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RESEARCH PAPER

Development of yield prediction model for wheat by using AquaCrop model with different nitrogen dose applications in Central Anatolia Region (semi arid) conditions

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Abstract

In this study, yield prediction was made for Tosunbey and Bayraktar bread wheat varieties under rainfall conditions and 4 different fertilizer ratios with AquaCrop model, one of the plant growth models. In this experiment conducted at Haymana Ikizce Research Farm, actual field observations and model predicted grain yield, biomass, and green area coverage ratio were evaluated. Mean deviation (α), standard error (RMSE), and model efficiency coefficient (E) tests were used to determine the performance of the model. The AquaCrop model was calibrated in the first year and validated based on observational data collected in the first and second years of the experiment, respectively. Based on the results obtained, it was observed that the AquaCrop model simulated grain yield at different levels of nitrogen fertilizer applications with higher precision for Bayraktar variety. For Bayraktar variety, grain yield E = 0.93 in the first year and 0.99 in the second year for grain yield, and E = 0.83 in the first year and 0.98 in the second year for biomass, indicating excellent agreement between model and observation was found. In Tosunbey variety, first-year grain yield E=0.66 and 2nd year grain yield 0.76 were found. The 2nd year RMSE value for grain yield of Bayraktar variety was 0.266, and the 2nd year RMSE value for the grain yield of Tosunbey variety was 0.664 and found to be statistically compatible. Grain yield, biomass, and percent cover (CC) values obtained from the model were found to be highly consistent with field observations.

Introduction

Determining the effects of soil, plant, and climate components on plant growth and yield is possible with plant simulation models. While these models serve the purpose of comparing potential and actual yields, they can also predict how far yields can be increased. One of the most important advantages of the models is that they save time and are also economical. It is also possible with models to analyze the extent and how the atmospheric parameters and soil will affect plant development, and to determine the most appropriate times for fertilization, spraying, and other activities. Many researchers in the world and our country use "Plant Growth Models" to examine the effects of climate factors on crops. These models are used to solve a wide range of problems encountered during plant development, to predict yields, and to realize decision mechanisms to ensure the continuity of maximum yield (Korkmaz et al., 2000; Köksal and Kanber, 2003).

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The AquaCrop model can be used by FAO as a planning tool in field studies. Particularly useful topics include understanding plant response to environmental conditions, estimating irrigation water requirements, comparing actual yield values with achievable yield values for a field or a whole region, identifying factors limiting crop production and water productivity, developing methods to maximize water productivity under water shortage, irrigation strategies (full irrigation, deficit irrigation, etc.), plant and land practices (planting date, variety selection, fertilization, organic mulch, etc.) (Raes et al., 2009).

Guo et al. (2020) evaluated the performance of the Aquacrop model for different irrigation depths and different nitrogen applications for maize crops. They estimated the performance of the model based on grain yield, biomass and plant coverage ratios and compared it with actual field values.

A field experiment was conducted with three nitrogen levels of 0, 150 and 300 kg N ha^{-1} (N_1, N_2 and N_3) with four irrigation depths corresponding to 60, 80, 100 and 120 cm of soil water. The AquaCrop model was calibrated in maize planted as a complete block according to the randomized plots experimental design with three replications between 2002 and 2004 and then validated based on field data collected from the first and second years of the study, respectively. Based on the results obtained, the AquaCrop model simulated the grain yield of maize with high accuracy under different levels of nitrogen fertiliser and irrigation depths (Ebrahimi et al., 2015).

Abedinpour et al. (2012) calibrated the model using different water regimes and nitrogen applications using two years (2009-2010) of maize data. In order to determine the performance of the model, they used the model efficiency (E), coefficient of determination (R2), standard error (RMSE), and mean deviation error (MDE) tests. The most accurate prediction was obtained from the scenario with full irrigation at field capacity (W4) and 150 kg ha^{-1} (N3) nitrogen application, while the lowest prediction was obtained from the scenario with no nitrogen and irrigation water application. The AquaCrop model was predicted with acceptable accuracy for all scenarios created in this study.

In another study, Abedinpour (2021) carried out a comparison between DSSAT-CERES and AquaCrop models to simulate wheat growth under different irrigation and nitrogen levels on the basis of accurate prediction. For this purpose, four irrigation treatments (rainfall-based, irrigation at 50% and 75% of field capacity and 100% irrigation) were considered as the main subject and the experiment was conducted with three nitrogen fertilizer levels (no fertilizer, 100 kg Nha $^{-1}$ and 200 kg N ha^{-1}) as sub-main subjects. Model efficiency (E), Wilmott fit index (d), Root Mean Square Error (RMSE) and Normalized Root Mean Square Error (NRMSE) were used to test model performances. The AquaCrop model was calibrated to simulate grain and biomass yields with prediction error statistics of $0.87 < E < 0.90$, $0.24 < RMSE < 0$. The DSSAT-CERES model was calibrated and its performance was found to be $0.88 < E < 0.93$, $0.92 < d < 0.96$, $0.19 < RMSE < 0.34$ t ha $^{-1}$ and $5.7 < NRMSE < 5.8$, then -1, $6 < NRMSE < 7.2\%$ and $0.90 < d < 0.93$, respectively.

In general, the simulation results of the DSSAT model were relatively more accurate than those of the AquaCrop model. However, considering that the data required for the DSSAT model would be difficult to obtain in developing and undeveloped countries, the Aqucrop model was considered to be more advantageous because it makes accurate calculations in less time using less input data.

Saab et al. (2015) compared the performance of AquaCrop and Cropsyst to simulate barley growth in a study conducted in Southern Italy. In this study, under three water treatments (full irrigation, 50% irrigation and sprinkler) and two nitrogen levels (high and low), in a 3-year study (2006-2008), they calibrated in the first year and validated in the following two years. Accordingly, they concluded that AquaCrop was superior to CropSyst. In terms of biomass, they found AquaCrop RMSE (0.09 to 0.15) lower than CropSyst (0.15 to 0.17). Similarly, in the case of yield, AquaCrop had a lower RMSE value than Cropsyst (from 0.16 to 0.23). Similarly, in the case of yield, AquaCrop had a lower RMSE value than Cropsyst (from 0.16 to 0.23).

Ghanbbari and Tavassoli (2013) simulated the effect of different irrigation and fertilisation practices on yield with AquaCrop in their study conducted in Iran. The researchers reported that the model predicted cover area percentage, biomass and grain yield well, but could not simulate water use efficiency.

Zhang et al. (2013) evaluated the performance of the FAO-AquaCrop model for winter wheat in the southern Loess Plateau of China. In this study, data obtained from experimental fields between 2004 and 2011 were used to estimate biomass, percent vegetation cover, soil water content and grain yield under non-aqueous conditions and to calibrate and validate the model. In general, the model predicted percent cover and yield better than biomass and soil water content. The results showed that AquaCrop is able to simulate winter wheat under water-free conditions. It is concluded that more progress is needed by applying different fertilisation and irrigation levels for this region.

In this study, the Aquacrop model was used to plant and observe 2 wheat varieties at different fertilizer ratios and the yield predictions of the model were compared with actual field trials. AquaCrop uses atmospheric, plant, soil, and management (irrigation, fertilisation, etc.) as inputs to estimate crop water consumption and yield. The model separates transpiration from the plant and evaporation from the soil in the estimation of plant water consumption and uses the percent cover (CC) parameter instead of leaf area index (LAI) to simulate plant growth.

