Soil Studies 13(2), 89-96
*http://doi.org/*10.21657/soilst.1601782

RESEARCH PAPER

Impact of climate change on olive suitability areas

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How to cite
Yıldız, H., Sırlı, B., Doğan, D., & Aydoğdu M. (2024). Impact of climate change on olive suitability areas. *Soil Studies 13*(2), 89-96. http://doi.org/10.21657/soilst.1601782

Article History
Received 15 August 2024
Accepted 30 October 2024
First Online 28 December 2024

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Keywords
Olive
Climate Change
Crop Suitability

Abstract

The impact of climate change is being felt more and more by everyone. This effect is particularly observed in crop production in agricultural areas. The region where olive cultivation is most widespread and where the effects of climate change are felt the most is the Mediterranean region. Olive cultivation in Türkiye is mostly carried out in the Aegean and Mediterranean regions. This study aims to determine the changes in olive suitability areas according to climate change projections. Three different global climate models (HadGEM2-ES, GFDL-ESM2M and CSIRO) were used in the study. The average of each dataset was calculated according to bioclimatic parameters. WorldClim data was used as reference climate data. The studies were conducted with RCP 4.5 and RCP 8.5 projection data. Data for three different periods-the reference period, the years of 2050s and 2080s- were used. Maxent and BioClim species distribution models were used to produce suitability maps for olive. In the BioClim Model, in the RCP 4.5 2050, RCP 4.5 2080, RCP 8.5 2080 and RCP 8.5 2050 periods, there was a decrease of 8%, 18.6%, 20% and 23.4% in very suitable areas compared to the reference period, respectively. In the Maxent model, there was a decrease of 59.3%, 40.6%, 69.7% and 5.8% in very suitable areas in RCP 4.5 2050, RCP 4.5 2080, RCP 8.5 2080 and RCP 8.5 2050, respectively, compared to the reference period. The mean AUC value for olive was 0.874 with a standard deviation of 0.002. The AUC test value obtained shows that the model is sensitive and descriptive for olives.

Introduction

Almost all of the world's production of olives (Olea europaea L) is realized in Mediterranean countries. Spain, Italy, Greece, Türkiye, Syria, Morocco, Portugal, Egypt and Algeria are the leading countries where olive production is intense (Aygün et al., 2019). Olive cultivation is practiced in five regions in Türkiye: Aegean, Marmara, Mediterranean, Southeastern Anatolia and Black Sea Regions. Approximately 75% of olive groves are located in mountainous rural areas, and 85% are not irrigated (Aşık et al., 2011; Özaltaş et al., 2016).

The olive tree (Olea europaea L.) is an ancient traditional crop best suited to and best adapted for the Mediterranean-type climate of the Mediterranean region (Fraga et al., 2021). It has been reported that these regions where olives are grown will be most affected by climate change (Giorgi, 2006; Türkeş, 2008).

Temperatures in the Mediterranean region have risen faster than the global average in recent decades, and model projections agree that the future will involve warming and drying, with heat waves and droughts likely to increase. Environmental problems are exacerbated from a societal perspective, as the entire region is densely populated and many countries are expected to double their populations by the middle of the twenty-first century. The growing dependence on irrigation in the countries in these countries will increase their economic and social vulnerability due to reduced total future water availability and rapidly increasing competitive urban water demands (Lionello et al., 2014). Numerous studies have indicated that the climate of the Mediterranean region in the twenty-first century will experience a decrease in precipitation and widespread warming in most areas (Planton et al., 2012). This makes the Mediterranean a potentially vulnerable region to climate changes triggered by increasing concentrations of greenhouse gases (Lionello et al. 2006; Ulbrich et al., 2006).

Olive trees are known to be drought tolerant. However, excessive drought stress during growth periods causes negative effects on crop yield and development in olive trees (Varol and Ayaz, 2012). The areas where olive cultivation is practiced in Türkiye are semi-arid and arid regions. Especially in recent years, there has not been enough rainfall in these regions during the periods when olives need it. Olive cultivation will become more difficult in the coming years due to increasing warming, the increased frequency of extreme weather events such as droughts and heat waves.

This study aims to determine the changes in olive suitability areas, which are important for the economy of our country and which are thought to be most affected by climate change, according to current and future projections.

Materials and Methods

In this study, BioClim and Maxent models were used to identify suitable areas for olive cultivation. SDMs utilize the location information of the species and environmental factors as input data. As environmental variables, bioclimatic data covers the reference period, 2050s and 2080s, RCP 4.5 and RCP 8.5 projections.

