Calibration and Validation of Aqua Crop for Full and Deficit Irrigation of French Bean in Njoro-Nakuru - Kenya

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Abstract: ***This experiment was conducted from June toSeptember, September to December 2016at the Agricultural Engineering Department/ demonstration farm/ Egerton University Nakuru Kenya. The objective of the study was to calibrate validate aqua crop model for full and deficit irrigation of French bean. The modified FAO Peneman Montieth method was used to calculate ETo by adapting ETo calculator, Crop coefficient was used to calculate evapotranspiration ETc, the water application levels was 100% of evapotranspiration (ETc), 80% ETc, 60%ETc, and 40%ETc, based on these irrigation levels. The experiment was laid out in Randomized Complete Block Design (RCBD) with four treatments and three replications. Data collection during the experiment was including weather data (Temperature, wind speed, relative humidity and rainfall)and other variables (soil moisture content, irrigation depth) as well as crop data (crop height, number of branches, leaf area index, biomass and final yield). Highest yield was found in treatment 100% ETc (9.180 t/h) and the lowest yield was found in treatment one 40% ETc (3.9 t/ha) the deficit irrigation was observed throughout the season except crop establishment (initial stage). The performance of the model was efficient in simulation of final biomass, pod yield and canopy cover but it performed less in simulation biomass and pod yield of the treatments less than 60% ETc (under the severe water stress throughout the season). Aqua Crop model require less inputs and easy to use and its good degree of simulation and accuracy make it useful decision –making tool for investigation deficit irrigation and French bean growth in the region.***

Keyword: Deficit irrigation, French bean, Aqua Crop, Calibration, Yields, Water requirement

1. Introduction

The demand for water resources continue to increase with increasing population and diversification of uses. To optimize yield, irrigation should be done at the right time. Conventional irrigation has resulted in losses of water which can be minimized through use of modern irrigation technology that minimizes losses in accordance with crop water need (Hsiao *et al*,2007).The challenge is to create a management system that will reduce the negative impact of the expected water stress to crop. Kenya is among the major French beans (*PhaseolusValgarisL*) producer in East Africa [11], it's the most important export vegetable account for over 60% of all exported vegetable[13].Many sophisticated crop growth models based on physiological processes have been developed and applied in water management projects with varying degrees of success. Many of these models however, have not been tested under deficit irrigation conditions in Sub-Saharan. Some of the widely accepted cereal models are hybrid model, such as CERES [4], and the DSSAT model. These two models simulate the growth of crop under water limited conditions [17]. WOFOST model, crop syst model [19], and the Hybrid Maize model [8] have been used for the prediction of yield of maize crop. CROPWAT model is an appropriate tool for irrigation planning. All these models are however, quite sophisticated and require advanced modelling skills for their calibration and subsequent application. They also require a large number of model input parameters. In this context, the recently developed FAO Aqua Crop model [15] and [18] which require less number of input parameters. It is designed to balance simplicity, accuracy, and robustness and is practically suited to address conditions where water is a key limiting factor in crop production. Aqua Crop is a simulation model that quantifies the effects of water on yield at the farm level, so can be a valuable tool in water and irrigation management [2]. It is a new decision support tool used in modeling and devising strategies for efficient management of crop water productivity at farm level [18]. Aqua Crop can be used as a planning tool to assist in management decision making for both irrigation and rain-fed agriculture [5]. The model is particularly useful in developing irrigation strategies under water deficit condition [16] :[14] It can be used to study the effect on crop yield of various land management techniques, to compare the attainable against actual yields in a field, farm or a region, to identify the constraints limiting crop production and water productivity, and also to predict climate change impacts on crop production [10].[6] Therefore, Aqua Crop model can be applied in irrigation development technology to achieve increased crop productivity, which may lead to poverty mitigation. Aqua Crop was being tested deficit irrigation management of Cabbages, in Keiyo Highland of Kenya, the model provided excellent simulation of canopy cover and yield. To date no study on simulation of the effect of deficit irrigation on French bean with Aqua Crop has been reported in literature.The objectives of the study therefore were to Calibrate and evaluate the Aqua crop model for full and deficit irrigation of French bean.

