POLITECNICO DI TORINO

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Master of Science in Civil Engineering

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Historical evolution of the spatial distribution of food production and consumption on a global scale

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Abstract

The following thesis tries to analyze the historical evolution of the spatial distribution of food production and consumption. For this, we analyze how spatially and temporally the food crop is distributed, that we interpret it as production, and how spatially and temporally the population is distributed, that we interpret it as food consumption. In order to analyze these two parameters, we based on the analysis of data that we have available, that give us information on the amount of hectares cultivated and the population of each part of the world for the different years we analyze. With these data we reach results to be able to appreciate this spatial distribution between food production and consumption. One of these results is the calculation of the differences, which allows us to appreciate different colors on maps that will indicate the places where consumption prevails, where there is a good balance between production and consumption and where production prevails and to what extent it does. Other results are the Lorenz curve and Gini index that gives us an estimate of the inequality between these two parameters.

1. Introduction

For more than ten thousand years, sedentary settlements of our race have been registered, which makes man occupy a particular geographical space. Today the human race uses most of the land that we know is suitable for life. Most of this area is used for food crops to supply the population's consumption, which it uses to live in much smaller areas. To get to the land use that we use today, the human race has evolved over time, increasing its population and the used of land to supply its food consumption. This evolution will be studied in depth in this thesis, analyzing the evolution of land use from the year 0 AD to the present.

Human populations and their use of land have transformed most of the terrestrial biosphere into anthropogenic biomes (anthromes), causing a variety of novel ecological patterns and processes to emerge. To assess whether human populations and their use of land have directly altered the terrestrial biosphere sufficiently to indicate that the Earth system has entered a new geological epoch. At present, even were human populations to decline substantially or use of land become far more efficient, the current global extent, duration, type and intensity of human transformation of ecosystems have already irreversibly altered the terrestrial biosphere at levels sufficient to leave an unambiguous geological record.

In this thesis the spatial distribution between food production and consumption will be analyzed. This will be done by analyzing data on cultivated hectares and population geographically located throughout the world map. With these data it will be possible to differentiate how much consumption and how much food production prevails in each part of the world. This will be evaluated for different years from the year 0 AD to the present to evaluate the historical evolution of this spatial distribution. Where we will see how the areas used for production and areas used for consumption are expanding from one year analyzed to the other. Calculations will also be made with these data to be able to appreciate enough other aspects about each region of the world and for the entire world map. They will be able to appreciate with graphs that show us evolution over time of these aspects, such as the population, the number of hectares cultivated, the number of hectares cultivated per person, Gini index, among others, for different regions and for the entire world map. .

The objective of this thesis is to analyze the historical evolution of the spatial distribution of food production and consumption on a global scale. We will analyze this distribution using the crop area as production and the population as consumes. Therefore, it will be based on the analysis of the distribution of the population according to the area where the food its grown. This is going to be carried out through the analysis of data that we have available for each geographical location in the world thanks to the HYDE3 data manual. This data is represented by raster files that is nothing more than an array with data separated in area comprised in a 5-minute equidistant distance in longitude and 5 minutes of latitude.

As soon as we talk about crop area, we were able to analyze both the cultivated areas with artificial irrigation, and the cultivated areas without artificial irrigation, that is supplied with rainwater. Being able to compare things like how they differ in terms of quantity and evolution.

With the analysis of these data, many things could be appreciated and deduced, which allow studying different aspects of the global behavior of society. Among them you can find population quantities and where they are located geographically, for each year analyzed. Another aspect that is going to study to a greater extent is the data of the differences, which will allow us to appreciate if in the analyzed area the consumption prevails, the production prevails or if there is a balance between these two. If this value is negative, its means that the consumption prevails. If this value is positive, means that production prevails. And if this value is zero, it means that there is a balance between production and consumption in that area. That is, the prevalence value of that area between consumption and production, which will indicate where these areas are spatially distributed.

With this data, maps will be represented to help us study how food production and consumption in the world are distributed spatially and how this evolves over time. These maps will be analyzed and compared with historical facts.

In addition, aspects that can help the study of this distribution will be analyzed by investigating the variables with the Lorenz Curve and its respective Gini index.

The analysis will start by framing the problem to understand better what we are going to work with on this thesis. Then the data and methods used to arrive at the results will be shown, to understand what results will be reached and how to understand them. These results are then shown, interpreted and explained. Finally, the analysis of the results will be concluded. You will also be able to find the Bibliography and an annex with the necessary content to carry out the analysis at the end of the thesis.

2. Framing the problem

The problem we have next is in the analysis of data from both cultivated area with artificial irrigation and without artificial irrigation, and population data for all points of the world map for all the years that we are interested in analyzing. These data are provided by the HYDE 3.1 database, which is a spatially explicit database of the global change in man-induced land use in the last 12,000 years. This database is an update of the History Database of the Global Environment (HYDE) with estimates of some of the underlying demographic and agricultural driving factors. Historical population, cropland and pasture statistics are combined with satellite information and specific allocation algorithms (which change over time) to create spatially explicit maps, which are fully consistent on a 5′ longitude/ latitude grid resolution, and cover the period 10,000 BC to 2000 AD.

In general, two approaches can be distinguished for global historical land-use/land-cover inventories.

1. Modelling with so-called dynamic global vegetation models (DGVMs), which explicitly represent the interaction between the ecosystem carbon and water exchange and vegetation dynamics to compute long historical transient time series of land cover. *Crameret al*. (2001) compared six DGVMs and demonstrated that simulated historical land-cover distribution varied strongly among the models. Most DGVMs are based on biomes representing an envelope of plant functional types. These biomes are generalized ecosystem representations and they lack fragmentation or human influences.

2.Historical land-cover datasets based on statistical information. A number of historical land-use datasets have been prepared on the basis of statistics at the subnational and national scale, for example for Burgundy in France (*Crumley*, 2000), the Ardennes in Belgium (*Petit & Lambin*, 2002), Colombia (*Etter & Van Wyngaarden*, 2000; *Etter* et al., 2008) and the USA (*Maizel* et al., 1998). Other historical land-cover inventories were made at the regional and continental scale, for example for Australia (AUSLIG, 1990), for China (*Ge* et al., 2008), for Southeast Asia (*Flint & Richards*, 1991) and for Europe (*Williams*, 2000; *Kaplan* et al., 2009). Global estimates of the historical areas of cropland and grassland are rare and rather uncertain (see Table 1). Different approaches were used in the available global estimates. *Ramankutty & Foley* (1998) calibrated the International Geosphere– Biosphere Programme

(IGBP) 1-km resolution global landcover classification (GLCC) dataset against cropland inventory data for 1992 to create a global map of cultivated land for 1992. Subsequently, they used a ‘hindcast’ modelling technique to extrapolate these data, using a compilation of historical cropland inventory data to create a spatial dataset of croplands for the period ad 1700–1992 (*Ramankutty & Foley*, 1999). Others used a book-keeping model with conversion rates of different land-cover types (including cropland and pasture) to estimate carbon fluxes (*Houghton* et al., 1983; *Richards*, 1990; *Houghton*, 1999; *Houghton & Hackler*, 2001). *Pongratz* et al. (2008) reconstructed agricultural areas for the last millennium from ad 800 to 1992 (see Table S1 in Supporting Information for details on the different approaches). The original HYDE 2 database (*Klein Goldewijk*, 2001) was a consistent dataset of historical land-use and land-cover data of the 20th century on a spatial resolution of 0.5° ¥ 0.5°. HYDE 2 includes both general topics such as land use and land cover, population, livestock, gross domestic product (along with valueadded generated in industry and the service sector), and specific data on energy, the economy, atmosphere, oceans and the terrestrial environment. Most data were organized on the national scale for the period ad 1890–1990 and, where available, for ad 1700–2000. An update of HYDE 2 was presented in *Klein Goldewijk & van Drecht* (2006). HYDE 3.0 included several improvements compared with its predecessor: the HYDE 2 version used a Boolean approach with a 30′ resolution, while HYDE 3.0 used fractional land use on a 5′ resolution; more and better subnational (population) data (*Klein Goldewijk*, 2005) to improve the historical (urban and rural) population maps as one of the major driving forces for allocation of land cover; updated historical land-cover data for the period ad 1700–2000; implementation of different allocation algorithms with time dependent weighting maps for cropland and grassland used for livestock. This study presents a revision and extension of HYDE 3.0. This version, HYDE 3.1, is an updated and internally consistent combination of historical population estimates and also the implementation of improved allocation algorithms with time dependent weighting maps for cropland and grassland, while the period covered now extended to 10,000 BC to 2000 AD.

We have used data for our analysis from this database from the year 0 AD until the most recent year of HYDE 3.1 database which is 2017 AD.

Now we have to get this data for our analysis, but we have two problems to solve the interpretation of this data. One of these problems is that we have to can extract from the array the data for specifics regions for do specifics analysis. And two, not all the cells have de same area because they are spared from equidistant of latitude, and if you move away from the equator line, this area begins to shrink.

To solve these two problems, we have an array from the same database that have the different regions with specifics numbers that we used for the calculation as tool to find data from specifics regions, and for the area problem we used some calculations using an area matrix as tool.

With these data, different calculations will be carried out to interpret them and arrive at results that are of interest to us in order to study the historical evolution of the spatial distribution of food production and consumption on a global scale.

3. Data and Methods

3.1 Starting data of the analysis

By dividing the world map into a 5′ longitude/ latitude grid resolution, we get a geographically referenced matrix of 2160 rows and 4320 columns. If, as each cell comes to represent a real geographic area, representative data of that area can be put in them. Thus, we would have in each file the values of particular data in each cell of the world.

As explained, this is how you could define where our data comes from. These matrices are represented in a georeferenced raster file, which is what we have as data.

The data that we have explained in raster files are:

- ✓ Hectares cultivated with irrigation (area): These are the number of hectares cultivated without the use of artificial irrigation in each geographically referenced cell.
- ✓ Hectares cultivated without irrigation (area): These are the number of hectares cultivated with the use of artificial irrigation in each geographically referenced cell.
- ✓ Population (n. Hab): These are the number of people who habit each cell.

Like we wrote before, these data had been extracted from The HYDE 3.1, that is a spatially explicit database of human-induced global land-use change over the past 12,000 years.

We have used data for our analysis from this database from the year 0 AD until the most recent year of HYDE 3.1 database which is 2017 AD.

We also have as data two arrays from the same dimensions of the data of population and cultivated area, that we extracted from the same database, that were very useful for the analysis. One of these arrays is the one who haves the area data of each cell that is going to be useful for the correction of the calculation of differences maps. The other one is the one of regions, who have separated the world in countries by having specific numbers in the different specific cells. This one is very useful to calculated data for different specific regions.

3.2 Programs used

For the calculation and interpretation of results, two programs have been used as tools. These programs are Matlab, mainly used as a calculation tool and the QGIS, used for printing and representing these calculated data.

Millions of engineers and scientists across the globe use MATLAB® to analyze and design the systems and products that transform our world. The MATLAB language, based on matrices, is the most natural way in the world to express computational mathematics. The integrated graphics facilitate the visualization of the data and the obtaining of information from them. All of these MATLAB tools and functions are rigorously tested and designed to work together.

MATLAB helps you take ideas beyond the desk. You can run your analyzes on larger data sets and expand to clusters and clouds. The MATLAB code can be integrated with other languages, allowing you to implement algorithms and applications in web, business or production systems.

We have used MATLAB as a tool to calculate matrices and produce matrices and then be used by the QGIS program to interpret them.

QGIS is a free software Geographic Information System for GNU / Linux, Unix, Mac OS and Microsoft Windows platforms. It allows you to manage raster and vector data formats through libraries and databases. This is an organized integration of hardware, software and geographic data in order to capture, store, manipulate, analyze and visualize in all its forms the spatially referenced information that allows to characterize the geographical space for its study or management.

In our study, QGIS was used to visualize spatially referenced data and import images in specific parts of the world of interest.

Another program used during the thesis was Microsoft Excel, which is a spreadsheet, a powerful tool for viewing and analyzing data. This program was used to order and calculate different data. It was also used to print some graphs of results.

3.3 Calculation Methodology

3.3.1 Preliminary analysis

With these data, the first thing that has been done is the interpretation. These are raster files that are georeferenced in the world, so it is easy to represent them with the help of the Q-GIS program. This allows us, among other things, to open georeferenced raster files and represent this data on the world map to make it easier to appreciate them.

Examples of population data (figure 1, 4 and 7), area cultivated with artificial irrigation (figure 3, 6 and 9) and area cultivated without artificial irrigation (figure 2, 5 and 8) for three areas of the world map will be shown below. These three zones are North America, Europe and the area where India and China are noted. These examples are all for our most recent year (2017 AD).

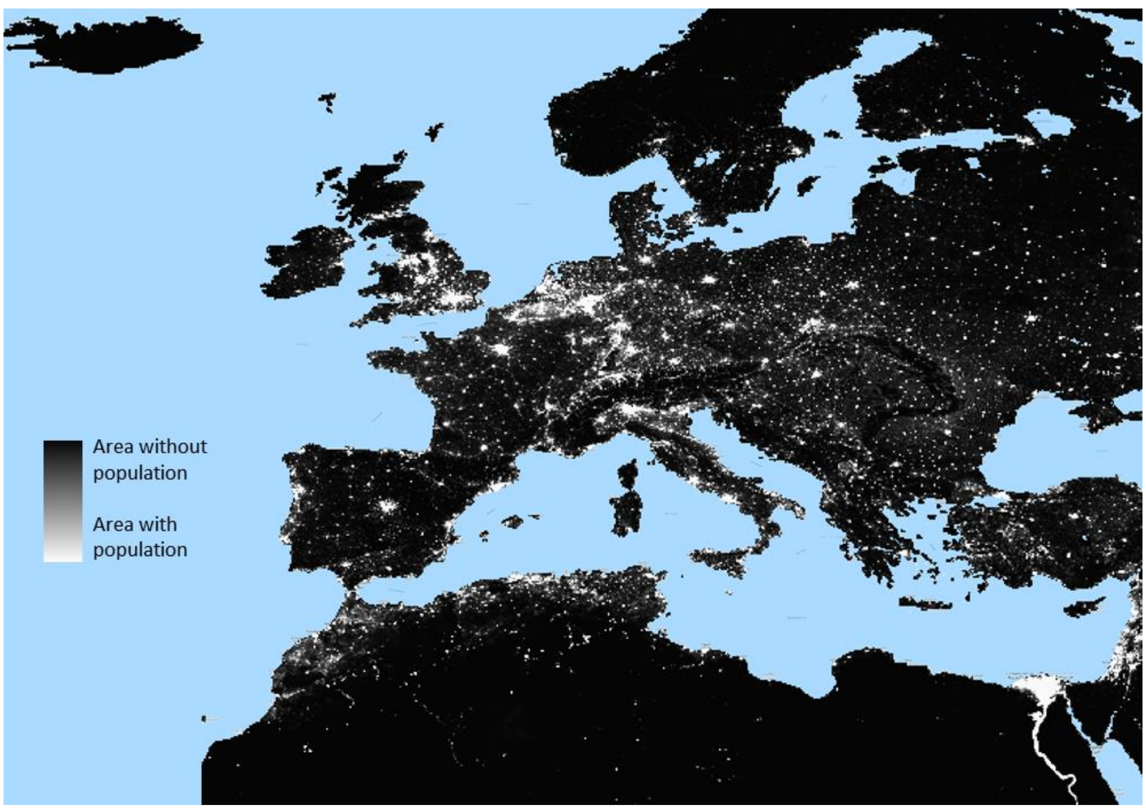

Figure 1 Europe population (2017 AD)

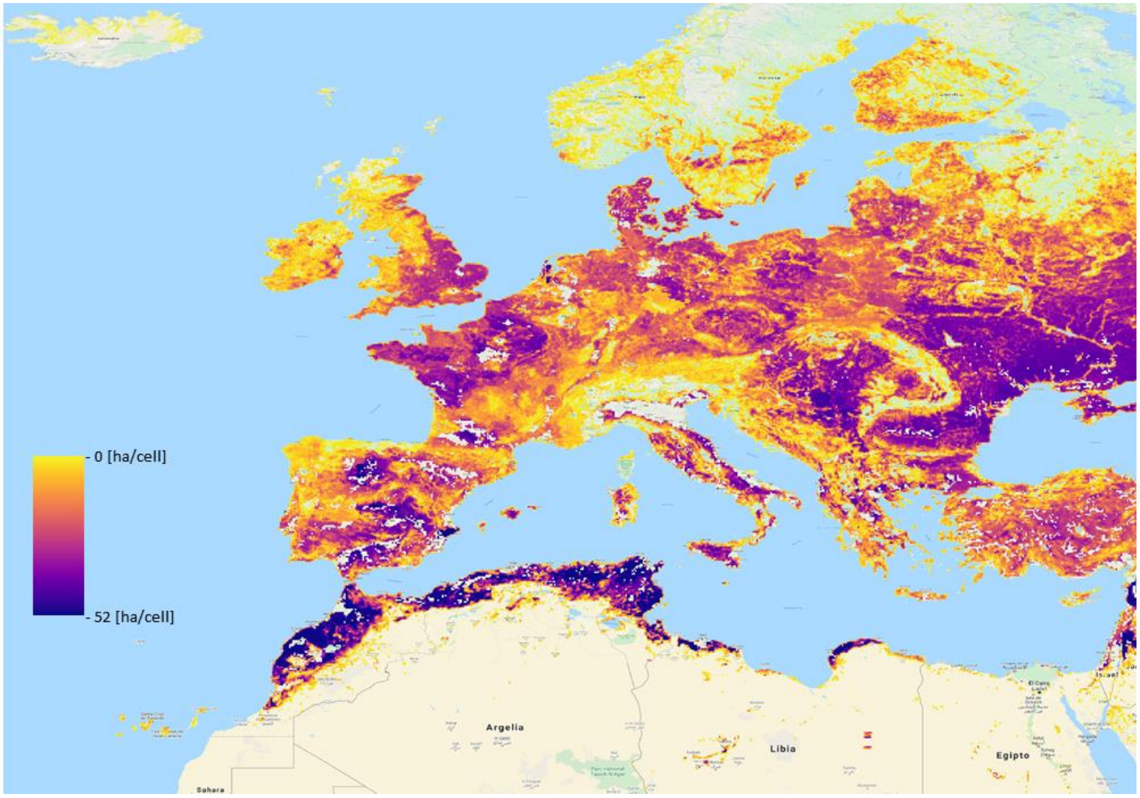

Figure 2 Europe cultivated area without artificial irrigation (2017 AD)

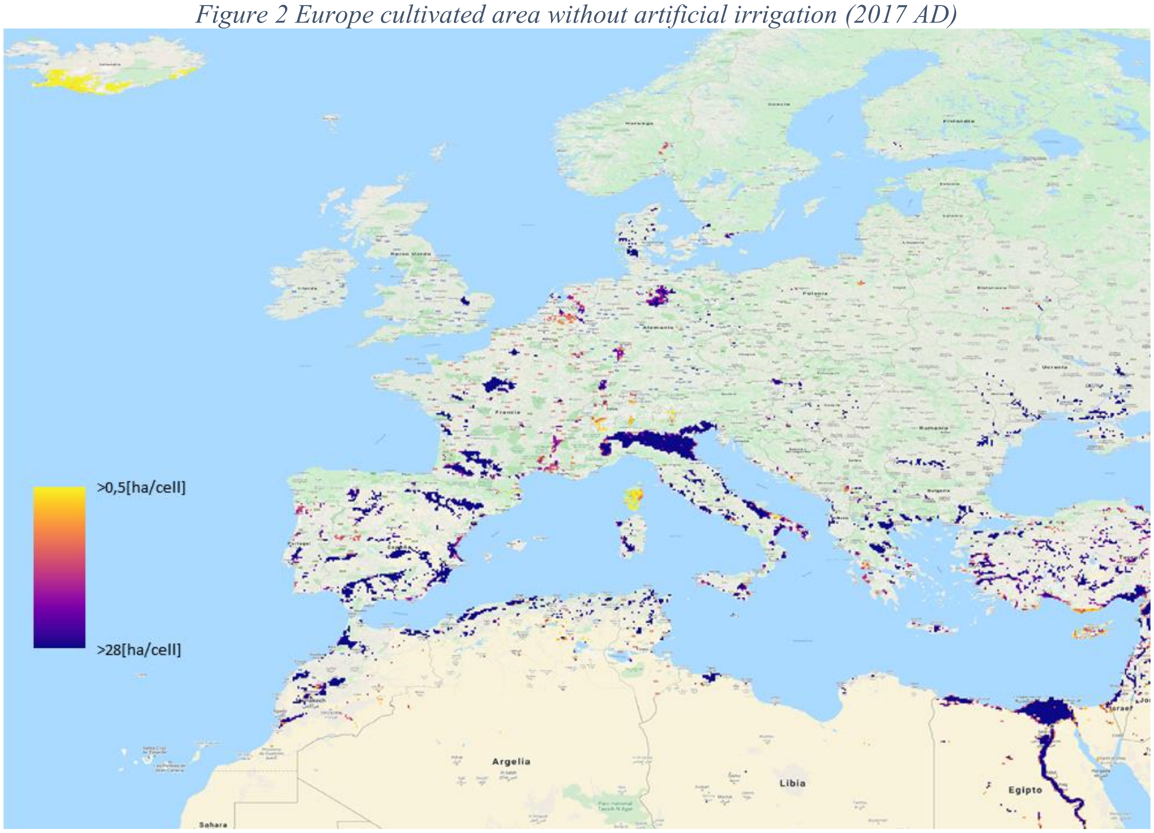

Figure 3 Europe cultivated area with artificial irrigation (2017 AD)

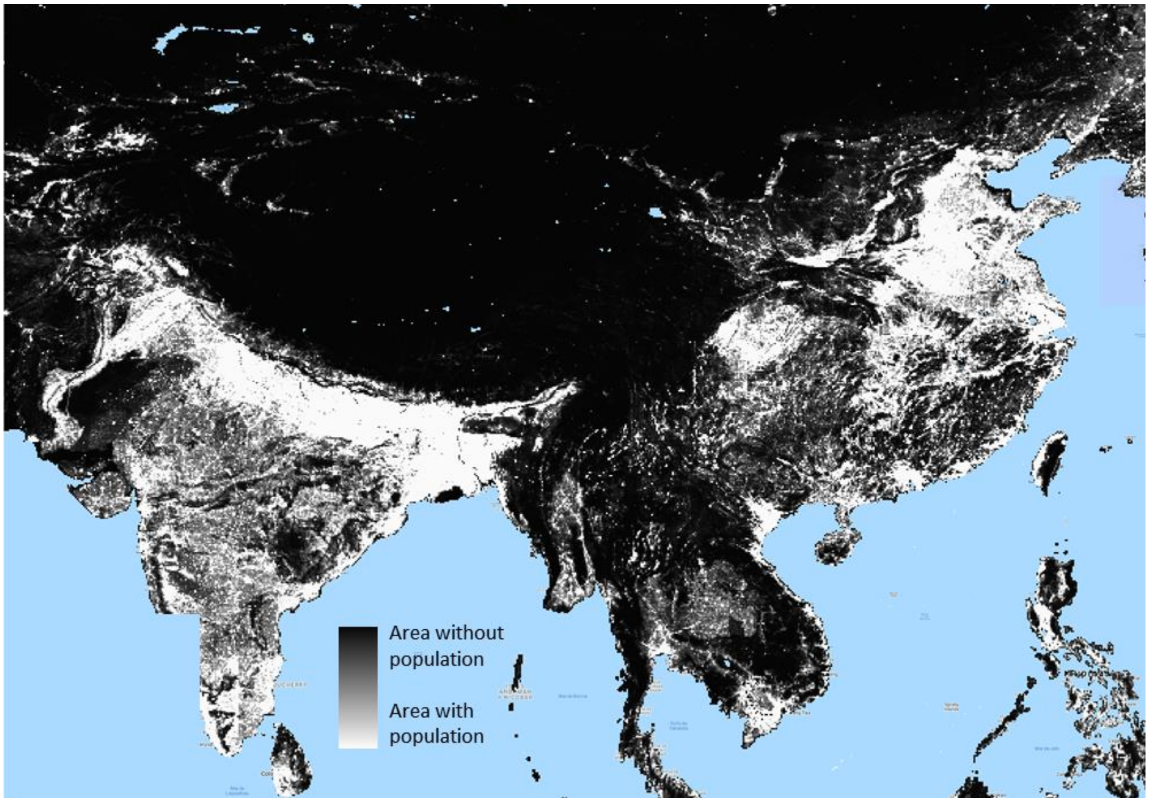

Figure 4 India and China populations (2017 AD)

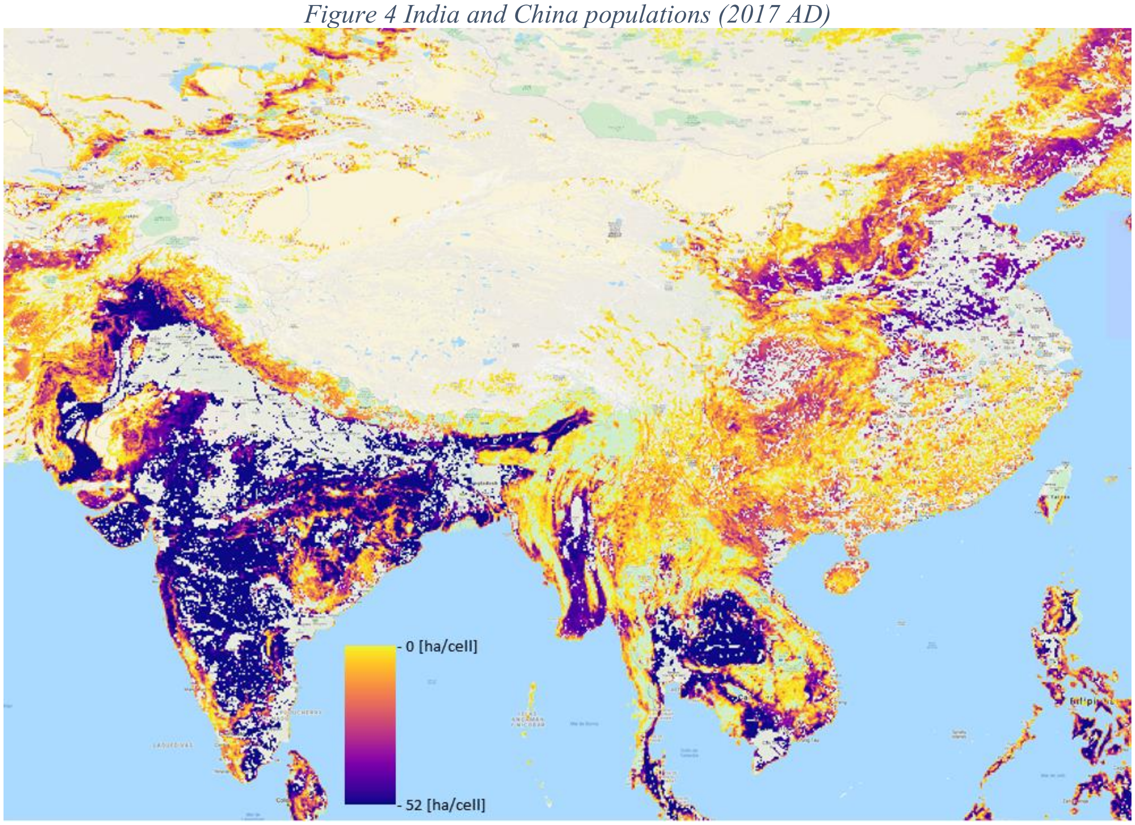

Figure 5 India and China cultivated area without artificial irrigation (2017 AD)

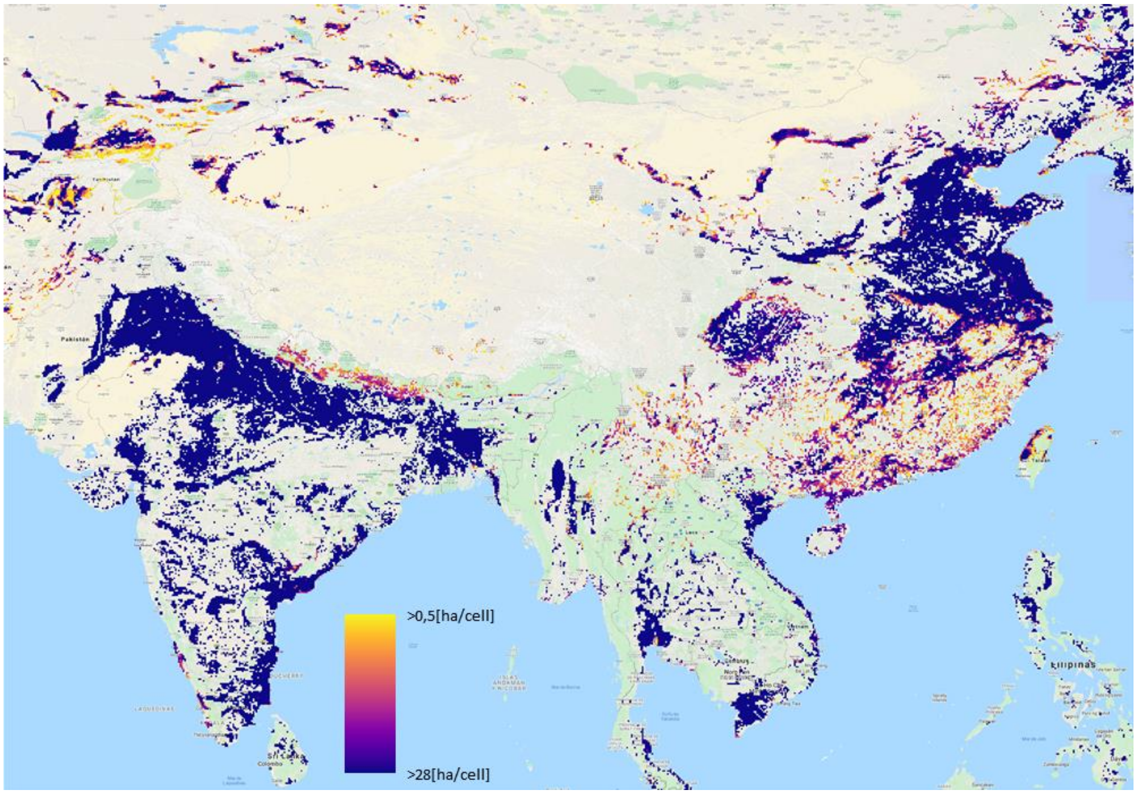

Figure 6 India and China cultivated area with artificial irrigation (2017 AD)

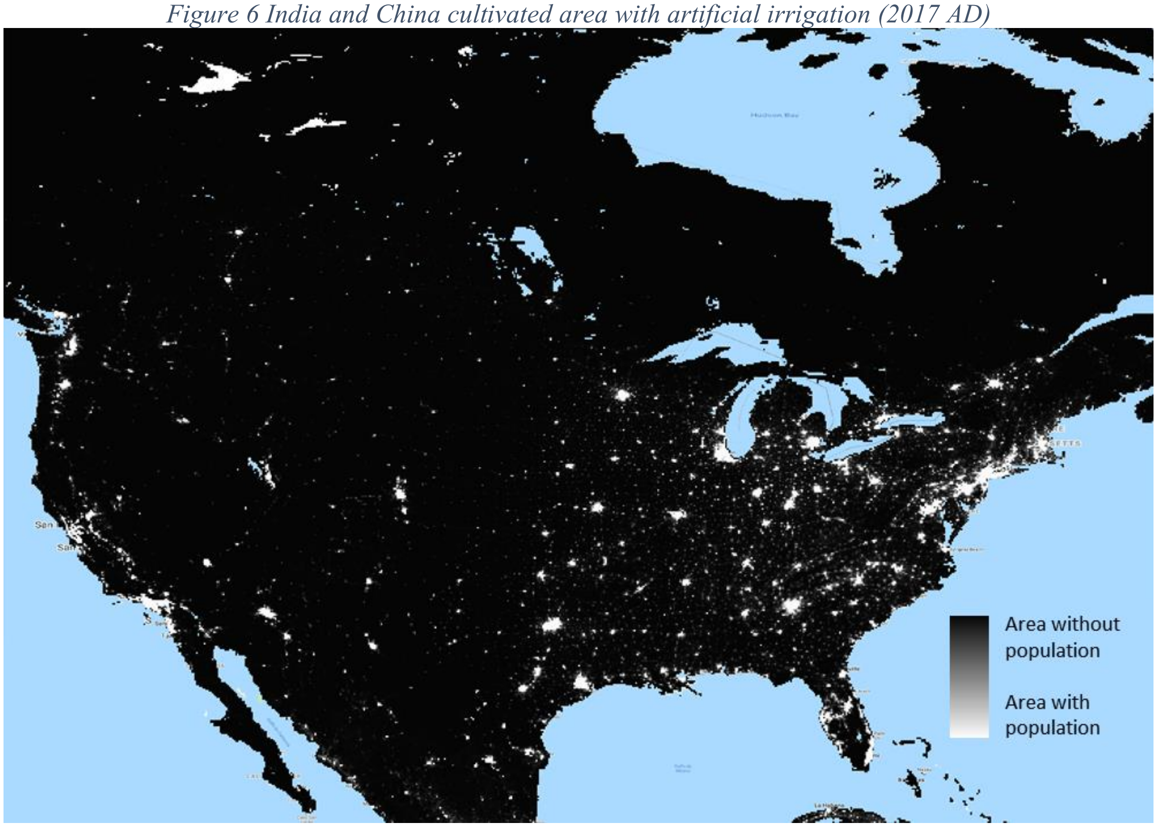

Figure 7 North America population (2017 AD)

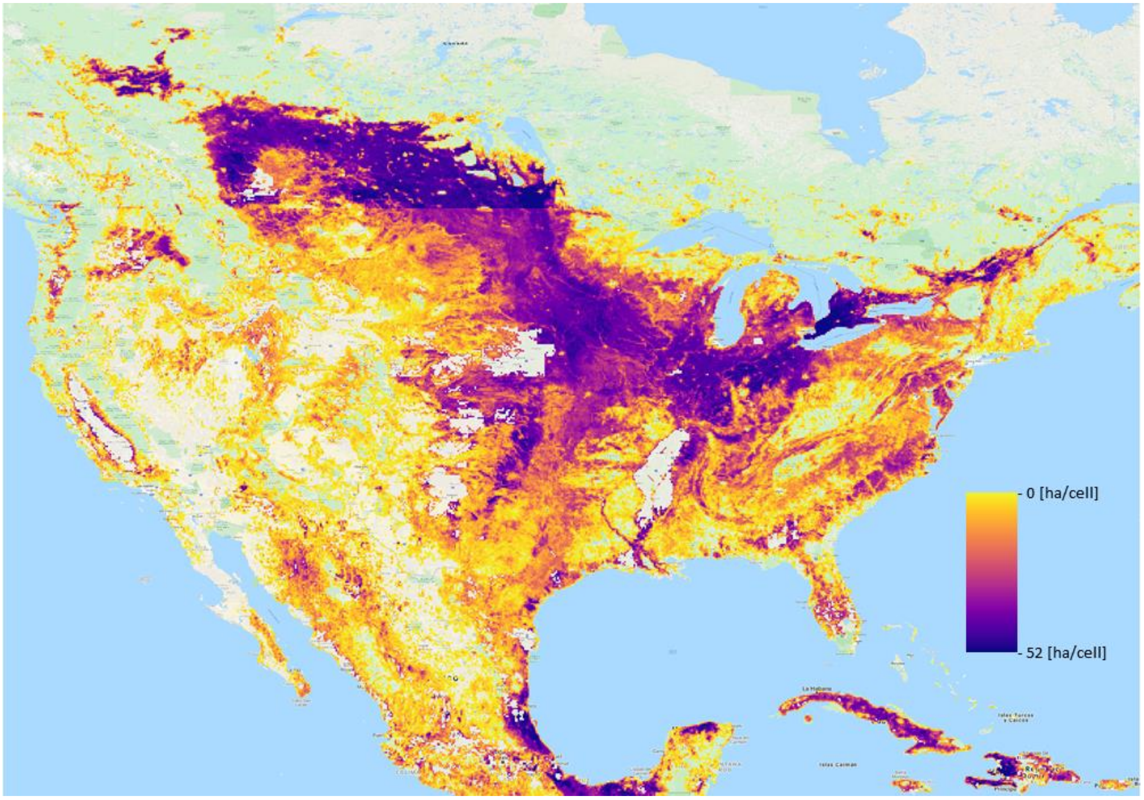

Figure 8 North America cultivated area without artificial irrigation (2017 AD)

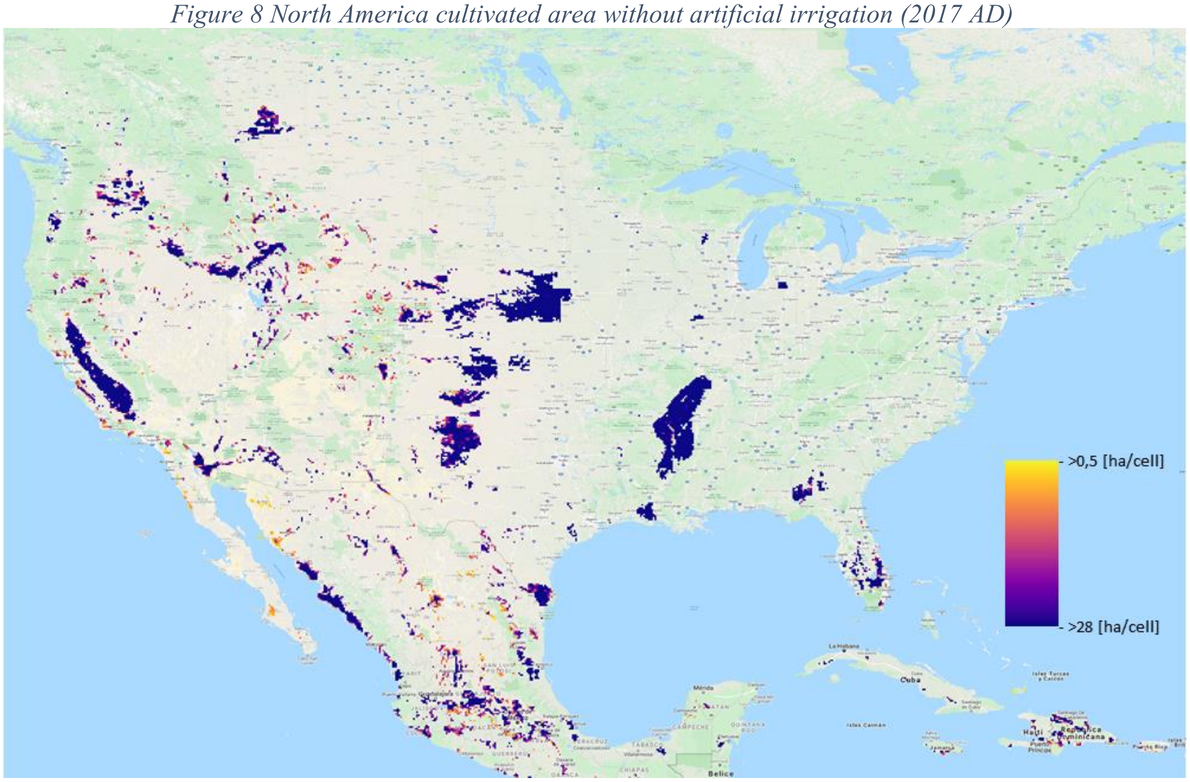

Figure 9 North America cultivated area with artificial irrigation (2017 AD)

Once represented and understood, another program has been used for making calculations with this data. This program is Matlab, where we were able to identify and calculate various data points from our raster file. This was done first by transforming the raster file into a vector file to be able to identify each data point separately and thus be able to make calculations more easily.

