perspective of the intended use of the model [3]. Some of the common models include; CROPWAT and Aquacrop. In this study Aquacrop model was used because of its ability to simulate yields in response to water (water productivity), simplicity and the small number of parameter requirements.

### 1.2 Aquacrop Model

The FAO Aquacrop model estimates crop productivity, water requirement, and water use efficiency (WUE) under water-limiting conditions. The ease of use of the Aquacrop model, low input parameter requirement and its sufficient degree of simulation accuracy makes it a valuable tool for estimating crop productivity. It has been used under rainfed conditions, supplementary, deficit irrigation, and on-farm water management strategies for improving the water use efficiency in agriculture [4].

There are several equations governing the Aquacrop model which are, Equations 1, 2, 3, 4, 5, 6, 7, 8, 9 and 10.

Aquacrop model uses the FAO Penman Monteith method to estimate the reference evapotranspiration and is given by Equation 1.

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma(900/T + 273)U_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \quad (1)$$

where:

$ET_0$  = Grass reference evapotranspiration (mm day<sup>-1</sup>),

$\Delta$  = The slope of the saturated vapor pressure curve (kPa °C<sup>-1</sup>),

$$\Delta = \frac{4098 \left[ 0.6108 \exp\left(\frac{17.27T}{T + 237.3}\right) \right]}{(T + 237.3)^2} \quad (2)$$

$R_n$  = the net radiation (MJ m<sup>-2</sup> day<sup>-1</sup>),

$G$  = the soil heat flux density (MJ m<sup>-2</sup>). It is null for daily estimates,

$T$  = daily mean air temperature (°C) at 2 m based on the average of maximum and minimum temperature

$$T = \frac{T_{\max} + T_{\min}}{2} \quad (3)$$

$U_2$  = average wind speed at 2 m height (ms<sup>-1</sup>)

$$U_2 = U_z \frac{4.87}{\ln(67.8z - 5.42)} \quad (4)$$

where:

$U_2$  = wind speed at 2 m above ground surface (m/s)

$U_z$  = measured wind speed at z m above ground surface (m/s)

$z$  = height of measurement above ground surface (m)

$e_s$  = the saturation vapour pressure (kPa),

$$e_s = \frac{e^{\circ}(T_{\max}) + e^{\circ}(T_{\min})}{2} \quad (5)$$

$$e^{\circ}T_{\max} = 0.6108 \exp\left[\frac{17.27T_{\max}}{T_{\max} + 237.3}\right] \quad (6)$$

$$e^{\circ}T_{\min} = 0.6108 \exp\left[\frac{17.27T_{\min}}{T_{\min} + 237.3}\right] \quad (7)$$

$e_a$  = the actual vapour pressure (kPa)

The actual vapour pressure was determined using the actual vapour pressure calculator from the relative humidity and the saturated vapour pressure.

$(e_s - e_a)$  = the saturation vapour pressure deficit ( $\Delta e$ , kPa) and  
 $\gamma$  = the psychrometric constant ( $0.0677 \text{ kPa } ^\circ\text{C}^{-1}$ )

$$\gamma = \frac{C_p P}{\epsilon \lambda} = 0.665 \times 10^{-3} P \quad (8)$$

$\gamma$  = Psychrometric constant (kPa/ $^\circ\text{C}$ )  
 $P$  = Atmospheric pressure (kPa)  
 $\lambda$  = Latent heat of vaporization 2.45 (MJ/kg)  
 $C_p$  = Specific heat at constant pressure  $1.013 \times 10^{-3}$  (MJ/kg/ $^\circ\text{C}$ )  
 $\epsilon$  = Ratio molecular weight of water vapour/dry air = 0.622

$$P = 101.3 \left[ \frac{293 - 0.0065z}{293} \right]^{5.26} \quad (9)$$

$P$  = Atmospheric pressure (kPa)  
 $z$  = elevation above sea level (m)

Yield response to water is expressed by Equation 10.

$$1 - \frac{Y}{Y_x} = K_y \left[ 1 - \frac{ET}{ET_x} \right] \quad (10)$$

where:

$Y_x$  = Maximum yield (kg)  
 $Y$  = Actual yield (kg)

$$1 - \frac{Y}{Y_x} = \text{The relative yield decline (Ratio)}$$

$ET_x$  = Maximum evapotranspiration (mm/day)

$ET$  = Actual evapotranspiration (mm/day)

$\left[ 1 - \frac{ET}{ET_x} \right]$  = Relative water stress (Ratio)

$K_y$  = Proportionality factor between relative yield decline and relative reduction in evapotranspiration (Ratio)

The objective of the study was to model tomato water productivity under the interactive effect of deficit drip irrigation and mulching systems.

### 1.3 Water Extraction Pattern

Plants normally have a higher concentration of roots in the upper part of the root zone and near

to their base. The extraction pattern is shown in Fig. 1 [5].

The total root volume determines the total amount of water that can be extracted out of the root zone. In the upper quarter of the maximum rooting depth 40% of the water extraction occurs, the second quarter 30%, the third quarter 20% and the bottom quarter 10%.