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2. Material and Methods

The experiments were conducted at the Agricultural Engineering Research Field of Egerton University, Njoro. Kenya. The field lies at latitude of 0°23 S, longitude 35°35 E and altitude of 2200 m.a.s.l. The mean temperature; rainfall and evaporation data during the study period is presented below.

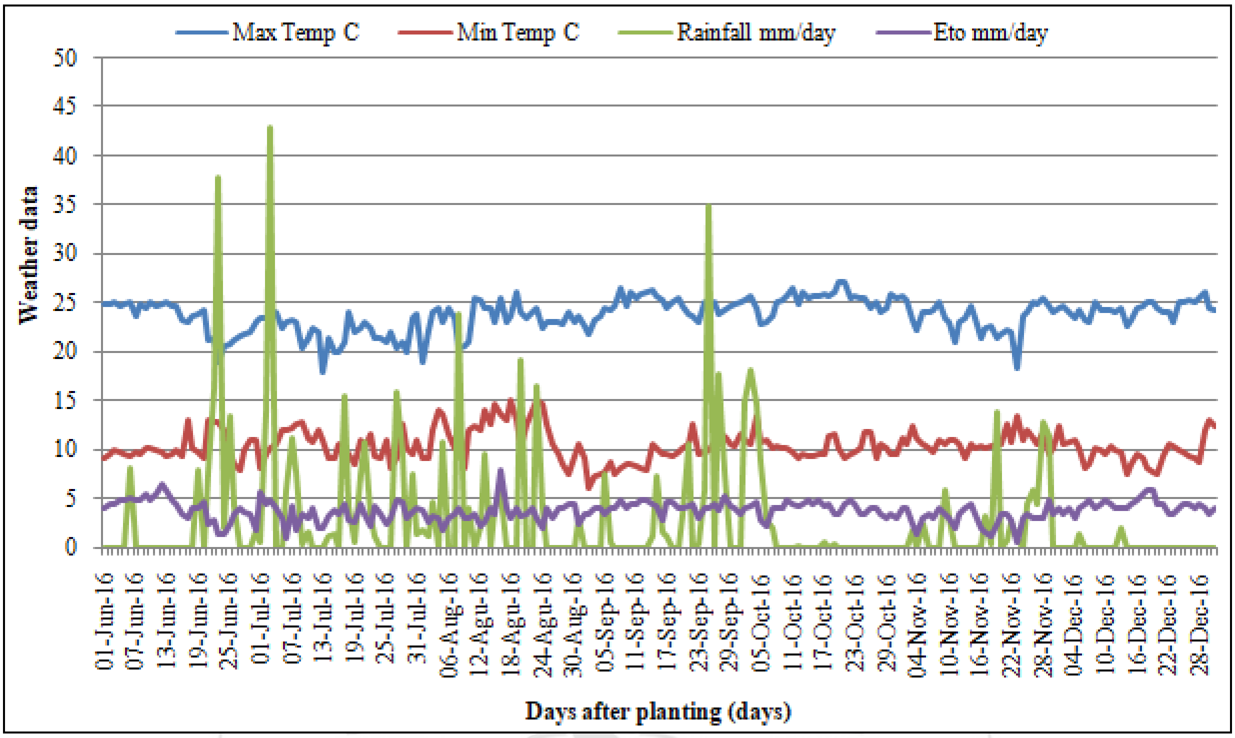


Figure 1: Daily minimum and maximum temperature, rainfall and evapotranspiration from June to December, 2016

a) Soil characteristics and weather data

Soil samples were collected from 0-15 cm depth to characterize the soil in term of physical characteristics such as textural class (soil texture). EC. PH. Organic matter and the average bulk density. Soil parameter were analysed at the soil laboratory of Egerton University and Kenya Agricultural and Livestock Research Organization (KARLO)Njoro. Table 1 showed soil Characteristics:

Table 1: Soil characteristics

Soil depth cm	Soil texture			Soil type	FC %	PWP %	TAW %	pH
	Sand %	Silt %	Clay%					
0 -30	64	26.5	9.4	SL	19.65	11.5	8.15	5.84

SL= Sandy loam, FC = field capacity, PWP = permanent wilting point, TAW = total available water.