Material and Methods

Description of the Research Site

The experiment was conducted at the Research and Application Farm of the Central Research Institute of Field Crops Directorate İkizce/Haymana. The experiment area is between 39' 12''- 43' 6'' north latitude and 35' 58'' - 37' 44'' east longitude. The experiment area is located in the south of Ankara province, within the borders of Haymana district center, at the 22nd km of Haymana-Gölbaşı State Highway, with Topaklı village in the northwest and İkizce village in the southwest of the farm and covers an area of 968.3 ha. The slope of the land varies between 2-15 % (Dengiz and Yüksel, 2001). Considering the topographical characteristics of the location of the research area, the altitude is between 820-1470 m and the altitude of the experiment area is 1069 m (Figure 1).

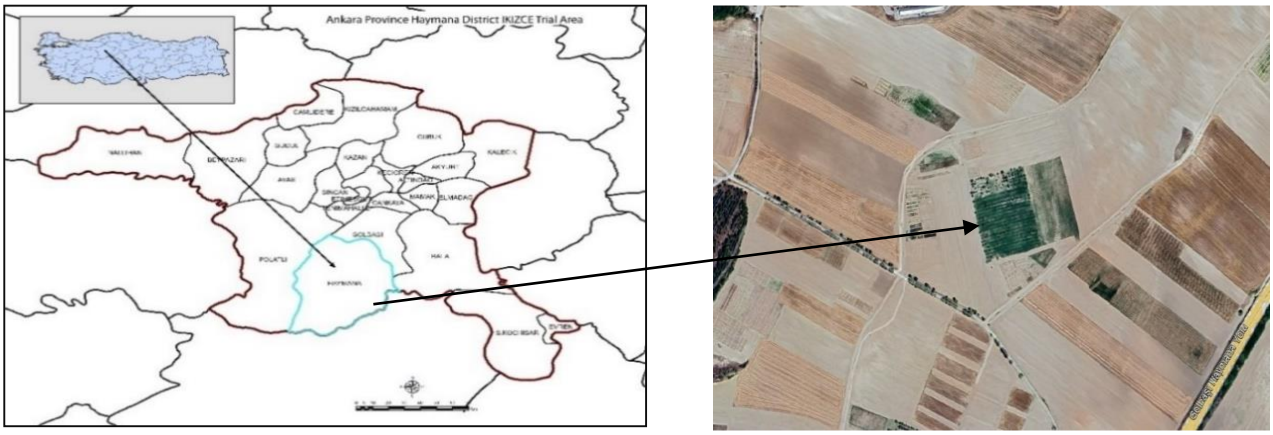

Figure 1. Experimental area (İkizce-Haymana/ANKARA)

Climatic Characteristics of The Research Site

Haymana İkizce Research Farm is located in a region where the typical steppe climate of Central Anatolia prevails in terms of climatic characteristics. Summers are hot and dry and winters are cold (Table 1).

Table 1. Climatic data of the experiment area

	Average of Monthly Rainfall Total (mm)			Average monthly temperature (°C)			Average monthly min. temperature (°C)			Average monthly max. temperature (°C)		
	2017-2018	2018-2019	Long Years mean	2017-2018	2018-2019	Long Years mean	2017-2018	2018-2019	Long Years mean	2017-2018	2018-2019	Long Years mean
October	9.8	68.4	27.9	9.9	12.1	11.9	5	6.4	0.2	16.5	19.3	25.7
Kasım	11.2	15.4	31.7	4.7	6.5	5.6	0.2	1.9	-7.5	10.7	12.2	19.4
Aralık	26.2	53	44.1	2.1	1	0.8	-1.5	-1.3	-10.1	7.3	4	14.9
January	19.2	36.2	39.7	0.9	-0.8	-1.2	-1.8	-3.3	-13.8	4.3	2.3	11.7
February	39.6	36.4	35.1	4.1	2.2	1.1	-0.2	-1.4	-12.3	10	7.3	13.6
March	74.6	20.6	39.1	7.9	4.7	5.1	3.2	-0.9	-8.3	13.3	11.2	20.5
April	2.6	23.4	41.9	12.2	7.9	9.5	4.6	2.5	-2.2	19.9	14	23.3
May	122.8	3.8	51.8	15.3	15.1	14.3	9.8	8.5	2.4	22.2	21.9	27.5
June	27	15	34.3	18.7	18.7	18.5	11.9	13.2	6.9	25.9	25.9	31.6
July	4.2	7.2	13.5	22	17.8	22.2	14.7	12.5	9.7	29	26	35.8

Wheat Varieties Used in the Study and Their Characteristics

In the research area, an experiment design was established by using Tosunbey and Bayraktar bread wheat varieties.

Agricultural Characteristics:

BAYRAKTAR 2000

Institute: The Field Crops Central of Research Institute

Grain Yield (kg/da): 350-400

1. Alternative developmental nature and early,
2. Resistant to cold, drought and lodging,
3. High reaction to fertilizer,
4. Evergreen and good threshing ability

(https://arastirma.tarimorman.gov.tr/tarlabitkileri/Belgeler/cesit_katalogu.pdf)

TOSUNBEY

Institute: The Field Crops Central of Research Institute

Grain Yield (kg/da): 300-400

1. Alternative developmental nature,
2. Good cold resistance,

3. Good drought and lodging resistance,
4. Good reaction to fertilizer.

(https://arastirma.tarimorman.gov.tr/tarlabitkileri/Belgeler/cesit_katalogu.pdf)

Establishment of Experimental Design and Nitrogen Applications

Two varieties of bread wheat were planted in the experiment area in 2017-2018 and 2018-2019. These are the Tosunbey and Bayraktar varieties. On 24.10.2017, the first year planting took place and on 11.10.2018, the second year planting took place. Sowing was done in two blocks and each block was treated with 4 different Nitrogen ratios, including two different variety controls. Nitrogen Dose Applications in the experiment N_0: Sowings, one of which is control plot (without fertilizer), N_{12}: Normal fertiliser application (12 kg/da), N_6: 50% reduced fertiliser application (6 kg/da.), N_{18}: 50% increased fertiliser application (18 kg/da.) was applied. Parcel length was calculated as 26.50 m. and parcel width as 9.45 m. Total parcel area is calculated as 26.5 m* 9.45 m = 250 m^2. Plot spacing was determined as 5 m. Parcel length was calculated as 30.0 m and parcel width as 3.0 m. Total parcel area is calculated as 30.0 m* 3.0 m = 90 m^2. Plot spacing was determined as 1.5 m (Figure 2). Physical analyses of soil samples taken from the project area at 0-30, 30-60, 60-90 cm depths are given in Table 5. These data were entered into the "Soil characteristics" section of the programme (Table 2).

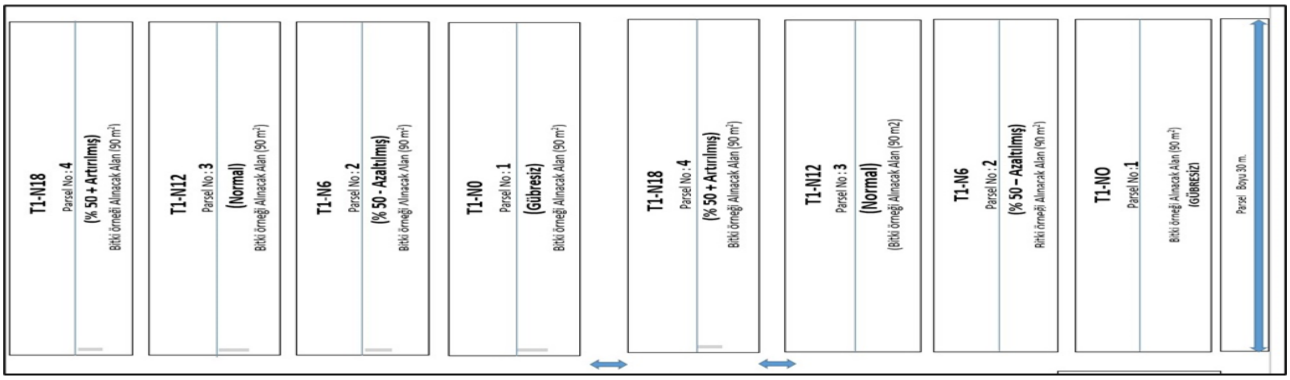

Figure 2. Experiment pattern

Table 2. Soil physical analysis results of the experiment area

Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Texture	Field Capacity (%)	Wilt Point (%)	Volume Weight (g cm^{-3})	Hydraulic Conductivity (cm h^{-1})
0-30	15.8	41.5	42.7	SİC	32.90	14.76	1.22	0.05
30-60	9.8	37.7	52.5	C	38.55	18.42	1.17	0.76
60-90	10.8	33.9	55.3	C	39.08	18.84	1.17	0.71