Based on the vectorization of cultivated area with artificial irrigation, cultivated area without artificial irrigation and population data for each raster file cell, different calculations have been made for each year analyzed (from year 0 AD to 2017 AD). These calculations are:

3.3.1.1 Maximum number of hectares cultivated without artificial irrigation (rainfed)

This refers to the value in hectares cultivated of a cell with the largest number of hectares cultivated without artificial irrigation in the world. This data is calculated with the help of Matlab program, using the function to find maximum value in our case in a matrix. This matrix to which this function is applied is the data matrix of hectares cultivated without artificial irrigation. This function is applied to the matrices of all the years that we are analyzing, so we will obtain the value of the maximum number of hectares cultivated without artificial irrigation in a cell, for each year analyzed. The codes used in this program are found in the annex.

3.3.1.2 Maximum number of hectares cultivated with artificial irrigation (irrigated)

This refers to the value in hectares cultivated of cell with the largest number of hectares cultivated with artificial irrigation in the world. Like the previous calculation, this data is calculated with the help of Matlab program, using the function to find maximum value in our case in a matrix. This matrix to which this function is applied is the data matrix of hectares cultivated with artificial irrigation. This function is applied for the matrices of all the years that we are analyzing, so we will obtain the value of the maximum of hectares cultivated with artificial irrigation in a cell, for each year analyzed. The codes used in this program are found in the annex.

3.3.1.3 Maximum population number

This refers to the value in number of population of the cell with the largest number of population in the world. Like the previous calculations, this data is calculated with the Matlab program, using the function to find maximum value in our case in a matrix. This matrix to which this function is applied is the population data matrix. This function is applied for the matrices of all the years that we are analyzing, so we will obtain the maximum population value in a cell, for each year analyzed. The codes used in this program are found in the annex.

3.3.1.4 Total amount of hectares cultivated without artificial irrigation (rainfed)

This value is the number of a total amount of hectares cultivated without artificial irrigation worldwide in a particular year, which results from adding all the values we have in each cell of the matrix of hectares cultivated without artificial irrigation in that particular year. This value is calculated with the help of the Matlab program, using the summation function in our case applied to a matrix. The matrices to which this function applies are the data matrices of hectares cultivated without artificial irrigation for each year that we are analyzing. The codes used in this program are found in the annex.

3.3.1.5 Total amount of hectares cultivated with artificial irrigation (irrigated)

This value is the number of a total amount of hectares cultivated with artificial irrigation worldwide in a particular year, which results from adding all the values we have in each cell of the matrix of hectares cultivated with artificial irrigation of that particular year. This value is calculated with the help of the Matlab program, using the summation function in our case applied to a matrix. The matrices to which this function applies are the data matrices of hectares cultivated with artificial irrigation for each year that we are analyzing. The codes used in this program are found in the annex.

3.3.1.6 Total amount of Population in a particular year

This value is the number of population worldwide in a particular year, which results from adding all the values we have in each cell of the population matrix of that particular year. This value is calculated with the help of the Matlab program, using the summation function in our case applied to a matrix. The matrices to which this function applies are the data matrices for each year that we are analyzing. The codes used in this program are found in the annex.

3.3.1.7 Total amount of cultivated area without artificial irrigation per habitant

This value is the number of hectares cultivated without artificial irrigation per habitant worldwide in a particular year, which results from adding all the values we have in each cell of a matrix resulting from the division of the matrix of hectares cultivated without artificial irrigation for that particular year, divided the population matrix of that same year. This value is calculated with the help of the Matlab program, using the division function of two matrices to obtain a first matrix. To which a sum function of all the values of each cell of that matrix will be applied. The matrices to which this function applies are the data matrices of cultivated area without irrigation and population for each year that we are analyzing. The codes used in this program are found in the annex.

3.3.1.8 Total amount of cultivated area with artificial irrigation per habitant

This value is the number of hectares cultivated with artificial irrigation per habitant worldwide in a particular year, which results from adding all the values we have in each cell of a matrix resulting from the division of the matrix of hectares cultivated with artificial irrigation. for that particular year, divided the population matrix of that same year. This value is calculated with the help of the Matlab program, using the division function of two matrices to obtain a matrix to which a sum function of all the values of each cell of that matrix will be applied. The matrices to which this function applies are the data matrices of cultivated area with irrigation and population for each year that we have data. The codes used in this program are found in the annex.

3.3.1.9 Total amount of total cultivated area per habitant

This value is the total number of hectares cultivated in the world in a particular year, which is obtained by adding the last two calculated values for each particular year.

The calculation of the preliminary analysis was made first for the entire world map calculated with the data of the entire world map. Also, these calculations were made for nine regions to which we can differentiate the specific data of those regions to make more differentiated analysis, only with the data of the analyzed region.

3.3.2 Differences between population density and crop uses

3.3.2.1 Concept and calculation

Worldwide, food production is directly related to the population. In our analysis, we have data from cultivated hectares and population from all around the world, divided into geographical areas (or cells) that make up an area that is equidistant from 5 minutes longitude by 5 minutes latitude.

If we now divide the amount of hectares cultivated (production) from a geographical area, divided by the maximum value of hectares cultivated, we would obtain an order of greatness between 0 and 1 that would indicate an estimate of percentage, with respect to the maximum, of the amount of cultivated hectares in that cell. Also, if we divide the population of that geographical area, divided by the maximum population of all geographic areas, we get an estimate of the percentage of how many people live in that area. If we take these two estimates and subtract the production estimate minus the population estimate, we get a number equal to zero if there is a balance between the two variables, a negative number if the population (consumption) prevails, or a positive number if cultivated area (production) prevails. We call this number Difference, which is the data that we are going to analyze deeply in this thesis to understand the spatial distribution between food production and consumption. This number is then calculated for each geographical area using the following formula:

$$Diff = \left[\frac{A_{cultivated}}{\max\,[A_{cultivated}]} - \frac{Pop}{\max\,[Pop]}\right]$$

Where:

$A_{cultivated}$ = cultivated area of the respective geographical area (rainfed area or irrigated area)

$\max\,(A_{cultivated})$ = maximum cultivated area of a geographical area

Pop = population of the respective geographical area

$\max\,(Pop)$ = maximum population of a geographical area

The calculation of differences was made both for hectares cultivated with irrigation and without irrigation, for each year and for each place in the world.

In order to get these results, the following steps were performed:

1- Calculate the maximum number of cultivated area of both the matrix with data of irrigated cultivated area than with the matrix with data of rainfed cultivated area.

2- Calculate the maximum population number of the matrix with population data.

3- Calculate the matrix of differences by applying the formula seen above to the data matrix of cultivated area (either irrigated or rainfed) and the population data matrix.

4- Use the QGIS program to see the results and print images of these results in different areas of the world.

The first three steps were performed with the help of the Matlab program, whose codes for calculation can be found in the annex.

Later in the thesis, this concept will be shown and analyzed over time in different areas of the world. Before beginning to analyze any particular area, it is necessary to comment about the results we will see in each graph.

In each graph you can see different "pixels" of different colors, these "pixels" are the geographical areas for which each calculation of differences has been made. The color of this pixel indicates the value of this result. If this color is strong red, it means that the result is negative, and its means that consumption prevails over production in that area. If the color is green, it means that there is a balance between production and consumption in that area. Then if the value is positive, as this is very predominant in relation to the other two cases, this will be represented in a range of colors that varies gradually from yellow to violet, as can be seen in the legend of the graph. This range will make it clear to us which area prevails production by little (yellow) and how it gradually increases until it reaches values where production is much greater than the population (violet). In areas where there are none of these colors, it means there is no data, so in this area there is not population and also it is not cultivated.

The calculation of the differences was made first for the entire world map calculated with the data of the entire world map.

This calculation was not perfect, because it has an error because of the comparation between cells with different areas. Not all the cells have the same area because they are separated from an equidistant of latitude, and if you move away from the equator line, this area begins to get smaller.

To solve this problem, we have an array from the same database we extract the data, that have the data of area for each cell of the matrix. So, with the data of this array we made some calculations to correct the differences calculation. These calculations are the correction of the population part of the difference's equation, and the correction of the cultivated area part of the equation. For this we present two new corrected parts of the equation. The first one is the population corrected α_i, that is corrected by a multiplication of a rapport between the maximum area of a cell and the area of this cell. This correction is a number superior to one and is bigger if you move away from the equatorial line. This correction is like that because, if I tries to correct the value calculated for a smaller area, for them being compared with a bigger area, I have to correct this value of the smaller area with a number superior to one.

On the second part of the equation we have the correction of the cultivated area γ_i, that is the rapport between two parameters, the first one is a rapport also between the cultivated area of that cell and the area of that cell β_i, and the second one is the maximum value of the rapport we said before of all the cells max(β_i).

To explain better the calculations are organized bellow:

1. First, we do the calculation of the maximum area of a cell.
2. Secondly, we calculated the array for the correction of the population part of the equation with the following formula for each cell value:

$$\frac{A_{max}}{A_i}$$

3. Then, we calculated the corrected population part of the difference's equation α_i with the following formula:

$$\alpha_i = \frac{Pop_i}{\max(Pop_i)} . \frac{A_{max}}{A_i}$$

4. After that, we calculated the percentage of cultivated area of the cell by the following equation:

$$\beta_i = \frac{A_{cult,i}}{A_i}$$

5. Then, we calculated the maximum value of the previous rapport of all the cells max (β_i).

6. After that, we calculated the correction for the cultivated area part of the difference's equation with following formula:

$$\gamma_i = \frac{\beta_i}{\max[\beta_i]}$$

7. Finally, we can calculate the different value corrected by subtracting the cultivated corrected area part γ_i for the corrected population part

$$Diff_{Corr,i} = [\gamma_i - \alpha_i]$$

This is the correct value of differences that we are going to use in the analysis.

In addition to these differences' calculations, the differences data have been calculated with the data of specific zones. This means that we calculated the differences maps of a specific region with only the data of that specific region. This was done for the following 9 regions:

1. Africa sud Sahara, including the states of Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Comoros, Congo, Democratic Republic of the Congo, Coste d'Ivoire, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mayotte, Mozambique, Namibia, Niger, Nigeria, Reunion, Rwanda, Saint Helena, Ascension and tristan da Cunha, Sao Tome and Pricipe, Senegal, Seychelles, Sierra Leone, Somalia, South Africa, Sudan, Swaziland, Tanzania, Togo, Uganda, Western Sahara, Zambia y Zimbabwe.
2. Middle East and North Africa, including the states of Algeria, Bahrain, Djibouti, Egypt, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Libya, Morocco, Occupied Palestinian Territory, Oman, Saudi Arabia, Syria, Tunisia, United Arab Emirates, Yemen, Yemen Ar Rp y Yemen Dem.
3. East Asia and Pacific, including the states of American Samoa, Brunei Darussalam, Cambodia, China (Hong Kong SAR), China(Macao SAR), China(mainland), China, Taiwan Province of, Christmas Iseland, Cocos Giselands(keeling), Fiji, Indonesia, Japan, Kiribati, Democratic People's of Korea, Republico of Korea, Lao People's Democratic Republic, Malaysia, Marshall Iselands, Micronesia, Mongolia, Myanmar, Palau, Papua New Guinea, Phillippines, Samoa, Singapore, Solomon Iselands, Thailand, Timor-Lestre, Tonga, Tuvalu, Vanuatu y Viet Nam.

4. South Asia, including the states of Afghanistan, Bangladesh, Bhutan, British Indian Ocean Territory, India, Maldives, Nepal, Pakistan y Sri Lanka.
5. East Europe, including the states of Abania, Armenia, Azerbaijan, Belarus, Bosnia and Herzegovina, Croatia, Cyprus, Czech Republic, Czechoslovakia, Estonia, Faroe Iselands, Georgia, Hungary, Kazakhstan, Kyrgyzstan, Latuia, Lithuania, Macedonia, Moldova, Montenegro, Poland, Romania, Russian Federation, Serbia, Serbia and Montenegro, Slovakia, Slovenia, Tajikistan, Turkey, Turkmenistan, Ukranie, USSR, Uzbekistan and Yugoslavia.
6. Europe, including the states of Andorra, Austria, Belgium, Belgium-Luxembourg, Denmark, Finland, France, Germany, West Germany, East Germany, Gibraltar, Greece, Holy See, Iceland, Ireland, Italy, Liechtenstein, Luxembourg, Malta, Monaco, Netherlands, Norway, Portugal, San Marino, Spain, Svalbard and Jan Mayen Islands, Sweden, Switzerland and United Kindom.
7. Northern America, including the states of Bermuda, Canada, Greenland, Saint Pierre and Miquelon, United States Of America and United States Virgin Islands.
8. Latin America and Carribean, including the states of Anguilla, Antigua and Barbuda, Argentina, Aruba, Bahamas, Barbados, Belize, Bolivia, Brazil, British Virgin Islands, Cayman Islands, Chile, Colombia, Costa Rica, Cuba, Dominica, Dominican Republic, Ecuador, El Salvador, Falkland Islands (Malvinas), French Guiana, Grenada, Guadeloupe, Guatemala, Guyana, Haiti, Honduras, Jamaica, Martinique, Mexico, Montserrat, Netherlands Antilles, Nicaragua, Panama, Paraguay, Peru, Puerto Rico, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Surname, Trinidad and Tobago, Turks and Caicos Islands and Uruguay.
9. Oceania and New Zeland, including the states of Australia, Cook Islands, French Polynesia, Guam, Nauru, New Caledonia, New Zeland, Nive, Norfolk Island, Wallis and Futuna Islands.

3.3.2.2 Dispersion of data

Parallel to the calculationof the differences, the dispersion of these data represented through the standard deviation has been calculated for each year, and then it was evaluated as it was changing over time. With this ability, the variability of the distribution of these data is shown, indicating by means of a number, if the data obtained from the calculation of the differences are very far from the average[1]. The higher that value, the greater the variability. The smaller it is, the more homogeneous it will be on average. Thus, it is known if all cases are similar or vary greatly between them.

This value is calculated for each particular year and is obtained from the following formula:

$$\sigma = \sqrt{\sum_{1}^{n} \frac{(diff_i - \overline{diff})^2}{n}}$$

Where:

σ = standard deviation of the difference data of a particular difference matrix

$diff_i$ = difference value of the i-cell of the matrix

$\overline{diff}$ = average difference value of all cells in that particular year

n = total number of cells in the difference matrix analyzed (2160x4320 = 9,331,200)

As they are very extensive data located in a matrix of 2160 rows and 4320 columns, in order to calculate the value of the standard deviation for each year, the Matlab program has been used as a tool, using the standard deviation calculation function applied to the matrix of differences. This calculation was made both for the matrix of differences of cultivated area without artificial irrigation, and for the matrix of differences of cultivated area with artificial irrigation. The codes used in the program can be found in the annex.

3.3.3 Lorenz curve and Gini Index

In addition to the calculation of the differences, to interpret from another point of view the historical evolution of the relationship between production and consumption of the food, the

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[1] In colloquial language, an average is a single number taken as representative of a list of numbers. Often "average" refers to the arithmetic mean, the sum of the numbers divided by how many numbers are being averaged. In statistics, mean, median, and mode are all known as measures of central tendency, and in colloquial usage any of these might be called an average value

Lorenz curve has been made for these two variables and then calculated the respective Gini index for each year analyzed.

This index indicates the inequality between two parameters analyzed, in our case production and consumption of the food. This index varies between 0 and 1. If this index is equal to zero it means that there is no inequality, so it is produced in the same place it is consumed, or rather the same population produces what they consume. And if this index is equal to one, it means that the inequality is total and that only one person produces and the rest consumes.

To build the Lorenz curve the following steps are performed:

1- The population and cultivated area data that we have in matrix are vectorized, in our case they are matrices of 2160 rows and 4320 columns.

2- I do the rapport between cultivated area over population.

3- Order from least to greatest the data based on the previous calculation.

4- I make the accumulated sum for both the cultivated area and the population

5- Graph the rapport between the accumulated cultivated area and the total sum of the cultivated area on the vertical axis and the rapport between the accumulated population and the total sum of population on the horizontal axis.

To calculate the Gini index, I have to calculate the area between the Lorenz curve and a line F (x) = 1, that is, the line at 45° because the Lorenz curve goes between 0 and 1 value, both in accidents and in abscissa.

To perform these calculations, the Matlab program has been used as a tool. That's necessary because in our case we have matrices of 2160x4320 data. The codes used are attached in the annex.

The calculation of the Lorenz curve and Gini index were made for both irrigated cultivated area and rainfed cultivated area, the latter two used as food production variables. And as the other variable we use the population data, which would come to represent consumption.

4. Results

4.1 Preliminary analysis

The Matlab tool was used for the calculation, whose codes are attached in the annex. These data were calculated for each year in analysis. Our study is based on the evolution of these data over time. These data were tabulated according to the years to then be able to make the analysis of them in a simpler way.

The results of these simple time-based calculations are as follows:

Table 1 Total area cultivated (irrigated and rainfed) and population for all years

YEAR	Total area irrigated	Total area rainfed	Population
	[km2]	[km2]	[10^3 hab]
0	26079	1424600	232,12
100	27596	1432800	236,90
200	29429	1411500	240,61
300	30401	1250000	227,55
400	31197	1282800	241,54
500	31958	1293200	253,24
600	32519	1356200	271,48
700	34418	1350300	278,19
800	36444	1360800	285,71
900	39601	1516500	310,97
1000	41091	1574300	323,41
1100	39592	2046600	397,92
1200	38426	2372900	444,75
1300	40043	2408200	456,39
1400	38008	2149100	442,48
1500	42009	2516200	503,24
1600	34288	2656000	515,75
1700	44708	2886500	591,72
1720	54513	3122600	642,72

1750	69004	3482300	745,67
1780	83536	3866100	891,05
1810	131370	4384300	1016,70
1840	245200	5159100	1194,30
1870	357150	6142900	1326,90
1900	474610	7923200	1642,00
1910	589690	8708700	1765,00
1920	704990	9087500	1895,50
1930	820250	9802300	2073,20
1940	936020	10553000	2289,20
1950	1052900	11175000	2529,80
1960	1332300	12438000	3022,80
1970	1500800	12843000	3694,10
1980	1778000	12735000	4447,20
1990	2072400	13150000	5297,80
2000	2330500	12982000	6110,40
2001	2381700	12966000	6187,60
2002	2424600	12885000	6264,80
2003	2485300	12898000	6342,10
2004	2513700	12925000	6419,30
2005	2539200	12971000	6496,50
2006	2556700	12864000	6573,70
2007	2576800	12866000	6650,90
2008	2593500	12895000	6728,10
2009	2612100	12867000	6805,30
2010	2642100	12810000	6882,50
2011	2665300	12900000	6957,40
2012	2683500	13057000	7032,30
2013	2707600	13027000	7107,20
2014	2732300	13068000	7182,10

2015	2755600	13158000	7257,00
2016	2777200	13201000	7331,90
2017	2800300	13229000	7406,80

Once calculated, with the help of the same program the data will be plotted as a function of time to be able to appreciate and analyze them better.

One of these graphs is the cultivated area, both rainfed and irrigated on the vertical axis and the time in years on the horizontal axis.

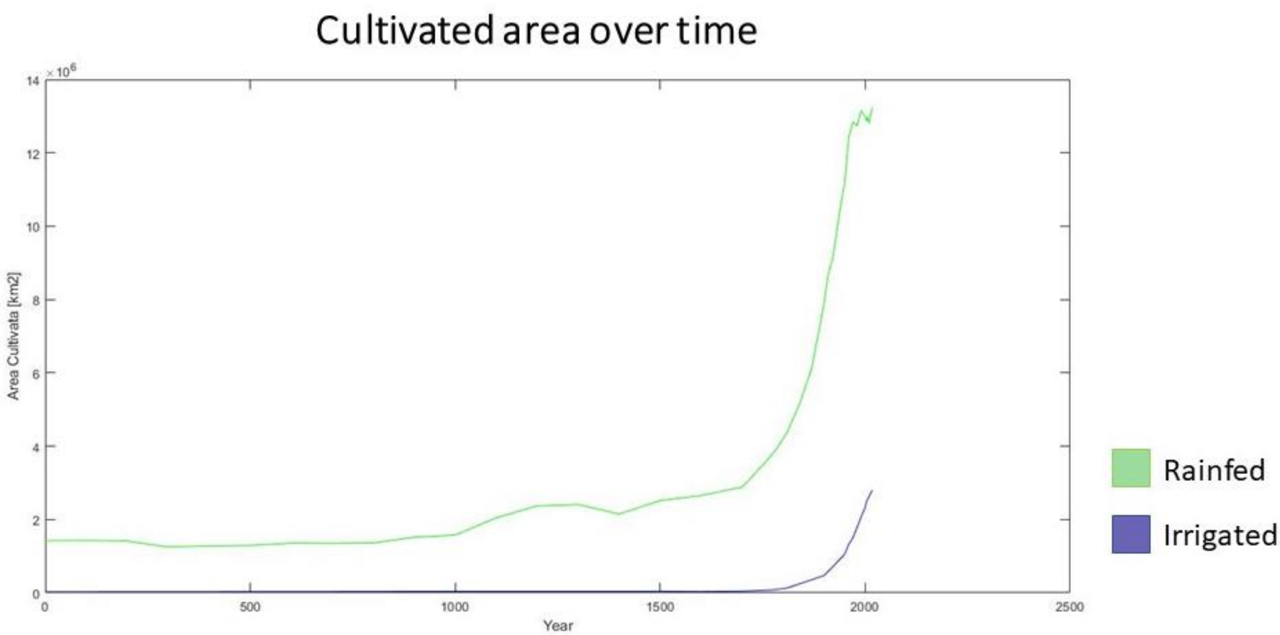

Figure 10 Cultivated area over time

From this graph and from table 1 you can see the great difference in cultivated area with irrigation to the rainfed cultivated area. This difference is noticeable and until 1800 AD the area cultivated irrigated is less than or equal to 2% of the rainfed cultivated area, from there it begins to increase gradually up to 10% in 1950 AD and from then on gradually increases until the year 2000 AD that The irrigated area reaches about 20% of the rainfed area and remains almost constant until today.

Also another thing that can be seen in this graph is that the total cultivated area begins to have a strong increase after the year 1750 AD in which, according to our calculations, 3,551,304 km2 of total cultivated area in the world were produced, which They are the beginnings of the industrial revolution. This value grew to 6,500,050 km2 in 1870 AD. After that year, it can be seen in the graph that the increase is even greater. This makes sense beacuse starting this last year, the industrialization of agriculture was beginning, when industrial innovations aimed at the agricultural sector began to appear. From this year to the present it can be seen that the increase continued until it reached a current value (2017 AD) of 16,029,300 km2 of total cultivated area in the world.

Another of these graphs is the population in billions on the vertical axis and the time in years in the horizontal axis.

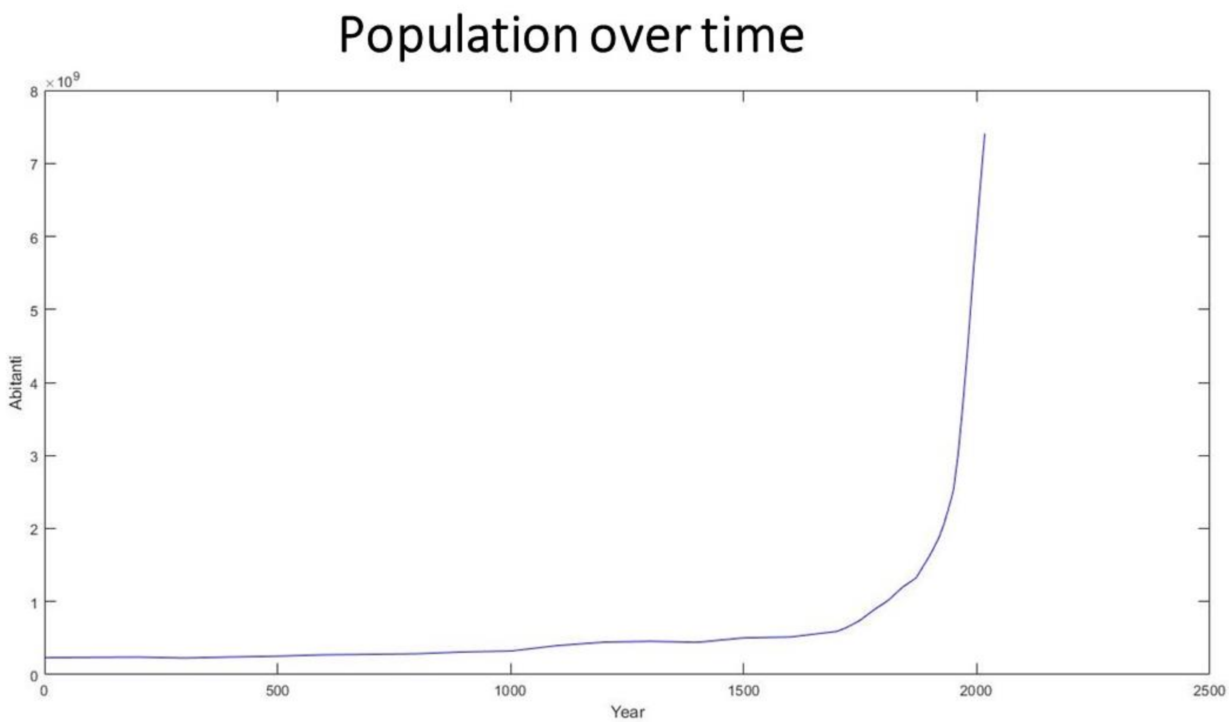

Figure 11 Population over time

From this graph and from table 1.1 you can see a small growth until not much more than an annual rate of 0.1% until the year 1700 AD, hence a gradual increase in the rate until reaching 1% per year in the year 1950 AD and from that year until the year 2000 AD an enormous growth with an annual rate of not less than 1.6%. From the year 2000 AD to the present, growth is also great but it grows at an average rate of 1.12% per year.

Another calculation that has been made is the one of total cultivated area per habitant, which is then plotted with cultivated area per person in hectares per habitant on the vertical axis and time in years on the horizontal axis.

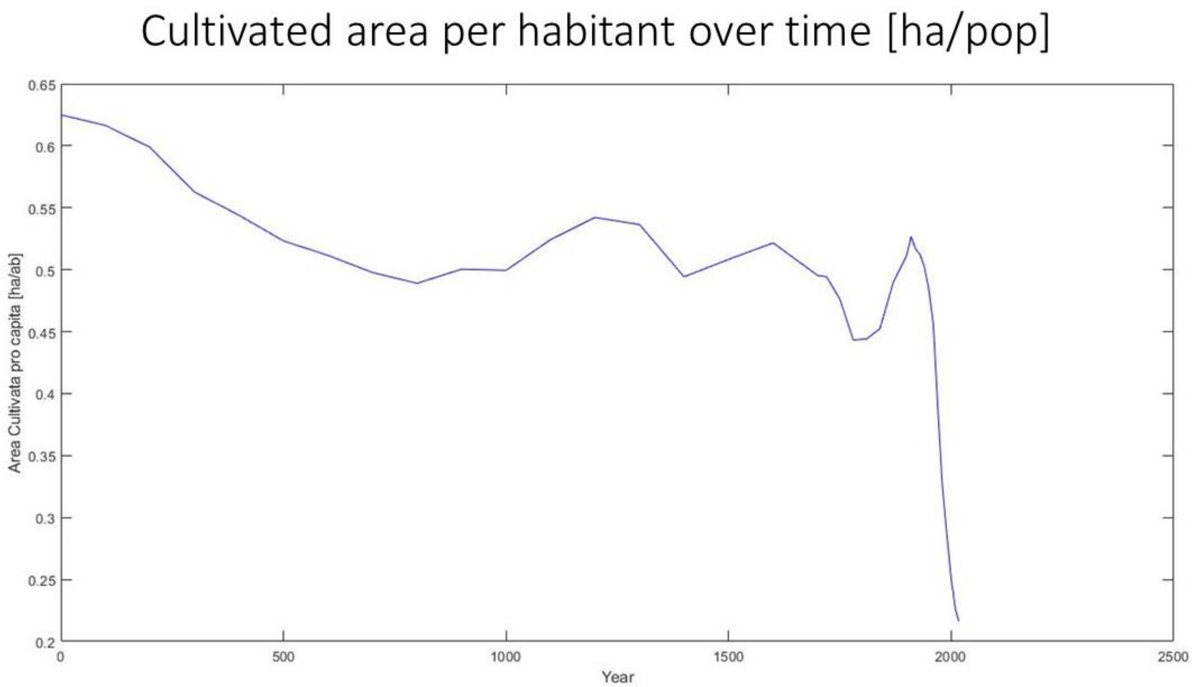

Figure 12 Cultivated area per habitant over time

From this graph you can see how the production varies per habitant over time. You can see how in the year 0 AD starting from a value of 0.62 hectares per person, the production per unit of habitant was gradually decreased to a negative peak in the year 800 AD where the value reaches 0.49 hectares per person. After this year there is an increase until reaching a positive peak in the year 1200 AD with a value of 0.54 hectares per habitant, which is maintained and goes back down to a negative peak in the years 1400 AD to a value of 0.495 hectares per habitant. Then this value increases slowly until it reaches a positive peak in 1600 AD, reaching a value of 0.52 hectares per habitant. This then begins to decrease until it reaches a negative peak in the year 1780 AD with a value of 0.44 hectares per person. As of this year, the increase in production per habitant grows rapidly until reaching a last positive peak in 1910 AD with a value of 0.53 hectares per habitant. Finally, after this year this value begins to decline steadily until it reaches the present time in which we are at a production value of 0.22 hectares per habitant, a value almost 2.5 times less than 100 years ago. Since in this graph we analyze the relationship between cultivated area and population, the results of the graph make sense if we compare them with the data of these two variables that we analyzed in the previous graphs.

It can be noted that the increase in cultivated area resulted in an increase in the population, but as the increase in cultivated area occurred before, it can be seen in this graph how this relationship significantly increased since 1840 AD with the increase in the area cultivated but this reaches a peak in the year 1910 AD in which from there the increase in population becomes greater than the increase in cultivated area so in this graph the value of this relationship between cultivated area and population begins to descend with a steep slope until today.

Like the previous calculation, it has been done for rainfed cultivated area per habitant, where the graph is made with rainfed cultivated area per person in hectares per habitant on the vertical axis and the time in years on the horizontal axis.

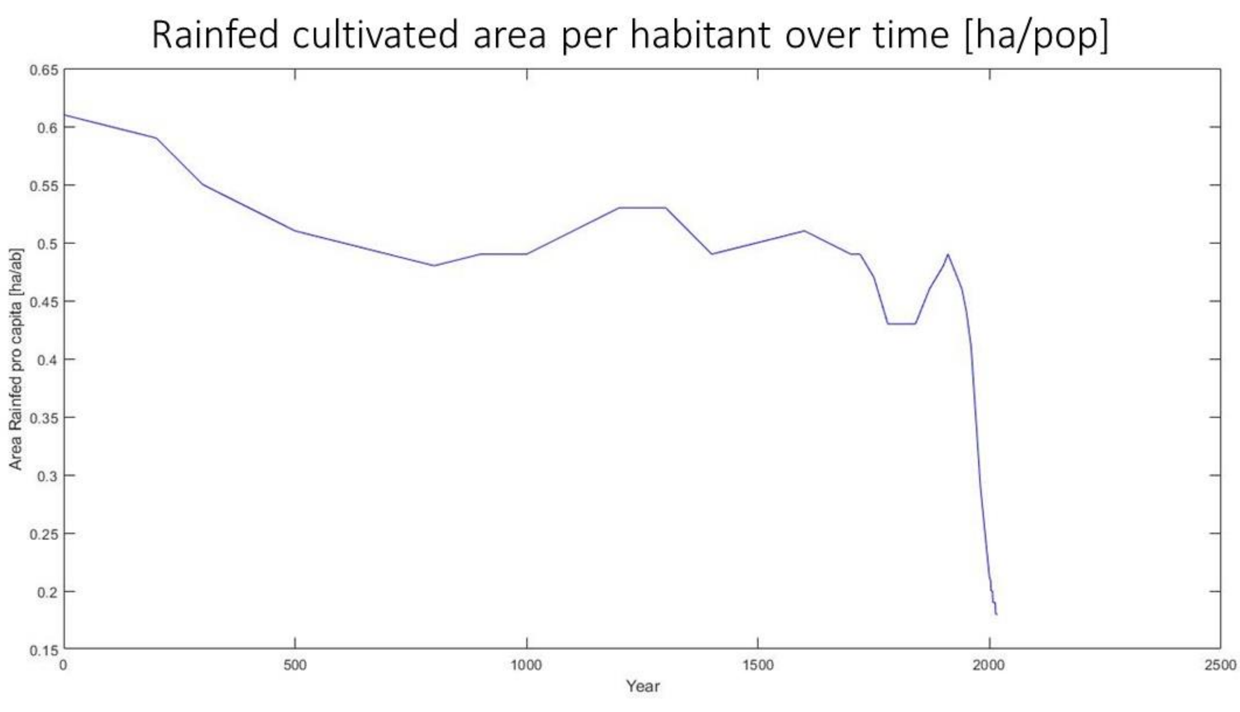

Figure 13 Rainfed cultivated area per habitant over time

This graph represents the relationship between the rainfed cultivated area and the population, as does the previous with total cultivated area. It can be seen that the cultivated area is irrigated by less than 10% of the rainfed cultivated area until 1950 AD (after the peak of the graph), so the area cultivated rainfed per person varies in the same way as the total cultivated area does, beacuse it is at minus 90% of this until that year. So we can say that this graph varies in the same way as the one analyzed above.

It has also been made for cultivated area with irrigation per habitant, where the graph is made with cultivated area with irrigation per person in hectares per habitant on the vertical axis and time in years on the horizontal axis.

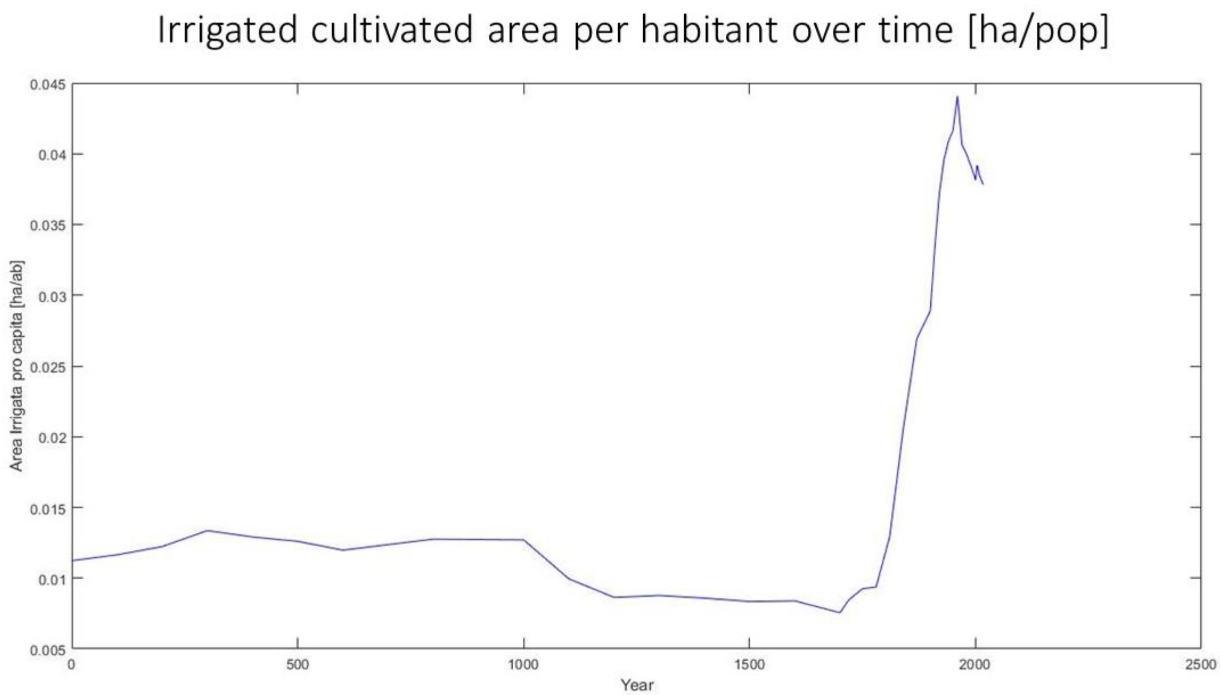

Figure 14 Irrigated cultivated area per habitant over time

At first glance we can see the great difference of this graph with the graph of rainfed cultivated area per person. This graph shows a notable increase from the year 1780 AD in which the value was only 0.0094 hectares per person to a peak in 1960 AD, reaching a value of 0.044 hectares per person. After this last year it begins to decrease due to a much greater increase in the population with respect to the increase in the area cultivated with irrigation until reaching a current value of 0.038 hectares per habitant.

4.1.1 Preliminary analysis in characteristic regions

The same preliminary analysis has been performed for each region of the world map in particular. This was done by differentiating the data of each region through an array of data from the regions, which has as data the number of the region to which each cell belongs. With the help of this matrix and data matrices of cultivated area without artificial irrigation, cultivated area with artificial irrigation and population of each year, a differentiated preliminary analysis has been made in the different regions of the world, with the help of the program Matlab as a calculation tool. This analysis has been done in this case for the years of interest of the analysis, which are years 0 AD, 500 AD, 1000 AD, 1500 AD, 1700 AD, 1810 AD, 1900 AD, 1950 AD and 2017 AD.

4.1.1.1 Region 1: Africa

With the help of the Matlab program, we have been able to differentiate the starting data of the analysis for the different regions that we want to analyze. In this case we will show the results for region 1 of our analysis, which is the region of Africa, including the states of Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Comoros, Congo, Democratic Republic of the Congo, Coste d'Ivoire, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mayotte, Mozambique, Namibia, Niger, Nigeria, Reunion, Rwanda, Saint Helena, Ascension and tristan da Cunha, Sao Tome and Pricipe, Senegal, Seychelles, Sierra Leone, Somalia, South Africa, Sudan, Swaziland, Tanzania, Togo, Uganda, Western Sahara, Zambia y Zimbabwe. The results of the preliminary analysis for each year of the analysis for region 1 will be shown tabulated below.

Table 2 Preliminary analysis results of region 1

Year	Population [hab]	Raifed Cultivated Area [km2]	Irrigated cultivated area [km2]	Total cultivated area [km2]	Cultivated área per capita [ha/hab]	Rainfed Cultivated área per capita [ha/hab]	Irrigated Cultivated área per capita [ha/hab]
0	6,56E+06	4,32E+04	1,21E+02	4,33E+04	6,60E-01	6,60E-01	1,85E-03
500	1,34E+07	8,32E+04	1,64E+02	8,34E+04	6,20E-01	6,20E-01	1,22E-03
1000	2,90E+07	173020	284,8662	173300	6,00E-01	6,00E-01	9,83E-04
1500	4,96E+07	2,92E+05	6,09E+02	2,92E+05	5,90E-01	5,90E-01	1,23E-03
1700	6,50E+07	3,88E+05	9,13E+02	3,89E+05	6,00E-01	6,00E-01	1,40E-03
1810	7,06E+07	4,30E+05	2,64E+03	4,33E+05	6,10E-01	6,10E-01	3,74E-03

1900	1,01E+08	5,97E+05	7,79E+03	6,05E+05	6,00E-01	5,90E-01	7,73E-03
1950	1,81E+08	1,10E+05	2,14E+04	1,12E+06	6,20E-01	6,10E-01	1,18E-02
2017	9,92E+08	2,43E+06	6,93E+04	2,50E+06	2,50E-01	2,50E-01	6,99E-03

Once calculated, the data will be plotted as a function of time to be able to appreciate and analyze them better.

One of these graphs is the cultivated area, both rainfed and irrigated on the vertical axis (in Km2) and the time in years on the horizontal axis.

