RESEARCH ARTICLE

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

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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

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).

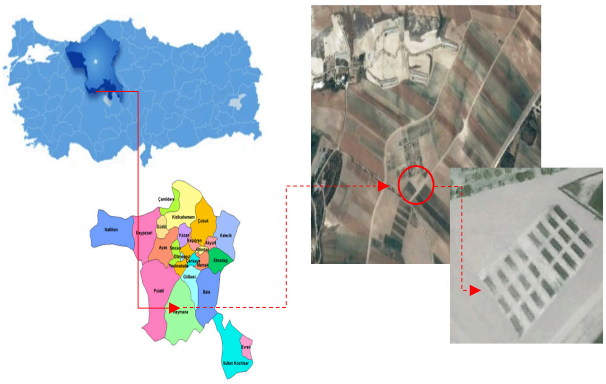

Figure 1. Experimental area.

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^{-3} respectively. The soil saturation hydraulic conductivity is about 0.75 cm h^{-1}.

"Konya 2000" winter wheat variety was used in this research. This variety has high yield potential (400-750 kg da^{-1}) 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_2 amount (by default AquaCrop obtains the atmospheric CO_2 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^2 (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_1: 0 mm, I_2: 275 mm (G:30 mm, T; 70 mm and H:145 mm), I_3: 175 mm (G:30 mm and H:145 mm), I_4:100 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_1 (Normal sowing date)	I_1 (rainfed - no irrigation)	-	-	-
	I_2 (irrigate at germination, tillering and heading stage)	x	x	x
	I_3 (irrigation at germination and heading stage)	x	-	x
	I_4 (irrigation at germination and tillering stage)	x	x	-
SD_2 (Late sowing date)	I_1 (rainfed - no irrigation)	-	-	-
	I_2 (irrigate at germination, tillering and heading stage)	x	x	x
	I_3 (irrigation at germination and heading stage)	x	-	x
	I_4 (irrigation at germination and tillering stage)	x	x	-

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

growing season.

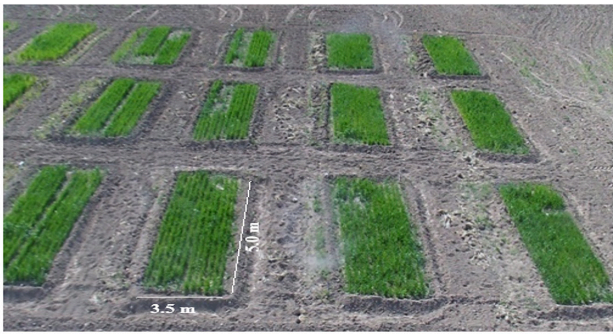

Figure 2. Field experimental design.

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 (Moriasi et al., 2007).

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

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

$$NRMSE = \frac{RSME}{O_{avg}} x100 \quad [4]$$

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

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 - ∞ 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 m² (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
Conservative input parameters		
Base temperature (^{0}C)	0	Local experience
Upper temperature (^{0}C)	26	Local experience
Canopy cover per seedling at 90% emergence 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, 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, g m^{-2}	15	Default (Steduto et al. 2012)
Non-Conservative input parameters		
Sowing rate kg seed ha^{-1}	180	Measured
1000 seed mass g	43.7	Measured
Plant density plant m^{-2}	477	Measured
Canopy cover per seeding (cm^2 $plant^{-1}$)	1.5	Measured
Germination rate %	98	Measured
Sowing date (for SD_1 and SD_2 sowing date)	October 12th/ November 8rd	
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	

