

## PAPER DETAILS

TITLE: Yield prediction of wheat at different sowing dates and irrigation regimes using the AquaCrop model

AUTHORS: Belgin Alsancak Sirli,Sema Kale Çelik,Hakan Yildiz,Metin Aydogdu

PAGES: 874-886

ORIGINAL PDF URL: <https://dergipark.org.tr/tr/download/article-file/3426317>

# Yield prediction of wheat at different sowing dates and irrigation regimes using the AquaCrop model

Belgin SIRLI<sup>1</sup>  • Sema KALE CELIK<sup>2</sup>  • Hakan YILDIZ<sup>1</sup>  • Metin AYDOGDU<sup>1</sup> 

<sup>1</sup> Soil, Fertilizer and Water Resources  
Central Research Institute, Ankara,  
Turkiye

<sup>2</sup> Isparta University of Applied  
Sciences, Agricultural Structure  
and Irrigation Department of  
Agricultural Faculty, Isparta, Turkiye

**Citation:** Sirli, B., Kale Celik, S., Yildiz, H., Aydogdu, M. (2023). Yield prediction of wheat at different sowing dates and irrigation regimes using the AquaCrop model. *International Journal of Agriculture, Environment and Food Sciences*, 7 (4), 874-886

## Abstract

Water efficiency models are playing an increasingly important role in helping agricultural activities adapt to climate change. AquaCrop is one of the models that can accurately correlate water-plant-climate parameters. In this study, the effects of irrigation strategies ( $I_1$ ; rainfed,  $I_2$ ; irrigation at Germination (G)+Tillering (T)+Heading (H) stages,  $I_3$ ; irrigation at G+H stages,  $I_4$ ; irrigation at G+T stages) and sowing dates ( $SD_1$ ; normal sowing date,  $SD_2$ ; late sowing date) on winter wheat yield and soil water conditions were investigated in semi-arid climate conditions. Biomass, grain yield, soil water content and crop canopy cover values observed in field conditions and simulated by AquaCrop. According to results  $SD_1$  did not have a negative effect on grain yield and biomass however  $SD_2$  would significantly reduce grain yield and biomass amount. Considering the biomass and grain yields in terms of irrigation, the highest yield was obtained in the irrigation water applied during the  $I_2SD_1$  treatment. The yield reduction was 39% in rainfed treatments, 22% when irrigated in G+T periods, and 5% when irrigated in G+H stages. The model predicted 2-year grain yield and biomass values more accurately in  $SD_1$  than in  $SD_2$ . The model predicted yield, biomass, soil moisture content and canopy cover values with an acceptable accuracy.

**Keywords:** Yield prediction, AquaCrop, Winter wheat, Sowing date, Canopy cover, Irrigation regimes

**Received:** September 22, 2023

**Accepted:** December 6, 2023

**Published Online:** December 26, 2023

**Correspondence:** Sema KALE CELIK

**E-mail:** semakale@isparta.edu.tr

Available online at  
<https://jaefs.com/>  
<https://dergipark.org.tr/jaefs>



This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution-NonCommercial (CC BY-NC) 4.0 International License (<https://creativecommons.org/licenses/by-nc/4.0/>).

Copyright © 2023 by the authors.

## INTRODUCTION

The pressure on fresh water resources to meet food demand of the growing population is increasing because of the rapid growth in world population. In order to produce enough food to meet the demand, it is possible with irrigated agriculture. Therefore, agriculture is the largest water consumer sector with a usage share of 75% (Aouade et al., 2016; Tan et al., 2017; Zhuo and Hoekstra, 2017). Especially in arid and semi-arid regions, water is the main limiting factor. The water used in irrigation constitutes 73% of the total water resources in Türkiye (Gokalp and Cakmak, 2016). Ankara is located in center part of Central Anatolia Region in Türkiye. Drought and water scarcity is an iterative climate phenomenon in this region which leaves many socioeconomic and ecological challenges (Delju et al., 2013). Because of that, assignation sustainable methods to increase water use efficiency is becoming the aim of many studies (Debaeke and Aboudrare, 2004). The most widespread approach for overcoming current and future water-related challenges is to focus firstly on improving agricultural water productivity by applying irrigation water -saving strategies. If considered in more detail, these difficulties can be solved owing to efficient agronomic planning, including appropriate irrigation scheduling with considering such as

deficit irrigation and suitable sowing dates, which would allow the same amount of agricultural production with less water (Davarpanah and Ahmadi 2021).

The global wheat production came to about 778.6 million tons in 2021-2022 growing season (Shahbandeh, 2022). Wheat are main cultivated crops in Türkiye where wheat cultivation area has a value of 2.4% in the world as of 2020-2021 production season (USDA, 2021). However, production occurs highly variable from year to year depending on climatic variability (TUIK, 2021). In order to prevent this fluctuation in wheat production, which is also affected by climate change, it should be a priority to increase water efficiency in agriculture.

In different climatic conditions, it is very important to monitor plant development, estimate yield, choose appropriate planting dates and develop crop management strategies. The effects of environmental factors and agricultural inputs on crop production are generally tested by conducting field studies. However, these studies take a long time, are expensive, and the application method is quite complex when more than one variable is involved. For this reason, computer simulation models that empirically formulate the ecosystem environment have been developed. It is assumed that this mathematically formulated system will respond to different environmental factors like a real plant system.

FAO's AquaCrop water efficiency model is developed to predict the effects of different irrigation practices and all parameters affecting plant growth on crop yield (Steduto et al., 2012). The model has been tested to simulate the yield response to water for most of the major field crop such as the forage plants, vegetables, cereals, fruits, root and tuber crops grown worldwide (Hsiao et al., 2009; Raes et al., 2009a; Steduto et al., 2009; Kale Celik et al. 2018). Simulation results of the model have shown high accuracy (Salemi et al., 2011; Zhang et al 2013; Tavakoli et al., 2015; Kale Celik et al. 2018).

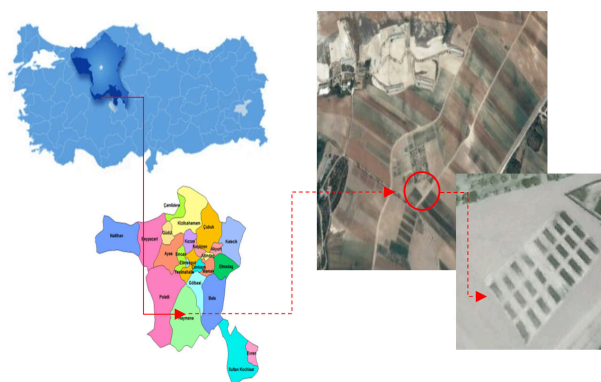
In this study, calibration and validation of the AquaCrop model was performed using experimental field data under various irrigation strategies and different winter wheat planting dates. By using the model simulation results it will be possible; i) to estimate the yield at the regional level under semi-arid climate conditions ii) to determine the changes in yield, water use efficiency and the moisture levels of soil profile under several irrigation strategies and different planting dates. This model was used in this study to simulate the effects of different irrigation strategies and different seed planting dates on winter wheat yield and biomass. Thus, it will be possible to make management strategies to prevent yield losses that may occur due to climate change, such as changing the irrigation regime or planting date.