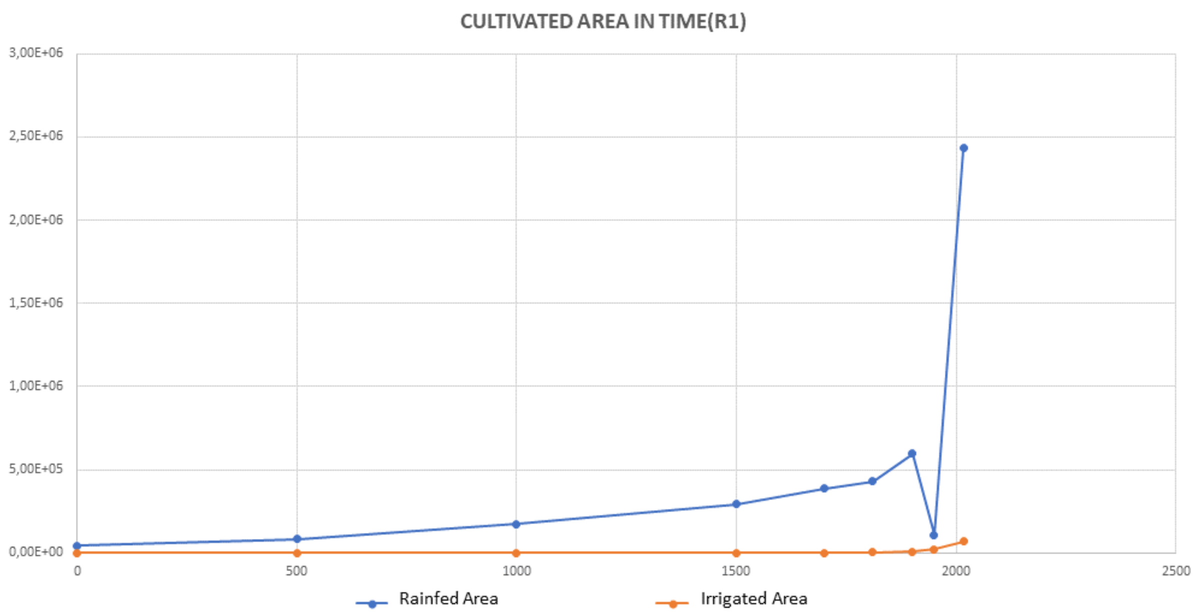

Figure 15 Cultivated area over time for region 1

Another of these graphs is the one of population on the vertical axis and time in years on the horizontal axis.

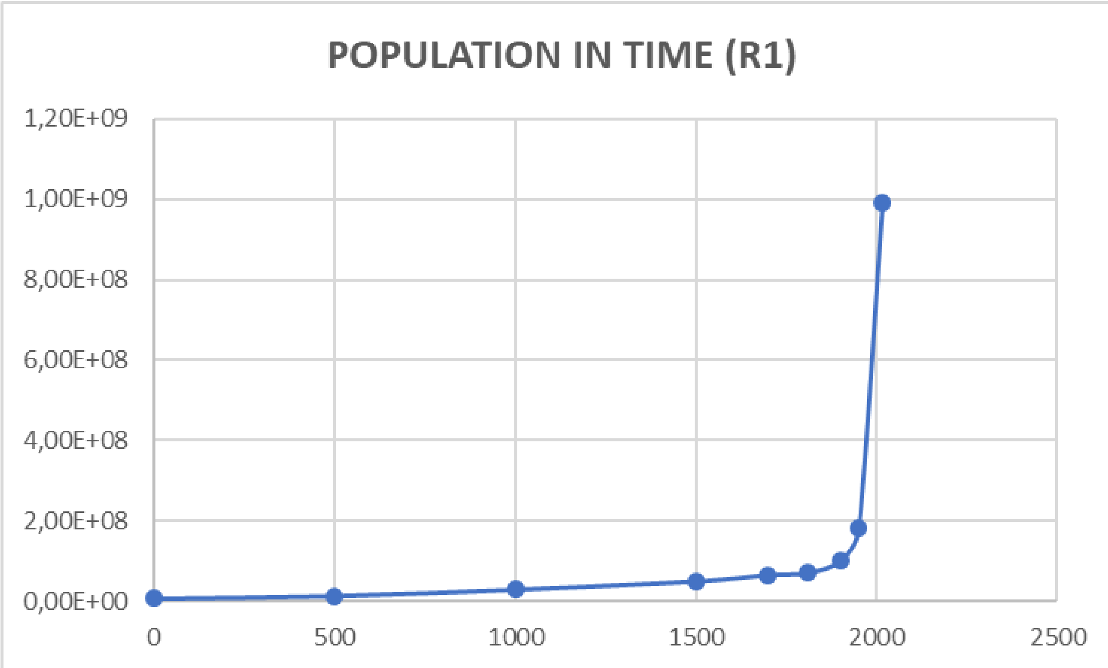

Figure 16 Population over time for region 1

Another calculation that has been made is the one of total cultivated area per habitant, which is then plotted with cultivated area per person in hectares per habitant on the vertical axis and time in years on the horizontal axis.

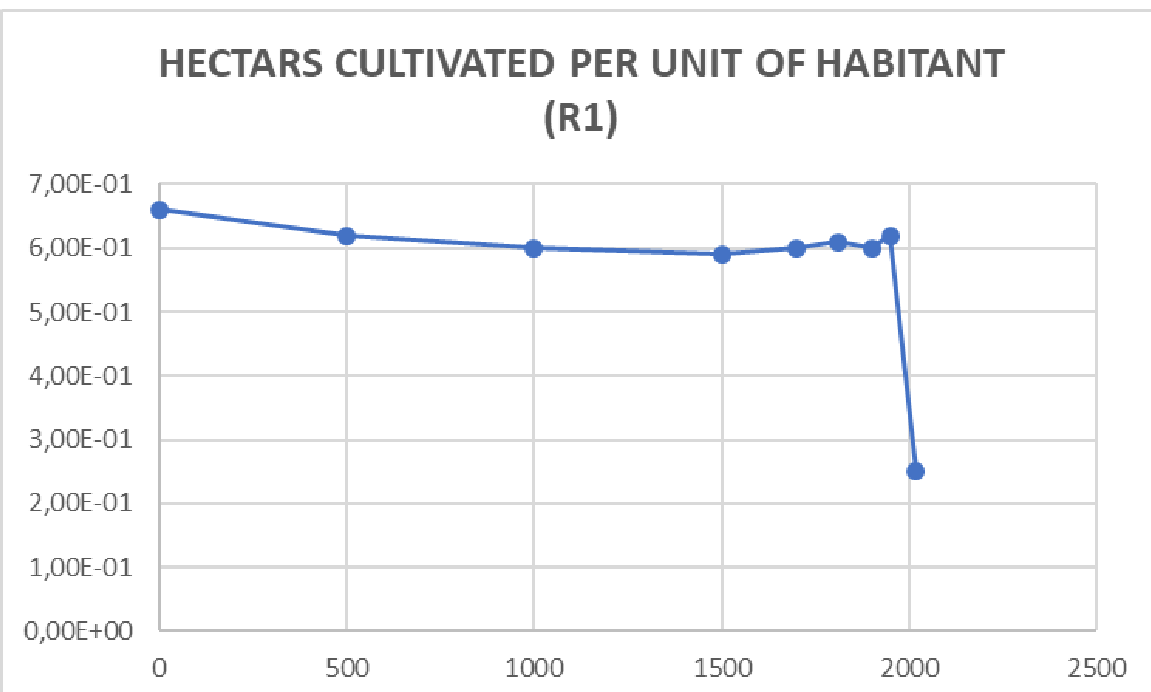

Figure 17 Cultivated area per habitant over time for region 1

4.1.1.2 Region 2: Middle East and North Africa

With the help of the Matlab program, we have been able to differentiate the starting data of the analysis for the different regions that we want to analyze. In this case we will show the results for region 2 of our analysis, which is the region of Middle East and North Africa, including the states of Algeria, Bahrain, Djibouti, Egypt, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Libya, Morocco, Occupied Palestinian Territory, Oman, Saudi Arabia, Syria, Tunisia, United Arab Emirates, Yemen, Yemen Ar Rp y Yemen Dem.

The results of the preliminary analysis for each year of the analysis for region 1 will be shown tabulated below.

Table 3 Preliminary analysis results of region 2

Year	Population [hab]	Raifed Cultivated Area [km2]	Irrigated cultivated area [km2]	Total cultivated area [km2]	Cultivated área per capita [ha/hab]	Rainfed Cultivated área per capita [ha/hab]	Irrigated Cultivated área per capita [ha/hab]
0	1,80E+07	1,51E+05	1,21E+04	1,63E+05	9,10E-01	8,40E-01	6,70E-02
500	2,23E+07	1,56E+05	1,51E+04	1,71E+05	7,70E-01	7,00E-01	6,76E-02
1000	2,33E+07	1,32E+05	1,83E+04	1,50E+05	6,40E-01	5,60E-01	7,85E-02
1500	1,96E+07	9,49E+04	9,89E+03	1,05E+05	5,90E-01	4,80E-01	5,04E-02
1700	2,19E+07	1,04E+05	8,60E+03	1,13E+05	5,10E-01	4,70E-01	3,93E-02
1810	2,53E+07	1,48E+05	9,50E+03	1,58E+05	6,20E-01	5,80E-01	3,75E-02
1900	4,97E+07	2,52E+05	2,39E+04	2,76E+05	5,40E-01	5,10E-01	4,80E-02
1950	8,10E+07	3,29E+06	8,99E+04	4,19E+05	5,20E-01	4,10E-01	1,10E-01
2017	4,16E+08	4,35E+05	2,08E+05	6,43E+05	1,50E-01	1,00E-01	4,99E-02

Once calculated, the data will be plotted as a function of time to be able to appreciate and analyze them better.

One of these graphs is the cultivated area, both rainfed and irrigated on the vertical axis (in Km2) and the time in years on the horizontal axis.

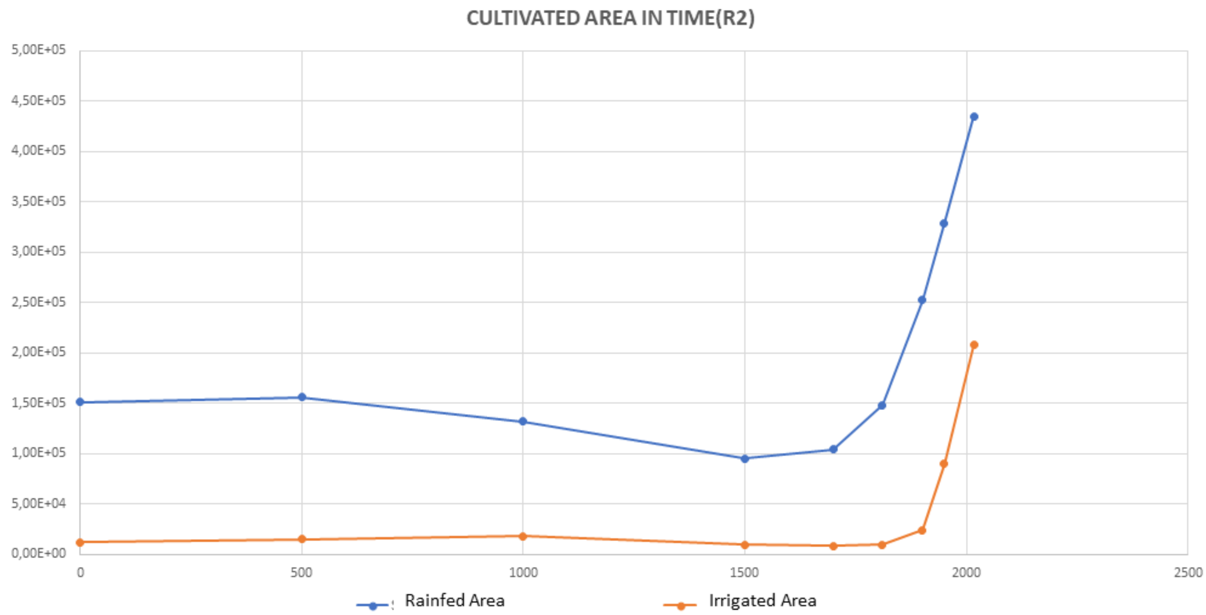

Figure 18 Cultivated area over time for region 2

Another of these graphs is the one of population on the vertical axis and time in years on the horizontal axis.

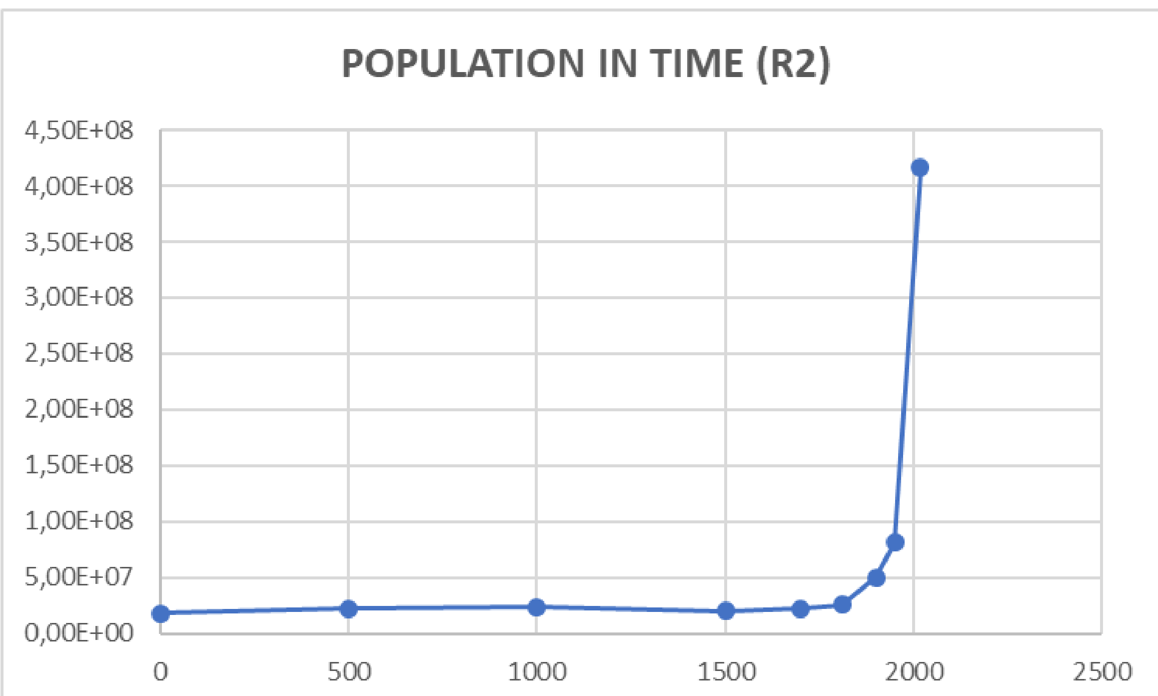

Figure 19 Population over time for region 2

Another calculation that has been made is the one of total cultivated area per habitant, which is then plotted with cultivated area per person in hectares per habitant on the vertical axis and time in years on the horizontal axis.

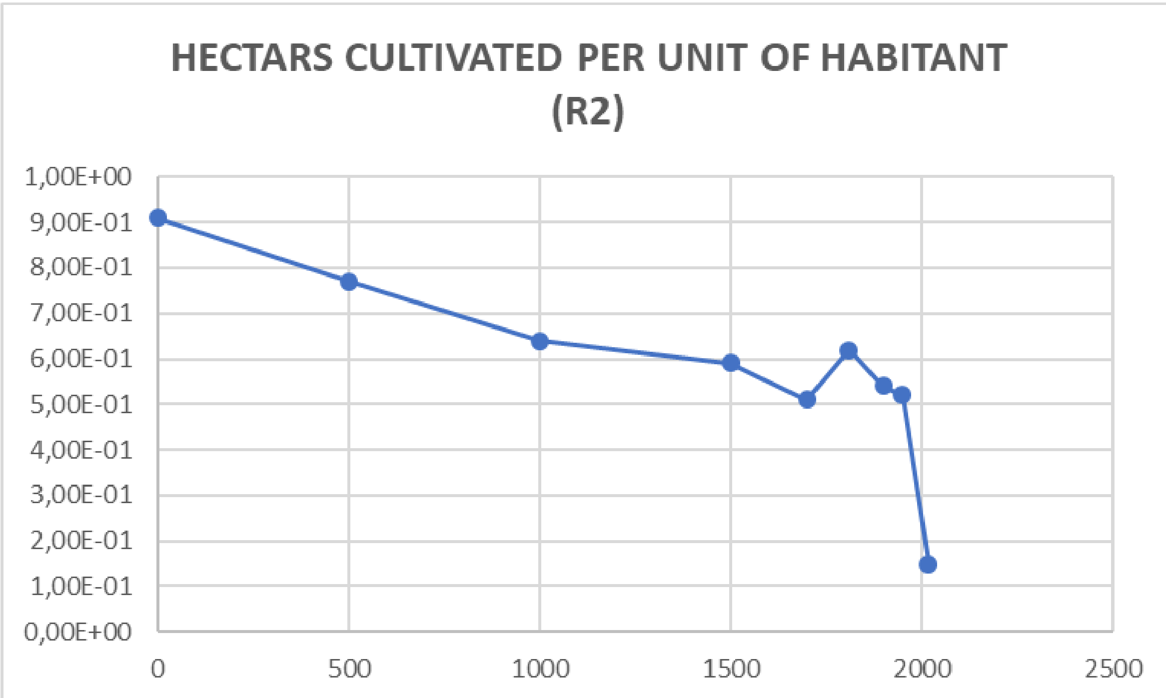

Figure 20 Cultivated area per habitant over time for region 2

4.1.1.3 Region 3: East Asia and Pacific

With the help of the Matlab program, we have been able to differentiate the starting data of the analysis for the different regions that we want to analyze. In this case we will show the results for region 3 of our analysis, which is the region of East Asia and Pacific, including the states of American Samoa, Brunei Darussalam, Cambodia, China (Hong Kong SAR), China(Macao SAR), China(mainland), China, Taiwan Province of, Christmas Iseland, Cocos Iselands(keeling), Fiji, Indonesia, Japan, Kiribati, Democratic People's of Korea, Republico of Korea, Lao People's Democratic Republic, Malaysia, Marshall Iselands, Micronesia, Mongolia, Myanmar, Palau, Papua New Guinea, Phillippines, Samoa, Singapore, Solomon Iselands, Thailand, Timor-Lestre, Tonga, Tuvalu, Vanuatu y Viet Nam.

The results of the preliminary analysis for each year of the analysis for region 1 will be shown tabulated below.

Table 4 Preliminary analysis results of region 3

Year	Population [hab]	Raifed Cultivated Area [km2]	Irrigated cultivated area [km2]	Total cultivated area [km2]	Cultivated área per capita [ha/hab]	Rainfed Cultivated área per capita [ha/hab]	Irrigated Cultivated área per capita [ha/hab]
0	6,38E+07	4,84E+05	9,13E+03	4,93E+05	7,70E-01	7,60E-01	1,43E-02
500	4,80E+07	2,99E+05	1,02E+04	3,09E+05	6,40E-01	6,20E-01	2,12E-02
1000	5,55E+07	2,92E+05	1,33E+04	1,88E+04	5,50E-01	5,30E-01	2,40E-02
1500	1,27E+08	6,42E+05	1,88E+04	6,61E+05	5,20E-01	5,00E-01	1,47E-04
1700	1,58E+08	7,09E+05	2,15E+04	7,31E+05	4,60E-01	4,50E-01	1,36E-04
1810	4,21E+08	9,34E+05	5,91E+04	9,93E+05	2,40E-01	2,20E-01	1,40E-02
1900	5,49E+08	1,12E+06	1,58E+05	1,27E+06	2,30E-01	2,00E-01	2,88E-02
1950	8,28E+08	1,41E+06	3,00E+05	1,71E+06	2,10E-01	1,70E-01	3,62E-02
2017	2,21E+09	1,58E+06	9,01E+05	2,48E+06	1,10E-01	7,16E-02	4,07E-02

Once calculated, the data will be plotted as a function of time to be able to appreciate and analyze them better.

One of these graphs is the cultivated area, both rainfed and irrigated on the vertical axis (in Km2) and the time in years on the horizontal axis.

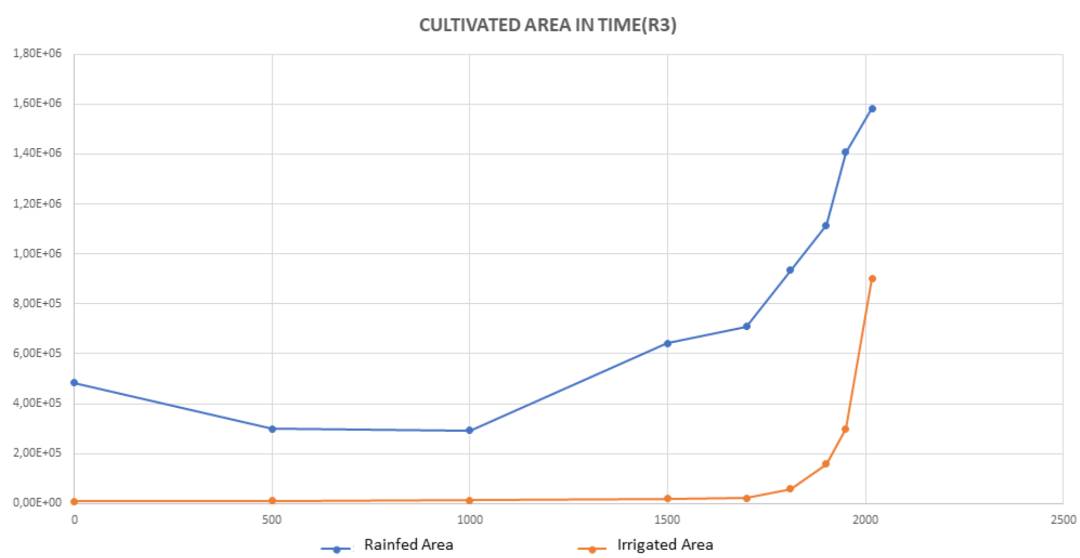

Figure 21 Cultivated area over time for region 3

Another of these graphs is the one of population on the vertical axis and time in years on the horizontal axis.

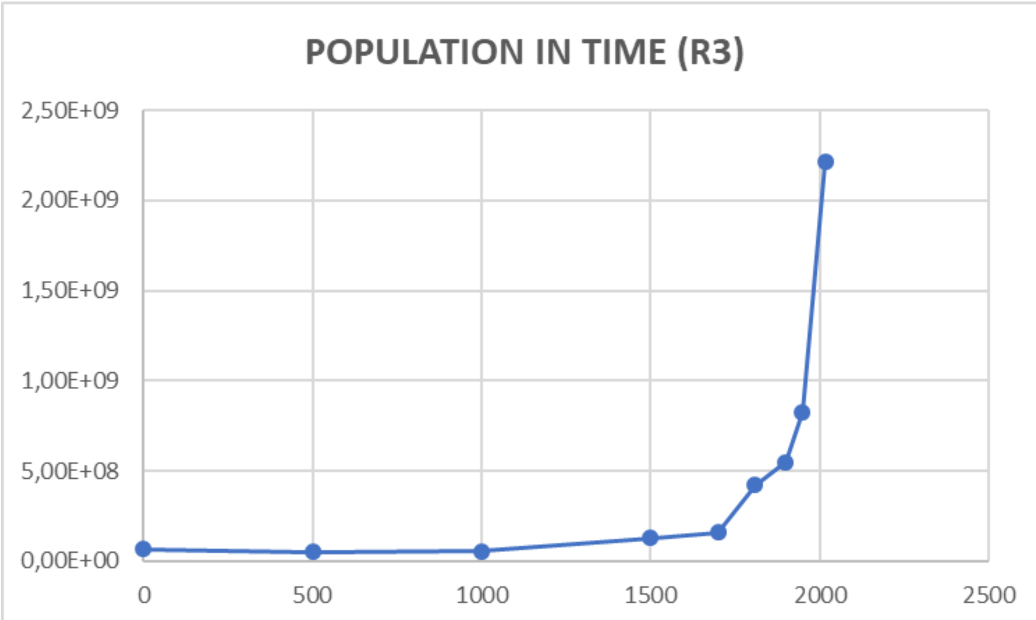

Figure 22 Population over time for region 3

Another calculation that has been made is the one of total cultivated area per habitant, which is then plotted with cultivated area per person in hectares per habitant on the vertical axis and time in years on the horizontal axis.

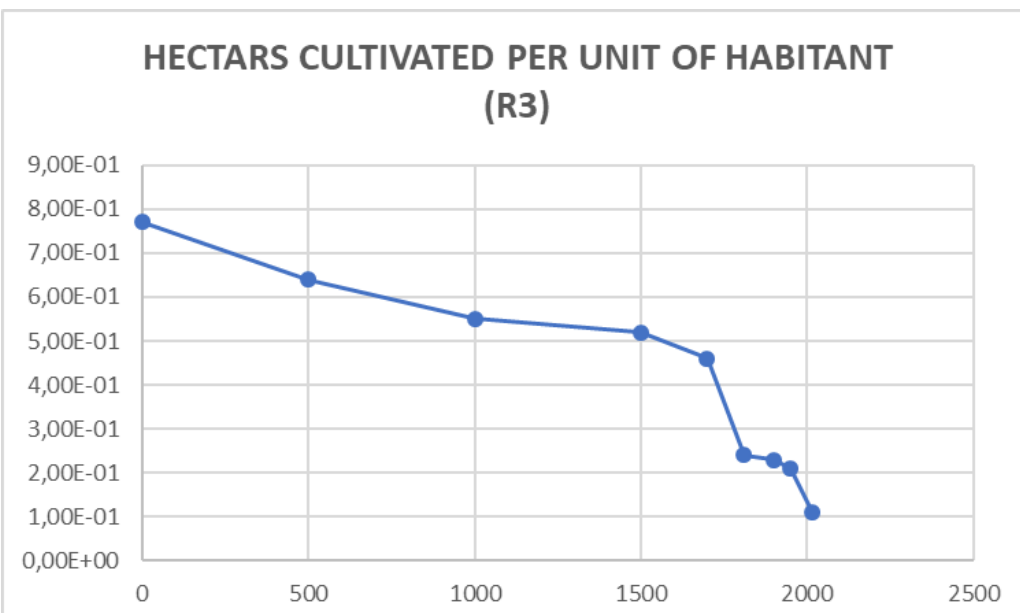

Figure 23 Cultivated area per habitant over time for region 3

4.1.1.4 Región 4: South Asia

With the help of the Matlab program, we have been able to differentiate the starting data of the analysis for the different regions that we want to analyze. In this case we will show the results for region 4 of our analysis, which is the region of South Asia, including the states of Afghanistan, Bangladesh, Bhutan, British Indian Ocean Territory, India, Maldives, Nepal, Pakistan y Sri Lanka.

The results of the preliminary analysis for each year of the analysis for region 1 will be shown tabulated below.

Table 5 Preliminary analysis results of region 4

Year	Population [hab]	Raifed Cultivated Area [km2]	Irrigated cultivated area [km2]	Total cultivated area [km2]	Cultivated área per capita [ha/hab]	Rainfed Cultivated área per capita [ha/hab]	Irrigated Cultivated área per capita [ha/hab]
0	8,37E+07	2,13E+05	2,05E+03	2,15E+05	2,60E-01	2,50E-01	2,45E-03
500	1,06E+08	2,67E+05	2,73E+03	2,70E+05	2,60E-01	2,50E-01	2,59E-03
1000	1,30E+08	3,21E+05	3,87E+03	3,25E+05	2,50E-01	2,50E-01	2,98E-03
1500	1,53E+08	3,72E+05	4,79E+03	3,76E+05	2,50E-01	2,40E-01	3,14E-03
1700	1,99E+08	4,85E+05	7,11E+03	4,92E+05	2,50E-01	2,40E-01	3,57E-03
1810	2,47E+08	9,71E+05	3,42E+04	1,00E+06	4,10E-01	3,90E-01	1,39E-02
1900	3,44E+08	1,25E+06	1,64E+05	1,42E+06	4,10E-01	3,60E-01	4,77E-02
1950	4,76E+08	1,52E+06	3,19E+05	1,84E+06	3,90E-01	3,20E-01	6,71E-02
2017	1,76E+09	1,32E+06	8,76E+05	2,20E+06	1,20E-01	7,51E-02	4,96E+00

Once calculated, the data will be plotted as a function of time to be able to appreciate and analyze them better.

One of these graphs is the cultivated area, both rainfed and irrigated on the vertical axis (in Km2) and the time in years on the horizontal axis.

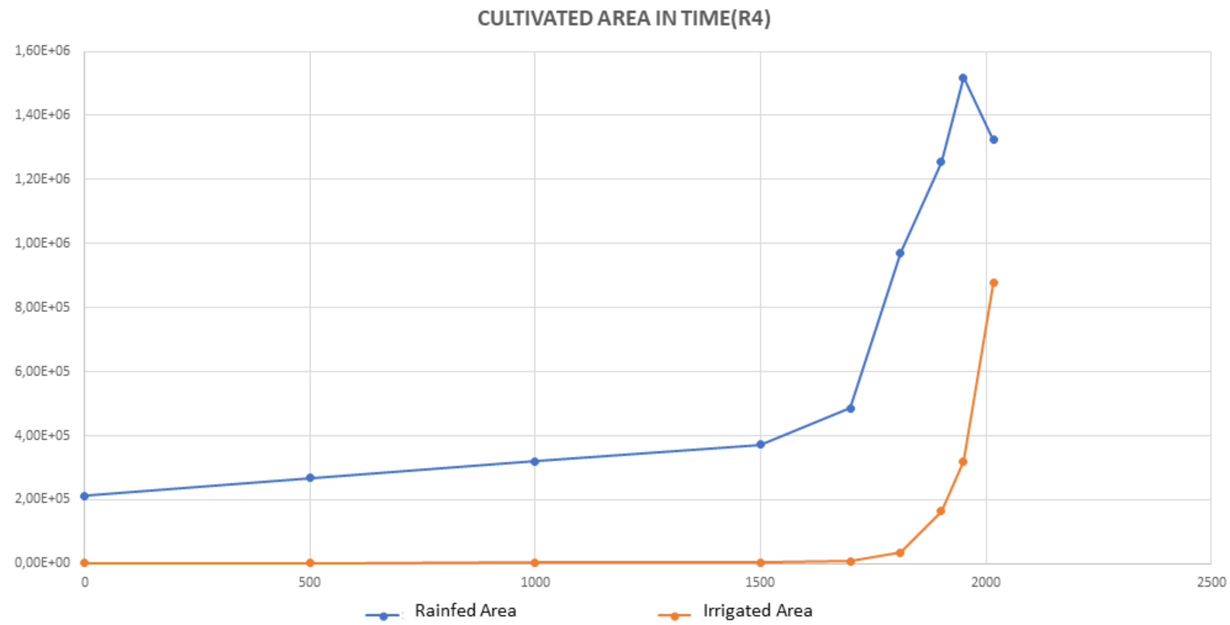

Figure 24 Cultivated area over time for region 4

Another of these graphs is the one of population on the vertical axis and time in years on the horizontal axis.

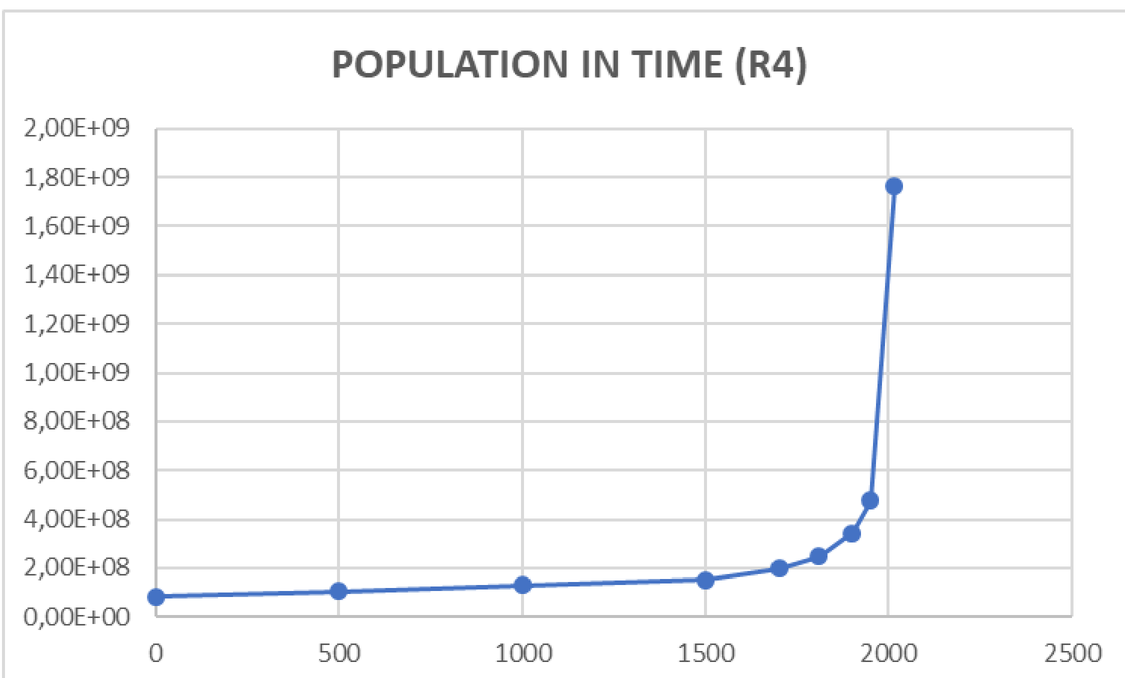

Figure 25 Population over time for region 4

Another calculation that has been made is the one of total cultivated area per habitant, which is then plotted with cultivated area per person in hectares per habitant on the vertical axis and time in years on the horizontal axis.

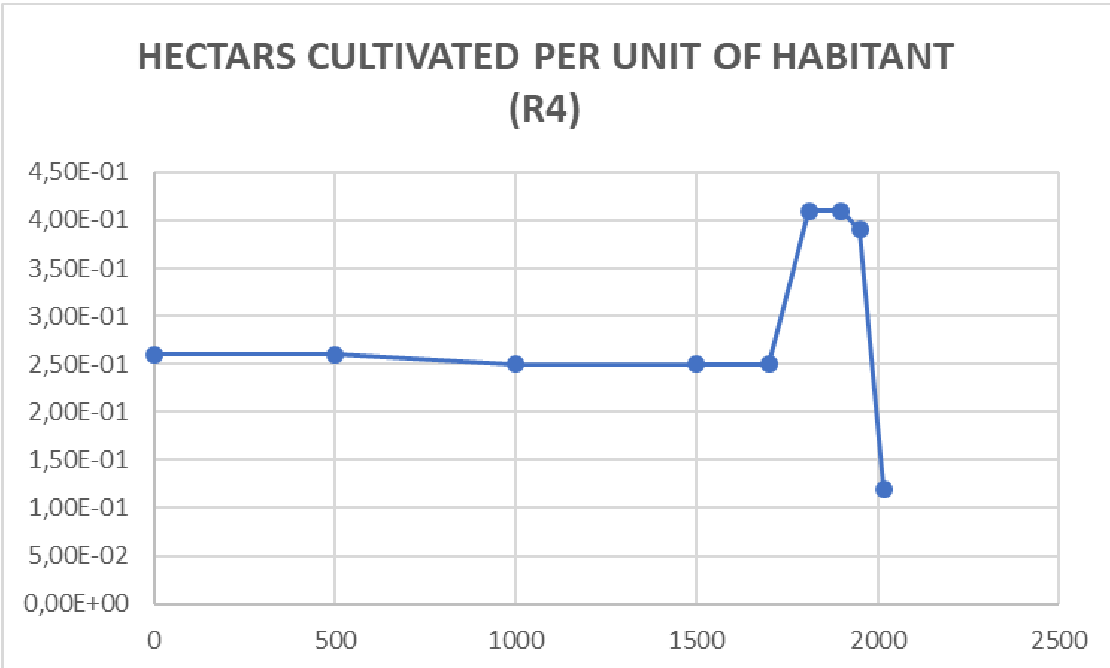

Figure 26 Cultivated area per habitant over time for region 4

4.1.1.5 Region 5: East Europe and Central Asia

With the help of the Matlab program, we have been able to differentiate the starting data of the analysis for the different regions that we want to analyze. In this case we will show the results for region 5 of our analysis, which is the region of East Europe, including the states of Abania, Armenia, Azerbaijan, Belarus, Bosnia and Herzegovina, Croatia, Cyprus, Czech Republic, Czechoslovakia, Estonia, Faroe Iselands, Georgia, Hungary, Kazakhstan, Kyrgyzstan, Latuia, Lithuania, Macedonia, Moldova, Montenegro, Poland, Romania, Russian Federation, Serbia, Serbia and Montenegro, Slovakia, Slovenia, Tajikistan, Turkey, Turkmenistan, Ukranie, USSR, Uzbekistan and Yugoslavia.

The results of the preliminary analysis for each year of the analysis for region 1 will be shown tabulated below.

Table 6 Preliminary analysis results of region 5

Year	Population [hab]	Raifed Cultivated Area [km2]	Irrigated cultivated area [km2]	Total cultivated area [km2]	Cultivated área per capita [ha/hab]	Rainfed Cultivated área per capita [ha/hab]	Irrigated Cultivated área per capita [ha/hab]
0	1,40E+07	1,79E+05	1,23E+03	1,80E+05	1,28E+00	1,27E+00	8,75E-03
500	1,52E+07	1,79E+05	1,50E+03	1,80E+05	1,18E+00	1,17E+00	9,82E-03
1000	2,02E+07	2,25E+05	1,91E+03	2,27E+05	1,12E+00	1,11E+00	9,46E-03
1500	3,48E+07	3,46E+05	2,45E+03	3,48E+05	1,00E+00	9,90E-01	7,05E-03
1700	4,89E+07	4,55E+05	3,25E+03	4,58E+05	9,40E-01	9,30E-01	6,65E-03
1810	8,73E+07	8,34E+05	1,08E+04	8,45E+05	9,70E-01	9,60E-01	1,24E-02
1900	1,97E+08	1,84E+06	3,64E+04	1,87E+06	9,95E-01	9,30E-01	1,85E-02
1950	2,79E+08	2,57E+06	6,87E+04	2,64E+06	9,50E-01	9,20E-01	2,46E-02
2017	4,67E+08	2,48E+06	1,71E+05	2,65E+06	5,70E-01	5,30E-01	3,66E-02

Once calculated, the data will be plotted as a function of time to be able to appreciate and analyze them better.

One of these graphs is the cultivated area, both rainfed and irrigated on the vertical axis (in Km2) and the time in years on the horizontal axis.