The bioclimatic variables are calculated from monthly minimum and maximum temperatures and monthly precipitation data. These data are as follows (Anonymous, 2024): B01: Annual average temperature; B02: Average diurnal range (Monthly average (maximum- minimum temperature)); B03 Isothermality (P2/P7) (* 100) (Annual average temperature/monthly temperature range); B04: Seasonal temperature (standard deviation * 100); B05: Maximum temperature of the hottest month; B06: Minimum temperature of the coldest month; B07 Annual average temperature range; B08: Average temperature of the wettest quarter; B09 Average temperature of the driest quarter; B10: Average temperature of the warmest quarter; B11: Average temperature of the coldest quarter; B12: Average annual precipitation; B13: Precipitation of the wettest month; B14: Precipitation of the driest month; B15: Seasonal precipitation; B16: Precipitation of the wettest quarter; B17 Precipitation of the driest quarter; BI18 Precipitation of the warmest quarter; B19 Precipitation of the coldest quarter.

WorldClim data was used as reference data in this study. WorldClim has a spatial resolution of 30 seconds in scale. These data can be downloaded from http://www.wordclim.org for the whole world. These data are derived from climate data measured at meteorological stations around the world. It mostly covers the years between1950-2000 and consists of average monthly climate data.

Climate Requirements of Olives

The Mediterranean climate, which represents the transition between the arid climate of North Africa and the temperate rainy climate of Central Europe, has the most favorable climatic conditions for the cultivation of the olive tree, (Moriondo et. al., 2013). The olive tree typically cannot withstand temperatures below 8 °C for more than a week (Palliotti and Bongi, 1996). Very high summer temperatures (higher than 30 °C) can limit their yield performance. Generally, in regions where olive cultivation is practiced, annual average temperatures between 15-20°Care desired. The average temperature requirements of olive trees according to phenological periods are 5-10°C from shoot initiation to the next formation (February-March), 15-20°C during flowering (May-June), 20-25°C during fruit formation and growth (May-June), and 5°C from full ripening to the end of harvest (November-January) (Sevim et al., 2022).

Meeting the chilling requirement plays an important role in determining olive flowering (Ayerza, and Sibbett, 2001). Olive can only meet its chilling requirement at temperatures between 7ºC and -7ºC. In the period from January to April, chilling (at least 50-60 hours below 7.2 ºC and up to more than 1200 hours) is required (Ayaz and Varol, 2015).

Approximately 90% of olive trees grown in the Mediterranean Basin are primarily under rain-fed conditions (Gómez et.al. 2001). Although olive trees are drought-tolerant, their distribution in arid regions is limited by annual rainfall of less than 350 mm (Ponti et. al., 2014), and water availability remains important resource to increase final yields.

Climate Projection Data

Climate projection data is a set of data that shows how the climate of a given region is expected to change in the future. This data is typically produced by running climate models, which are computer programs that simulate the behavior of the atmosphere and oceans.

There are four different RCP scenarios (RCP 2.6, 4.5, 6, and 8.5). Projections 2.6, 4.5, 6 and 8.5 represent radiative forcing in units of watts per square meter. The relationship between the energy that reaches the Earth from the sun and the energy that is reflected back forms the global energy balance (Wayne, 2013). RCP 4.5 and

RCP 8.5 projection data for the 2050s and 2080s were used in the study. These data were downloaded from http://www.ccafs-climate.org/ as raster data. Each parameter has a spatial resolution of 30 seconds.

Global Climate Models (GCM)

Global climate models are simulations of the Earth's climate system using mathematical models. These models attempt to predict future climate changes by considering the interactions of Earth's atmosphere, ocean, glaciation and other factors. These models use computer-based data to generate possible future climate scenarios, taking into account the physical properties of the planet, the impact of human activities and other variables.

The average of three global climate models was calculated for each climate parameter in order to reduce the deviations caused by the differences in the methods and data used in the production of climate models. These models are HadGEM2-ES (Collins et al., 2008), GFDL-ESM2M (Dunne et al., 2012) and CSIRO (Whetton et al., 2015).

