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# Modeling of Different Irrigation Methods for Maize Using AquaCrop Model: Case Study

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## Abstract

Modeling of irrigation methods is one of the most important techniques that contribute to the future of modern agriculture. This will conserve water as water scarcity is a major threat for agriculture. In this study, AquaCrop model was used to model different irrigation methods of maize in field trails in Al-Yousifya, 15 km Southwest of Baghdad. Field experiments were conducted for two seasons during 2016 and 2017 using five irrigation methods including furrow, surface drip and subsurface drip with three patterns of emitter depth (10, 20 and 30 cm) irrigation. AquaCrop simulations of biomass, grain yield, harvest index and water productivity were validated using different statistical parameters under the natural conditions obtained in the study area. For 2016 and 2017 seasons, results of $R^2$ were 0.98 and 0.99, 0.99 and 0.99, 0.99 and 0.97, and 0.8 and 0.73 for biomass, grain yield, harvest index and water productivity, respectively. The study has conducted that simulation using AquaCrop is considered very efficient tool for modeling of different irrigation applications for maize production under the existing conditions in the central region of Iraq.

## Keywords

AquaCrop Model, Grain Yield, Maize, Subsurface Drip Irrigation, Water Productivity

## 1. Introduction

Agriculture faces a major challenge in the arid and semi-arid areas, which Iraq is due to the lack of irrigation water supplies as a result of climatic change and increased water demand for industrial and civil utilization [1]. Thus, food production will be effected either by the decrease in the areas currently cultivated or the inability to expand horizontally, to bridge the gap between the supply and demand for agricultural products [2].

Improving irrigation water management and increasing water use efficiency through prudent practices up to one drop is one of the best management irrigation techniques. Maize is the most important cereals planted in Iraq. The cultivated area of maize, in Iraq, for the last nine years reached around (781,322) hectares, with a production amount of (2,916,928) tons [3]. It's used for human and animals' consumption, especially poultry feeding. Maize is also one of crops most involved in several industrial products such as biofuels production [4] [5]. Maize is a summer crop that growth coincides with the hottest and driest months of the year in Iraq (July, August, and September) when it is completely lacks of precipitation [6]. Maize is a C4 crop that has high efficiency to produce much biomass rapidly with high water consumption compared to other crops. High yield of maize requires approximately 750 - 900 mm water per-season; this high-water requirement due to poor water management such as the use of the traditional irrigation methods will cause a massive waste in irrigation water and lower water use efficiency [7] [8] [9] [10]. Modern irrigation methods provide more water use efficiency through water in the root zone.

Moreover, good irrigation scheduling system could be achieved by the use of sprinkler, drip, and subsurface drip irrigation systems. Recent researches [11] [12]: Documented that required water for irrigation could be decreased by 35% - 55% under the sprinkler or drip irrigation with high water use efficiency compared to traditional irrigation methods. Thus, efforts should always focus on improving water management to meet maximum yield with high water use efficiency, which is the main aim of irrigation management in arid and semi-arid regions [13]. The Food and Agriculture Organization (FAO) contributed to these efforts by the development of a Crop Simulation Model (AquaCrop). This model is characterized by its simplicity, accuracy and robustness. AquaCrop model emphasizes water as a key limiting factor in crop production, which is the difference between the actual and potential yield that can be known and determine the water use efficiency under field conditions [14] [15].

In addition the advantage of AquaCrop requires minimum data which is easy to obtain or assume. Although, these standards may not be sufficient so that data should be calibrated and adjusted to local conditions, genotypes, and crop managements practice. On the other hand, input data such as plant density, irrigation schedule, and weather data are necessary to be provided by the user of this model. The engine of plant growth in this model is driven-water from the soil that has been transpired by the plant [16] [17].

AquaCrop model converts the daily crop transpiration coefficient (Tr) directly into daily biomass production by conservative crop-specific parameters. Biomass production response to water application represents the atmosphere evaporation and the $CO_2$. Therefore, the reference evapotranspiration (ETo) has been adopted in this model. As a result, this model used the plant canopy instead of leave area index to calculate transpiration and separate transpiration from soil evaporation, crop production calculated based on Biomass and harvest index.

In AquaCrop model, water deficit, which ranged between field capacity [18]. It responds to the daily water equilibrium that included all influxes, infiltration, deep percolation, evaporation, transportation, runoff, and any changes in soil water content. The effect of water deficit on crop production due to poor management of crop or water could be represented in equivalents according to relative water depletion of available water in roots' zone. These equivalents are: leaves growth, sustainability of stomata conductance plant canopy aging and failure of pollination, this activities are the most sensitive to water stress. AquaCrop should calibrate according to a geographical location under different climatic conditions, soil type, phenotype, irrigation method, and crop management to improve model simulation [19] [20].

The results of several researches [21] [22] indicated that the use of AquaCrop model to manage irrigation of the maize was satisfactory and efficient, so that these studies [23] [24] [25] recommended the use of this model to simulate maize yield response to different environmental conditions and irrigation systems. The input data from field experiment used different irrigation method that contested five irrigation methods (*i.e.* furrow irrigation ($I_0$) surface drip irrigation ($I_1$) and subsurface drip irrigation with three patterns of emitters depth, 10 cm ($I_2$), 20 cm ($I_3$) and 30 cm ($I_4$) were used to test of AquaCrop.

The input data standard was obtained from previous studies [26] [27] was used to add test of AcuaCrop performance validity compared to the simulation of the biomass accumulation, grain yield, harvest index, and water productivity. Data that obtained from field experiment was carried out over two consecutive seasons (2016 and 2017) under the central region of Iraq environment on maize cultivar Kalimeras hybrid F1 by using different irrigation method. The study aims at making validation and calibration of AquaCrop model by using different irrigation methods coefficients of Maize (Zea mays L.) in order to get the calibrations necessary to apply simulations and predict the use of AquaCrop model of Maize in different irrigation ways by using statistical calibration method, which will be studied for several plant measures (Water productivity, Biomass, Dry Yield and Harvest Index) and compare them with the values that are simulated by using AquaCrop model as well as study the compatibility level in accordance with statistical measurements that have used in this study.

## 2. Material and Methods

### 2.1. Study Area

Experiments were conducted in a field of a maize farmer in the Yousifya area, 15 km southwest of Baghdad, Iraq, which is located at 33˚07'84"N Latitude, 44˚18'75"E Longitude and 34m Altitude, as shown in **Figure 1**. The climate of this region is

**Figure 1.** Experiment location in Al-Yusufiya, south of Baghdad Iraq.

characterized by high temperature, intense solar radiation, without rainfall and an increase in the evaporation rates. **Figure 2** shows climate variations of maize growing during the 2016 and 2017 seasons. As for soil, some of its physical, chemical and hydraulic properties are shown in **Table 1** at a depth of 0 - 30 cm.

## 2.2. Experimental Procedure and Treatments

The experiment land was prepared in terms of tillage, cultivation and leveling; then, it was divided into plots to represent the experimental unities according to a randomized completely block design (RCBD) with three replicates. The measured values was analyzed using analysis of variance (ANOVA) and significant difference were tested by Least Significant Differences method (LSD) at (0.05) level. SAS version 2012 was used [28]. The experiment included five irrigation systems that were furrow irrigation ($I_0$) surface drip irrigation ($I_1$) and subsurface drip irrigation with three patterns of emitters depth, 10 cm ($I_2$), 20 cm ($I_3$) and 30 cm ($I_4$) (**Figure 3**). Kalamaras maize hybrids were planted on 7 August for 2016 and 2017 seasons with a population (62,500) plant $ha^{-1}$. Experimental unit is fertilized with the use of 60 $kg \cdot ha^{-1}$ P of Diamonium phosphate DAP fertilizer (18:46:0) with urea 200 $kg \cdot ha^{-1}$ of (N: 46%) and $kg \cdot ha^{-1}$ 120 Potassium sulphate $K_2SO_4$ (0:0:50%) [29].

## 2.3. Soil Moisture and Irrigation Management

Initial soil moisture for experimental units was measured using a gravimetric method which was converted into volumetric water content at depth 0 - 90 cm and it was divided into four layers (0 - 15, 15 - 30, 30 - 50 and 50 - 90 cm) where the moisture for the four layers was calculated, this is used to represent soil water through the root zone. Moisture depletion was monitored in the root zone of the experimental units for the furrow irrigation treatments either as the experimental units for the drip irrigation (surface and subsurface). Moisture was monitored using a system of sensors (manufactured by Decagon Device Company) and

