A GIS BASED METHOD OF MODELING THE MAXIMAL RESISTANCE TEMPERATURES OF CORN IN THE TERRITORY OF EUROPE

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Abstract: *Climatic properties of the world have been changing through time. However, changed or unchanged, climatic properties influence the distribution of some plants. In this paper, we used three different prediction models of climate changes: global model (CMIP5 30-seconds), for the time period extending to 2100, in the territory of Europe. Furthermore, we embedded four possibilities of climate changes within this prediction model. Slight, when there are no climate change effects and temperatures increase for 0.5^{0}C. Moderate temperatures' increase would be up for 2.0^{0}C, whereas severe temperatures' increase would be up for 5.0^{0}C. Incredibly, temperatures will increase to the maximum resistance of predicted crops. With the help of GIS multi-criteria analysis and agroclimatological modeling, we showed models for corn in case of temperatures' increase in the territory of Europe. The mapping of this hazard could be very important for climatology, plants sciences, agronomy, geography and economy.*

Keywords: *GIS, corn, multi-criteria analysis, Europe, Mapping*

1. INTRODUCTION

Corn is a crop which is the most wide-spreaded in the world, as well as in Europe. Without corn, life and economy would be very difficult. Properties of corn show that this plant covers areas between 100 and 1200 m (Food and Agricultural Organization of the United Nations, 2016 [1]. In this research we were investigating the territory of Europe with area of 13,460.990 km^2. According to climate change influence in the territory of Europe Köpen's climate classification must be changed and refreshed. The data of Köpen's climate classification has been established since 1900, but some authors present refreshed and updated Köpen classification, with new data from 2000 [2]. In this research the hazardous predictions were established with the use of different softwares for climate analysis such as CLIMEX, DIVA-GIS, Climatology, Menex etc. [3]. With the use of CLIMEX software, some of the changes of climate properties were successfully applied in the territory of North America. This prediction included early growing corn properties along with hazardous effects in case of temperatures' increase between 2.7 and 4.0^{0}C until 2100 [4]. That prediction model includes the territories of Malaysia and Indonesia and approaches the production of palm oil. Other researchers tried to find patterns between corn growth and extreme weather conditions [5]. One of the predictions showed that crops would migrate to higher latitudes and to the higher altitudes [6]. Wheat and corn were growing in difficult conditions, but the necessity for food and crops doubled, especially in the regions of Southern Africa and South Asia [7]. The relationship

