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Possible Impacts of Climate Change on Sunflower Yield in Turkey

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Abstract

Sunflower (*Helianthus annuus* L.) is the main raw material used to produce oil for consumption and oilseed in Turkey; however, its production is not sufficient, even for only domestic consumption. Therefore, studies were needed to determine how to increase both the production area and yield in Turkey. The aim of the study was to evaluate the possible effects of climate changes on future sunflower yield. A total of 29 provinces with intense sunflower cultivation during years of 1985–2014 were evaluated. Sunflower production values and meteorological data, which belong to years of 1985–2014, on climate projections, based on HadGEM2-ES Global Climate Model and RCP8.5 scenario that cover period of 2016–2099, were used as material. In the first part of the study, linear regression analyses were conducted between the observation and production data using the least squares method. In the second part, the possible effects of climate changes on sunflower yield for 2016–2040, 2041–2070, and 2071–2099 were determined using regression equations and climate projection data. Projections indicate that decreases in yield are expected, especially in the second half of this century. In Tekirdag and Konya provinces, where there is intensive sunflower cultivation, severe decreases in yield are expected for all studied periods.

Keywords: climate change, sunflower yield, regression analysis, HadGEM2-ES, RCP8.5

1. Introduction

Sunflower (*Helianthus annuus* L.) cultivation began after World War II after immigrants brought the plant to the Thrace region in Turkey. Thanks to the plant is drought resistant, sunflowers have a wide adaptability to climate changes and have become the main raw material used as a source of vegetable oil in Turkey.

According to TURKSTAT data, from 2004 to 2018, both cultivation area and yield in sunflower production have increased. During this period, the cultivated areas increased approximately by 32.4%, while the yield increased by 56.5%. The production volume also increased by 108.1% [1]. According to 2018 production data, sunflower (oil type) cultivation has produced 1.8 MT on 649 kha. The mean

yield was 277 kg/Da; however, because of the increase in the population of Turkey and changes in dietary habits, sunflower production cannot meet domestic consumption. According to the product balance reports published by TURKSTAT, as of 2018, the domestic sufficiency ratio of sunflowers was 64.3% [2], which suggests that the oilseed production and vegetable oil sectors rely heavily on foreign sources.

Because of its ability to adapt to drought conditions, most of the sunflowers are cultivated under rainfed conditions. According to 2018 data, 64% of sunflower (oil type) is produced under rainfed agricultural conditions, whereas 36% are produced under irrigated agricultural conditions. Given that most production is based on rainfed farming conditions, the crop tends to be sensitive to changes in climate; therefore, serious differences have been observed in production volume and yield over several years. The 2007–2008 drought in Turkey caused significant losses in sunflower yield in addition to that in many other crops. Sunflower (oil type) production in 2007 decreased by 23.8% compared to that in the previous year.

It is inevitable that sunflower production, which is directly affected by climate change factors, will also be affected by the predicted climate changes. According to the climate change reports published by Turkish State Meteorological Service (TSMS), expected changes in rainfall and precipitation regime are predicted with increases in temperatures. For 2016–2099 and based on climate projections, the average temperature is expected to increase by 1.5–3.7°C. The total annual precipitation is expected to regionally decrease; however, in general, changes in precipitation balance during the year have been projected [3, 4].

Turkey is located within an area sensitive to climate change. Climate change in Turkey would inevitably affect the country's agriculture, and numerous studies have been conducted to determine these impacts [5–10].

The aim of this study was to determine the possible effects of climate change on sunflower (*Helianthus annuus* L.) yield, which would continue to have increasing importance in terms of Turkey's agriculture and economics.

2. Materials and methods

2.1 Material

2.1.1 Sunflower production

In the current study, TURKSTAT yield data on 29 provinces (Adana, Afyon, Aksaray, Amasya, Ankara, Aydın, Balıkesir, Bilecik, Bursa, Çanakkale, Çorum, Diyarbakır, Edirne, Eskişehir, İstanbul, İzmir, Karaman, Kayseri, Kırklareli, Kırşehir, Kocaeli, Konya, Kütahya, Osmaniye, Sakarya, Samsun, Tekirdağ, Tokat, and Uşak) in which there is intensive sunflower production were discussed (**Figure 1**).

To best determine the relationship between climate factors and yield, 1985–2014 (30 years) were considered and analyzed.

