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The future of edible crops in Europe and their maximum point of resistance in temperature increase

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Abstract— In the last decades, knowledge about the climate has increased significantly. Climate change today is the subject of many sciences, including meteorology, climatology, geology, geography, geophysics, astronomy, etc. The present predictions with updated meteorological data and with data of the number of particles of CO_2 in the troposphere may give satisfying results. Forecasting for industrial grains such as maize, soybean, and wheat will be essential for industry and everyday life. Within the last agreement of climate change in Paris, global temperatures will continuously be increasing by 2100. In this research, we used a synthetic grid with agroclimatological data which comprises predictions until 2100. These data were found in the sub-section called World Clim Version 1 or in the CMIP5 database. After numerical and geospatial GIS analysis, we got the following predictions: (i) slight- no temperature changes or changes including the increase of temperature by 0.5 °C, (ii) moderate- temperature increases by 2.0 °C, (iii) severe- temperature increases by 5.0 °C, and (iv) incredible- temperature increases to extreme values, incase of which the survival of plants will be endangered.

Key-words: plants, Europe, GIS, geospatial, agroclimatology, predictions, future

1. Introduction

Wheat, corn, and soybean are the most widespread edible plants in the world. The same edible plants are present in Europe's temperate zones (Food and Agricultural Organization of the United Nations, 2016). For this study, we used the physical and geographical properties of Europe, covering 13,460,990 km^2 (*Rumford*, 2007; *Newman*, 2006).

Climate change has an enormous influence on the population, future migration, dispersion of goods, and economic growth, not only in Europe but also throughout the world (*Kottek et al.,* 2006). The consequence may also be the changing of land fertility and land quality. With the constant increase of temperatures, we may expect the expansion of non-fertile soils, especially in arid areas (*Perry et al*., 2004 *Lenihan et al.,* 2003).

The harmful effect of climate change can put to risk agricultural production and sustainable development. The influence of such climate parameters was successfully included in the modelling of soybean and maize during their early growth phase, in the territory of the United States of America (*Liheng et al*., 2016).

Specific climate models are necessary for oil palm growth, to which authors applied 2.7 °C – 4.0 °C temperature increase until 2100. Recently, many types of researches have been predicting surface and sea-surface temperatures at a global scale (*Köppen,* 1900). Using different kinds of simulations, including sea-ice concentration and sea-surface temperatures, the authors gave a new perspective of global circulation and climate change. In this research, many relation models of temperature-precipitation were tested (*Dittus et al.,* 2018; *Gouda, et al.,* 2017). For this purpose, the authors used the CLIMEX software modelling (*Paterson et al.,* 2015).

With the prediction of low precipitation and extreme weather conditions to 2050, the modelling of wheat was performed, along with the display of its vulnerability (*Beck et al.,* 2005). The damage of some species of grain would be 30%, especially in the vegetative period (*Semenov* and *Shewry*, 2011). The relationship between edible grains and meteorological measurements was successfully established and studied on new resistant species of grains. These new species could be adapted to extreme temperatures and extreme meteorological parameters to a great extent. For example, newly modified grains may grow at higher altitudes or in hotter regions and semi-arid and arid areas (*Challinor et al*., 2009.)

According to the estimation of the influence of climate changes on the food production and food reserves, in the case of doubling the CO_2 level, the food production, especially the production of grains, can become minimal in developing countries, which would have fatal consequences for their economies (*Rosenzweig* and *Parry*, 1994).

Climate change has already affected the southern part of California, where regional increases in temperature and vegetation may be destructive for some plants. The data of these effects have been observed and estimated for a long term period. In this research, CMIP5 temperature projection was used with the parameters of particularly extreme conditions. Researchers used a vegetation model to illustrate temporal and spatial shifts in land cover, in response to changes in environmental conditions (*Bachelet et al.,* 2016). In the study of land use and land cover changes in eastern Sudan, researchers investigated the changes of land cover with the help of the aridity index, temperature, and rainfall changes of land cover. In this research, soil erosion effects and agricultural influence on new lands were used (*Suleiman* and *Elagib*, 2012).

Similar predictions based on numerical simulations and geographical parameters showed that some grains might survive, even if temperature increases by more than 3.0 °C. This study presupposes that the bad influence of climate change will not be manifested equally in different places, while the temperatures will be the same everywhere (*Asseng et al.,* 2013). Temperature extremes' influence on the growth was successfully tested on some plants with different phonological characteristics. Temperature is a primary factor affecting the rate of plant development. Warmer temperatures expected with climate change, and the potential for more extreme temperature events will impact plant productivity (*Hatfield* and *Prueger*, 2015; *Ayal* and *Filho,* 2017).

Each of the seven continents has its climate properties, and therefore, the effect of climate change will not be the same for all of them. Many researchers have studied the influence of climate change on local, regional, and global scales. *Barrow* (1993) analyzed the effects of climate change using a generalized circulation model (GCM) applied in the territory of Europe.

By studying the spatial aggregation between crops and climate, it is possible to adapt to the plants' productivity with the help of digital analysis. In the territory of Ethiopia, in the area of highlights, researchers applied climate variability effect on agricultural production. They concluded that humanity must use the adaptive capacity to climate change in many aspects, including tourism and suitability (*Kovacs et al.,* 2017; *Vukoičić et al.,* 2018). The analyzed winter species of wheat crops and the effect of climatic variability in Canada's territory for 30 years showed better results than the summer species of wheat (*Qian et al.,* 2009).

Climate modeling of various zones was applied by (*Zhang et al*., 2012). In this research, the authors compared the phenology of rice with the phenology of wheat and with a large number of different climate parameters. A particular influence of climate change and the vulnerability of corn have been applied to the crops in Slovenia using modern phenology methods (*Ceglar et al*., 2011). Global warming also influences the energy, which is necessary for better crop growing. Thus, high energy imposed on plants during their growth may produce irretrievable damage (*Sanderson*, 1999*; Mohareb et al.,* 2017).