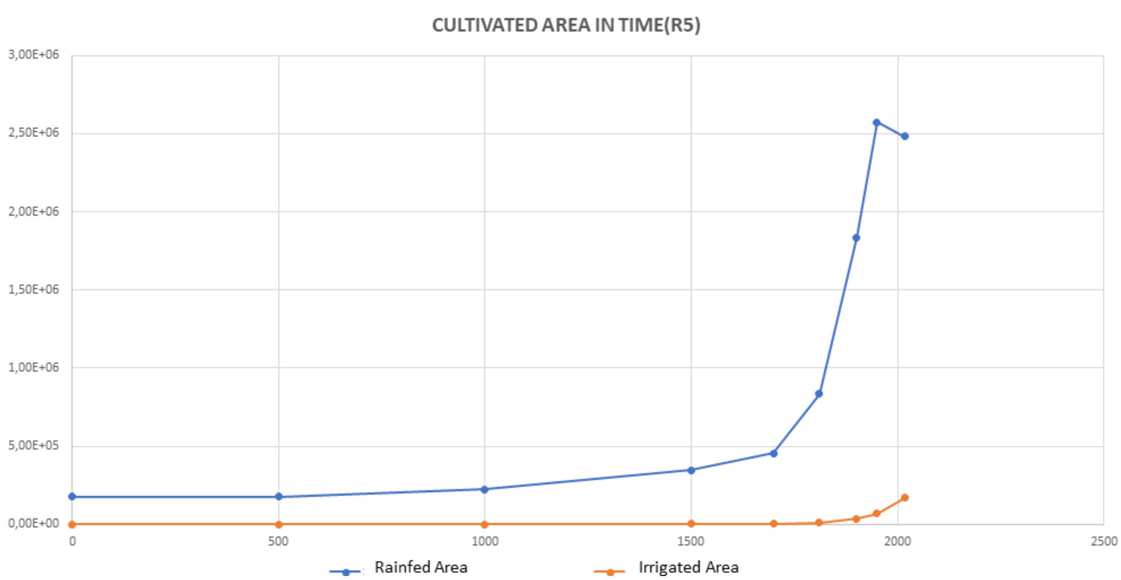

Figure 27 Cultivated area over time for region 5

Another of these graphs is the one of population on the vertical axis and time in years on the horizontal axis.

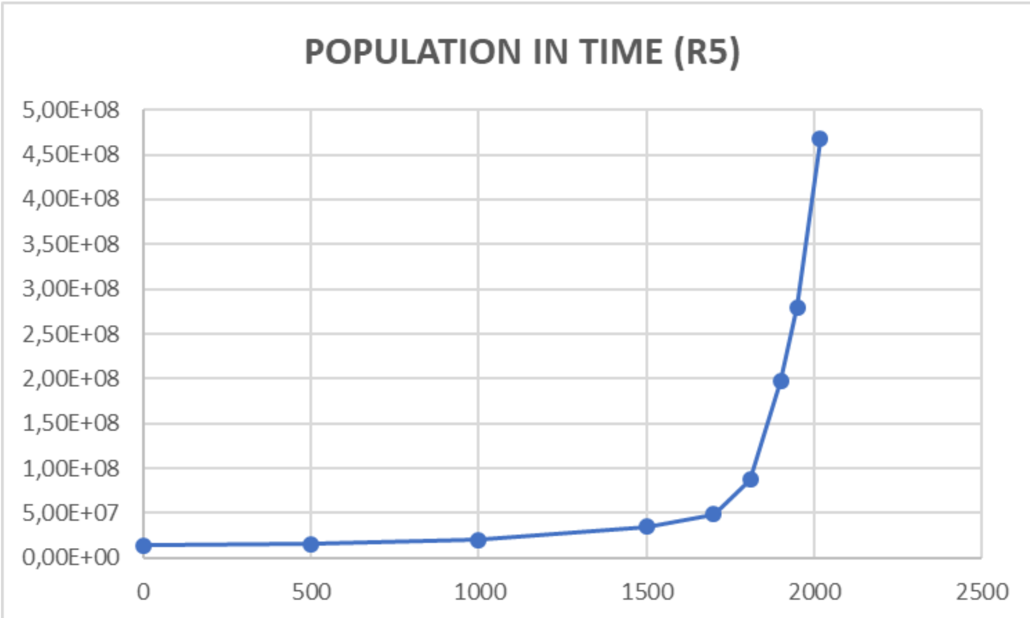

Figure 28 Population over time for region 5

Another calculation that has been made is the one of total cultivated area per habitant, which is then plotted with cultivated area per person in hectares per habitant on the vertical axis and time in years on the horizontal axis.

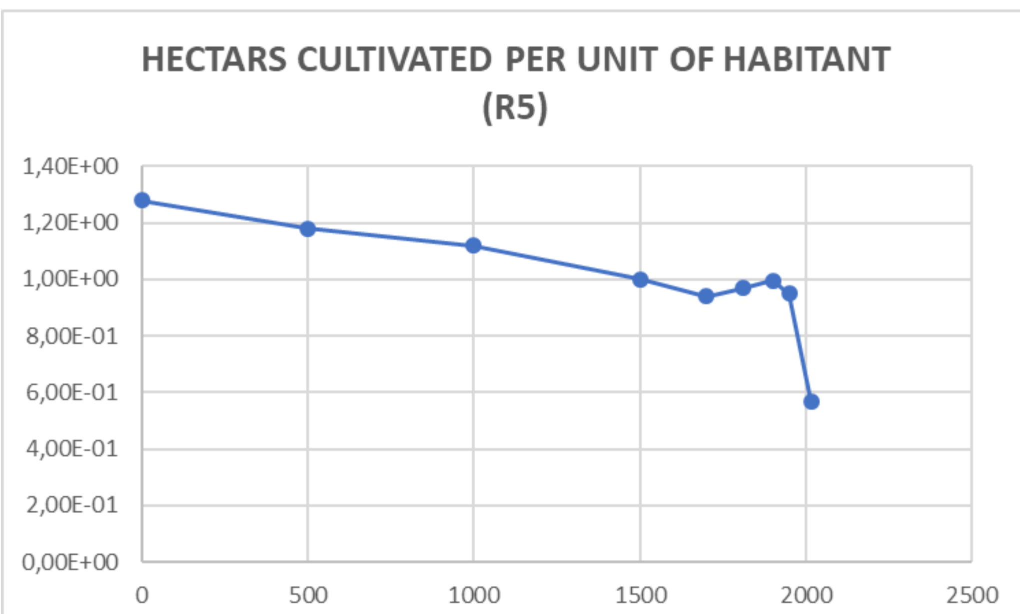

Figure 29 Cultivated area per habitant over time for region 5

4.1.1.6 Region 6: Europe

With the help of the Matlab program, we have been able to differentiate the starting data of the analysis for the different regions that we want to analyze. In this case we will show the results for region 6 of our analysis, which is the region of Europe, including the states of Andorra, Austria, Belgium, Belgium-Luxembourg, Denmark, Finland, France, Germany, West Germany, East Germany, Gibraltar, Greece, Holy See, Iceland, Ireland, Italy, Liechtenstein, Luxembourg, Malta, Monaco, Netherlands, Norway, Portugal, San Marino, Spain, Svalbard and Jan Mayen Islands, Sweden, Switzerland and United Kindom.

The results of the preliminary analysis for each year of the analysis for region 1 will be shown tabulated below.

Table 7 Preliminary analysis results of region 6

Year	Population [hab]	Raifed Cultivated Area [km2]	Irrigated cultivated area [km2]	Total cultivated area [km2]	Cultivated área per capita [ha/hab]	Rainfed Cultivated área per capita [ha/hab]	Irrigated Cultivated área per capita [ha/hab]
0	2,51E+07	2,66E+05	3,41E+02	2,66E+05	1,06E+00	1,06E+00	1,36E-03
500	2,05E+07	1,94E+05	6,39E+02	1,95E+05	9,50E-01	9,50E-01	3,12E-03
1000	2,55E+07	2,66E+05	8,12E+02	2,67E+05	1,05E+00	1,04E+00	3,19E-03
1500	5,30E+07	4,86E+05	1,36E+03	4,88E+05	9,20E-01	9,20E-01	2,57E-03
1700	7,89E+07	6,16E+05	1,71E+03	6,17E+05	7,80E-01	7,80E-01	2,17E-03
1810	1,24E+08	7,57E+05	5,89E+03	7,63E+05	6,20E-01	6,10E-01	4,77E-03
1900	2,30E+08	9,60E+05	2,85E+04	9,89E+05	4,30E-01	4,20E-01	1,24E-02
1950	3,03E+08	9,49E+05	5,96E+04	1,01E+06	3,30E-01	3,10E-01	1,97E-02
2017	4,11E+08	7,12E+05	1,04E+05	8,16E+05	2,00E-01	1,70E-01	2,54E-02

Once calculated, the data will be plotted as a function of time to be able to appreciate and analyze them better.

One of these graphs is the cultivated area, both rainfed and irrigated on the vertical axis (in Km2) and the time in years on the horizontal axis.

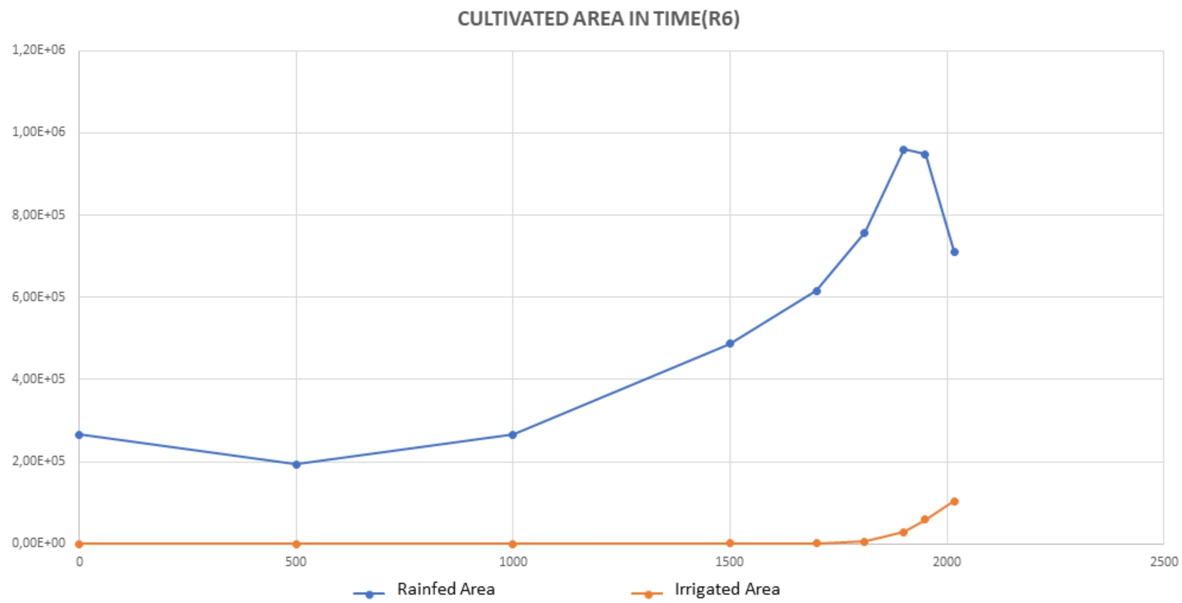

Figure 30 Cultivated area over time for region 6

Another of these graphs is the one of population on the vertical axis and time in years on the horizontal axis.

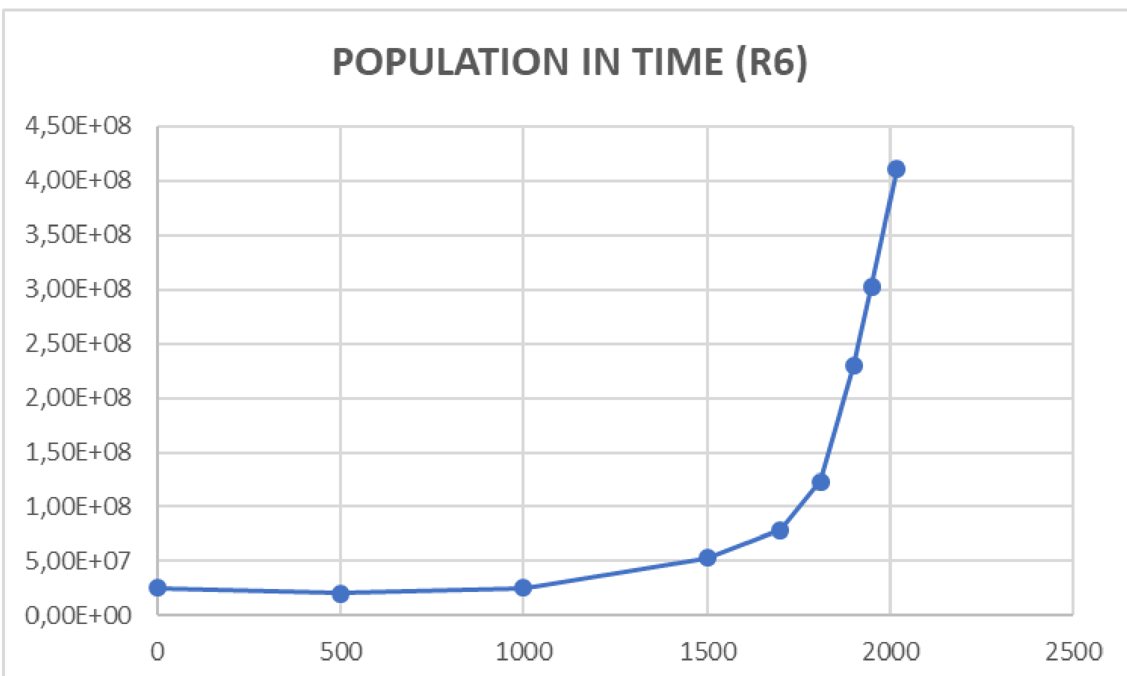

Figure 31 Population over time for region 6

Another calculation that has been made is the one of total cultivated area per habitant, which is then plotted with cultivated area per person in hectares per habitant on the vertical axis and time in years on the horizontal axis.

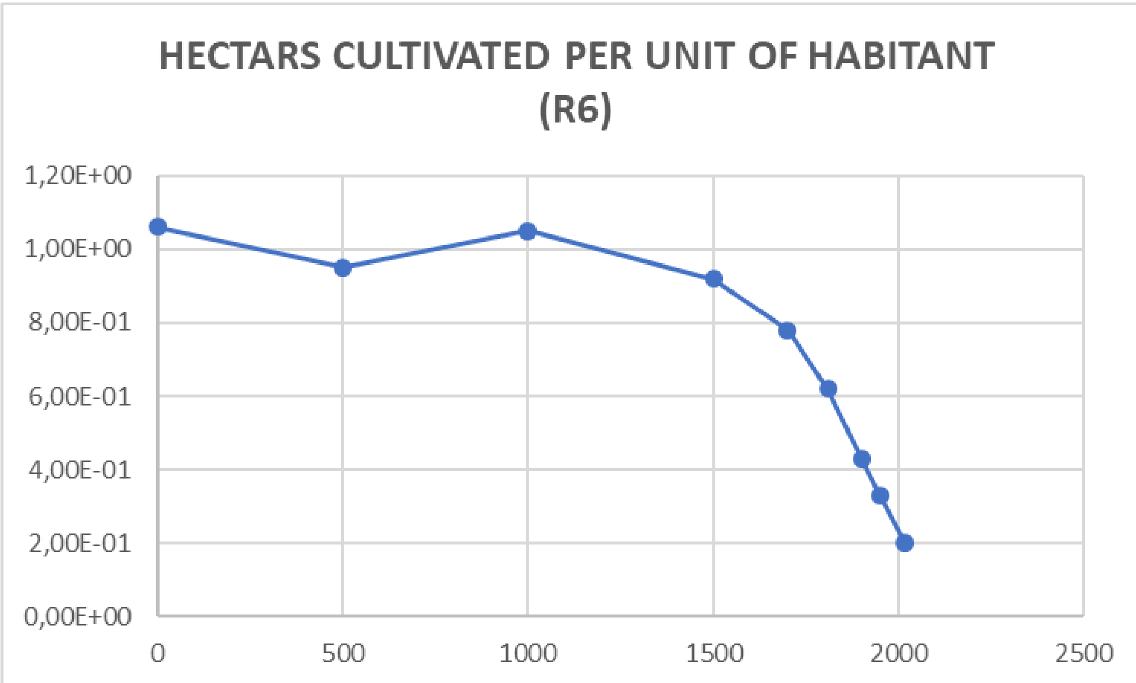

Figure 32 Cultivated area per habitant over time for region 6

4.1.1.7 Region 7: Northern America

With the help of the Matlab program, we have been able to differentiate the starting data of the analysis for the different regions that we want to analyze. In this case we will show the results for region 7 of our analysis, which is the region of Northern America, including the states of Bermuda, Canada, Greenland, Saint Pierre and Miquelon, United States Of America and United States Virgin Islands.

The results of the preliminary analysis for each year of the analysis for region 1 will be shown tabulated below.

Table 8 Preliminary analysis results of region 7

Year	Population [hab]	Raifed Cultivated Area [km2]	Irrigated cultivated area [km2]	Total cultivated area [km2]	Cultivated área per capita [ha/hab]	Rainfed Cultivated área per capita [ha/hab]	Irrigated Cultivated área per capita [ha/hab]
0	7,17E+05	4,22E+03	0,00E+00	4,22E+03	5,90E-01	5,90E-01	0,00E+00
500	9,19E+05	5,32E+03	0,00E+00	5,32E+03	5,80E-01	5,80E-01	0,00E+00
1000	1,31E+06	7,65E+03	4,53E+01	7,69E+03	5,90E-01	5,80E-01	3,45E-03
1500	2,08E+06	1,24E+04	8,07E+01	1,25E+04	6,00E-01	6,00E-01	3,88E-03
1700	1,12E+06	7,64E+03	4,61E+01	7,69E+03	6,90E-01	6,80E-01	4,38E-03
1810	9,24E+06	1,11E+05	3,31E+03	1,14E+05	1,24E+00	1,20E+00	3,59E-02
1900	8,09E+07	1,49E+06	3,15E+04	1,53E+06	1,89E+00	1,85E+00	3,89E-02
1950	1,69E+08	2,19E+06	1,36E+05	2,32E+06	1,38E+00	1,30E+00	8,05E-02
2017	3,53E+08	1,87E+06	1,04E+05	2,09E+06	5,90E-01	5,30E-01	6,22E-02

Once calculated, the data will be plotted as a function of time to be able to appreciate and analyze them better.

One of these graphs is the cultivated area, both rainfed and irrigated on the vertical axis (in Km2) and the time in years on the horizontal axis.

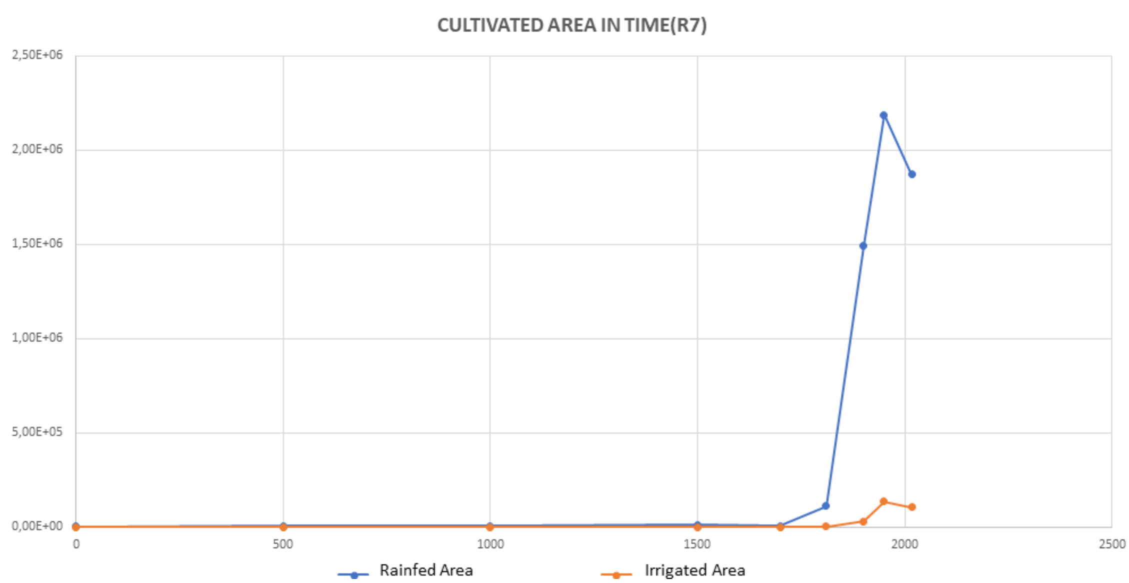

Figure 33 Cultivated area over time for region 7

Another of these graphs is the one of population on the vertical axis and time in years on the horizontal axis.

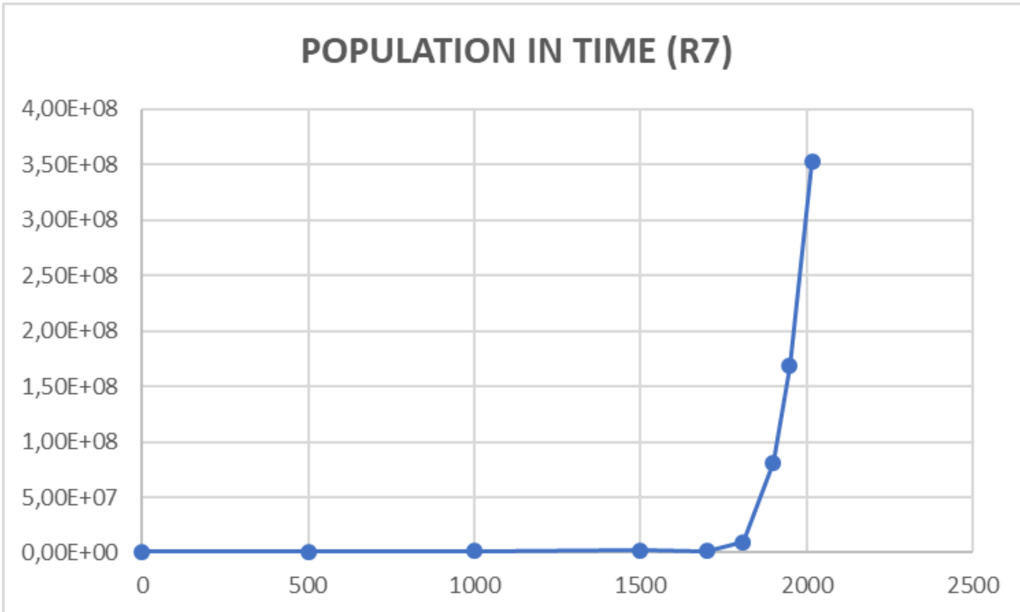

Figure 34 Population over time for region 7

Another calculation that has been made is the one of total cultivated area per habitant, which is then plotted with cultivated area per person in hectares per habitant on the vertical axis and time in years on the horizontal axis.

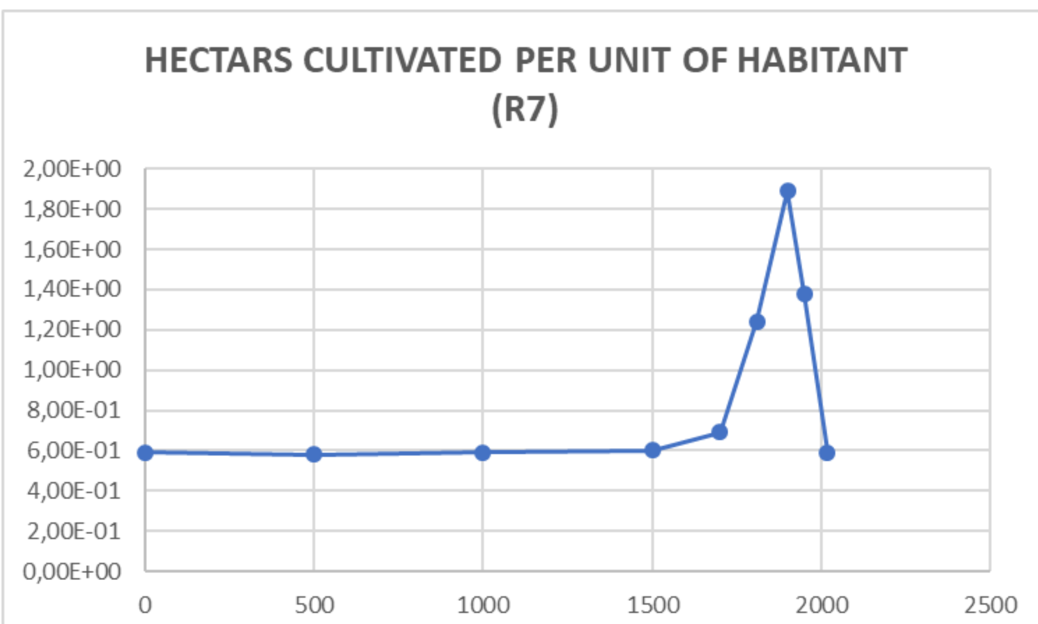

Figure 35 Cultivated area per habitant over time for region 7

4.1.1.8 Region 8: Latin America and Carribean

With the help of the Matlab program, we have been able to differentiate the starting data of the analysis for the different regions that we want to analyze. In this case we will show the results for region 8 of our analysis, which is the region of Latin America and Carribean, including the states of Anguilla, Antigua and Barbuda, Argentina, Aruba, Bahamas, Barbados, Belize, Bolivia, Brazil, British Virgin Islands, Cayman Islands, Chile, Colombia, Costa Rica, Cuba, Dominica, Dominican Republic, Ecuador, El Salvador, Falkland Islands (Malvinas), French Guiana, Grenada, Guadeloupe, Guatemala, Guyana, Haiti, Honduras, Jamaica, Martinique, Mexico, Montserrat, Netherlands Antilles, Nicaragua, Panama, Paraguay, Peru, Puerto Rico, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Surname, Trinidad and Tobago, Turks and Caicos Islands and Uruguay.

The results of the preliminary analysis for each year of the analysis for region 1 will be shown tabulated below.

Table 9 Preliminary analysis results of region 8

Year	Population [hab]	Raifed Cultivated Area [km2]	Irrigated cultivated area [km2]	Total cultivated area [km2]	Cultivated área per capita [ha/hab]	Rainfed Cultivated área per capita [ha/hab]	Irrigated Cultivated área per capita [ha/hab]
0	1,83E+07	7,04E+04	1,11E+03	7,15E+04	3,90E-01	3,90E-01	6,09E-03
500	2,48E+07	9,21E+04	1,52E+03	9,36E+04	3,80E-01	3,70E-01	6,12E-03
1000	3,60E+07	1,38E+05	2,39E+03	1,40E+05	3,90E-01	3,80E-01	6,64E-03
1500	5,98E+07	2,44E+05	3,76E+03	2,48E+05	4,10E-01	4,10E-01	6,28E-03
1700	1,29E+07	9,88E+04	1,32E+03	1,00E+05	7,70E-01	7,60E-01	1,02E-02
1810	2,45E+07	1,71E+05	5,27E+03	1,76E+05	7,20E-01	7,00E-01	2,15E-02
1900	7,16E+07	3,37E+05	2,23E+04	3,59E+05	5,00E-01	4,70E-01	3,11E-02
1950	1,75E+08	8,36E+05	5,24E+04	8,88E+05	5,10E-01	4,80E-01	3,00E-02
2017	6,29E+08	1,86E+06	2,23E+05	2,08E+06	3,30E-01	3,00E-01	3,54E-02

Once calculated, the data will be plotted as a function of time to be able to appreciate and analyze them better.

One of these graphs is the cultivated area, both rainfed and irrigated on the vertical axis (in Km2) and the time in years on the horizontal axis.

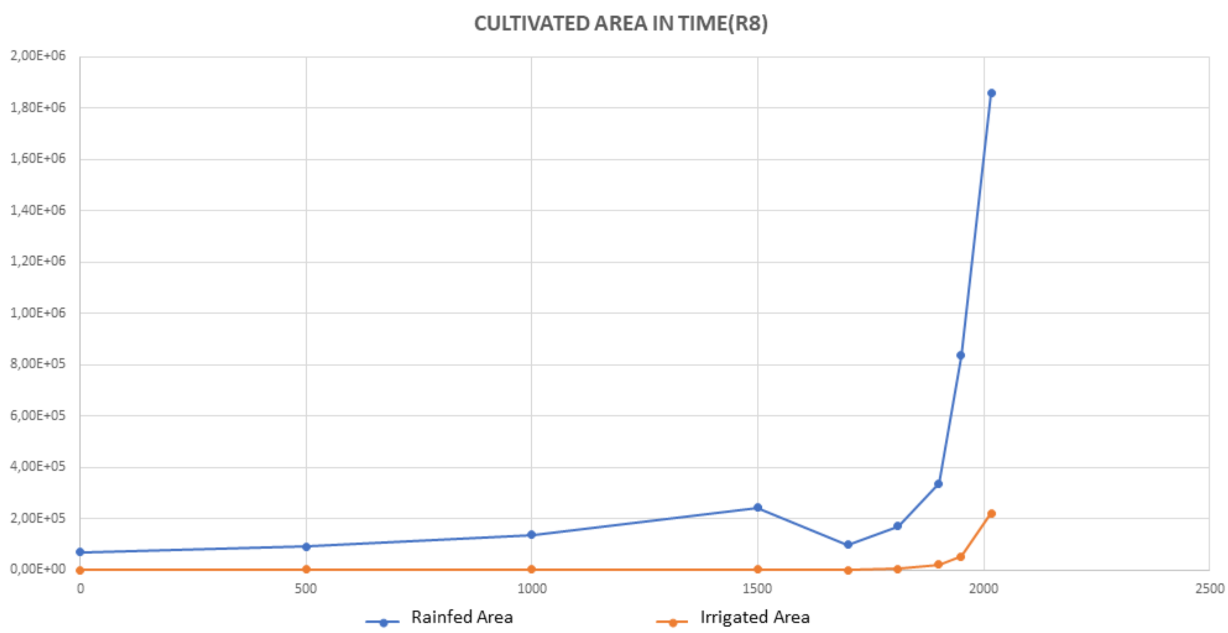

Figure 36 Cultivated area over time for region 8

Another of these graphs is the one of population on the vertical axis and time in years on the horizontal axis.

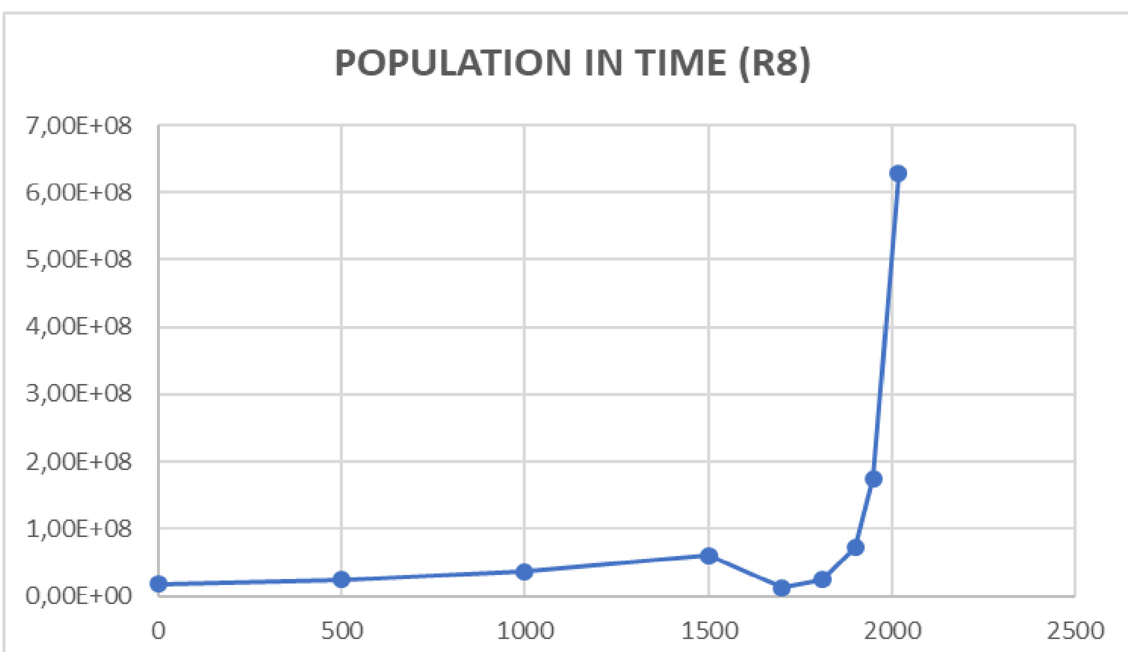

Figure 37 Population over time for region 8

Another calculation that has been made is the one of total cultivated area per habitant, which is then plotted with cultivated area per person in hectares per habitant on the vertical axis and time in years on the horizontal axis.

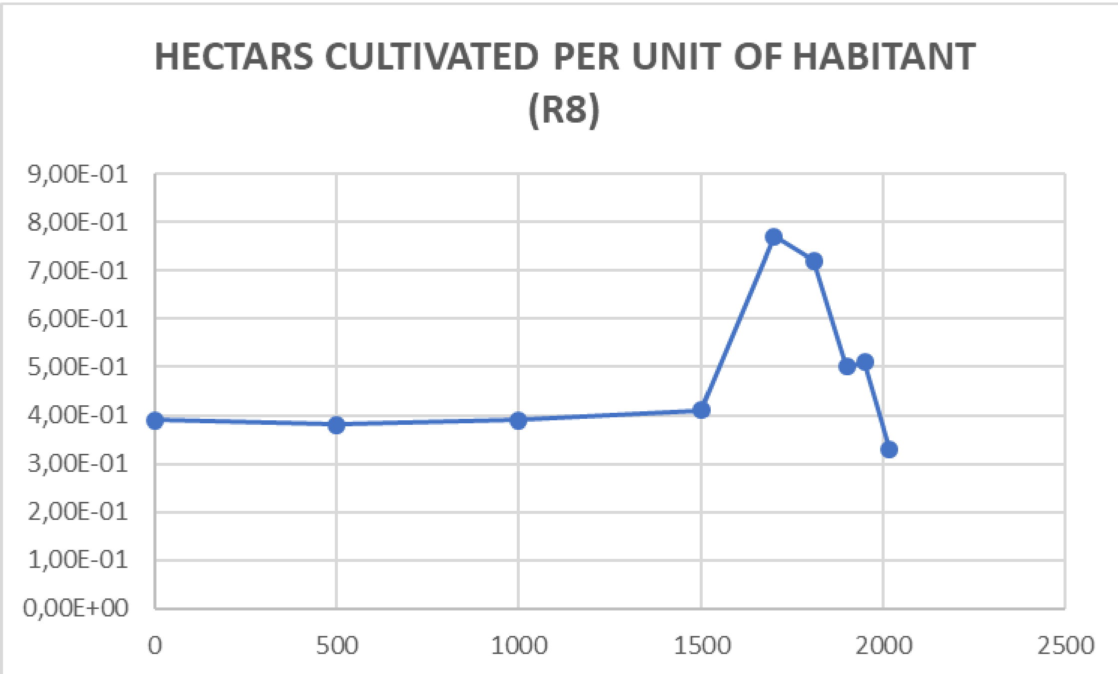

Figure 38 Cultivated area per habitant over time for region 8

4.1.1.9 Region 9: Oceania and New Zeland

With the help of the Matlab program, we have been able to differentiate the starting data of the analysis for the different regions that we want to analyze. In this case we will show the results for region 9 of our analysis, which is the region of Oceania and New Zeland, including the states of Australia, Cook Islands, French Polynesia, Guam, Nauru, New Caledonia, New Zeland, Nive, Norfolk Island, Wallis and Futuna Islands.

The results of the preliminary analysis for each year of the analysis for region 1 will be shown tabulated below.

Table 10 Preliminary analysis results of region 9

Year	Population [hab]	Raifed Cultivated Area [km2]	Irrigated cultivated area [km2]	Total cultivated area [km2]	Cultivated área per capita [ha/hab]	Rainfed Cultivated área per capita [ha/hab]	Irrigated Cultivated área per capita [ha/hab]
0	2,56E+05	2,10E+01	0,00E+00	2,10E+01	8,21E-03	8,21E-03	0,00E+00
500	2,59E+05	3,23E+01	0,00E+00	3,23E+01	1,25E-02	1,25E-02	0,00E+00
1000	2,64E+05	4,76E+01	0,00E+00	4,76E+01	1,80E-02	1,80E-02	0,00E+00
1500	3,49E+05	6,31E+01	0,00E+00	6,31E+01	1,81E-02	1,81E-02	0,00E+00
1700	4,62E+05	8,22E+01	0,00E+00	8,22E+01	1,78E-02	1,78E-04	0,00E+00
1810	4,30E+05	3,86E+02	2,81E+01	4,14E+02	9,63E-02	8,98E-02	6,53E-03
1900	4,47E+06	4,03E+04	6,92E+02	4,10E+04	9,20E-01	9,00E-01	1,55E-02
1950	9,66E+06	2,31E+05	5,89E+03	2,36E+05	2,45E+00	2,39E+00	6,10E-02
2017	2,95E+07	4,68E+05	2,33E+04	4,91E+05	1,66E+00	1,59E+00	7,89E-02

Once calculated, the data will be plotted as a function of time to be able to appreciate and analyze them better.

One of these graphs is the cultivated area, both rainfed and irrigated on the vertical axis (in Km2) and the time in years on the horizontal axis.

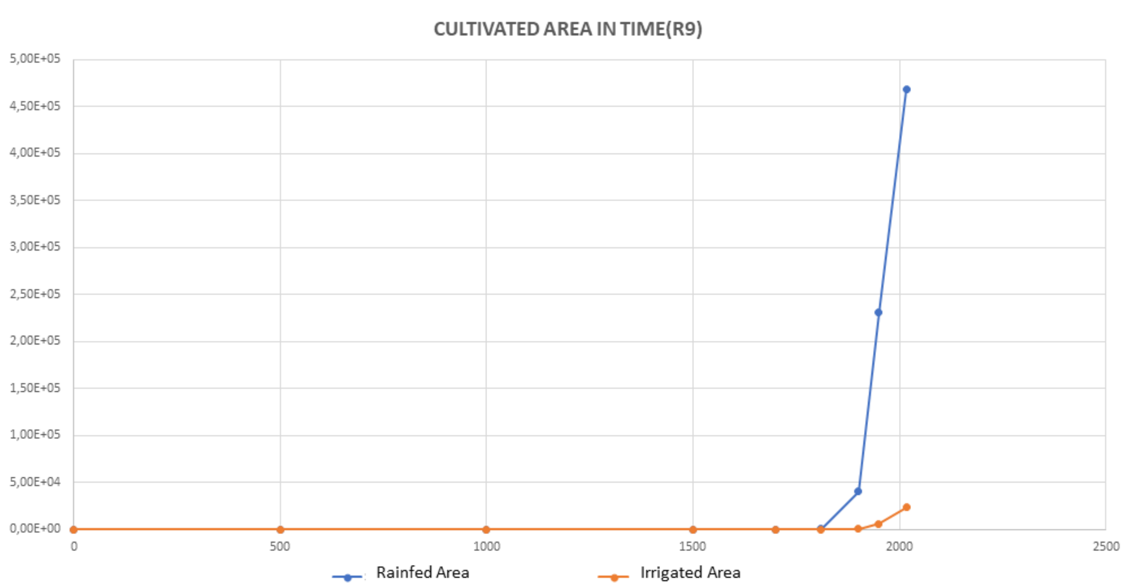

Figure 39 Cultivated area over time for region 9

Another of these graphs is the one of population on the vertical axis and time in years on the horizontal axis.