The separate obtained soil average values were 64% sand, 26.5 silt and 9.4 clay. The soil texture class is sandy loam textured throughout the profile investigated on USDA soil textural classification triangle.The soil moisture content at field capacity was 19.65 % at the depth of 0-30 cm. the permanent wilting point values was 11.5% the total available water was 8.5%. The pH of the soil at the experimental site was 5.84 indicating that the soil was still suitable for growing the French bean

Table 4.2: Soil chemical properties

Soil depth cm	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	Na (ppm)	OM %	N %	Fe (ppm)	Cu (ppm)	Zn (ppm)	Mn (ppM	EC
0-30	4.20	593.4	874.4	435.7	707.0	3.4	0.3	78.43	0.8526	6.0797	30.85	0.06

P= phosphorus, K= potassium, Ca= calcium, Mg= magnesium, Na= sodium, N= nitrogen, Fe= ferrous, Cu= cupper, Zn= zinc, Mn= manganese EC = electrical conductivity

The result indicated that the available P of the experimental site was low similarly the Organic matter content of the soil slightly less 3.39, Nitrogen (N %) was adequate 0.26. The recommended (diammonium phosphate) DAP was 50kg/acre (18-46-0).

b) Experimental Design

The experiment was laid out in a Randomized Complete Block Design (RCBD) withfour treatments replicated three times. The treatments were watered at the level of 100%, 80%), 60(%, and 40%ETcthroughout the season, crop growth stages were four according to (Allen *et al*, 1998). The size of each experimental plot was 2×2 m. The plots and replicates were separated by a path of 1 meter and the total numbers of experimental plots were12. The spaces between plants were 15cm, and between the lines were 45cm. The French bean seeds cultivars Source were sourced from Amiran Kenya. Source is a determinate variety and one of the most popular among the French bean grower in Kenya. Each plot had five irrigation drip lines spaced at 45cm and 15cmbetween plants.(the specifications of the drip line are a Netron drip, spacing 15cm, flow rate 1.2 L/ h (Litre per hour). thickness of 0.4mm).

c) Agronomic practices

The planting dates was June 22nd ,2016 for the first season and September 18th , 2016 for the second season, and planting density were 14 plants per m^2, the nutrient requirements were determined based on soil analysis and were done by fertilizer application DAP 50 kg/acre (18.46.0), weed were controlled by hand when it appeared.

d) Crop water requirement and irrigation management

The daily crop water requirements were calculated by multiplying the reference evapotranspiration values with the French bean crop coefficients (0.5, 0.75, 1.15 and 0.9) initial, development, mid and late stage respectively

$$I = ET_C = ET_O \times K_C \times K_S \tag{1}$$

Where:

I = irrigation water requirement (mm) ,Etc = crop water requirement (mm), ETo = reference crop evapotranspiration (mm) , Kc = crop coefficient that varies by crop development stage (range 0 to 1), Ks = coefficient for each irrigation treatment level in the experiment.

The reference evapotranspiration ETo was determined using FAO Blaney-Cridle method .For purposes of creating irrigation schedules historical weather data of 15 years (2000-20015) was collected from Egerton University Meteorological Department. Values of crop coefficients Kc were selected from the table according to FAO Irrigation and Drainage Paper no 24 by Doorenbos and Pruitt [3]. The coefficient of each irrigation treatment Ks(1) = 100% of ETc no stress, Ks (0.8)= 80% of ETc, Ks(0.6)= 60% of Etc, Ks(0.4)= 40% of Etc,. Water was applied by drip irrigation on the same day as that of fully irrigated plot, but the irrigation depths will be reduced to 80%, 60%, and 40%, of the full irrigation for T2, T3, T4, treatments respectively. The seasonal amount of irrigation water from each treatment was recorded.

e) Crop parameters and measurement

The crop parameters include the days from sowing to emergence, maximum canopy cover; start of senescence, and physiological maturity, as well as maximum effective rooting depth was obtained from the experimental plots by excavating pits at the root zone during maturity (destructive sampling). Leaf length, leaf width, number of leaf per plants, and number of branches per plants were measured at 10 days intervals throughout the season started from 28 days after planting. The dry above biomass were measured by destructive sampling. One sample per plot is taken from known quadrant of the experimental plots at an interval of 10 days during the season [20]. The samples were oven dried at a temperature of 65^{0}C for 48 hours and then weighed to determine their mass per area covered.

