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Original Research Article

Performance evaluation of aquacrop model for durum wheat (*Triticum durum* Desf.) crop in semi arid conditions in Eastern Algeria

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A B S T R A C T

This study was conducted on the experimental site of station INRAA in Setif, Algeria. The objective of this study was to adapt and test the ability of the FAO developed AquaCrop model (V 3.0) to simulate durum wheat production under semi-arid conditions in eastern Algeria. The AquaCrop model was evaluated with experimental data collected during three cropping seasons; the field experiments were conducted in Setif, Algeria. Results showed that durum wheat grain yield, Biomass and Harvest index can be simulated with relative accuracy using AquaCrop. Overall, the agreement between simulated and observed wheat grain yield was satisfactory with r = 0.99 ($p<0.05$), RMSE and AAE of 1.86 and 1.77 ton ha^{-1}, respectively. Regarding Final above-ground biomass comparison of simulated to observed values for all growing seasons resulted in an r = 0.98 ($p<0.2$), RMSE and AAE of 3.07 and 2.68 ton ha^{-1}, respectively. In addition, observed and simulated harvest index correlated giving an r = 0.88 ($p<0.31$), RMSE and AAE of 5.75 and 4.70 %, respectively. Overall, the student's t-test showed that the simulated Biomass and Harvest index was not significantly different from the observed values, but the simulated grain yield was significantly different ($p = 0.047$) from the observed grain yield. Therefore, in cases of limited input data and under semi-arid conditions the AquaCrop could be a promising model for estimating crop productivity.

Keywords

AquaCrop; Durum wheat; Semi-arid conditions; Grain yield; Algeria.

Introduction

Durum wheat is one of the most extensively cultivated crops under dryland conditions in the Mediterranean environments (Araus *et al*., 2002). It is an important source of human nutrition and serves as the raw material of numerous foods such as couscous (North Africa), pasta (Europe) and bulgur (Middle Eastern) in the alimentation of world population. The need and importance of wheat is increasing day by day due to increase in human population. Drought is one of the most important factors which strongly affect the production of wheat in the world and Algeria (Hannachi *et al*., 2013). Rainfall fluctuations play a significant role in determining the national economy of Algeria because many economic activities in this country depend heavily on rain-fed agriculture. Consequently, one of the main obstacles to developing sustainable agriculture in Algeria is seasonal crop water shortage. FAO recently developed a water-driven model for use as a decision support tool in planning and scenario analysis in different seasons and locations (Steduto *et al*., 2009; Hsiao *et al*., 2009). Once validated, models are easy and need less resource and could be useful to avoid cropping risks (Tsubo *et al*., 2005; Soltani and Hoogenboom, 2007). AquaCrop is a crop water productivity simulation model developed by the Food and Agriculture Organization (FAO) of the Unite Nations (Hsiao *et al*., 2009; Steduto *et al*., 2009). It simulates crop yield response to water, and is particularly suited to address conditions where water is a key limiting factor in crop production. The model evolved from the concepts of crop yield response to water developed by Doorenbos and Kassam (1979). AquaCrop attempts to balance accuracy, simplicity, and robustness. It uses a relatively small number of explicit and mostly intuitive parameters and input variables requiring simple methods for their derivation (Steduto *et al*., 2009). Simulations of crop growth and development are executed with daily time steps, using either thermal time, i.e., growing degree days (GDDs) or calendar days. The ability of AquaCrop to simulate yields for different crops has been extensively tested by several researchers around the globe in diverse environments and all have reported positive results, e.g., barley (*Hodeum vulgare* L) (Araya *et al*, 2010a), teff (*Eragrostis tef* L) (Araya *et al*., 2010b), cotton (*Gossypium hirsutum* L) (Baumhardt *et al*., 2009), quinoa (*Chenopodium quinoa* Willd.) (Geerts *et al*, 2009), maize (*Zea mays* L) (Heng *et al*., 2009) and wheat (*Triticum aestivum* L) (Andarzian *et al*., 2011). However, the model has not been tested in Algeria, particularly in eastern Algeria where crop yields are often limited by moisture deficit. The objectives of the study were to evaluate the model performance to simulate crop growth and production in durum wheat under semi arid conditions in eastern Algeria.