Species Distribution Models (SDM)

Species Distribution Models calculate the suitability of the species to grow by evaluating the relationship between the location of the species and environmental data (Guisan and Thuiller, 2005). In this study, the coordinates of the places where olives are grown were utilized from previous studies such as "Project for Determination of Potential Suitability Areas of Agricultural Ecological Regions and Crops in Türkiye (KAMAG1007_105G077)". Bioclimatic variables were used as environmental data. The most commonly used BioClim and Maxent models were used in the study to determine olive suitability areas.

BioClim establishes a set of thresholds covering the minimum and maximum value of each environmental variable and predicts that species can be found in all locations within these thresholds. To estimate the probability of a species' distribution in a given area, BioClim compares the values of environmental variables at the location of the species and summarizes climatic parameters within the known distribution range of the species, calculating their suitability for the species (Nix, 1986). The BioClim model can be run within the Diva-GIS software. Diva-GIS is an easy-to-use and free computer program (Hijmans et al., 2012).

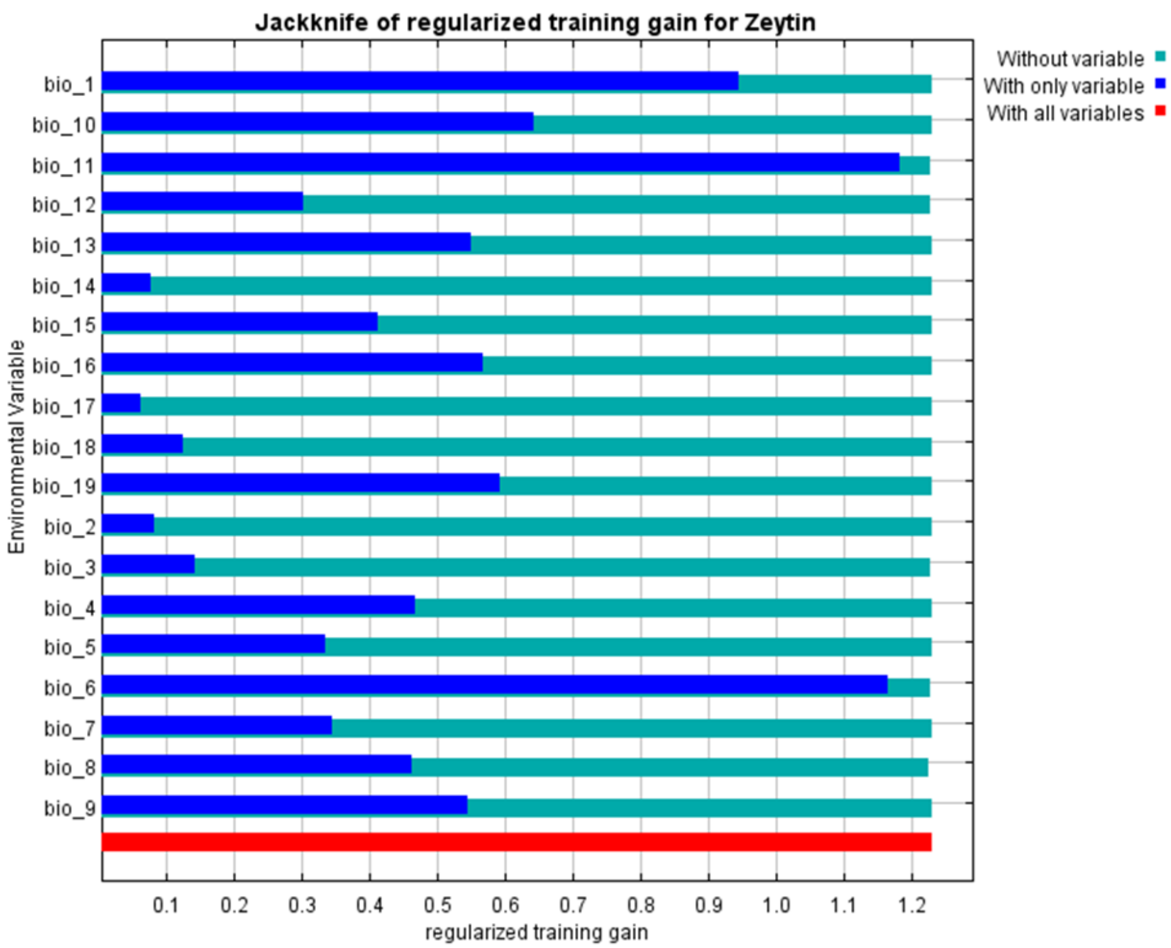

Figure 1. Jackknife test of variable importance

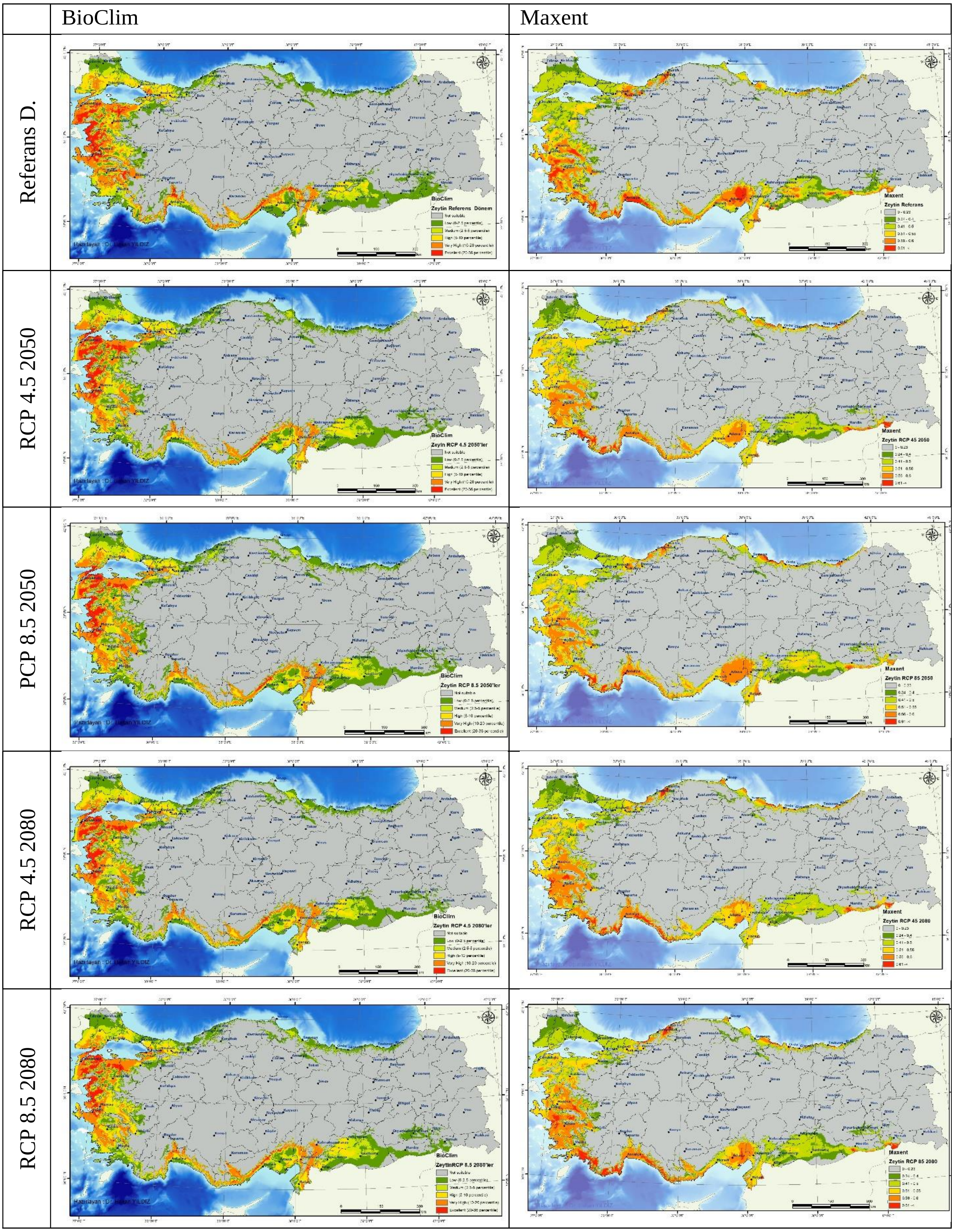

Figure 2. Olive suitability areas and changes according to projection

The Maxent Model works on the principle of maximum entropy (Phillips, 2006). Maxent is an algorithm that uses only available data and compares the location of a species with all available environments in the study area. It samples and identifies a large number of points throughout the study area. These points are called background points. For calculating the potential distribution of a species, Maxent calculates the probability of suitability of the total achievable environment for all points and the probability of suitability of the environment for the points present. The ratio between these two probability densities is calculated, and this gives the relative environmental suitability for the presence of a species in the study area.