Final yield were determined at the end of the season after the crop is harvested together with the final biomass from known quadrants of one square meter of the plots. The leaf area A (cm^2) for French bean was therefore calculated with the relationship.

$$A = 0.75 \sum_{i=1}^{m} L_i \times W_i \tag{2}$$

Where

L= leaf length and W= leaf width

$$LAI = \frac{Measuredleafareaperplant(cm^2)}{100 \times 100 cm^2} \times \frac{numberofplants}{m^2} \tag{3}$$

Aqua Crop simulate transpiration in terms of canopy cover (CC) of the crop, but often experimental studies measure LAI but not canopy cover, therefore, canopy cover was estimated from leaf area index based on (Hsiao *et al*,2009):

$$CC = 1.005 \times [1 - \exp(-0.6 LAI)]^{1.2} \tag{4}$$

Where CC (%) is canopy cover and LAI is leaf area index of the crop.

f) User- specific parameters

According to the [8]they grouped specific parameter to weather of the site, management, and crop specific parameters such as soil water characteristics, maximum rooting depth, plant density, sowing date, irrigations, and phenology all under the heading of user- specific input parameters. These parameters for our study are presented in Table 3.

Table 3: Experimental and agronomic information used in Aqua Crop model validation

Parameter	Value	Unit
Planting density, plant m^2	14.5	
Sowing date	22/June/2016	Day
Emergence	4/July/2016	Day
Physiological maturity	9/September/2016	Day
Harvest	31/8/2016	Day
Maximum Canopy Cover	95	%
Crop Water Productivity	20	g/m^2
Initial canopy cover	0.82	%
Seasonal ETo,mm	294	mm
Irrigation	347	mm
Maximum rooting depth	0.70	m

Out of all the crop parameters in AquaCrop model, 16 of them were demonstrated or assumed to be conservative (constant) . The same values of this set of 16 parameters (Table 3) were used in the validation reported here to further evaluate the performance and robustness of Aqua Crop model. These parameters are presumed to be applicable to a wide range of conditions and not specific for a given crop cultivar; the same parameters are used to simulate stress conditions, with stress effects manifested through the stress coefficients.

Table 4: Crop data input used in Aqua Crop to simulate French bean.

Parameter	Value	Unit
Base temperature	10	^{0}C
Cut-off temperature	30	^{0}C
CC per seeding at 90%emergence CC0	5	cm^2
Canopy growth coefficient CGC	19.1	Increase in CC relative to existing CC per GDD
Crop coefficient for transpiration at CC=100%	1.5	Full canopy transpiration relative to ETo
Decline in crop coefficient after reaching CC×	0.9	Decline per day due to leaf aging
Canopy decline coefficient	1	Decrease in CC relative to CC

CDC at senescence		per GDD
Water productivity	20	g(biomass)m^{-2}function of atmospheric CO_2
Leaf growth threshold p-upper	0.27	As fraction of TAW, above this leaf growth is inhibited
Leaf growth threshold p-lower	0.62	Leaf growth stops completely as this point
Leaf growth stress coefficient curve shape	3	Moderately convex curve
Stomata conductance threshold p-upper	0.50	Above this stomata begin to close
Stomata stress coefficient curve shape	3	Highly convex curve
Senescence stress coefficient curve p-upper	0.85	Above this early canopy senescence begin
Senescence stress coefficient curve shape	3	Moderately convex curve
Harvest index%	80	Common for good condition

g) Model performance evaluation

The performance of the model was evaluated using the following statistical parameters of the RMSE root mean square error was calculated by using equation 5[12]:

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(O_i - S_i)^2} \qquad (5)$$

And the model efficiency (ME) is calculated as:

$$ME = 1 - \frac{\sum_{i=1}^{N}(O_i - S_i)^2}{\sum_{i=1}^{N}(O_i - \overline{O_i})^2} \qquad (6)$$

Where Si and *O*i are the simulated and observed (measured) values as samples taken along the season or at the end of the season, N is the number of observations, $\overline{O_i}$ is the mean value of O_i .Model efficiency ranged from negative infinity to positive 1: the closer to 1, the more robust the model. The RMSE represents a measure of the overall, or mean, deviation between observed and simulated values, a synthetic indicator of the absolute model uncertainty. In fact, it takes the same units of the variable being simulated, and therefore the closer the value is to zero, the better the model simulation performance.

