Assessment of AquaCrop Model in Simulating Wheat Crop Water Use and Productivity in Middle Egypt

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ABSTRACT

The high cost of applied research and the effect of many environmental parameters limiting yield production encouraged researchers to develop and implement empirical models able to simulate and predict crop yield close to that obtained under field conditions. The Food and Agriculture Organization (FAO) AquaCrop model is one of these models. It was calibrated and validated for its ability to simulate growth, biomass and grain yields and crop evapotranspiration of wheat (Misr 2 cultivar) using two-year observed data of a field experiment conducted on clay soil under Giza (middle Egypt) condition during 2018/2019 and 2019/2020 seasons. The effect of three irrigation intervals (I1: 21 days; I2: 28 days; and I3: 35 days) on wheat yield and its components and on some water relations was tested. After model calibration/validation processes, four sowing dates (10 and 25 November, 10 and 25 December) with four irrigation intervals and one deficit irrigation treatment were used as scenarios for adaptation study. The root mean square error (RMSE), coefficient of determination (R2), and percentage difference (Pd) statistical parameters were used to evaluate the model performance. Results revealed that the predicted data by AquaCrop were in close agreement with the measured data. The observed values were within 90 to 99% of the predicted values in the 1st season, and within 91 to 100% in the 2nd season. Statistical analysis results showed a strong linear relationship between the simulated and the measured data under different irrigation interval treatments in both seasons. The best-fitting model result was obtained with growing session duration with average values of two seasons for R2(0.98), RMSE(5.23 days) and Pd(0.98%) followed by the simulated biomass yield with values of 0.97, 363 kg ha⁻¹ and 0.99%. The corresponding values of grain yield were 0.94, 355 kg ha⁻¹ and 0.95%, respectively. The crop water use values were 0.95, 35mm and 0.91%. The results of adaptation study showed that increasing soil moisture content increased simulated aboveground biomass, grain yield and ET crop. Results indicated also that sowing wheat cultivar Maser 2 at Giza region from 10 to 20 November with irrigating crop every 28 days maximize yield and save about 16.3% of irrigation water. The overall results based on extensive validation of the model indicated that AquaCrop is a valid model and can be used with a reliable degree of accuracy to predict wheat yield.

Keywords: AquaCrop, simulation and adaptation, irrigation interval, sowing date, wheat simulated yields

1. Introduction

Wheat is produced in Egypt as the most important strategic winter crop by about 4.3 million farmers, which is the main component of subsidized bread. The total cultivated area of 3.8 million acres all of which are irrigated, products amounted to approximately 8.77 million metric tons in 2018, with an increase of 1.48 % from the preceding year. Despite the scale of production, and due to the rapid increase of population, the production of wheat does not meet the county's demands (McGill et al., 2015). Therefore Egypt imports 11-12 million tons of wheat annually (Isin and Panos, 2017)’s annual brief). The main target of the agriculture sector is filling the gap between production and consumption.
by increasing production which will lower imports, save foreign exchange (Shideed et al., 2010). The agriculture sector accounts for about 86% of Egyptian water use (FAO 2017).

Water availability one of the most binding constraints to increased crop production, and it is increasingly scarce as urbanization and industrialization compete with agriculture for water use (El Kharrraz et al., 2012). Various studies have shown that one of the promising irrigation strategies may be deficit irrigation combined with economic crop production (Fereres and Soriano 2007; Farre and Faci (2009) and Geerts and Raes, 2009). Although this inevitably results in crop water stress and yield depression, high yield can still be obtained by supplying the required amount of irrigation water according to suitable irrigation frequency (interval days) to sensitive crop growth stages. The time interval between irrigation applications is a crucial factor for irrigation management due to it affects soil-moisture distribution, root distribution, water uptake by roots, and water percolation under the root zone Wang et al., (2006). For these reasons, crop yield and WUE depend on irrigation interval days and can thus differ even for the same total amount of irrigation. Irrigation frequency can change the spatial distribution of soil moisture and soil-water storage Cao et al., (2003). High-frequency (once every three days) under drip irrigation produced higher soil moisture in the 0–20 cm soil layer than in the deep soil layer, whereas low-frequency (once every 10 days) favored water infiltration and lateral infiltration Liu et al., (2011).

Compiling many cultivation practices i.e. the sowing date with irrigation frequency and crop varieties maybe lead to enhancing growth conditions and increases final production. In this respect, Meena et al., (2016) reported that wheat productivity irrigated with a moderate amount of water can be increased substantially by adjusting the sowing date to optimum atmospheric temperature for variety cultivated.

