VALIDATION OF AQUACROP MODEL FOR SIMULATION OF RAINFED BULB ONION (*ALLIUM CEPA* L.) YIELDS IN WEST UGENYA SUB-COUNTY, KENYA †

[VALIDACIÓN DEL MODELO AQUACROP PARA LA SIMULACIÓN DE RENDIMIENTOS DE CEBOLLA DE TEMPORAL (*ALLIUM CEPA* L.) EN EL SUB-CONDADO DEL WEST UGENYA, KENYA]

George N. Karuku and **Benedict A. Mbindah***

Department of Land Resources Management and Agricultural Technology (LARMAT), Faculty of Agriculture, University of Nairobi, Kenya,P.O. Box 29053-00625, Nairobi, Kenya. Email: benedictmbi@yahoo.com
**Corresponding Author*

SUMMARY

Background. The precision of crop growth simulation models is a paramount facet in their use for evaluating on-field management practices to improve crop yields. **Objective.** To validate the accuracy of AquaCrop model in simulating onion yields and canopy cover in the sub humid environment of West Ugenya Sub County, Kenya. **Methodology.** Aqua Crop model version 5.0 was evaluated for experimental yields of bulb onion (*Allium cepa* L.) grown in West Ugenya Sub County, Kenya for two seasons (March to May long rains season, and October to December short rains season) on soil integrated with organic and inorganic fertilizers i.e. 5 Mega grams ha^{-1} cattle manure combined with inorganic fertilizers containing 28 kg P Ha^{-1} and 30 kg N ha^{-1}. The model was calibrated based on its conservative parameters for C3 crops under the Growing Degree Days (GDD) mode. **Results.** Statistical comparison of the model's simulated yields versus experimental yields gave RMSE (Root Mean Square Error) values of 0.22 and 0.61 in season I and season II, respectively, which are generally closer to zero, indicating average to high model precision. Modified Willmott index of agreement (d_{mod}) was 0.44 (season I) and 0.69 (season II), while for Nash and Sutcliffe coefficient (E), 0.85 (season I) and 0.14 (season II). The constant for d_{mod} and E indicates high model accuracy if value is close to one. The values from the simulations were detached, generally indicating in both cases average to high model performance. The canopy cover development from germination to the crop's 150 days to physiological maturity gave a Pearson correlation coefficient (r) that averaged 0.9. The r-values were close to one, indicating a positive linear relationship between simulated and experimental canopy cover. **Conclusion.** Overall, the model provided acceptable simulation of onion crop yield and canopy cover.
Keywords: Aqua Crop model; simulation; onion (*Allium cepa* L.); West Ugenya

RESUMEN

Antecedentes. La precisión de los modelos de simulación de crecimiento de cultivos es una faceta primordial en su uso para evaluar las prácticas de manejo en campo para mejorar los rendimientos de los cultivos. **Objetivo.** Validar la precisión del modelo AquaCrop al simular los rendimientos de cebolla y la cobertura del dosel a en el ambiente subhúmedo del oeste del condado de Ugenya Sub, Kenia. **Metodología.** El modelo Aqua Crop versión 5.0 se evaluó para determinar los rendimientos experimentales de cebolla de bulbo (*Allium cepa L.*) cultivados en el condado de West Ugenya Sub County, Kenya durante dos temporadas (temporada de lluvias largas de marzo a mayo y temporada de lluvias cortas de octubre a diciembre) en suelos integrados con fertilizantes orgánicos e inorgánicos, es decir, 5 Mega gramos de estiércol de ganado ha-1 combinado con fertilizantes inorgánicos que contienen 28 kg de P Ha^{-1} y 30 kg de N ha^{-1}. El modelo se calibró en función de sus parámetros conservadores para cultivos C3 en el modo de grados días de crecimiento (GDD). **Resultados.** La comparación estadística de los rendimientos simulados del modelo versus los rendimientos experimentales arrojó valores de RMSE (error cuadrático medio) de 0.22 y 0.61 en la temporada I y la temporada II, respectivamente, que generalmente están más cerca de cero, lo que indica una precisión promedio a alta del modelo. El índice de concordancia de Willmott modificado (d mod) fue de 0.44 (temporada I) y 0.69 (temporada II), mientras que para el coeficiente de Nash y Sutcliffe (E), 0.85 (temporada I) y 0.14 (temporada II). La constante para d mod y E indica una alta precisión del modelo si el valor es cercano a uno. Los valores de las simulaciones se separaron, lo que generalmente indica en ambos casos un rendimiento medio a alto del modelo. El desarrollo de la cubierta del dosel desde la germinación hasta los 150 días del cultivo hasta la madurez fisiológica dio un coeficiente de correlación de Pearson (r) que promedió 0.9. Los valores de r fueron