Materials and Methods

Climatic data

The weather data required by AquaCrop model are daily values of minimum and maximum air temperature, reference crop evapotranspiration (ET0), rainfall and mean annual carbon dioxide concentration (CO_2). ET_0 was estimated using ET_0 calculator using the daily maximum and minimum temperature, wind speed at 2 m above ground surface and mean relative humidity (RH). Rainfall depths of 405.3 mm, 313.8 mm and 411.0 during the crop growth seasons were recorded during 2010/2011, 2011/2012 and 2012/2013, respectively. The temperature variations, ET_0 and rainfall depths during the crop growth seasons have been shown in Figure 1.

Crop data

Crop data was obtained from an experimental field. The experiment was laid in Randomized Complete Block Design (RCBD). Plots were 2.5 m × 6 rows with 0.20 m row spacing and sowing density was adjusted to 300 g m^{-2}. The crop component divided to 4 sub-components including initial canopy, canopy development, flowering and yield formation and rooting depth. The later two were observed visually while the canopy was measured in field at regular intervals. Canopy cover was estimated based on the method used by Geerts *et al*. (2009) and Farahani *et al*. (2009):

$$CC = 1 - \exp^{(-0.65LAI)} \quad \ldots\ldots\ldots (1)$$

Where CC is canopy cover and LAI is the leaf area index. LAI was calculated as LAP×NPM^2, LAP being the leaf area per plant (m^2), and NPM^2 the number of plants per m^2 (Royo *et al*., 2004). The final biomass and grain yield were obtained from all plots after maturity from an area of $6m^2$ in all cropping seasons.

Description of AquaCrop model

AquaCrop has four sub-model components: (i) the soil (water balance); (ii) the crop (development, growth and yield); (iii) the atmosphere (temperature, rainfall, evapotranspiration (ET) and carbon dioxide (CO_2) concentration); and (iv) the management (major agronomy practices such as planting dates, fertilizer application and irrigation if any). AquaCrop calculates a daily water balance that includes ail the incoming and outgoing water fluxes (infiltration, runoff, deep percolation, evaporation and transpiration) and changes in soil water content. There are five weather input variables required to run AquaCrop including daily maximum and minimum air temperatures (T), daily rainfall, daily reference evapotranspiration (ET_0) and the mean annual CO_2 concentration in the bulk atmosphere. While the first four are derived from typical agro-meteorological stations, the CO_2 concentration uses the Mauna Loa Observatory records in Hawaii. The advantage with AquaCrop is that it requires only a minimum of input data, which are readily available or can easily be collected. AquaCrop has default values for several crop parameters that it uses for simulating different crops including wheat, however, some of these parameters are not universal and thus have to be adjusted for local conditions, cultivars and management practices. For a more detailed description of the AquaCrop model see (Geerts *et al*, 2009; Heng *et al*., 2009; Hsiao *et al*., 2009; Steduto *et al*., 2009).

Performance evaluation of AQUACROP

For the performance evaluation of AquaCrop, following notations were used:
Si = simulated value,
Oi = observed value,
N = number of observations,
MS = mean of simulated value,
MO = mean of observed value.

Average Absolute Error (AAE)

Absolute percentage error between simulated and observed values may be calculated using the following equation (Loague and Green, 1991):

$$AAE = \frac{\sum_{i=1}^{n} |Oi - Si|}{N}$$

Root Mean Square Error (RMSE)

Root mean square error (RMSE) is calculated as follows (Loague and Green, 1991):

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} (Oi - Si)^2}{N}}$$

Index of agreement (d)

The index of agreement (d) was calculated using the Willmott (1985) equation:

$$d = 1 - \frac{\sum_{i=1}^{n}(Si - Oi)^2}{\sum_{i=1}^{n}(|Si - MO| + |Oi - MO|)^2}$$

Prediction error (Pe)

Model performance was evaluated using the following statistical parameter prediction error (Pe) (Nash and Sutcliffe, 1970), given by:

$$Pe = \frac{(Si - Oi)}{Oi} x\, 100$$

Correlation coefficient (r)

The correlation coefficient is an indicator of degree of closeness between observed values and model estimated values. The observed and simulated values are found to be better correlated as the correlation coefficient approaches to 1. If observed and predicted values are completely independent i.e., they are uncorrelated then r will be zero. The correlation coefficient was estimated by the following equation:

$$r = \frac{\sum_{i=1}^{n}(Oi - MO)(Si - MS)}{\sqrt{\sum_{i=1}^{n}(Oi - MO)^2 \sum_{i=1}^{n}(Si - MS)^2}}$$

