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Evaluating AquaCrop Model for Winter Wheat under Various Irrigation Conditions in Turkey

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ABSTRACT

Farming winter wheat in Central Anatolia of Turkey traditionally is rainfed. Crop yields are frequently affected in this region because of the drought events of varying severity. There is apparent necessary for an aim appraisal of the effect of dryness on this critical crop, to answer the contradiction whether irrigation is essential or not. For this reason the FAO-AquaCrop (Ver.5.0) crop water productivity model was preferred to predict attainable yields of winter wheat (*Triticum durum* L.) under four different irrigation regimes. Field experiment was conducted under four different irrigation treatments in Central Anatolia Region of Turkey during 2008-2010. The AquaCrop was calibrated with 2008-2009 field data and model validation was performed using 2009-2010 data. Model simulation results showed that model simulates soil water content in root zone (SWC), canopy cover (CC), grain yield (GY) and aboveground biomass (BM) of wheat reasonably well. The average root mean square error (RMSE) between simulated and observed SWC, CC, GY and BM were 21.1 mm, 7.1%, 0.32 t ha^{-1} and 0.34 t ha^{-1}. Nash-Sutcliffe efficiency (EF) and index of Willmott (d) also were obtained 0.89 and 0.98 for CC, 0.74 and 0.93 for SWC, 0.98 and 0.92 for BM, 0.95 and 0.82 for GY. Model predicted canopy cover, grain yields and biomass with high accuracy while soil water content at 90 cm soil depth was estimated in the moderate accuracy. The results presented that AquaCrop model can be suggested as a convenient model for decision-making whether irrigating wheat is in the priority or not at the limited water resources areas.

Keywords: AquaCrop; Grain yield; Irrigation; Canopy cover

Türkiye Koşullarında Kışlık Buğday için AquaCrop Modelinin Çeşitli Sulama Koşulları Altında Değerlendirilmesi

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ÖZET

Türkiye'de İç Anadolu Bölgesi'nde geleneksel olarak kışık buğday tarımı yağışa dayalı (susuz) olarak yapılmaktadır. Bu bölgede buğday verimi çeşitli seviyelerdeki kuraklık nedeniyle sıklıkla etkilenmektedir. Sulamanın gerekli olup olmadığı çelişkisinin çözülebilmesi için bu stratejik ürün üzerinde, kuraklık etkisinin objektif olarak değerlendirilmesine belirgin bir ihtiyaç vardır. Bu amaca yönelik olarak FAO-AquaCrop (Ver.5.0) bitki su verimliliği modeli, farklı sulama rejimi altında elde edilecek kışlık buğday (*Triticum durum* L.) verimlerini tahmin etmek için seçilmiştir. Arazi denemesi, dört farklı sulama konusunda 2008-2010 yılları arasında İç Anadolu Bölgesi'nde yürütülmüştür. AquaCrop 2008-2009 arazi verileri ile kalibre edilmiştir ve modelin validasyonu için 2009-2010 verileri kullanılmıştır. Model simülasyon sonuçları, modelin bitki örtüsü (CC), kök bölgesindeki toprak su içeriği (SWC), biyokütle (BM) ve buğday verimini oldukça iyi tahmin ettiğini göstermektedir. Ölçülen ve tahmin edilen SWC, CC, GY ve BM arasındaki hata kareler ortalaması (RMSE) değerleri sırasıyla 21.1 mm, % 7.1, 0.32 t ha^{-1} and 0.34 t ha^{-1} olmuştur. Nash-Sutcliffe etkinliği (EF) ve Willmott indeksi (d) CC için 0.89 ve 0.98, SWC için 0.74 ve 0.93, BM için 0.98 ve 0.92, GY için ise 0.95 ve 0.82 olarak bulunmuştur. Model dane verimi ve biyokütleyi yüksek doğrulukta tahmin ederken, kök bölgesi toprak su içeriğini orta doğrulukta tahmin etmiştir. Sonuçlar AquaCrop modelinin su kaynaklarının kısıtlı olduğu alanlarda buğday sulamasının öncelikli olup olmadığının karar verilmesinde tavsiye edilebilir bir araç olduğunu göstermiştir.

Anahtar Kelimeler: AquaCrop; Dane verimi; Sulama; Bitki örtüsü

1. Introduction

Wheat is very significant agricultural crop in Turkey, and 9.5 million ha which is around 65-70% of the total arable land of 27 million ha is utilized for wheat production. Central Anatolia Region of Turkey has semi-arid climate (Altın et al 2012), and available water is a significant restriction for wheat production. Accordingly, irrigation is essential for this region to avoid water stress and maximize crop yield. Several researchers have reported that wheat is not evenly sensitive to drought at different growing stages (Zhang & Oweis 1999; Sezen & Yazar 2008).

Large amount of water resources are consumed by agriculture on worldwide (Geerts & Raes 2009; Andarzian et al 2011). Production depends almost entirely on irrigation especially dry conditions (Musick et al 1994; Steven & Tolk 2009). Investigation of plant responds to different irrigation strategies in the field is difficult and expensive taking into consideration this kind of restrictions, precise crop water productivity models are significant equipments in order to assess impacts of water upon crop production (Heng et al 2007; Farahani et al 2009; Andarzian et al 2011; Levidow et al 2014).