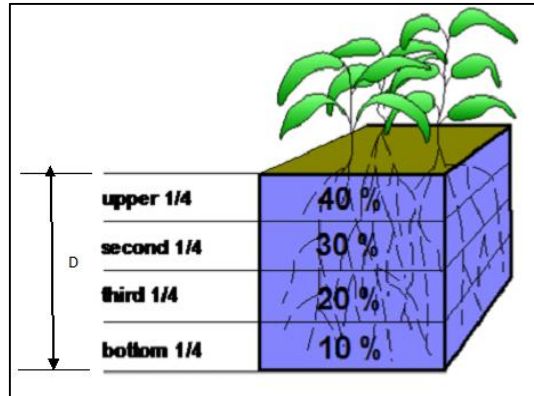


Fig. 1. The water extraction pattern

## 2. MATERIALS AND METHODS

### 2.1 The Study Area

The study was carried out in Njoro Sub - county, Nakuru County, Kenya. Njoro Sub - county covers an area of about 780 km<sup>2</sup>. Njoro Town is the headquarters of Njoro Sub - county and is located about 200 km North West of City of Nairobi and 18 km south west of Nakuru Town. With an average altitude of 2400 meters above sea level, Njoro lies between Latitude 0° 15'0 and 0° 42' 30 South and Longitude 35° 45'0 and 36° 10' 0 East.

The climate in Njoro Sub - county is classified as warm and temperate. Mean annual rainfall measured at Egerton University from 1987-2016 is 1073 mm. The least amount of rainfall occurs in January with the average being 20 mm. Most of the rain falls in April, averaging 140 mm. Njoro area has a trimodal rainfall pattern with the peaks in April, August and November as shown in Fig. 3 for average rainfall from 1987 to 2016.

The average maximum annual temperature for the area is 26.4 $^\circ\text{C}$  while the average minimum temperature is 7.8 $^\circ\text{C}$  [6]. The drainage classes of the soil in Njoro sub county range from poorly drained, moderately well drained, well drained to excessively drained, with textures ranging from

loam, clay to clay loam and structures in the range of moderately strong to strong [7].

A total area of 220 m<sup>2</sup> was used for the drip irrigation system study. Experimental plots

measuring 2.0 m by 2.0 m were used. Twelve treatments were administered in the plots using factorial experimental design with three replications, giving the total number of plots as thirty six.