## MATERIAL AND METHODS

### Materials

#### Experimental Area

The field experiment was carried out in the 2015-2016 and 2016-2017 growing seasons at the İkizce/Haymana Research Station of the Central Research Institute of Field Crops. The study area is in the Haymana plain, which is located in the central of Türkiye, Ankara province, extended between 39°12' and 43°6' northern latitudes, and 35°58' and 37°44' eastern longitudes (Figure 1).



**Figure 1.** Experimental area.

Climatic data including rainfall, average air temperature and relative humidity for the period of 2015-2017, were obtained from the Meteorological station of Haymana plain (Table 1). Average rainfall, air temperature and relative humidity for simulation years were 259.2 mm, 10.7 °C and 60.9% respectively (TSMS, 2018).

Silty clay at 0-30 cm of soil depth and clay at 60-90 cm of soil depth is the most dominant soil texture in the experimental area. Average volumetric field capacity, volumetric permanent wilting point and bulk density are 36%, 17%, and 1.19 gr cm<sup>-3</sup> respectively. The soil saturation hydraulic conductivity is about 0.75 cm h<sup>-1</sup>.

“Konya 2000” winter wheat variety was used in this research. This variety has high yield potential (400-750 kg da<sup>-1</sup>) and is recommended for irrigable areas of Central Anatolia Regions. This variety, which is sensitive to drought, has high tolerance to winter and cold (Aydoğan and Soylu 2017).

AquaCrop, simulation model developed by the United Nations Food and Agriculture Organization (FAO), is mostly used to simulate the response of plants to water and the impact of meteorological risks on plant development. In this study, version 5.0 of the AquaCrop model was used (Raes et al., 2016).

AquaCrop Model organized at several modules which are climate, soil, plant and agricultural activities. Model inputs;

- Climate input file (daily rainfall, minimum and

**Table 1.** Climate data on Haymana experimental station

Months	Rainfall (mm)			Average air temperature (°C)			Average Relative Humidity (%)		
	2015	2016	2017	2015	2016	2017	2015	2016	2017
January	42.2	87.3	20.2	-1.4	-0.7	-4.6	88.6	67.1	76.1
February	4.5	24.9	10.0	0.8	5.9	0.9	82.1	67.4	63.9
Mart	16.3	5.4	35.7	4.7	5.7	6.5	72.7	76.1	63.1
April	12.8	3.2	14.8	9.5	12.1	9.1	64.7	52.1	54.3
May	45.3	22.8	27.8	14.3	13.1	13	61.9	62.2	56.9
June	1.2	1.5	25.2	22.8	19.3	17.4	56.4	48.0	57.4
July	15.5	0.0	0.4	22.6	22.1	22.6	48.6	40.1	42.3
August	16.2	18.9	26.2	17.7	23.0	22.1	47.2	46.8	48.5
September	13.4	64.2	30.2	18.6	17.5	20.0	47.2	51.8	39.3
October	7.0	10.8	15.9	11.1	12.1	9.8	78.0	55.7	59.8
November	7.2	30.5	31.5	5.4	5.0	5.4	68.5	55.7	73.5
December	43.6	9.9	35.1	0.8	-1.9	2.9	75.8	69.5	72.6

maximum air temperature, wind speed, relative humidity, CO<sub>2</sub> amount (by default AquaCrop obtains the atmospheric CO<sub>2</sub> concentration for a particular year), sunshine hours, reference evapotranspiration). In this study, daily climate data were obtained from Haymana Meteorological Station of the General Directorate of Meteorology. ETo was calculated by FAO Penman-Monteith Equation (Allen et al., 1998) in the AquaCrop model.

- Soil input file (field capacity and permanent wilting point and saturated hydraulic conductivity, soil texture etc.)
- Crop input file (emergence, maximum root depth, time and duration of flowering, canopy senescence, maximum canopy cover and maturity),
- Field management input file (irrigation schedule, irrigation water quality, management practices) and
- Initial condition input (soil water content, soil salinity).

## Methods

The study was carried out through two growing seasons from 2015 to 2017. 2015-2016 growing season values were used for calibration and 2016- 2017 for validation processes. The experiment consists of 4 irrigation regimes

and two different sowing date with 3 replications. Field treatments are given at Table 2.

The experimental design was as a complete randomized block design with a split plot layout. Plot dimensions were taken 17.5 m<sup>2</sup> (5 m x 3.5 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 2). Before irrigation, soil moisture content was measured by the gravimetric method. Irrigation water was applied until the soil moisture reached the field capacity with surface irrigation method. Water meter was used to measure applied irrigation water amount. Water table depth around 4 m. Tensiometers were used to control deep seepage.

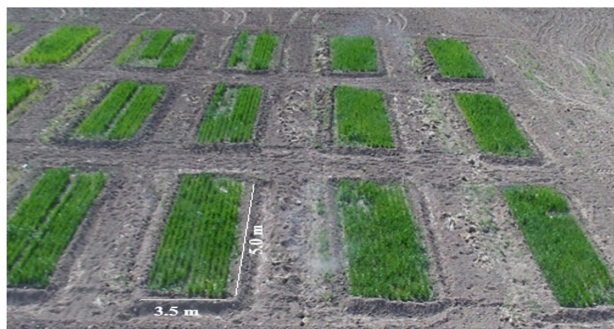
The irrigation treatments consisted of water application at different stages of the plant growth. Irrigation water was applied one time at the beginning of the growing stages (according to treatments which were given in Table 2) until the soil water content was reached to field capacity in 90 cm soil depth. The total irrigation amount (without rainfall) for irrigation treatments were I<sub>1</sub>: 0 mm, I<sub>2</sub>: 275 mm (G:30 mm, T: 70 mm and H:145 mm), I<sub>3</sub>: 175 mm (G:30 mm and H:145 mm), I<sub>4</sub>:100 mm (G:30 mm and T: 70 mm). Total rainfall has been 337.2 mm during the

**Table 2.** Irrigation treatments and sowing date of the experiment

Sowing dates	Irrigation treatments	Wheat growing stages		
		Germination (G)	Tillering (T)	Heading (H)
SD <sub>1</sub> (Normal sowing date)	I <sub>1</sub> (rainfed - no irrigation)	-	-	-
	I <sub>2</sub> (irrigate at germination, tillering and heading stage)	x	x	x
	I <sub>3</sub> (irrigation at germination and heading stage)	x	-	x
	I <sub>4</sub> (irrigation at germination and tillering stage)	x	x	-
SD <sub>2</sub> (Late sowing date)	I <sub>1</sub> (rainfed - no irrigation)	-	-	-
	I <sub>2</sub> (irrigate at germination, tillering and heading stage)	x	x	x
	I <sub>3</sub> (irrigation at germination and heading stage)	x	-	x
	I <sub>4</sub> (irrigation at germination and tillering stage)	x	x	-

(-); no irrigation, (x); irrigation

growing season.



**Figure 2.** Field experimental design.

In the model the Crop file inputs consist of conservative (crop development, crop transpiration, biomass production and stresses which is not change with management and time) and non-conservative parameters (sowing rate, plant density, time from germination to maturity etc.) (Raes et al., 2009b). The AquaCrop model was run in the basis of the growing degree day (GDD). GDD was calculated by Equation 1.

$$GDD = \left( \frac{T_{\max} + T_{\min}}{2} \right) - T_b \quad [1]$$

$T_{\max}$  and  $T_{\min}$  is daily maximum and minimum air temperature. The base temperature ( $T_b$ ) is the cool temperature at which a plant does not develop. Crop inputs for wheat used in the AquaCrop model were given in Table 3.