The FAO AquaCrop is simple, accurate, user friendly model which can be used by water managers, water use organizations, economists and policy makers to planning and analysis of irrigation scenarios. (Hsiao et al 2009). Besides, AquaCrop model predicts yield response to water of graminaceous crop (Heng et al 2009; Vanuytrecht et al 2014). Details of simulation processes are provided in irrigation and drainage paper number 66 (Steduto et al 2012). AquaCrop was tested for various crops under several environmental conditions (Heng et al 2009; Todorovic et al 2009; Araya et al 2010; Zeleke et al 2011; Amoah et al 2013; Ahmadi et al 2015; Trombetta et al 2016; Toumi et al 2016).

We focused on AquaCrop calibration and validation under several irrigation strategies using with experimental field data at this study.

2. Material and Methods

Experimental sites are located in Ankara, Murted Basin (40° 04' N and 32° 36' E, elevation 831 m) of Central Anatolia region of Turkey (Figure 1). A field experiment was conducted in two growing seasons of wheat between the years 2008 and 2010 in Research Farm Station of Soil, Fertilizer and Water Resources Central Research Institute in Murted Basin, Ankara, Turkey.

The climate is characterized as semi-arid in this region of Ankara. Long term monthly meteorological data was presented at Table 1. Daily data were obtained from meteorological station of the experimental site. The daily maximum-minimum temperature and ET_o, precipitation for growing season from 20th of October 2008 to 20th of July 2010 were given at Figure 2.

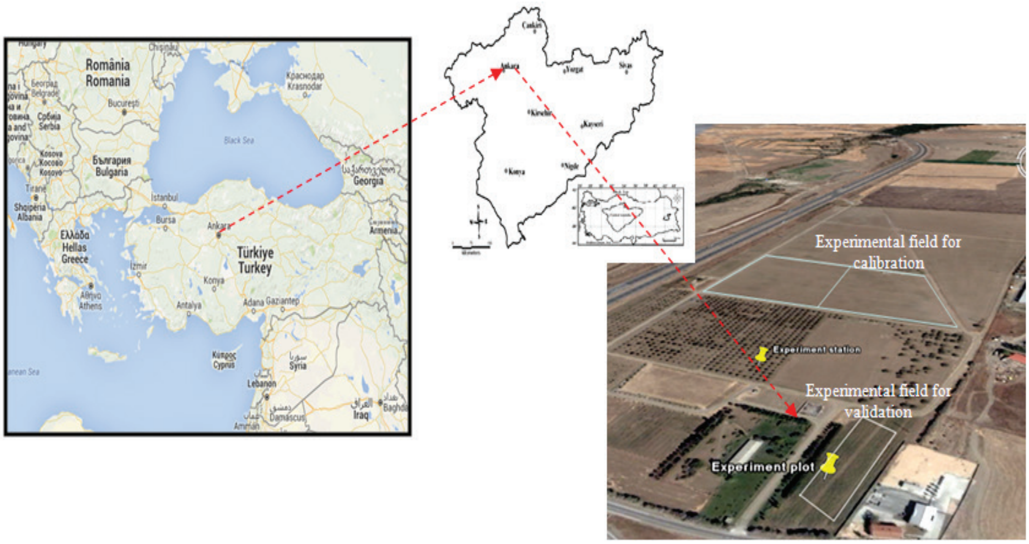

Figure 1- Location of experimental site

Table 1- Average climatological data of Ankara (1976-2011)

	Month												
Meteorological data	*X*	*XI*	*XII*	*I*	*II*	*III*	*IV*	*V*	*VI*	*VII*	*VIII*	*IX*	*Annual*
Max temperature (°C)	27.6	20.4	14.4	9.3	12.1	20.6	25.3	28	30.4	32.1	34.3	32	34.3
Min temperature (°C)	-2.9	-10.5	-14.5	-14.8	-14.6	-9.7	-3.1	-1.8	3.9	9.6	4.9	4.9	-14.7
Precipitation (mm)	23	31.9	38.9	30.4	33.1	36.7	43.1	55.2	22.1	15	5.4	15.2	350
Relative humidity (mm)	57	70	79	72	71	60	58	58	50	37	35	41	57
Evaporation (mm)	95	44	-	-	-	-	103	147	225	243	276	167	1300
Wind speed (m s^{-1})	1.2	1.3	1.3	1.2	1.3	1.4	1.2	1.3	1.2	1.2	1.2	1.1	1.2