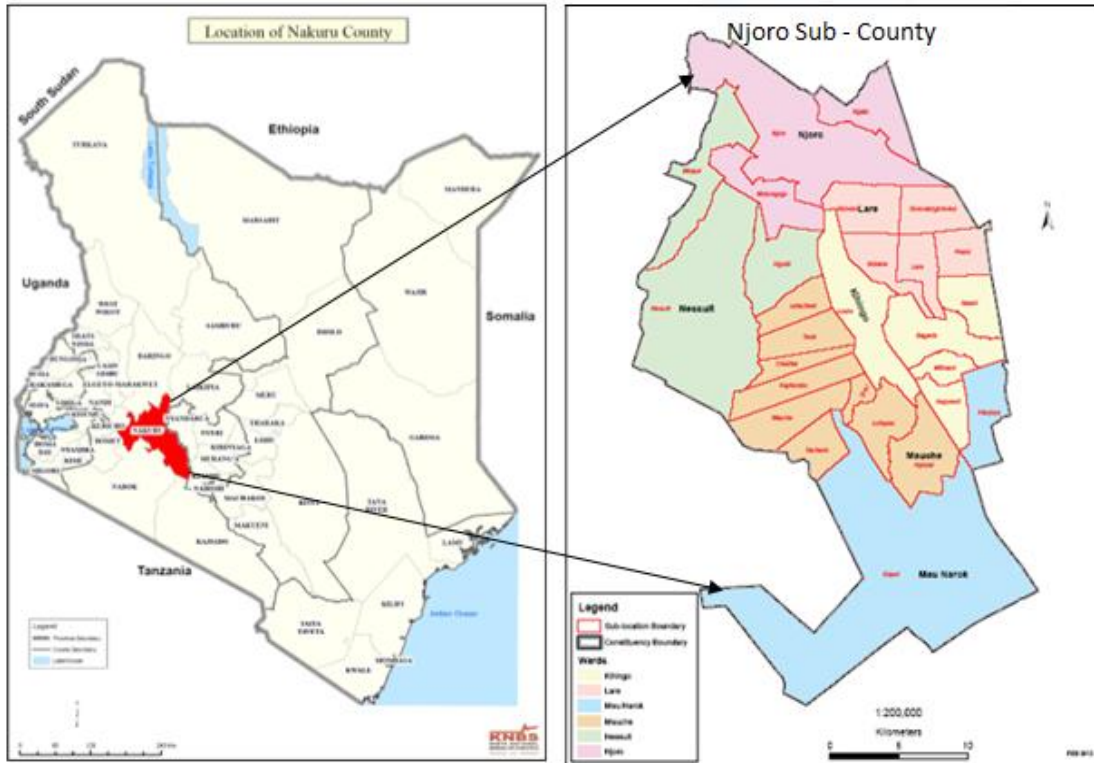


Fig. 2. Location of Njoro Sub County in Kenya

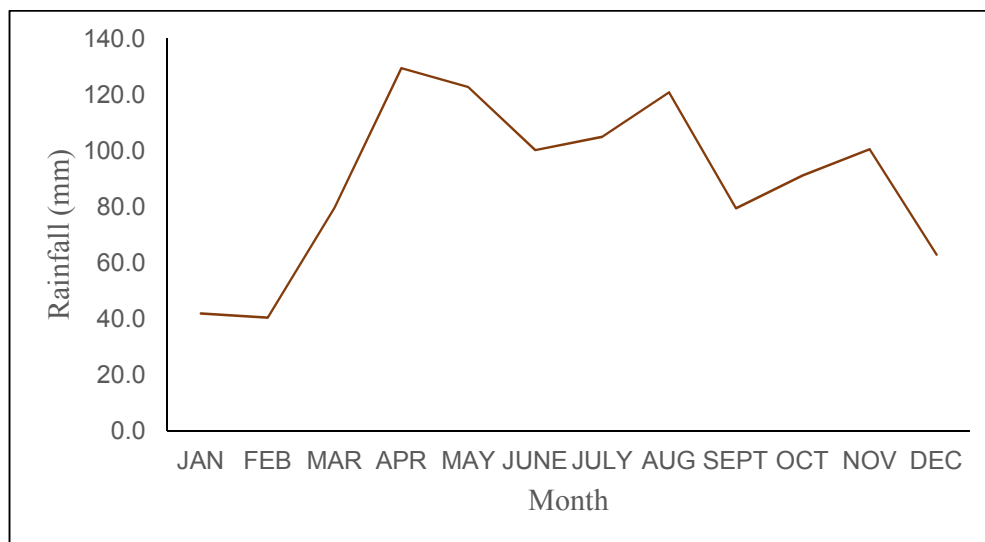


Fig. 3. Average Rainfall pattern for Njoro Sub-county (1987-2016)

**Table 1. Treatments and water levels**

Treatment number	Irrigation level (%ET <sub>c</sub> )	Mulching system
T <sub>1</sub>	100	Control (No mulch)
T <sub>2</sub>	80	No mulch
T <sub>3</sub>	60	No mulch
T <sub>4</sub>	100	Mulch (0.5 kg/m <sup>2</sup> )
T <sub>5</sub>	80	Mulch (0.5 kg/m <sup>2</sup> )
T <sub>6</sub>	60	Mulch (0.5 kg/m <sup>2</sup> )
T <sub>7</sub>	100	Mulch (1.0 kg/m <sup>2</sup> )
T <sub>8</sub>	80	Mulch (1.0 kg/m <sup>2</sup> )
T <sub>9</sub>	60	Mulch (1.0 kg/m <sup>2</sup> )
T <sub>10</sub>	100	Mulch (1.5 kg/m <sup>2</sup> )
T <sub>11</sub>	80	Mulch (1.5 kg/m <sup>2</sup> )
T <sub>12</sub>	60	Mulch (1.5 kg/m <sup>2</sup> )

## 2.2 Modeling Tomato Water Productivity under Deficit Sub – Surface Drip Irrigation and Mulching Using Aquacrop Model

The reference evapotranspiration and crop water requirement was estimated by the Aquacrop model with the input to the model being climatic, soil and crop parameters. The climatic parameters were obtained from Egerton weather station (Number: 9035092) during the period of the data collection. The soil parameters were determined during the study in the field and in the laboratory using different methods. Crop parameters were also determined in the field during the study. These climatic, soil and crop parameters were used as input to Aquacrop model to simulate the reference evapotranspiration, crop water requirement and the water productivity of tomato. The Aquacrop input and output parameters are summarized in Table 2.

## 2.3 Soil Data

Double ring infiltrometer method was used to determine the soil hydraulic conductivity for the field experimental site [8]. Volumetric water content at saturation of a soil sample is equal to the porosity of the soil. Porosity was estimated from Equation 11.

$$n = 1 - \frac{\rho_b}{\rho_p} \quad (11)$$

where:

n = Porosity (Ratio)  
 $\rho_b$  = Bulk density (g/cm<sup>3</sup>)  
 $\rho_p$  = Particle density (g/cm<sup>3</sup>)

The bulk density of the soil in the study area was determined using the core method. A soil sample was oven dried at 105°C after determining its volume [9]. The bulk density was then calculated using Equation 12.

$$\rho_b = \frac{m_s}{v_s} \quad (12)$$

where:

$\rho_b$  = Bulk density (g/cm<sup>3</sup>)  
 $m_s$  = Mass of dry soil (g)  
 $v_s$  = Volume of soil (cm<sup>3</sup>)

The average particle density of soil was estimated to be 2.66 g/cm<sup>3</sup>

Field capacity was determined in the laboratory using constant head permeameter method for soil samples obtained from different plots [10]. The permanent wilting point of the soil samples was determined in the laboratory by the pressure plate equipment [11]. The soil texture analysis was done using Hydrometer method and soil samples from different plots were analyzed [12].