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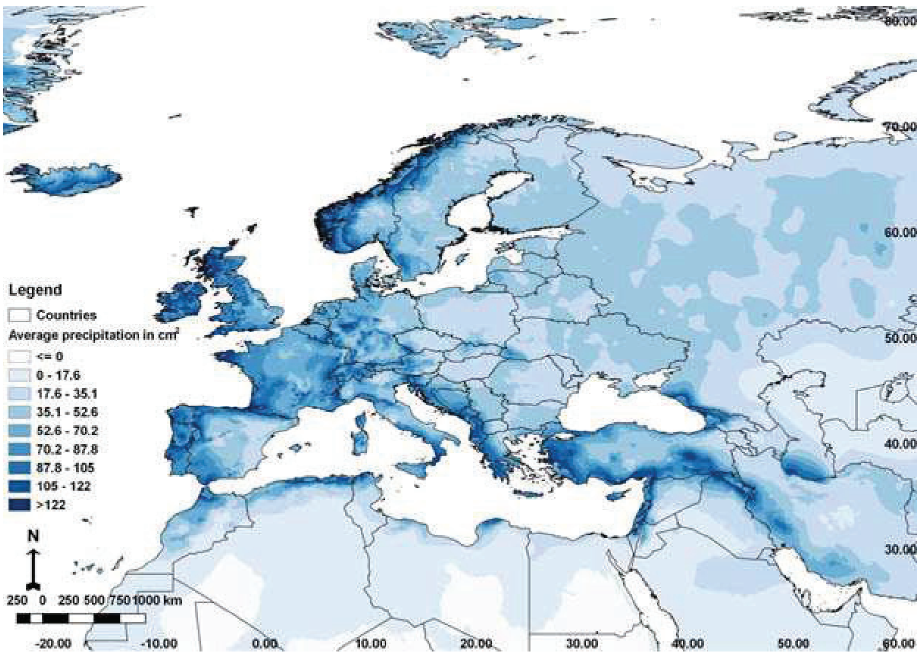
between edible plants i.e. corn and extreme climate has been successfully researched [8]. In this forecasting, the researcher established new species of corn which could be more resistant. For the following predictions, based on numerical simulations in the examination of the influence of hazardous weather on edible plants, the expected consequence is the movement of some plants to different longitude and latitude. Without some plants we can expect worse drought and floods everywhere [9]. According to the estimation of the influence of climate changes and with doubling of CO2 the food reserve may become minimal, especially in developed countries. In one study, the authors also explained the global situation for plants between periods of 1980 and 2008 in the United States. Factors like fertilization, enhancement of carbon dioxide emission and appliance of certain pesticides can alleviate the effects of climate changes on some plants [10]. Some studies in Europe show basic adaptation to climate changes with the help of agrotechnics. In this research, European continent has been divided into thirteen environmental zones, according to the questionnaire statistics. The first question would concern the main vulnerabilities of crops and cropping systems under present climate; (2) estimates of climate change impacts on the production of nine selected crops; (3) possible adaptation options as well as (4) adaptation observed so far. In addition, we focused on the overall awareness and presence of warning and decision support systems with relevance for adaptation to climate change [11]. One group of authors studied spring wheat and climate variability over 30 years in Canada [12]. In Slovenia [13], researchers adapted their research data for corn to the areas with predicted climate change. These authors used statistical emulator for the dynamic crop model of estimation for the areas in the inter-annual variability too. The potential impact of climate change on rice and corn in the Philippines was assessed by using the results from four general circulation models and the data of predicted temperatures. The effects of climate change influence the economy in the whole world. Also, this projection includes an adaptation of the economy with the use of new, adapted sorts of plants including corn and wheat, which must be more resistant [14]. Certain corn areas in Serbia are completely dependent on the effects of climate change. The economic price of corn in Serbia calculated with the help of irrigation systems, showed connection with the climate change effects [15]. Also, this projection includes an adaptation of the economy with the use of new, adapted sorts of plants. An experimental study was carried out in the most important agricultural regions of Serbia including the Province of Vojvodina. In this study, it was shown that if corn was growing in irrigated conditions for the period (2002-2010), yields would be increased for 40%. Corn areas and climate parameters were recorded in Serbia in the last forty years, and the results showed that each year, during the growing season, the crops were exposed to some degree of water deficit. In Serbia, the average water deficit is in June, July and August is 48 mm, whereas the required minimum for wheat is 98 mm and 88 mm for corn. During that period corn underwent phenological stages in which its sensitivity to drought was high. Rainfed corn grain yields varied considerably from year to year, ranging from 8.57 t ha^{-1} to 12.73 t ha^{-1} (average 10.46 t ha^{-1}). However, without GIS (Geographical Information System) we can't find real patterns between climate change and area under the influence of potential climate change. With the help of new advanced techniques such as remote sensing and GIS, prediction of climate change will be more precise. Some advanced GIS algorithms were successfully applied for reconstruction of forest properties in the Toplica region. These methods in this research were including remote data, analogue topographic maps, cadastre data, plans, etc. In addition to the changes in the forested areas, we had concurrent socio-economic changes which would be important for the distribution and density of the forest. The total number of trees in the Toplica region in 2013 was determined by applying numerical GIS methods and novel patent for determining the number of pixel in the field. These methods, called sub-pixel and pixel methods, are applied in determining the number of trees from the old analogue topographic maps. A very similar method may be applied to the research of corn in proposed areas. In analyzing the geospatial data we may include a few more methods. For geospatial analysis the priority is given to ordinary and global kriging method. These methods include autocorrelation and statistical relationship among the measured points [16, 17]. GIS numerical analysis may be applied also in calculating the renewability and dispersion of plants [18-21). In many ways we can use GIS analysis for geospatial calculation, as well as for climatology properties or predictions [22].