The average of the five layers obtained by repeating the Jacknife probability 5 times is used in the study. The 'jackknife test' excludes one environmental variable in each iteration. In this way, the success of each variable in explaining the species distribution and the informative performance of the model result is ensured. Analysis was performed five times. Thus, all locality data were divided into 5 groups in each replicate and one group was accepted as 'training data'. By selecting a different group in each replicate, sampling bias was prevented (Baldwin, 2009).

Figure 1 shows the results of the jackknife test of variable importance. The environmental variable with highest gain when used in isolation is bio_11, which therefore appears to have the most useful information by itself. It is followed by bio_6 and bio_1 respectively. Values shown are averages over replicate runs.

Results and Discussion

In order to determine the areas suitable for olive cultivation, the coordinates of olive cultivated areas were obtained from previous studies. The obtained coordinates and environmental parameters were evaluated together in BioClim and Maxent species distribution models and suitable areas were calculated based on the reference period, future periods and climate projections. For the evaluation of the changes in the obtained maps together (Figure 2).

On the maps, the probability of areas suitable for olive cultivation increases towards dark red and decreases towards dark green. In the BioClim model, the most suitable areas are concentrated in the North Aegean region, while in the Maxent model, they are towards the South Aegean and Mediterranean regions (Figure 2). The raster suitability maps produced according to different projections and periods were classified according to the threshold values of the assumption in order to see the changes between each other and their areas were calculated.

In the BioClim model, in the RCP 4.5 2050, RCP 4.5 2080, RCP 8.5 2080 and RCP 8.5 2050 periods, there was a decrease of 8%, 18.6%, 20% and 23.4% in very suitable areas compared to the reference period, respectively. Likewise, suitable areas decreased by 0.1% to 7.9%, while medium suitable areas decreased by 14.5% on average. The BioClim model showed an average increase of 19.3% in less suitable areas compared to the Maxent model. Not much change was observed in very little suitable areas and unsuitable areas (Figure 3).

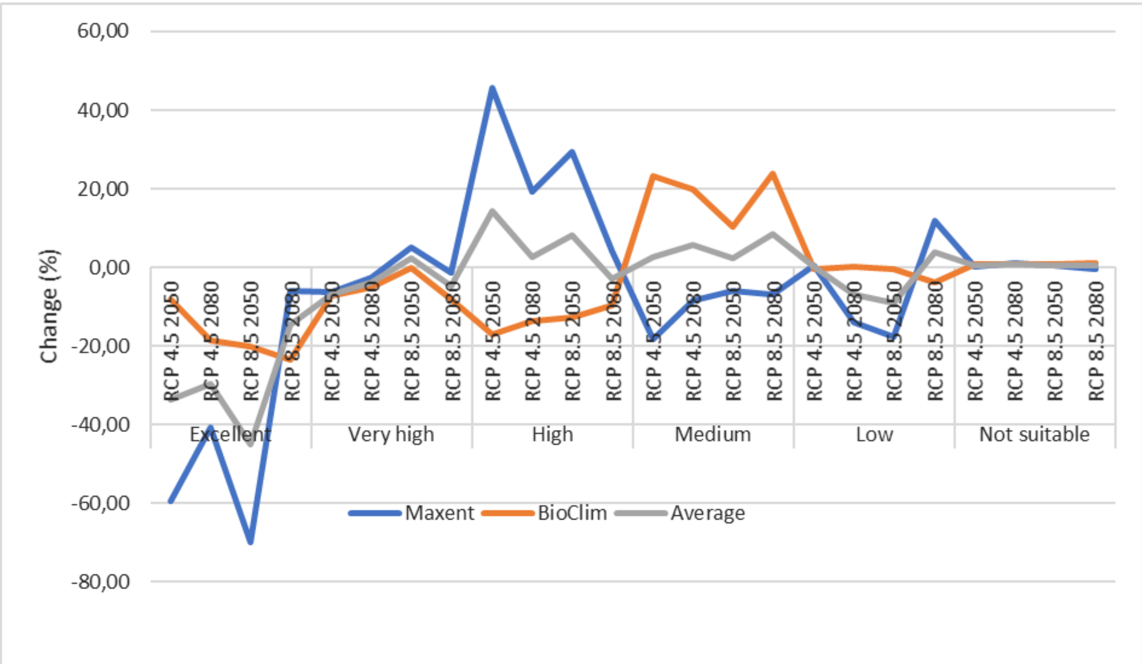

Figure 3. Changes in the % change of olive suitability areas of Maxent and BioClim models compared to the reference period.