The crop growth models have been successfully used for decades to inspect crop responses to environmental stresses and to test alternate management practices by researchers around the world (Stockle et al., 2003; Behera and Panda, 2009, and Steduto et al., 2009). The AquaCrop model (Raes et al., 2009; Steduto et al., 2009) was developed by the Land and Water Division of FAO to assess the effect of environment and management on crop production and simulates yield response to water use by crops. It is particularly suited to address conditions where water is a key limiting factor in crop production, which it helps the making decision and devising strategies for efficient management of crop-water productivity. In addition, AquaCrop simulates soil evaporation and crop transpiration explicitly as individual processes. The advantage of this model is that, maintains a balance between robustness and output accuracy with a minimum of input data as a generic crop water productivity (WP) model (Raes et al., 2009). However, due to various parameters of the culture and some are not universal, the model must be adjusted to local conditions, cultivars, and to different crop management practices to make it globally applicable. Many calibrations and performance evaluations have been done for wheat by Neha et al., (2017) in India, Jin et al., (2014) China. Andarzian et al., (2011) in Iran, Mkhabela and Paul (2012) in Canada and Touni et al., (2016) in Morocco.

The aims of the investigation were to: 1) evaluate the accuracy of the AquaCrop model in predicting the effect of three irrigation intervals (I1: 21 days; I2: 28 days; and I3: 35 days) on wheat biomass and grain yields and on some water relations, and 2) test the effect of different adaptation scenarios (four sowing dates: 10 and 25 November and 10 and 25 December) and five irrigation treatments on maximizing wheat yield, saving irrigation water, and optimizing water productivity under Middle Egypt (Giza region) conditions.

2. Materials and Methods

2.1. The field experiment

The field data used for model calibration/validation were obtained from a field experiment carried out at Giza Agricultural Research Station farm, Egypt, (30.03° latitude, 31.13° longitude, and 18.6m elevation) during the winter seasons of 2018-19 and 2019-20. The selected site represents the conditions of Middle Egypt. The experiment was laid out in a split-plot design with three replicates. The plot area was 48.0m² (6m x 8m). The main plots were assigned to three irrigation interval treatments (irrigation every 21, 28 and 35 days) and the sub-plots were assigned to three wheat cultivars namely: Giza 171, Misr 2 and Gimmiza 9. Sowing dates were 24 and 26 November in the first and second seasons, respectively. All cultural practices, including soil preparation, fertilization, weed and pest control, for wheat crop cultivation.
were followed according to the recommendation by the Ministry of Agriculture and Land Reclamation. Plant growth stages were monitored, recorded and used for model calibration. Plants were harvested on the 1st and 3rd of May of the two respective seasons. At harvest, the plants of each entire sub-plot were harvested in order to determine yield and yield components measurements. Traditional basin irrigation system was implemented and application of irrigation interval treatments started from the second irrigation. Data collected from Misr 2 cultivar were used to validate the AuaCrop model.

Soil samples were collected from the experimental site to determine particle size analysis (sand, silt, and clay %) and textural class (Table 2).

Crop water consumptive use (CU) values were determined by soil samples collected from the sub-plots just before and 48 hrs after each irrigation as well as at harvest. Sampling depths were taken at 15cm interval down to 60cm depth of the soil profile. The CU values were calculated according to Israelsen and Hansen (1962) as follows:

$$CU = \left( \frac{Q2 - Q1}{100} \right) \times Bd \times D$$

Where:
- **CU** = consumptive use or actual crop evapotranspiration (cm).
- **D** = effective root depth (cm).
- **Bd** = soil bulk density (g/cm$^3$).
- **Q2** = soil moisture percentage 48 hrs. after irrigation (% on mass basis).
- **Q1** = soil moisture percentage before irrigation (% on mass basis).

Agrometeorological data from the station located at Giza (Lat. 30:03°, Long. 31.13°, and 18.6m above mean sea level) were recorded. The station is 50m from the experimental site. Therefore, the weather data represent the field conditions reasonably well. Average monthly weather data for the two growing seasons are presented in Table (1).

