THE EFFECTS OF CLIMATE CHANGE ON SPATIOTEMPORAL CHANGES OF HAZELNUT (CORYLUS AVELLANA) CULTIVATION AREAS IN THE BLACK SEA REGION, TURKEY

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Abstract. Turkey ranks the first among the hazelnut producers in the world. The purpose of this study is to question whether or not the hazelnut plant that grows under natural climate conditions will be affected by climate change. Spatial and temporal change simulations have been done in order to define the actual and the future status of hazelnut cultivation areas. The Marmara and the Black Sea regions have been chosen as study areas of hazelnut production in Turkey. The possible evolution of the current climate conditions to affect hazelnut cultivation in the upcoming 90 years and the estimated changes to occur in hazelnut areas have been asserted in the study. In order to determine the future climate conditions, the set of temperature and rainfall data of the upcoming 90 year period (2011 - 2100) obtained from the A2 scenario of RegCM3 regional climate model has been used and by taking the averages of each 10 year period, it has been simulated with the MATLAB software. While an increase of up to 6 ºC in temperature for the upcoming 90 years can be expected to have negative effects on hazelnut cultivation depending on the A2 scenario (the worst), no change has been observed in the rainfall scale that may negatively affect hazelnuts. In particular, it has been observed that this temperature change may cause vertical and horizontal changes in hazelnut areas. Accordingly, it has been anticipated that hazelnut cultivation on the coast line between 0 - 250 m may get affected in a negative way and the areas exceeding 1500 m that are not currently suitable for hazelnut cultivation may become arable lands due to vertical change.
Keywords: *climate change, spatiotemporal change, hazelnut (Corylus avellana), Black Sea Region*

Introduction

The subject of this study is to determine the possible effects of climate change on hazelnut production in Turkey. Climate is a factor closely controlling the formation of geographical environment and living conditions of humans. Agricultural activities constitute one of the most important areas for the adaptation of various human activities with climate change (IPCC, 2007). Among human activities agriculture is the most highly dependent on weather conditions and climate. Climatic conditions have the greatest significance on the cultivation of agricultural products and their productivity (Szenteleki et al., 2012; Gaál et al. 2011; Adams et al., 2001; Atalay, 1994; Mall et al., 2007; Sivakumar et al., 2000; Sivakumar, 2006; Rotter et al., 1998). The variability in temperature especially plays a determining role in the productivity of horticulture (Wheeler et al., 2000, Trnka et al., 2004). For this reason, short and long term variations in weather conditions and climate affect agricultural activities and especially

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agricultural production and cause fluctuations in production (Challinor et al., 2003; Hansen, 2002; Oram, 1989). This situation poses a serious risk for the products that have an economic value in agricultural aspects. Besides type, technical and cultural factors, hazelnut growing is also related to environmental and particularly climatic conditions (Beyhan and Odabaş, 1996). The hazelnut, having found the world's most suitable ecology for its cultivation in the Black Sea Region of Turkey, has a significant share in agricultural economy of Turkey. Turkey ranks the first in hazelnut production and exportation in the world and provides 70% of the world production and about 75 % of the exports. The importance of hazelnut agriculture in Turkey can be better perceived by taking into consideration its share in the total hazelnut production of the world. The average hazelnut exports of Turkey in 2009 and 2010 amounted to 1.5 billion dollars (FTG, 2010). Based on the aforementioned reasons, the hazelnut and the prediction of its potential future production areas arise as an area that deserves attention.

So as to prevent or minimise the effects of climate change, climate change scenarios should be developed for the future and impact analysis should be accomplished according to these scenarios. The climate change shall have effects on a spatiotemporal scale. For the better preparation of countries against the results of climate change and so that they can adapt themselves to this change, determining which sectors in which areas will be affected and to what extent is highly important.

Fruits have a distinctive role in determining the effects of climate change on agricultural production. The areas that are suitable for fruit growing under today's conditions may not have adequate characteristics for cultivation in the future. Besides, as fruits are perennial plants, they need a couple of decades for growing. (Koski, 1996). It takes time to adapt to the changing climate for this reason. Since fruit growing is an agricultural activity with relatively high levels of economic return, it is necessary to implement pilot climate - agriculture projects in the fields where cultivation is the most suitable for the future. The aim here is to model whether the crop will change its geographical location rather than making crop estimations assuming that climate changes will be experienced on a regional basis. The primary thing to do in such studies is to identify the necessary environmental conditions for the cultivation of plants and to adequately model the growing process of the plant under these conditions. It has been observed in the literature search that the studies on annual plants are prevailing. Not a wide number of studies have been conducted on perennial plants up to know. This study will contribute to the literature in both terms of content and methodology for hazelnut being a perennial crop. Being the first study conducted on perennial crops in the field of impact assessment of climate change in Turkey and the first spatiotemporal analysis in terms of past - current - future phases of hazelnuts from the perspective of climate, it will provide a basis for the future studies.

Since the hazelnut is a perennial crop, like other perennial horticultural crops it takes many years to cultivate it in any ecology, to determine its ecologic conditions, to grow and to breed. On the other hand, in the case of any annual crop, while cultivators plant a crop in a field one year, they can plant another type of product in the same field for the next year in case the crop becomes less profitable especially by being affected by climatic conditions. However this situation is not valid for perennial crops. Another critical condition for the hazelnut is that as it is cultivated on sloping fields whose topographic characteristics are not suitable for the planting of annual crops, it is not easily replaceable with some other crop. Therefore it is crucial to take measures against possible climate changes in the future for these kinds of horticultural perennial crops that have a high economic value. The effects of temperature and rainfall are among the climatic parameters having a distinctive role in the natural cultivation conditions of hazelnuts that have been identified in this study.

Study Area and Data

It has been suggested that the hazelnut was cultivated for the first time in Northern Anatolia in the 4th and 3rd centuries (B.C.) (Köksal, 2002). The Black Sea region, the study area where hazelnut agriculture is done at the highest level in terms of area and crop amounts in Turkey, is also located in this area (*Fig. 1*).