2.1.2 Meteorological parameters

The World Meteorological Organization (WMO) acknowledges that to evaluate the climate characteristics of a region, it is necessary to consider those characteristics for 30 years; therefore, 30-year meteorological parameters were preferred in determining their effects on plant yield.

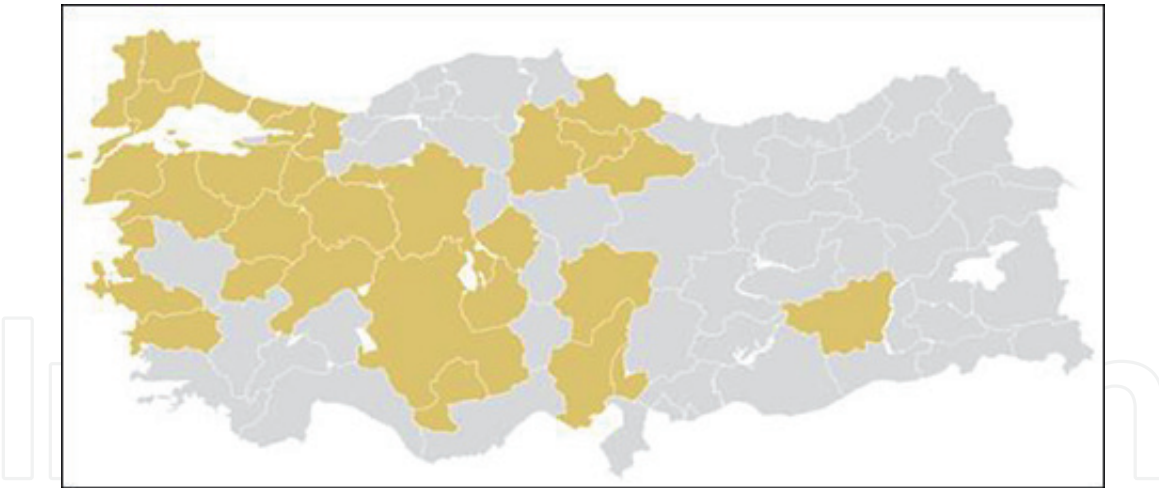


Figure 1.
Studied sunflower production areas.

In this study, the parameters that are supposed to affect yield were selected by considering the climate demands of the crop. The selected meteorological parameters that cover province-based sunflower vegetation period data were obtained from TSMS (2015). To determine the relationship between yield and climate factors, the following parameters were used:

- Number of days with daily minimum temperature $\leq -5^{\circ}\text{C}$
- Monthly average temperature ($^{\circ}\text{C}$)
- Number of days with daily maximum temperature $> 35^{\circ}\text{C}$
- Monthly average relative humidity (%)
- Number of days with daily average relative humidity $> 70\%$
- Monthly total sunshine duration (h)
- Monthly total precipitation (mm)

2.1.3 HadGEM2-ES global climate model

The most important tool in predicting the future climate is the modeling of climate [11]. Climate modeling studies have been conducted to determine the effects of climate changes that may occur in future periods. In Turkey, climate modeling studies were conducted within TSMS, and the final results were shared in 2015. In this study, the data on the selected meteorological parameters related to the 20-km-resolution climate projections were used on the basis of the report from HadGEM2-ES global model data and the RCP8.5 scenario used in “Turkey Climate Projections with New Scenario’s and Climate Change (TR2015-CC)” by TSMS [3] for Turkey and the neighboring region. The RCP8.5 scenario is the scenario with the highest predictive radiation forcing and greenhouse gas concentration. In other words, RCP8.5 expresses the most pessimistic condition for the future periods. In this scenario, the radiative forcing reaches 8.5 w/m^2 in 2100 and continues to increase after 2100. HadGEM2-ES is a second-generation