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cercanos a uno, lo que indica una relación lineal positiva entre la cubierta del dosel simulada y experimental. **Conclusión.** En general, el modelo proporcionó una simulación aceptable del rendimiento del cultivo de cebolla y la cubierta del dosel.
Palabras clave: modelo Aqua Crop; simulación; cebolla (*Allium cepa L.*); West Ugenya

INTRODUCTION

Yields are the simplest expression of crop productivity, but a direct relation between yield and input use is hard to estimate especially if the information is not directly registered in a crop database. Researchers have thus developed crop growth simulation models that can create a link between yields and input use based on information collected over time or by experimental methods (Donati *et al*., 2013). Crop growth simulation models are mathematical, computer-based representations of crop growth and interaction with weather, soil and other nutrients (Rao and Wani, 2011).

Traditionally, crop yield estimates have been based on empirical data but until recently, crop growth simulation models such as AquaCrop have been used to understand the effects of genotype, soil types and management practices on crops, and in climate change impact assessment on agriculture (Rinaldi *et al*. 2003; Rao and Wani, 2011).

AquaCrop model simulates attainable yields of the major herbaceous crops in rain fed, supplemental, deficit and full irrigation environments (Raes *et al.*, 2010). The model has been successfully used in parts of Sub-Saharan Africa to predict crop yields in Kenya (Wamari *et al*., 2012) and Zimbabwe (Masanganise *et al*., 2012; Simba *et al*., 2013; Temba and Chung, 2011).Kenya has been unable to meet the rapidly increasing market demand for horticultural products like onions (*Allium cepa* L.) due to low yields arising mainly from soil fertility decline, where neighboring Tanzania has been making up for this shortfall through exports to Kenya since the late 1980s and early 1990s (Sergeant, 2004). There is need to bridge the gap between demand and production, and with the help of crop growth models, simulate environmental and soil nutrient conditions to provide information particularly to policy makers to influence various beneficial activities in their regions (Ifejika *et al.*, 2010).

AquaCrop model, version 5.0, was selected for this study because it is less complex and with minimum input data requirements compared to APSIM (Agricultural Production Systems Simulator), DSSAT (Decision Support System for Agrotechnology Transfer), CERES-Maize (Crop Environment Resource Synthesis) and WOFOST (World Food Studies crop growth model) (Sarangi, 2012; Vote *et al.*, 2015). In terms of accuracy, studies have shown that the performance of AquaCrop is at par with other, more complex models such as CropSyst and WOFOST despite its simplicity (Steduto *et al*., 2009; Sarangi, 2012). Furthermore, unlike the previous version 4.0 which had a separate ETo calculator as companion package, AquaCrop version 5.0 has integrated it in the model (Raes *et al*., 2015), utilizing the FAO Penman−Monteith equation (Allen *et al.*, 1998).

The aim of this study was to validate the accuracy of AquaCrop model in simulating onion yields and canopy cover from a field experiment conducted in the sub humid environment of West Ugenya Sub County, Kenya. The precision of AquaCrop model was be revealed from statistical analysis of simulated and observed data.