2. GEOGRAPHICAL FEATURES OF EUROPE

Europe covers an area of 13,460,990 km^2 or 2% of total land on the Earth. In this research we used border between Europe and Asia on Ural Mountain, on 67^{0}E. Europe extends to Cape Litinon on 34.55^0 S and this is the southern point. Northern point is Cape Nordkap in Norway on 71.21^0 N. For the western point of Europe, the point on the Cape Dunmore Head must be taken, with geographical longitude 10.30^0 W. The coastline of Europe is 41,000 km long, so it follows that Europe with the area of 1000 km^2 has 4.1 km of coastline. Europe is divided on three different coastline belts Atlantic, Arctic and Mediterranean (Figure 1). The borders of Europe include Caucasus Mountain, the Ural River, the Black and the Caspian Sea. Politically, Europe is divided into about fifty sovereign states.

Figure 1: Precipitation in Europe between 1950-2000. according to the open source DIVA/GIS and World Climatological Data. The map drawn by the author Aleksandar Valjarević



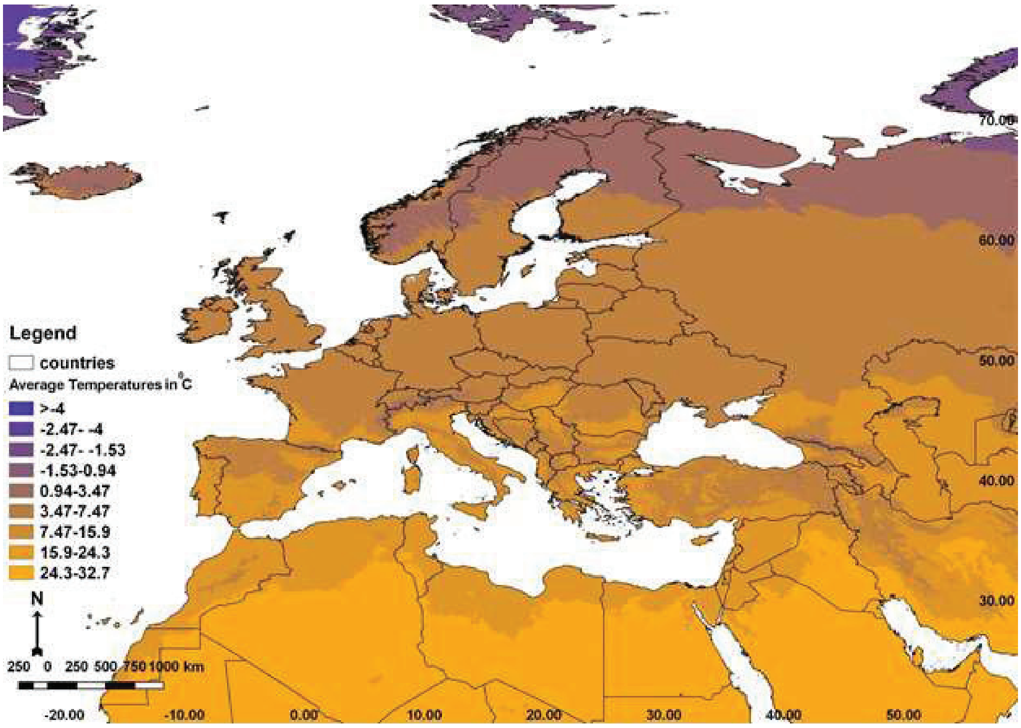
3. METHODS AND DATA

The CO_2 concentration is assumed following the estimate of the fifth Assessment Report AR5. The potential scenario is divided into four categories depending on the particle concentration (ppm) in the lower atmosphere. This information concerns the pre-industrial level which is calculated through the reference zero, the CO_2 quantities are between +2.6, +4.5, +6.0, and +8.5 W/m^2 [23]. We also used the special multi-criteria GIS analysis and climatological data, which are varied depending on the model and the examined plants. After geo-referencing of the European continent, we determined the boundary with Asia. The obtained results of the multi-criteria GIS analysis are divided into six classes: excellent, very suitable, suitable, marginal, very marginal, not situated. In the modeling of the whole European continent in connection with the resistance to climate (temperature) changes we used corn grown throughout Europe, latin *Zea Mays*, (abrev. Zea). This plant, except as food, can be also used in producing energy, edible oils, bio raw materials and others. Another reason why this plant is chosen is its importance for the survival of humankind, as well as the fraction in the export capacities of the European countries. Using the database of the World Meteorological Organization (WMO), from (DIVA GIS), as the basic grid we found the average quantities of precipitation and the average temperatures for the period of 1960-2000. The data for the prediction and temperature modeling were found in the grid of climatological data with 2100 as the final year [24]. The sets of the climatological data that are in the registered layers with a spatial resolution of 1 km^2 (30 arc-seconds) are used as the basis for obtaining geo-spatial