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# Assessment and modelling of crop yield and water footprint of winter wheat by aquacrop

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**Abstract**. Agriculture has a considerable impact on water resources and it is strongly affected by climate change. It is important to determine and forecast crop water use for controlling and planning water resources while ensuring agricultural sustainability. Crop Water Footprint (WF) is an indicator of water consumed for crop production. The aim of the study is to calculate WF of winter wheat using Water Footprint Assessment (WFA) and to simulate future WFs by means of AquaCrop model for the Thrace region in Turkey. Although winter wheat does not require irrigation, the estimation of the WF is of importance due to its extensive production throughout the country. The WFs is estimated using meteorological and CORDEX data. The emerging findings indicate an increase in average temperature between 0.9 and 4.0°C. Precipitation is expected to increase by 15% under the optimistic scenario (RCP 4.5) and decrease by 17% under the worst-case scenario (RCP 8.5) by 2099. Winter wheat yield will positively be affected by increasing temperatures by up to 17% under RCP 4.5 and 26% under RCP 8.5 scenarios.

**Keywords**. Climate Change, Green Water Consumption, Crop Productivity, Crop Growth Simulation Model, Cereal.

## INTRODUCTION

Climate projections emphasize that water scarcity will be one of the most important problem in the future. Therefore, determination of water consumption of crops has a crucial importance especially in arid and semi-arid countries in the world. To determine direct and indirect water use, the water footprint is widely used (Hoekstra, 2003). The WF represents the volume of freshwater used to production process and it is measured on all levels of the supply chain. Showing water consumption and polluted water volumes by source and type of pollution, WF comprises of components like blue, green and grey WFs. Blue WF is estimated in crop production with irrigated agriculture while green WF is determined in rainfed agriculture conditions. Grey WF involves the information about groundwater pollution because of fertilization.

Crop-climate models indicate that crop production may decrease because of high temperatures, while crop yield may increase as a consequence of rising CO2 concentrations in the atmosphere (Caldag and Saylan, 2005; Nakagawa et al., 2007; Özdoğan, 2011). Moreover, agricultural activities consume nearly 70% of global water resources (Huang et al., 2018; Taheri et al., 2019). In this study, WF of winter wheat is estimated and WF's future projections are realized by means of AquaCrop model developed by Food and Agriculture Organization (FAO). AquaCrop bases on soil-water balance method and it is one of the most common used models to determine crop yield and WF (Raes et al., 2009; Steduto et al., 2009). The input requirements of the model are soil, climate, crop and agricultural management data.

There are many applications of the AquaCrop model for estimating the WF and yield. For instance, Gobin et al. (2017) have analyzed variability of arable crop production in some parts of Europe. Results showed that WF of cereals was much bigger than WF of tuber and root crops and the biggest part of WF belongs to green WF. Variability of arable crops was mainly related to variability of crop yield and variability of crop water use. Others, Chouchane et al. (2018) assessed the WF of wheat, barley, potatoes, dates, olives and tomatoes for the period 1981-2010. The model is better in explaining net virtual water import (NVWI) of wheat, barley and potatoes than NVWI of dates, olives, and tomatoes. Alvarez et al. (2016) estimated the green and blue WF of maize in Argentina, observing a WF decrease with an increase in irrigation and fertilization. They have determined that green WF represented 92% of total WF. Zhuo and Hoekstra (2017) have analyzed the effect of different agricultural applications on green and blue WF, irrigation efficiency and of crop water usage efficiency. The results indicated that the deficit irrigation improved irrigation efficiency by 5% and decreased blue WF by 38%. Zhou et al. (2016) simulated WF of winter wheat production considering only water stress. According to their findings, the WF for irrigated winter wheat was 8-10% larger than rainfed winter wheat and the WF criteria for rainy years were 1-3% smaller than the dry years, 7-8% for the WF criteria for the hot years. Moreover, it was mentioned that WF criteria showed 10-12% differences in different soil types. Karandish and Hoekstra (2017) have predicted WF of 26 crops by means of AquaCrop in Iran. In the 1980-2010 period, it was determined that crop production, total crop production WF and blue WF have increased by 175%, 122%, 20%, respectively. During this period, the population has increased by 92%, while the crop consumption per person has grown by 20%, whereas the total crop consumption and total WF by 130 and 110%, respectively. Additionally, Lalic et al. (2018) have investigated monthly forecast of green water components and summer crops yield in Serbia and Austria using AquaCrop model and ensemble weather forecast. Tsakmakis et al. (2018) analyzed the effects of different irrigation schedules on WF of cotton with AquaCrop and CROPWAT for the north of Greece. The results showed that the effect of irrigation technology and strategy in green, blue and total WF were better predicted by the AquaCrop model, while the CROPWAT model can only evaluate changes in the irrigation strategy. Nouri et al. (2019) examined the reduction of WF with different soil mulching and drip irrigation methods. In the previous study, AquaCrop model and global Water Footprint Assessment (WFA) was used for estimating blue and green WF of ten major crops. The results showed that WF of crop production was more sensitive to climate and soil type. They have found that that the annual blue WF of the summer season was highest when water availability was lowest. Mulching has reduced the blue WF by 3.6% and mulching with drip irrigation have decreased the WF by 4.7%. Bakanogullari et al. (2017) used AquaCrop model and estimated that sunflower is more sensitive to soil water content than winter wheat.