Results and Discussion

Grain yield (GY)

Simulation results for all seasons and all traits are presented in Table 1. Figure 2A shows the relationship between observed and simulated grain yield for all seasons. Observed and simulated grain yield correlated very well giving an r = 0.99 ($p<0.05$) a slope of 0.49 and a d of 0.56 (Table 1) indicating that the model explained 99% of the relationship between observed and modeled wheat grain yield. Araya *et al*. (2010a) reported R^2 values > 0.80 when simulating barley aboveground biomass and grain yield using AquaCrop. The student's t-test showed that the simulated grain yield was significantly different ($p = 0.047$) from the observed grain yield with RMSE and AAE of 1.86 and 1.77 ton ha^{-1}, respectively (Table 1). These RMSE and AAE values when expressed as percent of average observed grain yield were 41.4% and 39.4%, respectively. Overall the difference between the simulated and observed grain yield was 1.77 ton ha^{-1} indicating that the model overestimated the grain yield by 39.4%. Araya *et al*. (2010a) used AquaCrop to simulate barley grain yield and reported that the simulated grain yield deviated from the observed yield with a range of −13% to 15%.

Final above-ground biomass (Bio)

Observed and simulated biomass correlated well giving an r = 0.98 ($p<0.2$) a slope of 0.29 and a d of 0.56 (Table 1, Figure 2B) indicating that the model explained 98% of the relationship between observed and modeled wheat biomass. Salemi *et al*. (2011) reported R^2 values = 0.96 when simulating winter wheat aboveground biomass using AquaCrop. The student's t-test showed that the simulated biomass was not significantly different ($p = 0.12$) from the observed biomass with RMSE and AAE of 3.07 and 2.68 ton ha^{-1}, respectively (Table 1). These RMSE and AAE values when expressed as percent of average observed grain yield were 29.1% and 25.4%, respectively. Overall the difference between the simulated and observed biomass was 2.68 ton ha^{-1} indicating that the model overestimated the biomass by 25.4%, but the student's t-test showed that the simulated biomass was not significantly different from the observed biomass. Zeleke *et al*. (2011) used AquaCrop to simulate both total biomass and grain yield for canola (B. napus L.) and reported that the difference between observed and simulated values was <10%. Meanwhile, Todorovic *et al*. (2009) when assessing the ability of three models (AquaCrop, CropSyst and WOFOST) to simulate sunflower growth reported that AquaCrop overestimated sunflower yield by 1.2%, while CropSyst and WOFOST underestimated yield by 4.6% and 0.3%, respectively. The authors concluded that although AquaCrop requires less input information compared to the other two models, it performed similarly to the other two models in modeling both total biomass and grain yield.

Harvest Index (HI)

In Aqua Crop, harvest index (HI) is simulated by a linear increase with time (Steduto *et al*., 2009). Observed and simulated harvest index correlated well giving an r = 0.88 (p<0.31) a slope of 0.38 and a d of 0.60 (Table 1, Figure 2C) indicating that the model explained 88% of the relationship between observed and simulated wheat harvest index. The student's t-test showed that the simulated harvest index was not significantly different (p = 0.18) from the observed harvest index with RMSE and AAE of 5.75 and 4.70 %, respectively (Table 1). Overall years of study the difference between observed and simulated harvest index was 4.7 % indicating that the model overestimated the biomass by 11.04%, but the student's t-test showed that the simulated harvest index was not significantly different from the observed HI. Harvest index in treatments with nearly optimal water condition (eight irrigations) increased with time and reached the reference level. But it did not increase in rainfed treatments because it was stopped by water stress. Aggarwal *et al*. (1986) found similar HI trend in wheat with irrigated treatments. The adjustment of harvest index to water stress depends on the timing and extent of water stress (Steduto *et al*., 2009). Adjustments for pollination failure, for inhibition of stomata, for reduction in green canopy duration, for pre-flowering stress were taken into account in the simulation.