## 2.4 Climatic and Crop Parameters

The climatic parameters in Table 2 were obtained from the Egerton University weather station (9035092) for the growing period of the tomato. The plant density of a certain bed of plants was described by the number of plants within a given unit of area. This was carried out by counting the number of plants per plot and dividing by the area of the plot. The fruit yield per hectare was determined by taking the mass of the fruits harvested weekly from the field using a digital electronic balance and adding to obtain the total yield. Biomass is the total quantity or mass of organisms in a given area or volume. This was done by measuring the mass of the tomato crop per plot and dividing by the area of the plot. Harvest index is the mass of the harvested product as a percentage of the total mass of the plant of the tomato. This was done by weighing the fruits harvested in the field and dividing by the total weight of the crop in the field. Effective rooting depth is the depth of soil used by the main body of the plant roots to obtain most of the stored moisture and plant food under proper irrigation. This was done by uprooting and measuring the rooting depth of the crop. Flowering and maturity time was estimated in terms of days from planting date to flowering and

maturity dates respectively. Green canopy cover is the aboveground portion of a plant community or crop, formed by the collection of individual plant crowns. Crop germination is the period of the tomato germination in days and was determined from the sowing time to germination time.

### 2.5 Irrigation Files

The irrigation file calibrated composed of the irrigation method which was drip, the percentage of the soil surface wetted which was 30% and the irrigation events which included the irrigation dates and the amount of irrigation water. The calibrated irrigation file was used as input to run the Aquacrop model.

### 2.6 Field Management Files

The field management practices calibrated include the soil fertility which is non limiting, mulches which varied in the different treatments as 0, 1.0 and 1.5 kg/m<sup>2</sup>. The relative cover of the weeds was maintained at 0%. The calibrated field management file was then used as input to run the Aquacrop model.

### 2.7 Data Analysis

The tomato yields, biomass and the water productivity were subjected to performance evaluation to determine their goodness of fit to the observed values. The data obtained from the study after analysis was subjected to several components since it is recommended that a good model efficiency evaluation should have at least three important components. The components should include: one dimensional statistic, one absolute error index statistic and one graphical technique whereby when applied all together

they form a set of model performance evaluation criteria which offsets the limitation of each other [13]. In this study the Analysis of Variance (ANOVA), Nash and Sutcliffe efficiency, Root Mean Square Error, Coefficient of Determination and graphical techniques were used to establish significant differences between the treatments. The components are described in the subsequent sub sections.

### 2.8 Nash and Sutcliffe Efficiency

The performance of the Aquacrop model was evaluated using the Nash and Sutcliffe Efficiency statistical parameter [4].

Nash and Sutcliffe Efficiency is a normalized statistic that determines the relative magnitude of the residual compared to the measured data variance. NSE ranges between  $-\infty$  and 1.0 (1 inclusive), with NSE of 1.0 being the optimal value. Values between 0.0 and 1.0 are generally viewed as acceptable levels of performance, whereas values less than zero indicates that the mean observed value was a better predictor than the simulated value, which indicates unacceptable performance [14]. The Nash and Sutcliffe efficiency is expressed by Equation 13.

$$NSE = 1 - \frac{\sum_{i=1}^n (O_i - S_i)^2}{\sum_{i=1}^n (O_i - \bar{O})^2} \tag{13}$$

where:

- S<sub>i</sub> = simulated values
- O<sub>i</sub> = observed (measured) values
- $\bar{O}$  = mean value of O<sub>i</sub>
- N = number of observations

**Table 2. The Aquacrop model input data and model output**

Soil data	Climatic data	Crop data	Management practices	Model output
Ksat	Daily rainfall	Plant density	Mulching	Crop productivity
FC	Max and min air temp.	Yield	Irrigation/rainfed	Crop water requirements
PWP	ET <sub>0</sub>	Biomass	Application method (drip)	
Soil texture	Mean annual CO <sub>2</sub> concentration	Harvest index	DI strategies	
Θ <sub>s</sub>		Effective rooting depth		
		Flowering and maturity time		

*The input parameters to the model were determined in the field using different methods as discussed as follows*

## 2.9 Root Mean Square Error

The root mean square error (RMSE) is a statistical indicator that measures the differences in average magnitude between simulations and observations. Good model performance is indicated by values that tend to zero while poor model performance by values that tend to positive infinity [15].

The root mean square error (RMSE) is expressed by Equation 14

$$RMSE = \sqrt{\frac{\sum_{i=1}^n (P_i - O_i)^2}{n}} \quad (14)$$

where:

RMSE = Root mean square error  
 $P_i$  = Predicted values  
 $O_i$  = Observed values  
 $n$  = Number of observations

## 2.10 Coefficient of Determination

The coefficient of determination ( $R^2$ ) is the proportion of the variance in observed data obtained by the model. It ranges from 0 to 1, with values closer to 1 indicating a good model performance with values greater than 0.5 considered acceptable in predictions [16]. It is expressed by Equation 15.

$$R^2 = \left[ \frac{\sum_{i=1}^n (O_i - \bar{O})(P_i - \bar{P})}{\sqrt{\sum_{i=1}^n (O_i - \bar{O})^2 \sum_{i=1}^n (P_i - \bar{P})^2}} \right]^2 \quad (15)$$

where:

$O_i$  = Observed values  
 $\bar{O}$  = Mean value of  $O_i$   
 $P_i$  = Predicted values  
 $\bar{P}$  = Mean value of  $P_i$

## 2.11 Aquacrop Model Sensitivity Analysis

Sensitivity analysis is a measure used to quantify the effect of parameter uncertainty on general simulation [17]. One at a time sensitivity measure was applied in this study where the parameters were varied then the impact on the model output

determined [18]. The parameters tested were harvest index, rooting depth and maximum canopy cover to determine their impact on yield output.