### Table 1: Meteorological data at Giza Agriculture Research Station in 2018/2019 and 2019/2020 growing seasons.

| Season | Month   | Tmax (°C) | Tmin | RH  | WS  | RF  | SS  | SR  |
|--------|---------|-----------|------|-----|-----|-----|-----|-----|
|        | November| 26.9      | 15.5 | 57.7| 1.8 | 0.0 | 10.5| 14.6|
|        | December| 22.0      | 11.2 | 60.7| 1.5 | 2.0 | 10.1| 12.1|
|        | January  | 19.6      | 7.0  | 51.7| 1.6 | 0.0 | 10.3| 13.2|
|        | February | 21.8      | 8.1  | 53.0| 1.6 | 2.0 | 11.0| 20.0|
|        | March    | 23.7      | 12.0 | 50.0| 2.0 | 4.0 | 11.8| 23.6|
|        | April    | 28.5      | 14.5 | 46.3| 2.1 | 0.1 | 12.8| 27.8|
|        | May      | 35.5      | 19.0 | 25.0| 2.3 | 0.0 | 13.5| 30.0|
|        | Mean     | 25.4      | 12.5 | 49.2| 1.9 | 1.2 | 11.4| 20.2|
|        | 2019/2020| 2019/2020 |
|        | November | 26.6      | 14.9 | 55.3| 1.8 | 0.0 | 10.5| 17.0|
|        | December | 22.2      | 10.8 | 60.9| 1.8 | 3.0 | 9.2 | 15.5|
|        | January  | 19.6      | 9.2  | 57.4| 1.9 | 2.4 | 10.4| 16.5|
|        | February | 21.2      | 9.4  | 45.3| 1.9 | 4.8 | 11.0| 19.7|
|        | March    | 24.8      | 12.2 | 45.0| 2.6 | 17.0| 12.0| 24.0|
|        | April    | 29.1      | 14.3 | 34.0| 2.0 | 0.0 | 12.8| 27.7|
|        | May      | 34.6      | 19.1 | 29.3| 2.4 | 0.0 | 13.5| 29.9|
|        | Mean     | 25.5      | 12.8 | 46.8| 2.1 | 3.9 | 11.3| 21.5|

* T_max and T_min = maximum and minimum air temperatures (°C); WS = wind speed (m/sec); RF = rainfall (mm/month); SS = actual sun shine (h); SR = solar radiation (cal/cm$^2$/day).

#### 2.2. AquaCrop Model

The FAO AquaCrop model is a crop growth model developed to assess the effect of environment and management on crop production. The model uses a relative small number of parameters and input variables. Inputs consist of weather data, crop characteristics for the specific cultivar and tuned to the environment, soil characteristics, and management practices that define the environment in which the
crop will develop. The inputs are stored in climate, crop, soil and management files and can be easily retrieved (Steduto et al., 2009, and Raes et al., 2009).

In this study, the AquaCrop model was used to simulate and predict wheat biomass and grain yields, crop evapotranspiration (ETc) and water productivity (WP) under Giza region which represents Middle Egypt conditions. The model was calibrated and modified using data from field experiment described above. In the calibration process, the normalized water productivity ($WP^*$) was set at 15 g m$^{-2}$, biomass yield (BY) and the grain yield (GY) were calculated according Raes et al., (2018).

2.3. AquaCrop model simulation input files

2.3.1. Weather Data

AquaCrop requires minimum and maximum air temperatures, reference evapotranspiration (ETo), rainfall, and the mean annual CO$_2$ concentration (provided in AquaCrop). The ETo is derived from weather station data by means of the FAO Penman-Monteith equation. The data presented in Table 1 were used to calculate ETo values.

2.3.2. Soil Data:

Soil particle size distribution and textural class of the experimental site were determined according to Page et al., (1982) and the obtained values are presented in Table 2. Soil moisture constants and saturated hydraulic conductivity (Ks) were estimated by SAPW model Saxton et al., (2006) and presented in Table 3. The obtained values were used in adjusting soil profile file (*.SOL) required for calibrating the AquaCrop model.

Table 2: Soil particle size distribution and textural class of the experimental site.

| Soil fraction | Content (%) |
|---------------|-------------|
| Coarse sand   | 2.91        |
| Fine sand     | 16.40       |
| Silt          | 32.41       |
| Clay          | 48.28       |
| Textural class| Clay        |

Table 3: Estimated soil moisture constants, bulk density, and saturated hydraulic conductivity values of the soil at Giza Agricultural Research Station.

| Depth (cm) | Moisture constants (%) | Available water (mm) | Bulk density (g cm$^{-3}$) | Ksat. (mm hr$^{-1}$) |
|------------|------------------------|----------------------|----------------------------|---------------------|
| 0-20       | 39.1                   | 32.3                 | 1.17                       | 3.40                |
| 20-40      | 38.4                   | 38.2                 | 1.18                       | 3.64                |
| 40-70      | 34.8                   | 54.1                 | 1.21                       | 3.91                |

2.3.3. Crop input data

Crop file (*.CRO), including: cultivar selected in the study (Misr 2), sowing and harvest dates, seeding rate, plant density, and canopy cover were used. All input crop parameters used for simulation are described in Table (4). The data were stored in standard files “Wheat GDD.CRO” to be used in adjusted crop cycle and model calibration.