These authors introduced a particular statistic emulator, which was presented by dynamical model of crops. Some authors meticulously presented food security challenges with the influence of climate change in the territory of Malaysia. This research included adaptations of the plants in case of temperature increase and variable precipitations (*Al-Amin* and *Ahmed*, 2016). Climate changes can produce significant consequences for crops productivity and food security at a global scale (*Lobell* and *Field*, 2007). Other researchers included plants diversity in the area of Europe when temperatures increase (*Lazzerini et al.,* 2015).

Other authors described future climate changes in the Apennine Mountains to find the connection between crops and climate (*Dibari et al.,* 2015). Most of the adaptation strategies included a large number of climate and water management scenarios. This water variability always included deficits of precipitations and a high rate of temperatures. Two climate change scenarios (CMP5 and GCMs models) were used in this research (*Huang et al.,* 2018; *He et al.,* 2018; *Fraga et al.,* 2018). There is also a research investigating post-Soviet cotton cultivation and integrated irrigation or non-irrigation parameters in Central Asia. The data downloaded from the Landsat satellite Modis (Modis Resolution Imaging Spectroradiometer) may help determine the mean value of the forest belt (*Conrad et al.,* 2016). In Spain, a researcher adapted a unique AdaptaOlive model to establish simulation for future climate change. This model may show a deficit of precipitation and irrigation and predict future strategies (*Lorite et al.,* 2018). All of the investigations must be delegated to better prediction of climate risk management. The climate risk management may be addressed and applied to plants, since the climate is always interacting with plants (*Araya et al.,* 2017; *Pramanik et al.*, 2018).

2. Physical geography of Europe

European geospace, including its borders, was the subject of this study. Some of the authors have used Europe independently, while others have been conducting their research on Eurasia (*Thuiller et al.,* 2004). Europe, including the European part of the Russian Federation, has an area of 13,460,990 km^2. The border between Asia and Europe is on the Ural Mountains at 67°E. In the south, the bordering point is Cape Litinon at 34.55° S, and in the north, it is Cape Nordkap in Norway at 71.21° N. In the west, this point is Cape Dunmore Head in Ireland, at 10.30° W. The main climatological advantage of Europe is its position in the northern temperate zone. The relief of Europe near the coastline is lower than 3° of the angle of slope. The other advantage could be that Europe has a long and indented coastline, with the average indent ratio of 4.1 km^2. A large number of islands and the indented coastline may be the advantage because of different climate variables. In the territory of Europe, there are three different coastal belts: the Atlantic, the Arctic, and the Mediterranean.

The Atlantic coast is located in Western Europe, and it reaches the shores of Norway in the northwest. The Arctic coast is located in Northern Europe. Northern Europe, in terms of region, belongs to the polar Arctic region. The Mediterranean coast is the third specific region of Europe. The Mediterranean belt has the Iberian, Apennine, and Balkan Peninsulas. The coastlines of Europe reach the seas of Africa. The relief in Europe does not abound in very high mountains. Furthermore, the energy of relief is low in comparison with other continents. Accordingly, Europe has excellent possibilities for plants' growth, especially for grains. The most dominant mountain system is the Alps (4807 m), the following is Ural, which presents the border between Europe and Asia with a length of 2500 km.

The essential plains in Europe present the most significant agricultural areas. These plains are located in East Europe, Central Europe, the Netherlands, and Pannonian Basin. The average production in the countries which belong to European plains is between 3,500,000 and 7,000,000 tons. The total area of plains is 4,000,000 km^2 (*Cocks,* 2000). In the east, the East European plain reaches the Ural. The Central European plain covers the northern parts of Germany and Poland.

In the north, Europe is open until the Baltic and North Seas, in the south its boundary is in central Germany, i.e., the Sudetes and the Beskids. The Pannonian plain's length is 1,000 km, whereas the average height is between 200 and 400 km. Its lowest parts are characterized by very fertile soils, covering the area of 125,000 km^2. The Pannonian plain is surrounded by the Alps, the Carpathians, and the Dinarides.

3. Methods and data

The CO_2 concentration is assumed following the estimate of the fifth Assessment Report AR5. This assessment is also used and implemented in the CMIP5 model. The potential scenario is divided into four categories; all scenes are connected with the concentration of particles in the lower belts of the atmosphere. The concentration of the pre-industrial level of CO2 was near 0 levels. After the industrial revolution, this concentration increased to +2.6, +4.5, +6.0, and to 8.5 in recent times (*Weyant et al.,* 2009; *Moss et al.,* 2008). In this study, we used a specially created algorithm and procedures in the Geo-Python code. This code is implemented in the architecture of the QGIS software. Using georeferencing, interpolation, semi-kriging, kriging, and sub-kriging, we studied the dispersion and properties of three grains (wheat, corn, soybean) using GIS software DIVA and QGIS. After a successful georeferencing of the European border, we continued with the process of downloading data from the DIVA-GIS database. Four kinds of data were downloaded: maximum, minimum, and average annual temperatures, and average annual precipitations (*Table 1*).

Table 1. Physical properties of plants following the change of precipitation and temperature

Sp.	Length of growing season in days			Temperature variables in C°					Precipitation in mm/m²			
	Gm	Gmix	Gu	Ktmp	Tmi	Tomi	Tomx	Tmax	Pmin	Pmx	Pomi	Pomx
Z.M	65	100	82	0	12	16	24	38	600	1800	800	1500
T.A	120	180	150	0	6	17	25	30	400	800	500	700
G.M	75	180	128	0	10	20	33	38	450	1800	600	1500

Abbreviations: Gm-Growing season minimal, Ga-Growing season maximal, Gu-Growing used, Ktmp-Killing temperature, Tmi-Temperature minimal, Tomi-Temperature optimal minimal, Tomx-Temperature optimal maximal, Pmin-Precipitation minimal, Pmx-Precipitation maximal, Pomi-Precipitation optimal minimal, Pomx-Precipitation optimal maximal, Z.M-Zea Mays, T.A-Triticum Aestivum, G.M-Glycine Max. (Source: Food and Crop UN organization)

All of these data are for the period between 2000 and 2100. The obtained results of GIS analysis after numerical analysis are divided into six classes. These classes are excellent, very suitable, suitable, marginal, very marginal, not situated. After in-depth analysis of plants, we obtained the areas of their dispersion. The properties of plants were used from the database Eco-crop, in which we found all the phenomenological data for investigated grains. This base belongs to the official plants support of the United Nations. In this database, we found 2568 common plants with complete physical and biological properties such as growth period in total, killing temperature of the root, minimal temperature for the proposed plant. These physiological properties, combined with climatological features, may give excellent results for dispersion of plants and prediction of growth in the future.