To assess the robustness of the Aqua Crop model for French bean crop under Njoro condition and the required quality of the input data, a sensitivity analysis was worked out by altering inputs and by keeping some inputs constant such as normalized water productivity (WP* = 20 for C3 crops), Temperature (base temperature = 10 and upper temperature = 30). The inputs for sensitivity analysis for this research were agronomic data, soil, meteorology, and irrigation management data. In order to compare the model outputs, the inputs were changed by trial and error in each step. After changing the values of input parameters, the model outputs were compared with the observed data. The difference in simulated above ground biomass and pod yield was used for the assessment.

3. Results and Discussion

a) Green Canopy Cover

Table 5: Green Canopy Cover for two seasons

	Season one (June- Sept 2016) (calibration)			Season two (Sept-Dec 2016) (validation)		
	Canopy cover (mean)			Canopy cover (mean		
Treat	Observed	Simulated	Dev%	Observed	Simulated	Dev%
40%ETc	49.5	67	35.5	47.5	55	15.78
60%ETc	64.5	69.75	8.56	65.75	69.75	6.08
80%ETc	67.5	71	5.55	67.30	69.78	3.68
100%ETc	70.75	73.75	4.2	73.03	76.23	4.38

The results on green canopy cover analysis are presented in Table 5. Water application rate had an effect on the development of canopy cover. The treatment under 100%and 80%f ETc had the largest canopy cover while the water stressed treatment (60 %,and 40% of ETc) had the lowest canopy cover. This could be attributed to the continued water stress during the growing season for the treatments under 60 %ETc. In addition, the treatment under 100 %ETc attained maximum canopy cover earlier (55 days) than the other treatments (>65 days). This could be attributed to the increased water availability. On the other hand, the other treatments (60%, and40 %ETc) achieved early maximum canopy cover due to water stress. Water stress forced the crop under this treatment to attain maximum canopy cover much earlier.Upon achieving maximum green canopy cover, within a few days, senescence was observed in all treatments influenced mainly due to the termination of irrigation water application, The treatment under 100 and 80% of ETc attained senescence later than the other two treatments because the plants were still receiving water application. The correct simulation of canopy cover (CC) is essential to Aqua Crop performance, for it affects the rate of transpiration and consequently biomass accumulation. Calibration first involved adjusting crop key variables to reproduce field observed CC.

Figure 4 presents the simulation of CC for non-water stressed conditions (100%ETc) with Aqua Crop after calibration. The observed and simulated CC development fitted well with adequate statistical values (Table 4) and followed standard logistic growth curve used for Aqua Crop for non-stressed conditions [15].

In this study the maximum CC of about 80% was reached 49 days after sowing. The observed canopy cover and simulated canopy cover values did not differ that much (RMSE = 7.85 %, R^2 = 0.97).

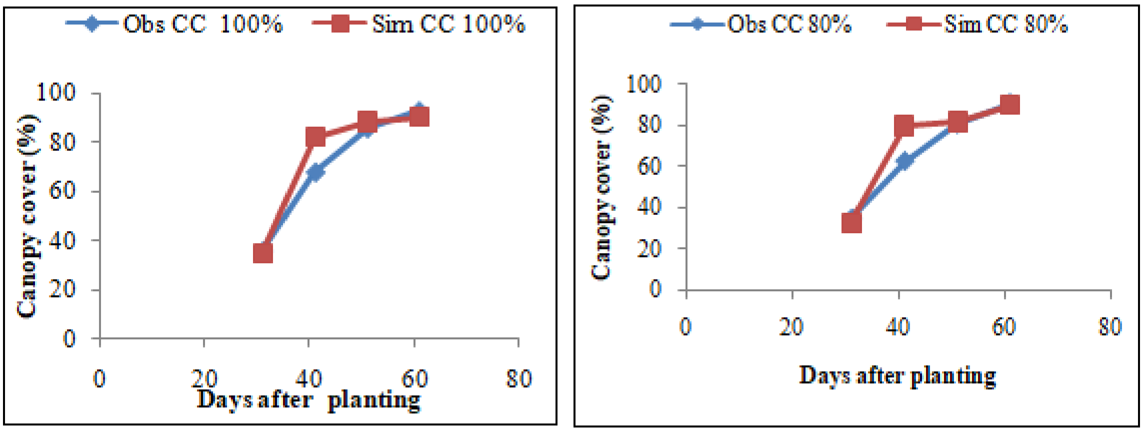


Figure 2: presents the simulation of CC for non-water stressed conditions (100%and 80%ETc)