MATERIALS AND METHODS

Study Site

The experimental study was conducted in a $^1/_2$-acre experimental field in Uriya at coordinates 0213410 N and 3471403 E at an altitude of 1,267 masl in West Ugenya Sub County, Kenya (Figure 1 and Figure 2). It falls under agro-climatic zone II, classified as sub humid (Jaetzold *et al*., 2009). Based on WRB, (2006) classification, Ferralsols are the dominant soil types in the study area (Jaetzold *et al*., 2009). The mean monthly temperature is 21.7°C with March being the hottest (22.6ºC) and July the coldest (20.7ºC) months. Rainfall is bimodal, with long rains occurring in March to June and short rains from September to November (Jaetzold *et al*., 2009). The physiography of the area presents a lower middle to level uplands comprising of gently undulating slopes of between 2 and 8% (Mango, 1999; Jaetzold *et al*., 2009). The major land use is intensive mixed farming accounting for 71% of the Ugenya population (KNBS and SID, 2013). Main crops grown include maize *(Zea mays)*, beans (*Phaseolus vulgaris*), sorghum *(Sorghum bicolor)*, cassava (*Manihot esculenta)* and sweet potatoes *(Ipomoea batatas)*. About 79% of the population own livestock consisting of indigenous (small East African Zebu) and hybrid cattle (Ayrshire and Friesian), goats, sheep, pigs, rabbits and poultry (KNBS, 2009; KNBS and SID, 2013).

Figure 1. Map of Kenya with location of Siaya County highlighted in red within which the study was conducted. Image credit: NordNordWest, 2015

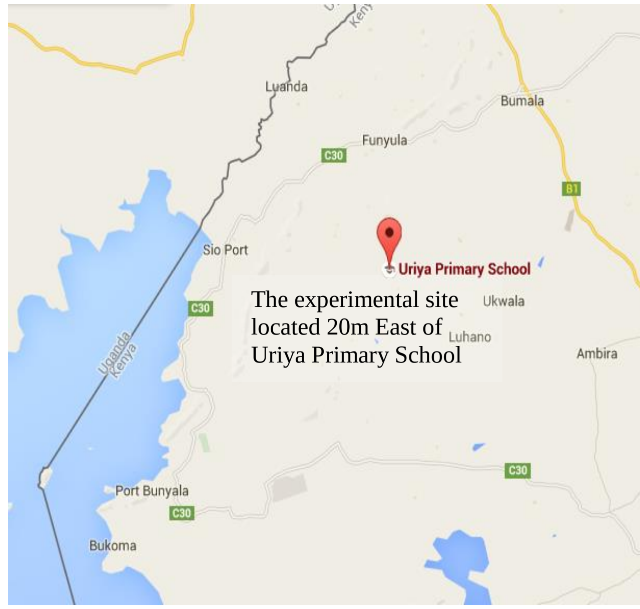

Figure 2. Map showing location of the study site at Uriya in Ugenya West sub-county, Siaya county. Image credit: Google Maps

Experimental Layout and Design

Experimental design was randomized complete block design (RCBD) with four treatments each replicated three times, namely: T_1 (5 Mg ha^{-1} cattle manure), T_2 (46 kg P ha^{-1} + 26 kg N ha^{-1} inorganic fertilizers), T_3 (unfertilized control), and T_4 (half of T_1 + half of T_2). Growth and development of onion under T_4 comprising of 5 Mega grams ha^{-1} cattle manure combined with 28 kg P Ha^{-1} and 30 kg N ha^{-1} inorganic fertilizers was used for AquaCrop model validation as it gave the highest onion yields in the two growing seasons. The sources of Phosphorous (P) and Nitrogen (N) was Triple Super Phosphate (TSP) containing 46% P_2O_5 and Calcium Ammonium Nitrate (CAN) containing 26% N, respectively, while composted cattle manure was obtained from a local farmer. The test crop was bulb onion *(Allium cepa* L.*)*, variety Neptune, directly planted at a spacing of 20 cm x 15 cm, at 3.1 kg ha^{-1} seed rate translating to about 333,000 plants ha^{-1}.