Further, considering the temperature changes, we performed the analysis of the areas for soybean (*Glycine*), maize (*Zea Mays*), and wheat (*Triticum aestivum*). All of the plants are very important not only for Europe but also for the whole world when it comes to the production of food and energy. The following features are the export capacity of Europe and the assessments of what would happen if temperatures increase to incredible condition.

If Europe became semi-arid and arid land with some agrotechnological support, it could be a leader in grains production. The data for the prediction were given in raster or Geo-tiff extension. This raster is very precise, and it was downloaded from the official web page DIVA at the free data of climate (http://www.worldclim.org/). This service includes free, simple, and effective climatological data from the past, present, and future. We used old version 1.4 of data, because all the data in this version were given in a couple of extensions. The extension used is Geo-tiff in the resolution of 10, 5, 2.5 minutes, and 30 seconds. Continuation of 30 seconds is exact and useful for climatological data predictions, giving prediction to the year 2100.

This year presents long-term analyses, and it is the right prediction for potential adapting (*Zabel et al.,* 2014). Long-term climatological data can be successfully changed and used to map and spatial modelling of bioclimatological data and properties (*New et al.,* 2000; *Saha* and *Khan*, 2000; Mitchell and Jones, 2005). Other data were used from the downloaded pages at the Davis University of California and the Stockholm Institute of Environment for the comparison (*Vicuna et al.,* 2007).

The first grid of precipitation is analyzed within nine classes. Average precipitations in Europe were presented by using QGIS, for the period between 1960 and 2000. Average temperatures are presented in *Figs. 1* and *2* between the same periods in the same territory. This grid is used for in-depth agroclimatological forecasting of three researched grains. After exporting grid data, we inserted this grid on the map. After that, we started with the analysis of data and their modelling (*Ward,* 2007; *Li et al*., 2015). The predictions were also divided into four classes. When the temperature increases by 0.5 °C up to 2100, it presents optimistic scenarios and is strongly connected with the Paris agreement.

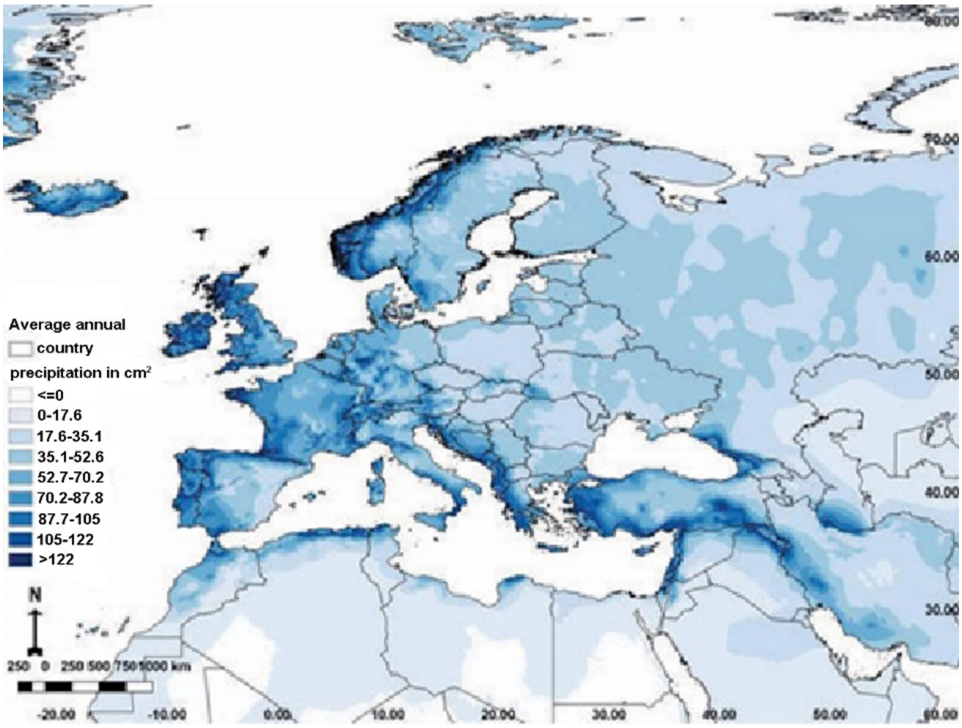

Fig. 1. Average annual precipitation in Europe within the period of 1960–2000.