Z matrix								W matrix	X matrix
$\sum s_i^2$	$\sum p_i s_i$	$\sum h_i s_i$	$\sum k_i s_i$	$\sum t_i s_i$	$\sum m_i s_i$	$\sum v_i s_i$	$\sum s_i$	$\sum s_{iy}$	A
$\sum s_i p_i$	$\sum p_i^2$	$\sum h_i p_i$	$\sum k_i p_i$	$\sum t_i p_i$	$\sum m_i p_i$	$\sum v_i p_i$	$\sum p_i$	$\sum p_i$	B
$\sum s_i h_i$	$\sum p_i h_i$	$\sum h_i^2$	$\sum k_i h_i$	$\sum p_i h_i$	$\sum m_i h_i$	$\sum v_i h_i$	$\sum h_i$	$\sum h_i$	C
$\sum s_i k_i$	$\sum p_i k_i$	$\sum h_i k_i$	$\sum k_i^2$	$\sum t_i k_i$	$\sum m_i k_i$	$\sum v_i k_i$	$\sum k_i$	$\sum k_i$	D
$\sum s_i t_i$	$\sum p_i t_i$	$\sum h_i t_i$	$\sum k_i t_i$	$\sum t_i^2$	$\sum m_i t_i$	$\sum v_i t_i$	$\sum t_i$	$\sum t_i$	M
$\sum s_i m_i$	$\sum p_i m_i$	$\sum h_i m_i$	$\sum k_i m_i$	$\sum t_i m_i$	$\sum m_i^2$	$\sum v_i m_i$	$\sum m_i$	$\sum m_i$	F
$\sum s_i v_i$	$\sum p_i v_i$	$\sum h_i v_i$	$\sum k_i v_i$	$\sum t_i v_i$	$\sum m_i v_i$	$\sum v_i^2$	$\sum v_i$	$\sum v_i$	G
$\sum s_i$	$\sum p_i$	$\sum h_i$	$\sum k_i$	$\sum t_i$	$\sum m_i$	$\sum v_i$	n^*	$\sum v_i$	N

Table 1.
Parameter matrices used in the least squares method.

global model developed by the Hadley Center, a research organization affiliated with the UK Met Office [12].

2.2 Method

2.2.1 Regression analysis

In this study, province-based regression equations were established using the least squares method (LSM) with sunflower yield values from the 29 provinces from 1985 through 2014 and the 7 selected climate parameters. After that, the potential impact of climate changes that are projected for the future periods (2016–2040, 2041–2070, and 2071–2099) on yield of sunflower has been put forward with using the generated high-rate regression equations and climate projection data (**Table 1**).

In the study, the regression analysis equation created by LSM was as follows:

$$y = As + Bp + Ch + Dk + Et + Fm + Gv + H \quad (1)$$

where the dependent variable $y = \text{yield}$. $A, B, C, D, E, F, G,$ and H are coefficients, and the independent variables were as follows:

- s = monthly total sunshine duration (h)
- p = monthly total precipitation (mm)
- h = monthly average relative humidity (%)
- k = number of days with daily average relative humidity >70%
- t = monthly average temperature (°C)
- m = number of days with daily maximum temperature >35°C
- v = number of days with daily minimum temperature ≤−5°C

3. Results and discussion

This study was conducted in order to determine the possible effects of climate change on sunflower yield in 29 provinces where intensive sunflower cultivation has been conducted in Turkey. The periods of 2016–2040, 2041–2070, and 2071–2099 were determined as future periods.

3.1 Province-based yield-meteorological parameter regression analysis

In the first part of the study, it is aimed to determine the quality of the relationship between the variables using regression analysis. According to the results of multiple regression analyses using LSM between climate factors and yield, the rates of predicting province-based yield were very high.

The results indicate that predictability was between 0.38 and 0.50 in three provinces (Karaman, Kırşehir, and Uşak), it was between 0.51 and 0.69 in 11 provinces (Afyon, Aydın, Çorum, Diyarbakır, İstanbul, Kayseri, Kocaeli, Kütahya, Sakarya, Tekirdağ, and Tokat), and very high predictability (0.70–0.91) was determined in 15 provinces (Adana, Aksaray, Amasya, Ankara, Balıkesir, Bilecik, Bursa, Çanakkale, Edirne, Eskişehir, İzmir, Kırklareli, Konya, Osmaniye, and Samsun) (Figure 2).

3.2 Province-based sunflower yield change projections

In the second part of the study, multiple regression equations were used with the 20-km-resolution climate projection data from the HadGEM2-ES global climate model and RCP8.5 scenario. Yield estimation analyses were conducted for 2016–2040, 2041–2070, and 2071–2099. The obtained results were compared to the average yield values of 1985–2014, and the changes that may occur in sunflower yield were periodically examined.

3.2.1 Years 2016–2040

The results of the analyses conducted for 2016–2040 using the climate projections data in the regression equations predicted that sunflower yield would increase in 16 of the 29 provinces, decrease in 12 of the 29 provinces, and no change in 1 of the 29 provinces (Figure 3).