### Calibration and validation of the model

Calibration and validation steps of the models are the basic required steps to increase the accuracy and validity of simulations. The AquaCrop model was calibrated during 2015-2016 cropping season using measured data set of grain and biomass yield (GY, BY) and canopy cover (CC) and validated during the 2016-2017 cropping season using measured data set.

The statistical evaluation of the validity of the model was carried out by comparing the measured and estimated grain and yield biomass and canopy cover percentages. Determination coefficient ( $R^2$ ), root mean square error (RMSE), normalized root mean square error (NRMSE) and model performance coefficient or model efficiency (EF) were used for determining the relationship between measured and estimated values. Those statistical parameters were calculated using equation 2, 3, 4 and 5 (Nash and Sutcliffe, 1970; Lyman, 1993; Janssen and Heuberger, 1995).

where  $n$  is the total number of observations,  $O_i$  and  $S_i$  are observed and simulated values respectively,  $O_{avg}$  and  $S_{avg}$  are average values of  $O_i$  and  $S_i$  ( $i$  from 1 to  $n$ ) respectively. Coefficient of determination ( $R^2$ ) ranges from 0 to 1,

with values close to 1 indicating a good agreement and typically values greater than 0.5 are considered acceptable simulation (Moriassi et al., 2007).

$$R^2 = \left( \frac{\sum_{i=1}^n (O_i - O_{avg})(S_i - S_{avg})}{\sqrt{\sum_{i=1}^n (O_i - O_{avg})^2} \sqrt{\sum_{i=1}^n (S_i - S_{avg})^2}} \right)^2 \quad [2]$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^n (S_i - O_i)^2}{n}} \quad [3]$$

$$NRMSE = \frac{RMSE}{O_{avg}} \times 100 \quad [4]$$

$$EF = 1 - \frac{\sum_{i=1}^n (O_i - S_i)^2}{\sum_{i=1}^n (O_i - O_{avg})^2} \quad [5]$$

The RMSE has the same unit as that of studied simulation variable. The closer RMSE value is to zero show the better match between the model simulation and field observation. According to Raes et al. (2015), the interpretation of the indices of NRMSE is lower than 5% shows model has been calibrated excellent, between 6% to 15% good, 16% to 25% moderately good, 26% to 35% moderately poor, 36% to 45% poor and more than 45% very poor.

The value EF is from  $-\infty$  to 1. The EF value is close to 1 indicates that there is a perfect fit between the model and the observation values, and if it is close to 0, the model should not be used.

### Determination of soil moisture values

Soil moisture was measured to gravimetric method before irrigation events. Soil samples were taken 30 cm increments from 0-120 cm for moisture analysis. According to the gravimetric approach, the amount of moisture in the soil has been determined after it has been dried at 105°C until soil moisture is constant (24 or 48 hours).

### Biomass measurements

During the growing period of the plant, biomass measurements were made by taking into account the above-ground vegetative part within a 50x50 cm frame at several times. The plants were cut from the soil surface and dried in an oven at 75°C until constant weight. Dry matter was determined by weighing the dry plants (Todd et al. 1998).

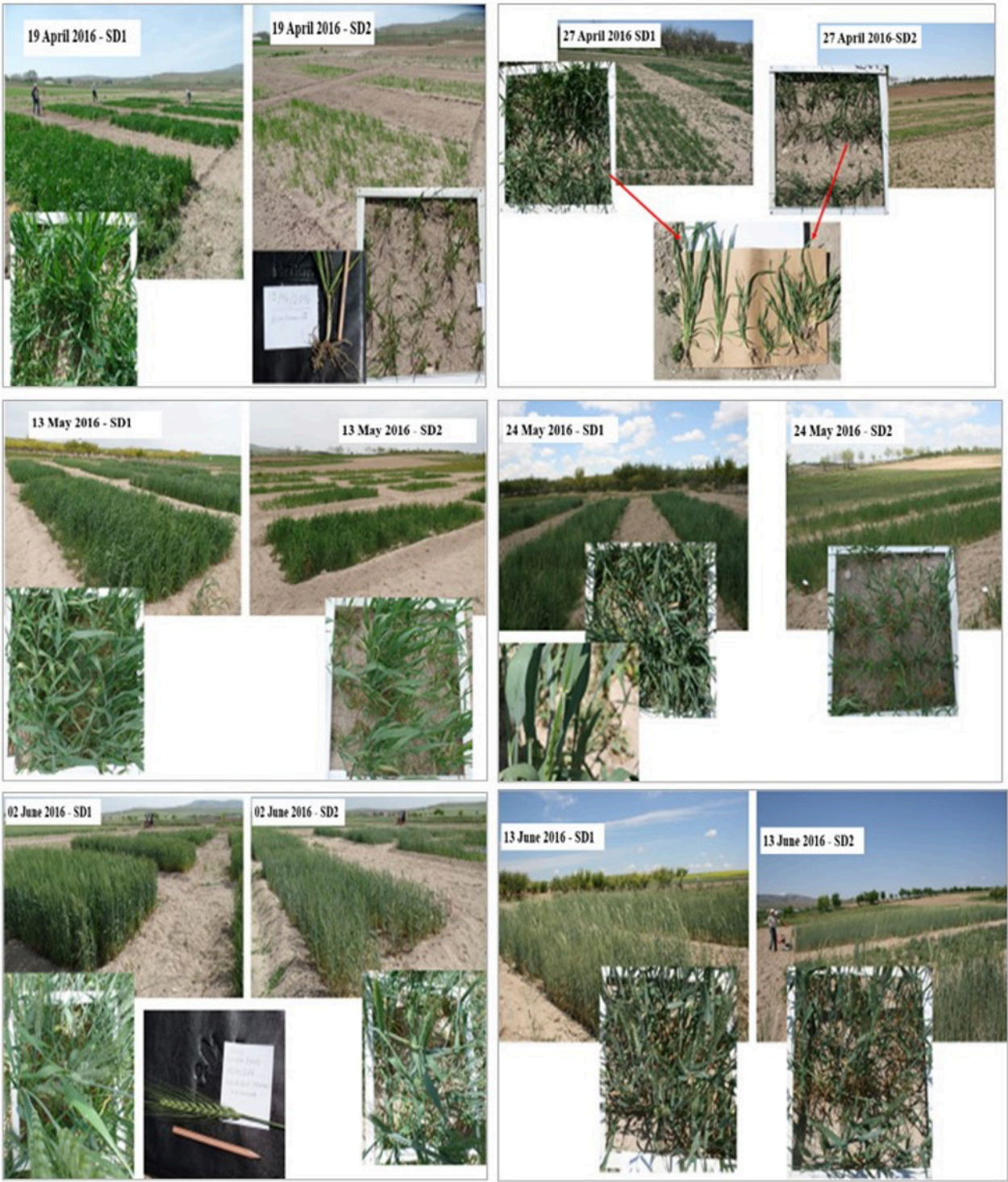
### Determination of Plant Green Cover Percentage (CC)

Digital photographs were taken from the fixed level with a high-resolution digital camera from an area of 0.25 m<sup>2</sup> (with 50x50 cm frame) at each plot from April to June (between 11:00 and 15:00). The percentage of green cover (vegetation) was determined by automatic classification using the Greencrop Tracer program. This program is a histogram-based program developed in



