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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Analyze of The Effects of Possible Climate Change Scenarios for Biomass and Grain Yields of Sunflower and Winter Wheat with AquaCrop Model in The Thrace Region of Türkiye

Trakya Bölgesi'nde Olası İklim Değişikliği Senaryolarının Ayçiçeği ve Kışlık Buğdayın Biyokütle ve Tane Verimine Etkilerinin AquaCrop Modeli ile Analizi

Fatih BAKANOĞULLARI

Abstract

Prediction of crop yield and biomass in agricultural production is crucial for both food safety and national economic projections. This study aimed to determine the relationship between the effects of climate change and biomass and grain yield of two crops (winter wheat and sunflower) at two locations, Kirklareli (KRK), Edirne-Orhaniye (EOR), with different soil textures, in the Thrace region. The scenarios (n=S1, S2,…,S65) of sensitivity analysis established by considering the expected trend of climate change were evaluated in terms of biomass and grain yield for sunflower and winter wheat crops with the AquaCrop model. The model predicted the highest losses of grain yield and biomass, when the air temperature was increased by 5 °C and the precipitation was decreased by 50% during the growing seasons of both crops (in the scenario S42). In the scenarios where only temperature was increased, grain and biomass yield values of sunflower was decreased, while those of winter wheat was increased. The combined effects of increased global solar radiation and decreased temperature had a negative effect on wheat production at EOR. For both sunflower and wheat, the most negative impacts on yield and biomass production were observed with the combined scenarios of various temperature increases and precipitation decreases during each growing season at each location. According to the simulation results of the defined single and combined scenarios in both spatial areas, while the grain and biomass yields of the summer planted sunflower plant were negative linear relations every scenario, non-linear relations were determined in the yields of the winter-wheat plant. Finally, with the defined sensitivity scenarios, the correlation coefficients between biomass and grain yield of sunflower and winter wheat under similar climate but different soil types in two locations were found to be R^2= 0.88 and 0.87 for KRK and R^2 = 0.56, and 0.79, for EOR, respectively.

Keywords: Agrometeorology, Winter wheat, Sunflower, Sensitivity analysis, AquaCrop

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Öz

Tarımsal üretimde ürün verimi ve biyokütlenin tahmini hem gıda güvenliği hem de ulusal ekonomik projeksiyonlar açısından büyük önem taşımaktadır. Bu çalışmada, Trakya bölgesinde, Kırklareli (KRK), Edirne-Orhaniye (EOR) de, farklı toprak bünyesine sahip iki lokasyonda iklim değişikliğinin etkileri ile iki ürünün (kışlık buğday ve ayçiçeği) biyokütle ve tane verimi arasındaki ilişkinin belirlenmesi amaçlamıştır. İklim değişikliğinin beklenen eğilimi dikkate alınarak oluşturulan hassaslık analizi senaryoları (n=S1, S2,…,S65) AquaCrop modeli ile ayçiçeği ve kışlık buğday bitkisi için biyokütle ve tane verimi açısından değerlendirilmiştir. Model, her iki ürünün yetiştirme sezonu boyunca hava sıcaklığının 5 °C arttığı ve yağışların %50 azaldığı senaryoda (S42) dane ve biyokütle veriminde en yüksek kayıpları tahmin etmiştir. Sadece sıcaklığın artırıldığı senaryolarda ayçiçeğinin dane ve biyokütle verim değerleri düşerken, kışlık buğdayın dane ve biyokütle verim değerleri arttı. Artan global güneş radyasyonu ve azalan sıcaklığın birleşik etkileri, EOR istasyonunda buğday dane üretimi üzerinde negatif bir etki yarattı. Hem ayçiçeği hem de buğday için, dane ve biyokütle üretimi üzerindeki en olumsuz etkiler, her iki gelişme sezonu boyunca, iki lokasyonda da çeşitli sıcaklık artışları ve yağış düşüşlerinin bir araya getirildiği senaryolarla gözlemlendi. Oluşturulan hassaslık analiz senaryolarının tekli ve birleşik senaryoların her iki mekânsal alanda simülasyon sonuçlarına göre, yazlık ekilen ayçiçeği bitkisinin tane ve biyokütle verimleri her senaryoda negatif doğrusal ilişkiler gösterirken, kışlık buğday bitkisinin dane verimlerinde doğrusal olmayan ilişkiler belirlenmiştir. Son olarak, tanımlanan duyarlılık senaryoları ile benzer iklim ancak farklı toprak tiplerine sahip iki lokasyondaki ayçiçeği ve kışlık buğdayın biyokütle ve tane verimi arasındaki korelasyon katsayıları sırasıyla KRK için R^2= 0.88 ve 0.87 ve EOR için R^2 = 0.56 ve 0.79 olarak bulunmuştur.

Anahtar Kelimeler: Agrometeoroloji, Kışlık buğday, Ayçiçeği, Hassasiyet analizi, AquaCrop

1. Introduction

Agricultural production is greatly influenced by the climate. Changes in greenhouse gas concentrations, global solar radiation, and air temperature patterns may have significant consequences for potential and rainfed yields. Except in the coldest regions where the temperature is currently below the optimum range, rising temperatures can affect crop production negatively by shortening the growing season and reducing the time for biomass accumulation (Supit et al., 2012).

Prediction of crop yield and biomass in agricultural production is crucial for both food safety and national economic politics. The effects of climate change on future yield rates of widely grown and potential crop types in different regions of the world have been a long-standing concern.