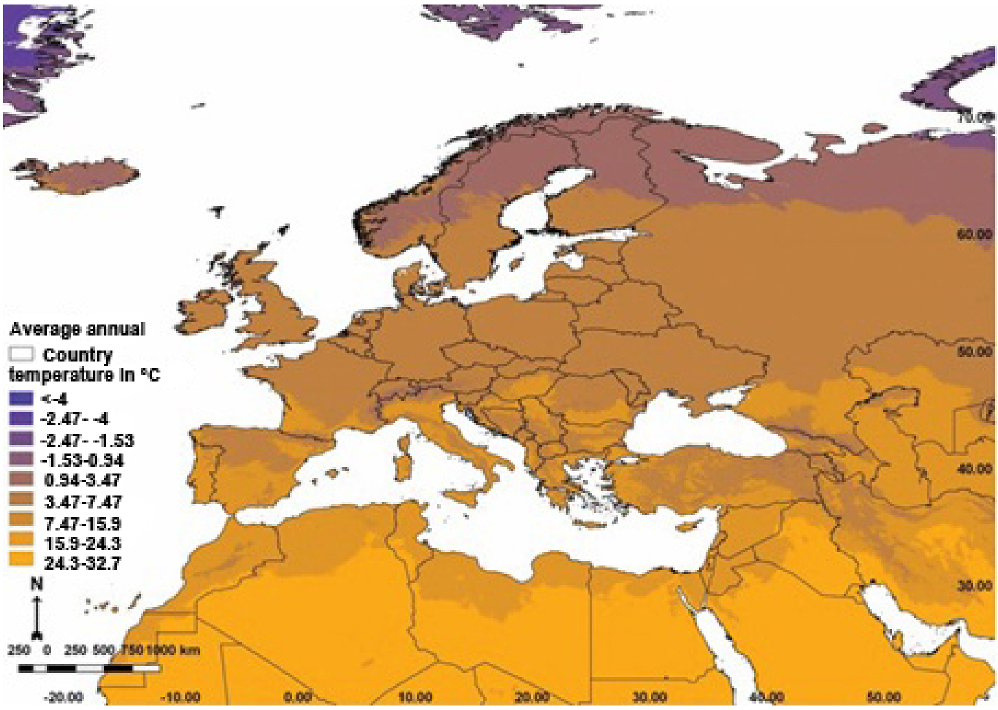

Fig. 2. Average annual temperature in Europe within the period of 1960–2000.

In the second class, we may expect 2.0 °C increase in temperature. This prediction shows that the Paris agreement is fulfilled but not in all countries. The third class shows the rise in temperature by 5.0 °C and the rejection of the Paris agreement by 60% of countries. Finally, the last fourth class presents catastrophic, devastating temperatures for the survival of plants.

In case of corn, the most optimal growth temperatures are between 16 °C and 24 °C, but for wheat, these temperatures are between 15 °C and 23 °C; soybean is more resistant, and its maximal point of resistance is between 20 °C and 33 °C. After setting the European border, we included all European countries according to the EU base. These countries are Albania, Andorra, Austria, Azerbaijan, Belarus, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Georgia, Germany, Greece, Hungary, Iceland, Ireland, Italy, Kazakhstan, Latvia, Lichtenstein, Lithuania, Luxemburg, Macedonia, Malta, Moldova, Monaco, Montenegro, The Netherlands, Norway, Poland, Portugal, Romania, Russia, San Marino, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine, United Kingdom, Vatican City, Cyprus. Between 1960 and 2000, the average and yearly precipitation over the territory of Europe was between 702 and 878 mm (*Fig. 1*). The average temperature in Europe within the 40 years was between 7.5 °C and 15.9 °C (*Fig. 2*).

4. GIS agroclimatological and numerical data analysis

Geographic Information System (GIS) and the modelling of agroclimatological data, as well as the plant distribution and properties, are fundamental approaches that can be used for presenting the spatial features of climate and climate changes. Climate modelling based on agroclimatological data may show the present condition and predict the future of plants. Ordinary kriging and semi-kriging methods were employed through QGIS and DIVA software. This algorithm was used to estimate plant properties called spatial analysis. Although there are many other algorithms, this algorithm is beneficial, because it is precise and fast in calculating the data. The kriging method was used as one of the most standard methods in interpolation and clustering. Also, this method reduced the errors of geostatistical analysis. By using the grid analysis, we estimated two cycles of 40 years.

In this way, we established a long-term analysis of meteorological data. The agroclimatological properties and plant distribution were obtained by applying open-source software DIVA-GIS for mapping and geographic data analysis. This software is robust with very high accuracy. The derived raster has a resolution of 1 km^2. After determining the grid, we inputted shape files extension. The advantage of DIVA-GIS software is that it can read many types of input files such as CSV, Excel, ESRI shape file, and KLM.

5. Results and discussion

After modelling the agroclimatological data, we used the interaction between average annual temperature and precipitation. The first prediction concerns a temperature increase of 0.5 °C until 2100. The second prediction, which would be more realistic, presupposes temperature increase of 2.0 °C. The third prediction included a 5.0 °C increase of temperature, and the fourth presents the ultimate limit for the survival of plants, thus presenting catastrophic scenarios.

After complete geospatial analysis for corn, the minimum temperature is 24.0 °C and the maximum is 50.0 °C. The condition for wheat is somewhat different, where the minimum temperature is 19.0 °C and the peak is 40.0 °C.

In contrast, for soybean, the minimum temperature is 26.0 °C and the maximum is 54.0 °C. This analysis gives novel results for the maximum resistance for the three investigated plants in 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 classes correspond to the minimum requirements for the growth, whereas the sixth one corresponds to the impossibility of plants' growing. Since GIS analyses were exact, we estimated areas for all European countries. According to the data from 2014, the total number of inhabitants in Europe is 853,215,836.

For corn, if the average annual temperature increases by 0.5 °C, the ratio of area classes in Europe will be the following: (excellent: 20.6%, very suitable: 6.4%, suitable: 6.7%, marginal: 8.9%, very marginal: 14.7%, and not situated: 42.7%). For the class marginal and very marginal, the possibility of growth of plants is minimal. If the temperature increases by 2.0 °C , the areas would be as follows: 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 temperature increases by 5.0 °C, the distribution of classes will 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 devastating temperatures, we got the following results for the territory of Europe- excellent: 0.3%, very suitable: 0.3%, suitable 0.34%, marginal: 0.02%, very marginal: 0.04%, not situated: 99%. For the areas of wheat, when temperature increases by 0.5 °C, classes will be distributed in the following way: excellent: 4.4%, very suitable: 9.1%, suitable: 15.9%, marginal: 21.2%, very marginal: 8.6%, not situated: 40.8%. In case of temperature increase of 2.0 °C, we may expect the following dispersion: excellent: 3.78%, very suitable: 5.04%, suitable: 10.7%, marginal: 20.47%, very marginal: 15.22%, not situated: 45.42%.