## 3. RESULTS AND DISCUSSION

The input files to the Aquacrop model were soil, crop, climate, irrigation and field management as mentioned in Table 2. The calibrated files were used as input to the Aquacrop model.

### 3.1 Soil Files

The soil data created for the soil files were collected from the experimental site and the results are presented in Table 3. The soil analysis was carried out at the Department of Agricultural Engineering, Soil Laboratory and the Department of Crops, Horticulture and Soil laboratory.

From Table 3 the textural class of the soil in the study area was classified as clay loam and salinity of 1.25 dS/m. The other soil hydraulic parameters are presented in Table 3. The calibrated soil files were used as input to run the model.

### 3.2 Crop Files

The tomato crop data were collected during the growing period from the experimental site at Tatton Agriculture Park, Egerton University and the results are shown in Table 4.

The tomato crop was transplanted on 12<sup>th</sup> January 2019 with the maturity period being 75 days and the entire growing period being 135 days. The plant density of the tomato crop was 2.25 plants/m<sup>2</sup> and the canopy size of the transplanted seedling was 5 cm<sup>2</sup>/plant. The initial canopy cover was 0.34% while the maximum canopy cover for the different treatments was as presented in Table 4. The averages of the other crop data obtained during the tomato growing period after transplanting to the experimental site for the calibration of the crop file are as shown in Table 4. The calibrated crop files created were used as input to run the Aquacrop model.

### 3.3 Climate Files

The climate files of the experimental site for the growing period of the tomatoes are presented in Table 5 and included rainfall, maximum temperature, minimum temperature and reference evapotranspiration.

Table 3. Hydraulic properties

Bulk density (g/cm <sup>3</sup> )	Volumetric water content (%)	Texture analysis				Hydraulic conductivity (cm/day)	Field capacity (%)	Permanent wilting point (%)	Soil salinity (dS/m)
		% sand	% clay	% silt	Textural class				
1.34	61.00	29.80	28.20	42.0	Sandy clay loam	11.17	30.7	15.9	1.25

Table 4. Crop data of tomato during the growing period

Treatment / crop data	Dry Yield (ton/ha)	Biomass (ton/ha)	Green canopy cover (%)	Harvest index	Effective rooting depth (m)	Flowering time (days)	Maturity time (days)
100% No mulch	2.463	3.18	0.9	0.57	40	30	75
80% No mulch	2.066	2.97	0.83	0.60	45	30	75
60% No mulch	2.024	3.05	0.80	0.74	35	30	75
100% 0.5kg	2.191	3.30	0.77	0.58	35	30	75
80% 0.5kg	2.188	3.72	0.85	0.79	40	30	75
60% 0.5kg	2.068	3.46	0.85	0.66	30	30	75
100% 1kg	2.670	3.23	0.82	0.58	37	30	75
80% 1kg	2.398	3.61	0.88	0.65	73	30	75
60% 1kg	2.736	3.85	0.77	0.74	65	30	75
100% 1.5kg	2.043	4.53	0.93	0.66	45	30	75
80% 1.5kg	2.257	3.45	0.92	0.63	35	30	75
60% 1.5kg	2.082	2.90	0.92	0.63	45	30	75



The climatic parameters in Table 5 were collected from the Department of Agricultural Engineering, Egerton University weather station for the tomato growing period that was January to May 2019. The climatic parameters formed the calibrated climate files and were used as input to run the Aquacrop model.

### 3.4 Simulation of Tomato Water Productivity Using Aquacrop Model

The crop data, climatic parameters, soil data and the management practices were input to the Aquacrop model to simulate the tomato water productivity during the growing period. The actual versus simulated yield are as shown in the Fig. 4.

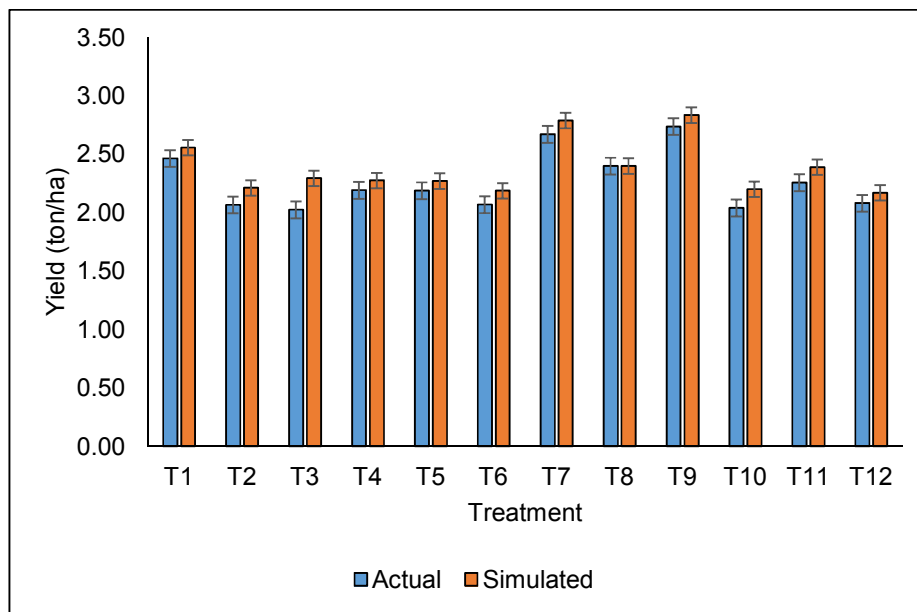
It can be seen that Aquacrop model was able to very well simulate yield response to water as indicated by the graph presented in Fig. 4. The performance of the model was found to be good as described by the Nash and Sutcliffe efficiency (NSE) of 0.636, Root mean square error (RMSE) of 0.130 and Coefficient of correlation ( $R^2$ ) of 0.937. The results concur with