For the estimation of winter wheat WF, different models such as linear and nonlinear regression model (Ye et al., 2019), Agro-Ecological Zones model (Wang et al., 2015), Soil and Water Assessment Tool (Luan et al., 2018), AquaCrop (Gobin et al., 2017; Zhuo and Hoekstra, 2017; Chouchane et al., 2018), Markov chain (Feng et al., 2017), CWUModel (De Miguel et al., 2015), global gridded crop model (Deryng et al., 2016), CROPWAT (Muratoglu, 2019), DSSAT (Ventrella et al., 2018), crop models within ensemble approach (Palosuo et al., 2011; Garofalo et al., 2019) and WFA methodology have been used (Ababaei and Etedali, 2017; Santos et al., 2017; Huang et al., 2019; Zhai et al., 2019).

The aim of this study was to investigate WF and yield of winter wheat for northwestern part of Turkey (for Edirne, Kırklareli and Tekirdağ cities) using WFA and AquaCrop model. Firstly, WF of winter wheat was calculated by means of WFA with meteorological variables. Secondly, AquaCrop model was performed under RCP (Representative Concentration Pathway) 4.5 and 8.5 scenarios to forecast potential WFs and yields in the future. As input EURO-CORDEX (Coordinated Regional Climate Downscaling Experiment) data, HadGEM2-ES global climate model data and HIRHAM5 regional climate model data were used. Finally, WF and yield from calculations and simulations were compared and evaluated.

## MATERIALS AND METHODS

### *Study Area*

This study covers the agricultural areas of the Edirne, Kırklareli and Tekirdağ provinces of Thrace region, in the northwestern part of Turkey. As shown by elevation data reported in figure 1, Istranca mountains are the highest ones of the region with 1032 m and locate in the north of the Kırklareli city. The blue dots and red triangles on the map represent the locations of the meteorological stations used to correct CORDEX data. AquaCrop was performed according to RCP 4.5 and 8.5 scenarios in grids (0.11° horizontal resolution) with the red triangles. AquaCrop was not performed in grids with blue dots because necessary input data such as meteorological, soil and crop phenological data for the model were insufficient. For this

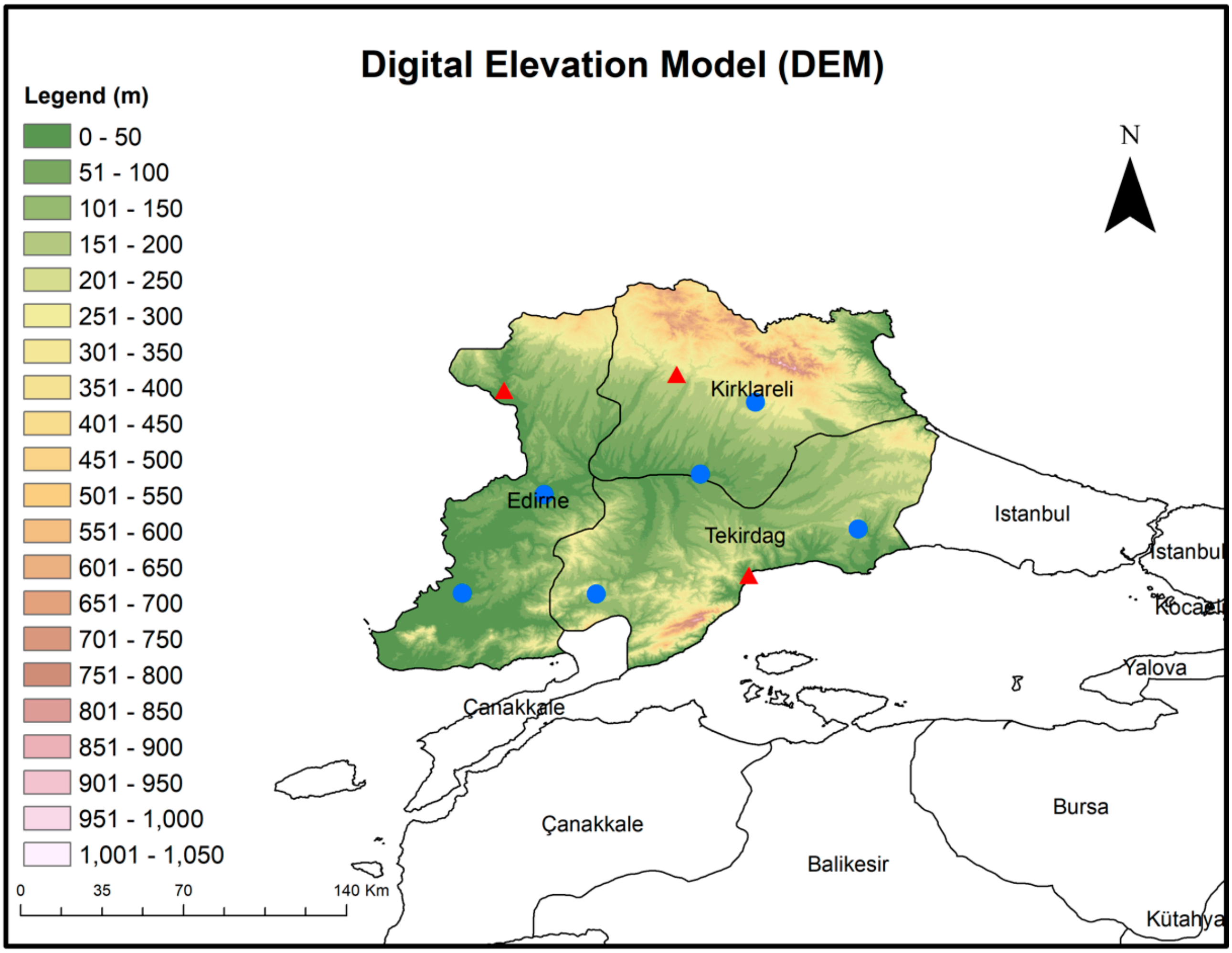



**Fig. 1.** Study area.

reason, AquaCrop model results were examined for each grid in 3 locations.