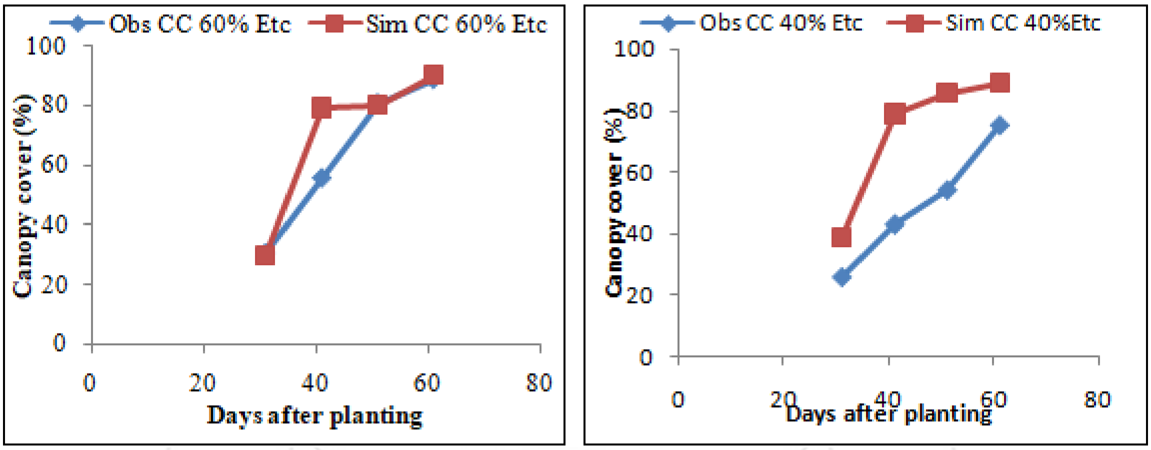


Figure 3: presents the simulation of CC for water stressed conditions (60 and 40%%ETc)

b) Yield and biomass

Table 6: Observed and simulated yield and biomass for first season (June to September 2016)

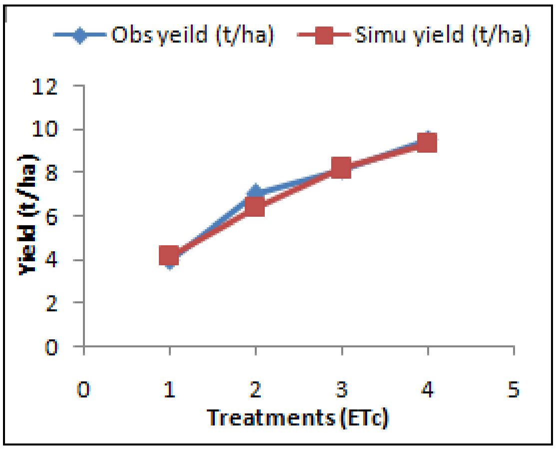
Treatments	Yield (t/ha)		Dev%	Biomass (t/ha)		Dev%
	Observed	Simulated		Observed	Simulated	
40%ETc	3.900	3.766	-3.43	5.15	7.714	49.78
60%ETc	6.960	6.638	-4.63	8.61	9.310	8.13
80%ETc	7.360	7.647	3.89	10.640	10.186	-4.27
100%ETc	9.180	8.666	-5.59	12.100	11.480	-5.12

Table 7: Observed and simulated yield and biomass for second season (September to December, 2016)

Treatments	Yield (t/ha)		Dev%	Biomass (t/ha)		Dev%
	Observed	Simulated		Observed	Simulated	
40%ETc	4.010	4.178	4.18	5.770	6.950	20.45
60%ETc	6.990	6.363	-8.97	8.770	9.120	3.99
80%ETc	8.130	8.187	0.70	10.09	10.700	6.04
100%ETc	9.55	9.330	-2.30	12.390	11.902	-3.94