Agronomic Practices

Land was tilled using oxen plough, and hand hoes used to prepare 40m x 1m raised beds at 10 cm above the ground with 1 m boundary between the raised beds. The raised beds were replicated into three blocks, so that each block had four beds. Onion (Neptune variety) seeds were sown directly along 5 cm deep furrows on the raised beds and covered lightly with soil at the beginning of September 2015 in season I, and March 2016 in season II as shown in table 2. The germinated seeds were thinned to attain a spacing of 15 cm within rows and 20 cm between rows, 6 weeks after emergence. Hand weeding was done after every 4 weeks or any time the weeds emerged to avoid competition for moisture, sunlight and nutrients. 20 g of Mistress 72 WP (Cymoxanil 8% + Mancozeb 64%) preventive and curative fungicide mixed with water in a 20 liters knapsack was sprayed at the onion vegetative stage to prevent downy mildew, purple blotch and blight diseases, while continuous visual inspection of plants in the field was done for any signs of pest or other disease attack. Harvesting was done 140 days after crop emergence in a 1m^2 quadrant, when 80% of the crops had their leaves fallen over, by uprooting the onions from the ground by hand and sun drying for 7 days.

AquaCrop Model Input and Output Data

Input parameters for the AquaCrop model include data on climate, crop, soil, irrigation and cultural management. Output files included crop growth, soil water balance, irrigation requirement, biomass production, yield, and water productivity. For this study, new climate files (file with CLI extension) were created from AquaCrop's climate menu. The CLI file holds together the rain (PLU file), ETo (ETo file), temperature (TMP file) and CO_2 (CO2 file) data for use in AquaCrop's simulation runs. Hence, CLI files were created for the experimental period for purposes of calibrating the model.

Table 1. Salient soil properties of the study site for validation of AquaCrop model.

Thickness (cm)	Soil texture (%)			OC (%)	Texture class	PWP (Vol. %)	FC (Vol. %)	AWC (Vol. %)	Ksat (mm day^{-1})
	Sand	Silt	Clay						
0 – 10	52	11	37	2.7	Sandy Clay	13.6	32.8	19.2	125.0
10 - 20	51	10	39	2.1	Sandy Clay	13.6	33.2	19.6	121.3

OC – organic Carbon, FC – field capacity; PWP – permanent wilting point; AWC – available water capacity; Ksat – saturated hydraulic conductivity

Table 2. Experimental and agronomic information of Ugenya West used in AquaCrop Validation.

Growing season	Season I	Season II
Planting density, plants m^{-2}	33	33
Sowing date	15 October 2015	9 March 2016
Emergence	22 October 2015	17 March 2016
Physiological maturity	9 February 2016	24 July 2016
Harvest date	24 February 2016	7 August 2016
Maximum canopy cover, %	97	89
Seasonal rainfall, mm	687.9	641.7
Seasonal ETo, mm day^{-1} (Average)	4.65	4.48

ETo – Reference Evapotranspiration

Four crop files (CRO) were created based on the growth and yield characteristics of the onion crop observed in the field for the soil fertility regime comprising of 5 Mega grams ha^{-1} cattle manure combined with 28 kg P Ha^{-1} and 30 kg N ha^{-1} inorganic fertilizers, in the two growing seasons. Soil files (SOL) were based on parameterization of the soil sampled in the study site (Table 1). Initial soil water conditions before planting was set to field capacity. Agronomic and experimental information used in the model validation are presented in Table 2.

Crop Canopy Cover Data

The growth parameters such as leaf area index (LAI) and canopy cover (CC) were recorded at radical and flag leaf emergence stage (two weeks after emergence), 1 to 2 true leaves, 3 to 4 leaves, 5 to 7 leaves and 8-12 leaves of bulb onion growth stages according to Schwartz and Cramer (2011). Data was collected in four evenly spaced sections along the 40m length of each plot, using a 1m^2 quadrant when at least 80% of the plants within the quadrant showed characteristic of each growth stage. Leaf area (LA) was obtained by a non-destructive indirect method utilizing a linear regression model described by Corcoles *et al*. (2015), Equ. 1:

$$LA = 0.000199 + 1.277\ L \times A25 \quad \ldots\ldots (1)$$

Where, L is total leaf length and A25 is leaf width taken from a distance of 25% from leaf base.

Canopy cover (CC) was obtained by use of a conversion formula by Hsiao *et al*. (2009), Equ.2:

$$CC = 1.005\left(1 - e^{(-0.6\mathrm{LAI})^{1.2}}\right) \ldots\ldots (2)$$

Where, LAI is leaf area index calculated as leaf area (LA) divided by ground area.