dispersion models for the chosen plant. Long-term climatological data can be used in the mapping and spatial modeling of the bio-climatological data [25,26]. The other data are from the version of GIS DIVA 1.4 developments by the University of California Davis and the Stockholm Institute of Environment [27]. In obtaining the first grid the precipitations are divided into nine classes. These data are the basis for further and more complex modeling, since the same principle is applied to the grid that concerns the average temperatures. After inserting both 30 arc-sec TIFFA in GIS QGIS, which is open-source software, we can start agroclimatological modeling [28]. The basic agroclimatological parameters for corn, (Eco Crop), is supported and updated by the Food and Agriculture Organization of the United Nations.

4. GIS AND CLIMATOLOGICAL DATA

Geographic Information System (GIS) and modeling of agroclimatology properties or distribution of crops is a very powerful tool for describing the climate change in an area. GIS and climatological modeling are always successfully used for agroclimatology. All geospatial data can be used for mapping and modeling of the climatological data, as well as for precipitation and temperatures, moisture, wind properties etc. The ordinary kriging and global-kriging algorithms were employed through QGIS and DIVA (GIS) on the extension of the spatial analyst tool. Although there are a few other methods, the priority is given to ordinary kriging and global kriging because it includes autocorrelation or the statistical relationship among the measured points in the map. These points after finishing the operation in the GIS software will be exported on the map. This approach, the weights of points is based not only on the distance between the measured points and the predicted locations, but on the overall spatial arrangement of the measured points, too. These methods in combination with other advanced GIS numerical methods may be used in the presentation of climatological properties and data. The maps of the average temperatures and precipitations of Europe are given (see Figure 1; Figure 2). The distribution of corn areas in Europe was determined with the use of special extension on the bottom in the open source DIVA (GIS) software. DIVA (GIS) and QGIS have priority because they are robust and very precise software. The grid cell of climate properties is divided into six classes (Not Situated, Very Marginal, Marginal, Suitable, Very Suitable, and Excellent) whose resolution is $1km^2$. After total GIS analysis, we got areas of Corn, in the whole territory of Europe excluding the Russian part of Asia. We not only got the data in vector and raster formats ,but also in formats such as CSV, Excel, ESRI shape file and KLM (Keyhole Merkup File), [29].