3.2.2 Years 2041–2070

Obtained results of the analysis conducted for 2041–2070 using the climate projections data in the regression equations, it is predicted that there will be an increase in sunflower yield in 17 of the 29 provinces and a decrease in yield in 12 of the 29 provinces (Figure 4).

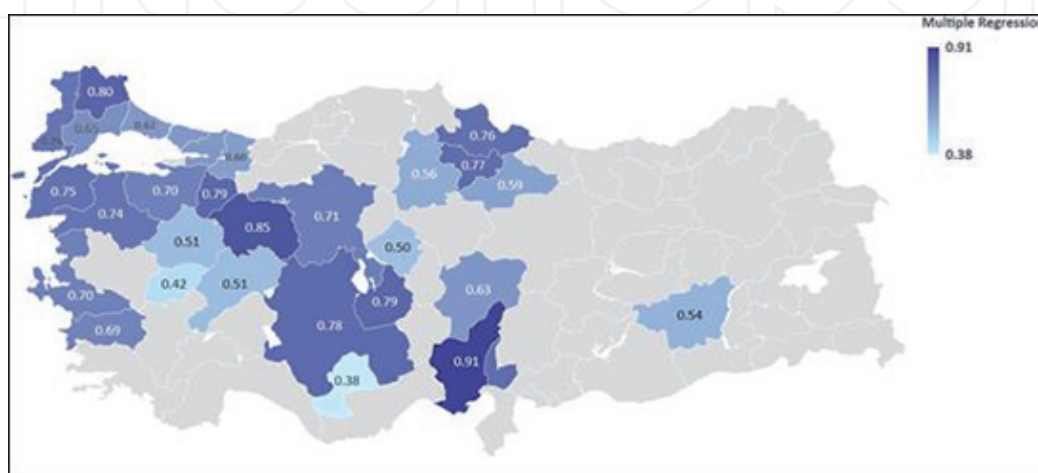


Figure 2.
Results of province-based yield meteorological parameter regression analysis.

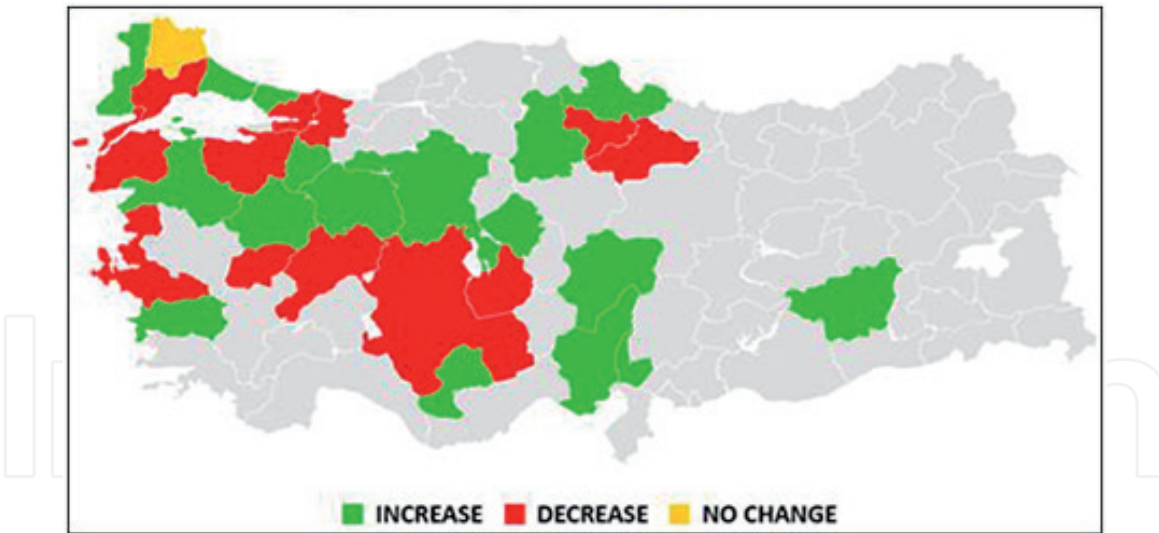


Figure 3.
Projected changes in sunflower yield for 2016–2040.