Figure 1. *Location map of the study area (Marma ra and Black Sea Region in Turkey)*

The annual average temperature and rainfall data recorded for the period 1930-2009 from 273 meteorological stations located in the Marmara and the Black Sea Regions have been used in the study as meteorology station data from Turkish State Meteorological Service. The temperature and rainfall conditions in Turkey have been investigated according to the agrometeorological requirements of hazelnuts. Accordingly, the areas where the hazelnut has been cultivated for economic purposes in Turkey have been determined statistically (production - hectare). Ordu, Giresun, Trabzon, Samsun, Düzce, and Sakarya in the Black Sea Region are the provinces that have been chosen as the sample areas. The long and common period of (1975 – 2009) annual average temperatures of these provinces have been determined as between 13-16 °C *(Fig. 2)* and the rainfall values have been determined over 700 mm *(Fig. 3)* in accordance with the optimal conditions of hazelnut cultivation. This means that these areas have optimum conditions for hazelnut cultivation statistically.

Temperature and rainfall data of the A2 scenario obtained from RegCM2 climate model have been used as model data. Temperature and rainfall data of this model are in netcdf data format and cover the years 2011 - 2100. They are in 30 km resolution and Turkey scale (Dalfes et al., 2008). NCEP / NCAR reanalysis data were used for the years 1961 - 1990 determined as the reference period (30 years) in the evaluation of the results of the model. In addition, by determining the reanalysis data from the obtained value, the difference in temperature and rainfall possibly to occur in the future is

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obtained. Temperature and rainfall values have been interpolated by taking into consideration the altitude values in the topography in both station data and model data. 1 km * 1 km Gtopo30 digital elevation model data have been used for this interpolation process (USGS, 2010).

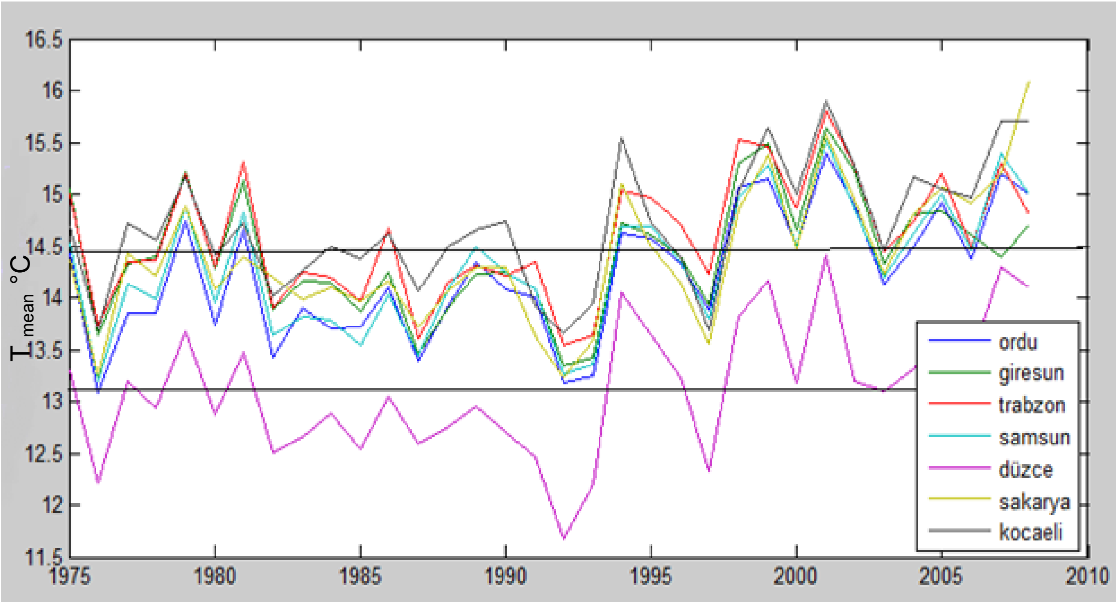

Figure 2. *Annual mean temperature (Tmean°C) of long years term in the study area (1975-2009)*

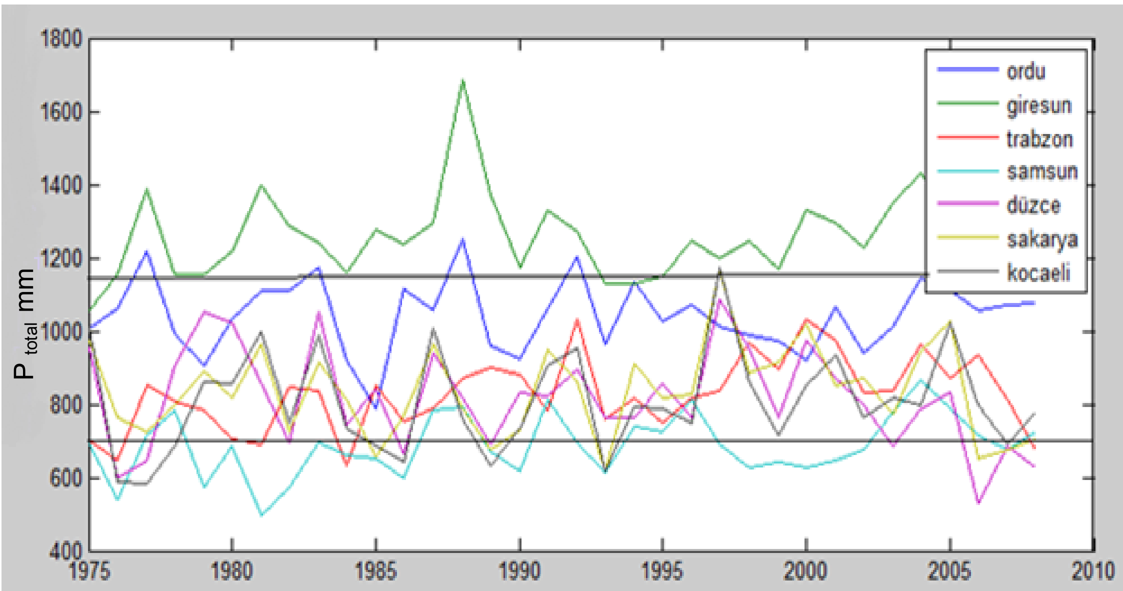

Figure 3*. Annual rainfall (Ptotal mm) of long years term in the study area (1975 - 2009)*

Methodology

The methodology used in the study is comprised of three steps. First of all, the optimal climate conditions of hazelnuts in the study area have been determined.