AquaCrop Plant Simulation Model

This study used the AquaCrop model, a plant-climate model developed by the Food and Agriculture Organization of the United Nations (FAO). The scientific basis of this model was has been described by Steduto et al. (2009), Raes et al. (2009) and Hsiao et al. (2009). AquaCrop is a water-oriented model developed to see the response of plants to water and its effect on yield and requires fewer parameters and input data than other simulation models. Most researchers around the world prefer the AquaCrop model because it is simpler and more reliable than other models. In this study, version 5.0 of the AquaCrop Model from the FAO official website (http://www.fao.org/nr/water/aquacrop.html) was downloaded and run (Figure 3).

After running the AquaCrop Model, there are sections on the main menu screen where environmental and plant related data are entered, simulation is performed and project and field data are entered (Figure 4).

It consists of climatic data, soil and plant characteristics and input data related to plant management practices that help define the environment in which the plant will be grown. Inputs are stored in climate, crop, soil and management files and can be easily modified by the user (Raes et al., 2011).

The AquaCrop model incorporates water balance from the soil component; plant growth, development and yield process from the plant component; thermal

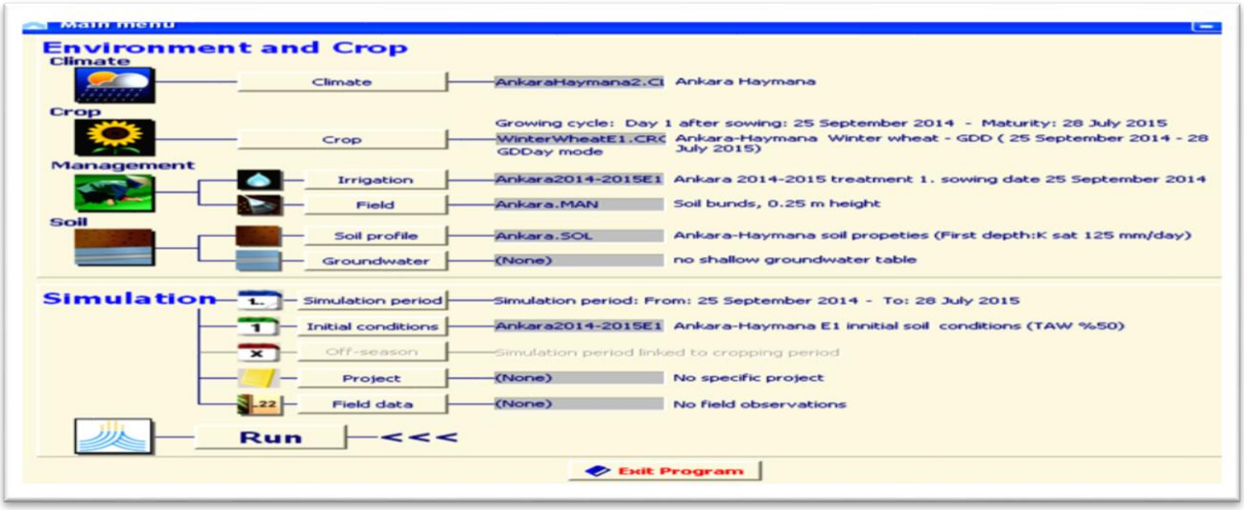

Figure 3. AquaCrop 5.0 software boot window

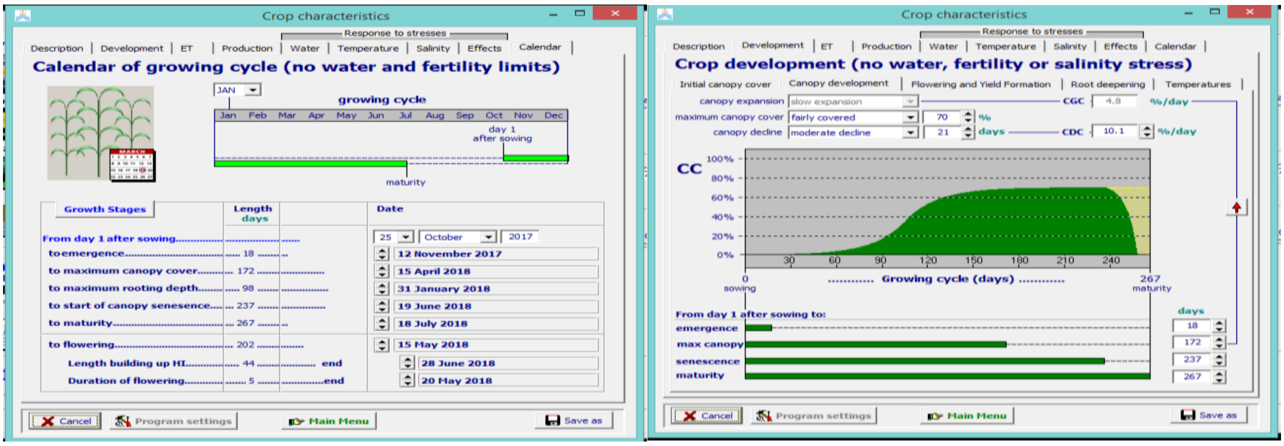

Figure 4. Inputting the plant phenological values of the Aqucrop program into the program, Canopy cover (CC%) calculations, running the simulation

balance, evaporation, precipitation and CO_2 concentration from the atmosphere component (Raes et al., 2009). It also incorporates soil-plant-atmosphere components as well as agricultural activities such as irrigation and fertilisation that affect these components and yield (Raes et al., 2009). As given in the AquaCrop application guide (Raes et al., 2009), some parameters are conservative and environmental and climatic conditions do not affect the change of these parameters. These parameters include vegetation cover (Figure 5) and the coefficient of vegetation decline, the plant coefficient for transpiration when the surface is completely covered by vegetation, water use efficiency or water productivity (WP) for biomass, and the threshold of soil water content at a level that inhibits leaf growth, stomatal conductance and accelerates yellowing of the vegetation surface. These parameters are assumed to be acceptable over a wide range except in very specific cases. The fixed parameters used in the simulation for the Aquacrop model are given in Table 3.