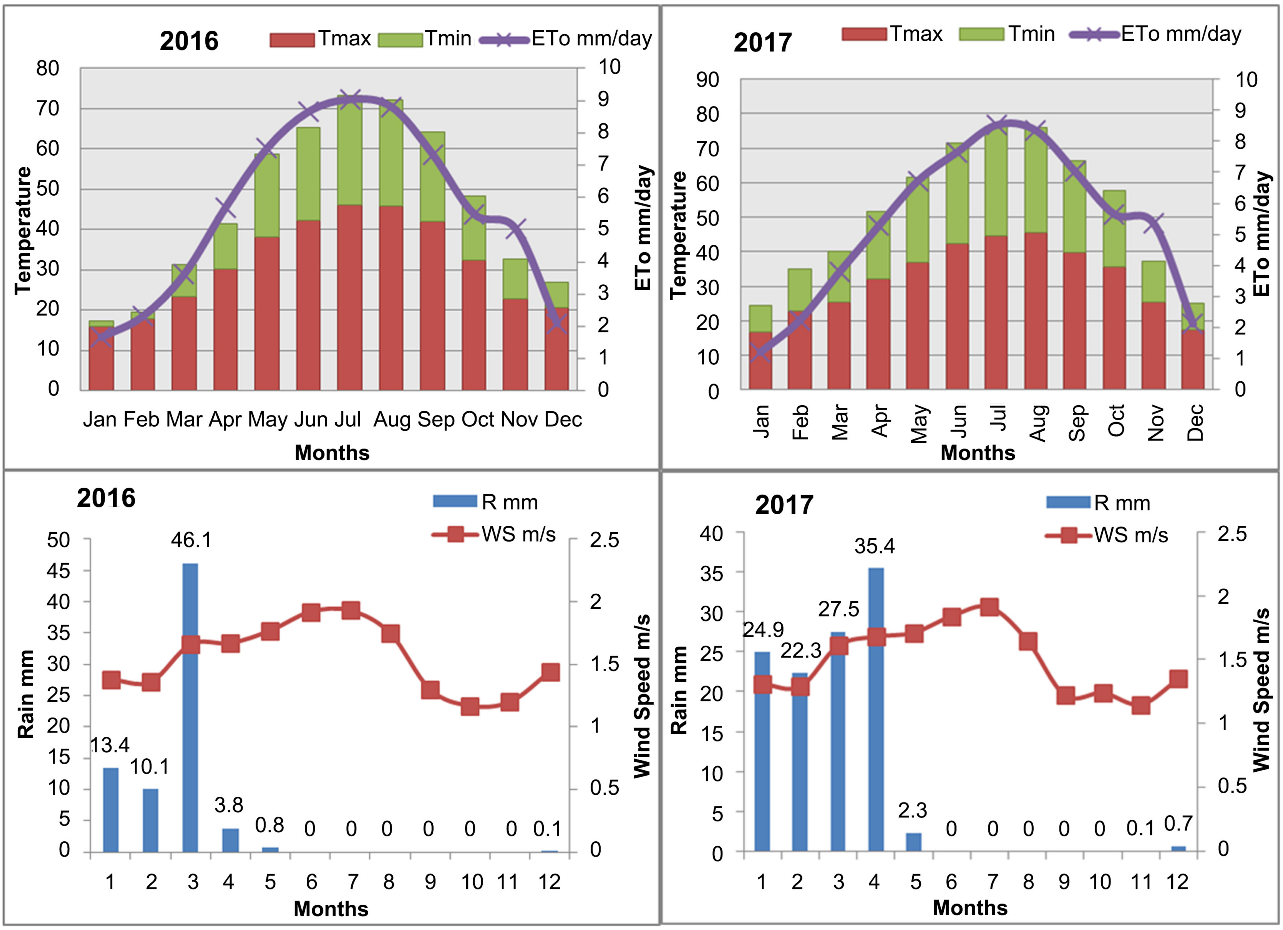


**Figure 2.** Temperature, total evapotranspiration and wind speed of study area in 2016 and 2017 seasons.

**Table 1.** Chemical and physical properties of experimental soil.

| Characteristics | 2016 | 2017 |
|---|---|---|
| | Soil depths (0 - 30 cm) | Soil depths (0 - 30 cm) |
| EC (dsm$^{-1}$) | 3.2 | 3.6 |
| pH | 7.6 | 7.8 |
| Sand (%) | 122 | 115 |
| Silt (%) | 624 | 648 |
| Clay (%) | 254 | 237 |
| Dominant texture | Silty Clay | Silty Clay |
| Organic Matter (%) | 4.50 | 3.73 |
| Bulk Density (mg·m$^{-3}$) | 1.38 | 1.39 |
| Particle Density (mg·m$^{-3}$) | 2.58 | 2.60 |
| Porosity (%) | 48 | 49 |
| Water Content at 33 kPa (cm$^{3}$·cm$^{-3}$) | 0.3361 | 0.3368 |
| Water Content at 1500 kPa (cm$^{3}$·cm$^{-3}$) | 0.1777 | 0.1779 |
| Available Water (cm$^{3}$·cm$^{-3}$) | 0.1584 | 0.1589 |

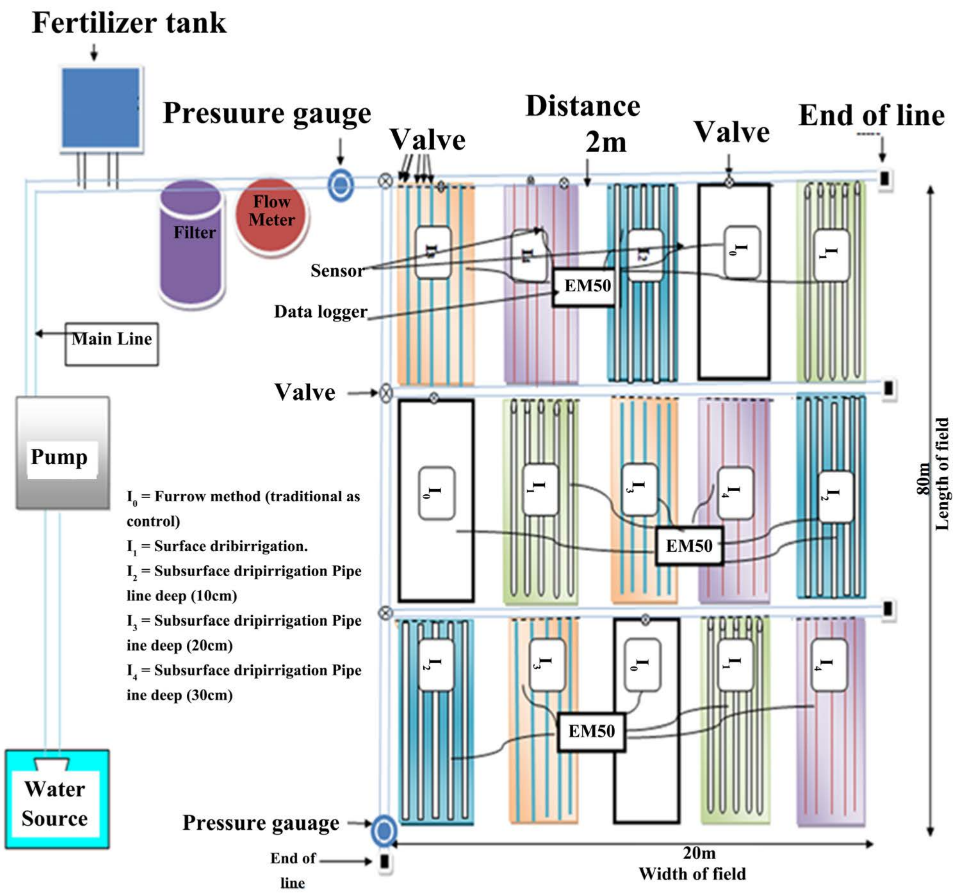


**Figure 3.** Layout of experimental treatments.

connected to the drip irrigation system that was used for the irrigation experimental unities $I_1$, $I_2$, $I_3$ and $I_4$ treatments irrigation frequency applied. After 50% of available water is depleted at the root zone (available water is equal to the percentage of soil moisture between the field capacity and wilting point).

The irrigation for $I_0$ treatment was applied by tubers with valves and flow meter to measure the amount of added water to experimental units of this treatment as in the following equation [30]:

$$d = \left(\theta_{FC} - \theta_w\right) D \tag{1}$$

where:

$d$ = Depth of water applied (mm),

$\theta_{FC}$ = Volumetric water content at field capacity,

$\theta_W$ = Volumetric water content before irrigation (depletion 50% of available water), and

$D$ = Effective root depth (mm).

As for the amount of water added to the experimental units for drip irrigation treatments ($I_1$, $I_2$, $I_3$ and $I_4$), it was calculated according to the following equation [31]:

$$NDI = RZD \times WHC \times Pd \times Pw \tag{2}$$

where:

$NDI$ = Net depth irrigation (cm),

$RZD$ = Root zone depth (cm),

$WHC$ = Water bearing capacity (mm of water in $\text{cm}^{-1}$),

$Pd$ = Percent of depletion (%), and $Pw$ = Percent of wetting (%).

The net irrigation requirement was calculated using soil water balance as in the following equation [32]:

$$(I+P+C)-(ET_a+D+R)=\mp\Delta s \tag{3}$$

where:

$P$ = precipitation (mm), $C$ = capillaries (mm),

$I$ = irrigation (mm),

$D$ = deep percolation (mm),

$ET_a$ = actual evapotranspiration (mm),

$R$ = runoff (mm),

$\Delta s$ = changes in the water storage during soil profile,

$C$ = 0 (limited contribution, water table depth = 3 m),

$R$ = 0 (no surface runoff),

$P$ = 0 (no rain),

$D$ = 0 (So irrigation at field efficiency is limited to the degradation).

Equation (3) becomes:

$$I+P-ET_a=\pm\Delta s \tag{4}$$

Throughout the present study, at the beginning of the study, the soil water content was observed to be similar to its content at the end of the experiment, $\Delta s$ = 0. The equation for water-consuming use becomes:

$$I=ET_a \tag{5}$$

Water use efficiencies were determined equation [33]:

$$WUE_f=\frac{GY}{WA} \tag{6}$$

where:

$WUE_f$ = field water use efficiency ($\text{kg}\cdot\text{m}^3$),

$GY$ = total grain yield ($\text{kg}\cdot\text{ha}^{-1}$),

$WA$ = water applied ($\text{m}^3\cdot\text{ha}^{-1}$).

## 2.4. Crop Measurements

Maturity biomass and grain yield were measured on dry weight after harvesting, harvest index was calculated as the ratio of grain yield to the total above-ground dry mass of shoot. As for water productivity, it was calculated by dividing the grain yield by the amount of water given to the crop.

## 2.5. Model Validation and Calibration

AquaCrop model was calibrated for simulating predicting maize growth and productivity under the field conditions of our study. Conservative and generally applicator parameters of the crop data file of AquaCrop with values were used is shown in **Table 2**. Then, we tested the calibrated model with two years of measured data (2016 and 2017).

The simulation was mainly focused on aboveground biomass, grain yield, harvest index and water productivity. There is a great need to calibrate the AquaCrop model, which includes the need to adjust to the original standards that apply before the model is used for simulation prediction. Calibration is done by including datasets on: climate, soil, crop and field management practices and also we need to modify some inputs such as planting date, plant population's plant growth stages duration [18] [34].