### *Data*

#### Meteorological Data

Daily temperature (mean, maximum, and minimum), precipitation, global solar radiation, relative humidity and wind speed measurements were obtained from meteorological stations located in Edirne, Kırklareli (connected to Atatürk Soil Water and Agricultural Meteorology Research Institute, AMRI) and Tekirdağ (connected to Turkish State Meteorological Service, TSMS). Besides, meteorological data in between the reference years (1971-2000) were used for correction of CORDEX data. Table 1 contains the longitude, latitude, and mean sea level (msl) information of meteorological stations.

In Fig. 2, annual mean air temperature and total precipitation maps are illustrated for reference years (1971-2000).

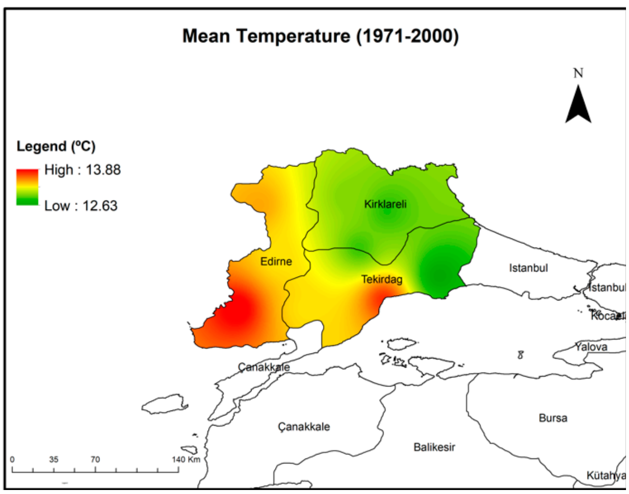
The annual mean air temperature was 13.2°C and the annual total precipitation was 588 mm. Mean temperature and precipitation values of southwestern part of Thrace were about 0.5°C and 100 mm higher than the region average, respectively. In the reference years, Kırklareli had about 60 mm lower precipitation and about 0.5°C lower than the region's mean precipitation and temperature, respectively. Similarly, Fig. 3 shows the mean air temperature, precipitation and effective precipitation in the growing season of winter wheat.

**Tab. 1.** Locations of Selected Meteorological Stations.

| Stations | Longitude (°) | Latitude (°) | Msl (m) |
|---|---|---|---|
| Pınarhisar (TSMS) | 27.52 | 41.63 | 225 |
| Edirne (TSMS) | 26.55 | 41.68 | 48 |
| Kırklareli (TSMS) | 27.22 | 41.74 | 232 |
| Çorlu (TSMS) | 27.92 | 41.14 | 153 |
| Tekirdağ (TSMS) | 27.50 | 40.96 | 14 |
| Lüleburgaz (TSMS) | 27.31 | 41.35 | 45 |
| İpsala (TSMS) | 26.39 | 40.89 | 73 |
| Uzunköprü (TSMS) | 26.71 | 41.27 | 22 |
| Malkara (TSMS) | 26.91 | 40.89 | 202 |
| Kırklareli (AMRI) | 27.21 | 41.70 | 170 |
| Edirne (AMRI) | 26.64 | 40.73 | 30 |

During the winter wheat growing season, the Thrace region recorded an annual temperature of and precipitation of were 9.9°C and 463 mm, respectively. Moreover, effective precipitation was calculated as 217 mm. The mean temperature and the precipitation during the growing period in the southwestern part of the region were higher than the region average.

According to TSMS measurements, Average temperatures of wheat during growing season between 1971-2000 were measured in Edirne, Kırklareli and Tekirdağ as 10.4, 10.0 and 10.9°C, respectively. However, after 2000s, the average temperature in wheat growing season increased by 1°C in the region (Fig. 4).