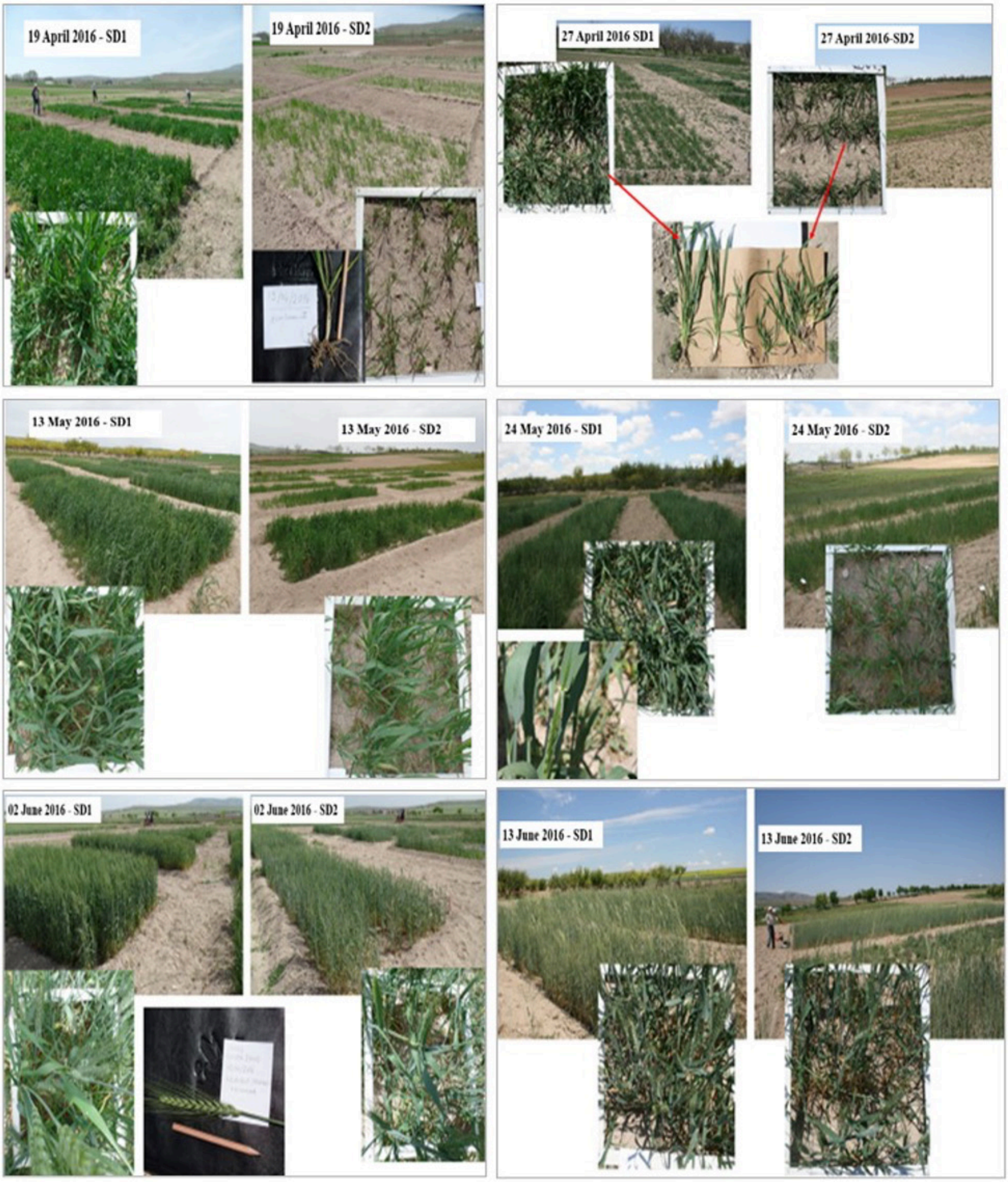

Figure 3. Canopy cover measurement during 2015-2016 growing season.

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^{-1} to 5.78 t ha^{-1} for SD_1 and from 1.84 t ha^{-1} to 4.71 t ha^{-1} for SD_2 while simulated grain yield had been found in the range from 4.11 t ha^{-1} to 6.20 t ha^{-1} for SD_1 and from 2.07t ha^{-1} to 5.14 t ha^{-1} for SD_2 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^{-1}) and simulated by the model (10.58 t ha^{-1}) was obtained in SD_1I_2.

Statistical evaluation of the treatments was given in Table 4. The higher R^2 and E values and lower NRMSE values indicated good model performance. According to grain and biomass yield results, R^2 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_1 and SD_2 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_1 and SD_2 and biomass yields for SD_2 a good performance was obtained between the predicted and measured values. The EF value of SD_1 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_2 irrigation application and SD_1, SD_2 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).