If temperature increases by incredible 5.0 °C, distribution is -excellent: 4.7%, very suitable: 3.87%, suitable: 2.78%, marginal: 10.35%, very marginal: 14.7%, and not situated: 63.6%. When the temperature reaches the highest value, distribution of wheat areas will be -excellent: 0.013%, very suitable: 0.008%, suitable: 0.82%, marginal: 1.54%, very marginal: 1.35%, not situated: 96.2%. The situation for soybean if temperature increases by 0.5 °C is excellent: 10.16%, very suitable: 10.1%, suitable: 16.28%, marginal: 2.,2%, very marginal: 9.22%, not situated: 30.04%.

If temperature increases by 2.0 °C, we have excellent: 8.16%, very suitable: 9.1%, suitable: 15.28%, marginal: 28.2%, very marginal: 11.22%, not situated: 28.04%. If temperature increases by 5.0 °C, we have the following classes: excellent: 2.16%, very suitable: 4.9%, suitable: 12.88%, marginal: 20.2%, and very marginal: 19.22, and not situated: 40.64%. If temperature increases to devastating rate we, may expect the areas as follows: excellent: 0,012%, very suitable: 0.002%, suitable: 0.004%, marginal: 0.005%, very marginal: 0.077%, and not situated 99.9%. In the interval between 0.5 °C and 5.0 °C, we have the increase of the class not situated for wheat by 9.7%, for corn by 4.62%, for soybean by 11.13%.

When we established the estimation country by country, the results were calculated in the following way: if temperature increases by 0.5 °C, France has 234,500 km^2, Italy has 150,040 km^2, Spain has 79,400 km^2 in the exellent class. If temperature increases by 0.5 °C, the class not situated will cover the territory of 2,718,450 km^2 in the Russian Federation, 660,450 km^{2}in Turkey, 400,661 km^2 in Ukraine. If temperature increases by 2.0 °C, we have the following results for excellent class: France: 198,600 km^2, Italy: 116,630 km^2, Turkey: 100,900 km^2. Countries in the not situated class are the Russian Federation with 2,866,470 km^2, Kazakhstan with 2,720,770, km^2, Ukraine with 412,196 km^2.

If temperature increases by 5.0 °C, we may expect an excellent area in the following countries: Italy: 131,100 km^2, France: 105,230 km^2, Turkey: 52,700 km^2. In the class not situated, we have the Russian Federation with 3,732,190 km^2, Kazakhstan with 2,726,060 km^2, Turkey with 697,760 km^2. For wheat, we have somewhat different situations. If temperature increases by 0.5 °C, excellent class will be distributed in Italy on 64,700 km^2, in Turkey on 52,100 km^2, in Portugal on 26,350 km^2. Not situated class will be distributed in Russia on 3,487,600 km^2, in Kazakhstan on 2,686,670 km^2, and in Turkey on 398,920 km^2. If temperature increases by 2.0 °C within excellent class, we have areas in Italy 76,910 km^2, in France 35,300 km^2, in Portugal 34,100 km^2. In not situated class, we have 3,554,470 km^2 in the Russian Federation, 2,666,210 km^2 in Kazakhstan, 481,380 km^2 in Turkey. If temperature increases by 5.0°C, we have in excellent class 38,600 km^2 in Italy, 24,400 km^2 in Portugal, 21,590 km^2. In the class not situated, we have 3,624,500 km^2 in the Russian Federation, 2,680,940 km^2 in Kazakhstan, and 587,940 km^2 in Turkey. The results are somewhat different for soybean, especially those concerning the temperature increase by 2.0 °C to 5.0 °C.

If temperature increases by 0.5 °C, we have the excellent class in the following countries: Turkey: 160,170 km^2, Italy: 119,300 km^2, Greece: 57,200 km^2. In the class not situated we have Kazakhstan with 2,710,250 km^2, Russia with 1,568,177 km^2, Turkey with 457,400 km^2. If temperature increases by 2.0 °C, in the excellent class, Turkey will have 91,500 km^2, Italy 80,000 km^2, Spain 47,300 km^2. For class not situated, we have the following countries: Russia with 2,753,900 km^2, Kazakhstan with 2,715,440 km^2, Turkey with 530,060 km^2. If temperature increases by 5.0°C, we have in the excellent class Italy with 89,200 km^2, Turkey with 34,200 km^2. For class not Situated, we have Russia with 3,234,560 km^2 and Kazakhstan with 2,900,400 km^2 (*Figs. 3–5*).