Table 6 and 7 shows French bean productive data. The simulated above ground biomass agreed well with the observed biomass for 100%ETc and 80%ETc for the all treatments there was under estimated by the model (Figure 8). There was strong relationship between the observed and simulated biomass (R2> 0.79). Table 6 and 7 show a deviation of the simulated pod yield and above ground biomass from their corresponding observed data. The deviation of the simulated above ground biomass from the observed data for the 80%ETc (6.04%) shows there was under estimated of above ground biomass by the model, Whereas the deviations of the simulated yield from the observed data for all the treatments from 100%ETc(-2.30%) and 80%ETc (0.7%) there was underestimated of the yield by the model. Although not largely different, the pod yield was better simulated by the model when compared with the above ground biomass which is in line with [2]. Both pod yield and above ground dry biomass were adequately simulated by the model.

c) Evaluation of yield and biomass



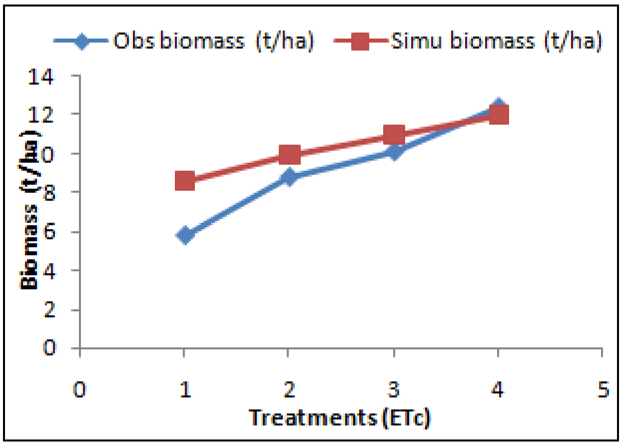


Figure 4, a and b: Observed and simulated yield and biomass

The observed and simulated yield and biomass for all the irrigation treatments are presented in Table 6 and 7 the model prediction of French bean yield showed a good agreement with observed values with an R^2 of 0.95, 0.96 and 0.97 for two seasons.

The 100 ETc irrigation treatment had the highest yield as compared to the other treatments due to lack of water stress. [18]explains that solar radiation is the driving force between biomass production and transpiration. Plants need to satisfy the evapotranspiration demand of the atmosphere. In order to capture carbon-dioxide, stomata need to be open for evaporation to take place. If there is water stress, stomata close thus reducing the rate of photosynthesis and consequently transpiration is reduced thus ultimately affecting the yield. The 80%, 60% and40% ETc irrigation treatments had lower yields because of the reduced evaporation rate due to closure of stomata which retarded growth. The observed and simulated biomass for all the irrigation treatments are presented in Table 6 and 7.The model prediction of French bean biomass showed a good agreement with observed values with an R^2 of 0.99 for two seasons. (Figure8). As a summary of the outcome of the simulations, the simulated final biomass and pod yield of the different irrigation treatments were compared with the measured values in Table 6and 7 with the deviation of the simulated value from the measured value expressed as a percentage of the measured value. When simulated final yield was compared with the measured yield, deviations ranged between 1.46 to 47.01%. The smallest deviation recorded of 3.16 % was observed in the 100% ETc and followed by 4.04 in 80%ETc, then largest deviation was 12.63 %, obtained under 40 % ETc. It was observed that the higher the amount of water application, the higher the accuracy in the predicted versus the measured yield. As regards biomass. Aqua Crop model did not compare the fruit yield well with the measured yield in all the treatments under water stress.

d) Model Performance Evaluation

Table 8: Statistical indices derived for evaluating the performance of Aqua crop in predicting yield biomass and canopy cover for first season

Statistical index	Dev%	RMSE	ME	R^2
Yield (t/ha)	4.19	0.315	0.96	0.94
Biomass (t/ha)	11.85	2.19	0.97	0.95
CC 40%TC	47.98	47.5	0.59	0.87
CC60%ETc	8.56	11	0.89	0.94
CC 80%ETc	5.55	7.5	0.93	0.95
CC 100%ETc	4.24	6	0.91	0.91