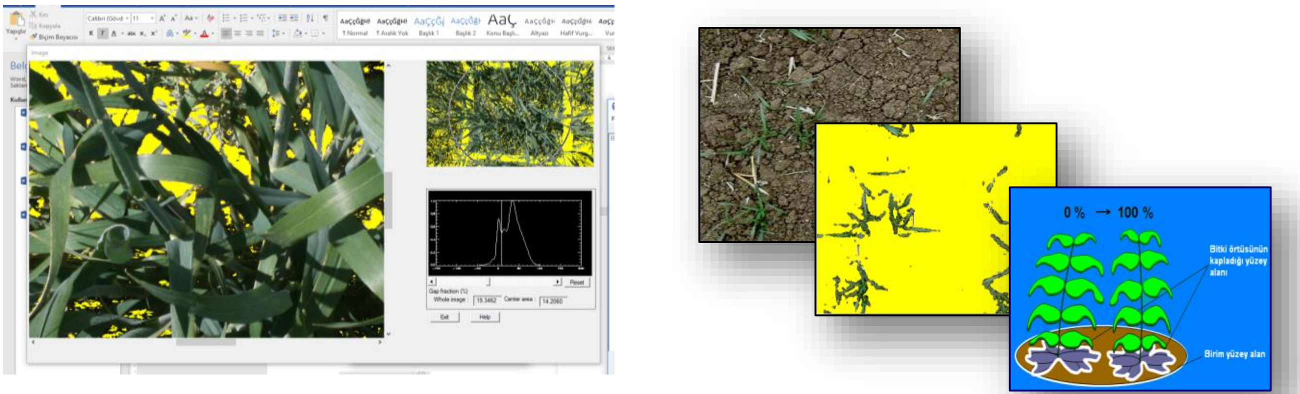

Figure 5. Processing the coverage ratios of the photos taken from the experiment in the program

Soil Studies 13(1), 17-31

Table 3. Fixed (conservative) parameters used in simulation (Raes et al., 2009)

Describing	Value	Unit and Description
The temperature at which the yield begins to decrease	26	˚C
Covering (CCo) at 90% output	7.16	cm^2
Cover development coefficient (CGC)	2.4	Coverage development rate in each GDD %
Maximum cover percentage (CC%)	95	A function of plant density %
Plant coefficient for transpiration at 100% cover level	1.10	Full coverage transpiration for relative ETo
Cover % reduction coefficient (CDC) in the dough setting period	0.39	Relative little % in CCx per CC reduction per GDD
Water efficiency	15	g (biomass) m^{-2}, atmos. A function of CO_2
Leaf growth threshold p-top	0.20	A function of soil water content
Leaf growth threshold p-sub	0.65	The point at which leaf growth completely stops
Leaf growth stress coefficient slope shape	5.0	Medium convex curve
Stoma conductivity threshold p-top	0.65	The point where the stomata begin to close
Stoma stress coefficient slope shape	2.5	Highly convex curve
Yellowing stress coefficient p-top	0.70	Below this value, early yellowing begins.
Yellowing stress coefficient slope shape	2.5	Medium convex curve

*GDD, growing degree days

In addition to these fixed parameters, variable (non-conservative) parameters are added to the model by the user as variable (non-conservative) parameters for special tillage, some management and environmental conditions, and applications that are not widely used. These parameters are usually established using data measured in the field during the plant growth period. Phenological parameters of Tosunbey and Bayraktar bread wheat varieties for two years (2017-2018 and 2018-2019) for Aquacrop model are given in Tables 4 and 5.

Table 4. Phenological parameters for Bayraktar varieties

Observations	2017-2018	2018-2019
Seed rate	18 kg/da	18 kg/da
Planting date	24/10/2017	11/10/2018
First germination	25/01/2018	27/01/2019
Jointing time	22/03/2018	28/03/2019
Tillering time	25/04/2018	25/04/2018
Flowering time	15/05/2018	13/05/2019
Flowering Time	5	7
Physiological maturity time	20/06/2018	22/06/2019
The date the yellowing started	27/06/2018	25/06/2019
Harvest time	18/07/2018	20/07/2019

Table 5. Phenological parameters for Tosunbey variety

Observations Taken	2017-2018	2018-2019
Planting date	24/10/2017	11/10/2018
First germination	25/01/2018	27/01/2019
Jointing time	22/03/2018	28/03/2019
Tillering time	25/04/2018	25/04/2018
Flowering time	18/05/2018	13/05/2019
Flowering period	7	5
Physiological maturity time	25/06/2018	22/06/2019
The date the yellowing started	01/07/2018	25/06/2019
Harvest time	18/07/2018	20/07/2019

Phenological observations taken for each variety depending on the nitrogen ratio applied during the plant growth period are entered into the "Crop charactericties" section of the programme to make separate calculations.

In this study, grain yield, dry biomass, and plant coverage ratio (CC) were used to determine the accuracy of the model. Statistical evaluation of the validity of the model was done by comparing observed and predicted biomass and grain yield values. Mean absolute deviation (α), standard error (RMSE) and model efficiency coefficient (E) were used to determine the relationship between measured and predicted values (Janssen and Heuberger, 1995; Lyman, 1993; Nash and Sutcliffe, 1970). For the accuracy of the model's predictions, the value of E (Model efficiency coefficient) should be between 0.5 and 1.0. The value of E is from negative infinity to 1. An E value is close to 1, it indicates that there is a perfect fit between the model and observation values, while E value close to 0, indicates that the model should not be used. Using the Green Crop Tracker program, the percentage of plant green area coverage (CC%) observed in the field is calculated. The results obtained can be compared with the simulation observations calculated by the Aquacrop model. The Green Crop Tracker (GCT) program is a software developed in Canada for processing digital photographs of agricultural crops. This program calculates the vegetation coverage in green areas based on photographs taken by a digital color camera at certain angles and heights. For this purpose, the percentage of green vegetation cover (CC%) is calculated by the program with the help of photographs taken at a certain height and angle with a digital color camera from each plot during plant growth periods (Sandhu et al., 2019).

Results

Inputs related to climate, soil, different fertilizer ratios, plant and environmental parameters of the experimental area where the project was carried out for 2 years in 2017-2018 and 2018-2019 were entered into the model. Parameters of plant phenological periods such as sown seed quantity, flowering, yellowing and ripening periods recorded during the plant development period were used as plant inputs in the program. Soil properties of the experimental area were entered into the model (Figure 6).

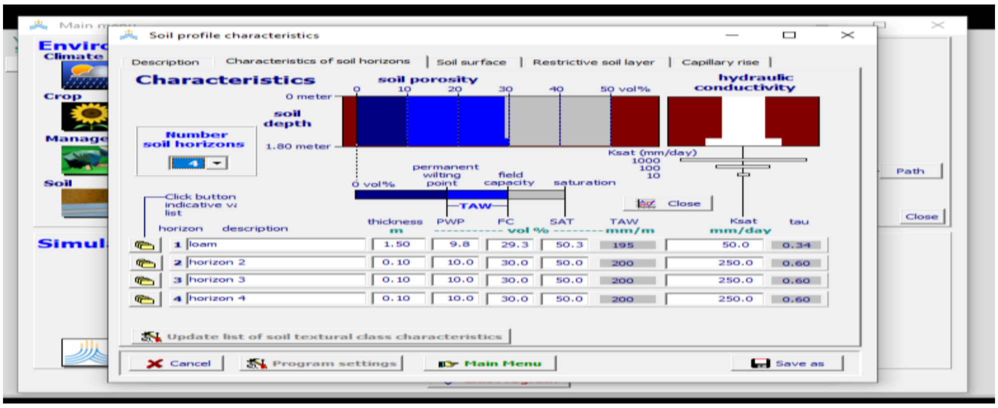

Figure 6. Aquacrop model soil characteristics section

Estimates based on rainfall without irrigation in the experiment. Daily climate data from Haymana Climate station were used. Simulations were made according to fertilization subjects and the predicted grain yield and biomass yield results were compared with the actual values measured in the experimental field (Table 6, 7, 8, 9, 10, 11).