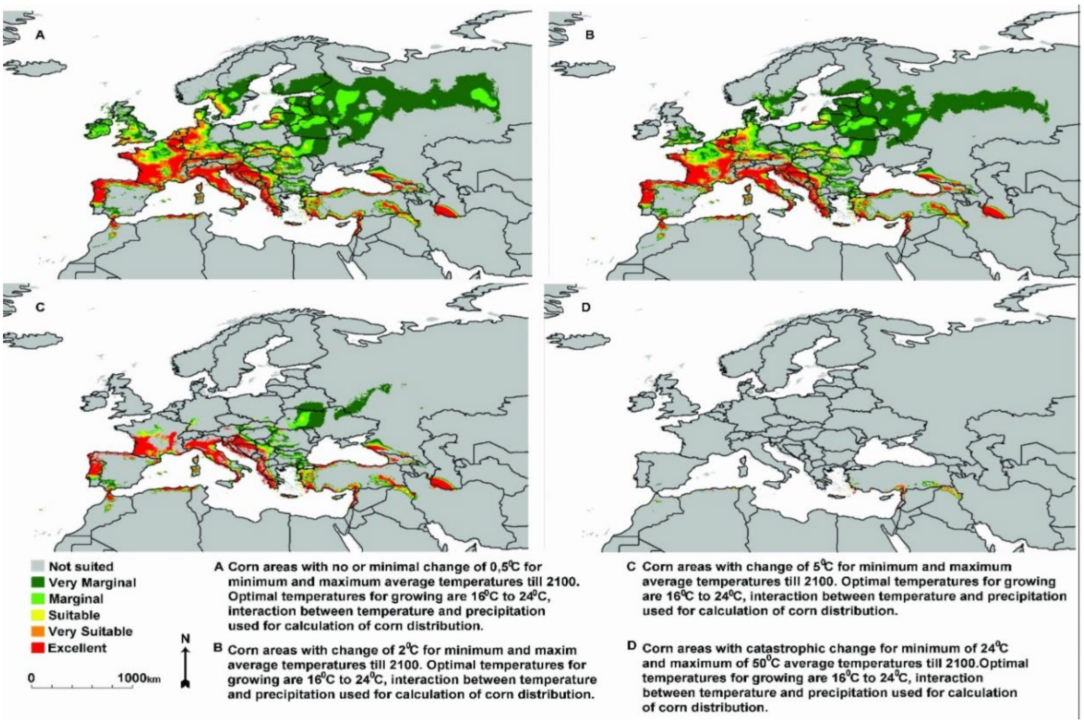

Fig. 3. Distribution of corn areas in different climate predictions (slight- there is no change of climate or maximum temperature increases by 0.5°C, moderate –maximum temperature increases by 2.0°C, severe –maximum temperature increases by 5.0°C, and incredible – the temperature further increases, and we may expect the disappearance of all plants.

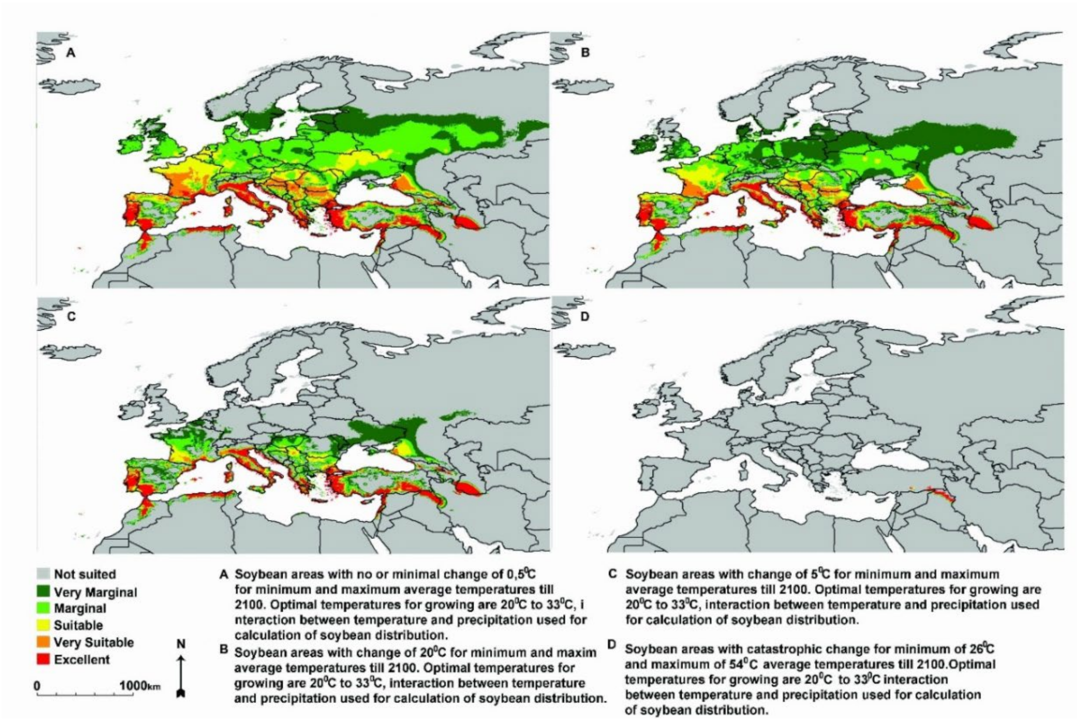

Fig. 4. Distribution of wheat areas in different climate (slight- there is no change of climate or maximum temperature increases by 0.5°C, moderate –maximum temperature increases by 2.0°C, severe –maximum temperature increases by 5.0°C, and incredible – the temperature further increases, and we may expect the disappearance of all plants.