In this study, AquaCrop model was used to simulate durum wheat yield and yield component responses to semi-arid region of Setif, Eastern Algeria. A field experiment was conducted for three growing seasons (2010-2013). Results showed that durum wheat grain yield, Biomass and Harvest index can be simulated with relative accuracy using AquaCrop (v3.0). Overall, the agreement between simulated and observed wheat grain yield was satisfactory with r = 0.99 (p<0.05), RMSE and AAE of 1.86 and 1.77 ton ha^{-1}, respectively. Regarding Final above-ground biomass comparison of simulated to observed values for all growing seasons resulted in a r = 0.98 (p<0.2), RMSE and AAE of 3.07 and 2.68 ton ha^{-1}, respectively. In addition, observed and simulated harvest index correlated well giving an r = 0.88 (p<0.31), RMSE and AAE of 5.75 and 4.70 %, respectively. Overall, the student's t-test showed that the simulated Biomass and Harvest index was not significantly different from the observed values, but the simulated grain yield was significantly different (p = 0.047) from the observed grain yield. Thus, we conclude that

Figure.1 Monthly rainfall, reference evapotranspiration (ET0) and max, min temperature for the cropping seasons 2010/2011, 2011/2012 and 2012/2013

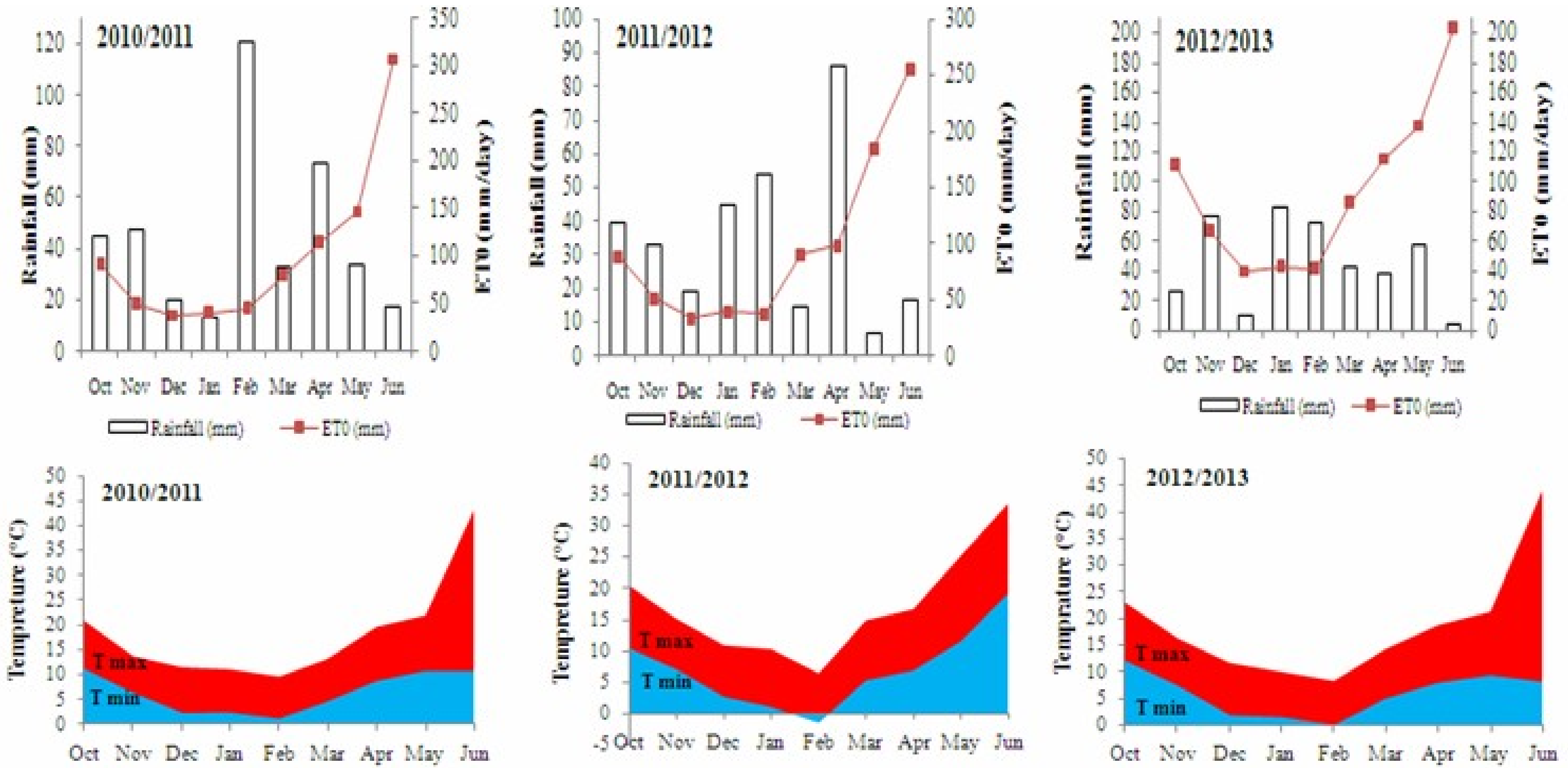
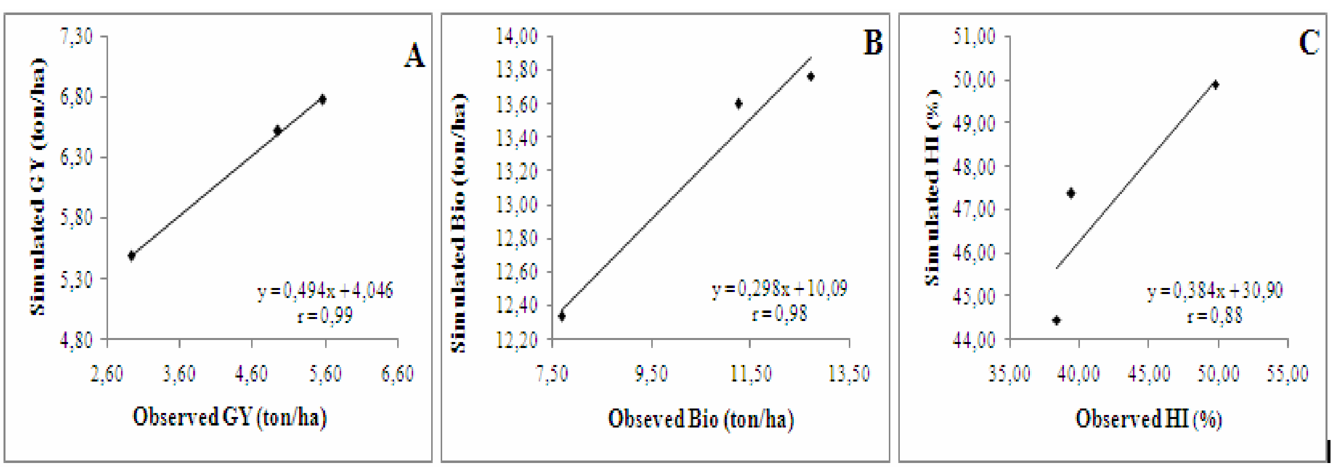