2.4. Irrigation management data

Irrigation files (*.IRR) were generated as suggested in the adaptation study scenarios. All input parameters required are presented in Table 5.

2.5. Crop model calibration/validation

All the data of climate, soil, crop growth, and yield collected from the two seasons were used as inputs in the standard file formats needed for execution of the model calibration. The model was validated by comparing observed data of grain and biological yield, cumulative ETc and growing season duration to the simulated values. The goodness of fit between the measured and predicted data was tested using the percent difference ($Pd$) as suggested by Wilmot (1982). Furthermore, statistics regression analysis; the coefficient of determination ($R^2$) and root mean square error (RMSE) were used to evaluate both calibration
and validation results. The Pd and $R^2$ were used to access the predictive power of the model, and the RMSE indicated the error in model prediction.

Table 4: Input parameters used for crop file.

| Parameters                        | Value      | Way of data determination |
|-----------------------------------|------------|---------------------------|
| Seed rate                         | 165 kg ha$^{-1}$ | F                         |
| Initial canopy cover (%)          | 4.14       | E                         |
| Maximum canopy cover (%)          | 94         | E                         |
| Base temperature ($^\circ$C)      | 6          | L                         |
| Upper temperature ($^\circ$C)     | 32         | L                         |
| Maximum crop coefficient value (Kc) | 1.12       | L                         |
| Harvest index (%)                 | 39         | F                         |
| Canopy expansion (% GDD)          | 7.1        | E                         |
| Canopy decline coefficient (% GDD)| 0.38       | E                         |
| Normalized water productivity WP* ($g\,m^{-2}$) | 15.5   | E                         |
| Shape factor for root expansion   | 1.5        | E                         |
| Maximum effective rooting depth (m)| 0.73     | F                         |
| days from sowing to emergency (day)| 9        | F                         |
| Time to reach full crop canopy (day)| 81       | F                         |
| Time to reach maximum root depth (day)| 65     | F                         |
| Time to reach flowering (day)     | 93         | F                         |
| Duration of flowering (day)       | 19         | F                         |
| Time to reach senescence (day)    | 112        | F                         |
| Time to reach maturity (day)      | 155        | F                         |

F: field  L: Laboratory  E: estimated

Table 5: Input parameters used for irrigation files (*IRR) and for the adaptation study.

| Adaptation Scenarios | Irrigation system: Surface irrigation method: Basin | Surface wetted by the irrigation: 100% | Farmer treatment | 70% of FAP | Water quality |
|----------------------|---------------------------------------------------|--------------------------------------|-----------------|------------|---------------|
| No of Irr.           | Days after sowing (day) | Applied water (mm) | IRR21 | IRR28 | IRR35 | | | |
| Sowing               | -                    | 70               | 48   |         |         | Fresh water No salinity |
| First                | 21                   | 23               | 70   | 48     |         |             |
| Second               | 42                   | 45               | 70   | 48     |         |             |
| Third                | 63                   | 66               | 70   | 48     |         |             |
| Fourth               | 84                   | 90               | 70   | 48     |         |             |
| Fifth                | 105                  | 111              | 70   | 48     |         |             |
| Sixth                | 126                  | 132              | 70   | 48     |         |             |
| Seventh              | 144                  | -                | -    | -      | -      |             |

2.6. Adaptation study

The adaptation study was conducted to determine best irrigation and sowing date scenarios that maximize yield, save irrigation water, and optimize water productivity under conditions of Middle Egypt (Giza region), and to apply the best findings of predicted results on future field trials. After verifying the accuracy of the model it was used to predict wheat yield production and ETcrop of Masir 2 variety (showed the best results in field trial) at different sowing dates: 10 and 25 November, 10 and 25 December, with five irrigation scenarios (Table 5) as follows:

I1. Irrigation every 21-day and refill soil profile to field capacity (as model suggest).
I2. Irrigation every 28-day and refill soil profile to field capacity.
I3. Irrigation every 35-day and refill soil profile to field capacity.
I4. Irrigation every 21-day with a fixed amount (70 mm) in each irrigation (farmer application).
I5. Irrigation every 21-day with 70% of (I4). This scenario represents the effect of water stress on the measured parameters.
3. Results and Discussion

3.1. AquaCrop validation results:

After calibration and running simulation, the model was validated by comparing the field experiment observed grain yield (GY), biomass yield (BY), crop evapotranspiration (ETc), and growing season duration (GSD) data with simulated data. The obtained results are presented in Table 6.