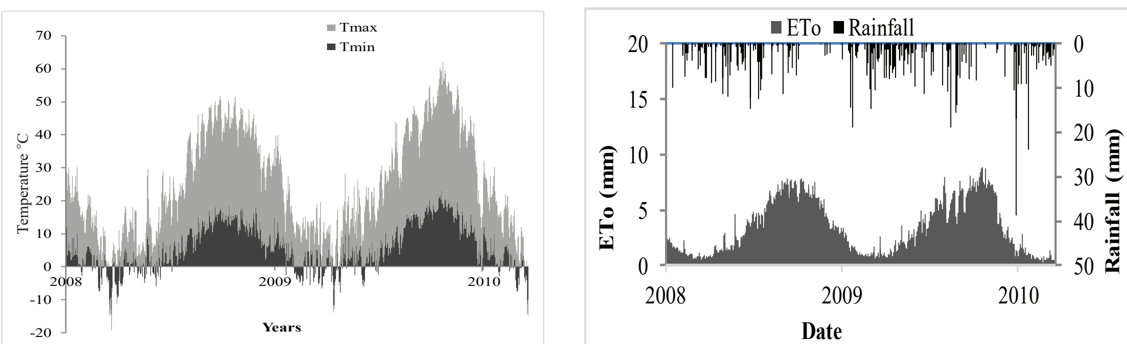

Figure 2- Daily maximum and minimum temperature ET_o and precipitation values for experimental area during the growing period during 2008-2009 and 2009-2010

The soils are mostly silty clay texture about 0.30 m soil depth, whereas clay is dominant texture approximately from 0.30 m to 1.5 m in the soil profile of experimental area. Field capacity on the volume basis of the top and basement soil layer is described to be 33 and 37%, and wilting point, 17 and 23% respectively. Some physical and chemical soil properties were given Table 2.

Table 2- Some physical characteristics of the soil in experimental sites

Depth (m)	*Moisture content*				*Bulk density (g cm^{-3})*	*K_{sat} (mm day^{-1})*
	FC (%, vol)	*PWP (%, vol)*	*Sat (%, vol)*	*TAW*		
0.0-0.3	33.8	17.4	45.0	164	1.24	230
0.3-0.6	36.2	22.1	47.0	141	1.27	175
0.6-0.9	36.9	22.2	47.0	147	1.21	125
0.9-1.50	37.4	23.0	50.0	144	1.20	125

FC, field capacity; PWP, permanent wilting point; TAW, total available water; Sat, water content at saturation; Ksat, saturated hydraulic conductivity

A locally adapted major wheat variety (Bayraktar-2000) was grown during the experimental studies. Wheat seeds were obtained from National Seeds Research Institute. Grain yield and biomass per plot was measured after harvesting. Weight of straws and grain (t ha^{-1}) were taken as dry biomass and grain yield, respectively.

The study was carried out through two growing seasons from 2008 to 2010. 2008-2009 growing season values were used for calibration and 2009-2010 for validation processes. The experiment consists of 4 irrigation regimes with 4 replications. Irrigation treatments were given at Table 3. The experimental design was as a complete randomized block design with a split plot layout. Plot dimensions were taken 20 m^2 (5 m x 4 m). There was 2 m distance between all plots. The plots have almost zero slope and were surrounded about 0.30 m high soil bunds (Figure 3).

Table 3- Irrigation treatments of experiment

Treatments	*Growing periods*			
	Germination	*Tillering*	*Heading*	*Grain filling*
I_1	-	-	-	-
I_2	x	x	x	x
I_3	-	x	-	x
I_4	-	-	x	x

I_1, rainfed; I_2, full irrigation

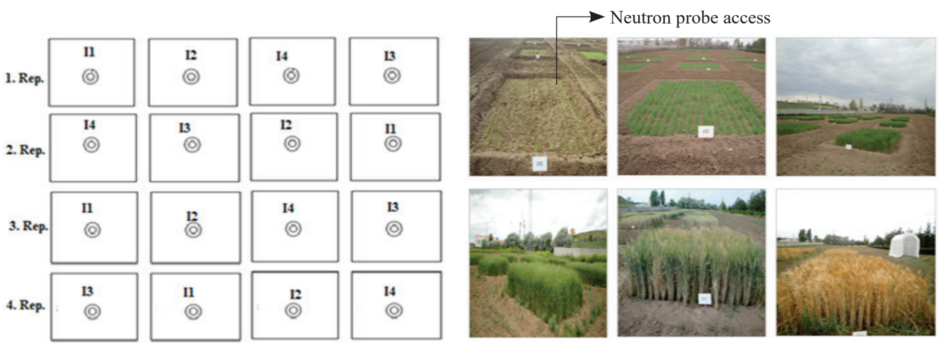

Figure 3- Experimental design

Winter wheat was planted around 20th October and harvested 20 of July for each year. The seed rate was 430 seed m^{-2} with 1.7 cm row spacing. According to soil fertility analysis results commercial N fertilizers were applied in a band about 10 cm near to the seed row (225 kg ha^{-1}, ammonium sulfate 21% were applied before sowing and 350 kg ha^{-1} ammonium sulfate were applied in second week of March). Sufficient rate of phosphorus was applied (178 kg ha^{-1}, DAP 18-46-0) to ensure adequate P nutrition.