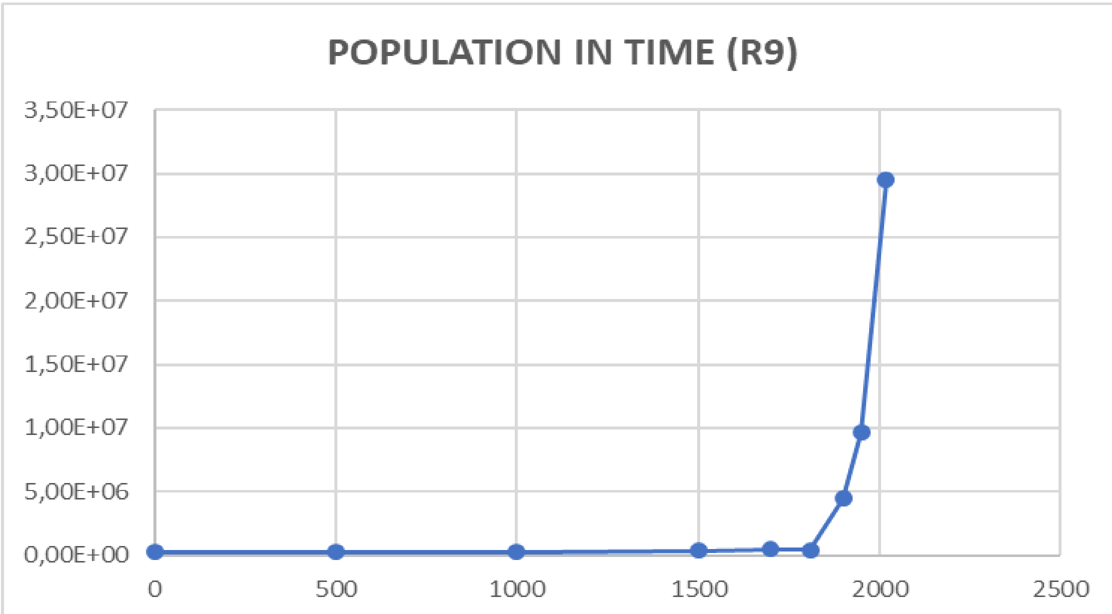

Figure 40 Population over time for region 9

Another calculation that has been made is the one of total cultivated area per habitant, which is then plotted with cultivated area per person in hectares per habitant on the vertical axis and time in years on the horizontal axis.

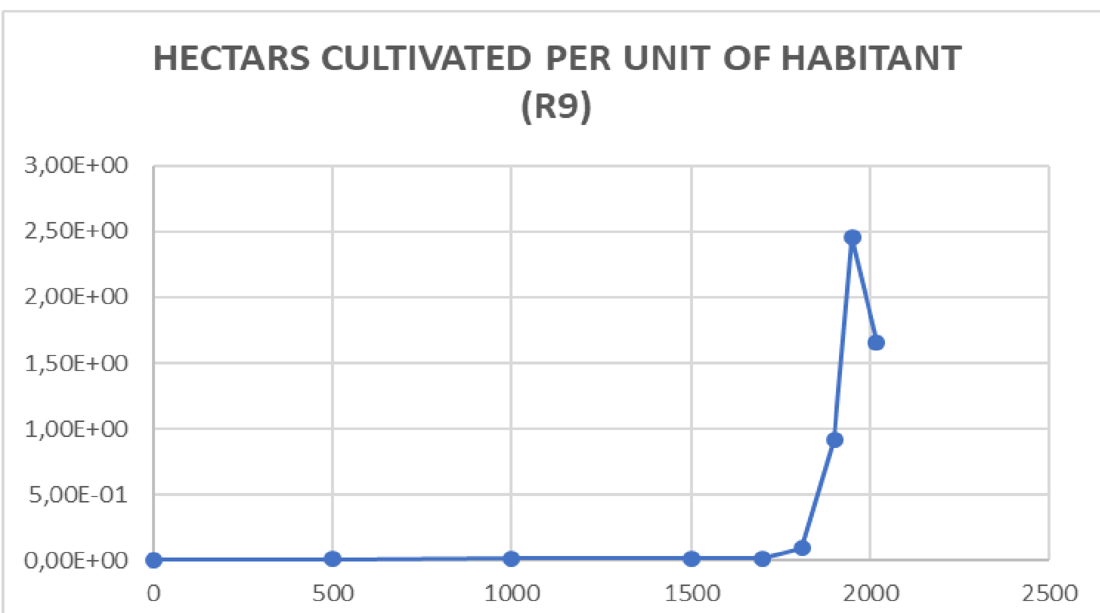

Figure 41 Cultivated area per habitant over time for region 9

4.2 Space-time relationship

4.2.1 Differences map analysis

In each of the following graphs you can see different "pixels" of different colors, these "pixels" are the geographical areas for which each calculation of differences has been made. The color of this pixel indicates the value of this result. If this color is strong red, it means that the result is negative, and its means that consumption prevails over production in that area. If the color is green, it means that there is a balance between production and consumption in that area. Then if the value is positive, as this is very predominant in relation to the other two cases, this will be represented in a range of colors that varies gradually from yellow to violet, as can be seen in the legend of the graph. This range will make it clear to us which area prevails production by little (yellow) and how it gradually increases until it reaches values where production is much greater than the population (violet). In areas where there are none of these colors, it means there is no data, so in this area there is not population and also it is not cultivated.

It will begin by studying the different specifics regions of our analysis.

4.2.1.1 Differences analysis for specific regions

The results seen previously were results of the differences calculated with data from the entire world map. Next, we will see how the results of the difference maps are in order to appreciate the spatial distribution between food production and consumption of the different regions that we did the preliminary analysis on.

By studying maps of specific regions calculated with specific data from those regions, we can more specifically analyze these regions. We have differentiated the world into eight different regions:

1. Africa sud Sahara, including the states of Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Comoros, Congo, Democratic Republic of the Congo, Coste d'Ivoire, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mayotte, Mozambique, Namibia, Niger, Nigeria, Reunion, Rwanda, Saint Helena, Ascension and tristan da Cunha, Sao

Tome and Pricipe, Senegal, Seychelles, Sierra Leone, Somalia, South Africa, Sudan, Swaziland, Tanzania, Togo, Uganda, Western Sahara, Zambia y Zimbabwe.

2. Middle East and North Africa, including the states of Algeria, Bahrain, Djibouti, Egypt, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Libya, Morocco, Occupied Palestinian Territory, Oman, Saudi Arabia, Syria, Tunisia, United Arab Emirates, Yemen, Yemen Ar Rp y Yemen Dem.
3. East Asia and Pacific, including the states of American Samoa, Brunei Darussalam, Cambodia, China (Hong Kong SAR), China(Macao SAR), China(mainland), China, Taiwan Province of, Christmas Iseland, Cocos Iselands(keeling), Fiji, Indonesia, Japan, Kiribati, Democratic People's of Korea, Republico of Korea, Lao People's Democratic Republic, Malaysia, Marshall Iselands, Micronesia, Mongolia, Myanmar, Palau, Papua New Guinea, Phillippines, Samoa, Singapore, Solomon Iselands, Thailand, Timor-Lestre, Tonga, Tuvalu, Vanuatu y Viet Nam.
4. South Asia, including the states of Afghanistan, Bangladesh, Bhutan, British Indian Ocean Territory, India, Maldives, Nepal, Pakistan y Sri Lanka.
5. East Europe, including the states of Abania, Armenia, Azerbaijan, Belarus, Bosnia and Herzegovina, Croatia, Cyprus, Czech Republic, Czechoslovakia, Estonia, Faroe Iselands, Georgia, Hungary, Kazakhstan, Kyrgyzstan, Latuia, Lithuania, Macedonia, Moldova, Montenegro, Poland, Romania, Russian Federation, Serbia, Serbia and Montenegro, Slovakia, Slovenia, Tajikistan, Turkey, Turkmenistan, Ukranie, USSR, Uzbekistan and Yugoslavia.
6. Europe, including the states of Andorra, Austria, Belgium, Belgium-Luxembourg, Denmark, Finland, France, Germany, West Germany, East Germany, Gibraltar, Greece, Holy See, Iceland, Ireland, Italy, Liechtenstein, Luxembourg, Malta, Monaco, Netherlands, Norway, Portugal, San Marino, Spain, Svalbard and Jan Mayen Islands, Sweden, Switzerland and United Kindom.
7. Northern America, including the states of Bermuda, Canada, Greenland, Saint Pierre and Miquelon, United States Of America and United States Virgin Islands.
8. Latin America and Carribean, including the states of Anguilla, Antigua and Barbuda, Argentina, Aruba, Bahamas, Barbados, Belize, Bolivia, Brazil, British Virgin Islands, Cayman Islands, Chile, Colombia, Costa Rica, Cuba, Dominica, Dominican

Republic, Ecuador, El Salvador, Falkland Islands (Malvinas), French Guiana, Grenada, Guadeloupe, Guatemala, Guyana, Haiti, Honduras, Jamaica, Martinique, Mexico, Montserrat, Netherlands Antilles, Nicaragua, Panama, Paraguay, Peru, Puerto Rico, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Surname, Trinidad and Tobago, Turks and Caicos Islands and Uruguay.

In order to differentiate the different regions of the world, we have as a data a matrix which had differentiated the different countries with a different number, so the value of each cell of this data matrix that we have is a number that identified which country it belonged to that cell. In addition to this matrix, we have a vector that differentiated us according to the number of the country that we found in this first matrix, the number of the region to which that country belongs. Therefore, with the help of this matrix, this vector and the Matlab program, it has been possible to arrive at a matrix whose value is the number of the region to which each cell belongs. Then with this matrix, it is possible to differentiate the data from each region and thus be able to analyze the differences specifically for each region.

The maps with the results of the difference analysis will be shown below. These maps will come with a scale bar and a legend. As in all our results, production prevails over consumption, or at most there is a balance between production and consumption. Because of that, this legend will be as follows:

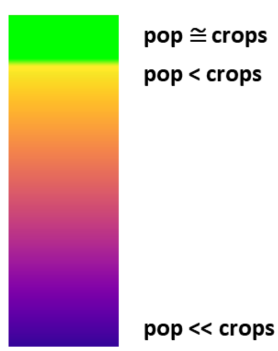

Figure 42 Legend of difference maps

Where, if the cell appears with the color green, it means that there is a balance between production and consumption in that geographical location. If this color is yellow, it means that production prevails, but not in a large excess. As this color tends to violet, as can be seen in the legend, the prevalence of production increases in number to a maximum value in a very dark violet.

Understanding the results that we are going to observe, the results for the different regions for the years 0 AD, 500 AD, 1000 AD, 1500 AD, 1700 AD, 1810 AD, 1900 AD, 1950 AD, 2017 AD will be shown below, for evaluate their evolution over time.

These regions are:

4.2.1.1.1 Africa

Difference analysis has been done for this area which can be seen on the map below.

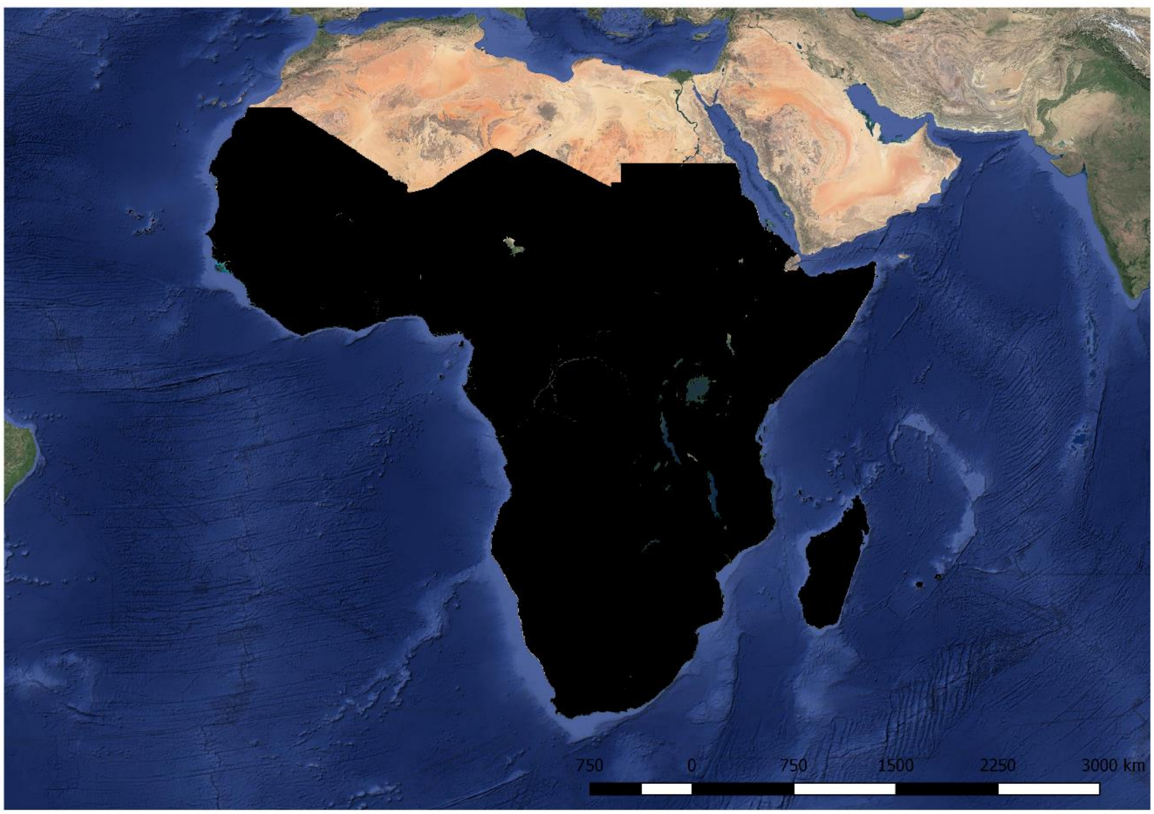

Figure 43 Region 1 map

The calculations were made with the Matlab program and the printing of the maps was made with the QGIS program. These maps will be represented below for the nine different years of the analysis in order to appreciate the evolution over time of these results, which will indicate the spatial distribution between food production and consumption.

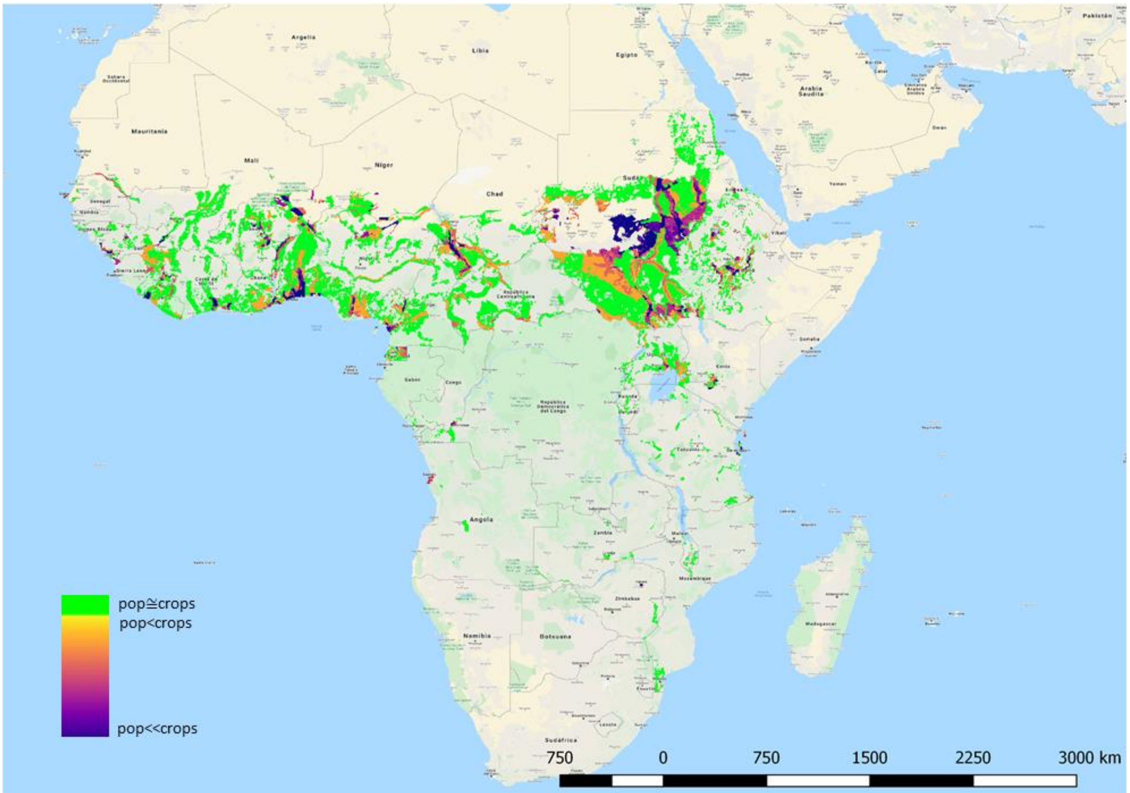

Figure 44 Difference map for Region 1, 0 AD

Starting from the year 0AD, you can see habited areas in Central Africa. These zones show a great extension of areas where there is a good balance between production and consumption. You can also see several concentrated areas where consumption largely prevails. This indicates a good spatial distribution between areas that are widely produced and those that are not. The largest number of areas where consumption prevails significantly can be seen in what is now Sudan. Towards southern Africa there are very few human settlements with very small areas where production and consumption have a good balance.

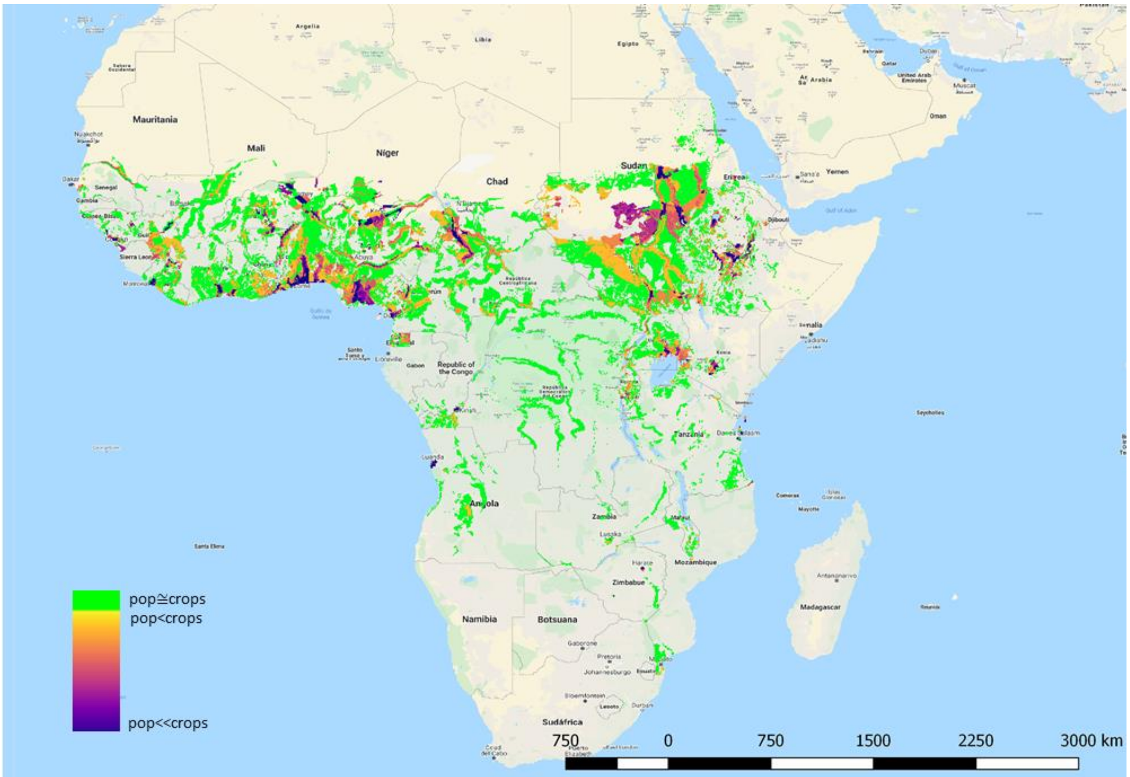

Figure 45 Difference map for Region 1, 500 AD

By the year 500AD, an increase in the area used in this region can be observed with respect to the year previously analyzed, these area increases can be seen in what is now Nigeria, the Kongo Republic, Angola, among others. In the vast majority of these areas, a good balance can be seen between production and consumption.

In the area in what is now Sudan, southern Sudan and Ethiopia, a decrease in the areas used and areas where there were a prevalence of production can be seen, compared to 500 years ago. These decreases in area are seen further north than what is now Sudan and what is now South Sudan. The spatial distribution between the most productive areas and those that we can see a balance between consumption and production continue in the same way with respect to the year previously analyzed.

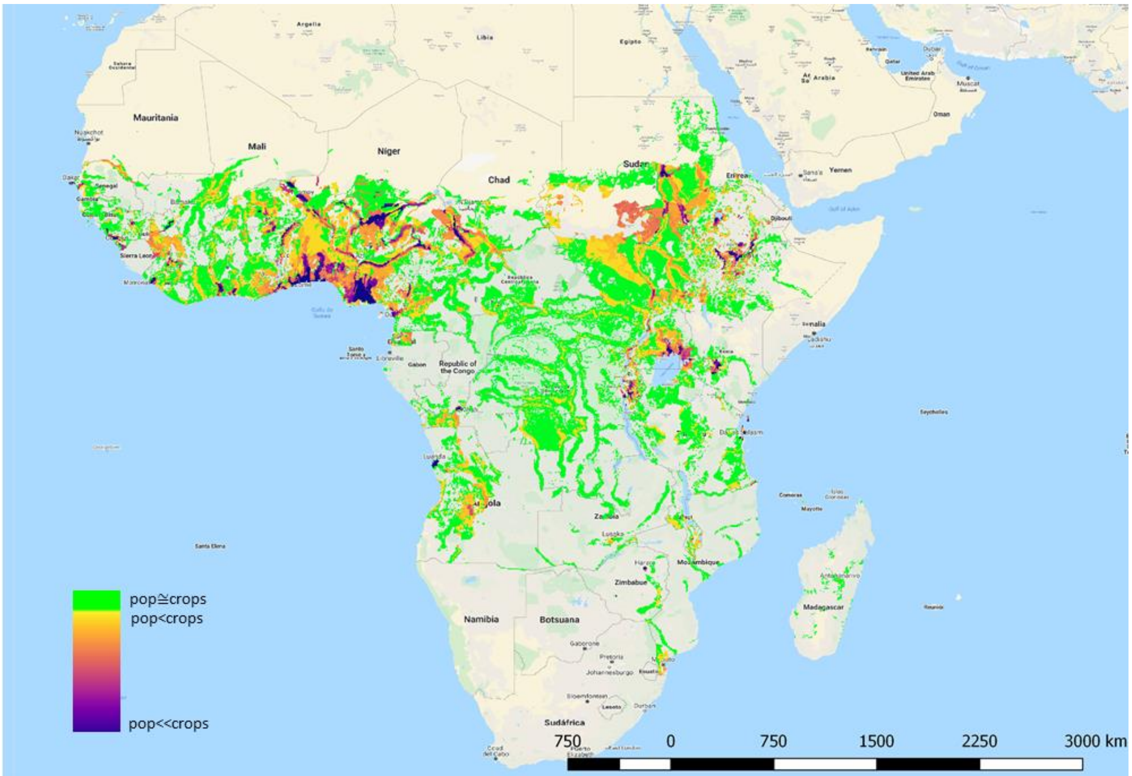

Figure 46 Difference map for Region 1, 1000 AD

Compared to the previous year, a large increase in area used can be seen throughout all this region. This can be seen well in the Democratic Republic of the Congo, Angola and Tanzanija.

Also, in this year you can see for first time areas used on the island of Madagascar, where there is a balance between production and consumption.

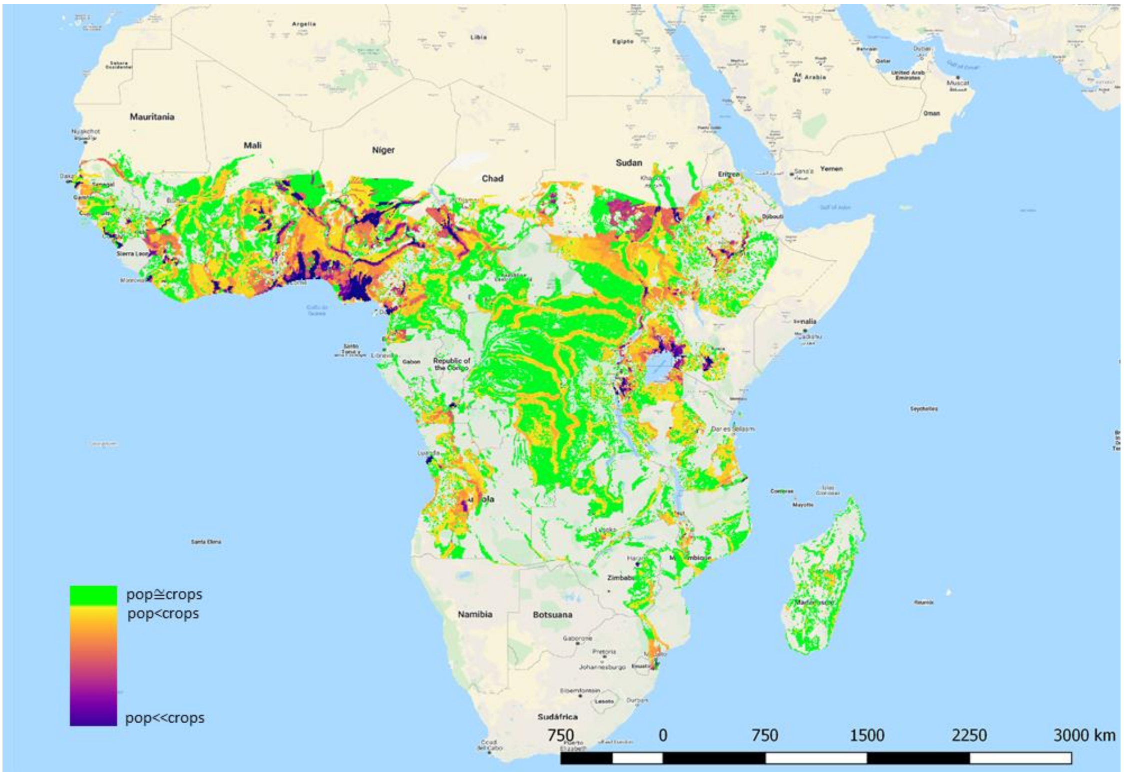

Figure 47 Difference map for Region 1, 1500 AD

By 1500AD, a large increase in the area used can be seen throughout the region. This can be clearly seen in the center of the region, in what is the Democratic Republic of the Congo. Where throughout this region there is a good balance between production and consumption, but this year we can also see some small regions where production prevails, but this is not done in large numbers. You can also notice the increase in area used to the west of this region and on the island of Madagascar.

In this year, a disappearance of an area previously used can be noted, where a good balance between production and consumption was seen in the north of what is now Sudan.

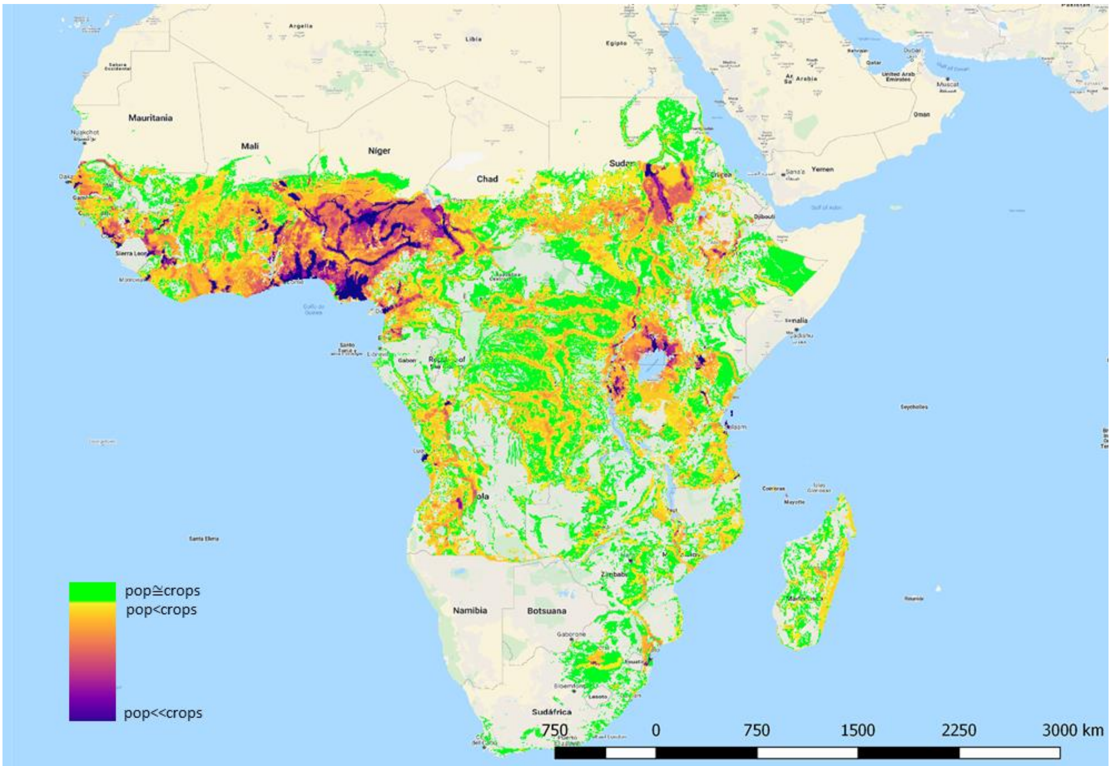

Figure 48 Difference map for Region 1, 1700 AD

Arriving to the year 1700AD, we can see a large increase in the area used throughout the region. This is noticeable to the East and South of this region, where we can see for first time areas used in what is now South Africa. In the previously disappeared areas of northern Sudan, they can be seen again and to a greater extent than before.

It can be seen in this year compared to the years previously analyzed, that in the majority of the region there is a prevalence of production over consumption. This prevalence of production occurs excessively in the area of what is now Nigeria, with extensive areas of violet color.

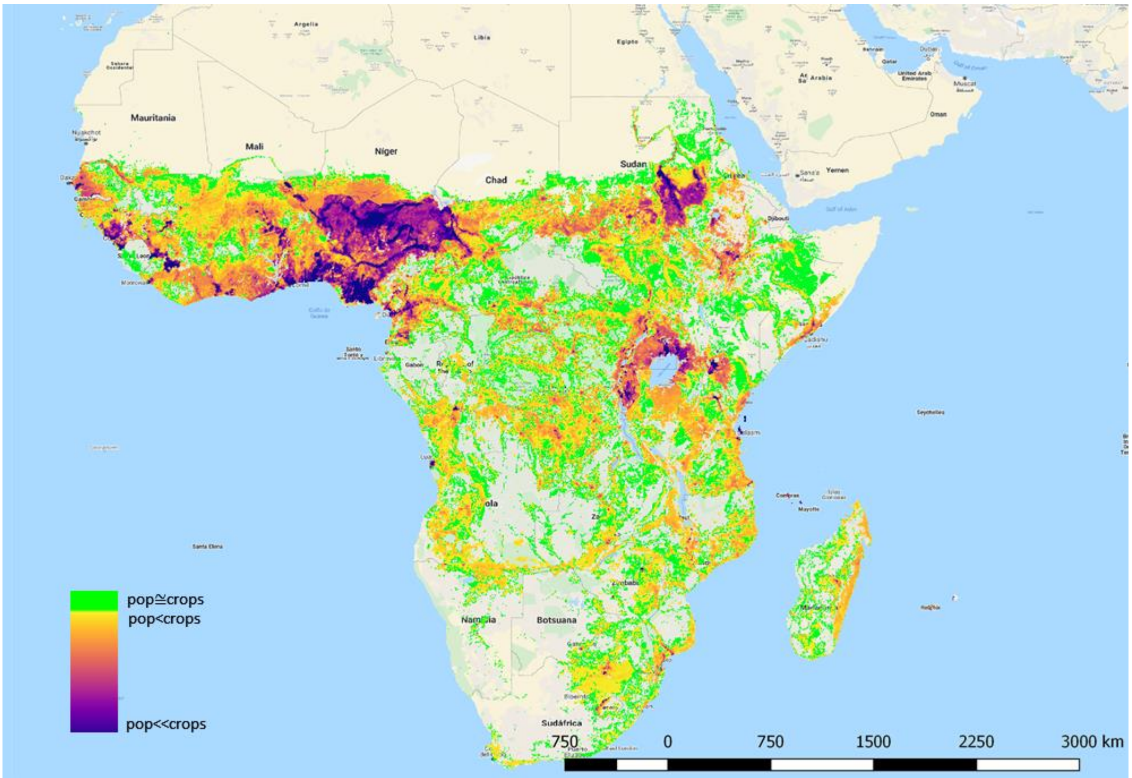

Figure 49 Difference map for Region 1, 1810 AD

For the year 1810 AD, compared to the year previously analyzed, a brief extension of new areas used can be seen, having data for first time in the countries of Namibia and Somalija.

A brief disappearance of areas where there was a balance between production and consumption can be seen throughout the Region, best noted in the Democratic Republic of the Congo.

Compared to the previous year, there is a higher prevalence of production throughout the entire region, seeing a homogenization of the violet areas in the Nigerian zone, where production is excessively prevalent.

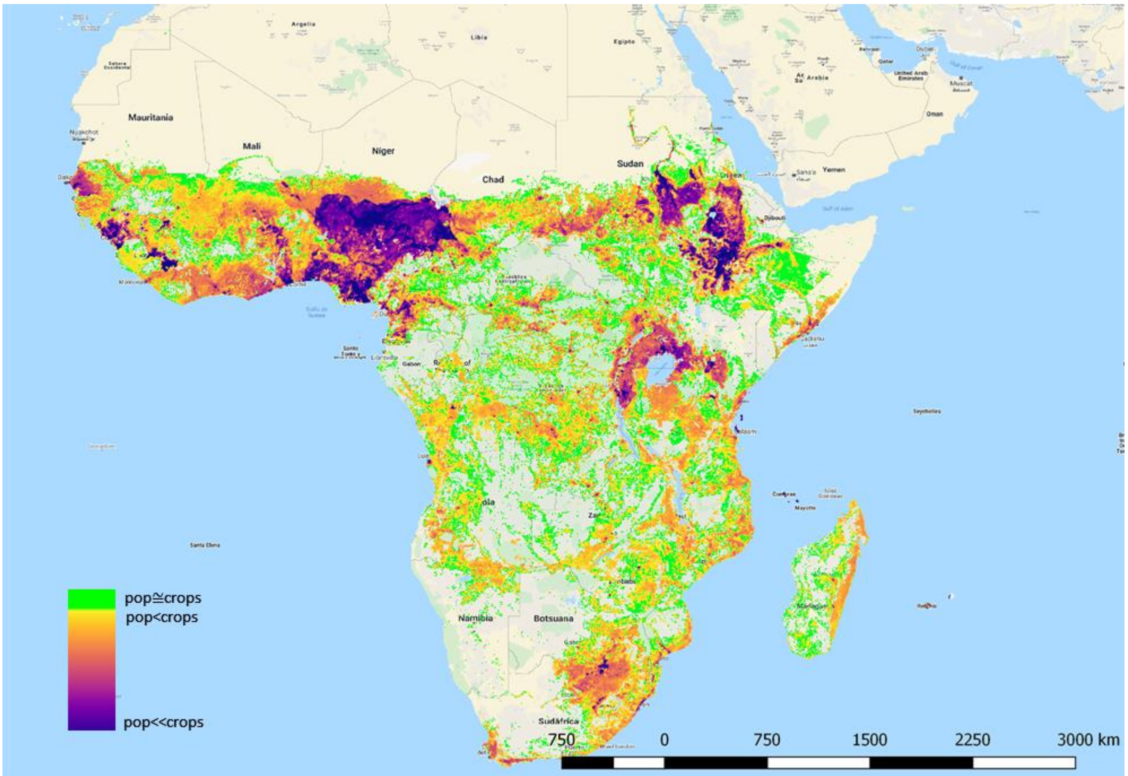

Figure 50 Difference map for Region 1, 1900 AD

Reaching the year 1900 AD, comparing it with the previous year, a similar extension of areas used throughout the region can be noted. As in the previous year, a disappearance of areas where a balance between production and consumption was seen throughout the region is noted. Thus, there are very few areas where a balance between production and consumption compared to the areas where consumption prevails, which are the majority for this year.

In this year you can see a new large violet area, where production prevails excessively, in the country of Ethiopia. You can also notice an increase in production in South Africa.

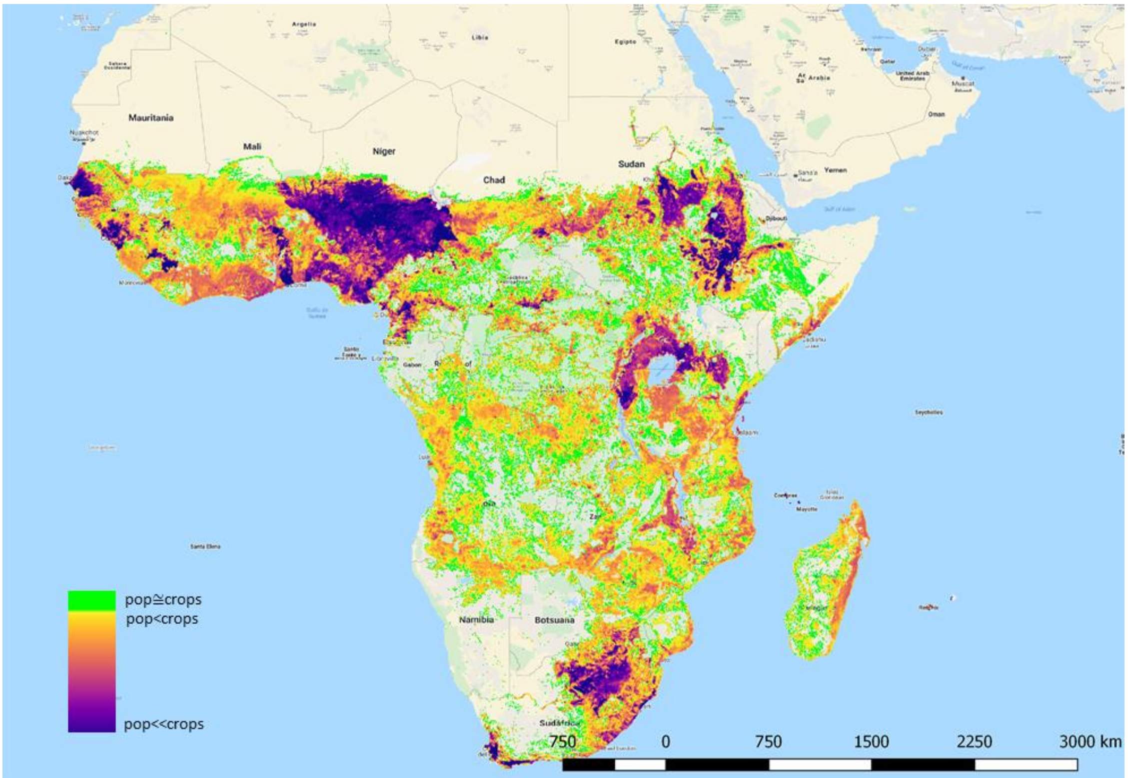

Figure 51 Difference map for Region 1, 1950 AD

For the year 1950 AD, you can see an increase in areas used throughout the region, better noted in Angola and Zambija.

In the violet zone that we spoke previously in the Nigerian zone, you can see an extension of this towards the north and west, occupying the country of Niger. An increase in the shade of violet can be seen to the west, in what is Senegal, which means that production at this time prevails in a more significant way.

You can notice new violet areas also in the country of South Africa, with a large extension of these to the north of this country, and a small extension of them to the southwest of this country.