Figure 2: Precipitation in Europe between 1950-2000. according to the open source DIVIA/GIS and World Climatological Data. The map drawn by the author Aleksandar Valjarević



5. RESULTS AND DISCUSSIONS

The results given in this research represent the forecasting for corn areas in case of global temperature increase for 0.5^0C. All the predictions until 2100 were given. The first prediction concerns a temperature change until 2100 not exceeding 0.50C. The second prediction, which seems to be more realistic, admits a temperature change to 2.0^0C. The third one, which can be regarded as catastrophic, admits that the temperature will be changed for almost 5.0^0C. The last prediction indicates the resistance degree for Europe. All results are classified into six classes (Excellent, Very Suitable, Suitable, Marginal, and Very Marginal, Not situated). The first three classes correspond to excellent and optimal conditions for the plant growth; the fourth and fifth class corresponds to the minimum conditions for the growth, whereas the sixth one corresponds to non-existing conditions for growth even in the case of applying agrotechnical measures. After the GIS analysis of 1 km resolution grid, we got areas for the territory of Europe. The total area of Europe is 13,460,990 km^2. According to the data from 2014 the total number of inhabitants in Europe was 853,215,836. The detailed analysis and complete modeling for corn in the case of temperature increase for 0.5^0C, in the territory of Europe showed that yield would be in the class of Excellent (20.6 %), Very Suitable (6.4%), and Suitable (6.7%). These three classes belong to the optimal ones in which the given plant would be grown fully. For the other three classes the results are Marginal (8.9%), Very Marginal (14.7%), and Not Situated with no possibility of growing the plant, which covers the area of (42.7%). For the two last classes (Marginal and Very Marginal) the possibility of growth of the plants is minimal. If the temperature increased to 2.0^0C, the area distribution would be as following - Excellent (14.3%), Very Suitable (7.6%), Suitable (4.2%), Marginal (7.8%), Very Marginal (13.7%), Not Situated (52.4%). If the average annual temperatures increased to 5.0^0C, the distribution of class would be - Excellent (10.3 %), Very Suitable (2.8%,), Suitable (2.1%), Marginal (5.1%), Very Marginal (5.3 %), and Not Situated (74.4%). In the case of hazardous temperatures, the corn areas in the territory of Europe would be as following - Excellent may cover (0.3%) of the territory, Very Suitable (0.3%), Suitable (0.34%), Marginal (0.02%), Very Marginal (0.04%) and Not Situated (99%). However, the results of agroclimatological modeling differ from country to country. For the temperature change for 0.5^0C the distributions and the areas covered by corn would be as following - France has a potential area of 234,500 km^2 with Excellent class, Italy has 150,040 km^2, Spain 79,400 km2. For Not Situated class, the largest areas would be in Russia 2,718,450 km^2, Turkey 660,450 km^2 and Ukraine 400,661 km^2. In the case of temperatures' increase for 2.0^0C, the areas of the excellent class would be distributed in countries as follows - the largest area would be in France 198,600 km^2, and in Italy 116,630 km^2, Turkey 100,900 km^2. Within the Not Situated class, Russia would have 2,866,470 km^2, Kazakhstan 2,720,770 km2, and Ukraine 412,196 km^2. If the temperatures increased to 5.0^0C, the excellent areas would be in Italy 131,100 km^2, France 105,230 km^2, Turkey 52,700 km^2. The countries with largest areas in Not Situated class are Russia with an area of 3,732,190 km^2, Kazakhstan 2,726,060 km^2, and Turkey 697,760 km^2.

Figure 3: Areas in Europe with excellent condition for corn growth in (%) with included changes of temperature and precipitation until 2100.