Secondly, daily climate data of meteorology stations at the study area have been analysed according to the agrometeorological requirements of hazelnuts. Thirdly, the climate data obtained from RegCM3 regional climate model of the A2 climate scenario to be used in the study and the NCEP_NCAR data of the reference period used as reanalysis data have been analysed according to the agrometeorological requirements of hazelnuts. With an aim to estimate the average temperature and rainfall amounts in Turkey in the period between 2011 - 2100, (a) the temperature and rainfall data sets of the determined periods shall be interpolated according to the Gtopo 30 digital elevation model data coordinates (1 * 1 km) and their resolution shall be increased. (b) The topography effect on the temperature and rainfall data of which the resolution has been increased shall be tried to be eliminated through altitude correction. (c) The difference between the temperature and rainfall data obtained from regional climate models and the rainfall data obtained from the reference period shall be accepted as the rate of change. (d) This difference change, by taking the average of each decade, shall be added to the meteorology station data (2011-2020, 2021-2030…2091-2100) and the temperature and rainfall data shall be simulated for the future using MATLAB 7.0 software.

The MATLAB 7.0 software has been used in the analysis and monitoring of the data used in this study. MATLAB is flexible software for analysing multidimensional climate data (Ustaoglu, 2012a). Gtopo30 digital elevation model data have been used to eliminate the topography effect on both station and model data.

Identification of agrometeorological characteristics of hazelnuts

First, it shall be determined statistically whether the study area is suitable for hazelnut cultivation according to specific climate requirements of the hazelnut. For this purpose, the threshold values (limit values) of temperature and rainfall data necessary for hazelnut cultivation in the Black Sea ecology have been extracted from literature and expert opinions. According to these, the hazelnut grows under the most suitable temperature conditions between 13- 16 °C. In terms of rainfall, rain amounts over 700 mm are suitable for hazelnut cultivation without requiring irrigation (Köksal, 2002). Hazelnut trees can be seen on bush layers of the forests up to an altitude of 1500 m (Yaltırık, 1988).

Analysis of station data

In order to determine the past and the current climate conditions at the study area, meteorological data for the period 1930-2007 from 273 stations have been analysed in the MATLAB software. In order to increase the resolution of the annual temperature, rainfall and altitude data of the meteorology stations dispersed over the topography, they have been interpolated with grid data commands and transformed into Gtopo30 (1*1 km) coordinate system. Altitude factor correction has been applied to the obtained temperature and rainfall values of meteorology stations of which resolution has been increased. While lapse rate (0.649) was used for temperature; Equation 1. was used for rainfall for altitude correction.

$$Y_h = Y_0 + 54h \quad \text{(Eq. 1)}$$

Y_o means the annual rainfall of the reference station; Y_h means the annual rainfall of the searched station; and h means the altitude difference between the two stations in hectometer (Erinç, 1996).

According to cultivation conditions of hazelnuts, the fields under 1500 m for altitude (*Fig. 4*), the fields having a temperature value between 13°C – 16°C for temperature and the fields receiving rainfall over 700 mm for rainfall have been investigated. By doing this, the long years temperature and rainfall data that have been interpolated and corrected from altitude factor, have been obtained and mapped.

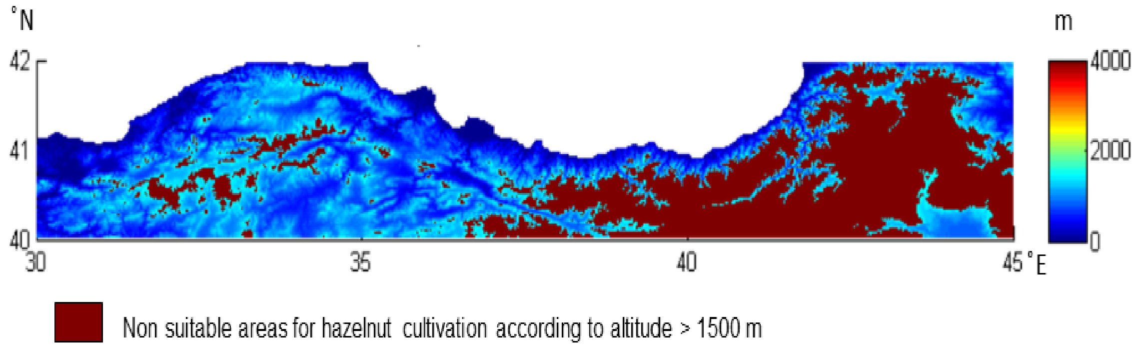

Figure 4. *The upper limit of hazelnut cultivation areas with a low level of 1500 metres altitude.*

Analysis of the model data

The global climate models used in climate simulations for the future have low resolutions (150-200 km) and they do not have any regional features. For this reason, a regional climate model that has a higher spatial resolution value (30 * 30 km) has been used in this study to gather more accurate results on the topography. Regional climate models as one of the dynamic downscaling methods are successfully used for this purpose. These models get their start and limit conditions from global model outputs and can be operated in higher resolutions (20-30 km) where the topographic features are also reflected (Demir et al., 2007). But the topography in Turkey shows a high level of diversity. For this reason, while this resolution is adequate on the shores and in areas at lower altitudes, the spatial resolution is hard to control in the highlands (Tubiello et al., 2002, Huntingford et al., 2005). To this end, the temperature and rainfall data sets have been interpolated with the linear interpolation method and their resolution has been increased in this study and altitude correction has been applied on the rainfall data set. The precision of the data has been increased in this way.