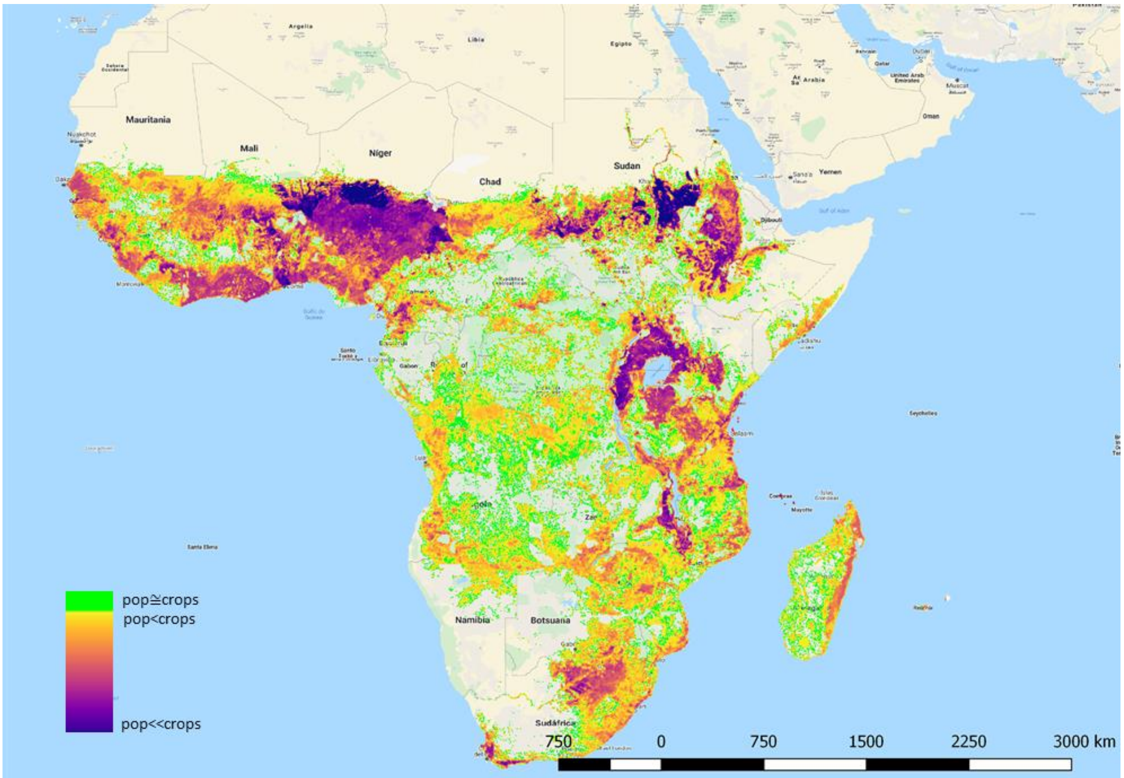

Figure 52 Difference map for Region 1, 2017 AD

We now come to the most current year of our analysis, 2017 AD. Compared to the year previously analyzed, the same distribution of area utilization can be noted. A notable disappearance of areas where a balance between production and consumption was seen (green areas) can be noted, as had happened previously in the analysis of this region. This disappearance of these areas can be seen throughout the entire region, with very few green areas remaining for this year.

We can observe the tone change in the areas where production previously prevailed excessively, where the shade of violet decreases. This can be clearly seen in the region of Nigeria, South Africa, Gvineja, Senegal and Ethiopia.

4.2.1.1.2 Middle East and North Africa

Difference analysis has been done for this area which can be seen on the map below.

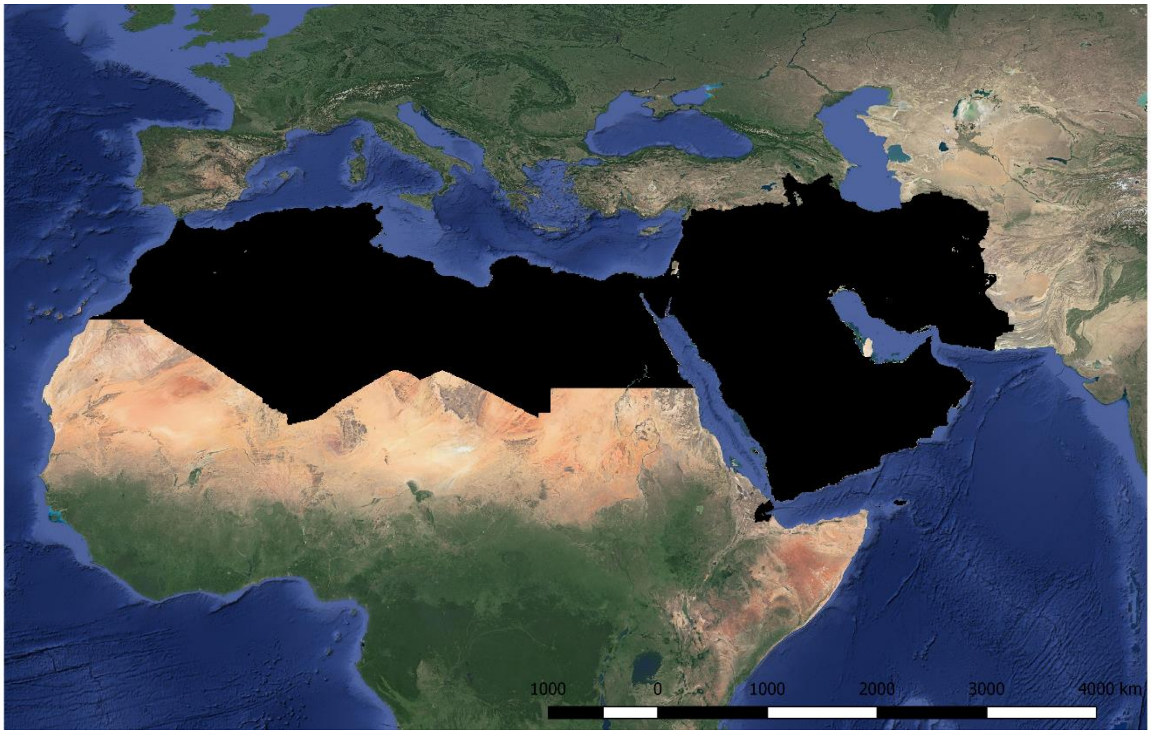

Figure 53 Region 2 map

The calculations were made with the Matlab program and the printing of the maps was made with the QGIS program. These maps will be represented below for the nine different years of the analysis in order to appreciate the evolution over time of these results, which will indicate the spatial distribution between food production and consumption.

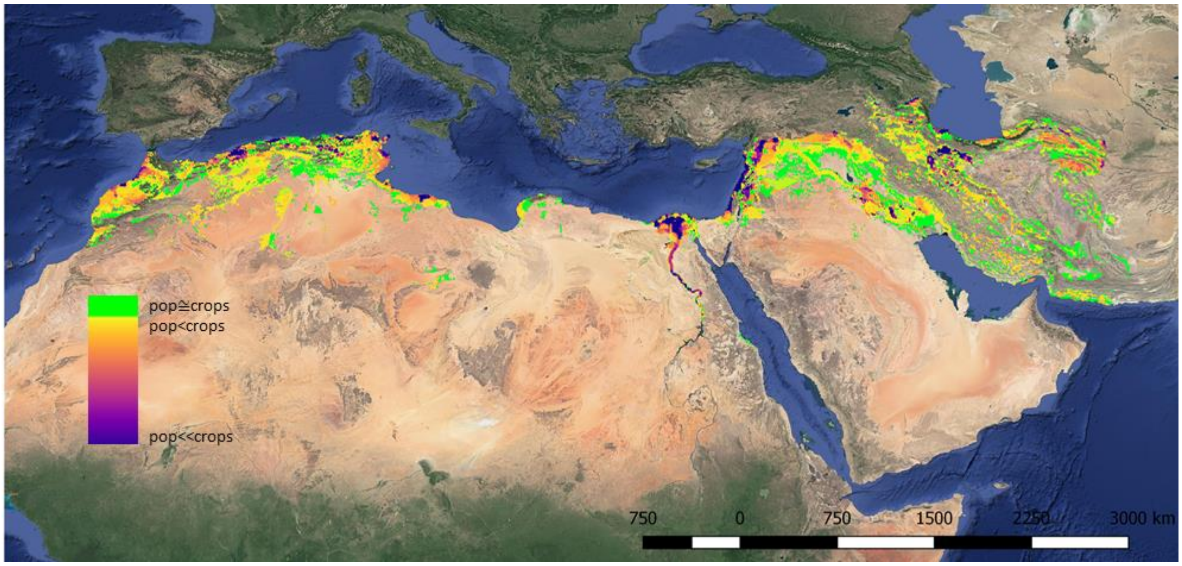

Figure 54 Difference map for Region 2, 0 AD

Starting the analysis of the Middle East and North Africa region in the year 0 AD, we can say that for this year we see a great use of this area, which is not much less area than what is currently used.

In these areas it can be seen that in most of these the production prevails, but in its majority it does in a not excessive number.

You can see smalls violet areas, where production prevails significantly in what are now the countries of Morocco, Algeria, Tunisia, Libya, Israel, Lebanon, Syria, Jordan, Iran and Egypt, where only in the latter country this violet area is almost the whole of this country.

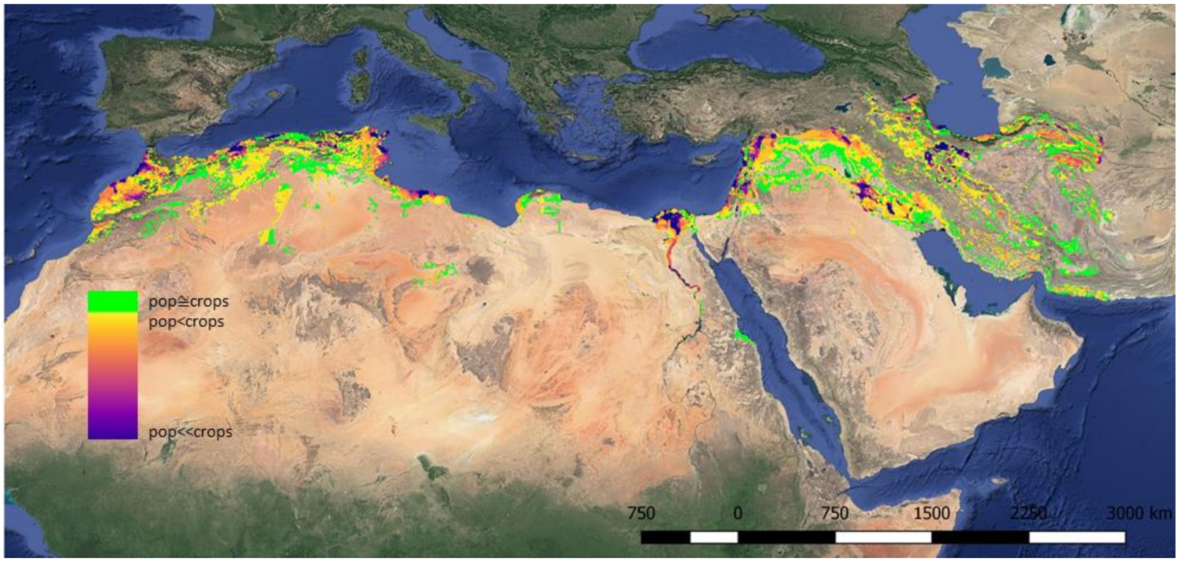

Figure 55 Difference map for Region 2, 500 AD

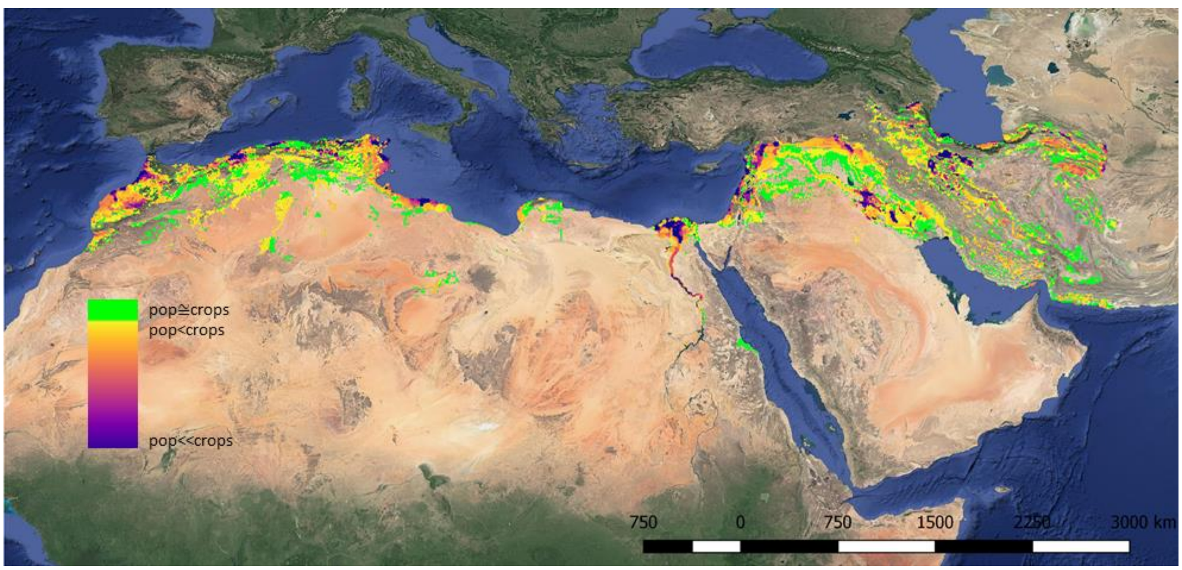

Figure 56 Difference map for Region 2, 1000 AD

Compared to 0 AD, 500 AD and 1000AD fail to see major changes. The areas where production prevails continue to prevail production and in areas where there is a balance between production and consumption continue with the same balance. We could comment as a change a decrease in the shade of violet for the year 500 AD in Egypt, but production continues prevailing. Another small change that can be noticed is for the year 500 AD, a few areas where there was a balance between production and consumption in Morocco, now production prevails, but in a very small number.

By the year 1000 AD, on the other hand, we can notice a brief increase in the color tone of the prevalence of production in Morocco and in the area of Syria, a small disappearance of an area where before there was a balance between production and consumption could be seen for this year. Also for this year, a decrease in the prevalence of production can be seen on the Mediterranean coast of the Middle East and an increase in production in Iraq, where small violet areas are reached.

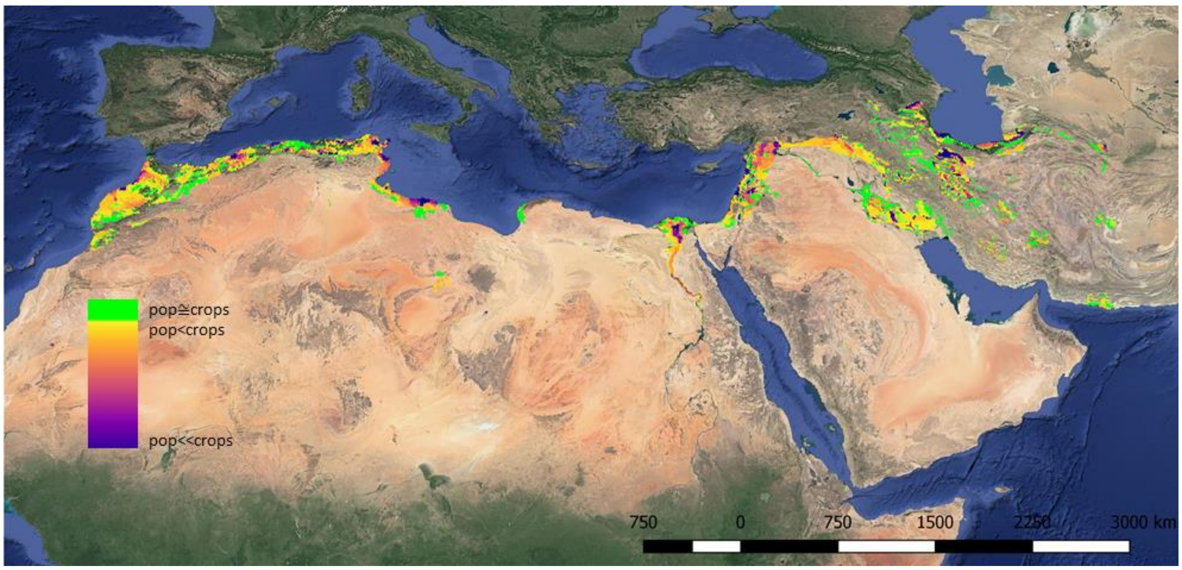

Figure 57 Difference map for Region 2, 1500 AD

By 1500 AD, a very noticeable area disappearance can be seen throughout this region compared to 500 years ago. Noticing very well in the Middle East and Algeria. Within the areas that were not eliminated, the changes that can be noticed are only the use of them. Although the vast majority prevail in the same way, a decrease in the number in which production prevails in northwest Africa can be seen, as in this area now where production prevailed, it does so to a lesser extent. This can also be seen in Egypt and throughout the Middle East. In Egypt it is clearly noticeable as there are very few violet areas. In what is Iraq, where before there was a violet area, for this year a green area is noted, where there is a balance between production and consumption.

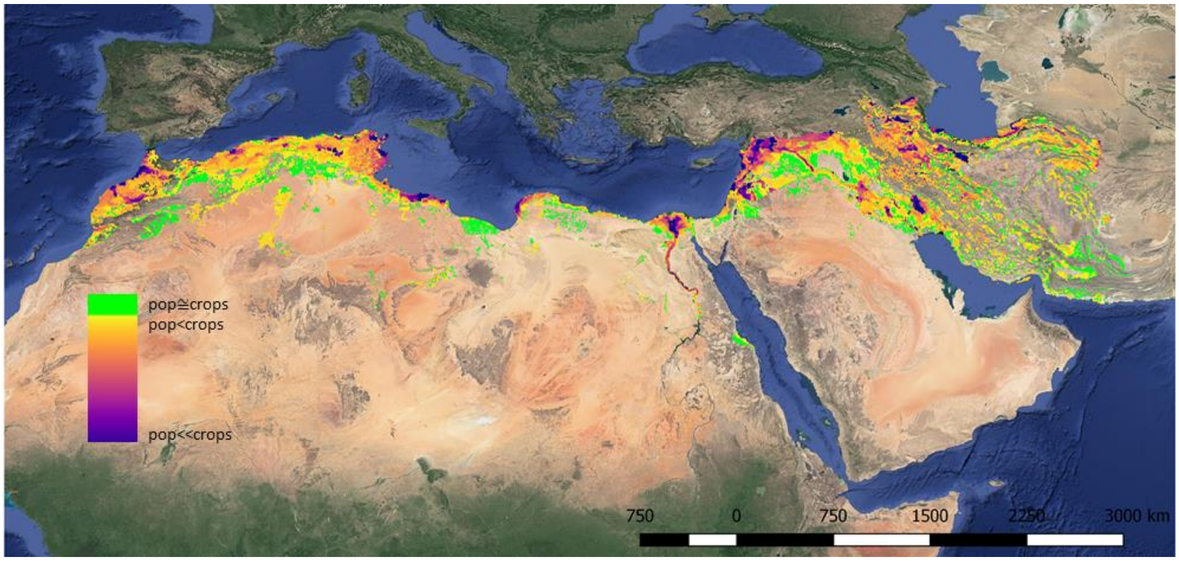

Figure 58 Difference map for Region 2, 1700 AD

By 1700 AD, all areas that had previously disappeared reappeared. For the entire region, compared to the year previously analyzed, a large increase in production prevalence can be noted. This is very clearly seen in what is Egypt, where most of the violet areas are seen again. This also looks very good in Northwest Africa and in the western part of the Middle East.

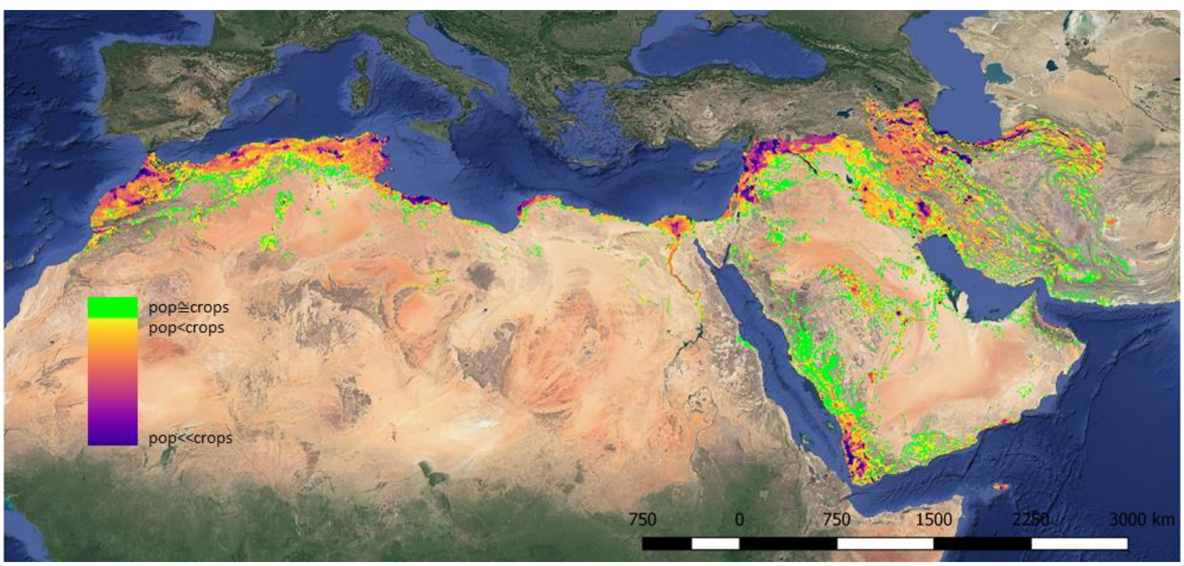

Figure 59 Difference map for Region 2, 1810 AD

Analyzing the year 18010 AD, a great change can be noticed with respect to the year previously analyzed. This great change is that it is seen for first time area used in south of the Middle East, in what is now Saudi Arabia, Yemen, Oman and the United Arab Emirates.

The areas seen in this region are very extensive, and in most of what is Saudi Arabia and the United Arab Emirates you see a balance between production and consumption in their used areas. In what is Yemen there is a high prevalence of production in most of its used area.

With respect to the areas that were already in the year previously analyzed, an increase in the prevalence of production can be noted in Northwest Africa, West Middle East and Iran. A decrease in production prevalence can also be noted in the hue of the colors appreciated in Egypt.

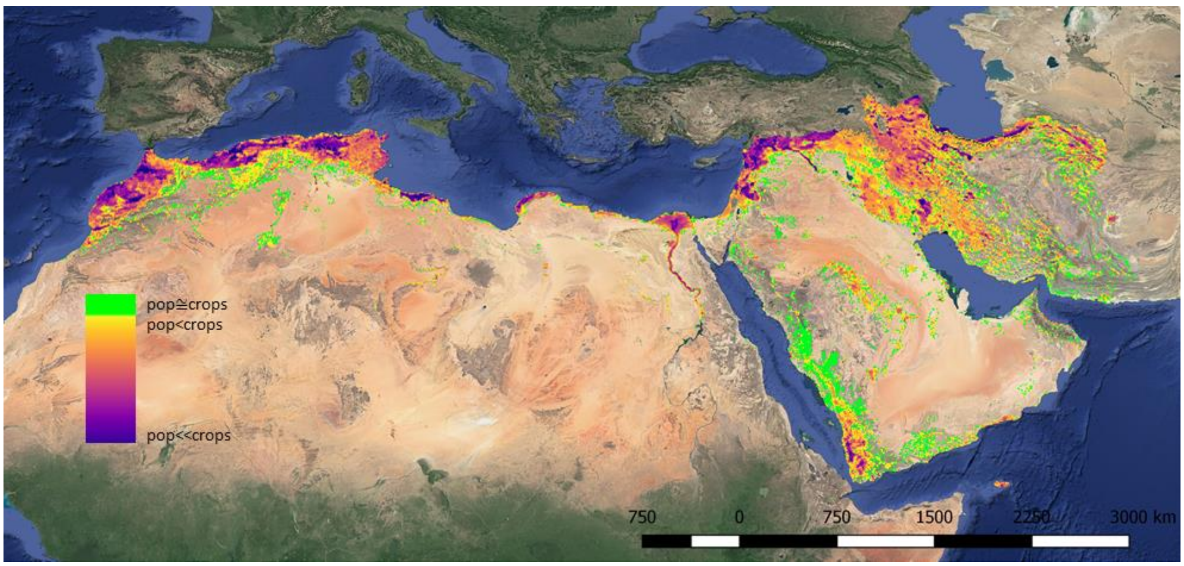

Figure 60 Difference map for Region 2, 1900 AD

Analyzing the year 1900 AD, we can see, compared to the previous year, a large increase in the area used in what is Iran, where in this area production prevails in large numbers with respect to consumption.

An increase in the prevalence of production can also be seen in this year in what is Northeast Africa and in Egypt, where the shades of violet increase, indicating a higher prevalence of production with respect to consumption.

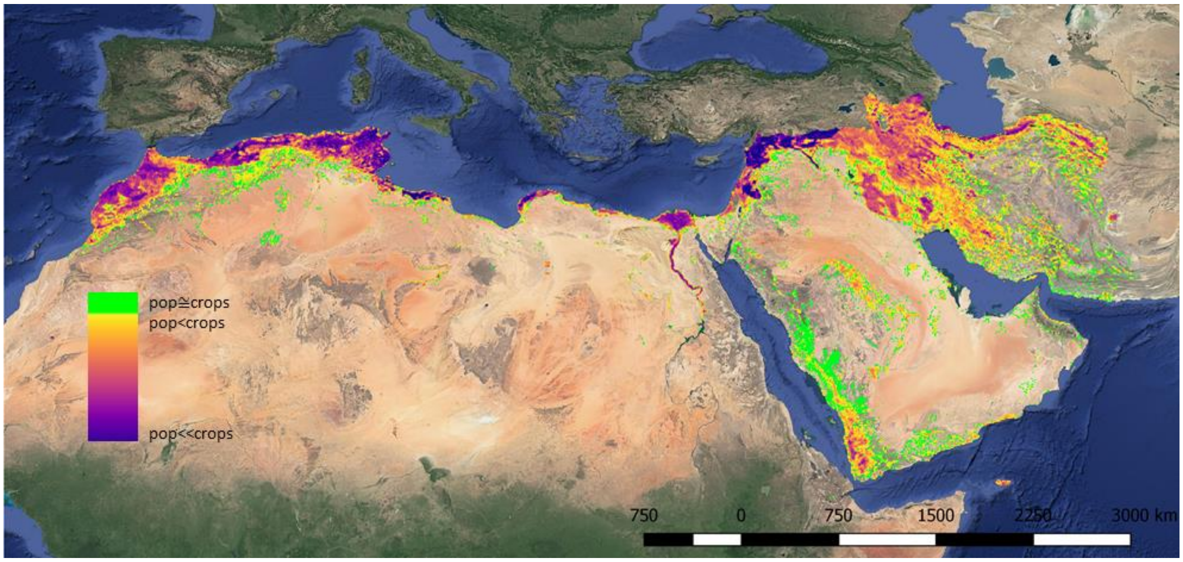

Figure 61 Difference map for Region 2, 1950 AD

In 1950 AD, compared to 50 years ago, the areas used are the same. Very few changes can be noticed, such as an increase in the prevalence of production in Tunisia, where it is now almost totally violet. This increase in production prevalence can also be briefly noted in Egypt and the western Middle East, where a strong violet tone is now seen.

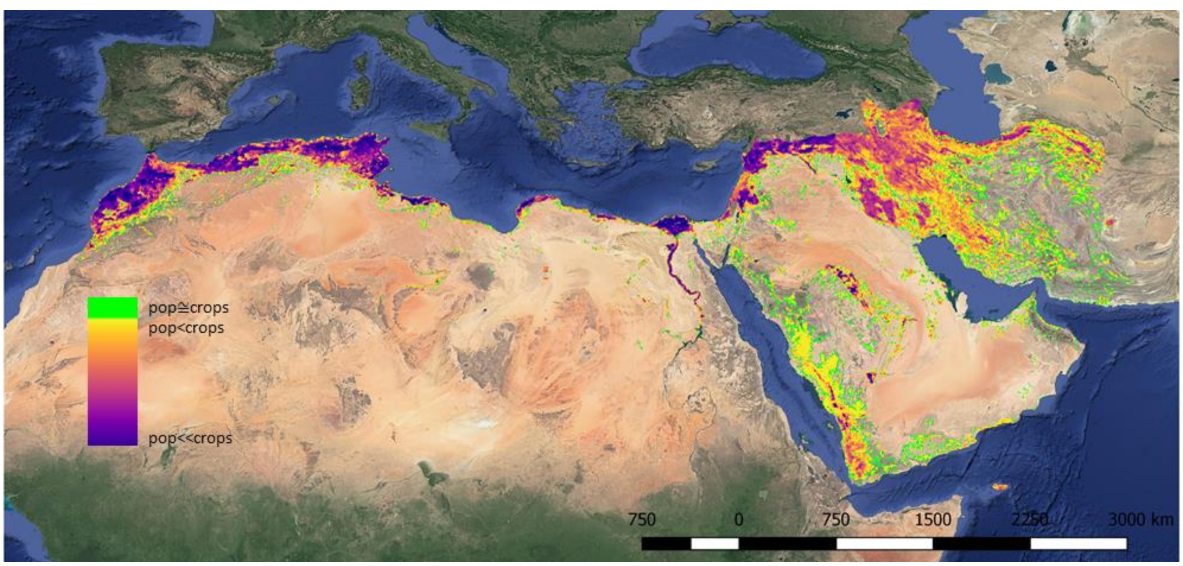

Figure 62 Difference map for Region 2, 2017 AD

Reaching the most current year of our analysis, 2017 AD, we can see that the used areas with respect to the previously analyzed year are the same, with the exception of a large disappearance of the area in Algeria, and small disappearances in the Middle East, mainly in

Syria and in Iran. In all these disappeared regions, they had a good balance between production and consumption.

In all areas where production prevalence is found in Africa, you can still see it, but these areas are currently seen to be overly prevalent, with high shades of violet throughout North Africa.

It can also be noted, a comparison with the previous year analyzed, a real prevalence of production in a large area of Saudi Arabia, where before in this area there were a balance between production and consumption. This prevalence of production is not excessive.

4.2.1.1.3 East Asia and Pacific

Difference analysis has been done for this area which can be seen on the map below.

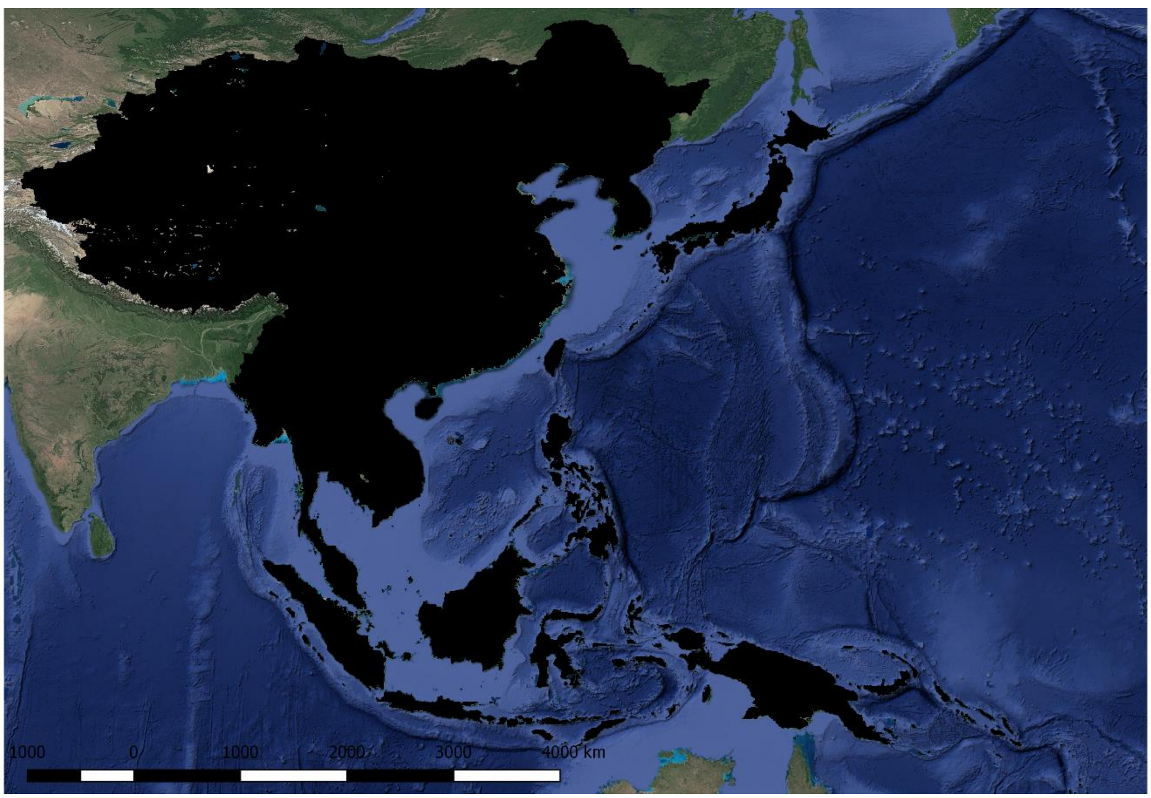

Figure 63 Region 3 map

The calculations were made with the Matlab program and the printing of the maps was made with the QGIS program. These maps will be represented below for the nine different years of the analysis in order to appreciate the evolution over time of these results, which will indicate the spatial distribution between food production and consumption.

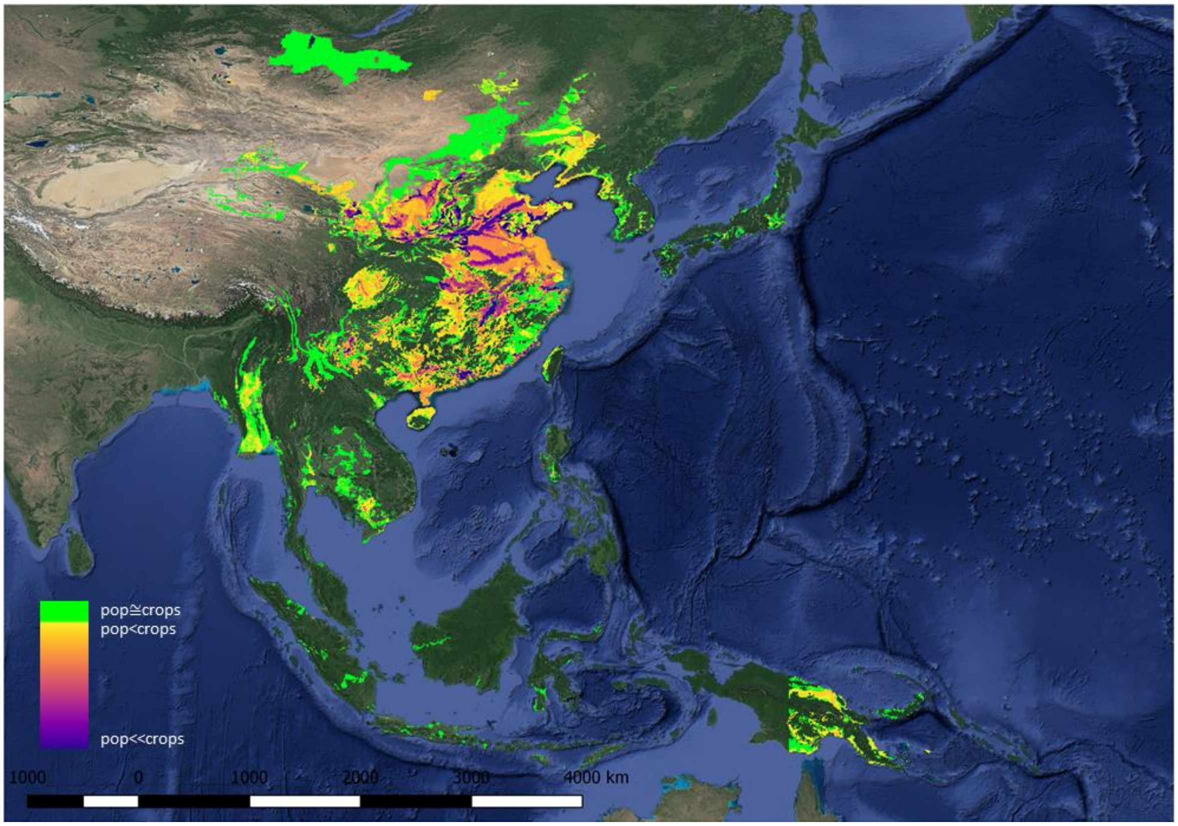

Figure 64 Difference map for Region 3, 0 AD

Starting the analysis of this region in the year 0 AD, we can say that for this year there was already a large amount of populated area, mostly in China. That, for this year, it is the only country in which production prevails to a great extent, and can be seen in small areas isolated from each other.

You can see many areas with a balance between production and consumption. In the country that is seen in greater extension is in Mongolia, where all the area used in this country is green, that is to say in balance.

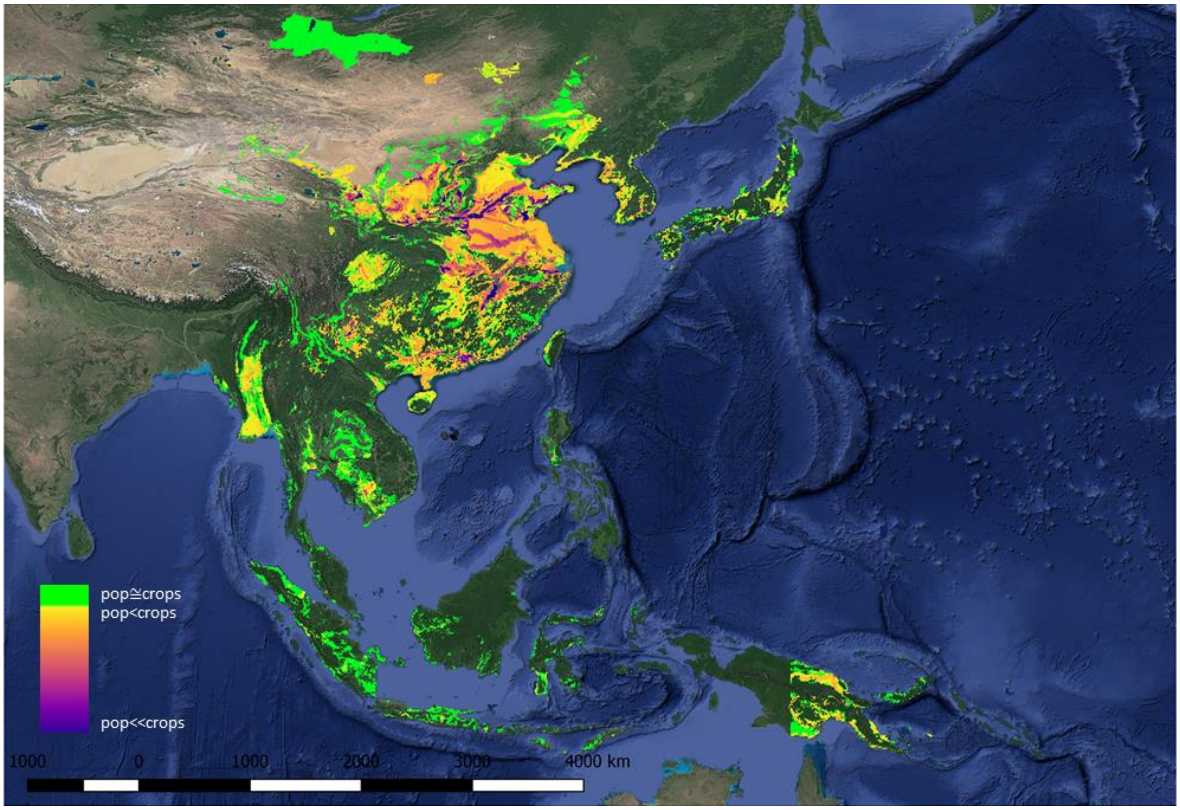

Figure 65 Difference map for Region 3, 500 AD

For the year 500 AD, with respect to the year previously analyzed, a brief extension of the areas used can be noted, being more noticeable in Southeast Asia, the Pacific Islands and Japan.