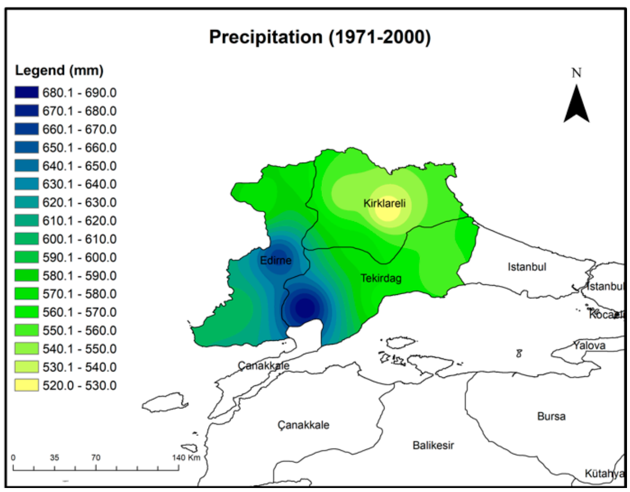




**Fig. 2.** Annual Mean Temperature and Total Precipitation Maps.

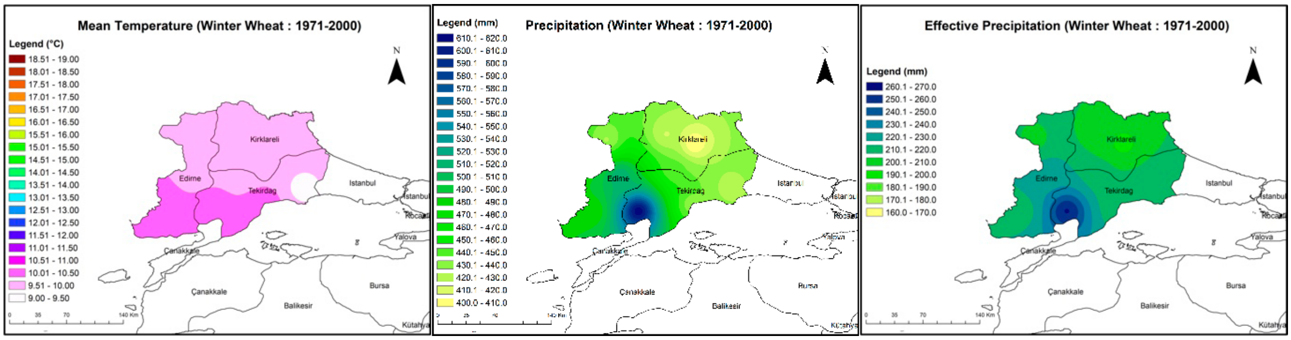



**Fig. 3.** Mean Temperature, Precipitation and Effective Precipitation in Winter Wheat Growing Season (Reference Years).

## Soil and Crop Data

Physical properties of locations' dominant soils are given in table 2 (Gobin et al., 2017; Gürbüz et al., 2019). Table 3 shows the reference sowing and harvest data for winter wheat (Gelibolu cultivar) cultivated in the region in 2015-2016 and 2017-2018 agricultural years.

## CORDEX Data

In the study, projection data of RCP 4.5 (optimistic) and RCP 8.5 (worst-case) scenarios were provided between the years of 1971 and 2099. Developed with the Hadley Meteorology Office and designed for the scenarios in the IPCC's 5$^{th}$ Assessment Report (AR5), the HadGEM2-ES global climate model, whose outputs are downscaled with HIRHAM5 (Christensen et al., 2007) regional climate model with a horizontal resolution of 0.11° (~12.5 km) and EURO-CORDEX temperature, precipitation, relative humidity, global radiation, and wind speed data were provided in the daily time interval.

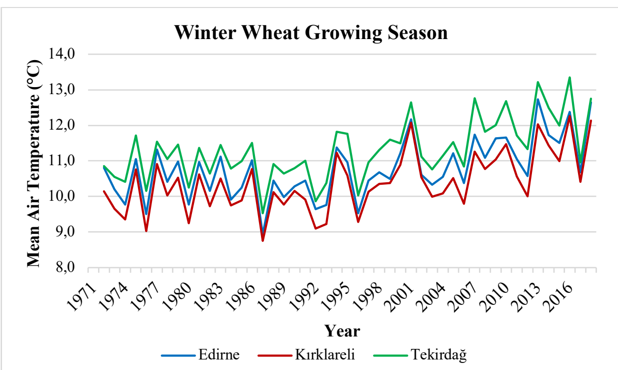



**Fig. 4.** Time Series of Mean Temperature of Winter Wheat Growing Seasons from 1971 to 2018.

### *Bias Correction*

The data produced by climate models generally do not match the measurement data in the reference period. These errors affect the simulations for the future. Future reliability of climate models is increased with bias correction. Due to the nature of meteorological variables, their distributions are different and different bias correction methods are used (Feigenwinter et al., 2018; Soriano et al., 2019; Zapata et al., 2020).

### *Simple Mean Seasonal Bias Correction*

Climate projection data require bias correction (Teng et al., 2015; Qian et al., 2015; Macadam et al., 2016; Mostafa et al., 2019). In the study, simple mean seasonal bias correction was used for daily mean, maximum, and minimum temperature data. Differences between measured and modelled data for both RCP 4.5 and 8.5 were corrected as computed as follows:

**Tab. 2.** Texture and hydrological parameters of dominant soils in the Thrace region.

| Location | Soil Type | Field Capacity (%) | Wilting Point (%) |
|---|---|---|---|
| Edirne | Clay | 37 | 23 |
| Kırklareli | Sandy Loam | 35 | 17 |
| Tekirdağ | Loamy | 39 | 28 |

**Tab. 3.** Sowing and harvest date for winter wheat cultivation.

| Practice | Edirne | Kırklareli | Tekirdağ |
|---|---|---|---|
| Planting | 20-October | 20-October | 20-October |
| Harvest | 20-June | 25-June | 20-June |

$$T_{i,cor} = T_i + \Delta T_i, \quad (1)$$

where $T_i$ is the temperature (mean, max, min) in a given month i, $\Delta T$ is the difference between the mean temperature of the climate model and the observations in a given month i, and $T_{i,cor}$ is the corrected temperature in month i.

*Quantile Mapping Bias Correction*

Quantile Mapping (QM) method is a widely used method for correcting projection data not only precipitation but also global solar radiation, relative humidity, wind speed correction (Themeßl et al., 2011; Teutschbein and Siebert, 2012; Gudmundsson et al., 2012; Chen et al., 2013; Feigenwinter et al., 2018). This method is based on the application of the measurement values of the cumulative distribution function (CDF) of the reference years from the models to the projection distribution functions by mapping them over the cumulative distribution functions (Heo et al., 2019; Soriano et al., 2019). Bias corrected data was calculated by using the following Eq. 2.

$$Q_m(t) = F_0^{-1}[F_s[Q_s(t)]] \quad (2)$$

where $Q_m(t)$ and $Q_s(t)$ are the bias corrected and simulated data from the regional climate model (RCM) during the reference period, $F_s$ and $F_0^{-1}$ are the CDF of the raw data from the RCM and the inverse CDF of the observed data, respectively.