2.1. Field observations

Soil volumetric moisture contents were measured by neutron probe (CPN-503DR Hydroprobe) in 20 cm interval from a depth of 0-100 cm at two times a week. Evapotranspiration of wheat was calculated based on Equation 1 (Allen et al 1998).

$$\mathrm{ET} = I + P \pm \Delta S - R - D \qquad (1)$$

Where; *I*, irrigation water amount (mm); *P*, precipitation (mm); ΔS, change in soil water content (mm); *R*, surface flow (mm, negligible; precision leveled to zero-grade); *D*, deep seepage (mm, negligible; irrigated until field capacity and water table depth is about 4 m).

For irrigation treatments, soil moisture was reached to the field capacity in the 0-90 cm depth. Irrigation water was applied 250 mm for I_2 treatment at 2008-2009 growing season. Irrigation water amount was 255 mm for I_2, 153 mm for I_3 and for 141 mm for I_4 at 2009-2010 growing season.

Emergence date, flowering length, beginning of senescence, maturity, maximum canopy cover and rooting depth were recorded during the experiment at the field.

Overhead photographs of canopy were taken with commercially available digital camera (Sony CyberShot DSC-H55 with a resolution of 14.1 mega pixels) at an invariable height of 1.5 m, between 11:00 and 15:00 every month from emergency to late senescence stage of wheat (Figure 4). Taken photographs were processed with the GreenCrop tracker software (Figure 5) which was freely distributed software from website. GreenCrop, tracker image processing software, is segmenting the green canopy from the background material. Several research results showed that the digital cameras images can be used for predicting canopy cover (Laliberte et al 2004; Guevara-Escobar et al 2005; Lee & Lee 2011).

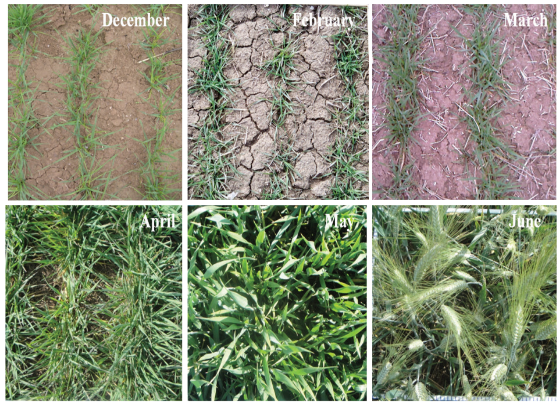

Figure 4- Canopy photographs of wheat from December to June

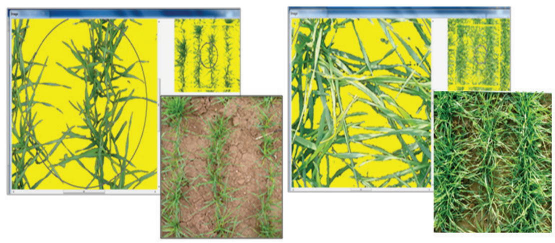

Figure 5- Some processed photographs with the GreenCrop tracker software to calculate canopy cover percent

2.2. Description of AquaCrop (Version 5.0) model

AquaCrop model was developed by FAO to predict yield response to water. The overall structure of the model and comprehensive information presented at Steduto et al (2008) and Raes et al (2009). AquaCrop predicts green canopy cover (CC) in place of leaf are index (LAI) and it calculates evapotranspiration (ET) from the flow water in and out of a system at the daily bases and partition ET into evaporation (E) and transpiration (T) (Araya et al 2010; Toumi et al 2016).

Input data for AquaCrop are climate file (minimum-maximum air temperature, ET_o, precipitation and CO_2), soil file (field capacity, permanent wilting points, saturated hydraulic conductivity), crop file (emergence date, start of flowering, length of flowering, max. canopy cover, canopy senescence, physiological maturity), management file (irrigation, field management practices) and initial condition file (initial soil water content) (Steduto et al 2012).

2.3. Methods of model calibration, validation

The AquaCrop (5.0) was calibrated for the full irrigation trail in 2008-2009. Canopy cover (CC) calculation parameters which highest canopy cover (CC_X), canopy decline and canopy growth coefficients (CDC and CGC, respectively) were used for calibration. A trial and error approach were used to minimize the difference between the simulated and measured data. The process of calibration was complied when the lowest root mean squared error between simulated and measured CC, soil water content and grain yield was obtained.

Field data set of all treatments at 2009-2010 growing season was used for model validation. Canopy cover, soil water content, biomass and grain yield were considered.

AquaCrop uses growing degree day (GDD) as a thermal time to calculate temperature values (Steduto et al 2009; Hsiao et al 2009). In AquaCrop model, base and the upper temperature are used to calculate GDD. In this study, the value 0 for base and 27 °C for upper temperature were used for the Bayraktar-2000 winter wheat cultivar (Tatar & Yazgan 2002). Two types of crop parameters are described in the model as conservative (not change with time, climate, management etc) and non-conservative (cultivar and conditions dependent) (Hsiao et al 2009; Raes et al 2009; Steduto et al 2012). These parameters used in the model for calibration and validation were presented in Table 4. Some of the data were obtained from conducted experiment between at the 2008 and 2010 cropping season, some of them were taken local experience, some of them were used from the reference manual for AquaCrop as a default (Raes et al 2012).