Table 6. Coverage percentage (%) values of varieties by growing periods (Haymana 2017-2018 Growth Period)

Period (Dates)	Coverage percentage (%) values (Tosunbey-Bayraktar)							
	Tosunbey				Bayraktar			
RATIOS	N_0	N_6	N_{12}	N_{18}	N_0	N_6	N_{12}	N_{18}
31.01.2017	14.0	16.0	33.0	32.0	26.0	14.0	15.0	8.0
01.03.2018	43.10	49.10	33.86	56.23	54.05	40.01	63.89	38.05
22.03.2018	41.61	64.23	52.95	64.25	44.32	50.76	68.63	41.74
10.04.2018	75.88	67.65	83.90	76.47	69.52	84.25	85.94	62.00
25.04.2018	79.69	83.59	82.78	84.49	77.82	70.68	77.03	81.29
08.05.2018	71.87	83.63	84.61	86.66	80.89	77.45	85.21	61.89
28.05.2018	74.92	78.23	79.60	74.29	80.01	77.32	80.91	93.96
13.06.2018	65.65	69.86	69.64	78.78	68.55	70.03	64.76	70.47

Table 7. Biomass-dry weight values of varieties by growing periods (g /0.25 m²) (Haymana 2017-2018)

Period (Dates)/ Does	Biomass (Dry weight) (g/ 0.25 m²)							
	Tosunbey				Bayraktar			
	N_0	N_6	N_{12}	N_{18}	N_0	N_6	N_{12}	N_{18}
22.03.2018	131.98	79.35	105.16	117.03	71.83	77.82	115.51	82.39
10.04.2018	287.52	156.80	160.32	126.08	202.88	197.92	377.60	379.36
25.04.2018	159.60	185.16	199.0	131.48	84.08	105.36	102.48	87.32
08.05.2018	219.80	250.40	193.12	254.84	152.64	170.52	115.68	131.04
28.05.2018	335.16	215.96	397.04	247.44	289.20	215.96	250.20	210.60
13.06.2018	683.72	458.08	429.64	589.60	812.28	299.20	909.96	541.84
18.07.2018	662.12	513.82	460.23	692.77	558.91	484.15	693.55	587.62

Table 8. Haymana harvest data (2017-2018)

Yield / Harvest Index	Variety name (Harvest date: 18.07.2018)							
	Tosunbey				Bayraktar			
Ratios	N_0	N_6	N_{12}	N_{18}	N_0	N_6	N_{12}	N_{18}
Dry Biomass (g/0,25 m²)	662.12	513.82	460.23	692.77	558.91	484.15	693.55	587.62
Grain Yield (kg/da)	560	320	240	560	320	400	720	400
Harvest Index	25.19	25.00	29.73	30.54	24.90	27.66	30.75	29.44

Table 9. Coverage Percentage (%) Values of Varieties by Growing Periods (Haymana 2018-2019)

Period (Dates)	Variety name (Percent coverage values) (%)							
	Tosunbey (II. Block)				Bayraktar (I. Block)			
Ratios	N_0	N_6	N_{12}	N_{18}	N_0	N_6	N_{12}	N_{18}
27.11.2018	10.0	8.0	11.0	17.0	17.0	11.0	12.0	16.0
20.02.2018	24.0	21.0	34.0	38.0	27.0	34.0	27.0	31.0
28.03.2019	45.12	49.28	34.79	57.73	55.02	42.24	64.56	39.44
30.04.2019	81.67	86.14	85.36	86.72	78.65	72.87	81.04	84.35
15.05.2019	71.87	83.63	84.61	86.66	80.89	77.45	85.21	61.89
30.05.2019	76.63	60.25	71.54	64.42	56.80	58.04	65.07	63.23
18.06.2019	70.20	65.56	59.98	62.39	65.20	57.92	52.80	51.33
25.06.2019	77.77	72.84	70.79	70.39	74.92	76.30	71.66	70.39

Table 10. Biomass-dry weight values of varieties by growing periods (g /m²) (Haymana 2018-2019)

Period (Dates)	Varety name (Biomass-Dry Weight (g/ m²)							
	Tosunbey (II. Block)				Bayraktar (I. Block)			
Ratios	N_0	N_6	N_{12}	N_{18}	N_0	N_6	N_{12}	N_{18}
20.02.2018	64.32	45.76	50.40	47.36	24.16	48.64	33.28	54.88
28.03.2019	97.60	60.96	96.96	132	176.16	231.20	193.28	183.68
30.04.2019	21.08	14.67	56.54	41.57	89.33	44.66	34.71	60.52
15.05.2019	879.20	1001.60	772.48	1019.36	610.56	682.08	462.72	524.16
30.05.2019	411.36	888.16	1707.52	1316.80	1845.28	1996.16	3206.56	1851.68
18.06.2019	487.36	490.24	1472.48	2559.20	1840.64	2617.92	2544.0	2745.12
25.06.2019	742.24	747.52	904.64	1263.20	2361.28	1818.88	1964.16	2046.08

Table 11. Haymana Harvest Data (2018-2019)

Period (Dates)	Variety name (Harvest data: 20.07.2019)							
	Tosunbey (II. Block)				Bayraktar (I. Block)			
Ratios	N_0	N_6	N_{12}	N_{18}	N_0	N_6	N_{12}	N_{18}
Dry Biomass (g/ m²)	3045.40	1909.96	3126.0	3374.12	2739.80	1972.24	2365.40	3342.88
Grain Yield (kg/da)	148.89	155.0	218.89	347.78	307.78	287.22	330.56	306.67
Harvest Index	14.55	11.81	25.17	29.78	3.55	12.49	22.37	22.79

Simulation Evaluation Results of Yield Parameters

The model was calibrated by evaluating the data measured from the trial area between 2017 and 2018. Validation is an important step in determining the accuracy of the model. Validation is the comparison of independent data measured in the field with data predicted by the model (Andarzian et al., 2011). The performance of the calibrated model was validated using data from the 2018-2019 growing period. The Aqucrop model processes the data entered into the program, such as plant, soil, irrigation, fertilization, etc. and produces its own simulated results using daily climate data. These results are statistically compared with the actual yield, biomass, coverage percentage (CC%) values obtained from the field. Accordingly, the comparisons of the observations made between the 2017-2018 and 2018-2019 periods with the model are summarized in the figures below (Figures 7, 8, 9, 10).

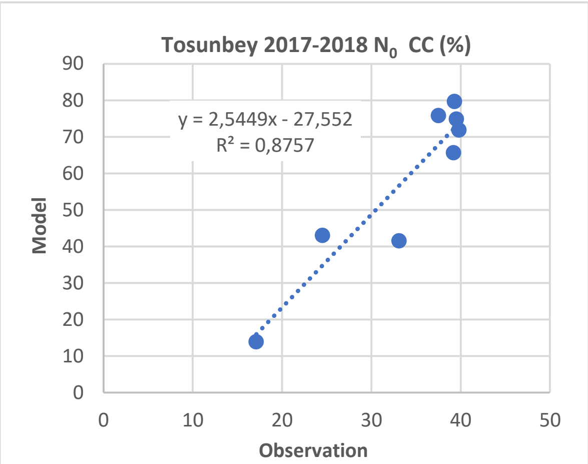

Figure 7. The relationship between the observation-model and the N_0 ratio of vegetation (CC%) percentages (Tosunbey, 2017-2018)

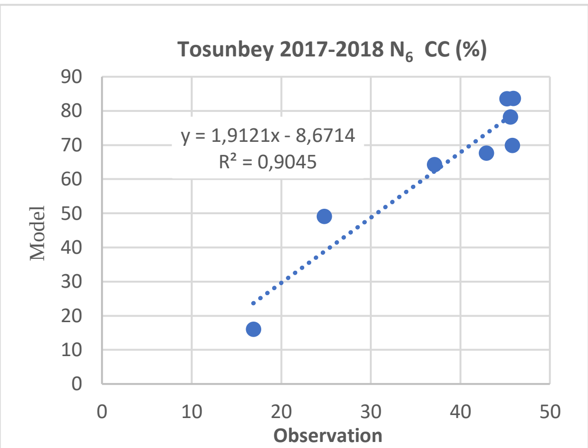

Figure 8. The relationship between the observation-model and the N_6 ratio of vegetation (CC%) percentages (Tosunbey, 2017-2018)