## 2.6. Statistical Comparison

Five Statistical measurements were applied to test the performance of the model and compare the simulated and measured results:

**Table 2.** Calibrated maize parameters of AquaCrop model used in this study.

| Parameters | Calibrated values |
|---|---|
| Base temperature ˚C | 9 |
| Cut-off temperature ˚C | 45 |
| Canopy cover per seedling ($cm^2$ $plant^{-1}$) | 6.7 |
| "Maximum rooting depth (m)" | 1.5 |
| Crop coefficient for transpiration (Kcb) | 1.08 |
| "Canopy expansion stress coefficient (Pupper)" | 0.13 |
| Canopy expansion stress coefficient (Plower) | 0.68 |
| "Canopy expansion curve shape" | 2.5 |
| Stomatal conductance threshold (Pupper) | 0.33 |
| "Stomatal closure shape factor." | 5 |
| Canopy senescence stress coefficient (Pupper) | 0.41 |
| "Canopy senescence shape factor." | 2.5 |
| Aeration stress coefficient (% vol saturation) | 4 |
| "Canopy decline coefficient (% $GDD^{-1}$)" | 0.69 |
| Reference harvest index (%) | 46 |
| "Crop growth stages (GDD)" | - |
| Time from sowing to emergence | 152 |
| "Time from sowing to max canopy cover." | 1440 |
| Time from sowing to senescence | 2400 |
| "Time from sowing to maturity." | 2880 |
| Time from sowing to flowering | 1368 |
| "Length of flowering stage." | 240 |

1) Root Mean Square Error (*RMSE*):

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(Si - Mi\right)^2} \tag{7}$$

where: *Si* and *Mi* are simulated and measured values; respectively, and *n* is the number of observations.

2) Coefficient of Determination ($R^2$):

$$R^2 = \frac{\sum SiMi - \sum Si + \sum Mi}{\sqrt{\sum Si^2 - \left(\sum Si\right)^2} \times \sqrt{\sum Mi^2 - \left(\sum Mi\right)^2}} \tag{8}$$

3) Mean Bias Error (*MBE*):

$$MBE = \frac{1}{n}\sum\nolimits_{i=1}^{n}\left(SiMi\right) \tag{9}$$

4) Index of agreement (*d*) of [35]:

$$d = 1 - \frac{\sum_{i=1}^{n}\left(Si - Mi\right)^2}{\sum_{i=1}^{n}\left(Si - \bar{M}\,| + Mi - \bar{M}\,|\right)^2} \tag{10}$$

where: $\bar{M}$ is the mean of the *n* measured values, and value of *d* range from-∞ to 1.0.

5) Coefficient of Efficiency (*E*)

$$E = 1 - \frac{\sum_{i=1}^{n}\left(Si - Mi\right)^2}{\sum_{i=1}^{n}\left(Mi - \bar{M}\right)^2} \tag{11}$$

## 3. Results and Discussion

Simulation values of AquaCrop model were compared with data obtained from the field experiment which was carried out for two seasons (2016 and 2017). This included five treatments for irrigation of maize under the natural conditions of the central region of Iraq, and the cultivation of hybrid Kalimeras (F1). Table 3 show the results of the simulated and measured values of the parameters for Aqua Crop, that was used for calibration the model, shows that the range of the calibrated values is well matching within the recommended vicinity of the simulated and the measured values and illustrated that the average calibrated values of the parameters are close to the simulated value for all irrigation treatments in this study for 2016 and 2017 seasons.

The values of the statistical analysis confirmed the accuracy of the calibration of AquaCrop in its simulation of the biomass, grain yield, harvest index and water productivity in the (Table 3). The model shows high correlation (1:1) between simulated and measured values. Generally, the correlation values ($R^2$) were (0.98 and 0.99) for Biomass, (0.99 and 0.99) for grain yield, and (0.99 and 0.97) for harvest index for the two seasons of 2016 and 2017; respectively. While the ($R^2$) for water productivity was (0.8 and 0.75) for the 2016 and 2017; respectively this indicates that the model has predicted a high degree of accuracy with respect to Biomass, grain yield and harvest index and this was confirmed by the

Table 3. Statistical indexes of AquaCrop simulated and measured results for the calibration datasets.

| Observation | $R^2$ | *RMSE* | *MBE* | *E* | *d* |
|---|---|---|---|---|---|
| **2016** | | | | | |
| **Biomass ($t \cdot ha^{-1}$)** | 0.98 | 0.33 | −0.32 | 0.87 | 0.971 |
| **Grain Yield ($t \cdot ha^{-1}$)** | 0.99 | 0.30 | −0.29 | 0.82 | 0.958 |
| **Harvest Index** | 0.99 | 0.84 | −0.77 | 0.92 | 0.978 |
| **Water productivity ($kg \cdot m^3$)** | 0.80 | 0.49 | −0.19 | 0.37 | 0.641 |
| **2017** | | | | | |
| **Biomass ($t \cdot ha^{-1}$)** | 0.99 | 0.28 | −0.24 | 0.90 | 0.972 |
| **Grain Yield ($t \cdot ha^{-1}$)** | 0.99 | 0.26 | −0.25 | 0.87 | 0.970 |
| **Harvest Index** | 0.97 | 0.83 | −0.74 | 0.85 | 0.960 |
| **Water productivity ($kg \cdot m^3$)** | 0.73 | 0.59 | −0.30 | 0.26 | 0.600 |

low (*RMSE*), (*d*) and (*E*) values (Table 3). While the *d* and *E* values were moderate for water productivity as they reached (0.37 and 0.26) in relation to *E* (0.641 and 0.600) in relation to (*d*) for the two seasons 2016 and 2017, respectively.

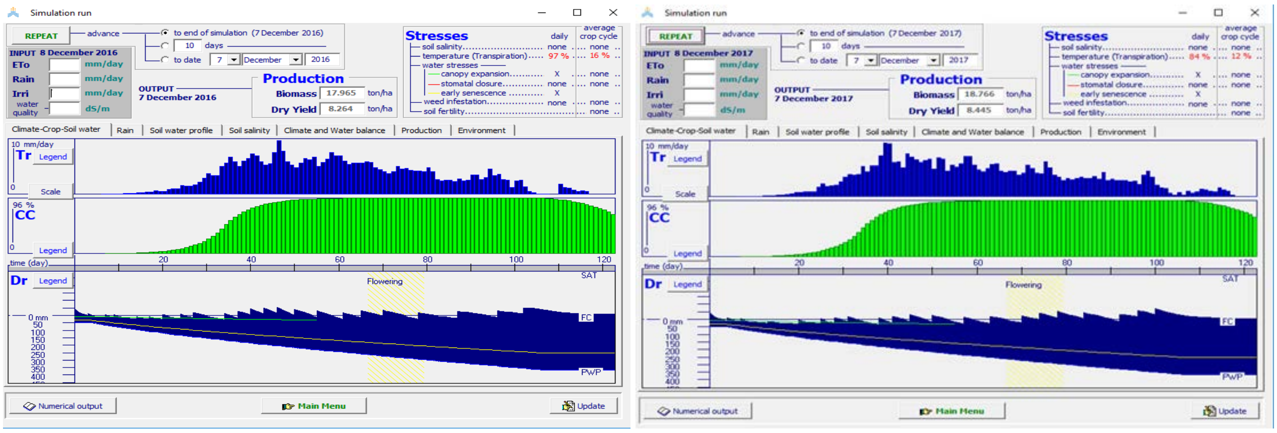
The (*MBE*) values suggested that AquaCrop reduce biomass, grain yield, harvest index and water productivity during calibration and none of these attributes have been overestimated during calibration. It was found that the highest decrease in harvest index (−0.77 and −0.74) for the two seasons 2016 and 2017; respectively while the lowest decrease was in water productivity it was (−0.19) in 2016 and (−0.30) in 2017 similar result are obtained by precise the authors [36] [37]. The (MBE) values of biomass (−0.32 and −0.24) and for the grain yield (−0.29 and −0.25) for the two seasons 2016 and 2017; respectively. The approximation of values for the two seasons indicates that the model was well able to simulate the values and their compatibility with the measured similar result are obtained by [38].

Through this study and Based on the performance evaluation of the AquaCrop model, which showed the simulation of biomass, grain yield and harvest index are reliable so that he simulated values of the Aquacrop model did not exceed 2.4%, 5.8%, 3.4% for each biomass, grain yield, harvest index respectively. These results are similar to the results of the others who test the validity of the Aquacrop model for irrigation management of maize [18] [19].

Table 4 and Figures 4-8 show the percentage of deviation between the simulated and measured values, which ranged between 1.3% in $I_2$ and 2.4% in $I_3$ and 0.9% in $I_1$ and 2.0% in $I_3$ treatments for biomass in 2016 and 2017seasons, respectively. As for the grain yield, it ranged between 2.5% in $I_2$ to 5.5% in $I_1$ and 2.1% in $I_0$ and 4.0% in $I_3$ treatments for 2016 and 2017seasons, respectively. This indicates that there is a correspondence between measured and simulated values of the AquaCrop model for biomass and grain yield under different irrigation

Table 4. Simulation values were compared with the measured value and standard deviations of biomass (t·ha$^{-1}$) and grain yield (t·ha$^{-1}$) for maize under different irrigation methods for the 2016 and 2017 seasons.

| Irrigation treatment | Biomass (t·ha$^{-1}$) | | | Grain yield (t·ha$^{-1}$) | | |
|---|---|---|---|---|---|---|
| | Measured | Simulated | Deviation (%) | Measured | Simulated | Deviation (%) |
| | | | 2016 | | | |
| $I_0$ | 17.59 | 17.96 | 2.1 | 7.93 | 8.26 | 4.1 |
| $I_1$ | 16.45 | 16.78 | 2.0 | 6.36 | 6.71 | 5.5 |
| $I_2$ | 17.03 | 17.25 | 1.3 | 7.4 | 7.59 | 2.5 |
| $I_3$ | 17.84 | 18.28 | 2.4 | 8.5 | 8.84 | 4.0 |
| $I_4$ | 17.37 | 17.62 | 1.4 | 7.7 | 7.94 | 3.1 |
| | | | 2017 | | | |
| $I_0$ | 18.38 | 18.76 | 2.0 | 8.26 | 8.44 | 2.1 |
| $I_1$ | 16.65 | 16.80 | 0.9 | 6.66 | 6.88 | 3.3 |
| $I_2$ | 17.54 | 17.59 | 0.2 | 7.53 | 7.74 | 2.7 |
| $I_3$ | 18.90 | 19.29 | 2.0 | 8.76 | 9.11 | 4.0 |
| $I_4$ | 18.05 | 18.29 | 1.3 | 7.96 | 8.24 | 3.5 |



Simulation run

● to end of simulation (7 December 2016)
○ 10 days
○ to date 7 December 2016

INPUT 8 December 2016

OUTPUT 7 December 2016

Production
Biomass 17.965 ton/ha
Dry Yield 8.264 ton/ha

| Stresses | daily | average crop cycle |
|---|---|---|
| soil salinity | none | none |
| temperature (Transpiration) | 97 % | 16 % |
| water stresses | | |
| canopy expansion | X | none |
| stomatal closure | none | none |
| early senescence | X | |
| weed infestation | none | none |
| soil fertility | | none |