*AquaCrop Model*

The AquaCrop model has been developed by the FAO, based on the principles of soil-water balance method and widely used by researchers, and was preferred in determining the WF and crop parameters (Alvarez et al., 2016; Zhuo et al., 2016; Gobin et al., 2017; Karandish and Hoekstra, 2017; Zhuo and Hoekstra, 2017; Chouchane et al., 2018; Lalic et al., 2018; Tsakmakis et al., 2018; Nouri et al., 2019). Input data required in this model are soil (soil type, field capacity, wilting point, initial soil water content etc.)-crop (phenological date, seed number etc.)-climate parameters (max and min temperature, global solar radiation, precipitation, relative humidity, $ET_0$) information on agricultural practices (fertilizer, cultivation etc.) with particular reference to irrigation (Raes et al., 2009; Steduto et al., 2009). In this study, AquaCrop model v6.1 was used in order to model of yield and WF of winter wheat.

*Water Footprint Calculations*

The WF [$m^3$ $ha^{-1}$] has 3 different components: blue, green and gray WF. The blue WF shows irrigated agriculture, while the green rainfed conditions (Mekonnen and Hoekstra, 2011), and the grey the amount of groundwater contaminated by fertilization. The WF of crops is the sum of blue and green WFs (Eq. 3). In this study, the amount of green WF was calculated since the winter wheat is grown in rainfed conditions in Thrace Region.

$$WF = WF_{Blue} + WF_{Green} \quad (3)$$

Blue and green WFs are calculated with Equations 4 and 5 (Hoekstra et al., 2011; Bocchiola et al. 2013).

$$WF_{Blue} = 10 \, x \, \frac{ET_{Blue}}{Yield} \quad (4)$$

$$WF_{Green} = 10 \, x \, \frac{ET_{Green}}{Yield} \quad (5)$$

The coefficient 10 is used to convert the specified ET quantity unit from mm to $m^3$ $ha^{-1}$, yield (t $ha^{-1}$) and WF is used in $m^3$ $t^{-1}$. Blue and green ET calculations from WF components are calculated with Equations 6 and 7, respectively.

$$ET_{Blue} = \max(0, ET_c - P_{eff}) \quad (6)$$

$$ET_{Green} = \min(ET_c, P_{eff}) \quad (7)$$

where $ET_c$, crop evapotranspiration (mm); $P_{eff}$, efficient precipitation (mm). In order to determine $P_{eff}$, USDA SCS method (Nearing et al., 1989) is used in daily time step (Eq. 8 and 9).

$$P_{total} < 8.3\,mm, \; P_{eff} = \frac{P_{total}(4.17 - 0.2P_{total})}{4.17} \quad (8)$$

$$P_{total} \geq 8.3\,mm, \; P_{eff} = 4.17 + 0.1P_{total} \quad (9)$$

$ET_c$ is calculated from modified Penman&Monteith (P&M) ET0 approach (Allen et al., 1998), detailed information can be found in Raes et al. (2009) and Steduto et al. (2009). Using soil water content measurements, the actual ET values of winter wheat are determined by the Soil Water Balance (SWB) method (Allen et al., 1998).

## RESULTS

### *Yield and Water Footprint*

The calibration of AquaCrop for winter wheat was performed on the basis of grain yield of 2015-2016 and 2017-2018 growing seasons. Measured mean temperature, total precipitation and effective precipitation during the growing seasons are also shown in Tab. 4.

According to Table 4, the daily mean temperature in the wheat development period in the reference years (1971-2000) was 9.9°C, while the mean temperature in the periods of model calibration was calculated as 12.9°C. The total precipitation in the years when the model was calibrated and in the reference years were 481.8 and 462.9 mm (approximately 19 mm lower in reference years), respectively. Although the amount of precipitation in the years when model calibration was performed is higher than the reference years, the effective rainfall amount is approximately 5 mm lower. When the actual and predicted yields were compared, the average relative errors (REs) in the cities of Edirne, Kırklareli and Tekirdağ were -2.4%, -1.6% and 5.6%, respectively.

Figure 5 shows the green WFs calculated from the measurements and estimated by the AquaCrop model. According to Figure 5, the REs between the WF calculated with SWB and the modelled green WF were 17.1%, -28.7% and -52.4% in Edirne, Kırklareli and Tekirdağ, respectively. The average green WF of the region was calculated as 452.7 m3 $t^{-1}$ with SWB method and it was 359.0 m3 t-1 for modelled green WF. The reason of this difference is that the ET values were calculated using the P&M method through meteorological variables while the SWB method uses the changes of soil water content values. Besides, infiltration and runoff were not taken into account in the calculation of SWB. WF differences between the provinces may be resulted from these assumptions and differences of the soil structure.