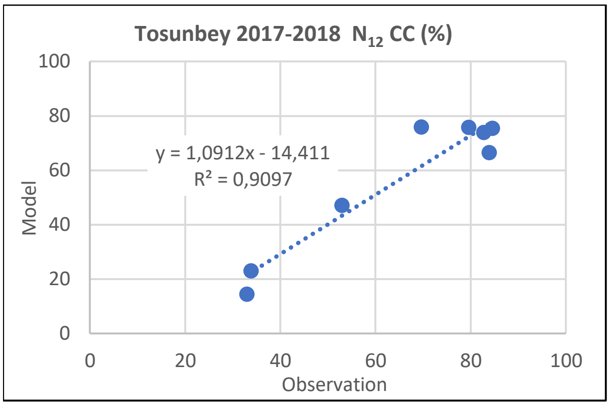

Figure 9. The relationship between the observation-model and the N_{12} ratio of vegetation (CC%) percentages (Tosunbey, 2017-2018)

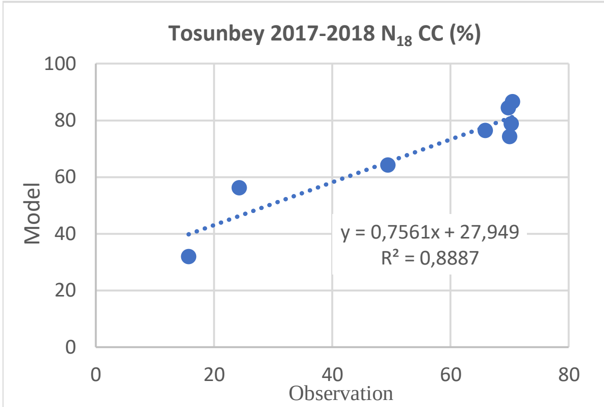

Figure 10. The relationship between the observation-model and the N_{18} ratio of vegetation (CC%) percentages (Tosunbey, 2017-2018)

In the 2017-2018 experimental year, the experiment conducted in the field with the N_{12} ratio gave the lowest grain yield value and the highest yield levels were the yield levels corresponding to the N_0 and N_{18} ratios. When the statistical evaluations between model and observation are analyzed, the relationships between grain yields model and observation for Tosunbey variety are given in Table 11, Table 12 and Table 13, and the relationships between grain yields model and observation for Bayraktar variety are given in Table 14 and Table 15. Bayraktar variety biomass yield model observation comparisons (2017-2018, 2018-2019) are also given in Table 16 and Table 17. Tosunbey variety biomass yield model observation comparison (2018-2019) is given Table 18. The efficiency coefficients for grain yield and biomass were calculated for Bayraktar and Tosunbey for the years 2017-2018 and 2018-2019 (Table 19).

Table 12. Model and observation comparison for grain yield (Tosunbey, 2017-2018)

Growing Year	Application	Grain Yield (t ha^{-1})	
		Observation	Model
	N_0	5.60	2.37
	N_6	3.20	2.81
2017-2018	N_{12}	2.40	4.32
	N_{18}	5.60	4.00
α		1.785	
RMSE(t ha^{-1})		2.051	
E		0.66	

Table 13. Model and observation comparison for grain yield (Tosunbey, 2018-2019)

Growing Year	Application	Grain Yeald (t ha^{-1})	
		Observation	Model
	N_0	1.49	1.79
	N_6	1.55	1.95
2018-2019	N_{12}	2.19	2.21
	N_{18}	3.47	2.24
α		0.353	
RMSE(t ha^{-1})		0.664	
E		0.91	

Table 14. Model and observation comparison for grain yield (Bayraktar, 2017-2018)

Growing Year	Application	Grain Yield (t ha^{-1})	
		Observation	Model
	N_0	3.20	3.17
	N_6	4.00	4.11
2017-2018	N_{12}	7.20	5.32
	N_{18}	4.00	5.55
α		0.893	
RMSE(t ha^{-1})		1.220	
E		0.93	

Table 15. Model and observation comparison for grain yield (Bayraktar, 2018-2019)

Growing Year	Application	Grain Yield (t ha^{-1})	
		Observation	Model
	N_0	3.08	2.66
	N_6	2.87	2.73
2018-2019	N_{12}	3.31	3.30
	N_{18}	3.07	3.36
α		0.216	
RMSE(t ha^{-1})		0.266	
E		0.99	

Table 16. Model and observation comparisons for biomass yield (Bayraktar, 2017-2018)

Growing Year	Application	Biomass (t ha^{-1})	
		Observation	Model
	N0	4.60	4.73
	N6	4.54	4.81
2018-2019	N12	4.91	5.87
	N18	5.11	5.97
α		0.555	
RMSE (t ha^{-1})		0.662	
E		0.98	

Table 17. Model and observation comparisons for biomass

Growing Year	Application	Biomass (t ha^{-1})	
		Observation	Model
	N_0	8.12	5.74
	N_6	11.97	7.14
2017-2018	N_{12}	9.1	9.29
	N_{18}	5.42	9.23
α		2.803	
RMSE (t ha^{-1})		3.299	
E		0.83	

Table 18. Model and observation comparisons for biomass yield (Tosunbey, 2018-2019)

Growing Year	Application	Biomass (t ha^{-1})	
		Observation	Model
	N_0	2.19	4.58
	N_6	2.51	4.86
2018-2019	N_{12}	3.68	5.70
	N_{18}	6.37	5.78
α		1.838	
RMSE(t ha^{-1})		1.979	
E		0.76	

Table 19. Model Efficiency Coefficient (E) comparisons by trial years

Growing Year	Model Efficiency Coefficient (E)	Tosunbey	Bayraktar
2017-2018	Grain Yield	0.66	0.93
	Biomass		0.83
2018-2019	Grain Yield	0.91	0.99