Table 6: Measured and predicted grain and biomass yields, crop evapotranspiration, growing season duration, and percent difference values for Misr 2 wheat cultivar during the 2018/19 and 2019/2020 growing seasons.

| Parameters          | Season   | Predicted |Measured | Pd % | Predicted | Measured | Pd % |
|---------------------|----------|-----------|---------|------|-----------|----------|------|
| Grain Yield (t ha⁻¹) | 2018/19  | 6.3       | 6.5     | 0.95 | 7.0       | 7.3      | 0.96 |
| Biomass Yield (t ha⁻¹) | 2018/19  | 16.7      | 17.0    | 0.99 | 16.5      | 16.5     | 1.00 |
| ETc (mm)            | 2018/19  | 325.4     | 361.2   | 0.90 | 345.3     | 378.9    | 0.91 |
| Growing season (day)| 2018/19  | 155       | 158     | 0.99 | 153       | 157      | 0.96 |
|                      | 2019/20  | 6.3       | 6.5     | 0.95 | 7.0       | 7.3      | 0.96 |
|                      |          | 16.7      | 17.0    | 0.99 | 16.5      | 16.5     | 1.00 |
|                      |          | 325.4     | 361.2   | 0.90 | 345.3     | 378.9    | 0.91 |
|                      |          | 155       | 158     | 0.99 | 153       | 157      | 0.96 |

Results indicated, in general, that there was a close agreement between the observed and predicted values in the two seasons. The observed values were within 90 to 99% of the predicted values in the 1st season, and within 91 to 100% in the 2nd season. Linear regression analysis models were developed between the measured and predicted values of GY, BY, ETc, and GSD (Figs. 1 to 4). The best-fitting model was obtained with a growing season duration, where the two-season average values were R²=0.98, RMSE=5.23 day, and Pd=0.98%. The two-year average simulated aboveground BY values were similar to those measured (R² = 0.97, RMSE = 363 kg ha⁻¹, and Pd = 0.99%). Corresponding values of wheat grain yield were 0.94, 355 kg ha⁻¹ and 0.95%. Results revealed also that, average statistical crop evapotranspiration (ETc) values of R², RMSE, and Pd were 0.95, 35mm, and 0.91%, respectively. Higher R² and Pd values and lower RMSE values indicate good model performance. These results indicate that the AquaCrop model was found to be valid in simulating winter wheat BY, GY, ETc, and GSD under the experimental conditions, and can be used in similar situations. The obtained results agreed with those reported by Heng et al., (2009) and Neha et al., (2017), who demonstrated that the AquaCrop model is a good predictor of biomass and grain yield R²= 0.94, RMSE = 0.27 ton ha⁻¹.

3.2. Crop simulation and adaption scenarios results:

3.2.1. Simulated biomass yield (BY):

Regarding irrigation interval treatments, the predicted biomass yield (BY) values (Table 6) showed a close agreement between (I₁) 21 days and (I₂) 28 days, since the BY of I₂ was less than 5% of I₁. Results showed also that, irrigating every 35 days (I₃) or applying 70% of farmer application water (I₅) caused biomass yield reduction of 18.5 and 20.3% (season 1) and by 25.6 and 32.3% (season two) as compared with I₁ treatment.

With respect to wheat sowing dates, the predicted biomass yield results revealed that early sowing on 10th November led to an increase in BY compared to other sowing dates in both growing seasons. The increase in BY due to DS₁ reached 3.2, 7.0, and 12.7% as compared to DS₂, DS₃, and DS₄, respectively in the 2018/19 season. In the 2019/2020 season, BY of DS₁ increased by 4.2, 10.2, and 16.8% as compared with DS₂, DS₃, and DS₄ sowing dates, respectively. These results agreed with that reported by Abd El-Monem (2007) and Mostafa et al., (2009). They concluded that, the exposure of wheat plants to high-temperature stress due to late cultivation could lead to reducing the vegetative and reproductive phases, and consequently reduce grain, straw and biological yields compared to plants sown at the normal date.
**Fig. 1 (a, b):** Simulated grain yield (kg) has related to observed data for 2018/2019 and 2019/2020 seasons