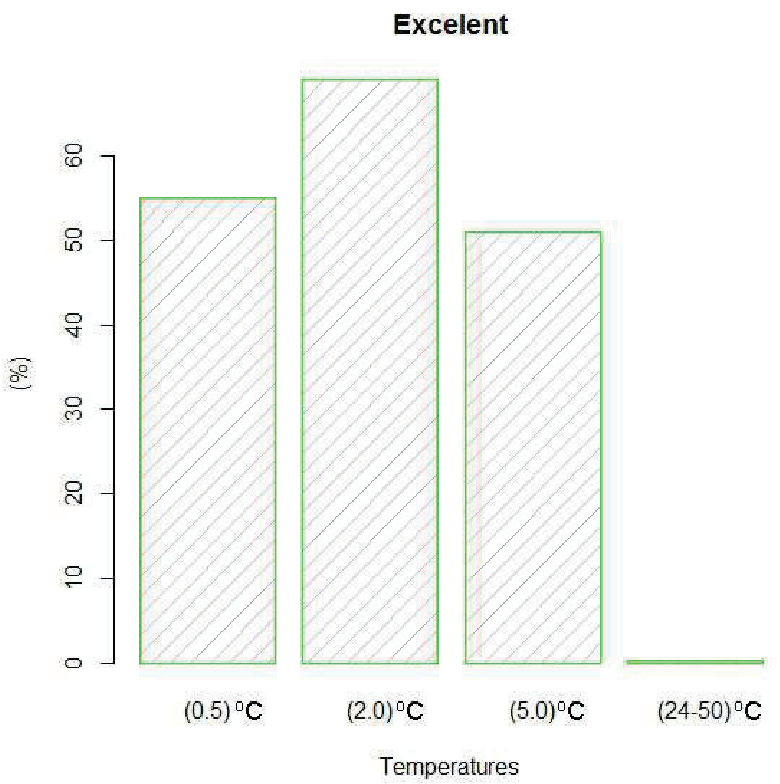
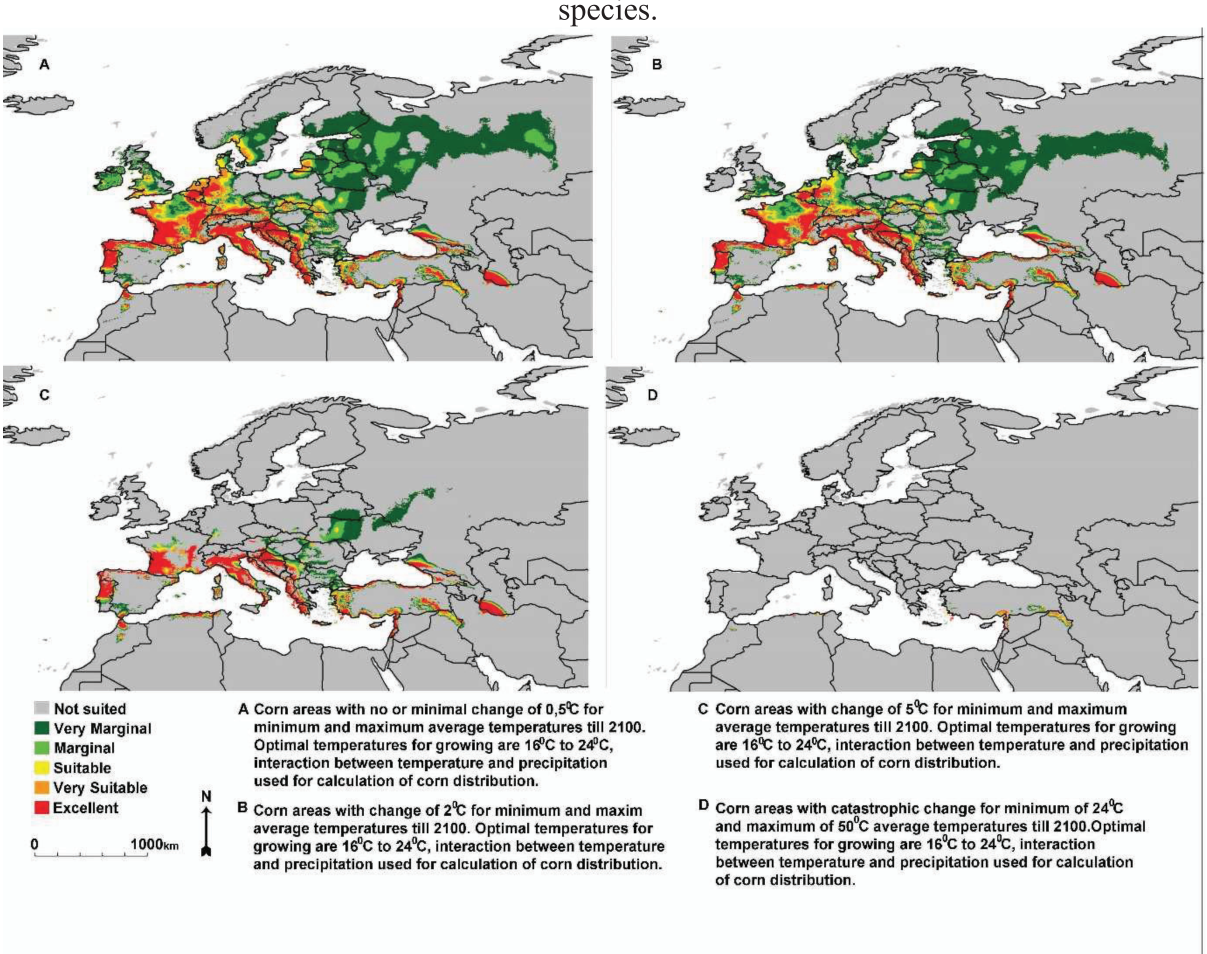