Effects of climate changes on future yield rates of currently grown and possible crop types in the different regions of the globe have long been at stake and many crop growth simulation models have been used to predict crop responses to possible climate changes for years. Among those, the AquaCrop model developed by the Food and Agriculture Organization of the United Nations (FAO) has become widespread in recent years (Raes et al., 2018). Researchers from different countries have used agrometeorological models to evaluate irrigation schedules and agricultural practices to better understand the possible impacts of agricultural drought on crop growth and yield (Andarzian et al., 2011; Mkhabela and Bullock, 2012; Nazeer and Ali, 2012; Vanuytrecth et al., 2014; Voloudakis et al., 2015; Kale, 2016; Zeleke and Nendel, 2020). The AquaCrop model has been used to estimate the grain yield and biomass of various plant species under rainfed conditions or different irrigation regimes (Iqbal et al., 2014; Paredes et al., 2015; Toumi et al., 2016; Bello and Walker, 2017; Jin et al., 2018; Nyathi et al., 2018; Pirmoradian and Davatgar, 2019). Especially, by the sensitivity analysis and calibration procedures, scientifically reasonable results were achieved by the AquaCrop model on major plant species grown under diverse agro-meteorological conditions (Trombette et al., 2016; Xing et al., 2017; Xiuliang et al., 2018). Argentel-Martinez et al. (2021) aimed to evaluate the existing correlation among vegetative and reproductive variables in wheat in a climate change scenario based on temperature increase, under field conditions, in the crystalline wheat cultivar CIRNO C2008, and recommend variables as precise indicators of heat stress tolerance.

Eitzinger et al. (2013) compared the performance of the AquaCrop model for winter wheat and maize yields. These authors reported that the greatest decrease in yield, by about 28% and 90%, respectively, was observed with the scenario of changes of +4°C in both minimum and maximum daily temperatures and zero precipitation. They also analyzed the sensitivity of crop models to extreme weather events for winter wheat and maize in Austria.

Some researchers have been used different crop growth simulation models to predict crop responses to possible long term climate changes in the Thrace Region. Şaylan et al. (2017) analyzed growing season (2010-2011) of the selected winter wheat in the KRK location used for two crop growth models, namely DSSAT and WOFOST that were calibrated for winter wheat and yield changes were estimated with the RegCm4 model and 1975-2010 and 2013-2040 projections. Çaldağ et al. (2017) monitored and analyzed two consecutive winter wheat growing seasons (2009-2010 and 2010-2011) in the selected field with the RegCM4 regional climate model for the data of the wheat plant in two growing seasons in the KRK location. Input databases of the CERES-Wheat and WOFOST models were provided regularly. Also, the sensitivity of the winter wheat grain and biomass yields changes has been determined for future projections using with same scenarios. Konukcu et al. (2020) investigated the effect of climate change on wheat yield in the short (2020-2030), medium (2046-2055) and long (2076-2085) term periods in the Thrace Region using AquaCrop and WOFOST models. RegCM3 Regional Climate Model, reference and A2 scenario outputs were used to predict climate change. Wheat yields obtained from farmer fields in Çorlu Pınarbaşı sub-basin in 2016-2017 growing period were compared with the model prediction in order to do the calibration and yields were focused to forecasted in the future periods. (Yeşilköy and Şaylan, 2020) investigated actual crop yield and Crop Water Footprint of winter wheat grown under rainfed conditions by using AquaCrop model for two growing seasons. RCP 4.5 and 8.5 scenario results produced by HadGEM2-ES model were used as input data to estimate the crop yield and water footprint of the future (2020-2099) by AquaCrop. The AquaCrop was performed according to RCP 4.5 and 8.5 scenarios with and AquaCrop was not performed because necessary input data such as meteorological, soil and crop phenological data for the model were insufficient. Öztürk (2024) compared the performance of the winter wheat genotype about abiotic conditions and reported that the importance of genotype and environmental effects on yield and quality.

Fuso et al. (2023) stated global circulation models (GCMs) provide climate projections on a coarse grid resolution, generally not suitable to represent climatic variability at a local scale.

Relevant literature shows that there are several models used to predict climate changes in the long term future periods and give different results in spite of using the same scenarios which extensively focused on cereal crops in the semiarid climates and Regional Climate Models, like as RCP 4.5, 8.5 and A2 scenario outputs were used to predict climate change. To fulfil this knowledge gap, this research has a focus not only on cereal crop but also on oil crop plant, sunflower, widely cultivated in the region. Additionally, Scenarios regarding possible climatic fluctuations in the future were compared with the changes in grain and biomass yields in the years when the experiments were carried out.

The northwest part of Turkey (Thrace region) plays an important role in rainfed sunflower and winter wheat cultivation and production, accounting for 65% and 15% of the total crop production of the country, respectively. However, the atmospheric conditions are becoming unpredictable in the region, which is expected to have both positive or negative impacts on regional agriculture under the recent fluctuations of climate variables. The aspect of crop productivity for the major cultivars is a concern that needs to be assessed by explanatory modelling approaches. The objectives of this study were to analyze the sensitivity of yield and biomass of winter wheat and sunflower under rainfed conditions to different the changes in meteorological variables for two different soil type and location using the AquaCrop model. The results obtained from this study can offer valuable insights for adaptation to the risks of the effects of climatic fluctuations and biomass and grain yield of sensitivity of climate change. Climate change is affecting agricultural production and pattern in the Thrace part of Turkey

The paper is structured as follows. In the “Material and methods” section, the study area, the agricultural practices, the meteorological data and plant materials, the model description, the statistical analysis and the climate scenarios methodology are presented. Results are in the “Results and discussion” section. Conclusion is the “Conclusion” section, respectively.

2.Material and Methods

2.1. Study area, agricultural practices, meteorological data and plant materials

This experimental study was conducted in the fields of Atatürk Soil Water and Agricultural Meteorology Research Institute to compare the AquaCrop model-based predictions with the measured values of biomass and grain yields of sunflower and wheat between the years 2014 and 2018 under rainfed conditions. The field studies were carried out at two sites: Kirklareli (KRK) (41°42′ N, 27°12′ E) and Edirne-Orhaniye (EOR) (41°43′ N, 26°26′ E), in the northeast and the southwest of the Thrace region of Turkey (*Figure 1*).

The total sizes of fields at KRK and EOR were 3.6 and 3.0 ha, respectively. The widely grown domestic cultivars of sunflower (Tunca) and winter wheat (Gelibolu) were planted under local conventional farming practices in the region. Sunflower was planted for three growing seasons (2014, 2015, and 2017) and winter wheat for two growing seasons (2015–2016 and 2017–2018) at both locations.