Table 1. BioClim Model product and AUC values according to bioclimatic factors

bio1	bio2	bio3	bio4	bio_5	bio6	bio7	bio8	bio9	bio10	bio11	bio12	bio13	bio14	bio15	bio16	bio17	bio18	bio19
0,87	0,39	0,63	0,26	0,72	0,90	0,28	0,67	0,79	0,81	0,90	0,73	0,81	0,43	0,72	0,80	0,46	0,38	0,81

In the Maxent model, there was a decrease of 59.3%, 40.6%, 69.7% and 5.8% in very suitable areas in RCP 4.5 2050, RCP 4.5 2080, RCP 8.5 2080 and RCP 8.5 2050, respectively, compared to the reference period. In suitable areas, there was an increase of 5% in RCP 8.5 2050, while there was a decrease of 6.2%, 2.4% and 1.3% in RCP 4.5 2050, RCP 4.5 2080 and RCP 8.5 2080, respectively. Medium suitable areas generally increased compared to the baseline period, reaching 45.7% at RCP 4.5 2050. Less suitable areas decreased by 9.8% on average. Very little suitable areas increased by 0.4% in RCP 4.5 2050 and 11.9% in RCP 8.5 2080, while decreasing by 13.7% in RCP 4.2080 and 17.7% in RCP 8.5 2050. There was no significant change in unsuitable areas. Similar to these results, Fraga et al. (2021) noted that the Mediterranean Basin is considered a climate change "hub" and that climate change could be particularly challenging for olive growers, with increasing evidence of significant climate change in the coming decades requiring adaptation measures to be taken.

To determine the performance of the model, the AUC (Area Under the ROC Curve) value obtained from Receiver Operating Characteristic (ROC) analysis was used (Wang et al., 2007a; Phillips, 2017). The AUC value obtained can be interpreted as the estimated probability of the presence of a randomly selected grid cell in a correctly tuned model. The AUC describes the success of the model with all possible thresholds. If this value is AUC > 0.5, it means that the model performs better than a random guess (Phillips and Elith, 2010). The closer the AUC test value is to 1, the better the separation, the more accurate and descriptive the model is (Phillips et al., 2006). AUC values are a numerical evaluation that shows the reliability and accuracy of the analysis result, and the reliability increases as it approaches 1 according to the evaluation between the numbers 0-1. AUC values above 0.90 indicate that the analysis gives a very good result.

In the BioClim model, AUC values are generated on a variable basis. Table 1 shows the AUC values of olives according to bioclimatic variables. The highest AUC values were obtained in bio_11, bio_1 and Bio_ 6.

In Maxent model the mean AUC value for olive was 0.874 with a standard deviation of 0.002. The AUC test value obtained shows that the model is sensitive and descriptive for olives (Figure 4).