Figure 4: Distribution and forecasting for corn with different temperatures' increase. Temperature is low 0.5^0 C, moderate – to 2.0^0C, severe – temperature changes to 5.0^0C, and incredible – temperature changes to maximal or complete disappearance of certain plant species.



5. CONCLUSIONS AND POSSIBILITIES

Some scientists think that, as a consequence of temperature increase to 4.0^0C, a large part of Europe, also of the whole world, would become a desert. In such studies there is also the prediction concerning the increase of the level of the world seas. According to these models Siberia, the central and southern parts of the Scandinavian Peninsula, Greenland and Iceland would become new rich soils for cereals, whereas many European countries, such as Austria, Germany, Hungary, all Balkan countries, also Spain and Portugal, would become uninhabitable deserts. According to our results, in the case of a temperature increase to 5.0^0C potential areas of classes (Excellent, Very Suitable, Suitable) are expected to become smaller by 85%, but there will be islands (isolated areas) where with watering or sufficient precipitation, growing of corn will be also possible in the future. Our model includes precipitation and temperatures as hypsometry, normal lapse rate (the rate of temperature decrease with altitude for 0.65^0C per 100 m). Therefore, our prediction is somewhat more optimistic, though the food production in many European countries will become questionable. Russia, Scandinavia, also Iceland, will not be able to become rich soils with minerals for potential plants, because each study of their soils has to take into account large quantities of ice (permafrost) since very rapid melting can produce river streams that would wash out the fertile soil converting it into mud. What is probable is that all the three cultures could adapt to the newly formed conditions at high altitudes or under mountain ridges, also along the large water areas, where periods of sufficient precipitation could exist, taking into account artificial watering as well. European farmers would use new adapted plants sorts that could more easily endure the newly formed climate. Such sorts would need less water or they could be successfully grown at high altitudes, as well as on less inclined slopes. In our study the relationship between temperature and water is also taken into account: what would occur if the number of days with precipitation became significantly smaller or no watering was done is that the results would be surely even more worrying. Areas modeled in the present paper for every European country separately appear as a theoretically usable soil that can also be used for other purposes, inter alia for seeding other plants. As an optimistic result of our modeling we can mention that after the climate change, suitable zones will be located within urban and sub-urban zones. Therefore, a new urban policy will be required, which should be directed against inevitable conversion of agricultural land into urban one. Alternative solutions could be in forming ecological zones and vertical farms within urban settlements. On sub-urban and open areas in such situations new parcels would be formed to be near large accumulations, even at higher altitudes. Any model of future climate is an essential prerequisite in order to reach local, regional and global predictions as good as possible. Only sufficiently good predictions offer possibilities to be successfully prepared and adapted to what could come with climate change.

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