**Fig. 2 (a, b):** Biomass yield (kg ha⁻¹) as related to observed data for 2018/2019 - 2019/2020 seasons

**Fig. 3 (a, b):** Simulated crop water use (Etc mm/season) as related to observed data for 2018/2019 and 2019/2020 season

**Fig. 4 (a, b):** Simulated growing season long (day) as related to observed data for 2009/2010 and 2010/2011 seasons
3.2.2. Simulated water productivity (WP):

Results shown in Table 6, indicated that simulated water productivity values (WP, kg m\(^{-3}\)) varied due to irrigation scenarios. The highest values of 1.47 and 1.54 kg m\(^{-3}\) were obtained under (I\(_5\), 70% farmer application amount) for seasons one and two, respectively. While irrigation every 35-day interval recorded the lowest WP values of 1.36 and 1.41 kg m\(^{-3}\) in 1st and 2nd seasons, respectively. The results are similar to those reported by Nematall \(\text{et al.},\) (2014), who found that the highest WUE value for wheat was achieved as irrigation practiced under irrigation at 0.75 evaporation pan coefficient (EPC) compared to 1.25 EPC.

Regarding sowing dates, results showed that delaying the sowing date from early November to late December decrease WP in both seasons. The highest values were 1.51 and 1.60 kg m\(^{-3}\) obtained from plants sown on 10th November, while lowest values were 1.32 and 1.40 kg m\(^{-3}\) recorded with sowing on 25th December in both seasons, respectively. The results are in harmony with those obtained by Duchemin \(\text{et al.},\) (2015), who found that the maximal WUE around 3.5 kg m\(^{-3}\) obtained with wheat crop sown the earliest compared to those sown the latest (minimal WUE around 1.5 kg m\(^{-3}\)).

Table 6: Simulated biomass yield (t ha\(^{-1}\)) and water productivity (kg m\(^{-3}\)) of wheat crop as affected by irrigation intervals and sowing dates scenarios at Giza region in 2018/19 and 2019/20 growing seasons.

| Seasons          | 2018/2019 | 2019/2020 |
|------------------|-----------|-----------|
| **Biomass yield (t ha\(^{-1}\))** |
| **Irrigation Scenarios.** | **I\(_1\)** | **I\(_2\)** | **I\(_3\)** | **I\(_4\)** | **I\(_5\)** | **Average** | **I\(_1\)** | **I\(_2\)** | **I\(_3\)** | **I\(_4\)** | **I\(_5\)** | **Average** |
| SD\(_1\)          | 16.5      | 16.2      | 14.1      | 15.7      | 14.1      | 15.3      | 17.5      | 17.2      | 14.5      | 16.6      | 14.1      | 16.7       |
| SD\(_2\)          | 16.3      | 15.8      | 13.6      | 14.8      | 13.7      | 14.8      | 17.4      | 16.7      | 14.2      | 15.6      | 13.1      | 16.0       |
| SD\(_3\)          | 15.9      | 14.9      | 13.4      | 13.7      | 13.2      | 14.2      | 17.2      | 15.7      | 13.6      | 14.5      | 12.7      | 15.0       |
| SD\(_4\)          | 15.2      | 14.1      | 12.7      | 12.3      | 12.1      | 13.3      | 16.7      | 14.7      | 12.4      | 13.0      | 12.2      | 13.9       |
| **Average**       | 16.0      | 15.3      | 13.5      | 14.1      | 13.3      | 14.4      | 17.2      | 16.1      | 13.7      | 14.9      | 13.0      | 15.4       |
| **Water productivity (kg m\(^{-3}\))** |
| **Irrigation Scenarios.** | **I\(_1\)** | **I\(_2\)** | **I\(_3\)** | **I\(_4\)** | **I\(_5\)** | **Average** | **I\(_1\)** | **I\(_2\)** | **I\(_3\)** | **I\(_4\)** | **I\(_5\)** | **Average** |
| SD\(_1\)          | 1.50      | 1.53      | 1.48      | 1.50      | 1.55      | 1.51      | 1.59      | 1.62      | 1.57      | 1.61      | 1.63      | 1.60       |
| SD\(_2\)          | 1.49      | 1.51      | 1.36      | 1.48      | 1.52      | 1.47      | 1.55      | 1.56      | 1.56      | 1.57      | 1.57      | 1.56       |
| SD\(_3\)          | 1.41      | 1.44      | 1.32      | 1.42      | 1.46      | 1.41      | 1.49      | 1.49      | 1.40      | 1.51      | 1.54      | 1.49       |
| SD\(_4\)          | 1.33      | 1.34      | 1.28      | 1.32      | 1.35      | 1.32      | 1.39      | 1.41      | 1.39      | 1.41      | 1.42      | 1.40       |
| **Average**       | 1.43      | 1.46      | 1.36      | 1.43      | 1.47      | 1.43      | 1.51      | 1.52      | 1.48      | 1.52      | 1.54      | 1.51       |