**Table 3.** Crop inputs for wheat used in the AquaCrop model

Defining	Values	Remarks
<b>Conservative input parameters</b>		
Base temperature ( $^{\circ}\text{C}$ )	0	Local experience
Upper temperature ( $^{\circ}\text{C}$ )	26	Local experience
Canopy cover per seedling at 90% emergence $\text{CC}_0$ (%)	7.16	Calibrated
Canopy growth coefficient (CGC) % in each GDD	2.4	Calibrated
Canopy decline coefficient at senescence % in each GDD	0.39	Calibrated
Maximum canopy cover percentage, $\text{CC}_x$ (%)	95	Calibrated
Upper threshold for canopy expansion	0.20	Default (Steduto et al. 2012)
Lower threshold for canopy expansion	0.65	Default (Steduto et al. 2012)
Leaf expansion stress coefficient curve shape	5.0	Default (Steduto et al. 2012)
Upper threshold for stomatal closure	0.65	Default (Steduto et al. 2012)
Stomata stress coefficient curve shape	2.5	Default (Steduto et al. 2012)
Canopy senescence stress coefficient	0.70	Default (Steduto et al. 2012)
Senescence stress coefficient curve shape	2.5	Default (Steduto et al. 2012)
Reference harvest index, HI (%)	38	Local experience
Normalized crop water productivity, $\text{g m}^{-2}$	15	Default (Steduto et al. 2012)
<b>Non-Conservative input parameters</b>		
Sowing rate $\text{kg seed ha}^{-1}$	180	Measured
1000 seed mass g	43.7	Measured
Plant density $\text{plant m}^{-2}$	477	Measured
Canopy cover per seeding ( $\text{cm}^2 \text{plant}^{-1}$ )	1.5	Measured
Germination rate %	98	Measured
Sowing date (for $\text{SD}_1$ and $\text{SD}_2$ sowing date)	October 12 <sup>th</sup> / November 8 <sup>rd</sup>	
Time from sowing to emergence date (GDD)	86 / 300	
Time from sowing to maximum root depth date (GDD)	866 / 903	
Time to reach flowering date (GDD)	1384 / 1409	
Duration of flowering stage	7 days	
Time to reach max canopy cover date	1239 / 1384	
Time to start senescence date	1815 / 1798	
Time from sowing to reach maturity date	2210 / 2210	
Minimum effective root depth m	1.2 Local experience	
Maximum effective root depth m	0.3 Local experience	



**Figure 3.** Canopy cover measurement during 2015-2016 growing season.

Canada (Liu and Pattey, 2010; Liu et al., 2013). Canopy cover measurement during calibration stage in 2015-2016 growing season were presented at Figure 3.

## RESULTS AND DISCUSSION

### Model calibration

The calibration is based on a trial-and-error method in which simulated and observed grain yields, biomass yields and canopy cover of plants are compared.

### Grain and biomass yields

The observed grain yield varied from 3.81 t ha<sup>-1</sup> to 5.78 t ha<sup>-1</sup> for SD<sub>1</sub> and from 1.84 t ha<sup>-1</sup> to 4.71 t ha<sup>-1</sup> for SD<sub>2</sub> while simulated grain yield had been found in the range from 4.11 t ha<sup>-1</sup> to 6.20 t ha<sup>-1</sup> for SD<sub>1</sub> and from 2.07 t ha<sup>-1</sup> to 5.14 t ha<sup>-1</sup> for SD<sub>2</sub> during the growing seasons in 2015–2016. As expected, the highest grain yield and biomass were measured at full irrigation treatment (irrigated at G+T+H stage). The highest biomass value observed in the field (10.25 t ha<sup>-1</sup>) and simulated by the model (10.58 t ha<sup>-1</sup>) was obtained in SD<sub>1</sub>I<sub>2</sub>.

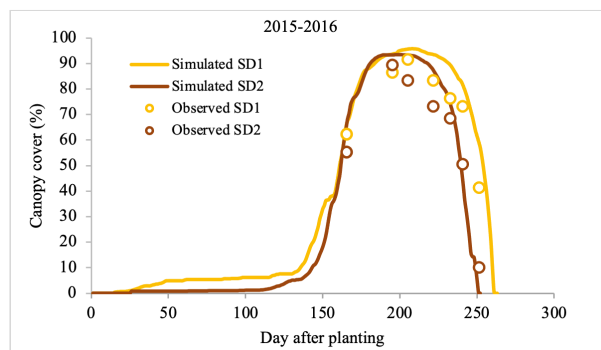
Statistical evaluation of the treatments was given in Table 4. The higher R<sup>2</sup> and E values and lower NRMSE values indicated good model performance. According to grain and biomass yield results, R<sup>2</sup> is close to “1” for all applications, which means there is a very good relationship between simulated and measured values (Raes et al., 2015). NRMSE values for grain yield and biomass of SD<sub>1</sub> and SD<sub>2</sub> was found 5.70 and 9.43% which ranged from 6 to 15%, indicating good agreement.

According to EF values of grain yields for SD<sub>1</sub> and SD<sub>2</sub> and biomass yields for SD<sub>2</sub> a good performance was obtained between the predicted and measured values. The EF value of SD<sub>1</sub> biomass yield is in moderate agreement with the number 0.49.

### Canopy cover (CC)

Canopy cover percentages of the treatments was determined by the GreenCrop Tracer program (Liu and Pattey, 2010). Observed canopy cover values for I<sub>2</sub>

irrigation application and SD<sub>1</sub>, SD<sub>2</sub> sowing date treatment in the date 19 and 27 April, 13 and 24 May, 02 and 13 June in 2016 was compared with model simulations (Figure 4).



**Figure 4.** Observed and simulated canopy cover values of wheat grain yield for SD<sub>1</sub>I<sub>2</sub> and SD<sub>2</sub>I<sub>2</sub> treatments.

There was an important linear relationship and good agreement between the measured and simulated canopy cover for SD<sub>1</sub> and SD<sub>2</sub> respectively, with R<sup>2</sup>=0.89, RMSE=5.87% and EF=0.92 for wheat under full irrigation and different planting dates in the cropping season 2015-2016.

### Model validation

#### Grain and Biomass yield

Winter wheat was planted as a normal sowing date on October 12<sup>th</sup> (SD<sub>1</sub>) and as late sowing date November 8<sup>th</sup> (SD<sub>2</sub>) during 2016-2017 growing season. Wheat that was planted on SD<sub>1</sub> had greater grain and biomass yield than did those planted on SD<sub>2</sub> for all irrigation strategies (Table 5). The highest and lowest biomass and grain yield was obtained in SD<sub>1</sub>I<sub>2</sub> (5.12 t ha<sup>-1</sup>) and SD<sub>2</sub>I<sub>1</sub> (1.76 t ha<sup>-1</sup>) respectively. There was a significant decrease in crop yield of 65% between the two treatments.