2.4. Data analysis

Measured and simulated data including soil water content, dry biomass and grain yield were compared statistically for evaluating model reliability. The agreement between predicted and measured values was defined by calculating coefficient of determination, the root mean square error (RMSE), normalized root mean square error (NRMSE) (Jacovides & Kontoyiannis 1995), Nash-Sutcliffe efficiency (EF) (Nash & Sutcliffe 1970) and index of Willmott (d) (Willmott 1982). Statistical parameters were expressed in Equation 2-5.

$$RMSE(\%) = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(S_i - O_i)^2} \tag{2}$$

$$NRMSE(\%) = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(S_i - O_i)^2}\, x\, \frac{100}{O_{avg}} \tag{3}$$

$$EF = 1 - \frac{\sum_{i=1}^{n}(O_i - S_i)^2}{\sum_{i=1}^{n}(O_i - O_{avg})^2} \tag{4}$$

$$d = 1 - \frac{\sum_{i=1}^{n}(S_i - O_i)^2}{\sum_{i=1}^{n}\left(\left|S_i - O_{avg}\right| + \left|O_i - O_{avg}\right|\right)^2} \tag{5}$$

Where; n, total observation numbers; O_i, observed value of the i^{th} observation; S_i, estimated value of the i^{th} observation; O_{avg}, mean of the observed values (i= 1 to n).

If RMSE is close to zero, the model performance can be described acceptable. If NRMSE is less than 10%, model simulation can be considered perfect (between 10 and 20%; acceptable, 20 and 30%; fair, greater than 30%; poor) (Jamieson et al 1991; Mohammadi et al 2016). EF values ranges from minus infinity (-∞) to 1.0. If EF value is 1.0 it is represents a perfect prediction and on the contrary lower values representing a gradually unsatisfactory prediction. Values of EF between 0.50 and 1.00 are assumed admissible. The index of agreement (d)

Table 4- Conservative and non-conservative crop inputs used in AquaCrop for winter wheat

Conservative parameters		
Description	*Value*	*Units or meaning*
Crop growth and development		
Base temperature[LE]	0	°C
Cut-off temperature[LE]	27	°C
Canopy cover (CC_o)[M]	6.47	% at 90% emergence
Maximum canopy cover, CCx (%)[C]	90	%
Canopy growth coefficient (CGC)[C]	2.7	% inc. in CC relative to existi. CC per GDD*
Canopy decline coeff. (CDC) at senescence[C]	0.34	%, decrease in CC relative to CC_x per GDD
Water stresses[D]		
Upper threshold of leaf growth	0.20	as frac. of TAW, above leaf growth is inhibi.
Lower threshold of leaf growth	0.65	leaf growth stops completely at this p
Curve shape of leaf growth stress coefficient	5.0	moderately convex curve
Upper threshold of stomatal conductance	0.65	above this stomata begin to close
Curve shape of stomatal stress coefficient	2.5	highly convex curve
Upper threshold of senescence stress	0.70	above this early canopy senescence begins
Curve shape of senescence stress coefficient	2.5	moderately convex curve
Biomass production and yield formation		
Harvest index[M]	36	%
Water productivity normal. for ET_o and CO_2[D]	15	g (biomass) m^{-2}
Non-conservative parameters		
Management dependent[M]		
Sowing rate	170	kg seed ha^{-1}
1000 seed mass	33.50	g
Germination rate	85	%
Cover per seeding	1.5	cm^2 $plant^{-1}$
Plant density	431.3	plant m^{-2}
Phenology (cultivar specific)[M]		
Sowing	20 October	date
Time from sowing to emergence	31 October, 11(123)	date,day, GDD
Time to reach max canopy cover	12 May, 204 (1276)	date,day, GDD
Time from sowing to maximum root depth	16 March, 146 (775)	date,day, GDD
Time to start senescence	10 June, 233 (1768)	date,day, GDD
Time from sowing to reach maturity	20 July, 274 (2605)	date,day, GDD
Time to reach flowering	15 May, 207(1320)	date,day, GDD
Duration of flowering stage	25 May, 10 (179)	date,day, GDD
Soil dependent[M]		
Minimum effective root depth	0.3	m
Maximum effective root depth	1.5	m
Hydraulic conductivity	125-230	(0-30 and 30-150 cm soil depth) mm day^{-1}

*GDD, growing degree days (°C); LE, local experience; M, measured; D, default (Steduto et al 2012); C, calibrated value is varies between 0 and +1 (Andarzian et al 2011; Tavakoli et al 2015; Mohammadi et al 2016). According to d values the closer to one indicates that estimated and observed values are identical.

3. Results and Discussion

3.1. Model calibration results

Data set (full irrigation treatment) in the 2008-2009 growing was used for calibration season. Canopy cover, total soil water content, grain yield and final aboveground biomass have been calibrated. Maximum canopy cover, canopy growth coefficient and canopy decline coefficients were modified and re-modified to simulate the measured canopy cover. Figure 6 showed that there was a good agreement between the observed and simulated canopy cover development and soil water content at 90 cm soil depth. It was also approved by statistical values at Table 5.