I\(_1\), I\(_2\), and I\(_3\) are 21, 28 and 35 day interval, and I\(_4\) traditional farmer irrigation, and I\(_5\) 70% of I\(_1\). SD\(_1\), SD\(_2\), SD\(_3\) and SD\(_4\) are sowing at 10\(^{th}\), 25\(^{th}\) November, 10\(^{th}\) and 25\(^{th}\) December .

3.2.3. Simulated grain yields (GY): The predicted grain yield values (Table 7) increased positively with increased irrigation frequency and amounts of applied water. The short irrigation interval 21 days (I\(_1\)) recorded the highest values in both seasons. The increases in GY for I\(_1\) reached 6.2, 20.2, 13.7, and 18.4% as compared with (I\(_5\)) 28 day, ( I\(_3\)) 35 day, ( I\(_4\)) farmer application, and (I\(_5\)) 70% of farmer application treatments, respectively in the 1\(^{st}\) season. In season two, corresponding values were 4.8, 17.2, 10.5, and 15.5%. Results of the two growing seasons pointed clearly to the effect of increasing irrigation period and/or water stress condition, generally led to yield reduction by about 25%.

Concerning the effect of sowing dates, results of predicted grain yield confirmed the priority of early sowing on 10\(^{th}\) November which led to an increase in GY compared to other sowing dates. This trend was true in both growing seasons with an overall two season average increase in DS\(_1\) of 6.0, 14.0, and 25.5% as compared to DS\(_2\), DS\(_3\) and DS\(_4\), respectively. Contrary to this, delaying sowing wheat from adopted sowing date (25\(^{th}\) November till to the10\(^{th}\) and 25\(^{th}\) December reduced grain yield by 7.5 and 16.2 % (season 1) and by 7.0 and 15.2% (season two), respectively.

The most effective interaction was noted with irrigating crop at 21 days interval combined with sowing at 10\(^{th}\) November. The obtained results indicated the role of sufficient soil water content and suitable weather conditions, especially temperature on plant growth and crop production. These results were in agreement with those reported by Eldey \(\text{et al.},\) (2018), who noticed that sowing wheat crop on 15\(^{th}\) November obtained maximum grain yield compared to sowing in October or December.
Meena et al. (2016) reported that wheat grain can be maintained by sowing it from 1st till mid-November with irrigation scheduling up to 50% depletion of available soil moisture.

3.2.4. Water saving and yield reduction:

The main purpose of adaptation scenarios is to determine the best scenario that decreases amounts of irrigation water with the least possible crop reduction. Results recorded in Table (7) and Figs. 5 and 6 showed, in general, that water saved (WS, %) is more than yield reduction (YD, %) under each irrigation treatment for all sowing dates (Fig. 5). The maximum averages WS were 36.7 and 47.6% recorded under irrigation at 70% of farmer application (I4) for the respective seasons. Whereas, the minimum WS of 13.0 and 16.4% were registered with 28 days (SD1) and 64 days (SD3) irrigation treatment for all sowing dates (Fig. 5). The maximum averages WS were 36.7 and 47.6% recorded under irrigation at 70% of farmer application (I4) for the respective seasons and two, respectively.

Table 7: Simulated wheat grain yields (t ha⁻¹), irrigation water depths (mm), and the calculated difference percentage values as affected by irrigation interval and sowing date scenarios at Giza region in 2018/2019 and 2019/2020 seasons.

| Seasons | 2018/2019 | 2019/2020 |
|---------|-----------|-----------|
| Irrig. Dates | Grain yield (t ha⁻¹) | Grain yield (t ha⁻¹) |
| SD1 | 7.86 | 36.7 |
| SD2 | 7.92 | 38.9 |
| SD3 | 7.24 | 44.8 |
| SD4 | 8.99 | 51.9 |
| Average | 7.66 | 40.0 |

Reduction (%) in grain yield as related to irrigation treatments

| Seasons | Reduction (%) in grain yield as related to irrigation treatments |
|---------|---------------------------------------------------------------|
| SD1 | 2.8 | 11.3 |
| SD2 | 3.7 | 7.2 |
| SD3 | 7 | 11.3 |
| SD4 | 11.3 | 6.2 |
| Average | 6.2 | 20.5 |