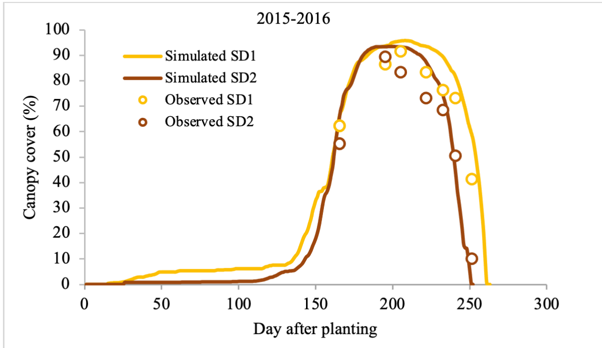

Figure 4. Observed and simulated canopy cover values of wheat grain yield for SD_1I_2 and SD_2I_2 treatments.

There was an important linear relationship and good agreement between the measured and simulated canopy cover for SD1 and SD2 respectively, with R^2=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 12th (SD_1) and as late sowing date November 8th (SD_2) during 2016-2017 growing season. Wheat that was planted on SD_1 had greater grain and biomass yield than did those planted on SD_2 for all irrigation strategies (Table 5). The highest and lowest biomass and grain yield was obtained in SD_1I_2 (5.12 t ha^{-1}) and SD_2I_1 (1.76 t ha^{-1}) respectively. There was a significant decrease in crop yield of 65% between the two treatments.

As it shown in Table 5, R^2 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_1				SD_2			
		Grain Yield (t ha^{-1})		Biomass (t ha^{-1})		Grain Yield (t ha^{-1})		Biomass (t ha^{-1})	
		Observed	Simulated	Observed	Simulated	Observed	Simulated	Observed	Simulated
2015-2016	I_1	3.81	4.11	7.02	8.37	1.84	2.07	4.56	5.51
	I_2	5.78	6.20	10.25	10.58	4.71	5.14	9.23	9.52
	I_3	5.18	5.36	9.09	9.85	3.54	3.70	7.45	8.16
	I_4	5.12	4.97	8.80	9.29	3.25	3.11	6.97	7.49
R^2		0.92		0.97		0.93		0.98	
RMSE (t ha^{-1})		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_1				SD_2			
		Grain Yield (t ha^{-1})		Biomass (t ha^{-1})		Grain Yield (t ha^{-1})		Biomass (t ha^{-1})	
		Observed	Simulated	Observed	Simulated	Observed	Simulated	Observed	Simulated
2016-2017	I_1	3.13	4.08	6.88	7.91	1.76	2.00	4.09	5.22
	I_2	5.12	5.89	8.99	9.38	4.17	4.89	7.91	8.37
	I_3	4.86	5.12	8.17	8.60	3.23	3.56	6.59	7.16
	I_4	3.98	4.58	7.72	8.01	2.35	2.97	5.88	6.14
R^2		0.90		0.96		0.98		0.96	
RMSE (t ha^{-1})		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 comparation between SD_1 and SD_2 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 12th compared to November 8th.