those of Algharibi, Schmitz [19] who conducted a research in Muscat, Oman where the performance of the Aquacrop model to simulate yield response to water was found to be good as determined by the NSE of 0.77, RMSE of 2.6 and  $R^2$  of 0.83. The results also concurs with those of Paredes, Wei [20] who conducted a research on soybean in North China Plain and revealed a better Aquacrop model performance with an  $R^2$  value of 0.83. Jin, Feng [21] Conducted a study in North China Plain and revealed a consistency in the measured yield to the Aquacrop model simulated yield with an  $R^2$  value of 0.93.

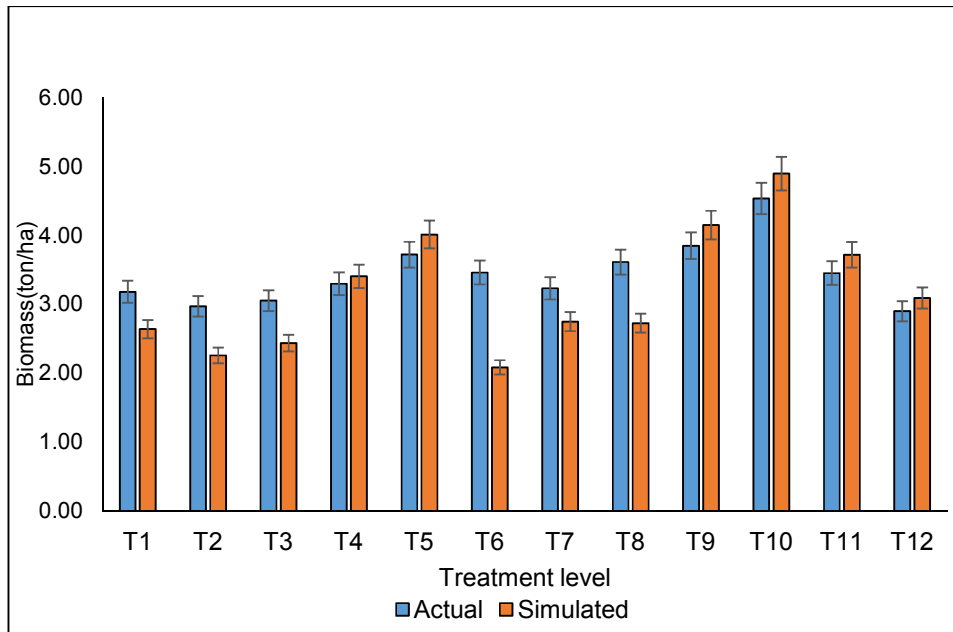
From Fig. 5 it can be seen that there was no significant difference between the actual and the simulate biomass as indicated by the error bars. The performance of the model was found to be good as described by the Nash and Sutcliffe efficiency (NSE) of 0.16, Root mean square error (RMSE) of 0.60 and Coefficient of correlation ( $R^2$ ) of 0.51. This goes in hand with the results of Abedinpour, Sarangi [22] who conducted a study in New Delhi where they found good Aquacrop model performance in simulating biomass of

**Table 5. The climatic parameters for the 2019 growing season**

Month/Climatic parameter	January	February	March	April	May
Rainfall (mm)	9.0	9.0	31.3	53.9	60.1
Maximum Temperature ( $^{\circ}$ C)	24.8	26.8	27.2	27.1	24.9
Minimum Temperature ( $^{\circ}$ C)	9.8	10.0	11.0	12.0	11.5
ET <sub>0</sub> (mm)	4.5	5.0	5.3	5.0	4.4



**Fig. 4. Graph of actual versus simulated dry yield**



**Fig. 5. Actual versus simulated biomass**

tomato crop with a RMSE of 0.42  $R^2$  of 0.91. The results also concur with those of Pawar, Kale [23] who carried out a research in India where the model was able to simulate biomass with a NSE of 0.96. A study by Lievens [24] carried out in North Eastern Thailand revealed that Aquacrop model was able to relate well the simulated to the actual biomass of sweet corn with a root mean square error (RMSE) of 0.56. In T2 and T6 there is greater difference between the observed and the simulated biomass which is associated to Aquacrop model underestimating the simulated biomass.

The actual and the simulated tomato water productivity using the Aquacrop model were as shown in Fig. 6.