The sunflower hybrid genotype Tunca and the Gelibolu cultivar of winter wheat were sown at a depth of 4–5 cm. The furrows were 30 cm apart with a plant spacing of 70 cm for sunflower, and 5 cm apart with a plant spacing of 10 cm for winter wheat, respectively. The experimental fields were monitored for pests and weeds, and pesticides were applied when needed. Seed bed and seed sowing operations were carried out by following a wheat-sunflower rotation system under traditional rainfed agriculture. Chemical fertilization for sunflower was carried out with 100 kg ha^{-1} di-ammonium phosphate (46-18-0) fertilizer as the base fertilizer and 100 kg ha^{-1} urea (46-0-0) in hoeing and additionally, 1500 ml ha^{-1} imazamox was used as an herbicide. For wheat fertilization, 150 kg ha^{-1} di-ammonium phosphate was applied as the base fertilizer and 150 kg ha^{-1} urea in tillering period and 100 kg ha^{-1} urea in the growing period along with 10 gr ha^{-1} of clorsulfuron and 1250 gr ha^{-1} of the mixture of prothioconazole + spiroxamine as a crown and 1250 gr ha^{-1} of the mixture of epoxiconazole and fenpropimorph as herbicides. Biomass analysis was conducted by taking three different samples from in the field every 15 days for each crop.

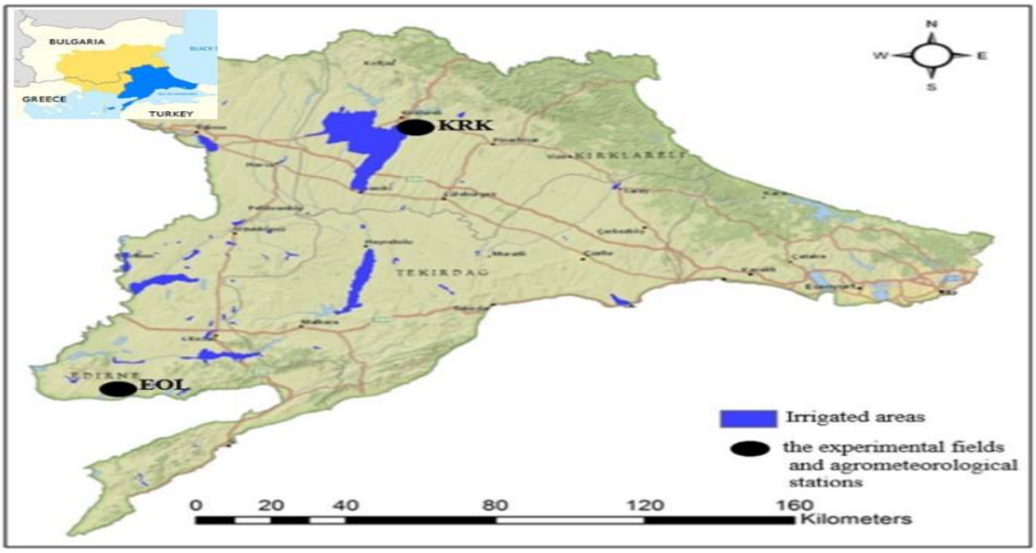

Figure 1. Site location map in the Thrace region. the experimental fields at the Kirklareli (KRK) and Edirne-Orhaniye (EOR) sites

Full-automated meteorological stations were installed at the research fields in each site including a datalogger (CR1000 Campbell Sci, Inc., Logan, UT, USA) which regularly recorded air temperature and relative humidity (Rotronic and Vaisala), wind speed and direction (NRG) and soil water content (CS616, Campbell Sci.) gauged at the depths of 0-30, 30-60, 60-90 cm by moisture sensors and a pyranometer (CMP6, Kipp and Zonen). Complete systems are capable to measure data in 30 sec. time interval, taking 10, 30, 60 min and 24-hour records, as well (*Figure 2*).

The ETo (Reference Evapotranspiration) calculator (FAO, 2009) estimated the daily reference evapotranspiration (ETo) during growing periods of plants. Mean values of monthly rainfall, mean monthly maximum and minimum air temperature for five-year periods (2014-2018) were regularly measured and recorded.

Figure 2. Meteorological stations in the KRK site (on the left) and the EOR site (on the right)

Additionally, all necessary data for the model were measured, collected, and observed during the measuring period such as phenological stages, soil properties, biomass, yield, and agricultural management (fertilization, irrigation, etc.). Before cultivation, soil samples were taken from each field at depths of 0-30, 30-60, and 60-90 cm. The physical and chemical properties of the soil in the experiment fields are given in *Table 1*.

Table 1. Properties of the soils measured at the experimental fields

Location	**KRK site**			**EOR site**		
Soil Parameters	**Soil Depth (cm)**					
	0-30	**30-60**	**60-90**	**0-30**	**30-60**	**60-90**
Saturation (%)	44	59	57	61	56	50
Sand (%)	66.67	54.17	56.25	22.92	27.08	27.08
Silt (%)	20.83	27.08	27.08	25.00	22.92	20.83
Clay (%)	12.50	18.75	16.67	52.08	50.00	52.09
Soil texture	Sandy loam	Sandy loam	Sandy loam	Clay	Clay	Clay
FC (%)	16.20	16.85	22.82	29.36	23.65	23.93
WP (%)	6.73	10.32	10.12	20.69	17.35	18.08

KRK: Kirklareli, EOR: Edirne-Orhaniye, FC: field capacity, WP: wilting point.

2.2. Model description

In this study, AquaCrop model v6.0 (Raes et al., 2018) was used to model biomass and grain yield of sunflower and winter wheat. This model was developed to help agronomists, consultants, irrigation engineers, and farm managers to increase crop water productivity under rainfed and irrigated conditions (Raes et al., 2009). Under water limiting conditions, AquaCrop can simulate water requirements, water use efficiency and crop productivity. Apart from being easy to operate when compared to other models, it also requires a limited set of input parameters for predictions. AquaCrop uses the first (Doorenbos and Kassam, 1979) equation for the biomass calculation and, finally, the crop yield, proportional to the biomass according to a "harvestable part". The software simulates Biomass (B) and Yield (Y) of crops, focusing on water stress conditions (Steduto et al., 2009). In the current study, Aqua Crop model v 6.0 was used to model biomass and grain yield of sunflower and winter wheat. The CO_2 (carbon dioxide in the air) data that the AquaCrop model needs is the mean annual atmospheric CO_2 concentration. The 'MaunaLoa.CO_2' file contains the observed yearly atmospheric [CO_2] concentration for the period 1902 till today. Annual atmospheric [CO_2] concentration data for the experiment periods (between 2014 and 2018) were taken from the relevant file.