As it shown in Table 5, R<sup>2</sup> for grain yield and biomass was found between 0.90 and 0.98 respectively. It can be said that the model prediction values were closer to the observed values. According to NRMSE (%) and EF values model simulations showed good agreement with

**Table 4.** Observed and simulated grain and biomass yields with statistical parameters in calibration stages (2015-2016)

Growing years	Treatments	SD <sub>1</sub>				SD <sub>2</sub>			
		Grain Yield (t ha <sup>-1</sup> )		Biomass (t ha <sup>-1</sup> )		Grain Yield (t ha <sup>-1</sup> )		Biomass (t ha <sup>-1</sup> )	
		Observed	Simulated	Observed	Simulated	Observed	Simulated	Observed	Simulated
2015-2016	I <sub>1</sub>	3.81	4.11	7.02	8.37	1.84	2.07	4.56	5.51
	I <sub>2</sub>	5.78	6.20	10.25	10.58	4.71	5.14	9.23	9.52
	I <sub>3</sub>	5.18	5.36	9.09	9.85	3.54	3.70	7.45	8.16
	I <sub>4</sub>	5.12	4.97	8.80	9.29	3.25	3.11	6.97	7.49
R <sup>2</sup>		0.92		0.97		0.93		0.98	
RMSE (t ha <sup>-1</sup> )		0.28		0.83		0.27		0.66	
NRMSE (%)		5.70		9.43		7.97		9.38	
EF		0.84		0.49		0.99		0.95	

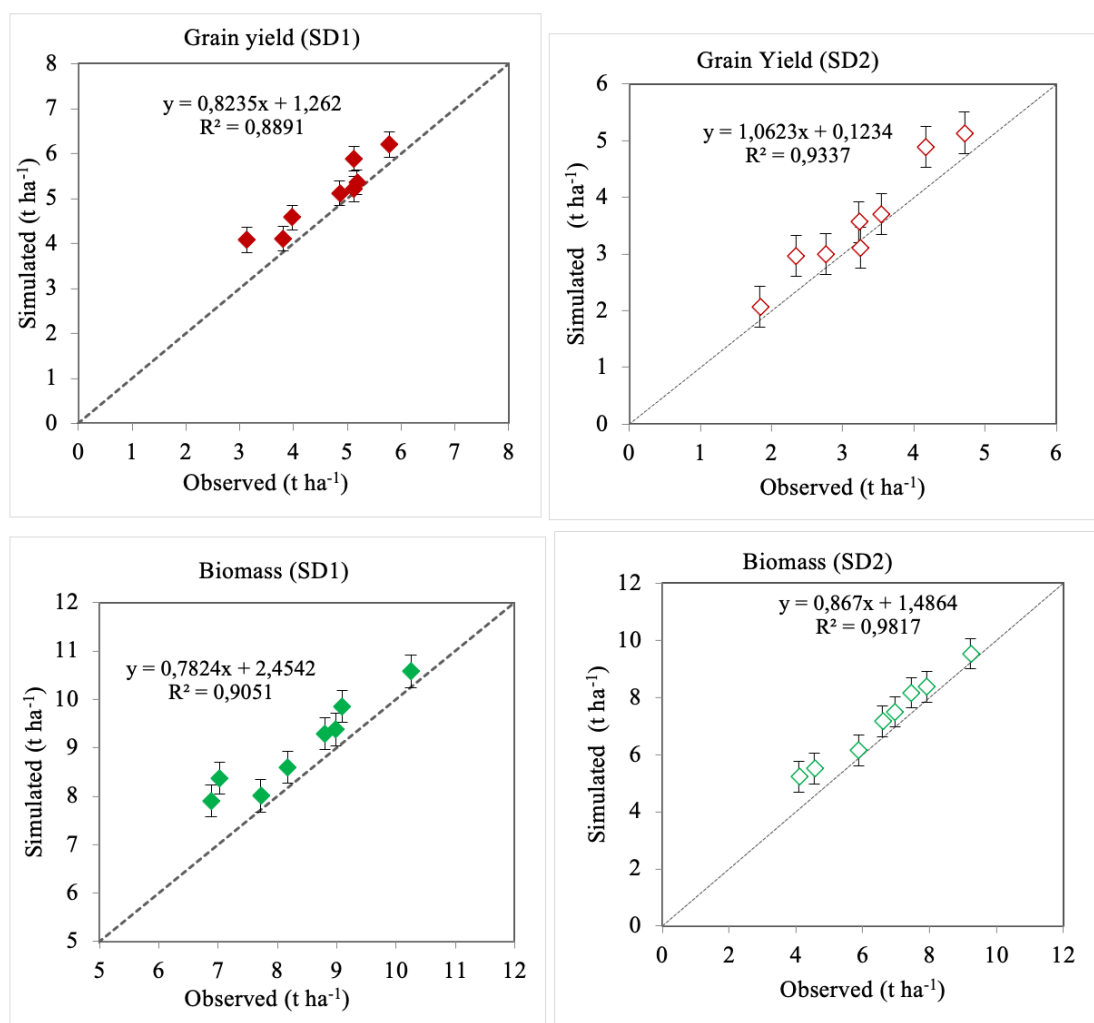


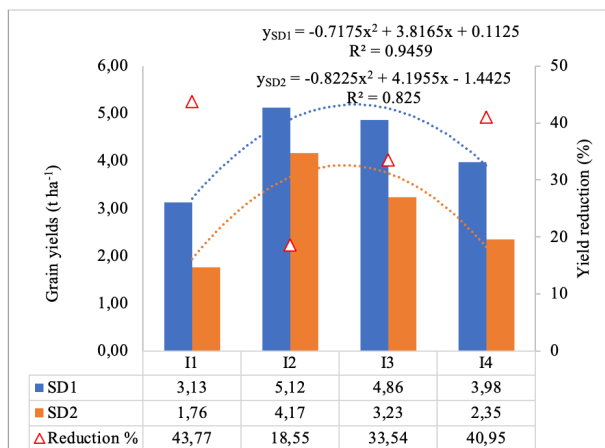
**Table 5.** Observed and simulated grain and biomass yields with statistical parameters in validation stages (2016-2017)

Growing years	Treatments	SD <sub>1</sub>				SD <sub>2</sub>			
		Grain Yield (t ha <sup>-1</sup> )		Biomass (t ha <sup>-1</sup> )		Grain Yield (t ha <sup>-1</sup> )		Biomass (t ha <sup>-1</sup> )	
		Observed	Simulated	Observed	Simulated	Observed	Simulated	Observed	Simulated
2016-2017	I <sub>1</sub>	3.13	4.08	6.88	7.91	1.76	2.00	4.09	5.22
	I <sub>2</sub>	5.12	5.89	8.99	9.38	4.17	4.89	7.91	8.37
	I <sub>3</sub>	4.86	5.12	8.17	8.60	3.23	3.56	6.59	7.16
	I <sub>4</sub>	3.98	4.58	7.72	8.01	2.35	2.97	5.88	6.14
R <sup>2</sup>		0.90		0.96		0.98		0.96	
RMSE (t ha <sup>-1</sup> )		0.62		0.69		0.47		0.69	
NRMSE (%)		14.40		7.67		14.74		11.21	
EF		0.56		0.72		0.95		0.90	

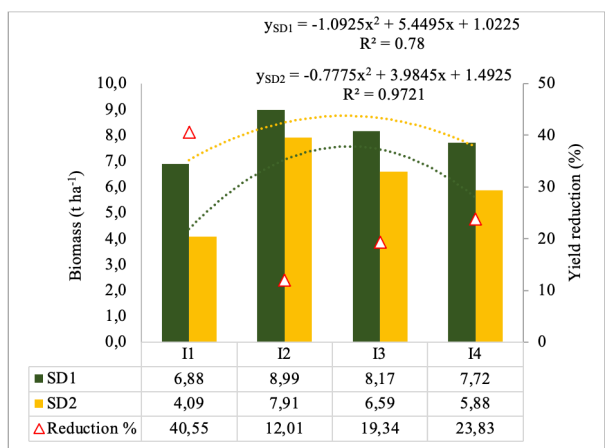
field observed values. Similar results were also found by Araya et al. (2010), Zeleke et al. (2011), Iqbal et al. (2014), Kale Celik et al. (2018), Davarpanah and Ahmadi (2021). A significant correlation was found between observed and simulated grain and biomass yield for the SD1 and SD2 sowing period (Figure 5) ( $P$  value=0.000 < 0.05 according to the F test).