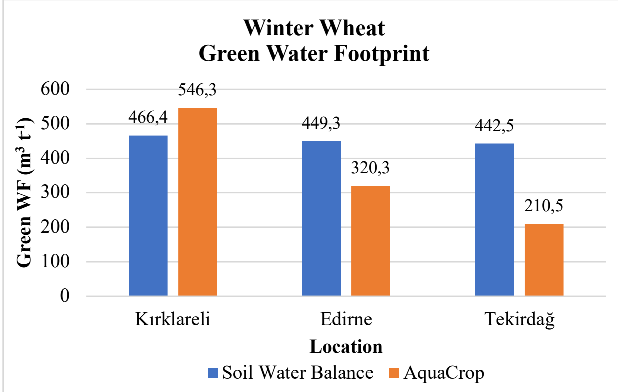



**Fig. 5.** Comparison of Winter Wheat Water Footprints.

### *Future Scenarios*

While making simulations for the future with the AquaCrop model, the concentration amount of RCP 4.5 and 8.5 scenarios was used as atmospheric CO2 concentration. It is projected that the increase in temperatures in recent years will continue in the RCP 4.5 and 8.5 scenarios. The mean temperature in the region is expected to increase by 0.9-1.6°C and 2.0-4.0°C under the RCP 4.5 and 8.5, respectively, by 2099. Variation of mean temperature for different scenarios in three periods (P1: 2020-2040, P2: 2041-2070, P3: 2071-2099) during the winter wheat growing seasons are shown in Figures 6 and 7, respectively.

The analysis of future precipitation (RCP 4.5) trends show that precipitation during the winter wheat season will increase 15% compared to baseline scenario, while a decrease of 17% is expected in the worst-case scenario (RCP 8.5). Effective precipitation changes in winter wheat growing season is expected to increase by 12% in the RCP 4.5 and 21% decrease in the RCP 8.5. In Figure 8, there are projected effective precipitation maps according to the RCP 4.5 scenario.

According to the RCP 4.5, effective precipitation is increased between 3% and 22% in P1. The lowest

**Tab. 4.** Statistics of 2015-2016 and 2017-2018 Winter Wheat Growing Seasons.

| | Actual Yield (t $ha^{-1}$) | AquaCrop Yield (t $ha^{-1}$) | Mean Temperature (°C) | Precipitation (mm) | Peff (mm) |
|---|---|---|---|---|---|
| Edirne | 4.86 | 4.74 | 12.5 (10.8*) | 518.8 (499.2*) | 225.4 (234.9*) |
| Kırklareli | 4.67 | 4.59 | 12.2 (10.4*) | 503.0 (492.1*) | 218.9 (231.7*) |
| Tekirdağ | 3.85 | 4.06 | 13.1 (11.3*) | 423.7 (495.7*) | 191.7 (232.1*) |
| Region Average (1971-2000) | - | - | 9.9 | 462.9 | 216.9 |

*Average of 1971-2019 in winter wheat growing seasons.