To do this, the temperature, rainfall and altitude values of long term average (1930 - 2007) of the temperature and rainfall data, gathered from 273 meteorology stations that are operated by General Directorate of State Meteorology and have different observation dates, have been interpolated with the linear interpolation method and have been mapped by correcting the altitude. As the interpolation will be made with the linear interpolation method in the analysis of the temperature and the rainfall data, numerous station data are necessary to obtain accurate results on the topography. For this reason, a common observation period has not been defined for the meteorology stations used in this study (Ustaoglu, 2012b).

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The temperature and rainfall data obtained from the RegCM3 regional climate model have been systematically organised and monitored in the MATLAB software. The gridded temperature, rainfall and model altitude data of the A2 scenario have been transformed into the Gtopo30 (1*1 km) coordinate system and have been interpolated to increase the resolution. Altitude factor correction has been applied on the temperature and rainfall values of which resolution has been increased. To do this, Gtopo30 altitude has been determined from the altitude data of the model of which resolution has been increased and has been multiplied with temperature (0.649) and rainfall (-54) coefficients and added to the temperature and rainfall of the model. NCEP / NCAR reanalysis data for the period 1961–1990 that was determined as the reference period have been used in the evaluation of the results obtained from the model (Dalfes et al. 2008). In addition, by determining the reanalysis data from the value obtained from the model, the possible difference in temperature and rainfall in the future has been obtained. Consequently, the temperature and rainfall data of the A2 scenario have been monitored by taking their annual averages per decade (2011 – 2020), (2021 – 2030)…. (2091 – 2100). The obtained values have been added to the station data and the future temperature and rainfall conditions of the hazelnut cultivation areas have been investigated.

Results

According to the simulation results of pessimistic scenario A2, the increase in temperature values for the upcoming 90 year period divided into decades has been determined as approximately 6 °C in Turkey *(Figs. 5a-5b).* This situation means more heating and exceeding the growing limit (13 - 16 °C) of the hazelnut cultivation areas according to the optimal temperature conditions of today. Thus, it has been predicted that a vertical zone shift will occur depending on the decrease in temperature with altitudes in hazelnut cultivation areas.

The results have shown that the changes to occur in the rainfall amounts of 2011-2100 at the study area tend to increase when compared to the rainfall amounts of today *(Figs. 6a-6b).* This condition shall have a positive effect on hazelnut cultivation as it exceeds 700 mm which is the minimum cultivation limit for hazelnuts on the whole of the study area. This increase is more significant especially in the Eastern Black Sea Region located in the east of the study area where hazelnut cultivation is intensive *(Figs. 6a-6b).* As a result, it has been detected that the changes in the temperature values between 2011–2100 are more significant compared to the rainfall values. This situation is more obvious in the maps drawn separately by adding the differences from the reference period to the A2 scenario according to the temperature and rainfall requirements of hazelnuts and also altitude conditions *(Figs.7a-7b).* Particularly after 2050, it has been seen that horizontal changes (shift from north to south) occur in hazelnut production areas according to climate change *(Figs. 5a-5b, Figs. 7a.-7b.).*

Conclusions

In this study, spatiotemporal change simulations have been made in order to define the actual and the future position of hazelnut production fields. The effects of climate change shall show differences in temporal and spatial scales. Based on the suggestion that climate changes will be experienced on a regional basis, the aim here is to model whether or not the product will change its geographical location rather than making crop estimations.