Table.1 Statistical indices derived for evaluating the performance of AquaCrop model in predicting grain yield, biomass and harvest index

		Observed	Simulated	AAE	RMSE	d	Deviation (%)
	GY	5,57	6,78	1,21	1,22	0,27	17,88
2010/2011	Bio	11,25	13,60	2,35	2,41	0,30	17,33
	HI	49,77	49,90	2,04	2,63	0,99	0,26
		Observed	Simulated	AAE	RMSE	d	Deviation (%)
	GY	2,94	5,49	2,55	2,58	0,95	46,55
2011/2012	Bio	7,69	12,34	4,65	4,66	0,06	37,69
	HI	38,41	44,45	6,03	8,04	0,98	13,58
		Observed	Simulated	AAE	RMSE	d	Deviation (%)
	GY	4,96	6,52	1,57	1,85	0,43	23,99
2012/2013	Bio	12,71	13,77	1,61	2,42	0,42	7,68
	HI	39,44	47,38	7,94	8,85	0,60	16,76
		Observed	Simulated	AAE	RMSE	d	Deviation (%)
	GY	4,49	6,27	1,77	1,86	0,56	28,38
Over all Years	Bio	10,55	13,24	2,68	3,07	0,56	20,31
	HI	42,54	47,24	4,70	5,75	0,60	9,95

AAE: Average Absolute Error, RMSE: Root Mean Square Error, d: Index of agreement and Deviation %= 100-((Oi*100)/Si) were Oi: Observed values and Si: Simulated values.

Figure.2 Linear relationship between observed and simulated Grain yield (A), Biomass (B) and Harvest index (C) for all growing seasons



Aqua Crop can be a valuable tool for simulate Harvest index, Biomass and Grain yield under similar conditions of eastern Algeria, but conservatively.

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