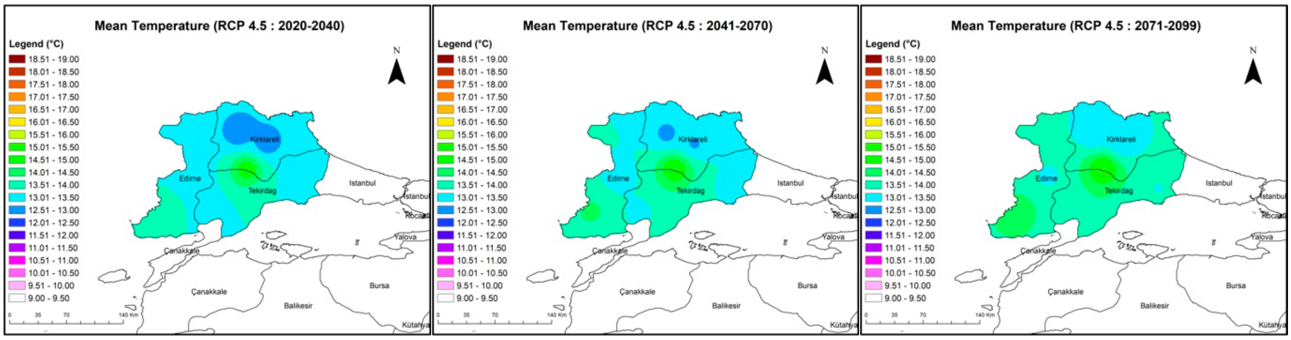



**Fig. 6.** Mean Air Temperatures in Winter Wheat Growing Season (RCP 4.5 Scenario).

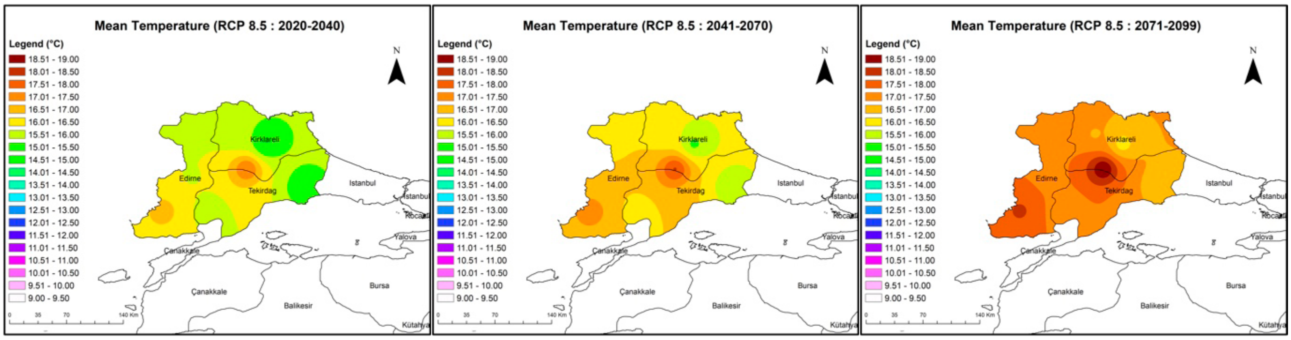



**Fig. 7.** Mean Air Temperatures in Winter Wheat Growing Season (RCP 8.5 Scenario).

increase is expected to be in the northeast and southwest of the region whereas the highest increase is expected to occur in Tekirdağ city center and some parts of Edirne. The changes in the effective precipitation that occurred in the P2 and P3 periods have similar increase patterns. In P2, the increases in effective precipitation are between 0.3% and 20%. Moreover, the increases in the period of P3 are between 5% and 26%. In Fig. 9, it can be seen maps of the effective precipitation according to the RCP 8.5, with the effective precipitation decreasing in contrast to the RCP 4.5. The percentage of such changes were estimated in a range of -14% and -26% in P1, -18% and -28% in P2, and 20% and -30% in P3.

### *Potential Yield and Water Footprint Estimations*

Potential yields and WF calculations of winter wheat in Edirne, Kırklareli and Tekirdağ are reported in Tab. 5.

According to Tab. 5, winter wheat yields show an upward trend in all scenarios except in P1 period in

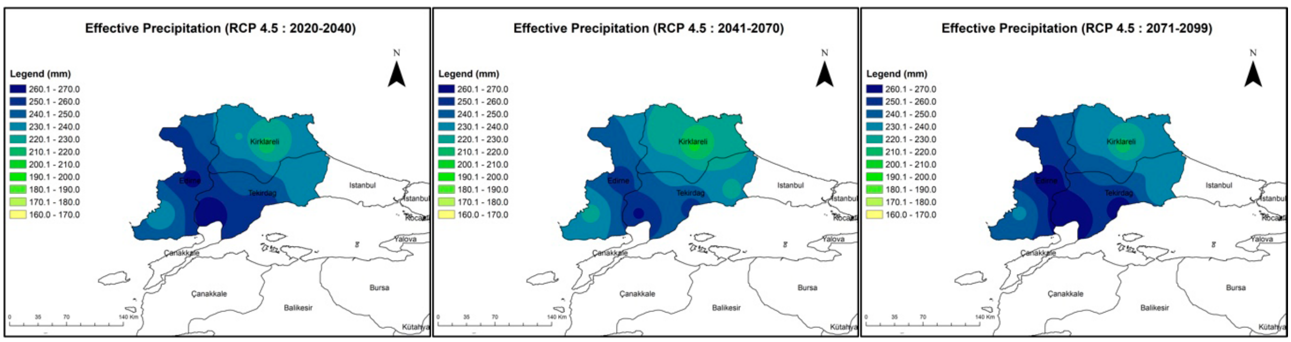



**Fig. 8.** Effective Precipitation Amount in Winter Wheat Growing Season (RCP 4.5 Scenario).

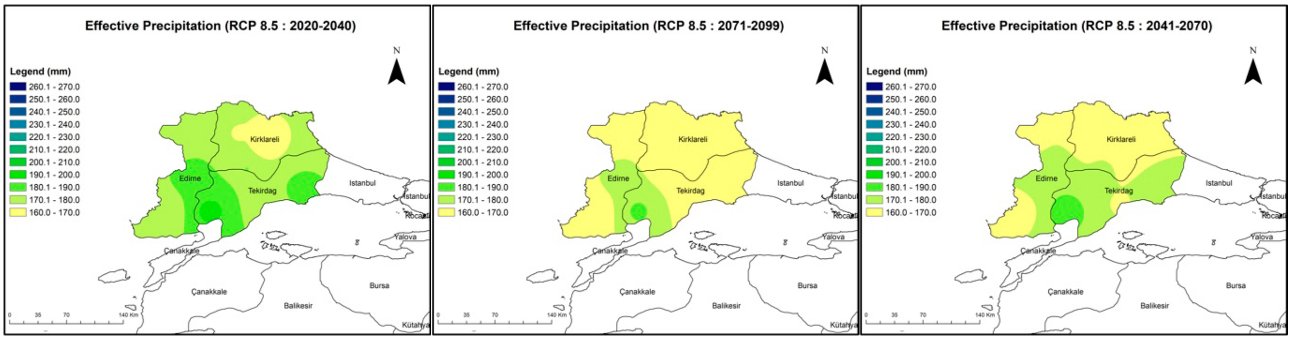



**Fig. 9.** Effective Precipitation Amounts in Winter Wheat Growing Season (RCP 8.5 Scenario).

**Tab. 5.** Potential Crop Yield of Winter Wheat by AquaCrop.

| Years | Winter Wheat Yield for RCP 4.5 (t ha$^{-1}$) | | | Winter Wheat Yield for RCP 8.5 (t ha$^{-1}$) | | |
|---|---|---|---|---|---|---|
| | Edirne | Kırklareli | Tekirdağ | Edirne | Kırklareli | Tekirdağ |
| Actual Yield | 4.86 | 4.67 | 3.85 | 4.86 | 4.67 | 3.85 |
| 2020-2040 | 5.46 ± 0.72 | 4.61 ± 0.24 | 4.52 ± 0.45 | 5.23 ± 0.77 | 4.72 ± 0.27 | 4.48 ± 0.44 |
| 2041-2070 | 5.94 ± 0.80 | 4.96 ± 0.26 | 4.88 ± 0.45 | 6.13 ± 0.82 | 5.29 ± 0.35 | 5.11 ± 0.41 |
| 2071-2099 | 6.28 ± 0.86 | 5.11 ± 0.30 | 5.05 ± 0.39 | 7.53 ± 0.84 | 6.19 ± 0.34 | 5.89 ± 0.44 |