EF, d and R^2 values are close to 1 which indicates simulated canopy cover and soil water content agreed well with observed. NRMSE values obtained with calibration are in the range 10 and 20% for canopy cover which indicated that simulation can be acceptable and smaller than 10% for soil water content which means that simulation can be considered as perfect. The results of this study are collaborated by other research studies (Andarzian et al 2011; Tavakoli et al 2015; Toumi et al 2016).

Table 6 shows both grain yield and aboveground biomass were sufficiently predicted by AquaCrop. The deviation of the predicted grain yield and biomass from observed calibration data set in 2008-2009 was 1.4% and 1.3%, respectively.

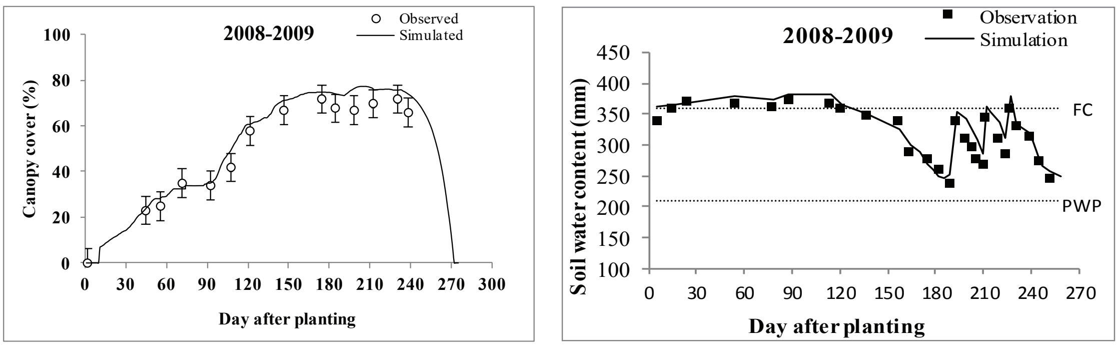

Figure 6- The observed and simulated canopy covers percent during the 2008-2009 growing season (vertical bars represents standard deviations)

Table 5- Statistical values belonging to simulated and observed canopy cover and soil water content for calibration under full irrigation of winter wheat

Year	*Variables*	*RMSE*	*NRMSE*	*EF*	*d*	*R^2*
2008-2009	Canopy cover (%)	5.6	10.9	0.90	0.98	0.99
	Soil water content (mm)	5.8	9.6	0.93	0.98	0.98

Table 6- Simulated and measured grain yield and biomass results for calibration under full irrigation of wheat

Year	*Yield (t ha^{-1})*			*Biomass (t ha^{-1})*		
	Measured	*Simulated*	*Deviation (%)*	*Measured*	*Simulated*	*Deviation (%)*
2008-2009	5.15	5.49	1.4	14.9	15.5	1.3

3.2. Model validation and testing results

In this study, the performance of the model was validated with simulating grain yield, biomass, canopy cover and soil water content. Validation was conducted with data for different irrigation treatments (rainfed, full irrigation, irrigation at tillering and grain filling, irrigation at heading and grain filling stage) in the 2009-2010 growing seasons.

3.2.1. Soil water content

The comparison of simulated and observed soil water content was presented in Figure 7. According to this figure, predicted soil water content has similarity of the measured values with slightly over-estimated for all treatments. Statistical results such as RMSE, NRMSE, EF, d and R^2 for four irrigation treatments were given in Table 7. According to statistical values the simulated soil water agreed with their corresponding observed values. Root zone soil water content is estimated in moderate accuracy by the model. The best fit was obtained between measured and simulated soil moisture at rainfed treatment. Similar observation results have been reported in various studies (Hussein et al 2011; Iqbal et al 2014; Toumi et al 2016).