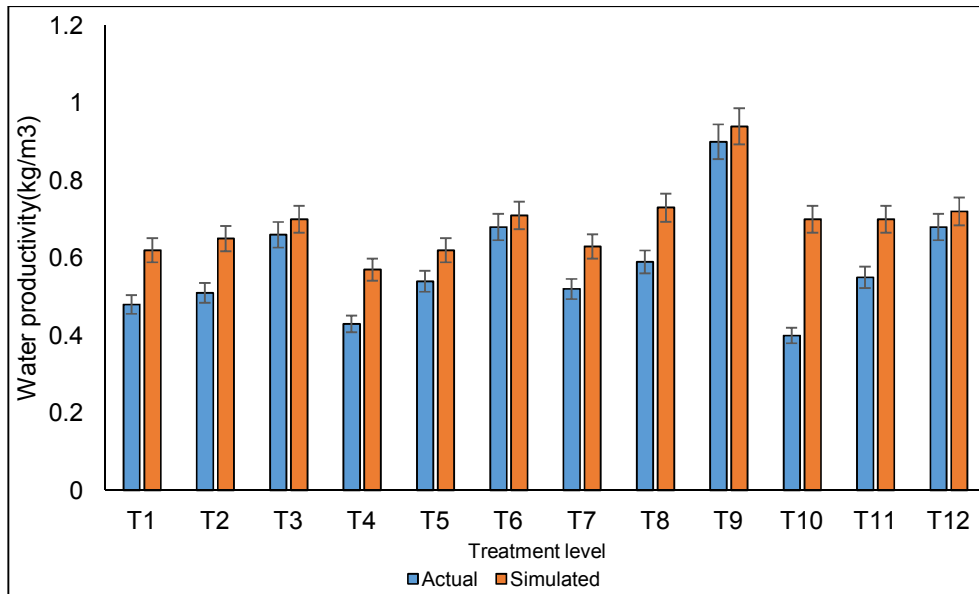
From Fig. 6 it can be seen that Aquacrop model was able to simulate tomato water productivity very well. It can be seen that there was no difference between the actual and the simulate water productivity as indicated by the error bars. The performance of the model was found to be good as described by the Nash and Sutcliffe efficiency (NSE) of 0.00, Root mean square error (RMSE) of 0.04 and Coefficient of correlation ( $R^2$ ) of 0.72. This goes in hand with the results of [25] who conducted a study in Northern Serbia where they found good Aquacrop model performance in simulating water productivity with a root mean square error of 0.88. The results also concur with those of Geerts, Raes [26] who

carried out a study in Central Bolivian Altiplano on Quinoa crop where the simulated water productivity related well to the field measurements with a Nash and Sutcliffe efficiency of 0.82.

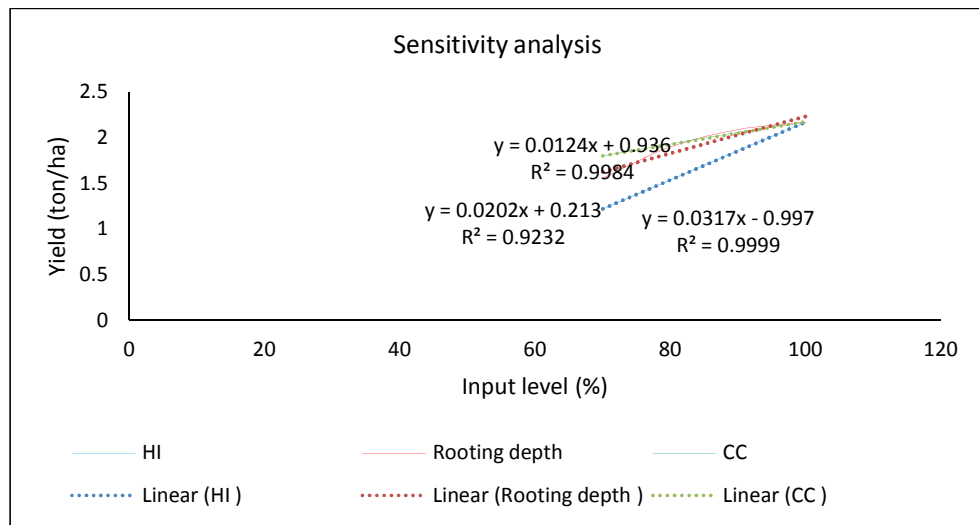
### 3.5 Aquacrop Model Sensitivity Analysis

The yield sensitivity to Aquacrop model input parameters was determined and is described by Fig. 7.

According to Fig. 7, the most sensitive variable to the yield output was the harvest index, followed by the rooting depth and finally the maximum canopy cover as described by the slope values in the graph. The value of the slope of the harvest index equation is greater than that of the rooting depth and maximum canopy cover equation. The results concur with those of Lievens [24] who conducted a study in North-eastern Thailand and found that the simulated yield is sensitive to both the harvest index and the rooting depth. The results also go in hand with those of [27] who carried out a study in Isfahan province, Iran that the yield output is sensitive to the rooting depth followed by the canopy cover. Similarly the results of [26] who carried out a research in Bolivian Altiplano revealed that the yield output was most sensitive to the harvest index and the rooting depth and moderately sensitive to the canopy cover.



**Fig. 6. Graph showing actual versus simulated tomato water productivity**



**Fig. 7. Sensitivity of the yield to the Aquacrop model input parameters**

#### 4. CONCLUSION

Aquacrop model was able to simulate yield and biomass of tomato crop relating well to the field measurements as described by the Nash and Sutcliffe Efficiency, Root Mean Square Error and the Coefficient of Correlation.

#### 5. RECOMMENDATIONS

Further studies to be carried out on other crops at Njoro Sub County to determine the interactive

effect of deficit irrigation and mulching systems on their water productivity using Aquacrop model.