Simulation run

● to end of simulation (7 December 2017)
○ 10 days
○ to date 7 December 2017

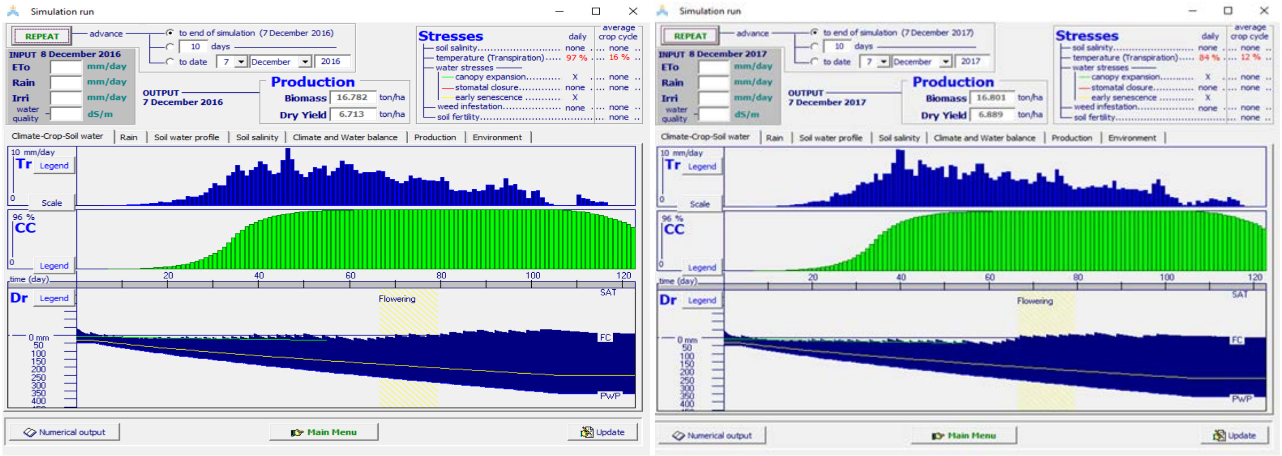
INPUT 8 December 2017

OUTPUT 7 December 2017

Production
Biomass 18.766 ton/ha
Dry Yield 8.445 ton/ha

| Stresses | daily | average crop cycle |
|---|---|---|
| soil salinity | none | none |
| temperature (Transpiration) | 84 % | 12 % |
| water stresses | | |
| canopy expansion | X | none |
| stomatal closure | none | none |
| early senescence | X | |
| weed infestation | none | none |
| soil fertility | | none |

Figure 4. Biomass and grain yield for $I_0$ 2016 and 2017 seasons.



Simulation run

● to end of simulation (7 December 2016)
○ 10 days
○ to date 7 December 2016

INPUT 8 December 2016

OUTPUT 7 December 2016

Production
Biomass 16.782 ton/ha
Dry Yield 6.713 ton/ha

| Stresses | daily | average crop cycle |
|---|---|---|
| soil salinity | none | none |
| temperature (Transpiration) | 97 % | 16 % |
| water stresses | | |
| canopy expansion | X | none |
| stomatal closure | none | none |
| early senescence | X | |
| weed infestation | none | none |
| soil fertility | | none |

Simulation run

● to end of simulation (7 December 2017)
○ 10 days
○ to date 7 December 2017

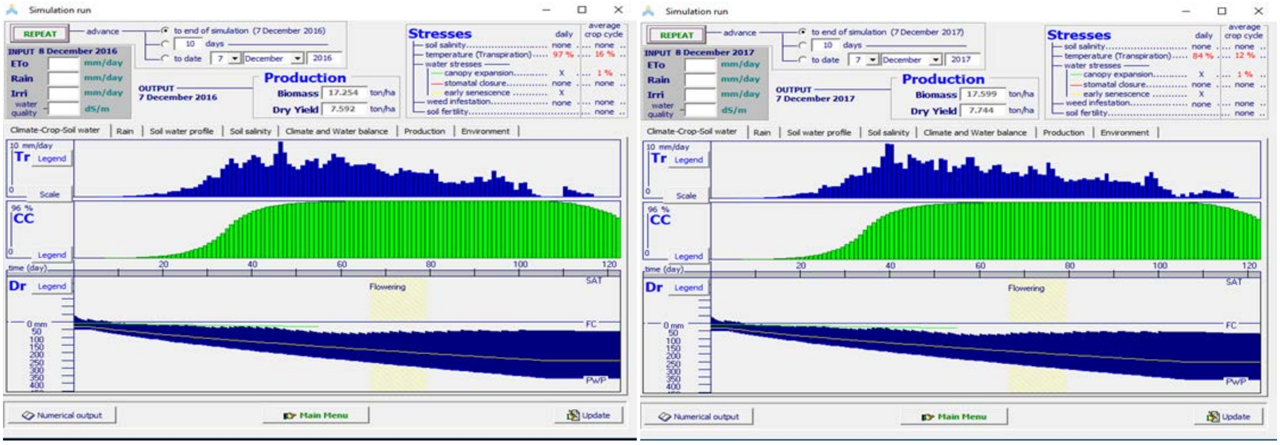
INPUT 8 December 2017

OUTPUT 7 December 2017

Production
Biomass 16.801 ton/ha
Dry Yield 6.889 ton/ha

| Stresses | daily | average crop cycle |
|---|---|---|
| soil salinity | none | none |
| temperature (Transpiration) | 84 % | 12 % |
| water stresses | | |
| canopy expansion | X | none |
| stomatal closure | none | none |
| early senescence | X | |
| weed infestation | none | none |
| soil fertility | | none |

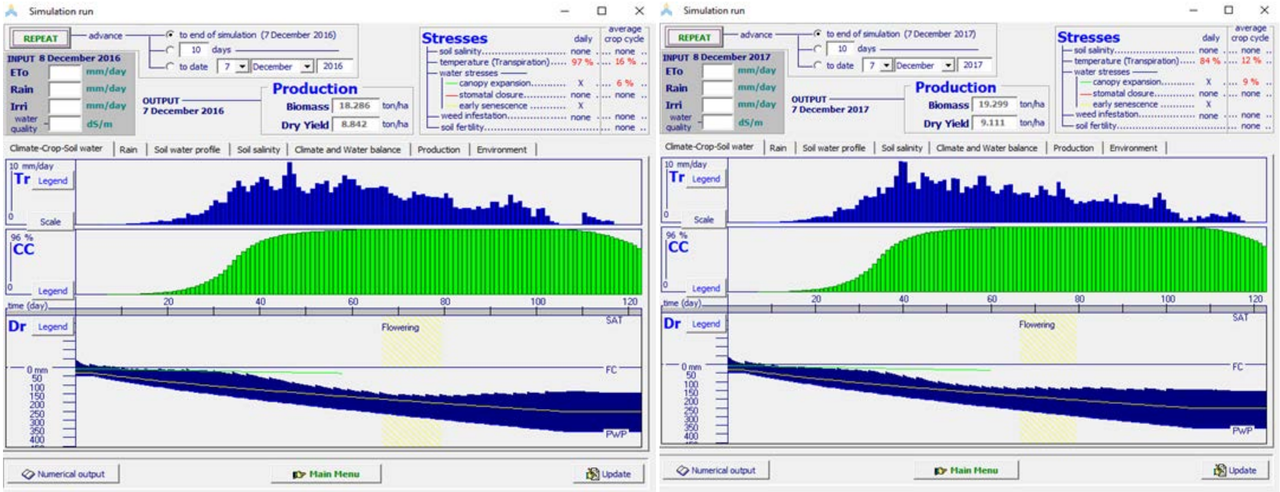
Figure 5. Biomass and grain yield for $I_1$ 2016 and 2017 seasons.



Simulation run — to end of simulation (7 December 2016); 10 days; to date 7 December 2016
INPUT 8 December 2016
OUTPUT 7 December 2016
Production: Biomass 17.254 ton/ha; Dry Yield 7.592 ton/ha
Stresses (daily / average crop cycle): soil salinity none / none; temperature (Transpiration) 97 % / 16 %; water stresses: canopy expansion X / 1 %; stomatal closure none / none; early senescence X; weed infestation none / none; soil fertility none

Simulation run — to end of simulation (7 December 2017); 10 days; to date 7 December 2017
INPUT 8 December 2017
OUTPUT 7 December 2017
Production: Biomass 17.599 ton/ha; Dry Yield 7.744 ton/ha
Stresses (daily / average crop cycle): soil salinity none / none; temperature (Transpiration) 84 % / 12 %; water stresses: canopy expansion X / 1 %; stomatal closure none / none; early senescence X; weed infestation none / none; soil fertility none

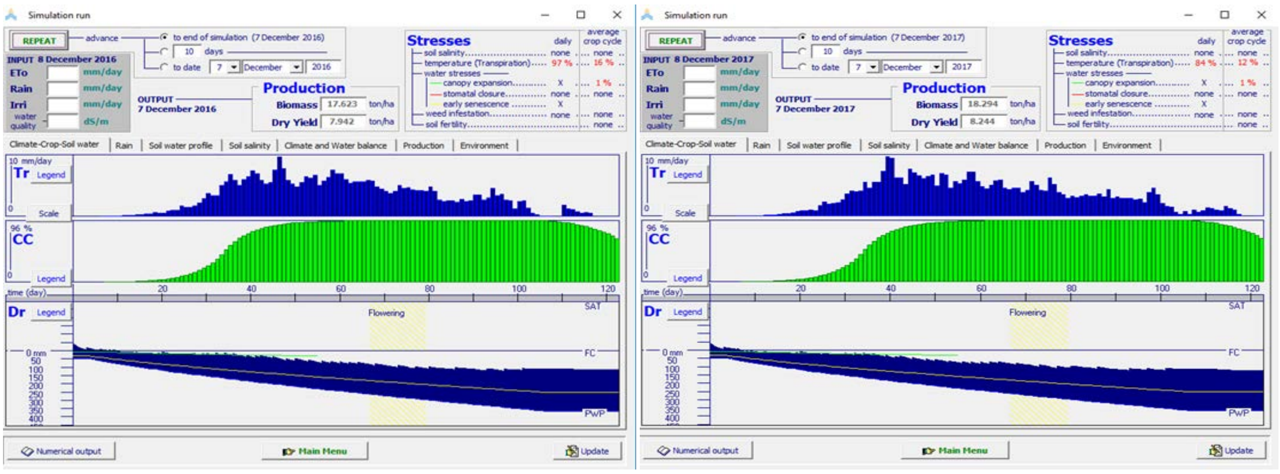
**Figure 6.** Biomass and grain yield for I₂ 2016 and 2017 seasons.