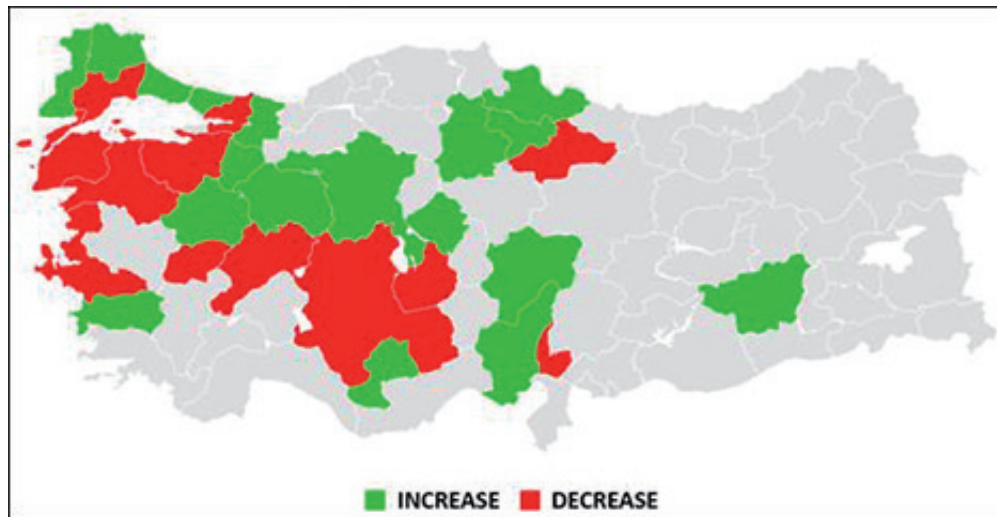


Figure 4.
Projected changes in sunflower yield for 2041–2070.

3.2.3 Years 2071–2099

The results of the analysis conducted for 2071–2099 using the climate projection data in the regression equations predicted that sunflower yield would increase in 16 of the 29 provinces, decrease in 12 of the 29 provinces, and no change in 1 of the 29 provinces (Figure 5).

3.3 Research results by region

3.3.1 Marmara region

Based on the evaluation results of the 10 provinces within the Marmara region, it is predicted that, in general, the region will be adversely affected by climate changes in the upcoming years, which would decrease average sunflower yields. The increases in the number of days with maximum temperatures $>35^{\circ}\text{C}$ would adversely affect the plant pollination period during the sunflower vegetation period throughout the region, which would have a negative impact on yield.

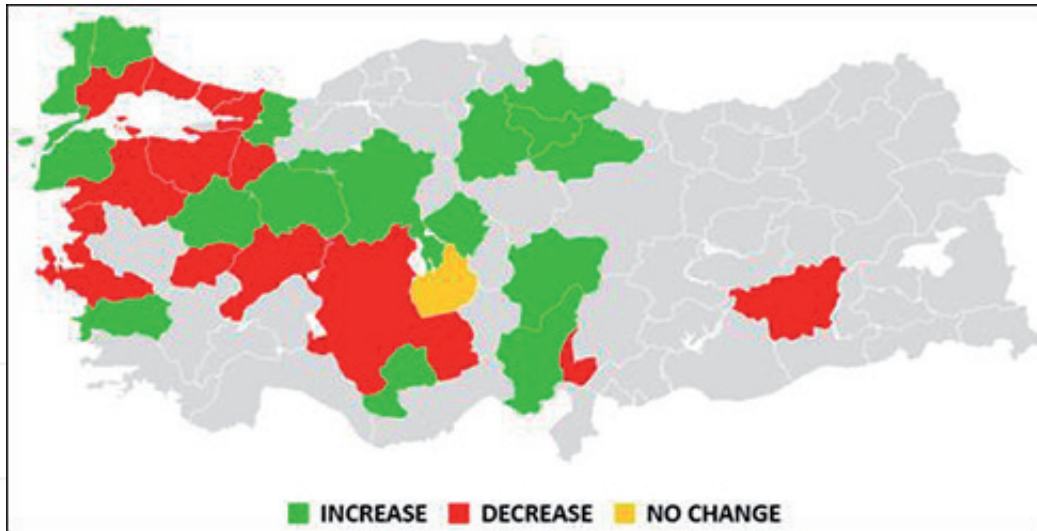


Figure 5.
Projected changes in sunflower yield for 2071–2099.

3.3.2 Central Anatolia region

The evaluation results within the seven provinces of the Central Anatolia region, it is predicted that the yield in Konya and Aksaray, where there is intensive sunflower cultivation, would decrease; on the other hand, it is predicted there will be increasing trend in other provinces of the region.