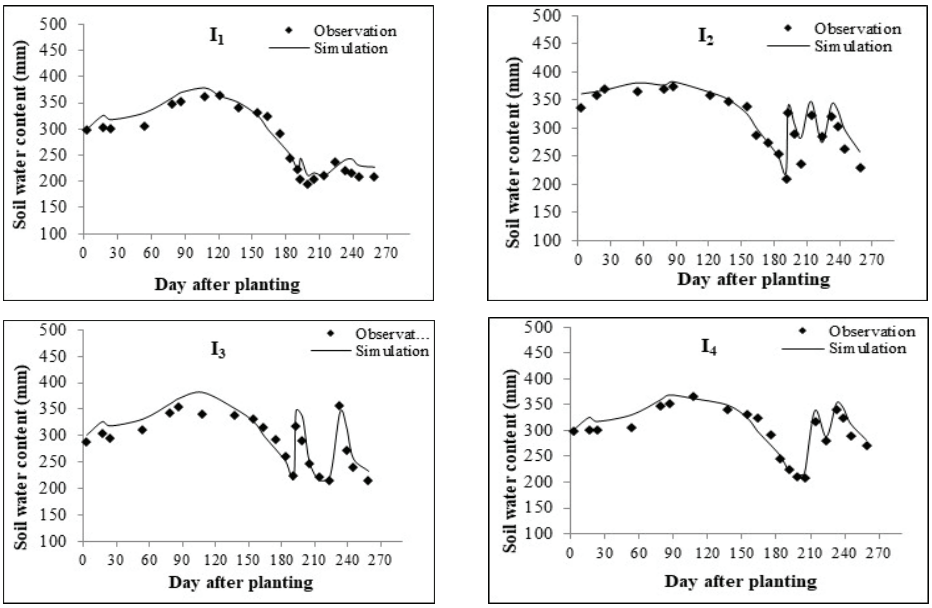

Figure 7- The observed and simulated water content at the top 0.90 m soil profile in the growing season 2009-2010 for four irrigation treatments

Table 7- Statistical values belonging to simulated and observed soil water content for validation during 2009-2010 growing season

Variables	*Treatment*	*RMSE*	*NRMSE*	*EF*	*d*	*r^2*
Soil water content (mm)	I_1	15.1	5.6	0.93	0.98	0.97
	I_2	25.2	7.9	0.73	0.94	0.94
	I_3	22.3	8.4	0.52	0.87	0.86
	I_4	21.8	7.7	0.78	0.94	0.90
	Average	21.1	7.4	0.74	0.93	0.92

3.2.2. Canopy cover

It is shown in Figure 8 that different irrigation treatments have slightly affected the canopy covers. Figure 8 shows the comparison between simulated and observed canopy development in irrigated and rainfed treatments. The results indicate that the simulated canopy cover was almost same to the observed values from sowing to senescence periods. But there was some inconsistency after senescence with measured CC. For all treatments CC values were mostly over estimated from the senescence to the end of the growing season which was also obtained by Andarzian et al (2011) and Toumi et al (2016) for wheat under different irrigation conditions.

Table 8 shows statistical analysis of the model performance for CC. According to results normalized deviation of predicted values from observed for CC percentage was between 10.3% and 18.5%, which is acceptable. Model efficiency and the index of agreement was in the range 0.84-0.93 and 0.97-0.98 which is close to 1.0 indicate the reliable performance of the model. The lowest CC was obtained at the rainfed condition whereas the highest value was in the full irrigation conditions. If we compare the average

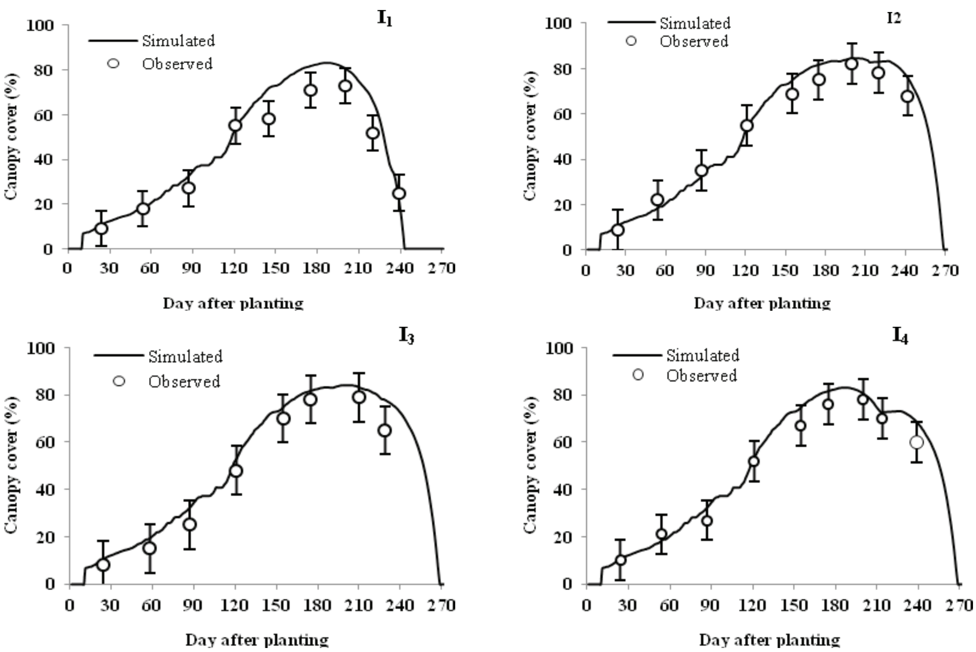

Figure 8- The observed and simulated canopy cover results in 2009-2010 growing season

Table 8- Statistical indices calculated for performing performance of AquaCrop model in predicting canopy cover and soil water content

Variables	*Treatment*	*RMSE*	*NRMSE*	*EF*	*d*	*R^2*
	I_1	7.9	18.5	0.89	0.98	0.94
	I_2	6.9	11.4	0.88	0.98	0.96
Canopy cover (%)	I_3	8.2	15.7	0.84	0.97	0.96
	I_4	5.7	10.3	0.93	0.98	0.98
	Average	7.1	13.9	0.89	0.98	0.96

canopy cover according to the treatments, the highest value was obtained from I_2 (full irrigation) and it was followed by I_4 and I_3 treatments. The lowest value was at I_1 (rainfed) treatment. Simulation of the results showed the same trend.