2.3. Statistical analysis

Model was calibrated and evaluated by using the default conservative parameters which were given the model for winter wheat and sunflower, along with local management-dependent parameters (measured) and phenological stages for the local cultivars during the growing seasons between 2014-2018, as listed in *Table 2*.

Calibration of the model for sunflower and winter wheat was carried out by comparing the simulated and measured biomass (BM) and grain yield (GY) of sunflower and wheat in the growing seasons of 2014, 2015, and 2017 and 2015–2016, and 2017–2018, respectively. The comparison criteria were the root mean square error (RMSE), mean absolute error (MAE), relative error (RE), as follows:

The agreement between the observed (Oi) and predicted (Pi) values were evaluated by the following statistical performance indicators: 1) RMSE, 2) MAE, and 3) RE [Eq. (1), (2) and (3), respectively].

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(O_i - P_i)^2} \quad \text{(Eq. 1)}$$

$$MAE = \frac{\sum_{i=1}^{N}|P_i - O_i|}{N} \quad \text{(Eq. 2)}$$

$$RE = \frac{|P_i - O_i|}{O_i} \times 100 \quad \text{(Eq. 3)}$$

Table 2. Measured values of certain local parameters used in the AquaCrop model to simulate sunflower and winter wheat growth and yield

Description, Location/Plant	**Measured values**			
	KRK Sunflower	**EOR Sunflower**	**KRK Winter wheat**	**EOR Winter wheat**
Number of plants per hectare	50000	50000	4500000	4500000
Maximum canopy cover (CCx) in fraction soil cover	0.9	0.9	0.9	0.9
GDDays: from sowing to emergence	67	200	127	138
VGDDays: from sowing to start senescence	1303	1560	1636	1873
GDDays: from sowing to maturity (length of crop cycle)	1730	2148	2397	2910
Base temperature (°C) below which crop development does not progress	6.7	6.7	0.0	0.0
Upper temperature (°C) above which crop development no longer increases with an increase in temperature	30.0	30.0	26.0	26.0
Calendar Days: from sowing to emergence	9	14	11	11
Calendar Days: from sowing to maximum rooting depth	90	80	223	181
Calendar Days: from sowing to start senescence	105	97	206	192
Calendar Days: from sowing to maturity (length of crop cycle)	135	129	248	243

KRK: Kırklareli, EOR: Edirne-Orhaniye.

Table 3. Single and combined climate scenarios (S) used in the sensitivity analysis

Scenario	**T +1**	**T +2**	**T +3**	**T +4**	**T +5**	**T -1**	**P -10**	**P -20**	**P -30**	**P -40**	**P-50**	**Rg +2**	**Rg +4**
	(°C)						**(%)**						
T +1°C	S1						S14	S20	S26	S32	S38	S44	S55
T +2°C		S2					S15	S21	S27	S33	S39	S45	S56
T +3°C			S3				S16	S22	S28	S34	S40	S46	S57
T +4°C				S4			S17	S23	S29	S35	S41	S47	S58
T +5°C					S5		S18	S24	S30	S36	S42	S48	S59
T -1°C						S6	S19	S25	S31	S37	S43	S49	S60
P -10%							S7					S50	S61
P -20%								S8				S51	S62
P -30%									S9			S52	S63
P -40%										S10		S53	S64
P -50%											S11	S54	S65
Rg +2%												S12	
Rg +4%													S13

S1, S2, S3, ……, S64 and S65: number of scenarios,
T+1 °C, T+2 °C, T+3 °C, T+4 °C, and T+5 °C indicate 1, 2, 3, 4 and 5 °C increases in the air temperature, respectively.
T-1 °C indicates 1 °C decrease in air temperature.
P -10%, P -20%, P -30%, P -40% and P -50% signify 10, 20, 30, 40 and 50 percent reductions in the precipitation, respectively.
Rg +2% and Rg +4% signify 2 and 4 percent increases in the global solar radiation, respectively.

2.4. Sensitivity scenarios methodology

Considering the boundary conditions of most of the General Circulation Models (GCM) and approaches from two different scenarios (RCP 4.5 and 8.5), average temperatures would show an increasing trend, whereas no such common result can be deduced for precipitation (Yeşilköy and Şaylan, 2020). Therefore, in the current study, instead of using global or regional climate scenarios, sixty-five (65) climate sensitivity analysis scenarios created by considering the expected trend of climate change were evaluated for the effects of single and combined variations of meteorological factors on plant grain and biomass yields. These sensitivity scenarios which are in *Table 3* were used to determine the changes in the biomass and yield of wheat and sunflower under rainfed conditions.

3. Results and Discussion

3.1. Model runs and evaluation

The calibrated Aquacrop model was used for the scenario of sensitivity analysis as shown in *Table 3* and simulated grain yield and biomass for each crop and location as shown in *Table 4*.

According to the mean data for three years for sunflower and two years for winter wheat, the average sunflower and winter wheat yields grown under rainfed conditions were 2.20 t ha^{-1-}and 4.77 t ha^{-1}, respectively. In addition, the average grain yields during the same growing periods in Thrace were 2.38 (8.2% more) for sunflower and 3.75 (21.4% less) t/ha for winter wheat. Simulations for the sunflower crop indicated that the average RMSE, MAE and RE values were 0.06; 0.06 and 2.8%, respectively. The performance indicators for winter wheat were 0.1, 0.1, and 2.1%. According to these performance criteria, the model predicted the observed values very well Iqbal et al. (2014) tested the ability of the AquaCrop model (v 3.1) to simulate winter wheat grain yield and biomass, and reported RMSE values of 0.58 and 0.87 t ha^{-1}, respectively. Kale (2016) tested the AquaCrop model (v 5.0) for winter wheat under fully irrigation and rainfed conditions in the semi-arid Central Anatolian region, comparing model predictions with actual results and reported RMSE values of 1.17 and 0.32 t ha^{-1}, respectively, for biomass and crop yield. These data suggest very good agreement between observed and simulated values, despite the slight overestimation by the model. Mkhabela and Bullock (2012) evaluated spring wheat yield and found RMSE and MAE values of 0.74 and 0.61 t ha^{-1}, respectively. Similarly, estimated winter wheat grain yield by Konukcu et al. (2020) MAE values between 0.15 and 0.31 t ha-1 and the average relative errors (RE) between 1.87% and 6.18% at the pinarbası watershed, by Yeşilköy and Şaylan (2020) RE in the cities of Edirne and Kirklareli were 2.4%, -1.6%, respectively.