It can be also notice a disappearance of areas where before there was a balance between production and consumption throughout China, where it can be better noticed in the north and southeast of this country. A relative reduction in the prevalence of production in its color tones is noted in this country, as this year there are other countries in which production prevails over consumption, although not in very high numbers. Countries like Japan, Korea and Myarmar.

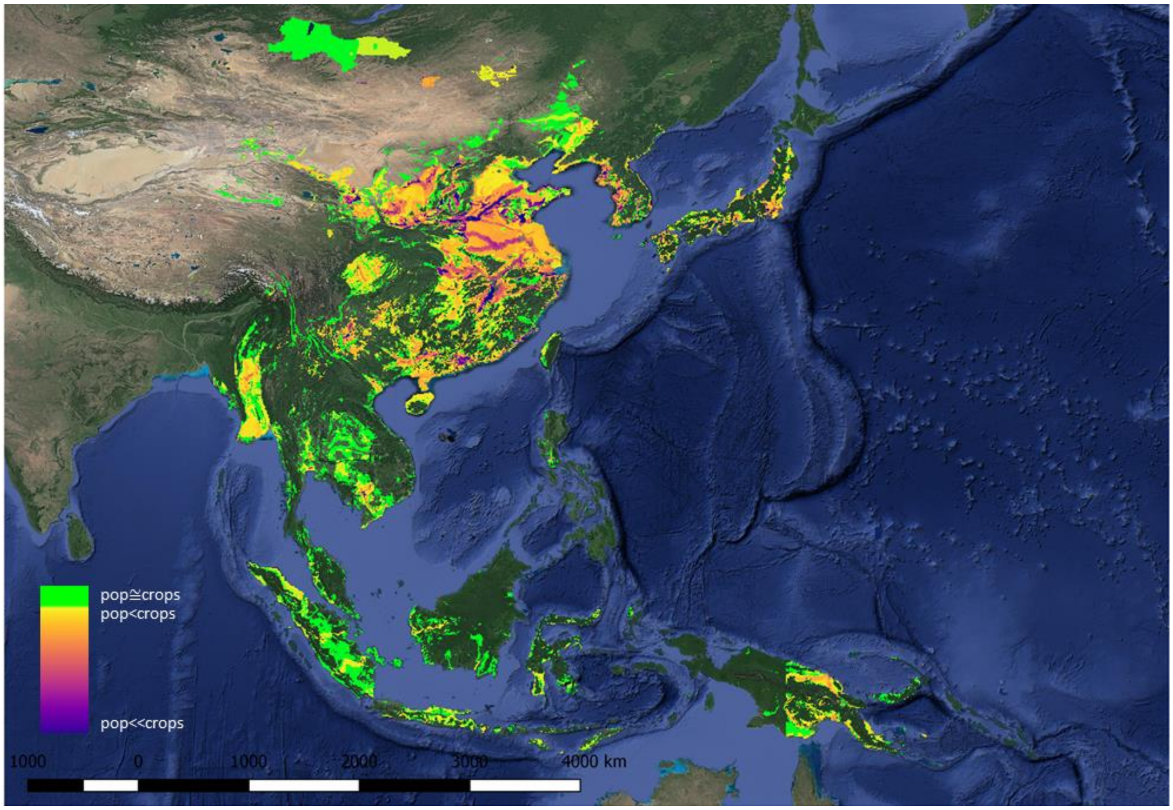

Figure 66 Difference map for Region 3, 1000 AD

For the year 1000 AD, there are no major changes from 500 years ago. You can see an increase in the area used in Southeast Asia and the west of the Pacific Islands, where in these new areas there is a balance between production and consumption.

For this year, a relative increase in the prevalence of production can be noted in both Korea and Japan.

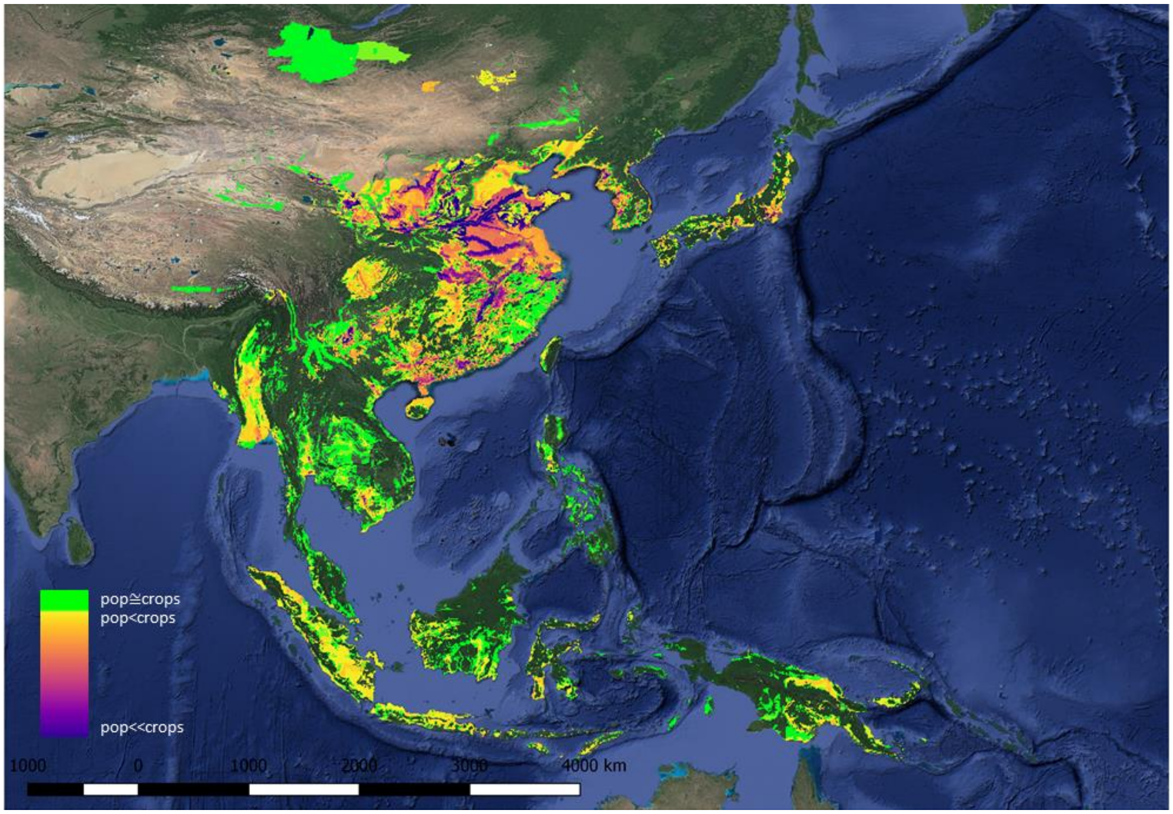

Figure 67 Difference map for Region 3, 1500 AD

Reaching 1500 AD, passing 500 years from the previous year analyzed, it can be notice the same areas used, with the exception of a disappearance of areas where before there was a balance between production and consumption in northern China. There is also an increase in the areas used in the south east and south west of China, where they had previously disappeared. Also, an increase of used area can be noticed in Mongolia, Southeast Asia and all the islands of the Pacific. In all these extensions of used areas there is a balance between production and consumption.

A large increase in color tone can be seen in the areas where production in China prevailed, which indicates that this year the prevalence of production is even higher with respect to consumption.

It can be seen that in the western Pacific islands in a large area where before there was a balance between production and consumption, there is now a prevalence of production, although this is not in a very significant number.

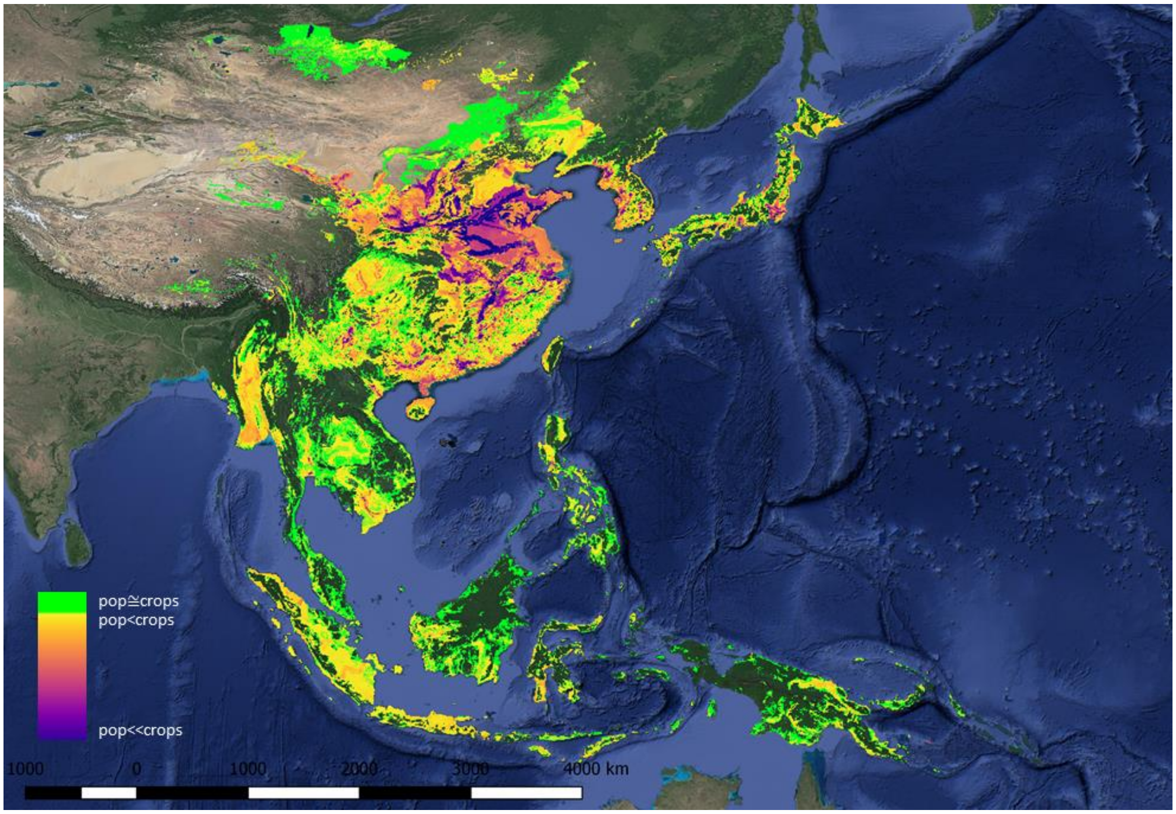

Figure 68 Difference map for Region 3, 1700 AD

Two hundred years later, in the year 1700 AD, a great increase in the areas used in this entire region can be seen, noting mostly in China, Japan and Korea.

For this year, it can be seen that in most of the areas that previously had a balance between production and consumption, now production prevails over consumption. This can be seen well in Southeast Asia and the Philippines.

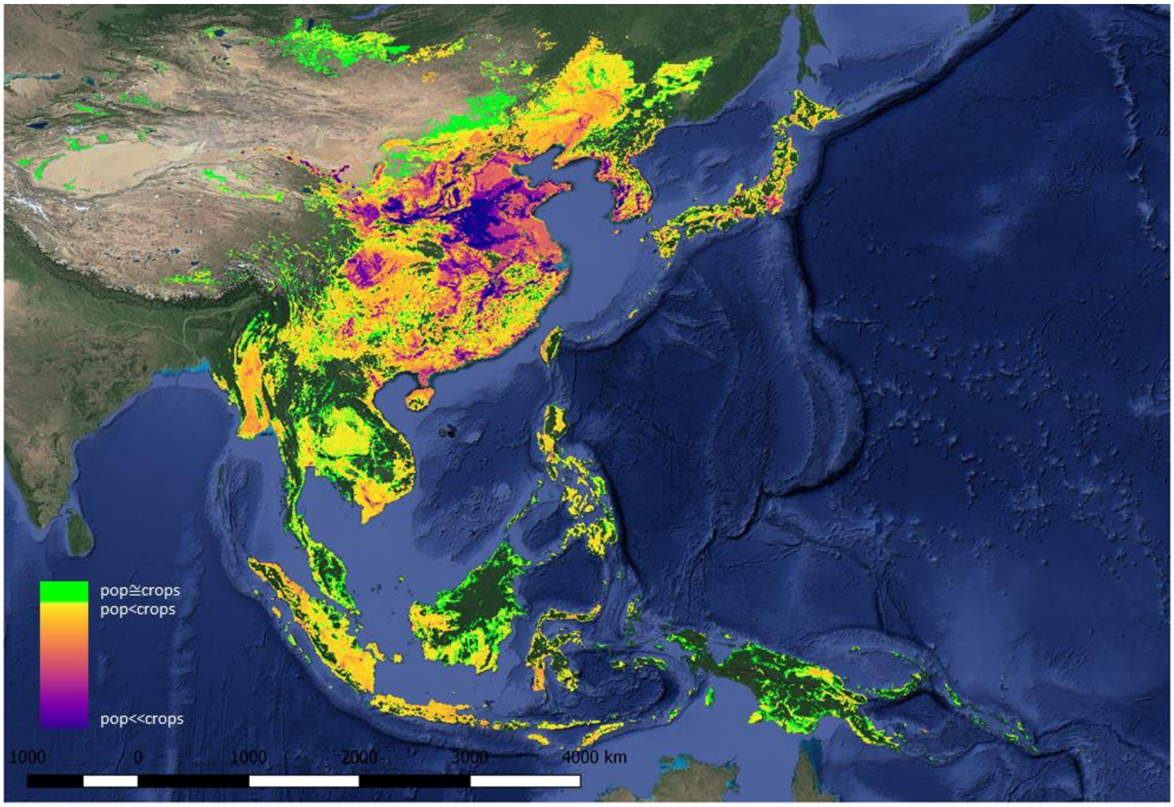

Figure 69 Difference map for Region 3, 1810 AD

For the year 1810 AD, the increase in areas used is noticeable compared to the previous year, being noticed mainly in China, in the north of this country. In these new areas used in northern China there is a prevalence of production over consumption.

In this year, it is well seen how production prevails over consumption. This is very noticeable in west central China, where the prevalence of production is excessive with respect to consumption.

For this year there is a disappearance of the area in Mongolia with respect to the year previously analyzed, where there was a balance between production and consumption.

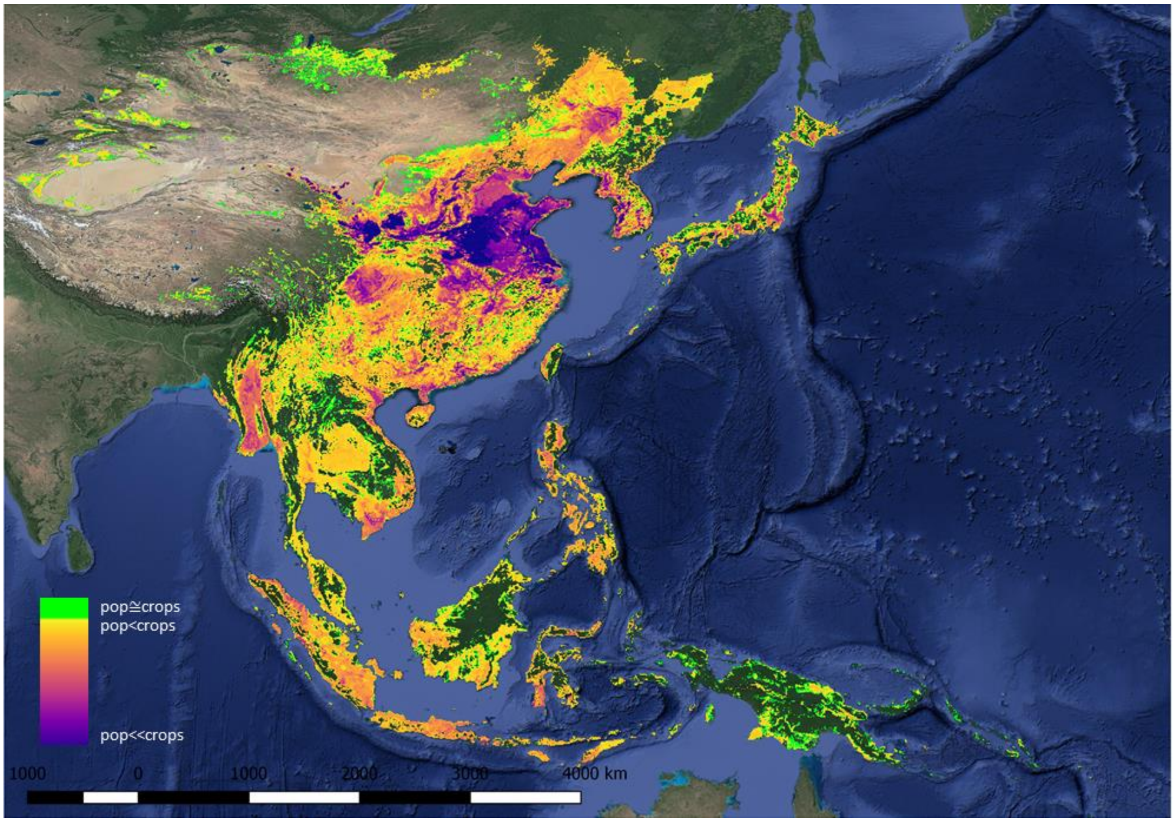

Figure 70 Difference map for Region 3, 1900 AD

For the year 1900 AD, a brief increase in the area used can be seen throughout the region and a brief disappearance of the area in northern China and in Mongolia of areas where there was previously a balance between production and consumption.

It can be seen for this year that there are very few regions where there is a balance between production and consumption, as in almost the entire region, production prevails over consumption. Where it is most prevalent is in central China and Myanmar.

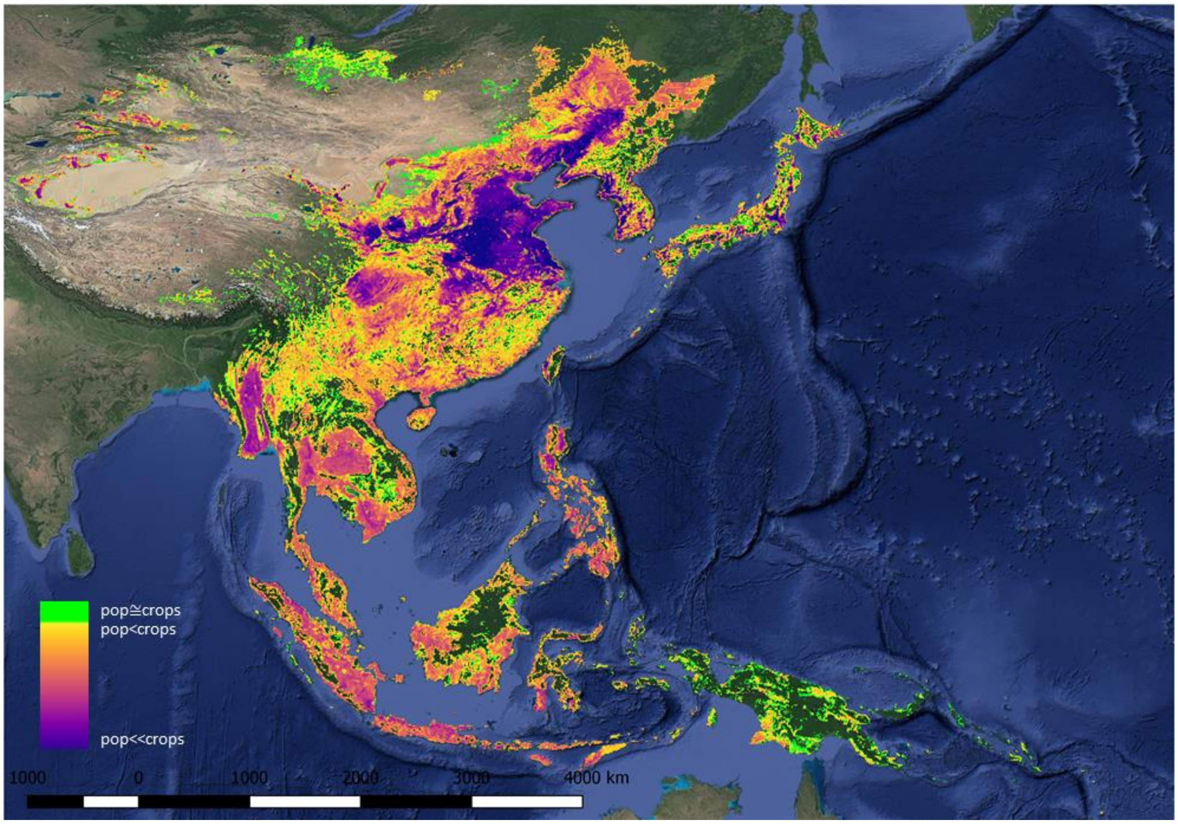

Figure 71 Difference map for Region 3, 1950 AD

Analyzing the year 1950 AD, compared to the year previously analyzed, almost the same extension of area used is noted. The biggest difference that can be noticed is that, in the entire region with the exception of some countries such as Papua New Guinea and Mongolia, the color tones of production prevalence have increased. This means that now the prevalence of production in the entire region is greater in number than in the year previously analyzed.

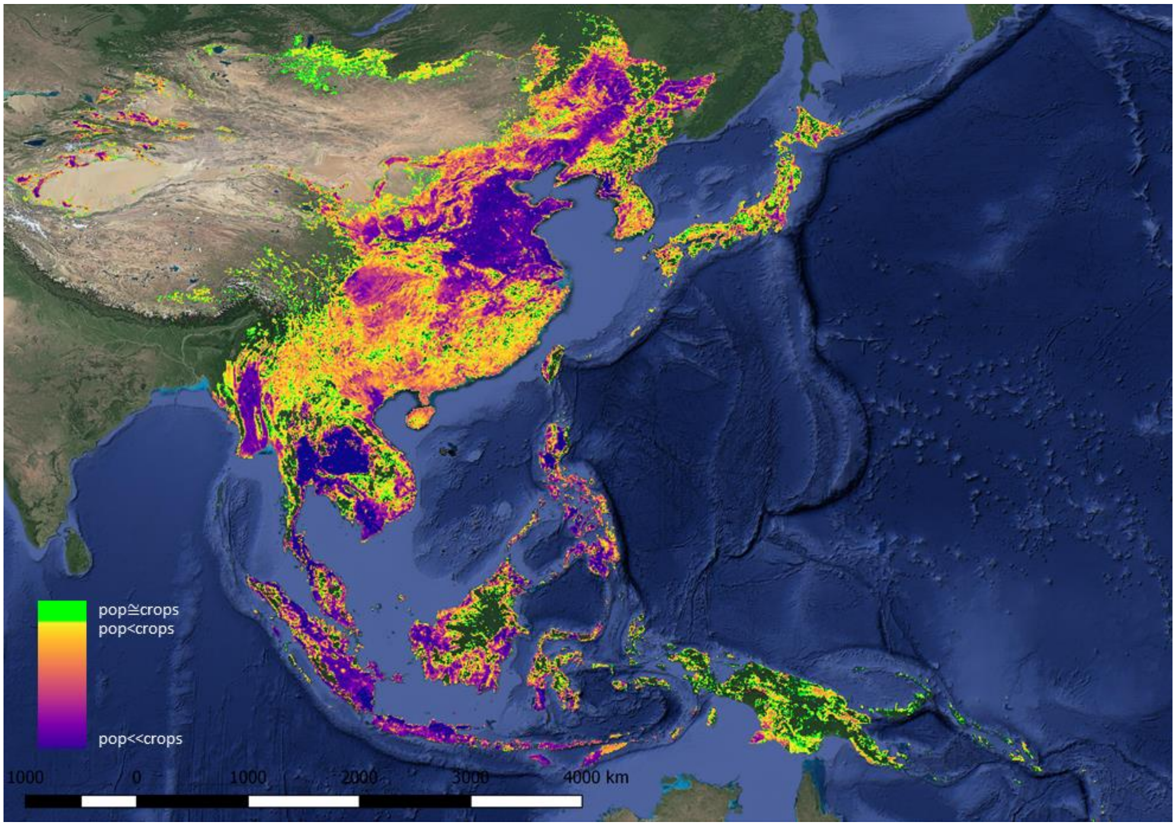

Figure 72 Difference map for Region 3, 2017 AD

Reaching the most current year of our analysis, 2017 AD, we can see that China is no longer the only country with areas of strong violet tones. This means that the prevalence of production is excessive not only in much of China but in other regions, such as Southeast Asia and the Pacific Islands, with the exception of Papua New Guinea, where half of its area is seen used in equilibrium between production and consumption, and in the other half, the prevalence of production over consumption, but not of great relevance.

It is also noted that today and throughout its history, in the areas used in Mongolia, in the vast majority there is a balance between production and consumption, with very few areas where production prevails, but very little.

You can see well in Japan the good spatial distribution of colors on the island. This indicates a good spatial distribution between areas where production prevails and areas where there is a balance between production and consumption.

4.2.1.1.4 South Asia

Difference analysis has been done for this area which can be seen on the map below.

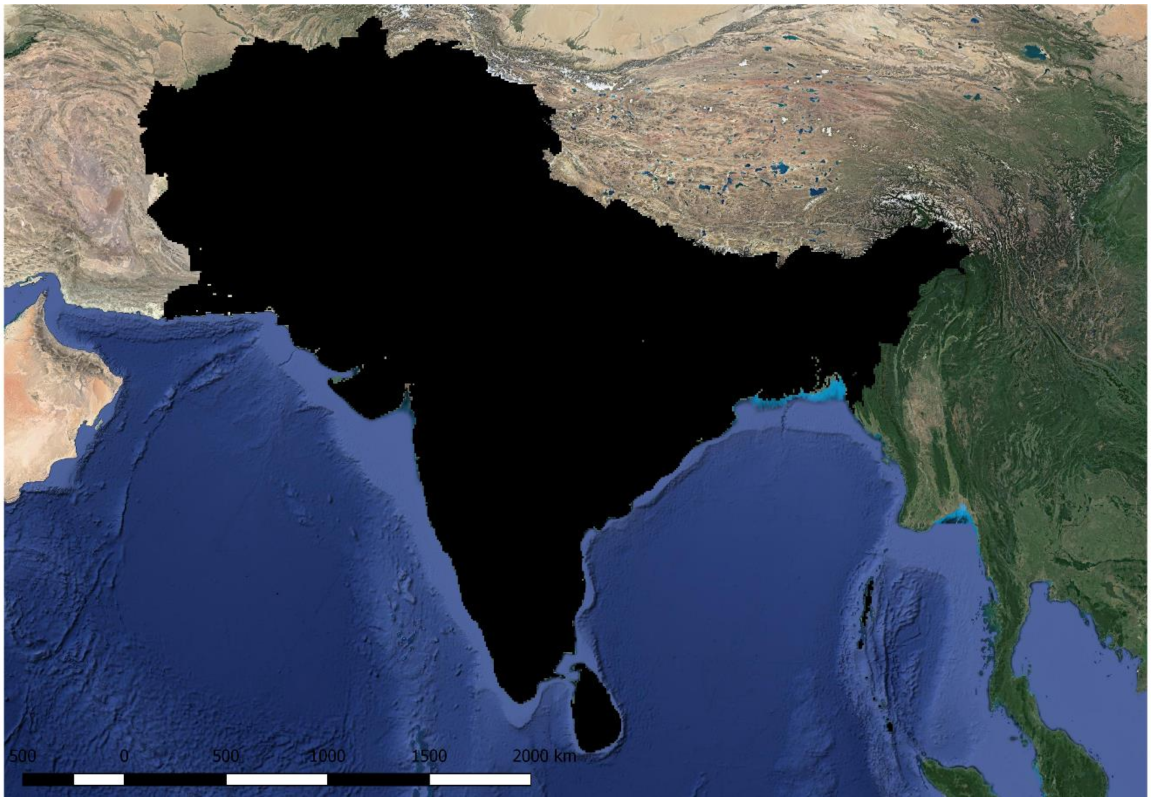

Figure 73 Region 4 map

The calculations were made with the Matlab program and the printing of the maps was made with the QGIS program. These maps will be represented below for the nine different years of the analysis in order to appreciate the evolution over time of these results, which will indicate the spatial distribution between food production and consumption.

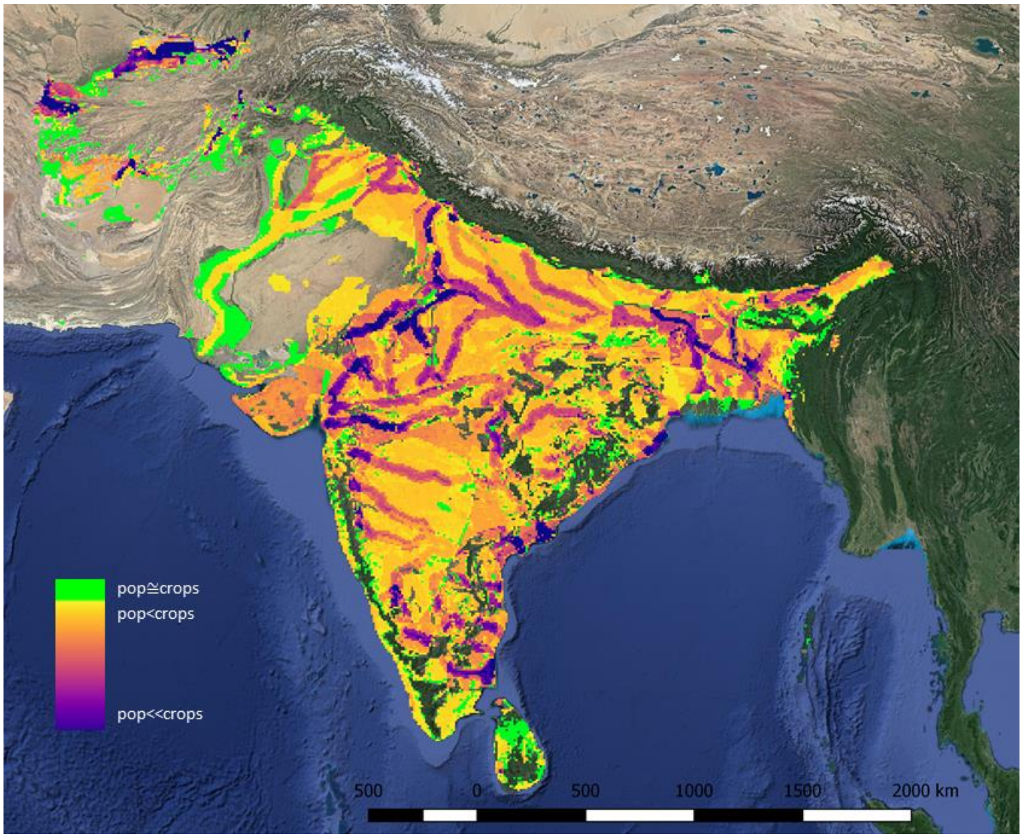

Figure 74 Difference map for Region 4, 0 AD

Starting the analysis in year 0 AD, we can see that this area for this time is already a place with a large area of habited and cultivated areas, where the land in India is almost completely used, and fully used in Bangladesh.

It can be seen that production prevails in most of this region, but this does so with less prevalence, with the exception of quite a few purple stripes that indicate a high prevalence of production distributed separately throughout India. These violet areas can be seen in a large extent in the north of Afghanistan, and a little of them in the south and east of this country. Also we can find this violet areas in all the center of Bangladesh.

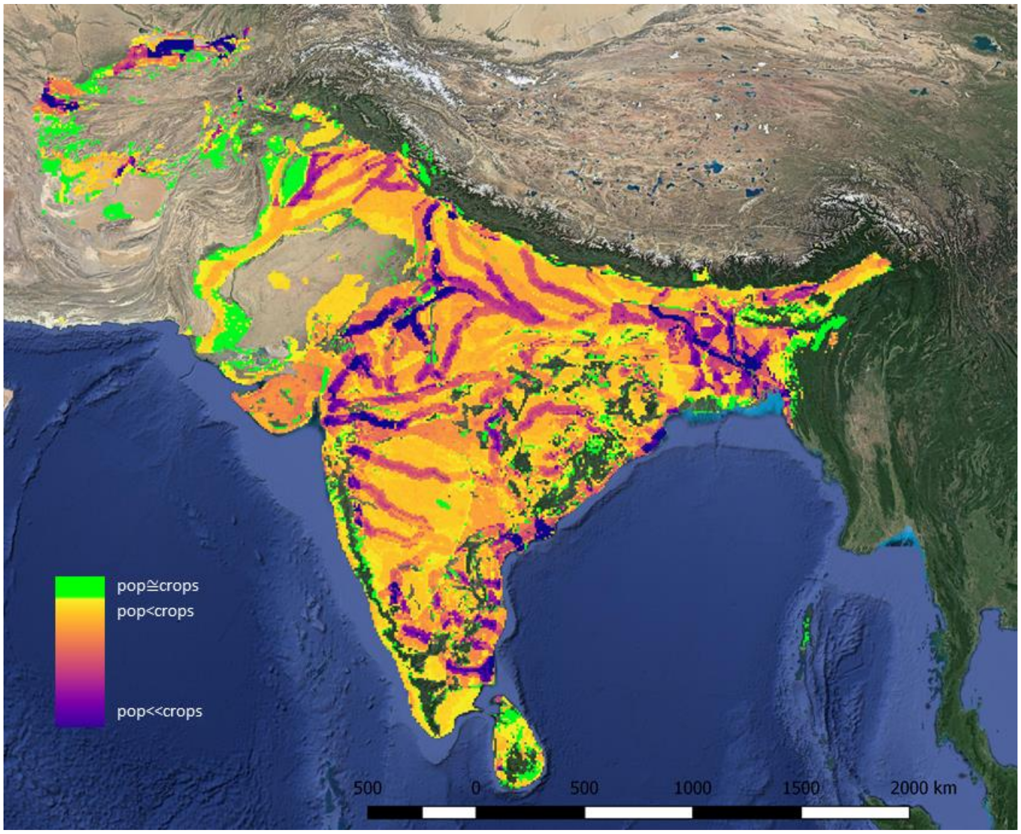

Figure 75 Difference map for Region 4, 500 AD

Turning to the year 500 AD, we see that things remain quite similar.

There is no significant increase in the areas used or the amount of production prevalence.

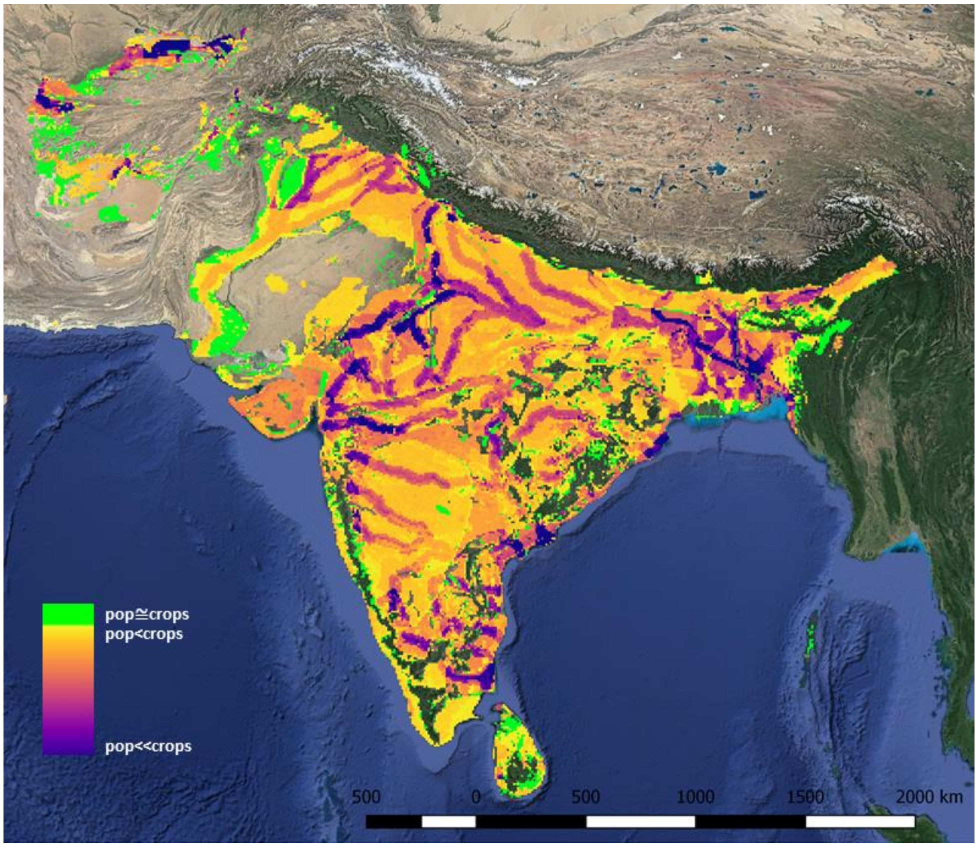

Figure 76 Difference map for Region 4, 1000 AD

If we now go to the year 1000 AD, we see that things remain quite similar, especially in India. We can see a small increase in areas where production prevails, but not in large numbers in Pakistan. A brief decline in relative production is seen in northern Afghanistan.

We can comment that like the years analyzed above, Bangladesh almost entirely prevails production, but in this year, it is seen that it has reached a point that production prevails by far, in most of its area.

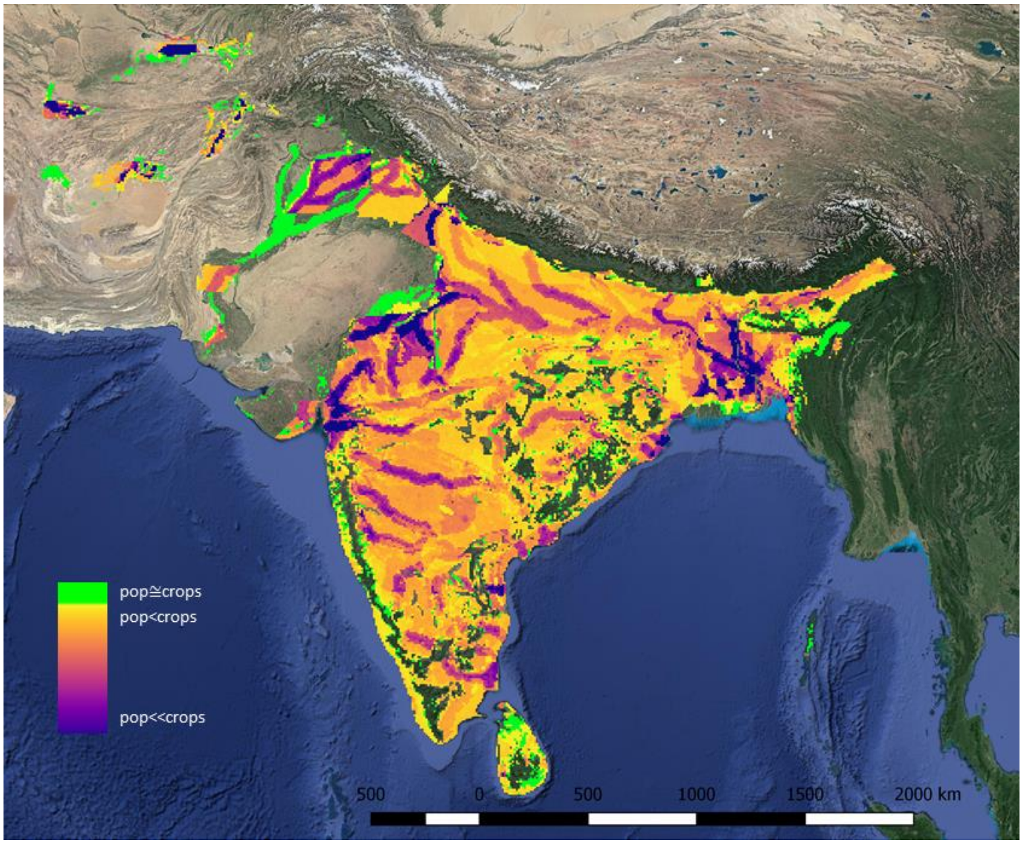

Figure 77 Difference map for Region 4, 1500 AD

In the year 1500 AD, things continue to be distributed very similarly, but a decrease in the prevalence of production can be noticed in the south east of India, where the color tones decrease. The most noticeable change between this year and the previous one is seen in the countries of Afghanistan, Pakistan and in the northwest of India, where you can see great disappearances of areas that were previously used by man. In the case of Pakistan, these areas decrease considerably and those that can be seen this year have a balance between production and consumption in the center of this country, where production previously prevailed. You can also notice in this country an increase in the number of prevalence of production in the north, where production already prevailed.