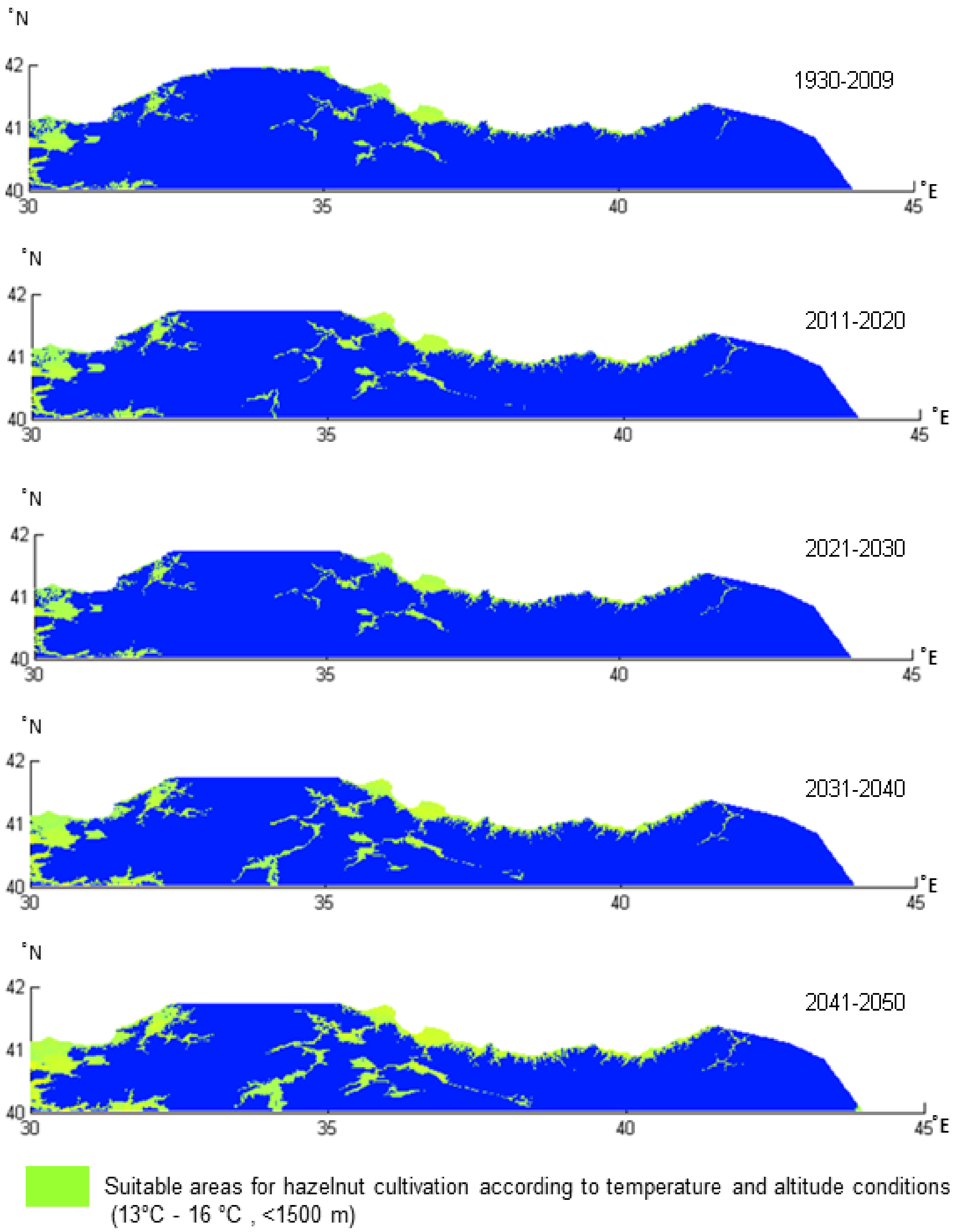

***Figure 5a**. Average temperatures (°C) and altitude conditions of potential hazelnut production areas (13 – 16 °C and < 1500 m.) in Turkey according to the long term years average meteorological stations temperature data (1930 - 2009); average temperatures (°C) and altitude conditions of possible hazelnut production areas (13 – 16 °C and < 1500 m.) in Turkey according to A2 scenario between 2011 - 2020, 2021 - 2030, 2031 - 2040, 2041 -2050.*

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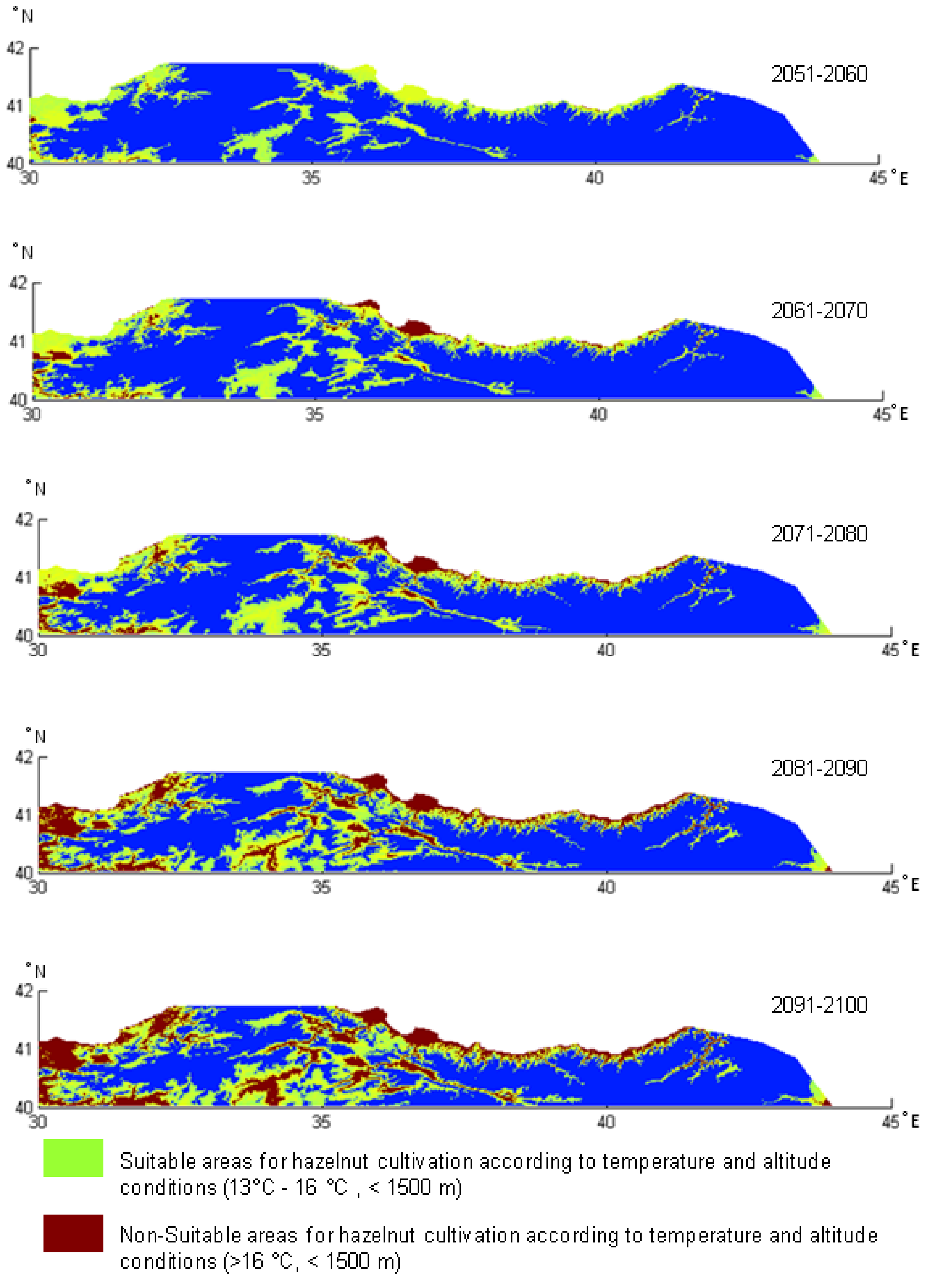

Figure 5b. *Average temperatures (°C) and altitude conditions of possible hazelnut production areas (> 16 °C and < 1500 m.) in Turkey according to A2 scenario between 2051 - 2060, 2061 - 2070, 2071 - 2080, 2081 - 2090, 2091 - 2100.*