Harvest Index

Total biomass was first recorded as the weight of the below and above ground parts, while yield was determined as bulb weight at the time of maturity measured in the field in 1m^{2}quadrant. Harvest index (HI) was then calculated as the percentage ratio of bulb yield to total biomass. Equ. 3.

$$\mathrm{HI} = \frac{\mathrm{Yield(Mg\ ha^{-1})}}{\mathrm{Total\ Biomass\ (Mg\ ha^{-1})}} \times 100\% \quad \ldots\ldots (3)$$

Soil data

Undisturbed core soil samples were collected in a transect at a depth of 0-20 cm using a coring cylinder of 53 mm diameter and 50 mm length. Soil texture was determined by hydrometer method as described by Glendon and Doni (2002). Bulk density was determined by calculating the weight of oven dried soil at 105ºC divided by the soil volume, equivalent to the volume of the core ring. Saturated hydraulic conductivity (Ksat) determination was done in the laboratory using the constant head method as described by Klute and Dirksen (1982). Soil moisture retention (pF) was determined according to Hinga *et al.* (1980). Soil organic Carbon (OC) was determinedfollowing a modified Walkley-Black protocol as described by Nelson and Sommers (1996).

Climate Data

Daily weather data during field experiment consisting of rainfall (mm), minimum and maximum temperature (°C), relative humidity (%), wind speed (m/s) and sunshine hours was obtained from Kisumu Kenya Meteorological Department station, ~ 50km from the study site. Following the Penman-Monteith equation (Allen *et al.*, 1998), potential evapo-transpiration (ETo) was automatically calculated using the ETo calculator integrated in the AquaCrop model v5.0 by first arranging the weather data in columns in a notepad txt file. By opening AquaCrop model, climate menu, the weather data in the txt file was imported by linking the corresponding weather data columns to those in AquaCrop. The resultant ETo file was saved in AquaCrop's 'Data' folder together with the rain (PLU file) and temperature (TMP file) files. Mean monthly CO_2 concentration was obtained from the dataset of the Mauna Loa observatory in Hawaii.

Model Calibration

Conservative crop parameters of AquaCrop model for C3 crops as shown in Table 3 were used for calibration under the Growing Degree Days (GDD) mode. Less conservative parameters that were adjusted based on field experiment data consisted of climate, canopy development and harvest index.

Table 3: Conservative parameters used to calibrate AquaCrop for simulation of onion development.

Description	Value		Units or meaning
	Season I	Season II	
[1] Base temperature	10.0	10.0	^{0}C
[2] Cut-off temperature	30.0	30.0	^{0}C
[3] Initial CC at 90% emergence	1.67	1.67	%
[4] Canopy size seedling	5.00	5.00	cm^2 $plant^{-1}$
[5] Canopy growth coefficient	1.061	0.173	% GDD^{-1}
[6] Canopy decline coefficient	0.80	0.59	% GDD^{-1}
[7] Maximum canopy cover	96.7	85.0	Function of plant density (%)
[8] Length of growing cycle	150	150	Days
[9] Water productivity (WP), as calibrated	15.1	15.0	gm^{-2}, function of atmospheric CO_2
[10] Canopy expansion growth threshold (P_{upper})	0.25	0.25	Fraction of TAW, below this leaf growth is inhibited
[11] Canopy expansion growth threshold (P_{lower})	0.55	0.55	As fraction of TAW, below this leaf growth is enhanced
[12] Effect of canopy shelter on soil evapotranspiration in late season (Ke)	60	60	%, soil evaporation coefficient
[13] Effect of crop transpiration (Kc_{Tr})	1.10	1.10	Transpiration coefficient for a well-watered crop
[14] Stomata closure threshold (P_{upper})	0.50	0.50	Above this stoma begin to close
[15] Early canopy senescence stress coefficient (P_{upper})	0.85	0.85	Above this early canopy senescence begins
[16] Shape factor for soil-water stress	3.0	3.0	Moderately convex curve
[17] Reference harvest index (HI_o)	79	70	%
[18] Maximum possible increase of HI_o due to water stress	15	15	%
[19] Ground water (Absent)	-	-	Default value, 2m depth to ground water with salinity of 2 dS/m