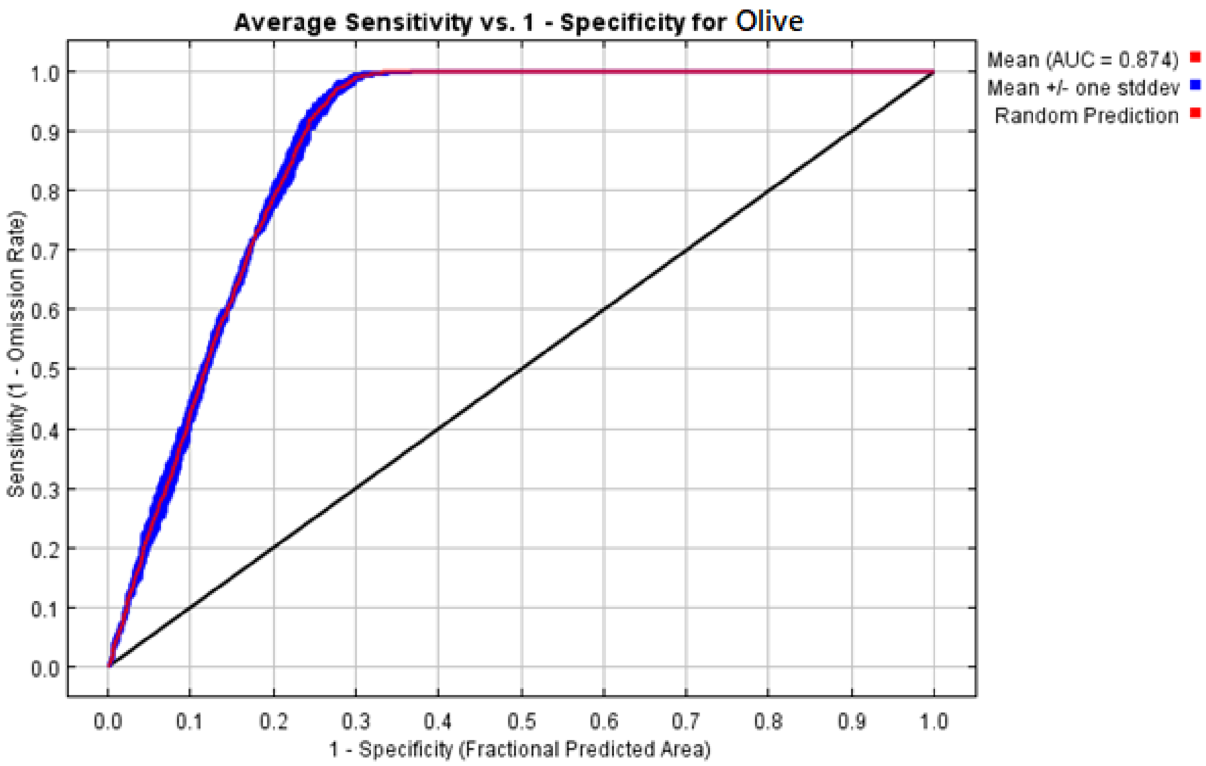

Figure 4. Olive sensitivity analysis graph according to the Maxent model

Conclusions

Human impact on the natural environment is increasing due to increasing population, growth in human needs, the need for more energy, higher industrial production and the expansion of settlements. As a result of these effects, greenhouse gas emissions increase. Greenhouse gas emissions negatively affect the climate. One of the most important factors affecting agricultural production is climate. The agricultural sector is the most vulnerable to the impact of climate and is most affected by climate change. Adams et al. (1998) reported that climate change is expected to affect crop and livestock production, hydrological balances, input supplies and other components of agricultural systems. Therefore, it is critical to understand and predict the impacts of climate change on production and food supply.

In determining the impacts of climate change on agriculture, raster climate parameters produced by considering climate projections are used with SDM. SDMs calculate the probability of species distribution for present and future periods by modeling the relationships between species location and environmental factors. Miller (2010) states that the use of SDM to map and monitor animal and plant distributions is becoming increasingly important in the context of awareness of environmental change and its ecological consequences.

Species coordinate information, raster environmental factors and digital maps can be used in GIS (Geographic Information Systems) software to calculate maps of changes in species distributions. GIS software consolidates, making it easier to visualize and analyze species distributions over time. This information can be used to determine how species respond to habitat changes and species adaptation.

This study concludes that very suitable areas for olives are decreasing. It is understood from the results that the regions where plant species grow comfortably will turn into more stressful regions due to climate change. As temperatures rise and weather conditions change, it can lead to potentially more distressing conditions for the olive. To mitigate the impact of climate change on plant species, scientists and researchers need to work on strategies such as conservation efforts, breeding programs and sustainable land management practices. While climate change poses challenges, research and collective efforts are needed to understand and address its impacts on plant species.

Funding Information

This article has been “TAGEM/TSKAD/Ü/19/A9/P6/1514” and named "Determination of The Effects of Climate Change on Some Important Agricultural Products Suitability Areas” produced from the data of the project funded by TAGEM.

Author Contribution

HY: Conceptualization, Data Curation, Formal Analysis, Funding Acquisition, Investigation, Methodology, Project Administration, Resources, Supervision, Visualization, Writing -original draft. **BS:** Data Curation, Formal Analysis, Funding Acquisition, Investigation, Methodology, Resources, Visualization, Writing -review and editing. **DD:** Data Curation, Formal Analysis, Investigation, Methodology, Resources, Writing -review and editing. **MA:** Data Curation, Formal Analysis, Investigation, Methodology, Resources, Writing -review and editing

Conflict of Interest

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

Acknowledgements

This manuscript was prepared from the data of research project numbered TAGEM/TSKAD/Ü/19/A9/P6/1514 and named "Determination of The Effects of Climate Change on Some Important Agricultural Products Suitability Areas".

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