Simulation run — to end of simulation (7 December 2016); 10 days; to date 7 December 2016
INPUT 8 December 2016
OUTPUT 7 December 2016
Production: Biomass 18.286 ton/ha; Dry Yield 8.842 ton/ha
Stresses (daily / average crop cycle): soil salinity none / none; temperature (Transpiration) 97 % / 16 %; water stresses: canopy expansion X / 6 %; stomatal closure none / none; early senescence X; weed infestation none / none; soil fertility none

Simulation run — to end of simulation (7 December 2017); 10 days; to date 7 December 2017
INPUT 8 December 2017
OUTPUT 7 December 2017
Production: Biomass 19.299 ton/ha; Dry Yield 9.111 ton/ha
Stresses (daily / average crop cycle): soil salinity none / none; temperature (Transpiration) 84 % / 12 %; water stresses: canopy expansion X / 9 %; stomatal closure none / none; early senescence X; weed infestation none / none; soil fertility none

**Figure 7.** Biomass and grain yield for I₃ 2016 and 2017 seasons.



Simulation run — to end of simulation (7 December 2016); 10 days; to date 7 December 2016
INPUT 8 December 2016
OUTPUT 7 December 2016
Production: Biomass 17.623 ton/ha; Dry Yield 7.942 ton/ha
Stresses (daily / average crop cycle): soil salinity none / none; temperature (Transpiration) 97 % / 16 %; water stresses: canopy expansion X / 1 %; stomatal closure none / none; early senescence X; weed infestation none / none; soil fertility none

Simulation run — to end of simulation (7 December 2017); 10 days; to date 7 December 2017
INPUT 8 December 2017
OUTPUT 7 December 2017
Production: Biomass 18.294 ton/ha; Dry Yield 8.244 ton/ha
Stresses (daily / average crop cycle): soil salinity none / none; temperature (Transpiration) 84 % / 12 %; water stresses: canopy expansion X / 1 %; stomatal closure none / none; early senescence X; weed infestation none / none; soil fertility none

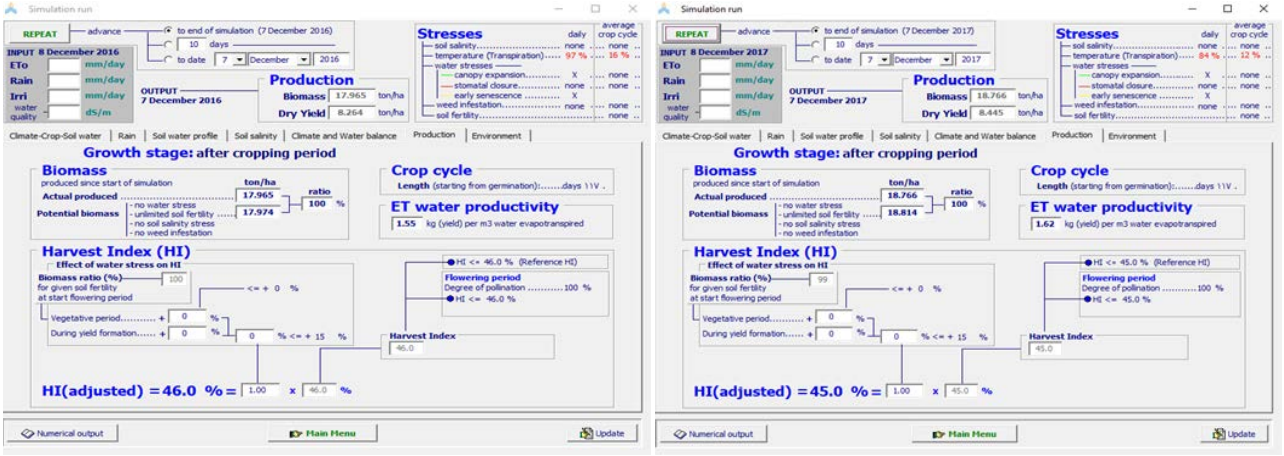
**Figure 8.** Biomass and grain yield for I₄ 2016 and 2017 seasons.

methods confirming the models validity for use in irrigation management of the maize. These results are consistent with findings of precise the authors [39] [40].

Simulating the final harvest index for all treatments are shown in **Table 5** and **Figures 9-13**. Deviation ranged for the harvest index values between 3.4% for $I_1$ treatment in 2016 as the highest value and lowest values of 0.1% for $I_0$ in 2017 season. The deviation from the harvest index values is very low due to the matching between the values of biomass and grain yield. Biomass and grain yield were slightly underestimating for all treatments. However, it was well matching within the recommended vicinity of the default and the measured values. As for water productivity, it showed high-value deviations between dated and measured that ranged between +38.3% for $I_0$ treatment in 2016 season and −32.7% in 2017 season. Deviation values for water productivity were negative for some irrigation treatments I2 (−9%), $I_3$ (−30.22) and $I_4$ (−24.2) in 2016 season and $I_2$ (−14.6%),

**Table 5.** Simulation values were compared with the measured value and standard deviations of harvest index and water productivity ($kg \cdot m^{-3}$) for maize under different irrigation methods for the 2016 and 2017 seasons.

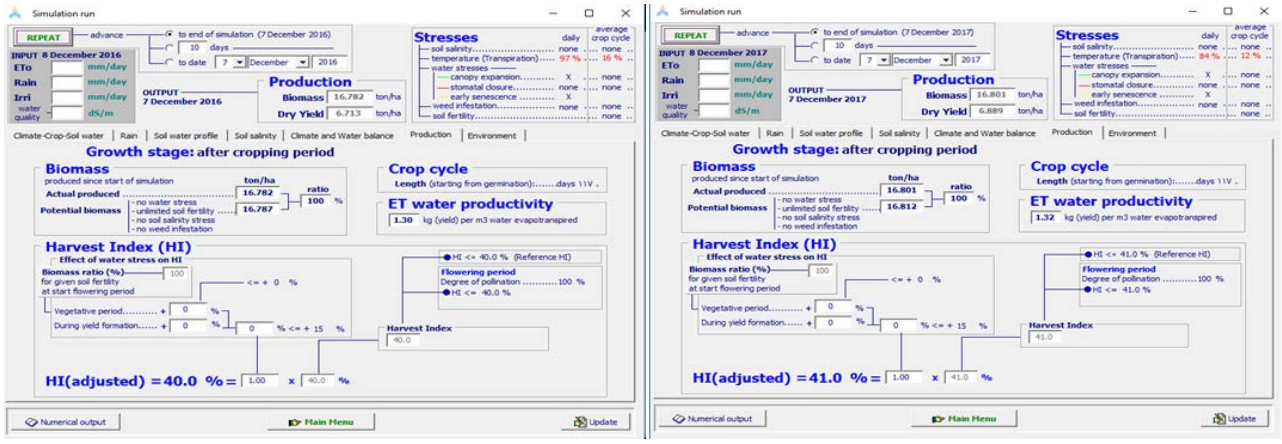
| Irrigation treatment | Harvest Index | | | Water productivity ($kg \cdot m^{-3}$) | | |
|---|---|---|---|---|---|---|
| | Measured | Simulated | Deviation (%) | Measured | Simulated | Deviation (%) |
| | | | 2016 | | | |
| $I_0$ | 45.1 | 46.00 | 2.0 | 1.12 | 1.55 | 38.3 |
| $I_1$ | 38.66 | 40.00 | 3.4 | 1.14 | 1.3 | 14.0 |
| $I_2$ | 43.42 | 44.00 | 1.3 | 1.85 | 1.68 | −9.0 |
| $I_3$ | 47.65 | 48.00 | 0.7 | 2.71 | 1.89 | −30.2 |
| $I_4$ | 44.33 | 45.00 | 1.5 | 2.23 | 1.69 | −24.2 |
| | | | 2017 | | | |
| $I_0$ | 44.95 | 45.00 | 0.1 | 1.2 | 1.62 | 35.0 |
| $I_1$ | 39.97 | 41.00 | 2.5 | 1.26 | 1.32 | 4.7 |
| $I_2$ | 42.97 | 44.00 | 2.4 | 1.98 | 1.69 | −14.6 |
| $I_3$ | 46.38 | 47.00 | 1.3 | 2.99 | 2.01 | 32.7 |
| $I_4$ | 44.02 | 45.00 | 2.2 | 2.45 | 1.72 | −29.7 |



Simulation run
advance: to end of simulation (7 December 2016)
INPUT 8 December 2016
OUTPUT 7 December 2016
Production: Biomass 17.965 ton/ha; Dry Yield 8.264 ton/ha
Stresses (daily / average crop cycle): soil salinity none / none; temperature (Transpiration) 97 % / 16 %; canopy expansion X / none; stomatal closure none / none; early senescence X; weed infestation none / none; soil fertility none
Growth stage: after cropping period
Biomass: Actual produced 17.965 ton/ha; Potential biomass 17.974 ton/ha; ratio 100 %
ET water productivity: 1.55 kg (yield) per m3 water evapotranspired
Harvest Index (HI): Biomass ratio (%) 100; Vegetative period + 0 %; During yield formation + 0 %; HI <= 46.0 % (Reference HI); Degree of pollination 100 %; HI <= 46.0 %; Harvest Index 46.0
HI(adjusted) = 46.0 % = 1.00 x 46.0 %

Simulation run
advance: to end of simulation (7 December 2017)
INPUT 8 December 2017
OUTPUT 7 December 2017
Production: Biomass 18.766 ton/ha; Dry Yield 8.445 ton/ha
Stresses (daily / average crop cycle): soil salinity none / none; temperature (Transpiration) 84 % / 12 %; canopy expansion X / none; stomatal closure none / none; early senescence X; weed infestation none / none; soil fertility none
Growth stage: after cropping period
Biomass: Actual produced 18.766 ton/ha; Potential biomass 18.814 ton/ha; ratio 100 %
ET water productivity: 1.62 kg (yield) per m3 water evapotranspired
Harvest Index (HI): Biomass ratio (%) 99; Vegetative period + 0 %; During yield formation + 0 %; HI <= 45.0 % (Reference HI); Degree of pollination 100 %; HI <= 45.0 %; Harvest Index 45.0
HI(adjusted) = 45.0 % = 1.00 x 45.0 %