#### ACKNOWLEDGEMENT

The authors of people acknowledge the scholars whose articles are cited and referenced and also the Staff of Egerton University, Department of Agricultural Engineering. They also acknowledge AFDB – Mohest for funding the research work.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

## REFERENCES

1. Moore TJ, et al. Modeling in engineering: The role of representational fluency in students' conceptual understanding. *Journal of Engineering Education*. 2013;102(1):141-178.
2. Velten K. *Mathematical modeling and simulation: Introduction for scientists and engineers*. John Wiley & Sons; 2009.
3. Ling Y, Mahadevan S. Quantitative model validation techniques: New insights. *Reliability Engineering & System Safety*. 2013;111:217-231.
4. Heng LK, et al. Validating the FAO Aquacrop model for irrigated and water deficient field maize. *Agronomy Journal*. 2009;101(3):488-498.
5. Raes D, et al. FAO crop water productivity model to simulate yield response to water. *Aquacrop Version*. 2011;3:1-1.
6. Sibomana I, Aguyoh J, Opiyo A. Water stress affects growth and yield of container grown tomato (*Lycopersicon esculentum* Mill) plants. *Gjbb*. 2013;2(4):461-466.
7. Mainuri ZG, Owino JO. Effects of land use and management on aggregate stability and hydraulic conductivity of soils within River Njoro Watershed in Kenya. *International Soil and Water Conservation Research*. 2013;1(2):80-87.
8. Pettyjohn WR. Infiltration rate and hydraulic conductivity of sand-silt soils in the Piedmont physiographic region. *Georgia Institute of Technology*; 2014.
9. Grossman R, Reinsch T. 2.1 Bulk density and linear extensibility. *Methods of soil analysis: Part 4 physical methods*. 2002;methodsofsoilan 4:201-228.
10. Cresswell H, Green T, McKenzie N. The adequacy of pressure plate apparatus for determining soil water retention. *Soil Science Society of America Journal*. 2008;72(1):41-49.
11. Romano N, Santini A. 3.3.3 Field. *Methods of Soil Analysis: Part 4 Physical Methods*. 2002; methodsofsoilan 4:721-738.
12. Gee GW, Or D. 2.4 Particle-size analysis. *Methods of soil analysis. Part*. 2002;4(598):255-293.
13. Ouédraogo WAA, Gathenya JM, Raude JM. Projecting wet season rainfall extremes using regional climate models ensemble and the advanced delta change model: Impact on the streamflow peaks in Mkurumudzi catchment, Kenya. *Hydrology*. 2019;6(3):76.
14. Moriasi DN, et al. Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. *Transactions of the ASABE*. 2007;50(3): 885-900.
15. Saad AM, Mohamed MG, El-Sanat GA. Evaluating Aquacrop model to improve crop water productivity at North Delta soils, Egypt. *Advances in Applied Sciences Research*. 2014;5(5):293-304.
16. Tran TN. *Modelling yield response to deficit irrigation by Aquacrop in the mekong Delta, Vietnam*. Ghent University; 2018.
17. Crosetto M, Tarantola S, Saltelli A. Sensitivity and uncertainty analysis in spatial modelling based on GIS. *Agriculture, Ecosystems & Environment*. 2000;81(1):71-79.
18. Hamby D. A review of techniques for parameter sensitivity analysis of environmental models. *Environmental Monitoring and Assessment*. 1994;32(2): 135-154.
19. Algharibi E, et al. Evaluation of field and greenhouse experiments with tomatoes using the Aquacrop model as a basis for improving water productivity. In *International Conference on Water Resources and Environment Research*; 2013.
20. Paredes P, et al. Performance assessment of the FAO Aquacrop model for soil water, soil evaporation, biomass and yield of soybeans in North China Plain. *Agricultural Water Management*. 2015;152:57-71.
21. Jin XI, et al. Assessment of the Aquacrop model for use in simulation of irrigated winter wheat canopy cover, biomass and grain yield in the North China Plain. *PLoS One*. 2014;9(1):e86938.
22. Abedinpour M, et al. Performance evaluation of Aquacrop model for maize crop in a semi-arid environment. *Agricultural Water Management*. 2012;110: 55-66.
23. Pawar G, Kale M, Lokhande J. Response of Aquacrop model to different irrigation schedules for irrigated cabbage. *Agricultural Research*. 2017;6(1):73-81.
24. Lievens E. Parameterization and testing of the FAO Aquacrop model to simulate yield response to water in North-eastern

- Thailand. Dissertação (Mestrado em Engenharia de Biociências): Ciência Agrícola; 2014.
25. Stricevic R, et al. Assessment of the FAO Aquacrop model in the simulation of rainfed and supplementally irrigated maize, sugar beet and sunflower. *Agricultural Water Management*. 2011;98(10):1615-1621.
26. Geerts S, et al. Simulating yield response of quinoa to water availability with Aquacrop. *Agronomy Journal*. 2009; 101(3):499-508.
27. Salemi H, et al. Application of Aquacrop model in deficit irrigation management of winter wheat in arid region. *African Journal of Agricultural Research*. 2011;610:2204-2215.

---

© 2020 Sang et al.; This is an Open Access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

*Peer-review history:*  
*The peer review history for this paper can be accessed here:*  
<http://www.sdiarticle4.com/review-history/54461>