Discussion

In the project, in order to determine the effectiveness of the Aquacrop model, grain yield, biomass, and canopy cover (canopy cover-CC) values were evaluated at 4 different nitrogen ratios and dry conditions for 2 years (2017-2018, 2018-2019) to compare the results obtained from the model with the real field trial results. However, some of the problems encountered also affected the results. In the first year of the project, 2017-2018, biomass measurements could not be measured properly, especially in the plots with Tosunbey variety due to the rye effect in the trial area. The plots were cleaned especially at the end of the emergence and spike periods because weeds and foreign species of rye were mixed between the plots. Rye was cut at the level of the wheat spike with the help of garden shears to reduce the negative effect on yield. Accordingly, when the model and observation results were evaluated together for the first year grain yield, the model efficiency coefficient E for Tosunbey variety was found to be 0.66 and 0.91 (Table 19). For Bayraktar variety, and it is seen that the model is compatible with field observations and predicts correctly. For Bayraktar variety, when the results between the model and observation were compared in the biomass value, E=0.83 was found (Table 17) and it was concluded that the model was quite compatible with the real field observations. Similar results showing that the grain yield and biomass values obtained in winter wheat in case of sowing on normal sowing date were correctly predicted by the model were also found by some researchers such as; Araya et al., (2010), Zeleke et al., (2011), Iqbal et al., (2014), Kale Çelik et al., (2018) and Sırlı Alsancak et al., (2023). In addition, Abedinpour, (2021) conducted a comparison between DSSAT-CERES and AquaCrop models to simulate wheat growth under different irrigation and nitrogen levels and found that the simulation results of DSSAT model were relatively more accurate than AquaCrop model. However, considering that it would be difficult to obtain the necessary data for the DSSAT model in undeveloped and developing countries, it was accepted that the Aqucrop model is more advantageous because it requires less input and makes accurate calculations in less time. Phenological observations were taken during the experiment period and entered into the model. In addition, photographs of plant coverage areas were taken from the same height and with a good quality digital camera throughout the growth period and then processed in GreenCrop Tracker programme to determine green area canopy coverage rates (CC%). Again, although the weed effect in the first year negatively affected the result in determining the coverage area, photographs were taken from clean plots to prevent this. The canopy coverage (% CC) rates determined were compared with the canopy coverage values on the days predicted simultaneously by the model. Accordingly, the coefficients of determination (R^2) for N_0, N_6, N_{12} and N_{18} fertiliser treatments in terms of percent plant cover (% CC) of Tosunbey wheat variety between 2017-2018 were found to be 0.88, 0.90, 0.91 and 0.89, respectively, and were found to be compatible with the model (Figures 7, 8, 9, 10). In the software used to determine the percent cover values with the observation values obtained from the field, there may be deviations in the actual values due to the fact that the grasses in the sampling area outside the wheat are also within the calculation area, albeit very slightly, since the percentage of green area coverage is calculated (Table 6). In this study, canopy coverage percentage (CC%) values obtained in 2018-2019 for Tosunbey variety were statistically close to each other when evaluated as model and observation. Similarity was found between the percentage of green vegetation cover predicted by the model and observed in the field. The correlation (R^2) values between the percentage coverage values (CC%) obtained for Tosunbey wheat variety and the observed values were calculated for different fertilizer application ratios for the years 2018-2019 and were found to be 0.95, 0.89, 0.89, 0.89 and 0.82 for N_0, N_6, N_{12} and N_{18} values, respectively (Figures 11, 12, 13, 14). Studies on winter wheat and various other crops have also shown that the model accurately predicted the percent cover (CC%) values (Heng et al., 2009, Hsiao et al., 2009, Farahani et al., 2009; Tavakoli et al., 2015).

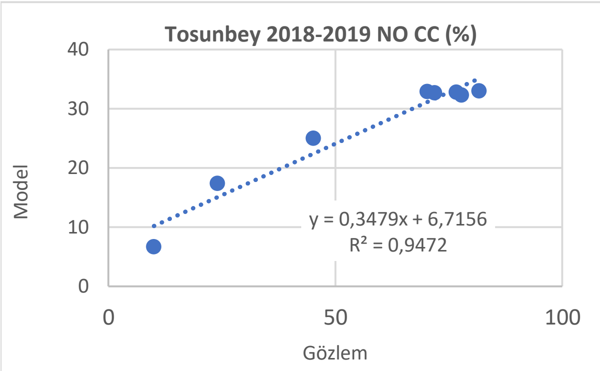

Figure 11. The relationship between the observation-model and the N0 ratio of vegetation (CC %) percentages (Tosunbey, 2018-2019)

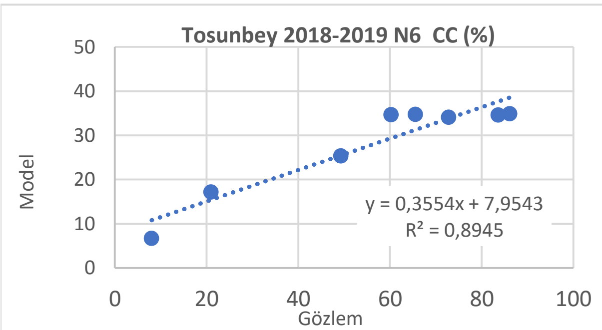

Figure 12. The relationship between the observation-model and the N_6 ratio of vegetation (CC%) percentages (Tosunbey, 2018-2019)

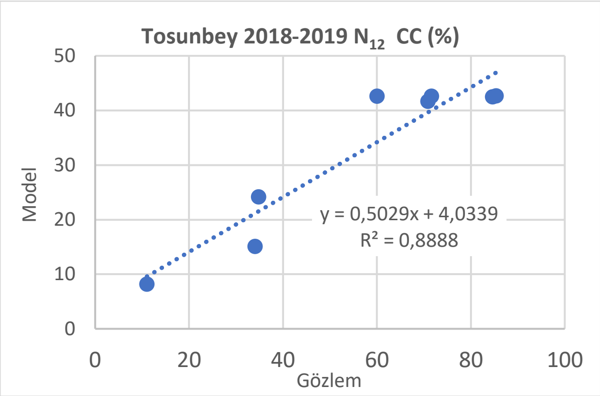

Figure 13. The relationship between the observation-model and the N_{12} ratio of vegetation (CC%) percentages (Tosunbey, 2018-2019)

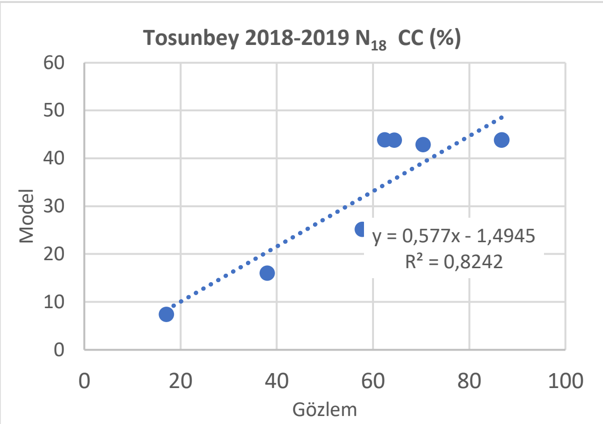

Figure 14. The relationship between the observation-model and the N_{18} ratio of vegetation (CC%) percentages (Tosunbey, 2018-2019)

The coefficients of determination (R^2) between the values observed in the field and the values predicted by the model in the first year of the experiment (2017-2018) for the Bayraktar variety were obtained for different fertiliser treatments N_0, N_6, N_{12} and N_{18}. These values were found to be 0.79, 0.91, 0.63 and 0.81, respectively (Figures. 15, 16, 17,18). These values were found to be 0.87, 0.87, 0.74 and 0.82 for the years 2018-2019, respectively (Figures. 19, 20, 21, 22). Accordingly, for Bayraktar variety, the value of N_6 fertiliser trial had the highest R^2 value in the first year (Figure 16), while N_6 trial had the highest value in the second year (Figure 20).

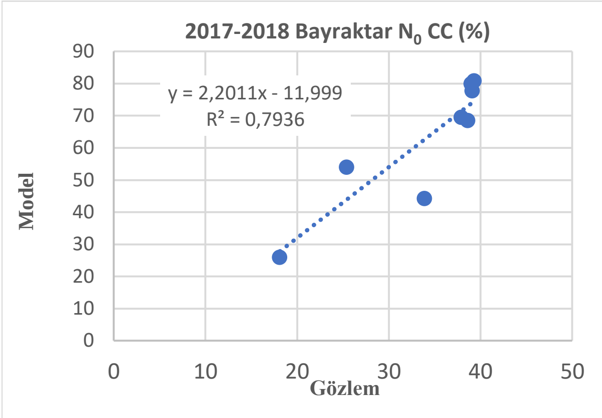

Figure 15. The relationship between the observation-model and the N_0 ratio of vegetation (CC%) percentages (Bayraktar, 2017-2018)