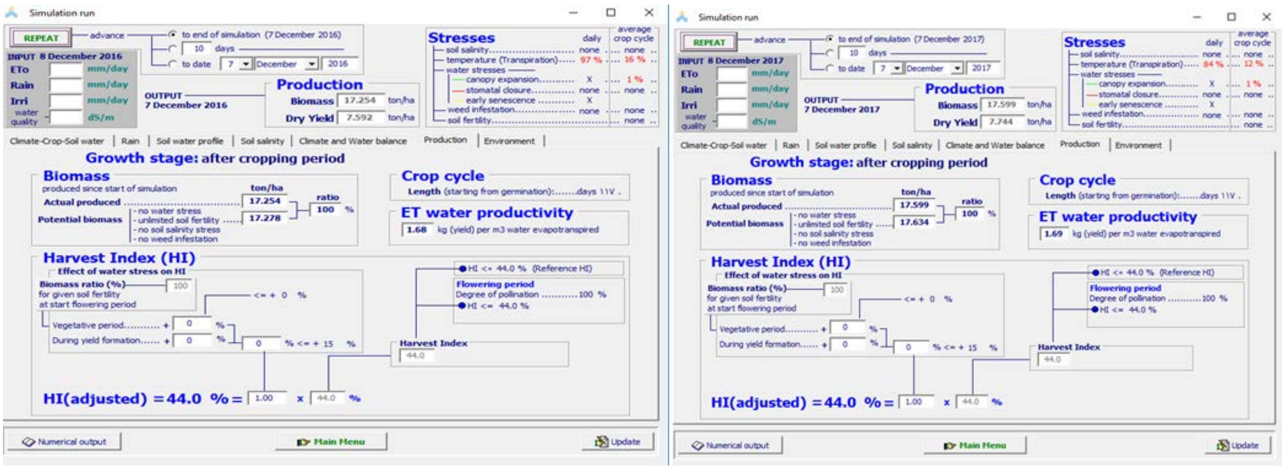
**Figure 9.** Harvest index and water productivity for $I_0$ 2016 and 2017 seasons.



Simulation run (2016)
advance: ● to end of simulation (7 December 2016); ○ 10 days; ○ to date 7 December 2016
INPUT 8 December 2016: ETo mm/day; Rain mm/day; Irri mm/day; water quality dS/m
OUTPUT 7 December 2016
Production: Biomass 16.782 ton/ha; Dry Yield 6.713 ton/ha
Stresses (daily / average crop cycle): soil salinity none / none; temperature (Transpiration) 97 % / 16 %; water stresses: canopy expansion X / none; stomatal closure none / none; early senescence X; weed infestation none / none; soil fertility none
Growth stage: after cropping period
Biomass produced since start of simulation (ton/ha): Actual produced 16.782; Potential biomass (no water stress, unlimited soil fertility, no soil salinity stress, no weed infestation) 16.787; ratio 100 %
Crop cycle: Length (starting from germination):.......days
ET water productivity: 1.30 kg (yield) per m3 water evapotranspired
Harvest Index (HI): Effect of water stress on HI: Biomass ratio (%) for given soil fertility at start flowering period 100; <= + 0 %; Vegetative period + 0 %; During yield formation + 0 %; 0 % <= + 15 %
HI <= 40.0 % (Reference HI); Flowering period: Degree of pollination 100 %; HI <= 40.0 %
Harvest Index 40.0
HI(adjusted) = 40.0 % = 1.00 x 40.0 %

Simulation run (2017)
advance: ● to end of simulation (7 December 2017); ○ 10 days; ○ to date 7 December 2017
INPUT 8 December 2017: ETo mm/day; Rain mm/day; Irri mm/day; water quality dS/m
OUTPUT 7 December 2017
Production: Biomass 16.801 ton/ha; Dry Yield 6.889 ton/ha
Stresses (daily / average crop cycle): soil salinity none / none; temperature (Transpiration) 84 % / 12 %; water stresses: canopy expansion X / none; stomatal closure none / none; early senescence X; weed infestation none / none; soil fertility none
Growth stage: after cropping period
Biomass produced since start of simulation (ton/ha): Actual produced 16.801; Potential biomass (no water stress, unlimited soil fertility, no soil salinity stress, no weed infestation) 16.812; ratio 100 %
Crop cycle: Length (starting from germination):.......days
ET water productivity: 1.32 kg (yield) per m3 water evapotranspired
Harvest Index (HI): Effect of water stress on HI: Biomass ratio (%) for given soil fertility at start flowering period 100; <= + 0 %; Vegetative period + 0 %; During yield formation + 0 %; 0 % <= + 15 %
HI <= 41.0 % (Reference HI); Flowering period: Degree of pollination 100 %; HI <= 41.0 %
Harvest Index 41.0
HI(adjusted) = 41.0 % = 1.00 x 41.0 %

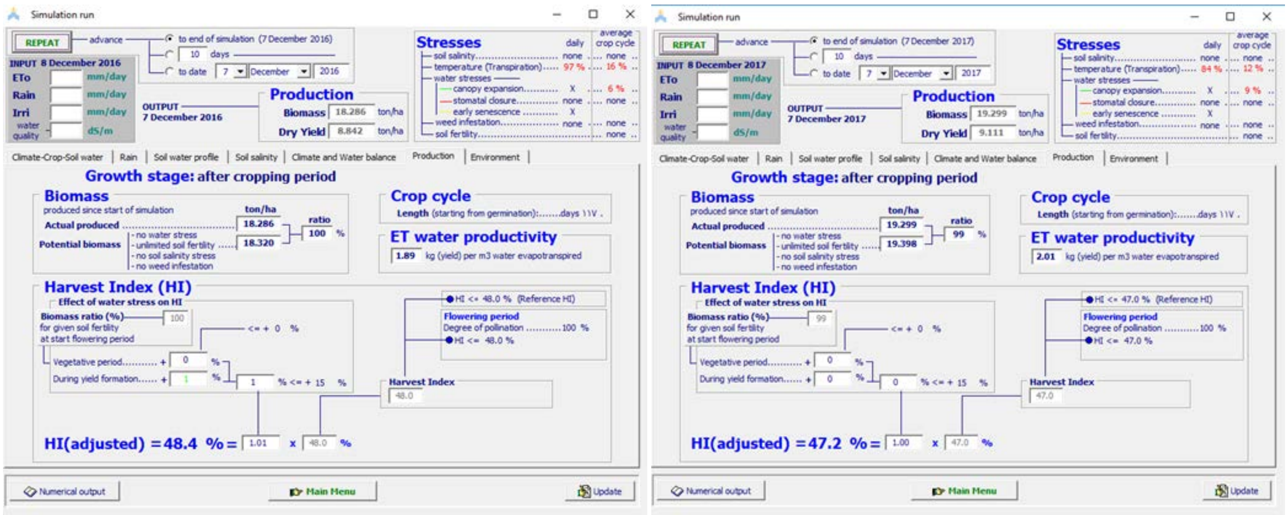
**Figure 10.** Harvest index and water productivity for $I_1$ 2016 and 2017 seasons.



Simulation run (2016)
advance: ● to end of simulation (7 December 2016); ○ 10 days; ○ to date 7 December 2016
INPUT 8 December 2016: ETo mm/day; Rain mm/day; Irri mm/day; water quality dS/m
OUTPUT 7 December 2016
Production: Biomass 17.254 ton/ha; Dry Yield 7.592 ton/ha
Stresses (daily / average crop cycle): soil salinity none / none; temperature (Transpiration) 97 % / 16 %; water stresses: canopy expansion X / 1 %; stomatal closure none / none; early senescence X; weed infestation none / none; soil fertility none
Growth stage: after cropping period
Biomass produced since start of simulation (ton/ha): Actual produced 17.254; Potential biomass (no water stress, unlimited soil fertility, no soil salinity stress, no weed infestation) 17.278; ratio 100 %
Crop cycle: Length (starting from germination):.......days
ET water productivity: 1.68 kg (yield) per m3 water evapotranspired
Harvest Index (HI): Effect of water stress on HI: Biomass ratio (%) for given soil fertility at start flowering period 100; <= + 0 %; Vegetative period + 0 %; During yield formation + 0 %; 0 % <= + 15 %
HI <= 44.0 % (Reference HI); Flowering period: Degree of pollination 100 %; HI <= 44.0 %
Harvest Index 44.0
HI(adjusted) = 44.0 % = 1.00 x 44.0 %

Simulation run (2017)
advance: ● to end of simulation (7 December 2017); ○ 10 days; ○ to date 7 December 2017
INPUT 8 December 2017: ETo mm/day; Rain mm/day; Irri mm/day; water quality dS/m
OUTPUT 7 December 2017
Production: Biomass 17.599 ton/ha; Dry Yield 7.744 ton/ha
Stresses (daily / average crop cycle): soil salinity none / none; temperature (Transpiration) 84 % / 12 %; water stresses: canopy expansion X / 1 %; stomatal closure none / none; early senescence X; weed infestation none / none; soil fertility none
Growth stage: after cropping period
Biomass produced since start of simulation (ton/ha): Actual produced 17.599; Potential biomass (no water stress, unlimited soil fertility, no soil salinity stress, no weed infestation) 17.634; ratio 100 %
Crop cycle: Length (starting from germination):.......days
ET water productivity: 1.69 kg (yield) per m3 water evapotranspired
Harvest Index (HI): Effect of water stress on HI: Biomass ratio (%) for given soil fertility at start flowering period 100; <= + 0 %; Vegetative period + 0 %; During yield formation + 0 %; 0 % <= + 15 %
HI <= 44.0 % (Reference HI); Flowering period: Degree of pollination 100 %; HI <= 44.0 %
Harvest Index 44.0
HI(adjusted) = 44.0 % = 1.00 x 44.0 %