Table 4. Statistics of the measured and simulated grain yield and biomass with the Aquacrop for sunflower and wheat at the KRK and EOR experimental sites

Location	**Plant**	**Parameter**	**Observed**	**Simulated**	**RMSE**	**MAE**	**RE**
			(t ha^{-1})	**(t ha^{-1})**	**(t ha^{-1})**	**(t ha^{-1})**	**(%)**
KRK	Sunflower	GY	2.24	2.28	0.002	0.04	1.87
		BM	14.57	15.34	0.59	0.77	5.28
EOR		GY	2.15	2.23	0.01	0.1	4.05
		BM	15.40	11.09	18.58	-4.31	-28.0
Average		GY	2.20	2.26	0.06	0.06	2.80
		BM	14.99	15.34	3.10	2.54	16.6
KRK	Winter Wheat	GY	4.67	4.59	0.006	-0.1	-1.63
		BM	17.62	16.27	1.69	-1.3	-7.39
EOR		GY	4.86	4.74	0.014	-0.1	-2.43
		BM	22.59	20.42	4.75	-2.18	-9.65
Average		GY	4.77	4.67	0.10	0.10	2.10
		BM	20.11	18.35	1.81	1.76	8.60

KRK: Kirklareli, EOR: Edirne-Orhaniye, BM: Biomass, GY: Grain yield, RMSE: root mean square error, MAE: mean absolute error, RE: relative error.

3.2. Sensitivity analysis of climate-changing on grain and biomass yields of plants

In the current study, instead of using global or regional climate scenarios, sixty-five (65) climate sensitivity analysis scenarios created by considering the expected trend of climate change were evaluated for the effects of single and combined variations of meteorological factors (air temperature, precipitation and solar radiation) on selected cultivars to future climatic conditions depends firstly on logical validation according to the corresponding variations in meteorological factors. In this context, expected changes and impacts of these factors are given in *Table 3*, where the examination was done individually or in combination.

Figure 3 and *4* show sunflower grain yield (KRKsfg), sunflower biomass (KRKsfb), winter wheat grain yield (KRKwwg) and winter wheat biomass (KRKwwb) at the KRK site, along with sunflower grain yield (EORsfg), sunflower biomass (EORsfb), winter wheat grain yield (EORwwg), and winter wheat biomass (EORwwb) at EOR site. Additionally, the response (sensitivity) of the model for every combination of parameters in 65 different scenarios are detailed in *Table 3*.

Figure 3-A shows the changes in sunflower grain yields compared to the reference values for the sensitivity scenarios at each site. Based on percent changes in sunflower grain yields, the highest yield loss was estimated for the scenario S42 (T+5°C, P -50%) with decreases of 61% and 59% at the KRK and EOR sites, respectively. The highest yield increase was observed for the scenario S6 (T -1°C) with increases of 6.8 and 7.2% at the KRK and EOR sites, respectively.