3.3.3 Aegean region

The evaluation results for the five provinces within the Aegean region suggest that the region would be adversely affected by climate changes, which would decrease the average sunflower yields within the region. It is expected that the climate changes during the studied future periods would positively affect sunflower yield in two of the provinces (Aydın and Kütahya) and negatively affect the yield in three of the provinces (Afyon, İzmir, and Uşak).

3.3.4 Black Sea region

The evaluation results of the four provinces within the Black Sea region suggest that the region would be positively affected by climate changes, especially during 2041–2070 and 2071–2099; therefore, there would be an increase in average sunflower yield. During these periods, the expected increase in the average temperature and changes in the average relative humidity are predicted to contribute positively to the yield.

3.3.5 Mediterranean region

Because of low number of provinces in the Mediterranean region in which sunflower was cultivated over the 30 years studied, the region could not be fully evaluated. Despite this, it is estimated that there will be increases in both provinces in the 2016–2040 period. In the second and third periods, excessive increases in both average temperatures and the number of days with daily maximum temperature $>35^{\circ}\text{C}$ are expected to adversely affect the sunflower yield.

3.3.6 Southeastern Anatolia region

Sunflower cultivation is not widespread in the Southeastern Anatolia region, and yield values are very low compared to those of the other regions. Nevertheless, the estimation results of Diyarbakır suggested that there would be increases in yield in 2016–2040 and 2041–2070. In the latter period, excessive increases in temperatures are expected to negatively affect yield, as is the case for the Mediterranean region.

3.4 Results based on the climate parameters

The following results are identified based on the climate parameters:

- The increase in average temperature generally contributes positively to yield.
- The average number of days with a minimum temperature $\leq -5^{\circ}\text{C}$ will not have a negative effect; however, any increase in the number of days would have a negative effect on yield.
- Limited increases in the number of days with a maximum temperature $>35^{\circ}\text{C}$ would have a positive effect on yield; however, excessive increases in those numbers would have a negative effect on yield, especially during 2041–2070 and 2071–2099.
- Decreases in average humidity and the number of days with an average humidity $>70\%$ are expected to have a positive effect on yield.

Because the average predictions for sunshine duration and total precipitation do not show significant province-based changes during all periods compared to that in 1985–2014, it can be suggested that they will not have negative effects on sunflower yield in the future periods; however, the rainfall parameter that was discussed in the study represents total for the growing season. Meteorological disasters, such as heavy rainfall and flooding, were excluded from the evaluations. As stated in the future climate projections, rather than increases in total rainfall, there are expected irregularities in the distribution of precipitation and meteorological disasters; therefore, it should be taken into consideration that precipitation parameter can have negative effect on yield in this way.

The results of the study showed that climate factors are not the sole determinant of sunflower yield but do have significant effects on production. According to the results of the analysis, it is concluded that especially temperature and humidity parameters have a significant effect on sunflower yield.

The yield estimations conducted with using the HadGEM2-ES global model and 20-km-resolution climate projections based on the RCP8.5 scenario indicate, regions in which sunflowers are cultivated will be affected by future climate changes. When regional comparisons were made in terms of sunflower cultivation based on climate changes, the Marmara and Aegean regions were found to be more sensitive to those changes. In terms of sunflower cultivation, decreases in yields in Konya and Aksaray in Central Anatolia were observed, whereas increases were predicted in other provinces within the same region. Similarly, in the study which examined the possible effects of climate change on oilseed cultivation in TR71 region, it was stated that temperature increases would increase water demand and disease probability and decrease in yield [7].

It is expected that the Mediterranean and Southeast Anatolia regions would be positively affected by climate changes in 2016–2040. It was shown that these two regions would be adversely affected by climate changes for 2041–2070 and 2071–2099. The Black Sea region is expected to be positively affected by climate changes, especially for 2041–2070 and 2071–2099.

4. Conclusion

In this study, a relationship between climate and yield was evaluated in areas in Turkey with intensive sunflower (oil type) production, and projections for changes in yield related to climate change were statistically analyzed. According to yield estimation projections, decreases are expected especially in the second half of the century. In the provinces of Tekirdağ and Konya, where intensive sunflower cultivation is conducted, the expectations of decreases in all future periods are remarkable. The results of this study can be compared with the yield projections using dynamic methods (crop simulation models), and the differences between the two methods can be determined. In addition, these results can be useful for determining the regions that should be encouraged in future product planning at the regional or national level, which can be conducted by taking into consideration the predicted changes in climate and sunflower yields.

Conflict of interest

The authors declare no conflict of interest.

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