**Figure 11.** Harvest index and water productivity for $I_2$ 2016 and 2017 seasons.

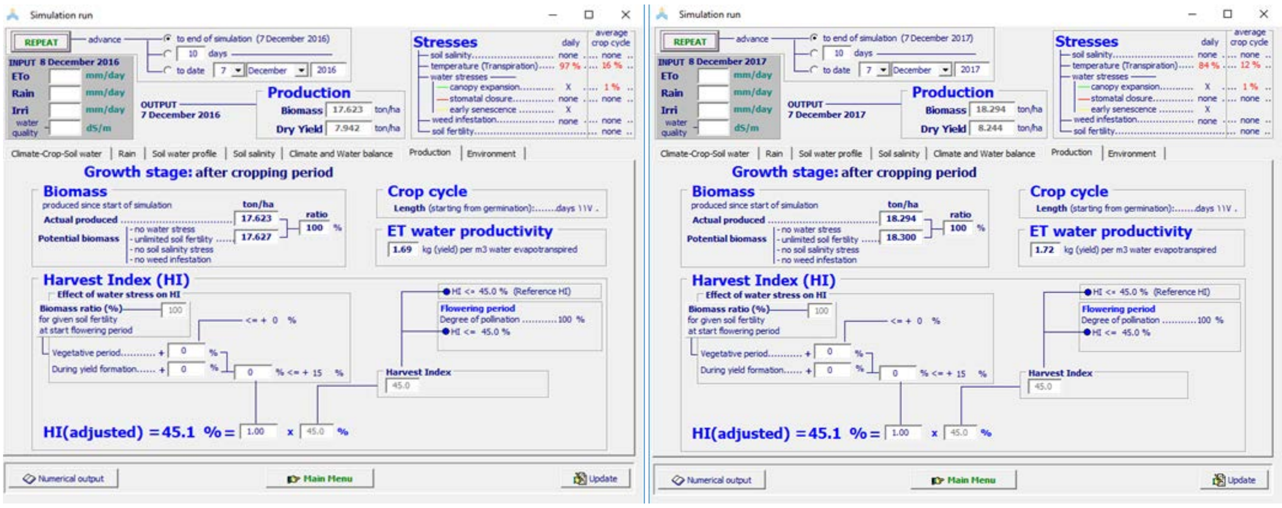


Simulation run (2016)
advance: ● to end of simulation (7 December 2016); ○ 10 days; ○ to date 7 December 2016
INPUT 8 December 2016: ETo mm/day; Rain mm/day; Irri mm/day; water quality dS/m
OUTPUT 7 December 2016
Production: Biomass 18.286 ton/ha; Dry Yield 8.842 ton/ha
Stresses (daily / average crop cycle): soil salinity none / none; temperature (Transpiration) 97 % / 16 %; water stresses: canopy expansion X / 6 %; stomatal closure none / none; early senescence X; weed infestation none / none; soil fertility none
Growth stage: after cropping period
Biomass produced since start of simulation (ton/ha): Actual produced 18.286; Potential biomass (no water stress, unlimited soil fertility, no soil salinity stress, no weed infestation) 18.320; ratio 100 %
Crop cycle: Length (starting from germination):.......days
ET water productivity: 1.89 kg (yield) per m3 water evapotranspired
Harvest Index (HI): Effect of water stress on HI: Biomass ratio (%) for given soil fertility at start flowering period 100; <= + 0 %; Vegetative period + 0 %; During yield formation + 1 %; 1 % <= + 15 %
HI <= 48.0 % (Reference HI); Flowering period: Degree of pollination 100 %; HI <= 48.0 %
Harvest Index 48.0
HI(adjusted) = 48.4 % = 1.01 x 48.0 %

Simulation run (2017)
advance: ● to end of simulation (7 December 2017); ○ 10 days; ○ to date 7 December 2017
INPUT 8 December 2017: ETo mm/day; Rain mm/day; Irri mm/day; water quality dS/m
OUTPUT 7 December 2017
Production: Biomass 19.299 ton/ha; Dry Yield 9.111 ton/ha
Stresses (daily / average crop cycle): soil salinity none / none; temperature (Transpiration) 84 % / 12 %; water stresses: canopy expansion X / 9 %; stomatal closure none / none; early senescence X; weed infestation none / none; soil fertility none
Growth stage: after cropping period
Biomass produced since start of simulation (ton/ha): Actual produced 19.299; Potential biomass (no water stress, unlimited soil fertility, no soil salinity stress, no weed infestation) 19.398; ratio 99 %
Crop cycle: Length (starting from germination):.......days
ET water productivity: 2.01 kg (yield) per m3 water evapotranspired
Harvest Index (HI): Effect of water stress on HI: Biomass ratio (%) for given soil fertility at start flowering period 99; <= + 0 %; Vegetative period + 0 %; During yield formation + 0 %; 0 % <= + 15 %
HI <= 47.0 % (Reference HI); Flowering period: Degree of pollination 100 %; HI <= 47.0 %
Harvest Index 47.0
HI(adjusted) = 47.2 % = 1.00 x 47.0 %

**Figure 12.** Harvest index and water productivity for $I_3$ 2016 and 2017 seasons.

$I_3$ (−32.7%) and $I_4$ (−29.75%) in 2017 season, and positive for others $I_0$ (30.3%) and $I_1$ (14%) in 2016 season and $I_0$ (35%) and $I_1$ (4.7%) in 2017 season. The



Simulation run (2016)

advance — ● to end of simulation (7 December 2016) ○ 10 days ○ to date 7 December 2016

INPUT 8 December 2016
ETo mm/day
Rain mm/day
Irri mm/day
water quality dS/m

OUTPUT 7 December 2016

**Production**
Biomass 17.623 ton/ha
Dry Yield 7.942 ton/ha

| Stresses | daily | average crop cycle |
|---|---|---|
| soil salinity | none | none |
| temperature (Transpiration) | 97 % | 16 % |
| water stresses | | |
| canopy expansion | X | 1 % |
| stomatal closure | none | none |
| early senescence | X | |
| weed infestation | none | none |
| soil fertility | | none |

Growth stage: after cropping period

**Biomass** produced since start of simulation (ton/ha)
Actual produced 17.623
Potential biomass (no water stress, unlimited soil fertility, no soil salinity stress, no weed infestation) 17.627
ratio 100 %

**Crop cycle** Length (starting from germination):.......days 11V .

**ET water productivity** 1.69 kg (yield) per m3 water evapotranspired

**Harvest Index (HI)**
Effect of water stress on HI
Biomass ratio (%) for given soil fertility at start flowering period 100 — <= + 0 %
Vegetative period + 0 %
During yield formation + 0 %
0 % <= + 15 %
HI <= 45.0 % (Reference HI)
Flowering period: Degree of pollination 100 %; HI <= 45.0 %
Harvest Index 45.0
HI(adjusted) = 45.1 % = 1.00 x 45.0 %

Simulation run (2017)

advance — ● to end of simulation (7 December 2017) ○ 10 days ○ to date 7 December 2017

INPUT 8 December 2017
ETo mm/day
Rain mm/day
Irri mm/day
water quality dS/m

OUTPUT 7 December 2017

**Production**
Biomass 18.294 ton/ha
Dry Yield 8.244 ton/ha

| Stresses | daily | average crop cycle |
|---|---|---|
| soil salinity | none | none |
| temperature (Transpiration) | 84 % | 12 % |
| water stresses | | |
| canopy expansion | X | 1 % |
| stomatal closure | none | none |
| early senescence | X | |
| weed infestation | none | none |
| soil fertility | | none |

Growth stage: after cropping period

**Biomass** produced since start of simulation (ton/ha)
Actual produced 18.294
Potential biomass (no water stress, unlimited soil fertility, no soil salinity stress, no weed infestation) 18.300
ratio 100 %

**Crop cycle** Length (starting from germination):.......days 11V .

**ET water productivity** 1.72 kg (yield) per m3 water evapotranspired

**Harvest Index (HI)**
Effect of water stress on HI
Biomass ratio (%) for given soil fertility at start flowering period 100 — <= + 0 %
Vegetative period + 0 %
During yield formation + 0 %
0 % <= + 15 %
HI <= 45.0 % (Reference HI)
Flowering period: Degree of pollination 100 %; HI <= 45.0 %
Harvest Index 45.0
HI(adjusted) = 45.1 % = 1.00 x 45.0 %

**Figure 13.** Harvest index and water productivity for $I_4$ 2016 and 2017 seasons.

increase in the deviation values between the simulated and measured values of water productivity may be due to the increased water requirement for $I_0$ treatment, and as a result of losses due runoff, deep percolation and evaporation compared to subsurface drip and the low water productivity in surface drip irrigation $I_1$ treatment This because the water droplets that fall on the surface of the soil are exposure to evaporation because the soil texture is heavy and does not allow the water to percolate in the depths of the soil quickly and due to the high temperature and exposure of the soil surface to direct sun radiation. Meaning that the evaporation of water is faster than its percolation to root zone, As for the furrow irrigation $I_0$ treatment, the soil receives a sufficient amount of moisture because the water column cause a pressure that helps to quickly Percolation the wash to the depths of the soil where the root zone.

However, the disadvantage of this method are losses due to surface run off deep percolation and evaporation from the soil surface Therefore water requirements in crease which reduces the water use efficiency for this method and since the efficiency of water use is the a main goal for the irrigation process in arid and semi-and regions. Water productivity is a measure of water use efficiency, and the efficiency is determined by their two factors the amount of irrigation water used and the amount of grain yield produced according to the Equation (6), as the efficiency to water use decrease as the amount of water used increase and this is what happened with the furrow irrigation method, or the yield may decrease by a high percentage, despite the decrease in the amount of water used, which cause a decrease in the efficiency of water use, which reflects on water productivity. [41] [42]. Thus, AquaCrop model is efficient in managing the irrigation of maize and predicting the outputs that will be obtained.