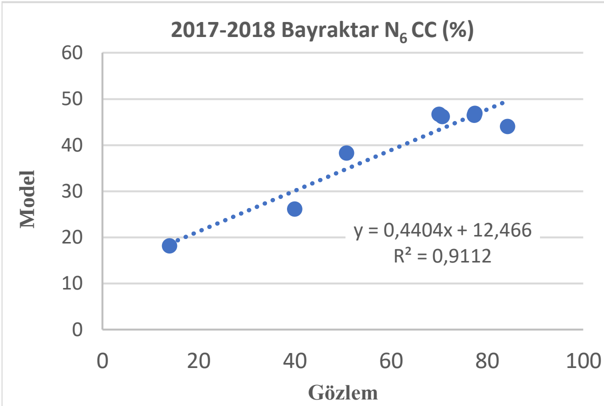

Figure 16. The relationship between the observation-model and the N_6 ratio of vegetation (CC%) percentages (Bayraktar, 2017-2018)

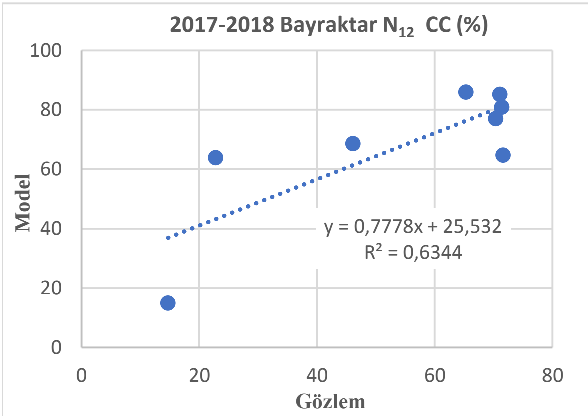

Figure 17. The relationship between the observation-model and the N_{12} ratio of vegetation (CC%) percentages (Bayraktar, 2017-2018)

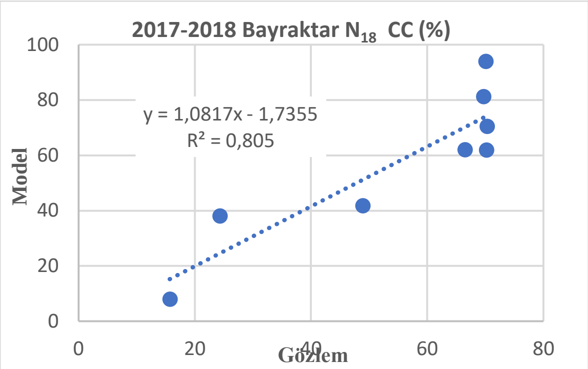

Figure 18. The relationship between the observation-model and the N_{18} ratio of vegetation (CC%) percentages (Bayraktar, 2017-2018)

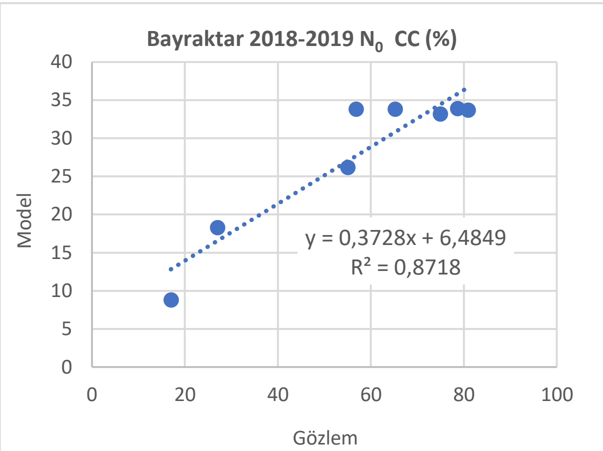

Figure 19. The relationship between the observation-model and the N_0 ratio of vegetation (CC%) percentages (Bayraktar, 2018-2019)

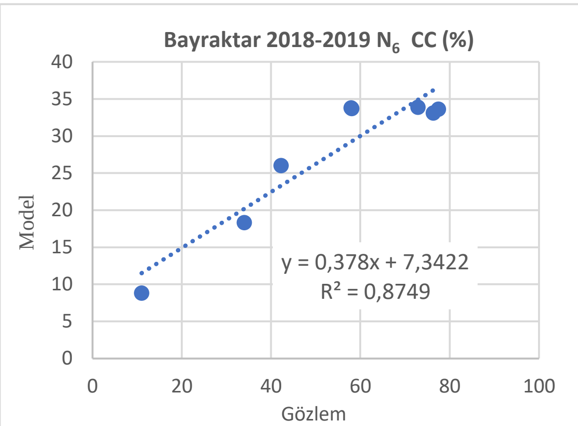

Figure 20. The relationship between the observation-model and the N6 ratio of vegetation (CC %) percentages (Bayraktar, 2018-2019)

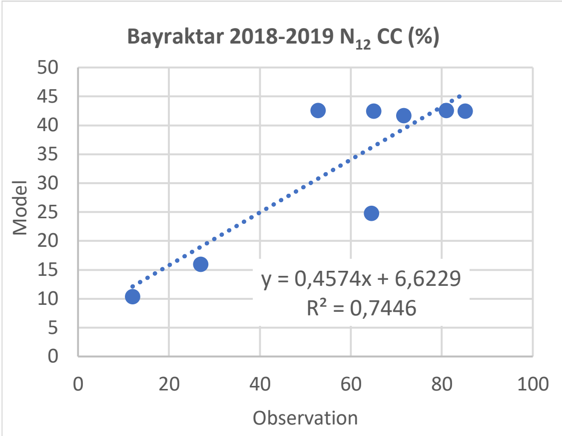

Figure 21. The relationship between the observation-model and the N12 ratio of vegetation (CC %) percentages (Bayraktar, 2018-2019)

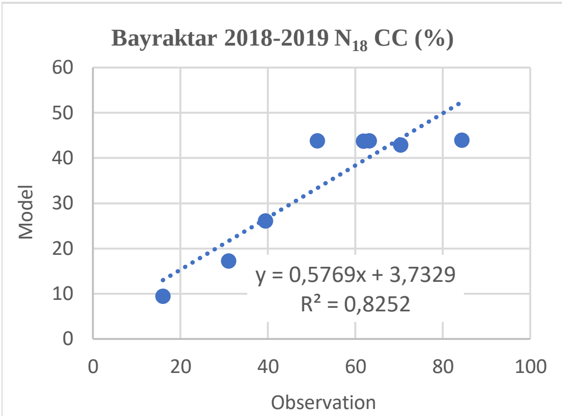

Figure 22. The relationship between the observation-model and the N_{18} ratio of vegetation (CC%) percentages (Bayraktar, 2018-2019)

Conclusion

In the studies conducted in 2018-2019, the second year of the experiment, Tosunbey variety grain yield was calculated as E=0.91 and Bayraktar grain yield was calculated as E=0.99, and an excellent agreement was found between the model and observation Considering the biomass evaluations, Tosunbey variety E=0.76 and Bayraktar variety E=0.98, and a very high agreement between the model and observation was found.

The Aquacrop model is intended for annual plants only. However, compared to other models, it provides much simpler and more reliable results. In such plant simulation models, the more accurately the data is entered, the more smoothly the model runs. These models constitute an important basis for yield estimation studies. With the Aquacrop model, it will be possible to reveal the yield deficit in a certain area or a region, to reveal the effects of inadequate fertilisation effects on yield, to evaluate the water-fertiliser interaction, to analyse future climate scenarios, to facilitate decision-makers in water distribution and other water policy-related events.

Conflict of Interest

The authors declare that they have no known competing financial or non-financial, professional, or personal conflicts that might appear to influence the work reported in this paper.

Author Contribution

BA: Idea/Hypothesis, Material, Method, Research, Data Processing, Data-Analysis, Visualization, Executive/Consultant, Thesis Management, Original Drafting, Writing- Reviewing & Editing; **HY:** Data processing, Executive/Consultant, Writing-Reviewing & Editing. **MA:** Data processing, Executive/Consultant, Writing-Reviewing & Editing. All authors have read and agreed to the published version of the manuscript.

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