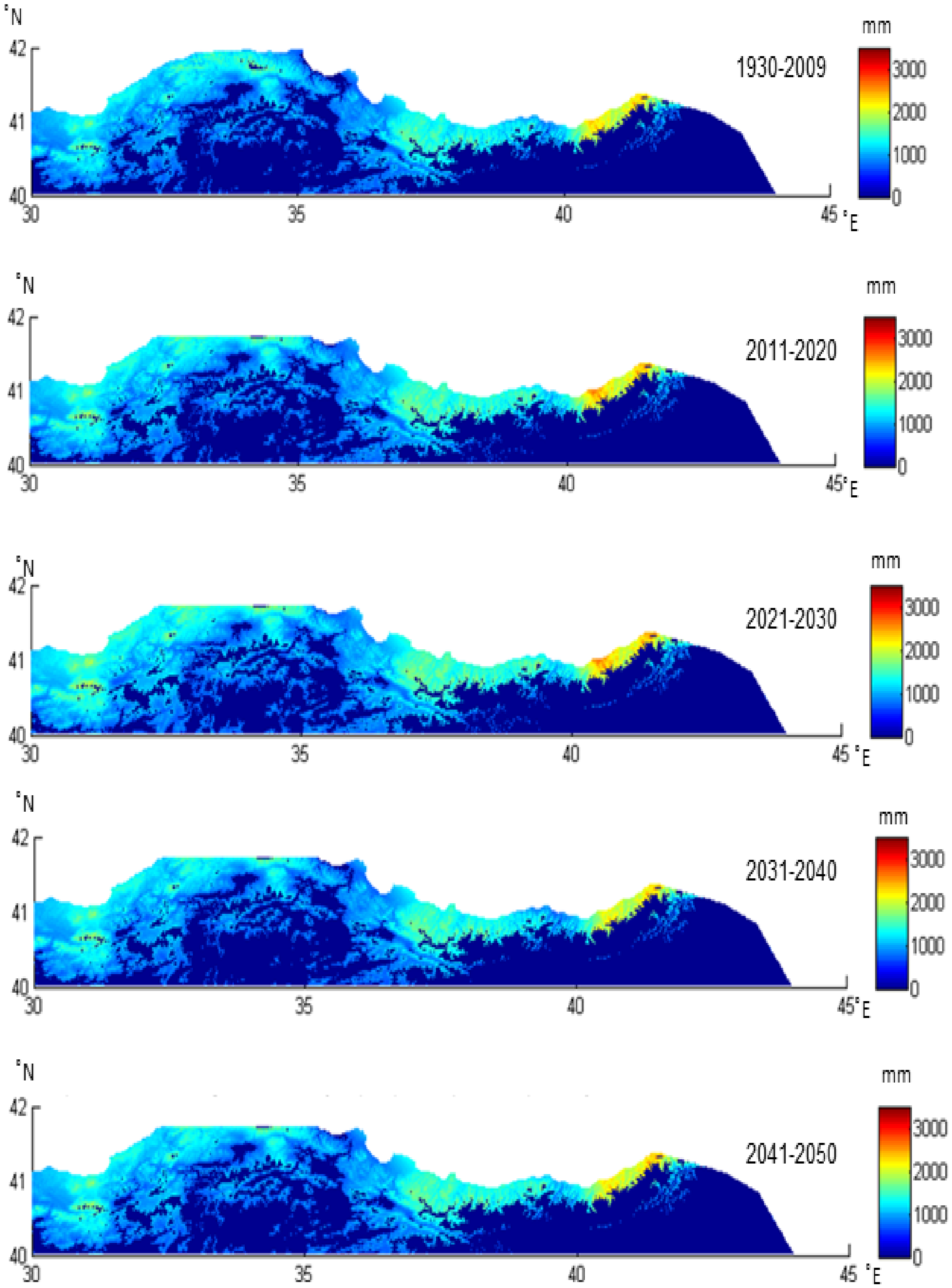

Figure 6a. *Annual rainfall (mm) and altitude conditions of potential hazelnut production areas (> 700 mm and < 1500 m.) in Turkey according to the long term years average meteorological stations temperature data (1930 - 2009); Annual rainfall (mm) and altitude conditions of possible hazelnut production areas (> 700 mm and < 1500 m) in Turkey according to A2 scenario between 2011 - 2020, 2021 - 2030, 2031 - 2040, 2041 -2050.*