3.2.3. Grain yield and biomass

Observed and simulated grain yield values and final aboveground biomass were presented at Table 9. Table 9 shows a deviation of the simulated grain yield (1.8% to 11.4%) and biomass (1.3% to 3.5%) from their corresponding observed data. The highest positive deviation was simulated for grain yield in the case of treatment I_1 (rainfed). This could possibly be due to the fact that the senescence of the canopy accelerates under severe water stress at the field conditions. Iqbal et al (2014) reported much greater deviation (14.1%) under rainfed conditions. Similar results have been obtained by Araya et al (2010) and Zeleke et al (2011). They reported much greater deviation under rainfed or severe water stress treatments, as compared to full irrigation treatments for different crops simulated by the model. The highest grain yield and biomass (5.6 t ha^{-1} and 14.9 t ha^{-1}) were obtained from I_2 (full irrigation) treatment. Grain yield and above ground biomass values at I_1 (rainfed), I_3 (irrigated tillering+grain filing) and I_4 (irrigated heading+grain filing) treatments were 3.5 t ha^{-1}, 4.2 t ha^{-1} and 4.4 t ha^{-1}, respectively. The estimated values of grain yield and biomass for all treatments are in the range of the observed one. The model efficiency (EF) showed good performance for biomass (0.92), moderate performance for grain yield (0.75). Model simulated biomass more accurately than grain yield. This was also confirmed by Moderate EF and lower RMSE (0.32 t ha^{-1} and 0.34 t ha^{-1}) values indicate that the AquaCrop model is able to simulate grain yield and biomass well. Figure 9 shows linear correlation between simulated and observed grain yield and biomass. Determination coefficient show that the model simulated grain yield and biomass with a high degree of reliability has a R^2 of 0.99 for both of them. The AquaCrop model could very well predict

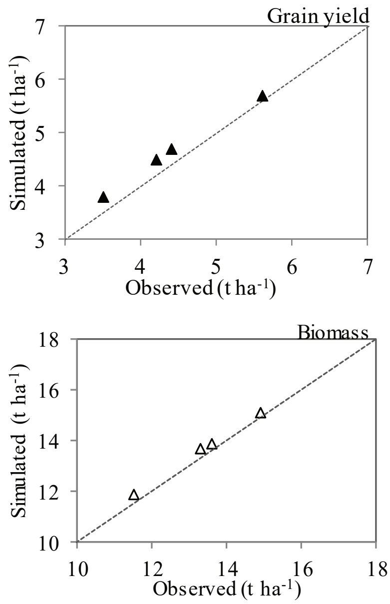

Figure 9- Relation between simulated and measured wheat grain yield and biomass

Table 9- Simulated and observed grain yield and biomass results for validated data set

Year	*Treatment*	*Yield (t ha^{-1})*			*Biomass (t ha^{-1})*		
		Observed	*Simulated*	*Deviation (%)*	*Observed*	*Simulated*	*Deviation (%)*
2009-2010	I_1	3.5	3.9	11.4	11.5	11.9	3.5
	I_2	5.6	5.7	1.8	14.9	15.1	1.3
	I_3	4.2	4.6	9.5	13.3	13.7	3.0
	I_4	4.4	4.7	6.8	13.6	13.9	2.2
RMSE (t ha^{-1})		0.32			0.34		
NRMSE (%)		7.32			2.52		
d		0.95			0.98		
EF		0.82			0.92		

grain yield and final aboveground biomass of winter wheat under semi-arid conditions.

It is important to note that in spite of the slight mismatching the overall results of this study intimate that AquaCrop model has adequately simulated grain yield, biomass, canopy cover as well as soil water content under various water availability conditions.

4. Conclusions

In this study AquaCrop model (5.0 version) was calibrated and validated for winter wheat crop grown under different irrigation treatments in the semi-arid region of Turkey (Central Anatolia). The results of the model for evaluation of simulate soil water content of root zone, seasonal canopy cover, grain yield and final harvested biomass showed sufficient accuracy of the model simulated and observed values. The average values of the root mean square error (RMSE) between observed and simulated CC, SWC, BM and GY were 7.1%, 21.1 mm, 0.34 t ha^{-1} and 0.32 t ha^{-1}, respectively. Nash-Sutcliffe efficiency (EF) and index of Willmott (d) also were obtained 0.89 and 0.98 for CC, 0.74 and 0.93 for SWC, 0.98 and 0.92 for BM, 0.95 and 0.82 for GY. Model predicted canopy cover, grain yields and biomass with high accuracy while soil water content in root zone is estimated in the moderate accuracy.

Despite model prediction slightly over-estimated, overall results of this study demonstrated that the AquaCrop model is a suitable tool for evaluating irrigation strategies of winter wheat in semi-arid regions.

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