CC – canopy cover; GDD – growing degree days; TAW – total available water

Statistical Analysis

The conformity between modeled and observed mean results was validated by use of Root Mean Square Error (RMSE) (Equ. 4), modified index of agreement (d_{mod}) as described by Willmott *et al.* (2012) (Equ. 5), and coefficient of efficiency (E) according to Nash and Sutcliffe (1970) (Equ. 6).

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(Si-Oi)^2}{n}} \quad \text{……..………… (4)}$$

$$\mathrm{d}\,mod = 1 - \frac{\sum_{i=1}^{n}|Si-\bar{O}i|}{\sum_{i=1}^{n}(|Oi-\bar{O}i|+|Si-\bar{O}i|} \quad \text{……......... (5)}$$

$$\mathrm{E} = 1 - \frac{\sum_{i=1}^{n}(Si-Oi)^2}{\sum_{i=1}^{n}(Oi-\bar{O}i)^2} \quad \text{…..……………. (6)}$$

Where, S_i and O_i are simulated and observed/experimental data, respectively. ō is the mean value of O_i, and *n* is the number of observations.

Level of model accuracy in simulating observed mean canopy cover was by use of the Pearson correlation coefficient (r) (Equ. 7).

$$\mathrm{r} = \frac{\mathrm{n}(\sum \mathrm{xy})-(\sum \mathrm{x})(\sum \mathrm{y})}{\sqrt{[\mathrm{n}\sum \mathrm{x}^2-(\sum \mathrm{x})^2]\,[(\sum \mathrm{y}^2-(\mathrm{n}\sum \mathrm{y}^2-(\sum \mathrm{y})^2]}} \quad \text{……… (7)}$$

Where, x and y are observed/experimental and simulated canopy cover data points, respectively; while n is the number of observations.

RESULTS AND DISCUSSION

Soil Characterization of the Study Site

The sandy clay soil of the study site exhibited 52% sand and 38% clay content. Due to the high sand content, the soil has low water retention capacity as water percolates rapidly, implying crop failure in the event of a slight drought. This agrees with Bationo *et al*. (2012) who indicated leaching and low water holding capacity as a problem in soils with greater than 35% sand. Low bulk density of 1.28 g cm^{-3}according to the general scale in Hazelton (2007) was observed in the soil's 0 – 20 cm surface layer, due to low clay content and higher level of less dense organic matter (Table 1); hence the tendency of soil bulk density to reduce with increasing soil organic matter and clay content reduction (Alemayehu *et al*., 2016; Karuku and Mochoge, 2016). Tillage also lowers bulk density through decompaction and loosening of soil aggregates (Landon, 2014; Abrougui *et al*., 2014).

Soil moisture content at permanent wilting point (pF 4.2), field capacity (pF 2.0) and saturated hydraulic conductivity (Ksat) were representative for sandy clays according to Saxton and Rawls (2006). The fairly high Ksat implied moderate resistance to water flow hence modest leaching was expected in the soils of the study area as established by Gaines and Gaines (1994) in their study on the effect of soil texture and subsequent permeability rates on nitrate leaching.

Validation of simulated Yields & Canopy Cover by AquaCrop Model

In season I and II, the model simulated yields adequately as RMSE on average was below 0.5 (Table 3), which is closer to zero.