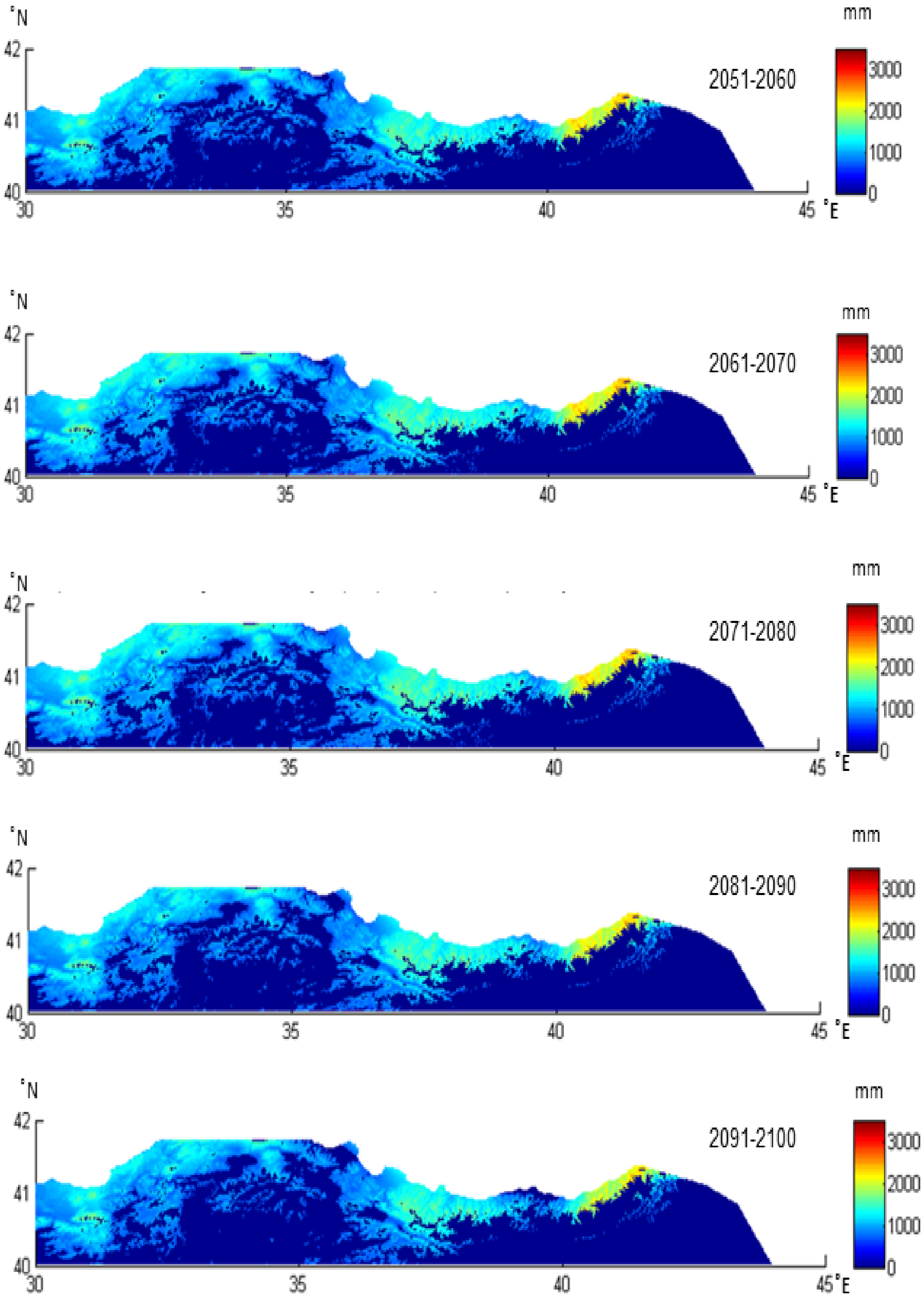

Figure 6b*. Annual rainfall (mm) and altitude conditions of possible hazelnut production areas (> 700 mm and < 1500 m.) in Turkey according to A2 scenario between 2051 - 2060, 2061 - 2070, 2071 - 2080, 2081 - 2090, 2091 - 2100.*

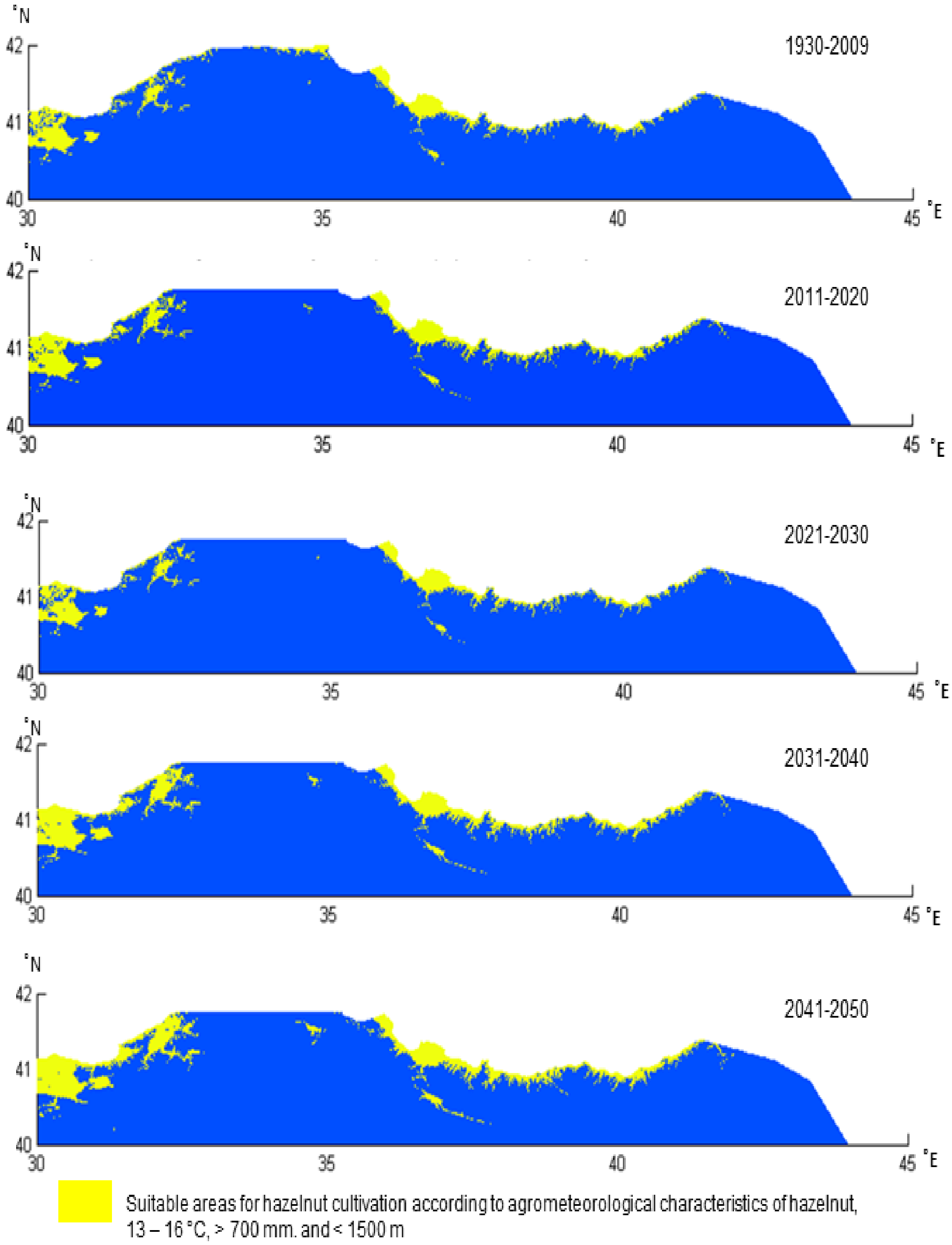

Figure 7a. *Average temperatures (°C) annual (mm) and altitude conditions of potential hazelnut production areas (13 – 16 °C, > 700 mm. and < 1500 m.) in Turkey according to the long term years average meteorological stations temperature data (1930 - 2009); average temperatures (°C) annual rainfall (mm) and altitude conditions of possible hazelnut production areas (13 – 16 °C, > 700 mm. and < 1500 m.) in Turkey according to A2 scenario between 2011 - 2020, 2021 - 2030, 2031 - 2040, 2041 -2050.*