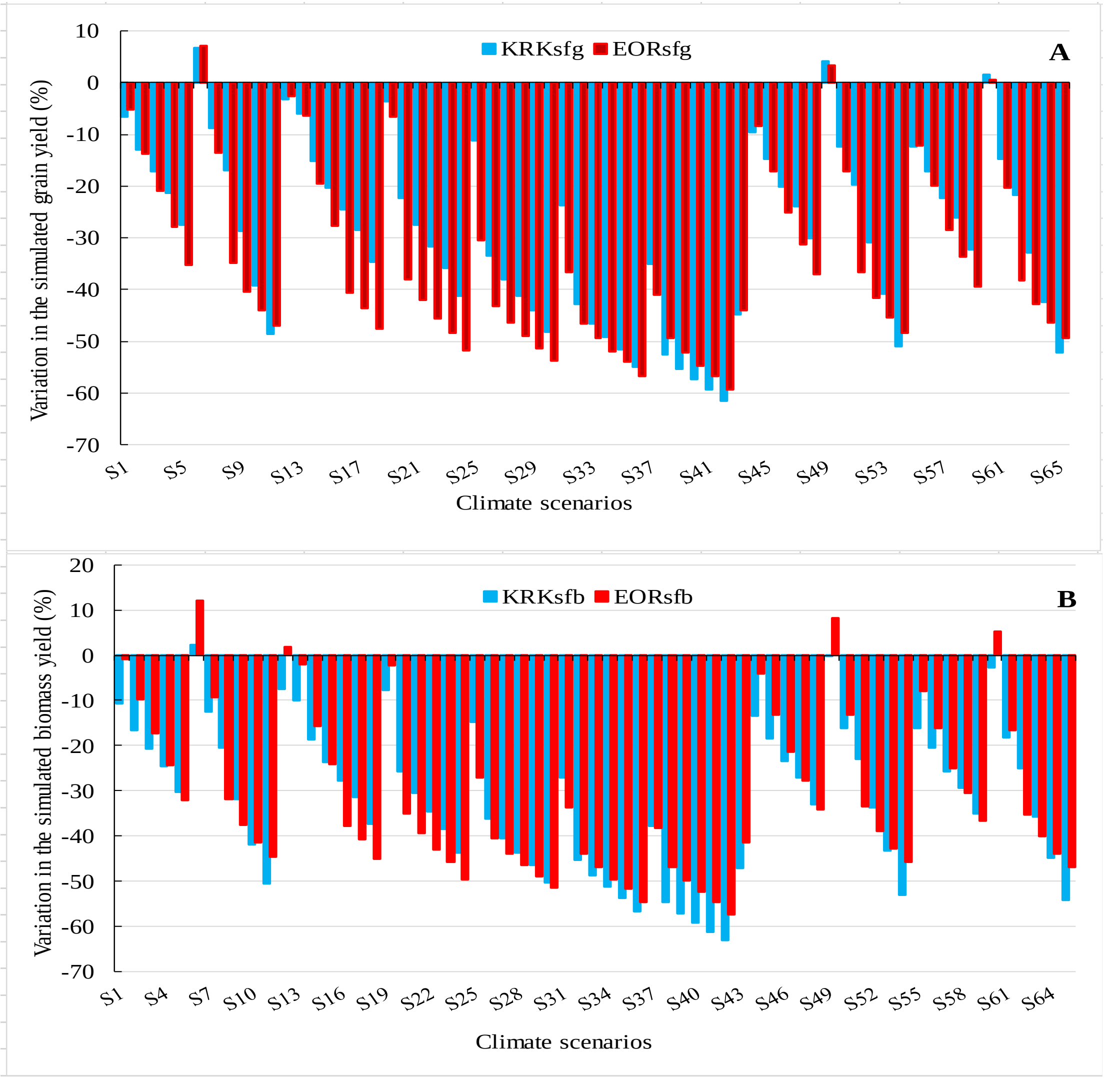

Figure 3. Relative deviations of simulated sunflower grain (sfg) yields (A) and sunflower biomass (sfb) yields (B) associated with selected climate scenarios at the Kirklareli (KRK) and Edirne-Orhaniye (EOR) sites

Single and combined scenarios of temperature increases (S1-S5) and precipitation decreases (S7-S10) were associated with decreases in yield. The scenarios of S12 and S13, which represented increases in global solar radiation, had a minor negative impact on the grain yield of sunflower in both sites. However, such increases were also observed in the S6 scenario (T -1°C) as well as in the scenarios of S49 and S60 (Rg +2% and Rg +4%, respectively).

Figure 3-B shows the changes in sunflower biomass yields by the climate change scenarios at both locations. The highest yield loss occurred with the scenario S42 (T +5°C, P -50%) showing decreases of -63.2% and -57.5% at the KRK and EOR sites, respectively. The highest yield increase was simulated for the scenario S6 (T -1°C) with increases of 2.3% and 12.2% at the KRK and EOR sites, respectively. Scenarios representing only temperature increases and precipitation decreases (S1-S5) and their combinations with other parameters (S7-S10) (*Table 3*) were all associated with a decrease in biomass yield. As expected, decreases in precipitation caused losses in the grain yield as well as in the biomass. Scenario S12 (Rg +2%) caused a minor increase of around 1.9% in biomass at the EOR site, but this was not the case with the scenario S13 (Rg +4%), which brought about a 2% decrease in the biomass at the same site. In the scenarios S49 and S60 [(T -1°C, Rg+2%) and (T -1°C, Rg +4%)], slight decreases in biomass of -0.2 and -2.8, respectively, were observed at the KRK site. On the contrary, increases in biomass of 8.3% and 5.3%, respectively, were observed at the EOR site.

Figure 4-A shows the grain yield variations of winter wheat due to climate change by considering only temperature rise (S1-S5). Here, an increase in grain yield was noted at both sites. The scenario S5 particularly led to the highest increases (15.9% and 19.3% for the KRK and EOR sites, respectively) in the grain yields. Similarly, scenarios S14-S18, in which precipitation was decreased and temperature was increased gradually, the grain yield was increased. For example, an increase of 6.8% for scenario S16 at the KRK site and 15.3% for scenario S18 at the EOR site were observed. Additionally, scenarios S44-S48 (temperature increases with both Rg +2%) and S55-59 (gradual temperature increases with both Rg +4%) resulted in increases in yield by up to 15.2% and 18.5% at both sites.

In the scenario S6, a decrease in temperature by as little as a 1°C caused 7.1% and 6.2% decrease in grain yield at the KRK and EOR sites, respectively. Likewise, decreases in precipitation had a significant negative effect on the grain yield of winter wheat, represented by 40.4% and 15.2% losses in the scenario S11 at the KRK and EOR sites, respectively. Evaluation of the possible effects of global solar radiation scenarios (S12 and S13) showed that both Rg +2% and Rg +4% had positive impacts on grain yield. In addition, their combinations with extreme increases in air temperature and decrease in precipitation (scenarios S38-S43) showed the most dramatic decrease in the grain yield of wheat.

Figure 4-B shows the biomass sensitivities of winter wheat grown at both sites. As observed with grain yield, the biomass values also tended to be affected positively by temperature increments. Moreover, there was a positive effect of extending the optimum growing period due to increased mean temperatures. Thus, the scenario S5, which simulated such conditions, was associated with the highest biomass increments of 10.5% and 22.0% at the KRK and EOR sites, respectively. A 1°C drop in temperature (scenario S6) decreased the biomass yield by 2.9% and 6.8% at KRK and EOR, respectively. Similarly, all scenarios representing decreases in precipitation resulted in a reduction in the biomass, as expected. In particular, the scenario S43 (T -1 °C and P -50%) resulted in biomass losses of 53.8% and 18.4% at the KRK and EOR sites, respectively.

Contrary to the results of the winter wheat model used in this study, in both models used in Çaldağ et al. (2017), losses in both grain and biomass yields were determined due to temperature increases for the selected year at the KRK station. Decreases in biomass and grain yields were determined when rainfall decreased, and increases in yields were determined when solar radiation values increased, and these results are similar to the results of my study. Eitzinger et al. (2013) stated that the grain yield and biomass of winter wheat showed an increase with increasing temperatures. Our data revealed that it is of pivotal importance to determine which meteorological parameters are more sensitive to the yield during the development period of the modelled plant. Calculations for the sensitivity analysis helped us to understand how plants primarily reacted to climate change. In this connection, temperature, precipitation, and global solar radiation come to the fore as the most important variables affecting plant phenological stages and yield.