The closer the RMSE is to zero, the higher the model accuracy as observed data indicates. T_3 however had an RMSE above 0.5 in season I due to a higher divergence between simulated and observed mean yields, lowering the performing efficiency of the model. The modified Willmott index of agreement (d) and Nash and Sutcliffe coefficient (E) were on average 0.9, closer to one in both cropping seasons thus indicating high model performance. Essentially, d and E are dimensionless and may assume values ranging from $-\infty$ to +1, but the closer they are to +1, the better the model simulation performance. Hence, d, E as well as RMSE values obtained in the two growing seasons indicated that AquaCrop model satisfactorily simulated onion yields in the study area. Similar findings have been reported by Agbemabiese, (2015) who found a RMSE of 0.09, Willmott's modified index of 0.99 and Nash-Sutcliffe efficiency of 0.96 while simulating onions yields under different irrigation regimes in Ghana. Similarly, Kiptum *et al*. (2013) found a RMSE value of 0.38 when simulating cabbage biomass in Kenya. However, Hussain (2012) found that performance indicators of RMSE and Nash Coefficient of efficiency on simulated onion biomass and yield under deficit irrigation experiment in Pakistan, during 2011 season gave overestimated results; hence the model was not satisfactory. These results were divergent as they gave values far from zero, indicating high variance between the observed data points to the model predicted values.

Table 4. Validation of simulated onion yields.

	Season I	Season II
Observed $_{mean}$	14.4	12.1
Simulated $_{mean}$	14.5	12.1
RMSE	0.218	0.606
d_{mod}	0.440	0.692
E	0.849	0.140

T - Treatment; RMSE - root mean square error, d_{mod} – Willmott's modified index of agreement, E – Nash and Sutcliffe coefficient

Comparison between observed and simulated mean canopy cover against days to physiological maturity shows that Pearson correlation coefficient (r) on average equaled 0.97 in all treatments in the two cropping seasons (Figure 2 and 3). The r-values per treatment were close to one, hence showed a positive linear relationship between observed and simulated canopy cover. Similar findings were reported by Kiptum *et al.* (2013) with a strong relationship (r = 0.94) between observed and simulated canopy cover despite overestimation in the initial stages of cabbage growth due to model adjustments with respect to number of days to maximum canopy cover and canopy decline.

CONCLUSION

This study focused on a rather under studied crop (onion) in AquaCrop modeling, and in a region (Kenya) with few studies conducted on the same.Good agreement was obtained by AquaCrop model in simulating the canopy cover in a non-water-stress and non-limited nutrients condition of the experimental site under a treatment incorporating the combined use of 5 Mega grams ha^{-1} cattle manure combined with 28 kg P ha^{-1} and 30 kg N ha^{-1} inorganic fertilizers.

Some difficulties were however encountered by AquaCrop in simulating bulb yield as the model's degree of accuracy determined by Wilmot's modified index of agreement gave divergent performance results between season I and season II. This could be the fault of the model, or it could also be errors in field measurement for season II. The RMSE and Nash and Suttcliffe constants gave positive indication of the model performance. However, the simplicity of AquaCrop in its required minimum input data, which are readily available or can easily be collected, makes it user-friendly and easily used by the practitioner-type of end users.