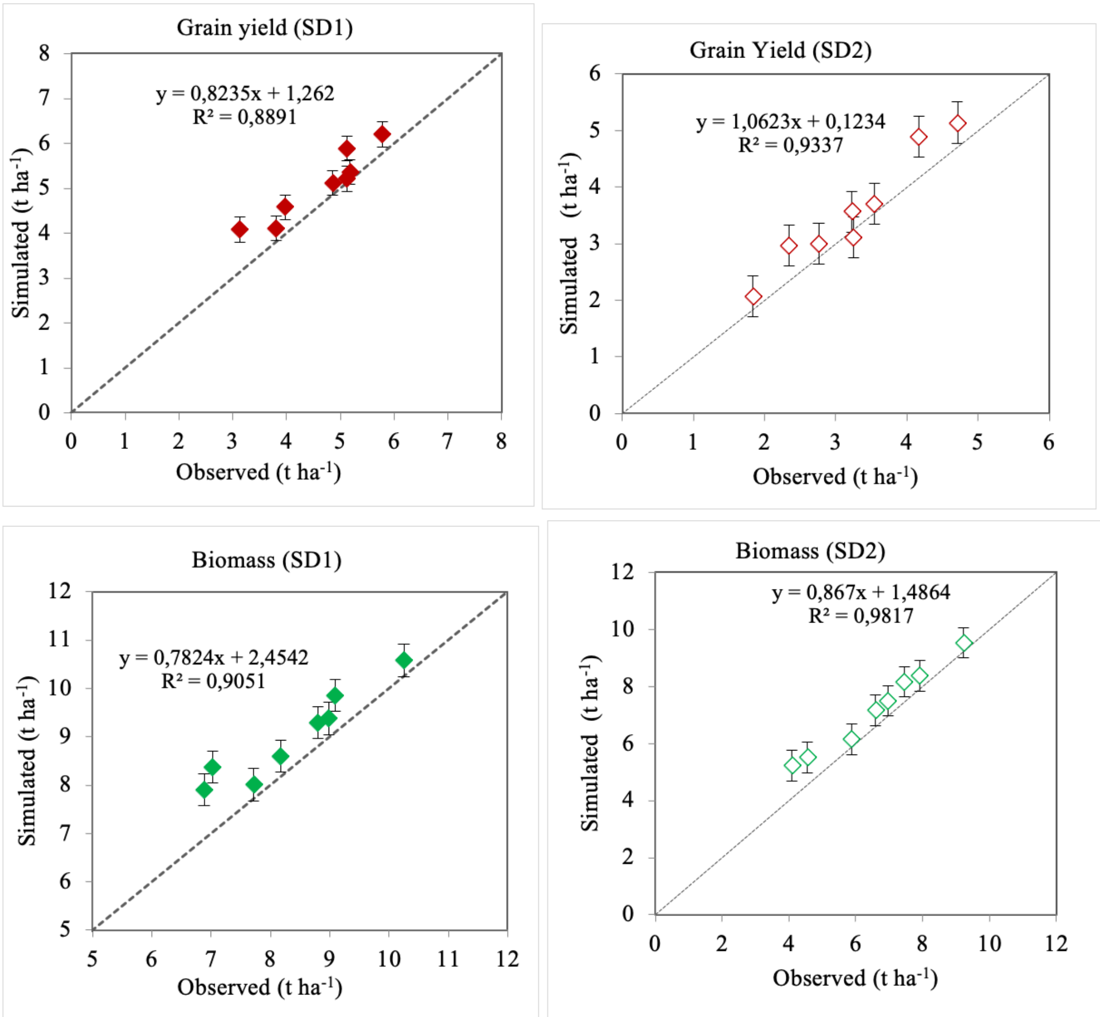

Figure 5. Relation between simulated and measured wheat grain yield and biomass.

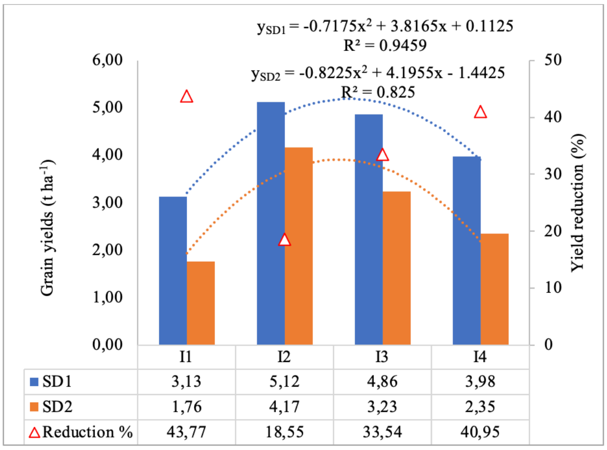

Figure 6. Observed winter wheat grain yield under irrigation strategies and different planting dates.

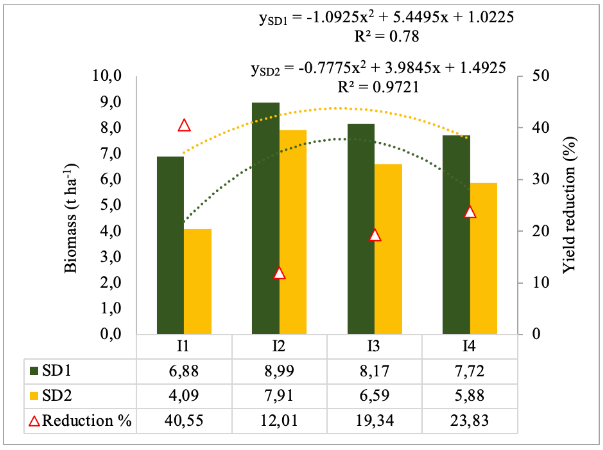

Figure 7. Observed winter wheat biomass under irrigation strategies and different planting dates.

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).