Figures 14-16 show that the simulated values of biomass, grain yield and harvest index had been concentrated to be close to the line 1:1 and this explains the overestimation or underestimation in yield between simulated and experimental values The low mean value of biomass, grain yield and harvest index in

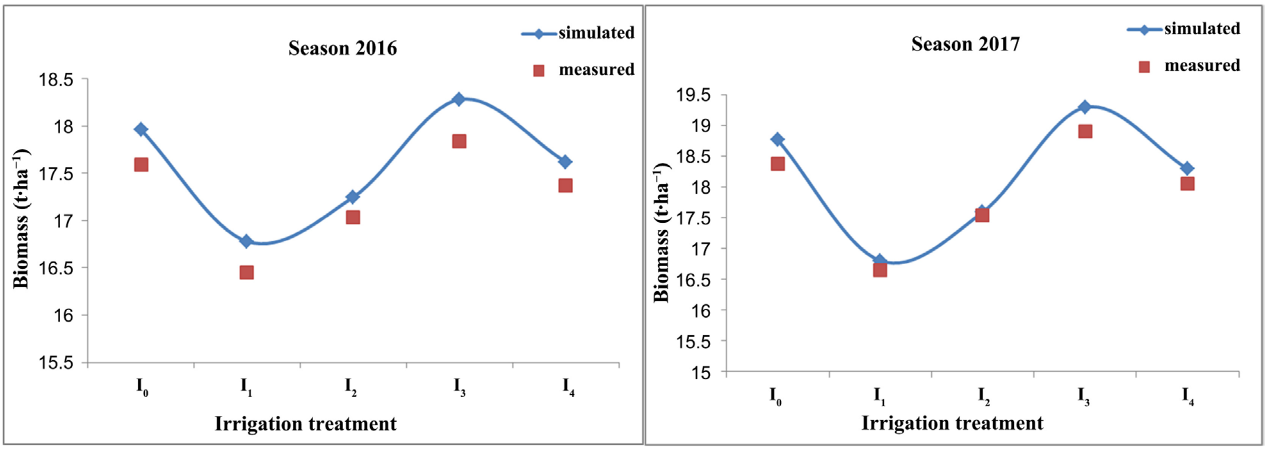


**Figure 14.** Simulated and measured biomass (t·ha$^{-1}$) 2016 and 2017 seasons.

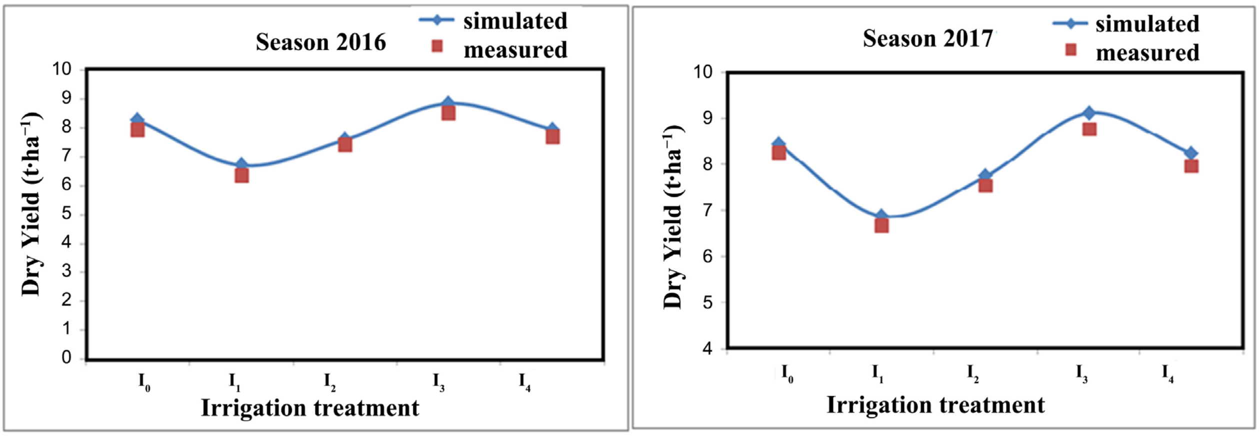


**Figure 15.** Simulated and measured dry yield (t·ha$^{-1}$) 2016 and 2017 seasons.

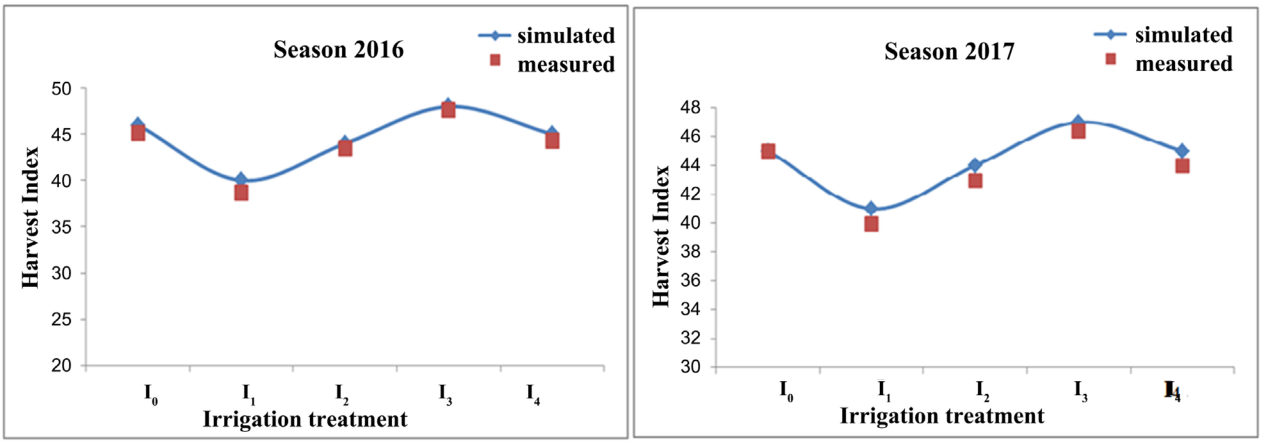


**Figure 16.** Simulated and measured harvest index 2016 and 2017 seasons.

the surface and subsurface drip irrigation $I_1$ and $I_2$ treatments are due to decrease of moisture, lead to disturbance such as photosynthesis, respirator, erosion, water absorption and nutrients. It also affects the cellular division that leads to a decrease in the number of divided cells and prolong the period needed to divide,

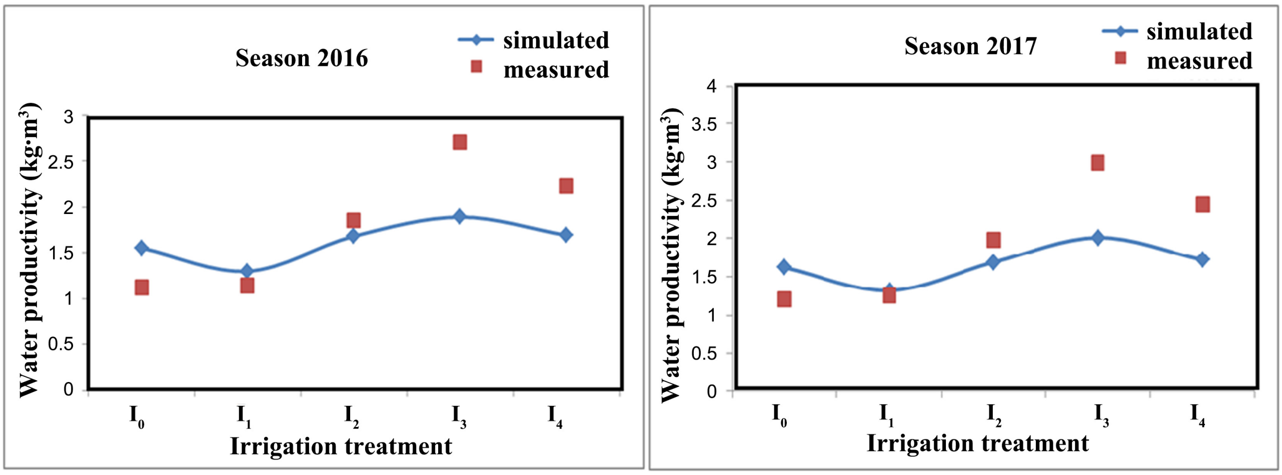


**Figure 17.** Simulated and measured water productivity (kg·m$^{-3}$) 2016 and 2017 seasons.

all of which has reduced the grain yield and the biomass while the harvest index reflects the efficiency of transporting Biomass from parts of the plant towards grains and that the process of transport depends on growth factors and the lack of exposure of the plant to environmental effects, including water stress for seasons 2016 and 2017 respectively [43] [44] [45]. The furrow irrigation method treatment $I_0$ provided sufficient moisture in the root zoon, but led to the consumption of high amounts of water due to the low efficiency of furrow irrigation method.

Figure 17 shows the presence of dispersion of the most simulated values of water productivity compared with other attributes (biomass, grain yield and harvest index). Simulation values of water productivity showed a lower estimate than the measured except for the two treatments $I_1$ and $I_0$ for the two seasons as it gave an increase in the measured compared with simulated by 14% and 38.3% in 2016 season and −47% and 35% in 2017 season. It is clear from the above that for the least experimental data of soil and crop management, AquaCrop gave superior and excellent results for biomass, grain yield and harvest index and, to a lesser extent, to water productivity considering lack of data we need to reach this accuracy [46] [47]. Applied descriptive statistics showed that AquaCrop predicts outputs very well with appropriate accuracy and the lowest input data and satisfactory performance in the central region of Iraq and finally simplicity cannot be overlooked, however, the performance of any model in any site depends on the ideal set of parameters and validation of performance under a wide range of crops conditions.

## 4. Conclusion

This study showed that the subsurface drip irrigation with a depth of 20 cm $I_3$ was the best among other irrigation methods in terms of yield and water use efficiency, which are the two main objectives of the irrigation process. The results of this study revealed that the AquaCrop model fits to predict biomass, grain yield and harvest index with a high degree of reliability under different irrigation methods through the agreement between simulated and measured value for biomass, grain yield and harvest index is considered satisfactorily. Then, it is concluded that the AquaCrop model is an efficient tool to help and support decision-makers for irrigation management strategies. The results indicated that the deviation of the measured values from the simulation was very low with respect to biomass, grain yield and harvest index, ranging between (1.3% to 2.4%) and (0.2% to 2%), (2.5% to 5.5%), (2.1% to 4%) and (0.7% to 3.4%), (0.1% to 2.5%) for the 2016 and 2017 seasons; respectively. This indicates that AquaCrop model simulates well the conditions in which water is the limiting factor for crop production. While the deviation value of water productivity ranged between (−30.2% to 38.3%), (−29.7% to 35.0%) for 2016 and 2017 seasons; respectively. Statistical procedure results of Mean Bias Error (MBE), Root Mean Square Error (RMSE), Coefficient efficiency ($E$) and Agreement index ($d$) confirm that AquaCrop has a high ability to simulate biomass yield, grain yield and harvest index with high accuracy

## Acknowledgements

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## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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