Table 9: Statistical indices derived for evaluating the performance of Aqua crop in predicting yield biomass and canopy cover for second season

Statistical index	Dev%	RMSE	ME	R^2
Yield (t/ha)	4.03	0.55	0.97	0.95
Biomass (t/ha)	8.49	2.12	0.97	0.93
CC 40%TC	41.5	39.4	0.55	0.89
CC60%ETc	7.67	10.5	0.91	0.95
CC 80%ETc	5.1	6.8	0.95	0.96
CC 1000%ETc	3.7	5.1	0.97	0.95

The model efficiency (ME) and root mean square error (RMSE), Deviation (Dev%) and regression coefficients (R^2) were used to evaluate the model performance. These parameters showed good to moderate performance for the pod yield (ME=0.55-0.97) for two seasons RMSE ranged between 0.55-39, R^2ranged between 0.89 -0.96. For the sensitivity analysis of the model it found that the water productivity was 20g/$m^{2,}$ initial CC was 95% plant density 14.5 plant per meter and Harvest index was 80%. According to the validation resultsthe calculated model efficiency was close to one that is the more robust the model. Good to moderate RMSE values indicate the good performance the model. But the model performs well to poor for more stress treatments for canopy cover.

4. Conclusions

The benefit of deficit irrigation lies in saving water and increase water productivity while maintaining optimum yield as close to fully irrigated farm. Applied 20% of the total crop water requirement throughout the season showed more yield reduction. On the other hand, applied 80% of the total crop water requirement deficit treatments had less yield reductions. However, even 60%ETc water application throughout the growing season except the first stage had significant yield reduction but acceptable compare with the yield production under the rain-fed area.. This indicates that prolonged water deficit below 60% of crop water requirement could significantly affect the yield. That means that with deficit irrigation, water and other irrigation expenses can be saved. By doing so more land can be irrigated with the saved water to enhance more production. Generally, over irrigation has not significantly improved the pod and dray biomass yield when compared with their corresponding deficit irrigation treatment. Besides to this. Moreover the most sensitive stage of any crop must be investigated to reduce sever yield reduction effects. The knowledge of the most sensitive stages of any crop to water deficit is crucial to manage and apply deficit irrigation technologies. Identifying sensitive growth stages of a particular cultivar under local conditions of climate and soil fertility allows irrigation scheduling for both maximum crop yield and most efficient use of scarce water resources. In general, water productivity has increased with decreasing water application which, however is also related to decreased pod yield and hence may not be desirable from the farmers' perspective. Other agricultural inputs need to be appropriately used to enhance productivity by maintaining improved water productivity. Aqua Crop model's calibration and validation is necessary for each crop and in every climate. The results of this research showed that this model is capable of simulating above ground biomass, canopy cover, and grain yield of a French bean for full deficit irrigation; but under sever water deficit less than 60%ETc of full irrigation)throughout the season the model performed less satisfactorily.

5. Recommendations

The highest yield was found to be (9.180t/ha) followed by (7.4360 t/ha) From treatment 100% ETc and 80%ETc respectively. Given 80% crop water requirement throughout the season gave good yield saved 20% of irrigation water with yield reduction of 18.20%. Therefore, we can recommend that application of irrigation water (100%, 80%) are best for Njoro environmental conditions. Aqua Crop version 4.9 has adequately simulated the above ground dry biomass, grain yield, HI, and canopy cover of French bean under various irrigation water conditions. There was under estimation of aboveground dry biomass and overestimation of pod yield of French bean crop by the model for treatment consequently subjected to water deficit (60% ETc) and for the severely deficit treatment (40%ETc). From this we can recommend that, Aqua Crop model is a less satisfactory simulating sever or prolonged water deficit below 60%ETc. Assuming that water is scarce and land is not scarce, the model has indicated the possibility of obtaining more yield and biomass from relatively larger fields of French bean crop by applying less water. These results may contribute to food security improvement through increased crop yields especially in water deficit areas.

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7. Abbreviations

HI= harvest index. AGB= above ground biomass, IWUE= irrigation water use efficiency. CC canopy cover, RMSE= root mean square error.

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