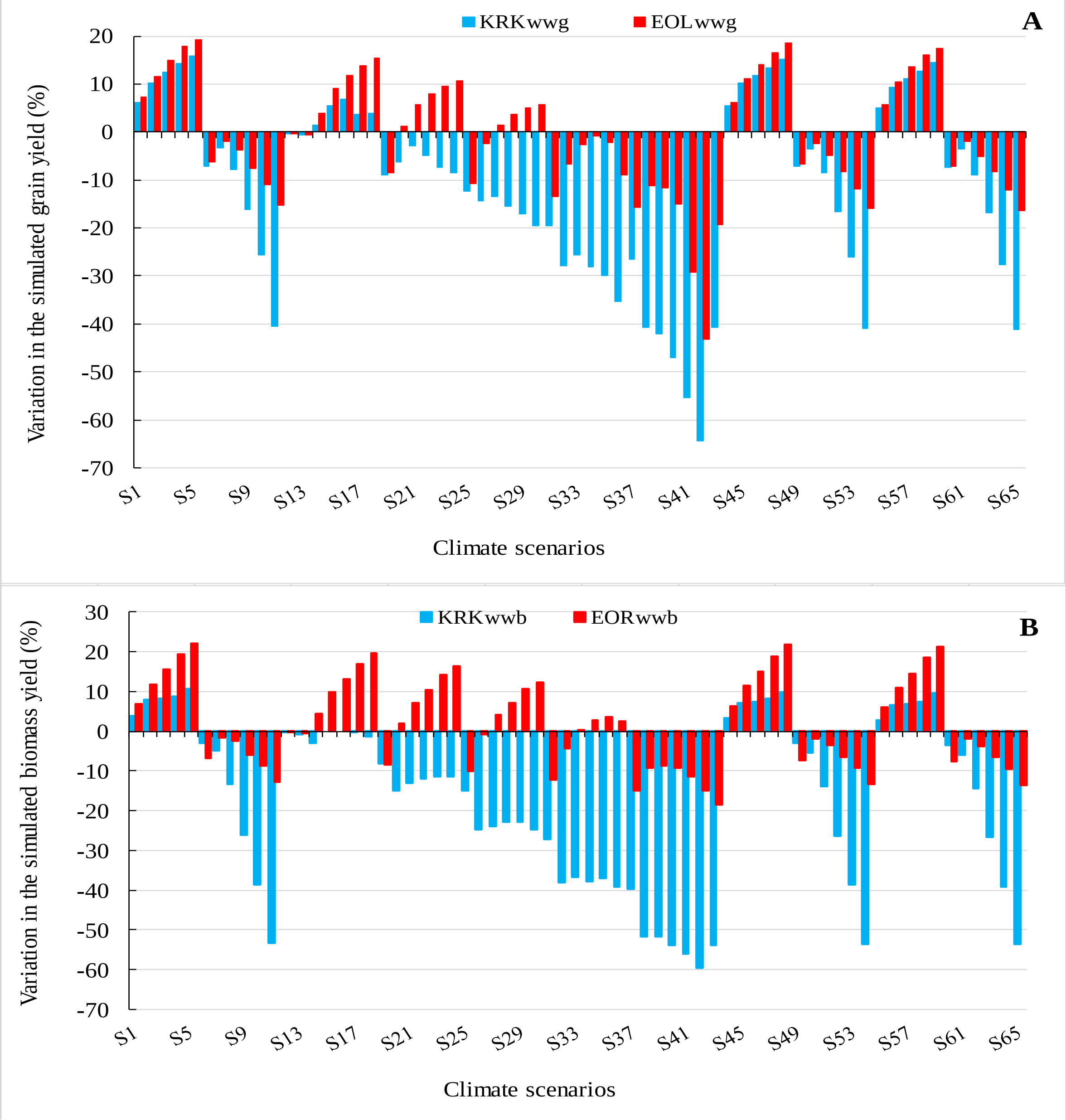

Figure 4. Relative deviations of simulated winter wheat grain (wwg) yields (A) and winter wheat biomass (wwb) yields (B) associated with selected climate scenarios at the Kirklareli (KRK) and Edirne-Orhaniye (EOR) sites.

As mentioned earlier, a series of sensitivity analyses was performed on the grain and biomass yields of two plants at the KRR and EOR sites under different climate conditions and soil structure. Since the KRK and EOR sites had very similar mean values of climatic factors, the changes in the grain yields were not different. However, temporal changes in the meteorological factors during the developmental stages of plants showed differences. The yield at the EOR field was higher than that at the KRK site. The reason for this may be a difference in the soil structure as well as the hydraulic properties of the soil, along with the time frame of meteorological factors during the development period in the EOR. As emphasized by Eitzinger et al. (2013), the yield of winter wheat is highly sensitive to differences in soil properties.

The variability of the model results in summer (sunflower) and winter (wheat) planted plants, in soils with different water retention capacities, in response to possible future scenarios of changes in two spatial areas was evaluated. The correlation results are shown between the defined single and combined scenarios of temperature, precipitation and global solar radiation and biomass and grain yield of two crops (winter wheat and sunflower) at spatial areas (KRK and EOR) in *Figure 5* and *Figure 6*.

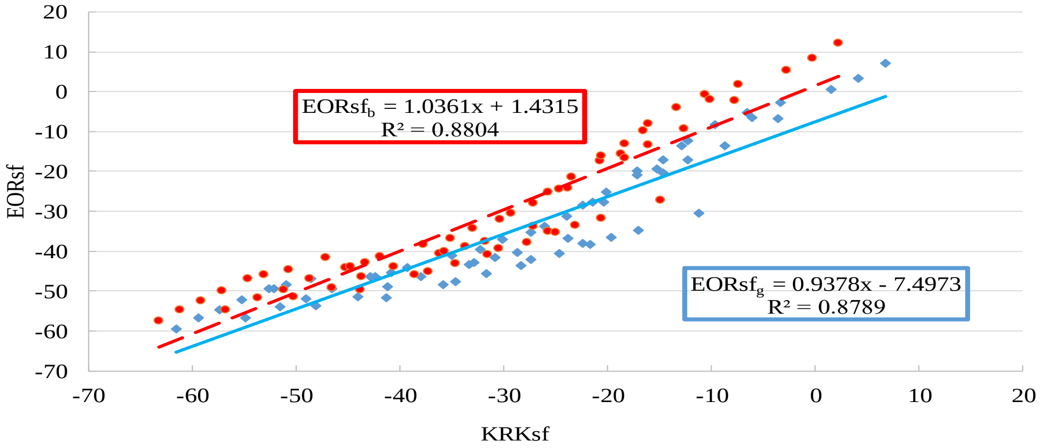

Figure 5. Correlation between biomass and grain yields of sunflower at the Kirklareli (KRK) and Edirne-Orhaniye (EOR) sites