The comparison between SD<sub>1</sub> and SD<sub>2</sub> grain yield and biomass values and yield reductions (%) were given Figure 6 and Figure 7. Higher grain yield and biomass were obtained when planting on October 12<sup>th</sup> compared to November 8<sup>th</sup>.

**Figure 5.** Relation between simulated and measured wheat grain yield and biomass.



**Figure 6.** Observed winter wheat grain yield under irrigation strategies and different planting dates.



**Figure 7.** Observed winter wheat biomass under irrigation strategies and different planting dates.

The higher than 40% grain and biomass yield reduction occurred in the rainfed treatment. When  $I_3$  and  $I_4$  applications are compared, irrigation during the germination and emergence period gives more reasonable results than irrigation during the germination and tillering period.

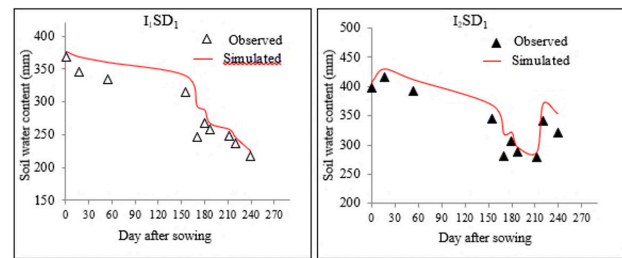
Jin et al. (2014) state that the reason for this difference is “due to higher growing degree days (accumulated warmth) promoting canopy cover growth and grain and biomass yield accumulation at an earlier planting date”. Presumably, the percent of canopy cover affected the transpiration rate and thus the accumulation of grain and biomass yields (Farahani et al., 2009).

### Soil moisture content

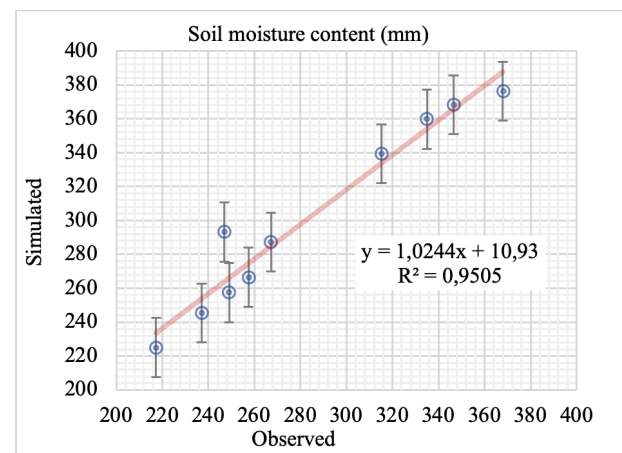
The soil moisture content was determined by gravimetric method. Soil moisture content for  $I_1$  and  $I_2$  for  $SD_1$  was given in Figure 8.

It was found that the model had overestimated soil water content compared to observation values. However, there was significant relation between observed and predicted

soil moisture content. (Figure 9).



**Figure 8.** Soil moisture content for calibration period.



**Figure 9.** Relation between simulated and measured soil moisture content for  $I_1SD_2$ .

The  $R^2$ , RMSE and E showed good performance between the simulated and the measured values for soil water content of  $I_1$  and  $I_2$  treatments ( $R^2 = 0.91-0.97$ , RMSE= 21.35-21.44 and E= 0.97–0.96). Higher  $R^2$  and E values and lower RMSE values indicated good model performance.

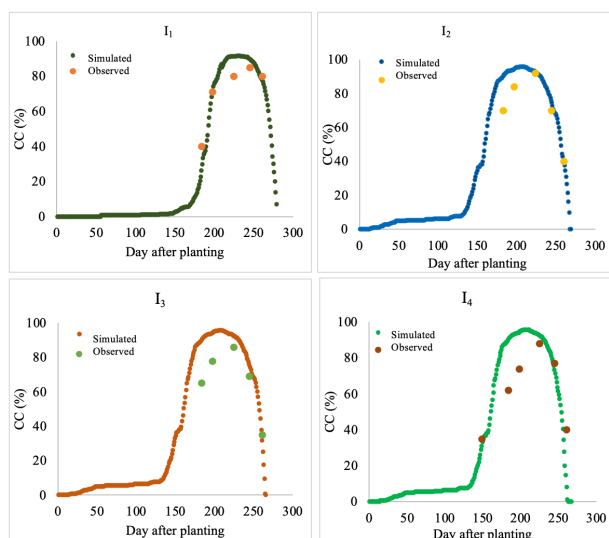
In general, the model can predict soil moisture content values with acceptable accuracy. Similar results have been found by various researchers (Farahani et al., 2009; Hussein et al. 2011; Mkhabela and Bullock, 2012; Kale and Tari 2012; Iqbal et al. 2014; Toumi et al., 2016).

### Canopy cover

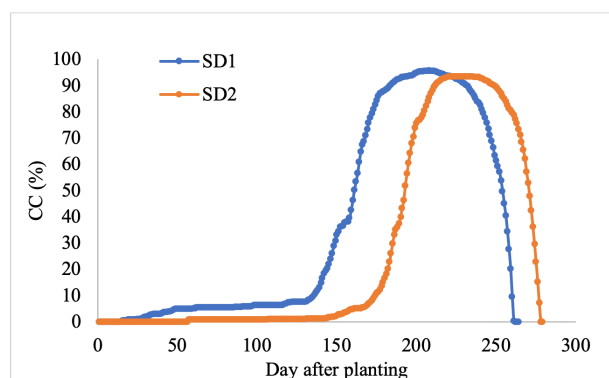
A high level of similarity was found between the canopy cover percentage predicted by the model and observed in the field. This similarity was presented as an example for  $SD_1$  and all irrigation treatments at Figure 10. While the coefficient of determination ( $R^2$ ) for the treatments  $SD_1I_1$ ,  $SD_1I_2$ ,  $SD_1I_3$  and  $SD_1I_4$  were 0.88, 0.90, 0.89 and 0.90 respectively and were 0.93, 0.97, 0.98 and 0.88 for  $SD_2$ . It was found that the model predicted CC values correctly in winter wheat and various other crops at the several similar studies also (Heng et al., 2009; Hsiao et al., 2009; Farahani et al., 2009; Tavakoli et al., 2015).

When CC values of different planting dates were compared for the whole year for  $I_2$ , it was seen that the plant started to cover the soil surface earlier in  $SD_1$  than

in SD<sub>2</sub> (Figure11).