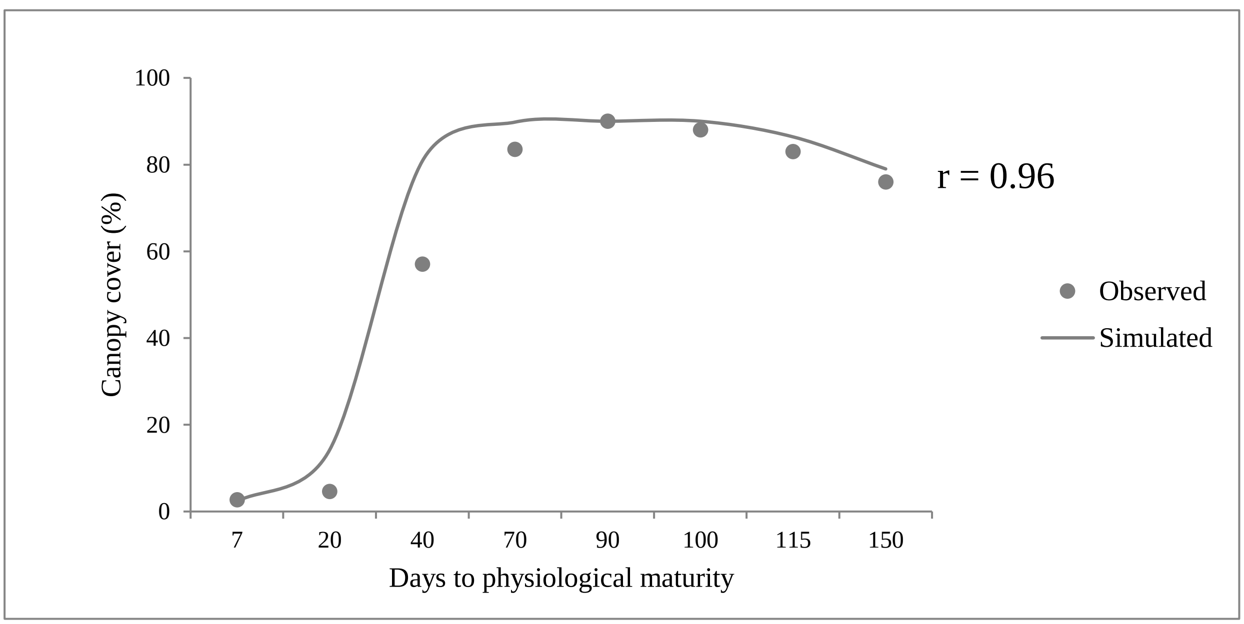

Figure 3. Observed versus simulated onion canopy cover in season I.

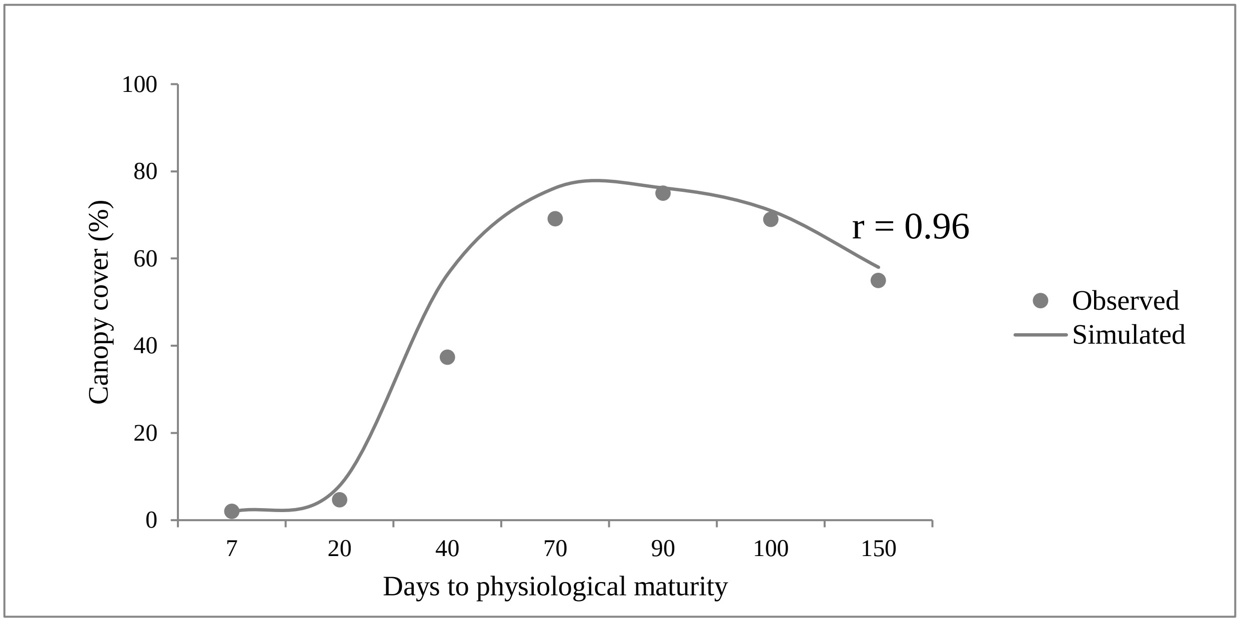

Figure 4. Observed versus simulated mean onion canopy cover in season II.

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Compliance with ethical standards. No human participants or animals were used in the studies undertaken in this article by any of the authors.

Data availability. Data are available with the corresponding author (benedictmbi@yahoo.com) upon reasonable request**.**

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