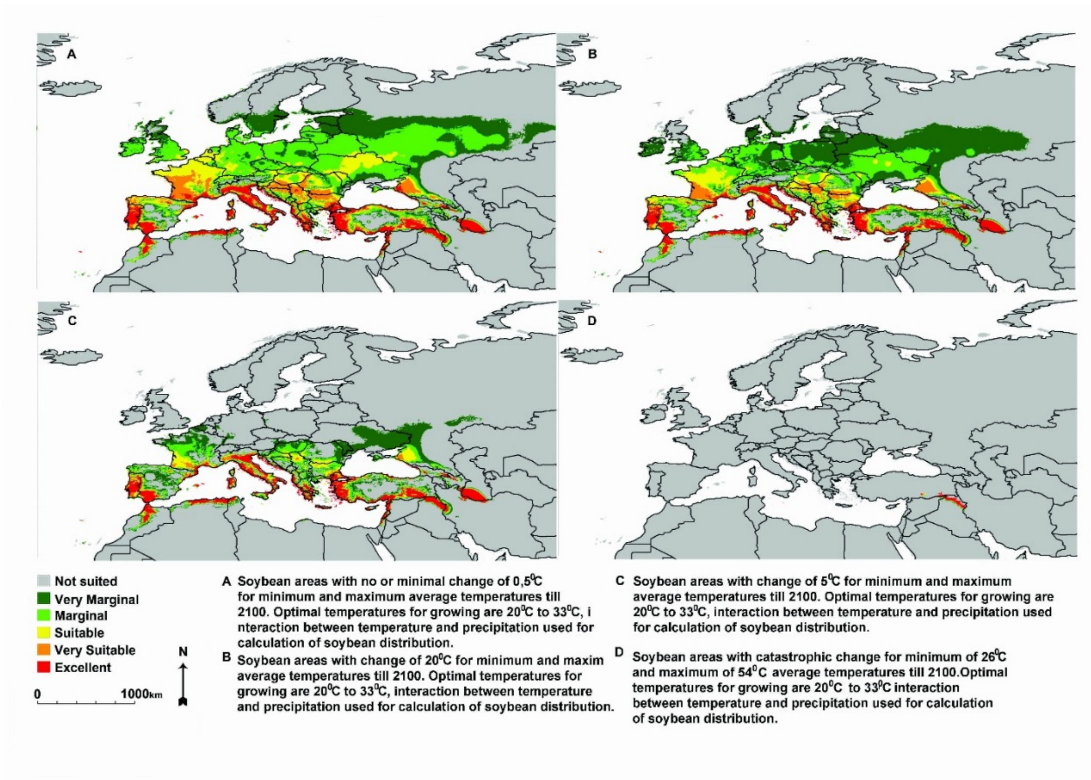

Fig. 5. Distribution of soybean areas in different climate predictions (slight- there is no change of climate or maximum temperature increases by 0.5°C, moderate –maximum temperature increases by 2.0°C, severe –maximum temperature increases by 5.0°C, and incredible – the temperature further increases, and we may expect the disappearance of all plants.

With the help of agroclimatological modelling, we gave geographical and climatological predictions for the future existence of the three plants (corn, wheat, and soybean) in the territory of Europe. After the complete analysis, we concluded that corn and wheat have very similar properties, especially in the dispersion after the increase of temperature. Meanwhile, wheat is slightly different if temperature increases by 0.5 °C, the difference in the territory covered across European countries. 3.5% of European countries have more substantial areas under wheat than under corn. If temperature changes by 2.0 °C, we can expect a similar dispersion of wheat and corn in the territory of Europe. If the temperature increases by 2.0 °C, for soybean we have 5% greater area than for wheat and corn; even if the temperature increased by 5.0 °C, soybean might cover some territories in Europe (*Fig. 6*).

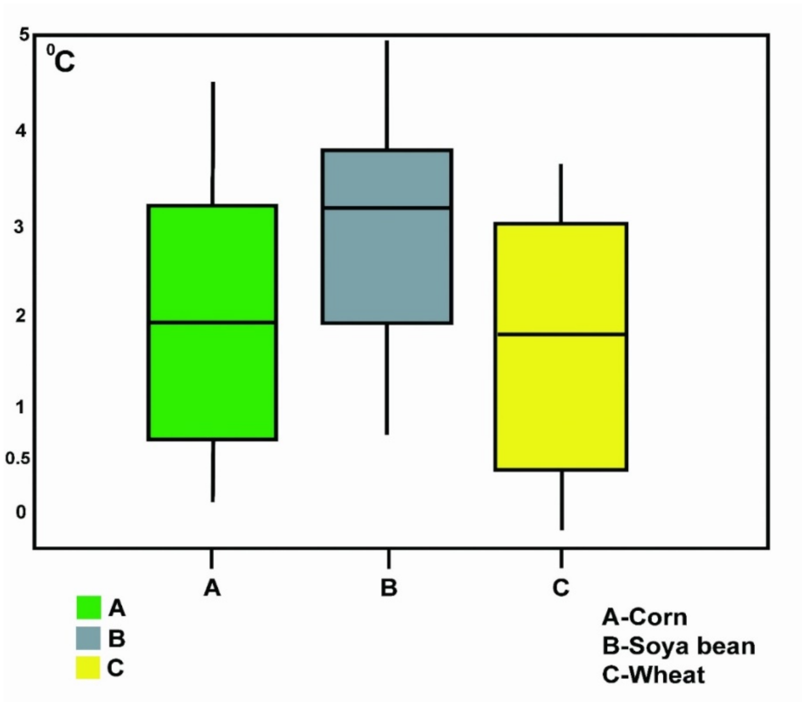

Fig. 6. The resistance of corn, wheat, and soybean by the increase of temperature in Europe per hectare.

However, even if temperature increases by 2.0 °C, the dispersion of three listed plants will be very similar, especially in the southern and south eastern part of Europe. The main changes will be in the territory of East Europe, the Russian Federation, and Scandinavia. The plants may survive on higher lands or under the mountains' basins. Some mountains could be the most resistant areas, and under them, at the elevation higher than 1200 m, there might be possibilities for wheat, corn, and soybean growing. These mountains are Prokletije Mountains, the Alps, the Central Massif, the Pyrenees, etc.

Also, one small area near the Sea of Azov with the line of 200 km, and line near the Caspian Basin may be useful even if the temperature increases. Along the frontier between France and Belgium, there will be a sufficiently broad belt in the Ardennes, under the mountains of Dinarides in Bosnia and Herzegovina and Croatia, and Throdos Mountains in Cyprus, Gascogne in France, and the Massif Central. Under the Eifel mountain range and the Black Forest, Bavarian Forest, and the whole sub-alpine zone, we may expect isolated but resistant zones. The entire sub-alpine area, the Balkan Peninsula, Mount Olympus in Greece, the Pindus Mountains, and the Arachova Mountains are expected to be more resistant, too.

Other resistant areas are in the Apennine Peninsula under the east Apennines, in the part of the Pannonian Basin that belongs slightly to Hungary, Serbia, and Romania. In western Poland, some parts of the Iberian Peninsula in the regions of Estremadura Alentejo in Portugal and Spain, an area under the Pyrenees, as well as the Sierra Nevada and Aragon may be resistant even if temperature increases by 5.0 °C. In the territory of the Russian Federation, a suitable area would be 300 km from the Sea of Azov, between Rostov-on-Don and Krasnodar, and in the Kazakhstan Atyrau Region 150 km from the Sea of Azov.