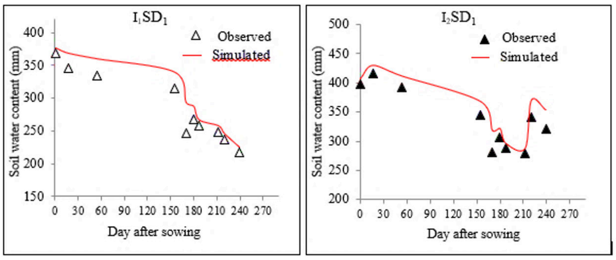

Figure 8. Soil moisture content for calibration period.

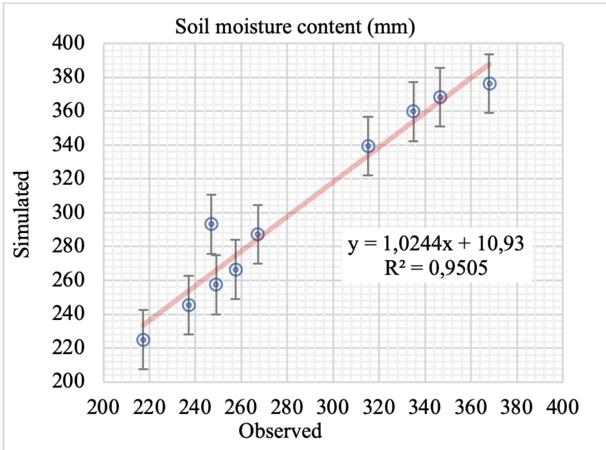

Figure 9. Relation between simulated and measured soil moisture content for I_1SD_2.

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 = 0.91-071, 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 Tarı 2012; Igbal 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 SD1 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 SD1 than in SD2 (Figure11).

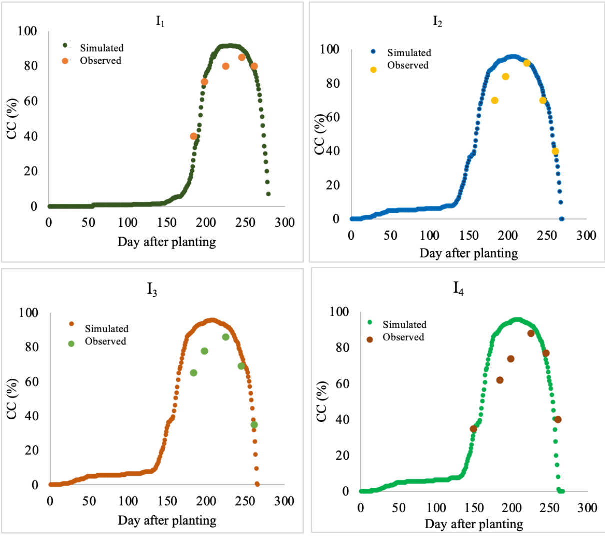

Figure 10. Comparation of observed and simulated CC values for SD1 and all irrigation treatments.

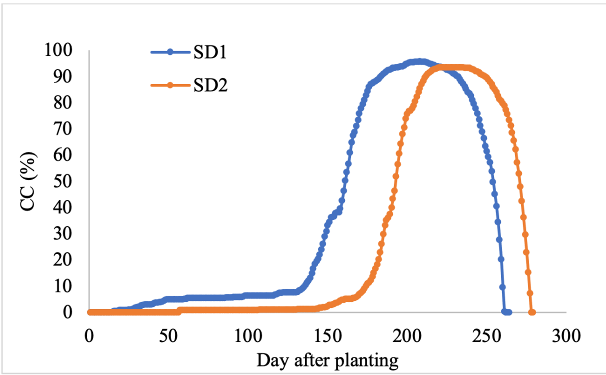

Figure 11. Comparation of simulated CC values for SD_1 and SD_2 treatments.

The model efficiency coefficient and RMSE values of SD1 and SD2 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_1	I_1	10.20	0.74
	I_2	13.2	0.62
	I_3	8.20	0.81
	I_4	10.29	0.69
SD_2	I_1	3.31	0.97
	I_2	4.45	0.95
	I_3	4.48	0.98
	I_4	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_1) did not have a negative effect on grain yield however late sowing dates (SD_2) 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_1I_2 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.

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Data availability

Not applicable.

Consent to participate

Not applicable.

Consent for publication

Not applicable.

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