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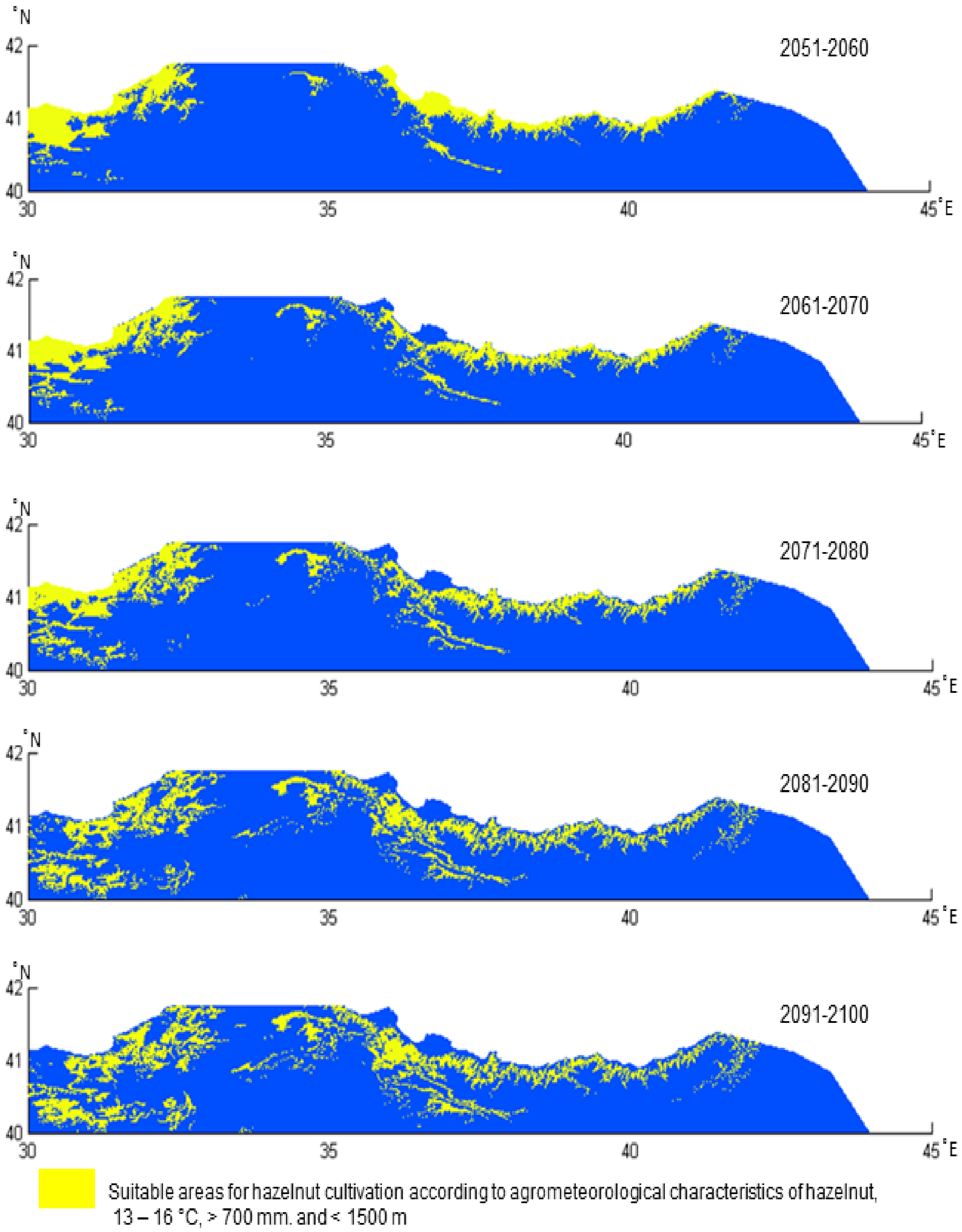

***Figure 7b**. Average temperatures (°C) annual rainfall (mm) and altitude conditions of possible hazelnut production areas (13 – 16 °C, > 700 mm. and < 1500 m.) in Turkey according to A2 scenario between in Turkey between 2051 - 2060, 2061 - 2070, 2071 - 2080, 2081 - 2090, 2091 - 2100.*

Taking A2 as the basis among the global climate change scenarios, the future hazelnut cultivation areas in Turkey have been investigated in 10 year periods with simulations to estimate the spatiotemporal change. According to the results of the simulation, it has been detected that the change in temperature values between 2011 - 2100 will be more significant when compared to the rainfall. Accordingly, an up to 6 ºC increase in the average temperature has been detected for the upcoming 90 years in the region. It has been estimated that the change in temperature conditions may cause a vertical and horizontal change in hazelnut cultivation areas. Especially the increasing temperature values may have a negative effect on hazelnut cultivation activities on the coast line between 0 - 250 m. A horizontal change has been seen particularly from coast to inland. On the other hand, the areas exceeding 1500 m that are not currently suitable for hazelnut cultivation may become arable lands due to vertical change. The possible need of cultivators for new hazelnut cultivation areas due to the climate change may result in deforestation of forested lands. Due to increasing temperature values on the coastal zone of the region, it is necessary to start developing alternative crops suitable for warmer conditions and introducing them to farmers. This should be considered especially on the coast line which has a dense population. If such operations are delayed until later, the effects of climate change on hazelnut cultivation which is the most significant crop and the most important income source of the region will bring along new socioeconomic problems.

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