In Turkey, similar zones may be found under the Taurus Mountains, Pontic, and Ararat. But, all of these areas would be converted into more isolated islands. 70% of those areas may survive even in temperatures between 24.0 °C and 50.0 °C. Corn areas would be reduced by 40%. The maximum threshold for soybean is between 26.0 °C and 54.0 °C, which shows that soybean is more resistant than wheat and corn. For wheat, we concluded that in the territory of Europe, this plant might survive the increase of 4.0 °C, while corn might survive 3.0 °C increase and soybean might survive 5.0 °C increase. The dispersion of these plants depends on geographical coordinates, longitude, and latitude (*Fig. 7*)

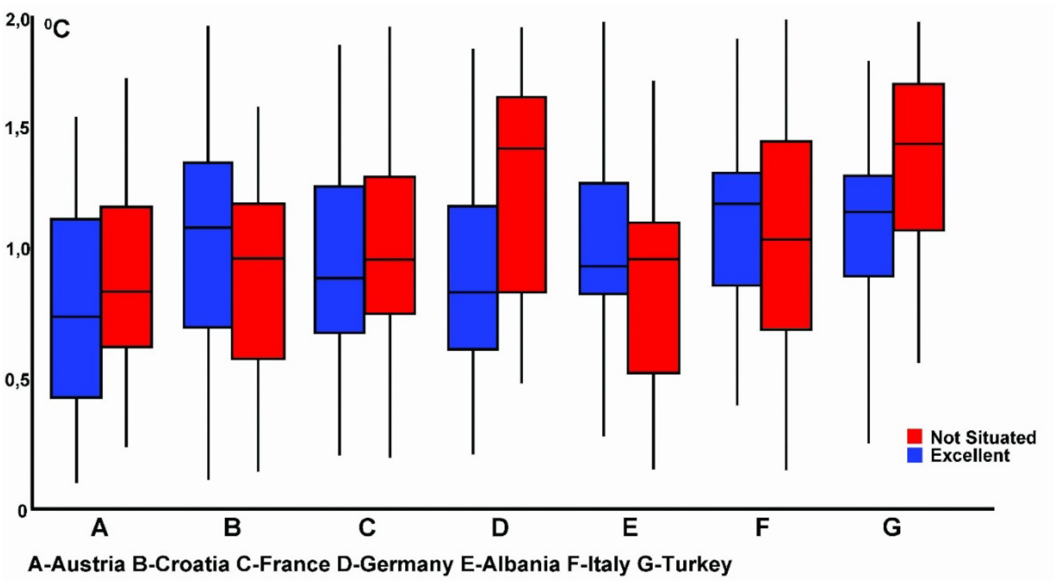

Fig. 7. Dispersion of the suitable and not suitable crop areas if temperature increases between 0.5 °C and 2.0 °C, an example of some countries used in this research.

6. Conclusions and possibilities

The first estimation stated that all three researched plants (wheat, corn, soybean) might resist the increase of temperature by 2.0 °C to a maximum of 4.0 °C. The crops of these species will be moved to a higher elevation, from 400 m to 1000 m. Some researches stated that if the temperature increases by 4.0 °C, a large part of the European continent would become desert and arid area. In other studies, some predictions included the rise of sea level, in case of which many fertile lands would disappear. Meanwhile, areas such as the Scandinavian Peninsula, Greenland, and Iceland could not become new fertile areas for plants, because of the high concentrations of ice in the permafrost. Many European countries, such as Austria, Germany, Hungary, all Balkan countries, also Spain and Portugal, would become inhabitable deserts. According to our results, in the case of temperature increase by 5.0 °C, potential areas within the classes (excellent, very suitable, suitable) would become smaller by 85%, or they would be islands (isolated areas), which may grow and give sufficient goods, with watering. Our model included the connection between precipitation and temperature and the growing period of plants. Plant analysis included the average elevation of all countries, according to which we obtained results in three dimensions (height, geographical latitude, and geographic longitude). Finally, our research gave an optimistic picture of European countries, namely, the list of European countries that may become resistant even with the increase of temperature by 4.0 °C.

As previously mentioned, Russia, Scandinavia, and Iceland will not become countries with fertile soils. When the ice starts melting, it may produce a large number of muddy rivers. The new species of investigated grains may adapt to high altitudes or with a new volume of precipitation. These new sorts can live with a smaller amount of water. In our study, the relationship between temperature and water is also taken into account. What would happen if the number of days with precipitation became significantly smaller or we did not have watering? These results may be very worrying. In this research, the areas investigated are those which could be suitable for new crops. As a positive result of our modelling, we can mention that appropriate zones would be located within urban and sub-urban zones after the climate changes. Therefore, a new urban policy would be required, which should be directed against the inevitable conversion of agricultural lands into urban ones.

For our climatological prediction, we used a moderate scenario made according to current data chosen from the official web page of open source GIS portal DIVA-GIS. These data were found in the sub-section called (WorldClim Version 1) or in the CMIP5 database. In this database, variables are monthly average minimum temperature, monthly average maximum temperature, and total monthly precipitation. CMIP5 database parameters include greenhouse gas scenarios, which included representative concentration pathways (rcp60 or moderate prediction). This grid is exact and presents a distance of 900 m from the equator in longitude and latitude. After numerical and geospatial GIS analysis, we got the following predictions: (i) slight- no temperature changes or changes including the increase of temperature by 0.5 °C, (ii) moderate- temperature increases by 2.0 °C, (iii) severe- temperature increases by 5.0 °C, and (iv) incredible- temperature increases to extreme values, in case of which the survival of plants will be endangered. The last climate properties present the devastation model of climate, and in that case, all plants will be destroyed. At the end of this research, this modelling of climate parameters was mapped, analyzed, and the optimal patterns between climate change and plants' growth were found.

Alternative solutions could be informing ecological zones and vertical farms within urban settlements. In the suburban and open areas, in such situations, new parcels would be formed that would be near significant accumulations, even at higher altitudes. Any future climate model is an essential prerequisite to reach local, regional, and global climate predictions as pleasant as possible. Only sufficiently good predictions offer possibilities to be successfully prepared and adapted for future climate changes. This research can be extended with new and precise data and applied to all countries in the world.

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