Reduction (%) in grain yield as related to sowing dates

| Seasons | Reduction (%) in grain yield as related to sowing dates |
|---------|------------------------------------------------------|
| SD1/SD2 | 2.0 | 2.7 |
| SD3/SD2 | -2.7 | -7.4 |
| SD4/SD2 | -7.4 | -14.6 |

Irrigation water amount (mm season⁻¹)

| Seasons | Irrigation water amount (mm season⁻¹) |
|---------|---------------------------------------|
| SD1 | 484 | 418 |
| SD2 | 509 | 452 |
| SD3 | 556 | 488 |
| SD4 | 612 | 560 |
| Average | 540 | 479 |

Reduction (%) in irrigation water as related to irrigation treatments

| Seasons | Reduction (%) in irrigation water as related to irrigation treatments |
|---------|------------------------------------------------------------------|
| SD1 | -50.0 |
| SD2 | 0.0 |
| SD3 | 0.0 |
| SD4 | 0.0 |
| Average | 0.0 |

Where: DS1, DS2 and DS4: sowing on 10th and 25th November, 10th December and 25th December, respectively and I1 to I5 refer to Irrigation application scenarios

Corresponding values of yield reduction under the same irrigation scenario were 20.6 and 18.1% for the respective seasons. Whereas, the minimum WS of 13.0 and 16.4% were registered with 28 days (I1) in both seasons. Corresponding yield reduction for (I5) was 7.4% for both seasons. It was noted also that, maximum YD was recorded with (I3) 35-day interval treatment. This may be due to the fact that plants under long irrigation period suffer from deficit water and high soil moisture tension, as well as high osmotic pressure in plant cell especially if it was compiled with heat stress which reflects high temperature and cause damage in plant growth components and decrease in final yield at late sowing date.
In is clear from the results that, implementing deficit irrigation strategies under full management may be beneficial in maximizing water save with minimal yield reduction, moreover the short interval irrigation with less water amount (scenario I₁) is more effective than irrigation at long intervals, even if the soil profile is refilled to field capacity (scenario I₃). Regarding sowing dates, results indicated that sowing wheat crop in 10 November decreased irrigation water and maximized yield as compared to other tested sowing dates (Table 7 and Figs. 5 and 6). The water saved at this date ranged from 4.2 to 9.7% with I₁ to I₅ scenarios, whereas 0.0 % at I₄ and I₅ related to constant amount of irrigation water applied for all sowing dates. The corresponding yield increased at this date ranged from 0.5% under normal conditions (I₁) to 9.8% under water stress (I₃) for both seasons. On the other hand, delaying the sowing date to 10 and 25 December caused an increase in ETC and decrease in grain yield (GY) under all irrigation scenarios. The increased percentage in ETC ranged from 5.7 to 9.2% for 10th December date (DS₃) and from 7.7 to 20.2% for 25th December (DS₄), respectively. Parallel GY reduction percentage ranged from 2.7 to 10.5% with (DS₃) and from 7.4 to 20.7% for (DS₄), respectively.

The results of the two season showed that the best sowing date minimizes irrigation water and maximizes yield was 10th November.

Moreover, the best interaction was found under this sowing date with I₂ (28 days interval), which allowed to save 16.6% irrigation water and increased grain yield by 2.8% as an average of both seasons

Fig. 5: Water saved related to yield reduction of wheat crop under different sowing date and irrigation scenarios at both growing seasons

Fig. 6: Seasonal water saved in related to yield reduction of wheat crop under different irrigation scenarios' "a" and at different sowing dates "b" for both season.
4. Conclusion

The current study evaluated the performance of AquaCrop model in simulating biomass and grain yield productivity of wheat crop at Giza region (Middle Egypt). A field experimental data were used in the calibration process. The results of the study suggest that:
- AquaCrop model is able to predict crop biomass and grain yields, and crop water use with acceptable accuracy.
- The adaptation study using the AquaCrop model reflected good performance in evaluating irrigation interval, sowing date scenarios, as a strategy that may be applied by the farmers. Adopting an irrigation interval of 28 days and sowing dates from 10 till 20 November ill increase the grain yield and save about 16% of irrigation water.
- It could be concluded that AquaCrop model can be used as a useful tool to help decision making for irrigation management and selecting proper sowing dates to optimize wheat yield. Also, the application of the parameters determined in this study needs to be tested for other wheat cultivars, environments and management scenarios.

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