Kırklareli. In this period, the decrease in the yield is estimated as 1.3%. Winter wheat yield was positively affected by the increase of temperatures and atmospheric CO2 concentrations. The decrease in precipitation did not have a considerable effect on yield. The largest increase in wheat yield was reported under RCP 4.5 in Tekirdağ. Average yield increases in Edirne, Kırklareli and Tekirdağ were calculated as 21%, 5% and 25%, respectively. When yields were analyzed by periods, it was predicted that the winter wheat yields in the region will increase by 9% in P1 (4.86±0.79 t ha-1), 18% in P2 (5.26±0.26 t ha-1) and 23% in P3 (5.48±0.42 t ha-1).

Additionally, winter wheat yield may increase more in RCP 8.5 than in RCP 4.5. The reason of this situation can be explained by the fact that the atmospheric $CO_2$ concentration and the temperatures will be about 1-2.5°C higher for RCP 8.5 than the RCP 4.5. Average yield increment in Edirne, Kırklareli and Tekirdağ were calculated as 29.6%, 15.6% and 34.0%, respectively. When the yields were analyzed by periods, it is predicted that the winter wheat yields in the region will increase by 8.3% in P1 (4.81±0.81 t ha$^{-1}$), 24.0% in P2 (5.51±0.32 t ha$^{-1}$) and 46.8% in P3 (6.54±0.42 t ha$^{-1}$). In addition to the yield of winter wheat, WF were also calculated with the AquaCrop model and shown in Tab. 6.

According to Tab. 6, the potential WFs of winter wheat decreases in all scenarios and for different time horizons. This is explained by an increase in win-

**Tab. 6.** Forecasted WF of Winter Wheat by AquaCrop.

| Years | Winter Wheat WF for RCP 4.5 (m$^3$ t$^{-1}$) | | | Winter Wheat WF for RCP 8.5 (m$^3$ t$^{-1}$) | | |
|---|---|---|---|---|---|---|
| | Edirne | Kırklareli | Tekirdağ | Edirne | Kırklareli | Tekirdağ |
| SWB Method | 449 | 466 | 442 | 449 | 466 | 442 |
| 2020-2040 | 169.7 ± 28.4 | 177.6 ± 32.8 | 212.9 ± 37.1 | 140.5 ± 29.7 | 143.6 ± 31.2 | 143.1 ± 26.7 |
| 2041-2070 | 147.0 ± 28.4 | 153.7 ± 27.7 | 179.4 ± 41.9 | 105.5 ± 31.1 | 109.6 ± 29.5 | 109.0 ± 28.0 |
| 2071-2099 | 137.6 ± 24.2 | 145.5 ± 29.6 | 166.4 ± 32.9 | 73.1 ± 18.1 | 77.9 ± 18.4 | 86.8 ± 22.0 |

ter wheat yield. The winter wheat WF decrease throughout the region in the periods of P1, P2 and P3 by 58.7% (186.7±0.27 $m^3$ $t^{-1}$), 64.6% (160.1±0.30 $m^3$ $t^{-1}$) and 66.9% (149.9±0.37 $m^3$ $t^{-1}$) in RCP 4.5, respectively. When compared the result of increases in yields between RCP 4.5 and 8.5, it can be said that the WFs in RCP 8.5 is lower than WFs in RCP 4.5. WFs of winter wheat decrease as 68.5% in P1 (142.4±0.29 $m^3$ $t^{-1}$), 76.1% in P2 (108.0±0.26 $m^3$ $t^{-1}$) and 82.5% in P3 (79.3±0.25 $m^3$ $t^{-1}$). The reason for this situation in WF can be explained not only by the increase in yield and atmospheric $CO_2$ concentration in RCP 8.5, but also with the decrease in the effective precipitation.

## CONCLUSION

In this study, actual crop yield and WF of winter wheat grown under rainfed conditions were compared 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 by AquaCrop. According to the AquaCrop simulation results, it is predicted that winter wheat yield would increase for the future in the Thrace part of Turkey. Although the precipitation decreased and temperature increased in the RCP 8.5 scenario, crop yield would be affected positively. On the other hand, increases in the crop yield would cause decreasing WF of winter wheat.

The results of our study were compared with other related studies. In the Kersebaum et al. (2016) study, the total WF of wheat (556 $m^3$ $t^{-1}$) is 23% more than our WF (452 $m^3$ $t^{-1}$) and their wheat yield was 28% higher (5.78 t $ha^{-1}$) than our research area (4.46 t $ha^{-1}$). Similarly, estimated WF by Zhuo et al. (2016) for winter wheat (1074±133 $m^3$ $t^{-1}$) in China is higher than our WF. Additionally, green WF of wheat determined by Zhuo and Hoekstra (2017) is also higher than our WF. As can be seen from these studies, dissimilarity of yield and WF of winter wheat can be attributed to the climatic characteristics, soil hydrological parameters, cultural genotype and management practices.

In future studies, current and potential crop yield and WF of winter wheat can be evaluated comparatively using different regional climate model results and crop growth simulation models in this study area. Performing the same processes in different regions and crop types are also important in terms of effective use of water in agricultural ecosystems. In order to enhance such studies, the input and output data required for the models must be continuously monitored and recorded in the countries. Data infrastructure should be created for better results.

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