Under the defined sixty-five (65) scenarios results, statistically significant relationships were found between sunflower biomass and grain yield for the KRK ($r^2 = 0.88$) and EOR ($r^2 = 0.87$) sites (*Figure 5*). However, weaker relationships were identified between the winter wheat biomass and grain yield at the KRK ($r^2 = 0.56$) and EOR ($r^2 = 0.79$) sites (*Figure 6*). According to the simulation results of the defined single and combined scenarios in both spatial areas, while the grain and biomass yields of the summer-sunflower plant were negative linear relations every scenario, non-linear relations were determined in the yields of the winter-wheat plant.

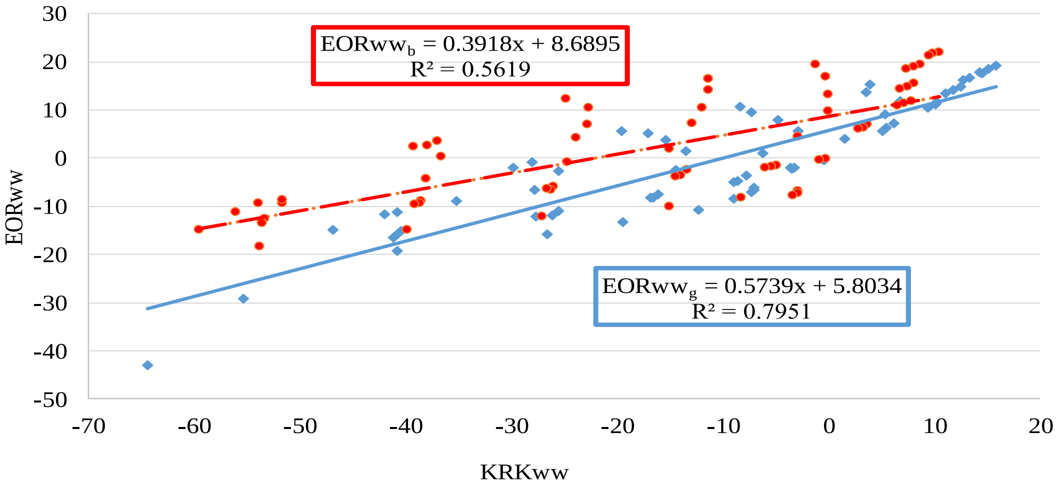

Figure 6. Correlation between biomass and grain yields of winter wheat at the Kirklareli (KRK) and Edirne-Orhaniye (EOR) sites.

4. Conclusion

This study has been analyzed the results of sensitivity analysis for the grain and biomass yields of the winter wheat and summer-sunflower in both locations using the AquaCrop model. With the highest yield loss and the highest yield gains for the sunflower grain and biomass yields were determined in the same scenarios (in the scenario S42 (T +5°C, P -50%) and S6 (T -1°C)) at both locations. The highest grain and biomass yield decreases were determined at -61.6, -63.2, -59.4, and -57.5% in the scenario S42 where precipitation decreased by 50% and temperature increased by 5°C in the KRK and the EOR sites, respectively. Loss of sunflower grain and biomass yields and increase in grain and biomass yields at the EOR site gave more positive results than the KRK site. The highest yield losses and the highest yield gains of winter wheat were determined in the same scenarios of S42 and S5 at both locations, with one exception that the biomass yield loss took place in the scenario S43 in EOR site. Although, the highest decreases in the grain and biomass yields were -64.4, -43.1, and -59.54%, for KRKwwg, KRKwwb and EORwwg in the scenario S42 where precipitation decreased by 50% and temperature increased by 5°C. The highest decrease in the biomass yield was -18.4% for EORwwb in the scenario S43 where there were decreases in both precipitation (P -50%) and temperature (T -1°C).

The winter wheat showed different rates of responds to climatic changes. Unlike the sunflower most of the scenarios had positive impacts on the grain and biomass yields of winter wheat in the two experimental sites.

According to climate scenarios analysis, increases in both temperature and global radiation along with decreases in precipitation had a negative impact on grain yield and biomass of sunflowers. This, however, was not the case for the winter wheat, suggesting that the grain yield and biomass of sunflowers could be more sensitive to heat and precipitation stress under defined climatic cases at the selected locations. Although an increase in average temperatures was associated with increases in wheat yield and biomass, the combined effects of increased global solar radiation and decreased temperatures had negative effects on wheat production at the EOR site. For both sunflower and wheat, the combined scenarios of temperature increase to varying extents and decreases in precipitation during each growing season at each location had the most detrimental effect on yield and biomass production. These results may provide important information to decision makers, especially in order to focus on winter-planted oil crops such as Canola oil plant instead of summer-grown oil crops in the region.

Instead of using global or regional climate scenarios, local agrometeorological measurement on the plant by considering the expected trend of climate change should have evaluated for the effects of single and combined variations of meteorological factors on plant grain and biomass yields. The results obtained from this study can offer valuable insights for adaptation to the risks of the effects of climatic fluctuations biomass and grain yield for two plant that can result precise indicators of the context of climate change. Moreover, the results of crop growth models couldn’t give same prediction in the same locations, so they should be supported by field studies to get better evaluations.

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Ethical Statement

There is no need to obtain permission from the ethics committee for this study.

Conflicts of Interest

The author declares that they have no conflict of interest.

Authorship Contribution Statement

Concept; Design; Data Collection or Processing; Statistical Analyses; Literature Search; Writing, Review and Editing: Bakanoğulları, F.

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