**Figure 10.** Comparison of observed and simulated CC values for SD<sub>1</sub> and all irrigation treatments.



**Figure 11.** Comparison of simulated CC values for SD<sub>1</sub> and SD<sub>2</sub> treatments.

The model efficiency coefficient and RMSE values of SD<sub>1</sub> and SD<sub>2</sub> treatments are given in Table 6 for each irrigation application of CC.

**Table 6.** Statistical evaluations of CC simulated and observed values

Treatments		RMSE	EF
SD <sub>1</sub>	I <sub>1</sub>	10.20	0.74
	I <sub>2</sub>	13.2	0.62
	I <sub>3</sub>	8.20	0.81
	I <sub>4</sub>	10.29	0.69
SD <sub>2</sub>	I <sub>1</sub>	3.31	0.97
	I <sub>2</sub>	4.45	0.95
	I <sub>3</sub>	4.48	0.98
	I <sub>4</sub>	10.82	0.81

Accordingly, the model efficiency values were between 0.62 and 0.98 and was within acceptable limits (Raes et al. 2015). AquaCrop was able to accurately simulate the canopy development and senescence over the season.

However, AquaCrop lightly overestimated the canopy development during the middle of the growing period. EF and R values close to “1 (one)” indicated the overall good agreement between the simulated and observed canopy cover.

## CONCLUSION

In this study, the effect of different sowing scenarios and irrigation strategies in order to adapt to water scarcity conditions, which is an important problem due to climate change, and to achieve optimum wheat yield, was investigated using the AquaCrop model. The model was calibrated and validated under the conditions of the Central Anatolia region and field data were collected in the experimental area during the 2015–2017 growing season. The model was run under two different planting dates and four irrigation treatments water applied at different growth stages. In comparing sowing dates to determine the optimum date of winter wheat, it was concluded that the current sowing date (SD<sub>1</sub>) did not have a negative effect on grain yield however late sowing dates (SD<sub>2</sub>) would significantly reduce grain yield and biomass yield. Considering the biomass and grain yields in terms of irrigation, the highest yield was obtained in the irrigation water had been applied during the Germination+ Tillering+Heading stages. Yield reduction was 38.9% in rainfed, 5.1 % when irrigated during Germination + Heading stages and 22.3% when irrigated during Germination+Tillering stages. Among all the treatments, the SD<sub>1</sub>I<sub>2</sub> treatment gave the best results. Simulation results were compared with observed the final biomass and yield, soil water content and canopy cover. These results showed that the AquaCrop model is useful for simulating winter wheat biomass, grain yield, soil water and canopy cover under different planting dates, and irrigation strategies.

## COMPLIANCE WITH ETHICAL STANDARDS

This research article complies with research and publishing ethics.

### Peer-review

Externally peer-reviewed.

### Conflict of interest

The authors declare that they have no competing, actual, potential or perceived conflict of interest.

### Author contribution

The contribution of the authors to the present study is equal. All the authors read and approved the final manuscript. All the authors verify that the text, figures, and tables are original and that they have not been published before.

### Ethics committee approval

Ethics committee approval is not required.

### Funding

This study was supported by General Directorate of Agricultural Research and Policies of The Republic of Türkiye Ministry of Agriculture and Forestry through Research Project Number TAGEM/TSKAD/15/A13/P08/10.

**Data availability**

Not applicable.

**Consent to participate**

Not applicable.

**Consent for publication**

Not applicable.

**Acknowledgements**

We gratefully acknowledge the technical and financial support of General Directorate of Agricultural Research and Policies of The Republic of Türkiye Ministry of Agriculture and Forestry.

**REFERENCES**

- Allen, R.G., Pereira, L.S., Raes, D. & Smith, M. (1998). Crop evapotranspiration: guidelines for computing crop water requirements. In: FAO Irrigation and Drainage Paper No.56, 17–27.
- Araya, A., Habtu, S., Hadgu, K.M., Kebede, A. & Dejene, T. (2010). Test of AquaCrop model in simulating biomass and yield of water deficient and irrigated barley (*Hordeum vulgare*). *Agricultural Water Management*. 97(11), 1838–1846. <https://doi.org/10.1016/j.agwat.2010.06.021>
- Aouade, G., Ezzahar, J., Amenou, N., Er-Raki, S., Benkaddour, A., Khabba, S. & Jarlan, L. (2016). Combining stable isotopes, Eddy Covariance system and meteorological measurements for partitioning evapotranspiration, of winter wheat, into soil evaporation and plant transpiration in a semi-arid region. *Agricultural Water Management*, 177, 181–192. <https://doi.org/10.1016/j.agwat.2016.07.021>
- Aydoğan S. & Soyulu S. (2017). Determination of yield, yield components and some quality properties of bread wheat varieties. *Journal of Field Crops Central Research Institute*, 2017, 26 (1), 24–30. <https://doi.org/10.21566/tarbitderg.323568>
- Davarpanah, R. & Ahmadi, S.H. (2021). Modeling the effects of irrigation management scenarios on winter wheat yield and water use indicators in response to climate variations and water delivery systems, *J. Hydrology* (598), 126–269. <https://doi.org/10.1016/j.jhydrol.2021.126269>
- Debaeke, P. & Aboudrare, A. (2004). Adaptation of Crop Management to Water-Limited Environments. *European Journal of Agronomy*, (21), 433–446. <https://doi.org/10.1016/j.eja.2004.07.006>
- Delju, A.H., Ceylan, A., Piguat, E. & Rebetez M. (2013). Observed climate variability and change in Urmia Lake Basin Iran, *Theor. Appl. Climatology*, (111), 285–296. <https://doi.org/10.1007/s00704-012-0651-9>
- Farahani, H.J., Izzi, G. & Oweis, T.Y. (2009). Parameterization and evaluation of the AquaCrop model for full and deficit irrigated cotton. *Agron. J.* 101, 469–476. <https://doi.org/10.2134/agronj2008.0182s>
- Gokalp, Z. & Cakmak, B. (2016). Agricultural water management in Turkey: past-present-future. *Current Trends in Natural Sciences*, 5, 133–138. <http://www.natsci.upit.ro>
- Heng, L.K., Hsiao, T., Evett, S., Howell, T. & Steduto, P. (2009). Validating the FAO AquaCrop model for irrigated and water deficient field maize. *Agron. J.* 101, 488–498. <https://doi.org/10.2134/agronj2008.0029xs>
- Hsiao, T.C., Heng, L., Steduto, P., Roja-Lara, B., Raes, D. & Fereres, E. (2009). AquaCrop- The FAO model to simulate yield response to water: Parametrization and testing for maize. *Agron. J.* 101, 448–459. <https://doi.org/10.2134/agronj2008.0218s>
- Hussein, F., Janat, M. & Yakoub, A. (2011). Simulating cotton yield response to deficit irrigation with the FAO AquaCrop model. *Span J Agr Res* 9:1319–1330. <https://doi.org/10.5424/sjar/20110904-358-10>
- Iqbal, M, A., Shen, Y., Stricevic, R., Pei, H., Sun, H., Amiri, E., Penas, A. & Rio, S. (2014). Evaluation of the FAO AquaCrop model for winter wheat on the North China Plain under deficit irrigation from field experiment to regional yield simulation. *Agricultural Water Management* 135:61–72. <https://doi.org/10.1016/j.agwat.2013.12.012>
- Janssen, P.H.M. & Heuberger, P.S.C. (1995). Calibration of process- oriented models. *Ecol Model* 83:55–66. [https://doi.org/10.1016/0304-3800\(95\)00084-9](https://doi.org/10.1016/0304-3800(95)00084-9)
- Jin, X.H., Feng, H., Zhu, X., Li, Z., Song, S., Song, X., Yang, G., Xu, X. & Guo, W. (2014). Assessment of the AquaCrop Model for Use in Simulation of Irrigated Winter Wheat Canopy Cover, Biomass, and Grain Yield in the North China Plain. Volume 9; Issue 1, pp:1–11. <https://doi.org/10.1371/journal.pone.0086938>
- Kale, S. & Tari, A.F. (2012). Evaluation of FAO-AQUACROP Model Performance for Winter Wheat under Irrigated and Rainfed Conditions. *Journal of Soil Water* .119–131.
- Kale Celik, S., Madenoglu, S. & Sonmez B. (2018). Evaluating AquaCrop Model for Winter Wheat under Various Irrigation Conditions in Turkey. *Journal of Agricultural Sciences*. 24:205–217. <https://doi.org/10.15832/ankutbd.446438>
- Liu, J. G. & Pattey, E. (2010). Retrieval of Leaf Area Index from Top-Of-Canopy Digital Photography over Agricultural Crops, *Agricultural and Forest Meteorology*, 150, 1485–1490. <https://doi.org/10.1016/j.agrformet.2010.08.002>
- Liu, J., Pattey, E., & Admiral, S. (2013). Assessment of in situ crop LAI measurement using unidirectional view digital photography. *Agricultural and Forest Meteorology*, 169, 25–34. <https://doi.org/10.1016/j.agrformet.2012.10.009>
- Lyman, O.R. (1993). An introduction to statistical methods and data analysis. Duxbury Press. Belmont. CA. USA. pp. 247–250.
- Mkhabela, M.S. & Bullock, P.R. (2012). Performance of the FAO AquaCrop model for wheat grain yield and soil moisture simulation in Western Canada. *Agric. Water Manage.* 110, 16–24. <https://doi.org/10.1016/j.agwat.2012.03.009>
- Moriasi, D., Arnold, J., Van Liew, M., Bingner, R., Harmel, R., & Veith, T. (2007). Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. *Trans. ASABE*, 50(3), 885–900. <https://doi.org/10.13031/2013.2315>
- Nash, J.E. & Sutcliffe, J.V. (1970). River flow forecasting through conceptual models: Part I-A discussion of principles. *J. Hydrology* 10. 282–290. [http://dx.doi.org/10.1016/0022-1694\(70\)90255-6](http://dx.doi.org/10.1016/0022-1694(70)90255-6)
- Raes, D., Steduto, P., Hsiao, T. C. & Fereres, E. (2009a). Chapter One: AquaCrop-The FAO crop model to simulate yield response to water. FAO. 1–10. <https://doi.org/10.2134/>



- agronj2008.0139s
- Raes, D., Steduto, P., Hsiao, T.C. & Fereres, E. (2009b). AquaCrop – The FAO crop model to simulate yield response to water: II. Main algorithms and software description. 438-447. <https://doi.org/10.2134/agronj2008.0140s>
- Raes, D. (2015). AquaCrop Training Handbooks. Book I. Understanding AquaCrop (Version 5.0. July 2015). Food and Agriculture Organization of the United Nations. Land and Water Division. Rome. Italy.
- Raes, D., Steduto, P., Hsiao, T.C. & Fereres, E. (2016). AquaCrop Version 5.0 Reference Manual Book. Food and Agriculture Organization of the United Nations, Rome, Italy
- Shahbandeh, M. (2022). Wheat - statistics facts. World of wheat. <https://www.statista.com/statistics/1094065/total-global-wheat-consumption-by-country>
- Salemi, H.M., Amin, S.M., Amind, M.S. & Mohd, S. (2011). Application of AquaCrop model in deficit irrigation management of Winter wheat in arid region, African Journal of Agricultural Research 610 (10):2204-2215. <https://doi.org/10.5897/AJAR10.1009>
- Steduto, P., Hsiao, T.C., Raes, D. & Fereres, E. (2009). AquaCrop- The FAO crop model to simulate yield response to water. I. Concepts and underlying principles. Agronomy Journal. 101: 426-437. <https://doi.org/10.2134/agronj2008.0139s>
- Steduto, P., Hsiao, T.C., Fereres, E. & Raes, D. (2012). Crop yield response to water. FAO Irrigation and Drainage Paper, No: 66 Rome, Italy, pp. 516. ISBN 978-92-5-107274-5
- Tan, Q., Zhang, S. & Li, R. (2017). Optimal use of agricultural water and land resources through reconfiguring crop planting structure under socioeconomic and ecological objectives. Water, 9(7), 488. <https://doi.org/10.3390/w9070488>
- Tavakoli, A.R., Moghadam, M.M. & Sepaskhah, A.R. (2015). Evaluation of the AquaCrop model for barley production under deficit irrigation and rainfed condition in Iran. Agricultural Water Management 16: 136-146. <https://doi.org/10.1016/j.agwat.2015.07.020>
- Todd, S.W., Hoffer, R.M. & Milchunas, D.G. (1998). Biomass estimation on grazed and ungrazed rangelands using spectral indices. Int. Journal of Remote Sensing, vol. 19, no. 3, pp.427- 438. <https://doi.org/10.1080/014311698216071>
- Toumi, J., Er-Raki, S., Ezzahar, J., Khabba, S., Jarlan, L. & Chehbouni, A. (2016). Performance assessment of AquaCrop model for estimating evapotranspiration soil water content and grain yield of winter wheat in Tensift Al Haouz (Morocco): Application to irrigation management. Agricultural Water Management, 163:219-235. <https://doi.org/10.1016/j.agwat.2015.09.007>
- TSMS. (2018). Meteorological Report. Turkish State Meteorological Services. Retrieved in August, 05, 2018 from <https://www.mgm.gov.tr/eng/forecast-cities.aspx>
- TUIK. (2021). Crop production statistics. Turkish Statistical Institute. Retrieved in October, 18, 2022 from <https://data.tuik.gov.tr/Bulten/Index?p=Bitkisel-Uretim-Istatistikleri-2021-37249>
- USDA. (2021). Grain and Feed Annual Report. United States Department of Agricultural. Retrieved in June 10, 2021 from <https://apps.fas.usda.gov/newgainapi/api/Report>
- Zeleeke, K.T., Luckett, D. & Cowley, R. (2011). Calibration and testing of the FAO AquaCrop model for canola. Agronomy Journal, 103: 1610-1618. <https://doi.org/10.2134/agronj2011.0150>
- Zhang, W., Liu, W., Xue, Q., Chen, J. & Han, X. (2013). Evaluation of the AquaCrop model for simulating yield response of winter wheat to water on the southern Loess Plateau of China. Water Science & Technology, 68:4-8. <https://doi.org/10.2166/wst.2013.305>
- Zhuo, L. & Hoekstra, A.Y. (2017). The effect of different agricultural management practices on irrigation efficiency, water use efficiency and green and blue water footprint. Frontiers in Agricultural Science and Engineering, 4(2), 185–194. <https://doi.org/10.15302/J-FASE-2017149>