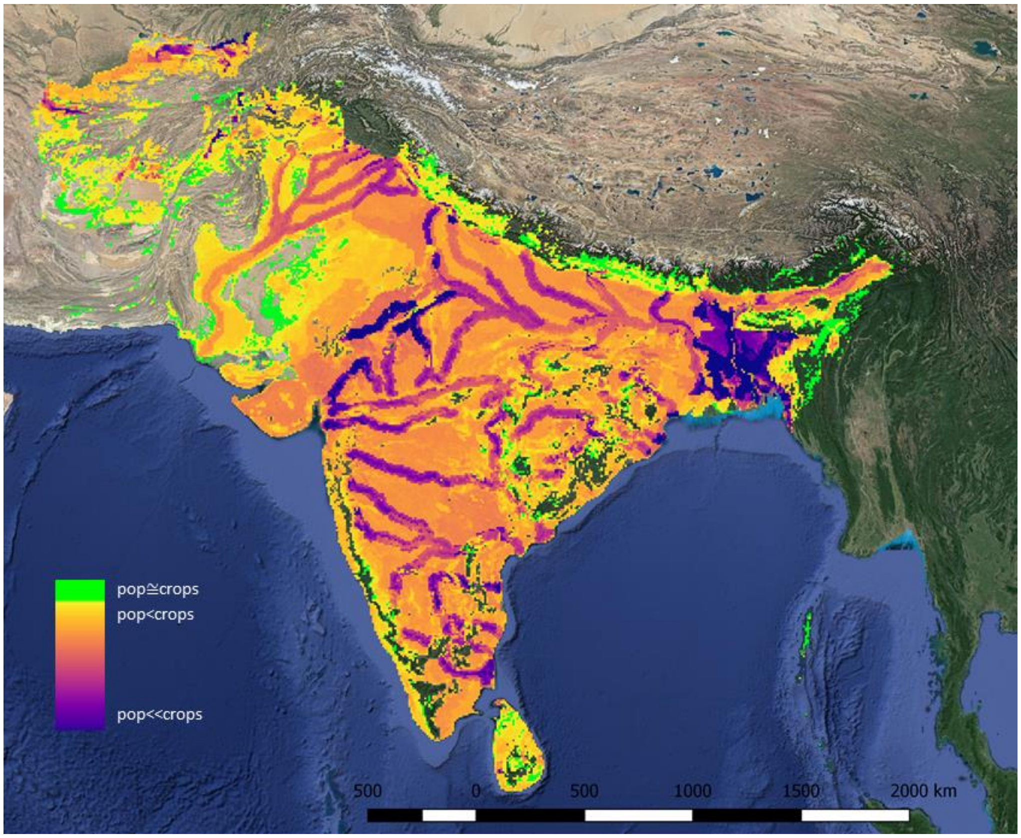

Figure 78 Difference map for Region 4, 1700 AD

For the year 1700 AD, things change a lot. The areas used increase significantly, where it can be clearly seen in western India, Pakistan, and Afghanistan. In all of them, production prevails, but it does not do so in large numbers. You can also see very small areas in western India with a balance between food production and consumption.

You can also notice the high increase in production throughout the region, all areas increased their color tone. This can be seen notoriously in Bangladesh, where the current tone is a strong violet in almost all of its territory.

In the case of Pakistan, in the area where before there was a balance between production and population, now there is an increase in production and this is balanced in quantity with the other regions of this country, where in the north there was a high relative production. , now it looks a bit lighter in color.

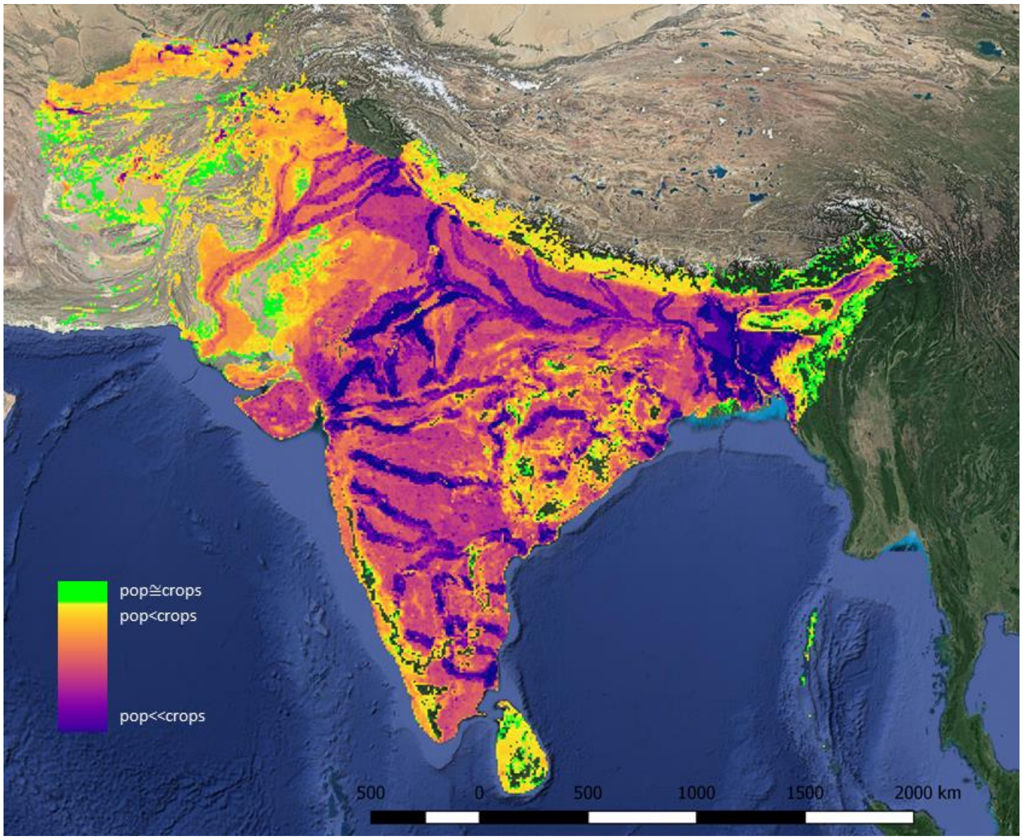

Figure 79 Difference map for Region 4, 1810 AD

Turning to the year 1810 AD, you can see a large increase in violet tone in almost all of India, which indicates that production prevails by far over consumption, also you can see this in Pakistan where there is also an increase in the area north of this country where production prevails over consumption.

You can see in Afghanistan an increase in the area in the north where production prevails over consumption, and in the south of this country there is a small decrease in production area and a small increase in areas where there is a balance between production and consumption.

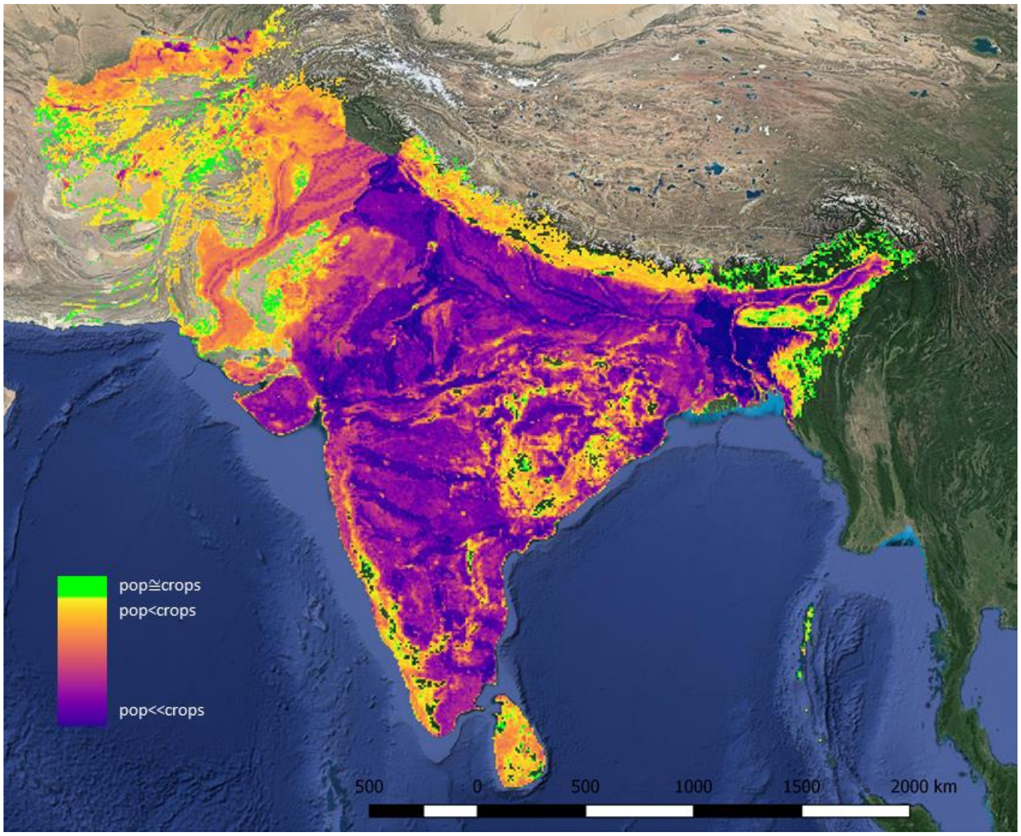

Figure 80 Difference map for Region 4, 1900 AD

In the year 1900 AD, the most noticeable difference in this year with respect to the previous one is seen in the color of the map, which is totally violet in almost all the extension of India, which says that the production in this country prevails significantly over the consumption in almost its entire region. This large increase in production generated a decrease in the prevalence tones of production in the countries of Afghanistan and Pakistan. This year you can also notice a large increase in the area used in Afghanistan, where production prevails over consumption.

The island of Sri Lanka for this year is fully utilized and in all its extension the production prevails but by a not so high number.

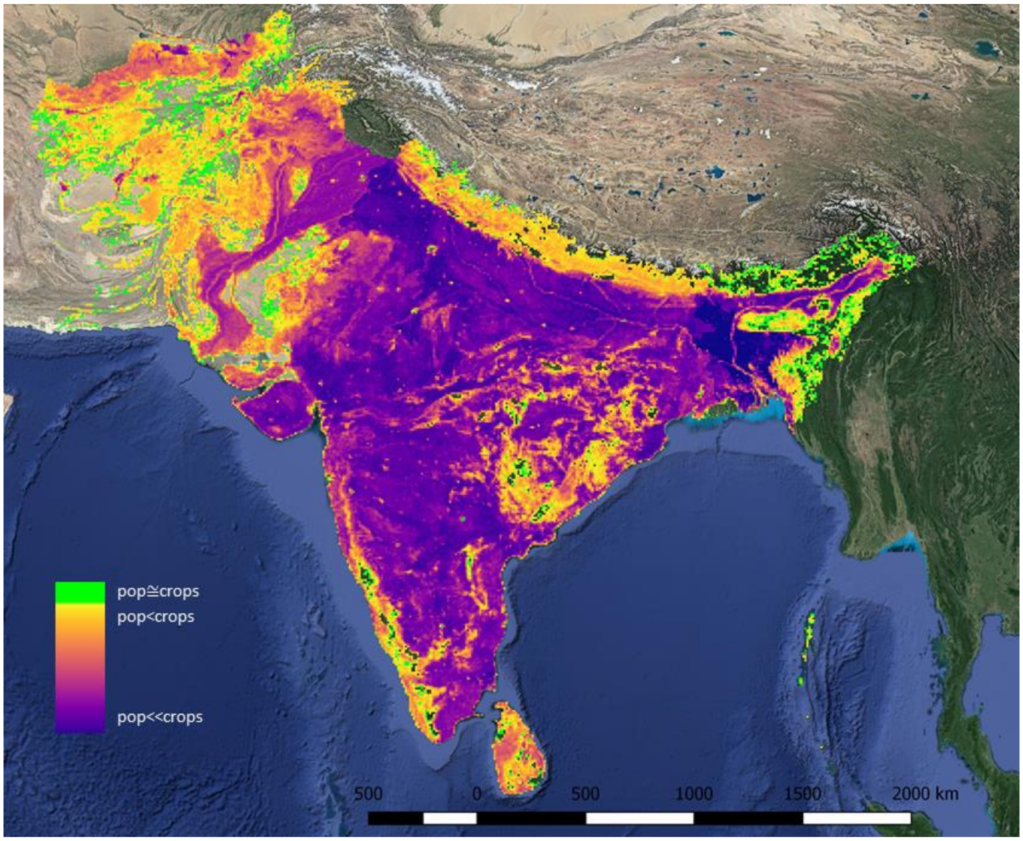

Figure 81 Difference map for Region 4, 1950 AD

For the year 1950 AD, you can see the very similar spatial distributions, with the difference that now the shades of violet have become more homogeneous in what is India, indicating that production largely prevails over consumption. There is also an increase in the tone of violet in Pakistan.

The areas used in both Pakistan and Afghanistan increased, with production prevalence in almost all of these, with the exception of some areas of Afghanistan where there is a balance between production and consumption.

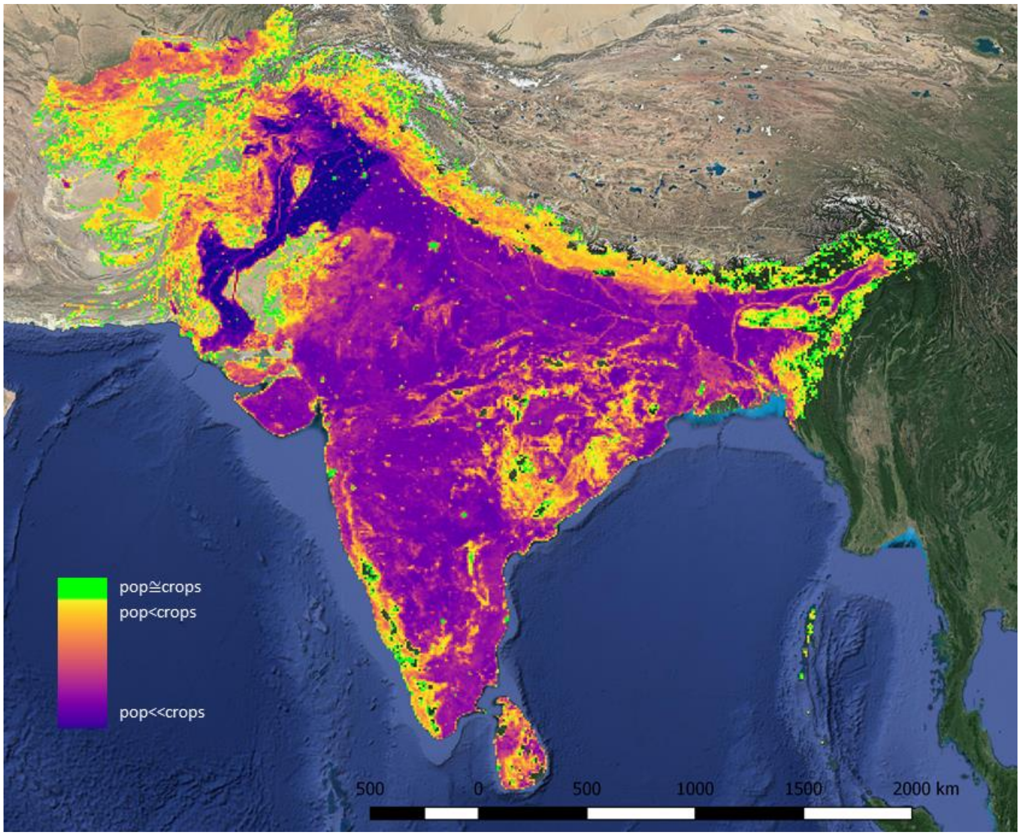

Figure 82 Difference map for Region 4, 2017 AD

We now reach the most current year of the analysis, 2017 AD, for this year, you can see how production in Pakistan has increased relatively to the rest of the countries in this region, where the shade of violet is much stronger than the rest. This means that it has more prevalence of cultivation in the same area, not that it produces more than the rest. This previously happened with Bangladesh, which differed until the year previously analyzed, just as Pakistan does today. There is also an extension of the area used in the north and south of Pakistan, where production prevails over consumption.

4.2.1.1.5 East Europe and Central Asia

Difference analysis has been done for this area which can be seen on the map below.

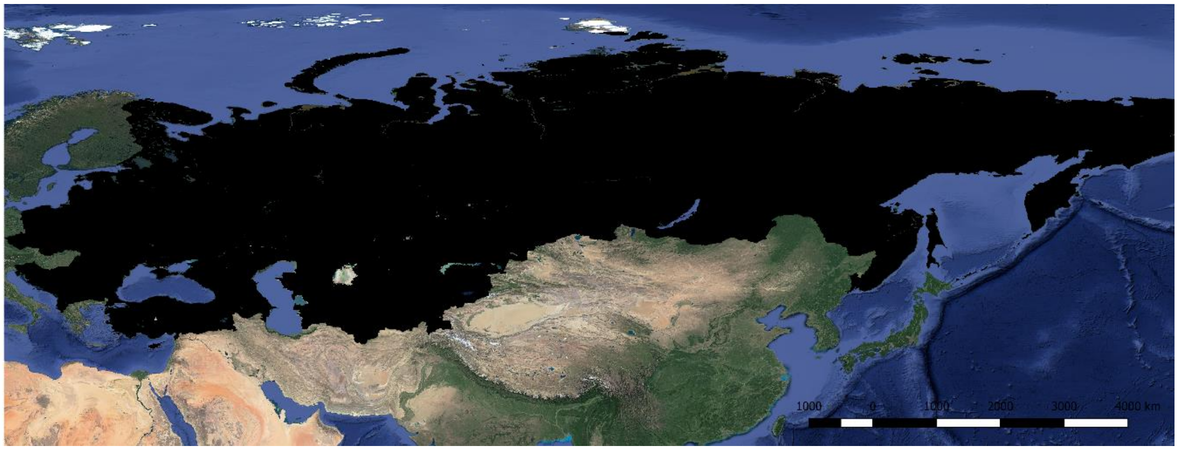

Figure 83 Region 5 map

The calculations were made with the Matlab program and the printing of the maps was made with the QGIS program. These maps will be represented below for the nine different years of the analysis in order to appreciate the evolution over time of these results, which will indicate the spatial distribution between food production and consumption.

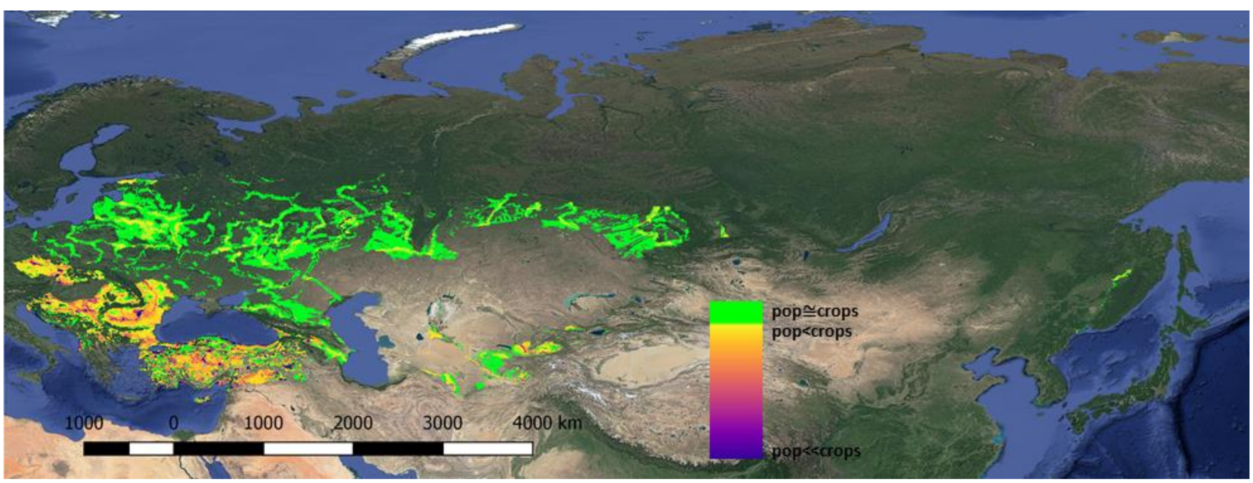

Figure 84 Difference map for Region 5, 0 AD

Starting the analysis of this region in the year 0 AD, we can comment that by this time there were already several used areas. In the case of Eastern Europe, it can be seen that in almost all of it used, production prevails over consumption. Instead, the entire used area of the Soviet

Union can be seen that in the vast majority of it there is a balance between production and consumption.

In Turkey, the spatial distribution of the different colors can be well appreciated, indicating a good distribution of the areas where production prevails by far, where there is a balance between production and consumption, and where production prevails but not in great quantity.

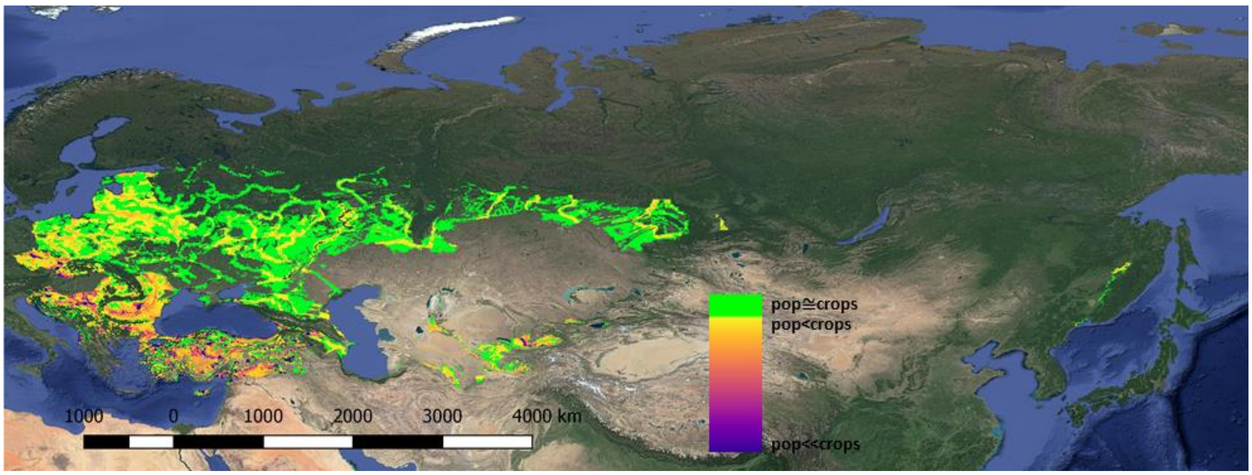

Figure 85 Difference map for Region 5, 500 AD

For the year 500 AD, in this region things remain very similar with the exception of the entire area of the Soviet Union, where a great increase in its used area can be noticed, mainly to the east of this region, where there is now a brief prevalence of production, in most of this territory. In Poland there is also a very great change in terms of the area used, where it increases from very small area used to almost the entire territory of this country, where production now prevails, although very little, in most of this country.

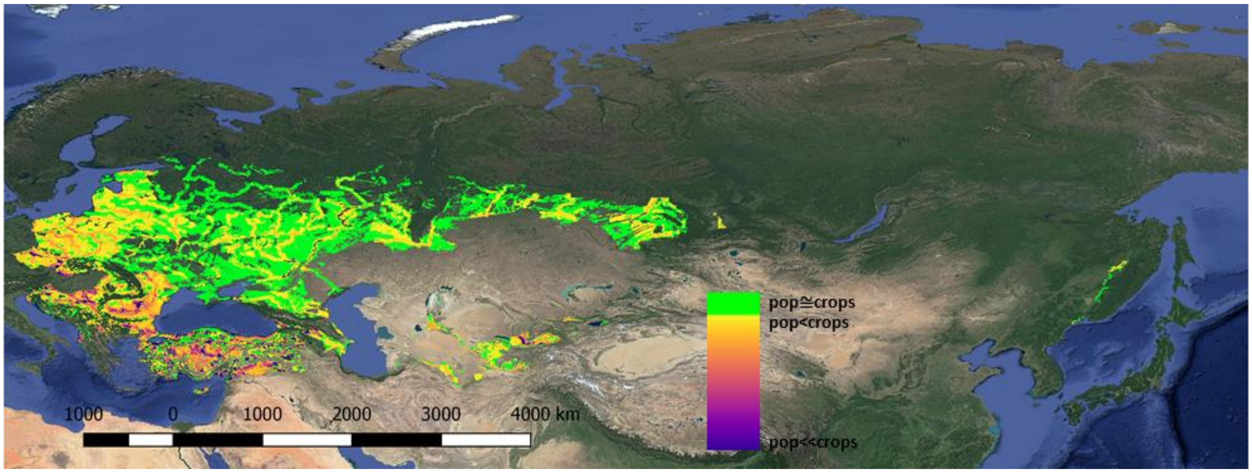

Figure 86 Difference map for Region 5, 1000 AD

By 1000 AD, in Eastern Europe things remain very similar, with a very brief extension of areas used in the country of Turkey. In the region of the Soviet Union there is a great increase in the area used, where there is mostly a balance between production and consumption, with several areas where production prevails, but this does not significantly.

In the country of Poland you can see an increase in the prevalence of production, where this country already does it in almost all its territory and in some parts of it there are large prevalences of production.

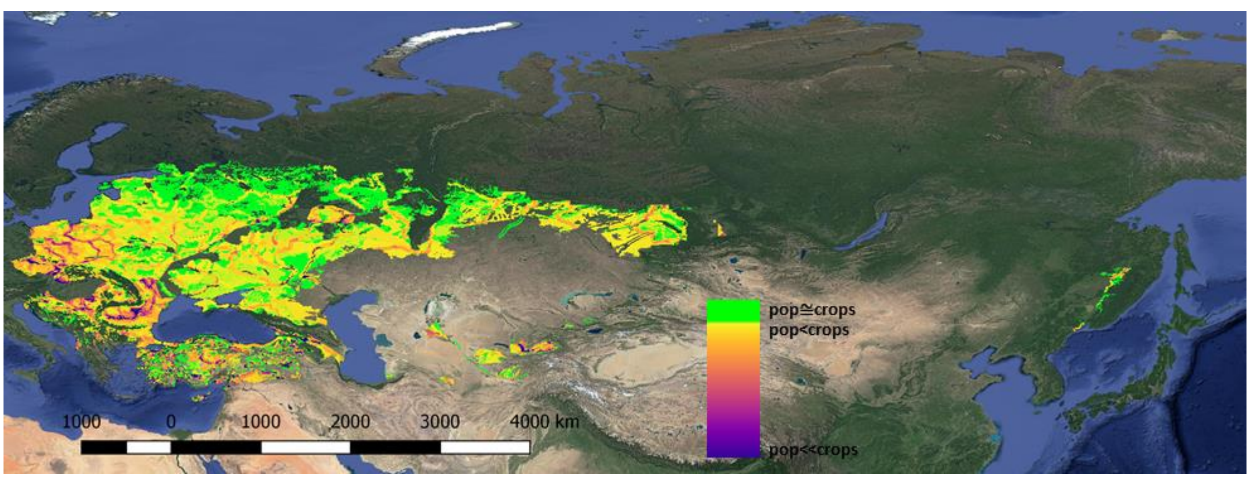

Figure 87 Difference map for Region 5, 1500 AD

For the year 1500 AD, the most significant change with respect to the year previously analyzed is seen in the Soviet Union, where a large increase in its used area is seen and most of this production prevails over consumption to a large extent of this territory.

In this year a relative decrease in production of the Turkish country can be noticed. A large relative increase in production prevalence can also be noted in Romania.

You can see a disappearance of the area used in a thin strip that passes through the center of Ukraine and extends northeast towards the north of Russia. A brief disappearance of used area can also be seen in Turkmenistan and some regions of Turkey.

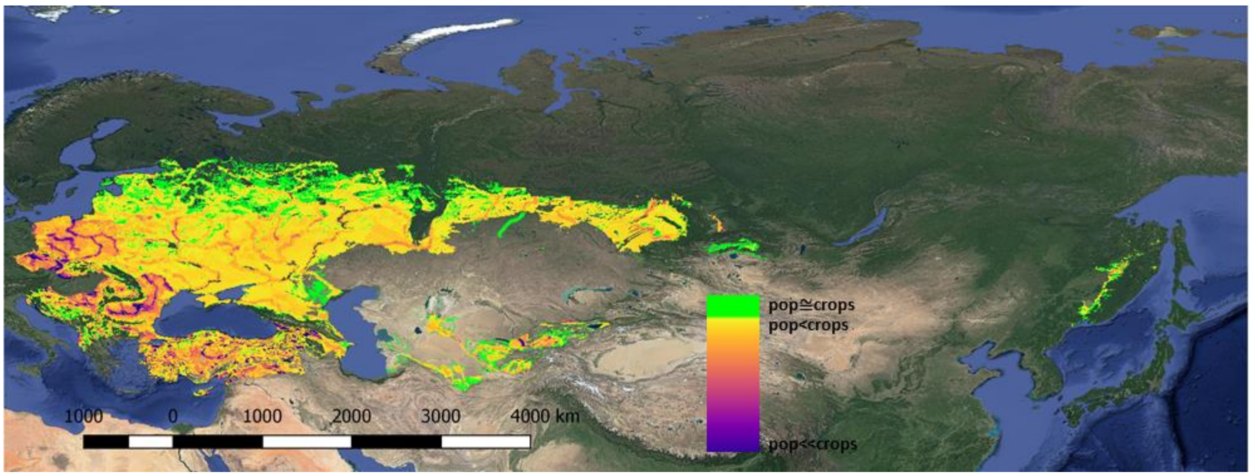

Figure 88 Difference map for Region 5, 1700 AD

For the year 1700 AD, production prevalence is already seen in almost all the analyzed region, with a great extension of these areas in Russia.

For this year we see an extension of areas used in Turkey and in the area of the countries of Turkmenistan and Uzbekistan.

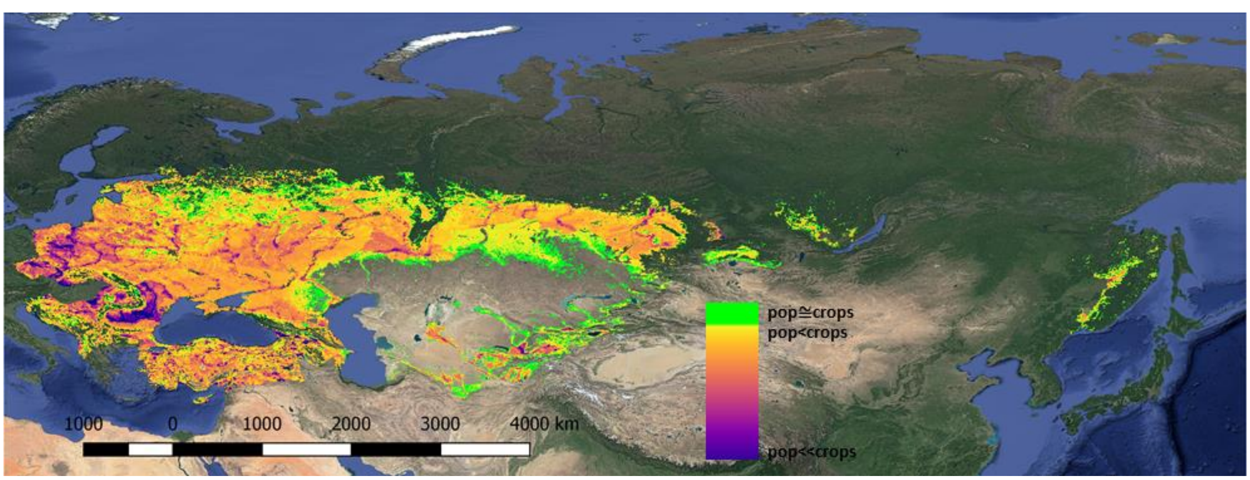

Figure 89 Difference map for Region 5, 1810 AD

In the year 1810 AD, with respect to the year previously analyzed, a large extension of the area used in northern Kazakhstan, on the border with Russia, can be noted.

Compared to the previous year, the most significant change that can be seen is the change in the color tone of the entire region, which indicates an increase in relative production compared to consumption.

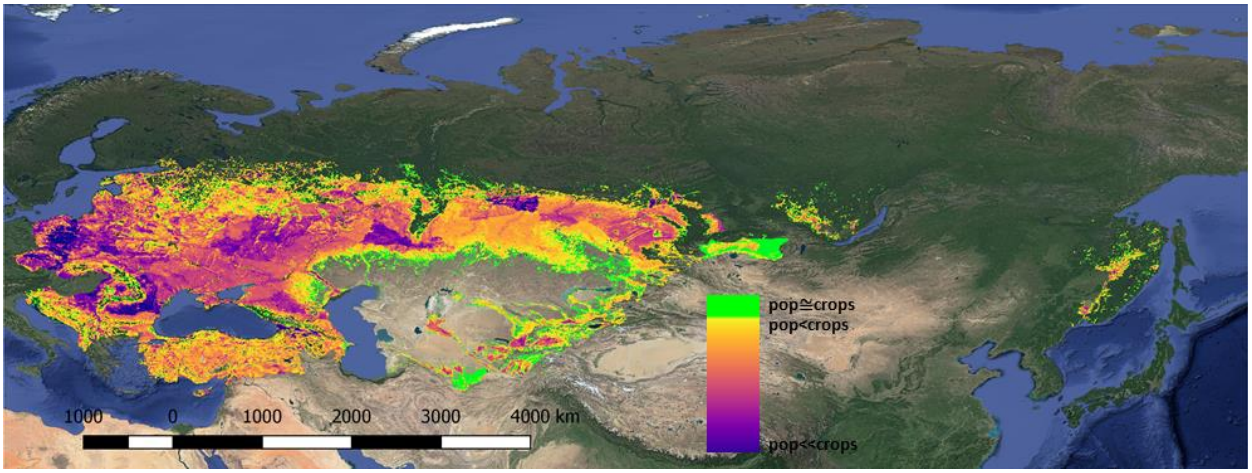

Figure 90 Difference map for Region 5, 1900 AD

For the year 1900 AD, the areas used do not vary much from the year previously analyzed, but an excessive change in the color tone of the entire region can be seen. Increasing to a color that indicates a high prevalence of production in terms of consumption throughout the region, mainly north of it.

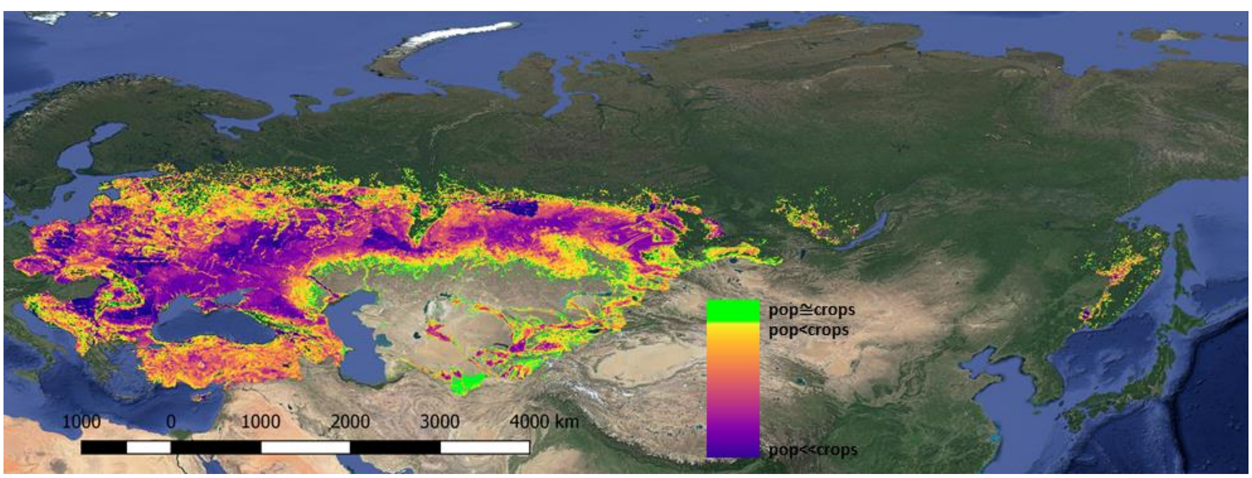

Figure 91 Difference map for Region 5, 1950 AD

For the year 1950 AD, the areas used did not vary much with respect to 50 years ago, but it can be seen, as in the year previously analyzed, an excessive change in the color tone of the entire region. Increasing to a stronger violet color, which indicates a high prevalence of production in terms of consumption throughout the region. This can be seen mainly in the north of this region.

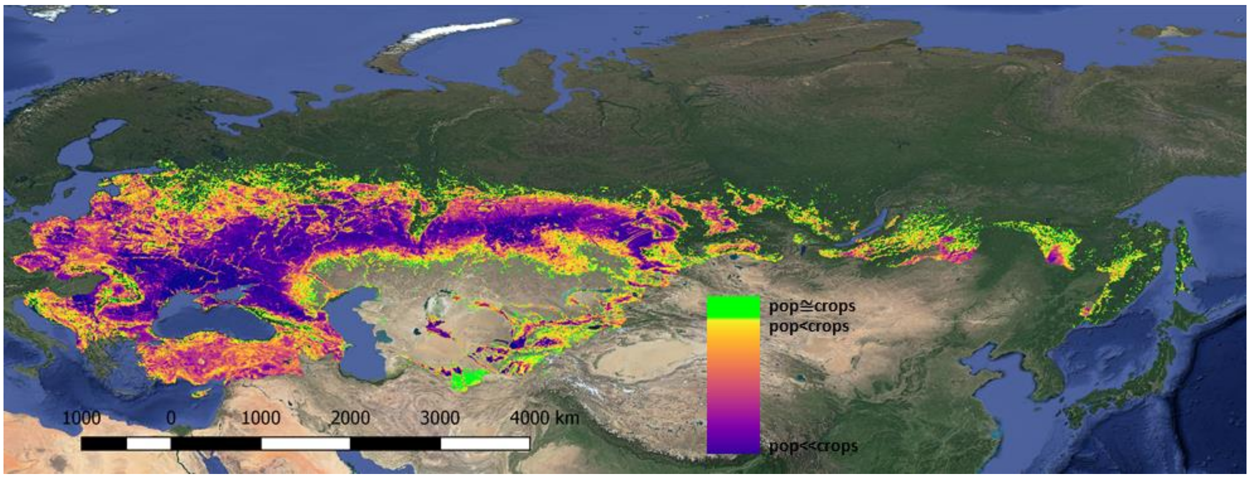

Figure 92 Difference map for Region 5, 2017 AD

Reaching the most current year of our analysis, 2017 AD, we can see that with respect to the year previously analyzed, a large extension of the area used can be seen in the west of the Russian country. The rest of the areas used are kept in similar extensions.

Another significant change that can be seen is the excessive increase in the violet color tone seen in Russia and Ukraine, which indicates that in these places, production now prevails more excessively than it did in the year previously analyzed.

4.2.1.1.6 Europe

Difference analysis has been done for this area which can be seen on the map below.

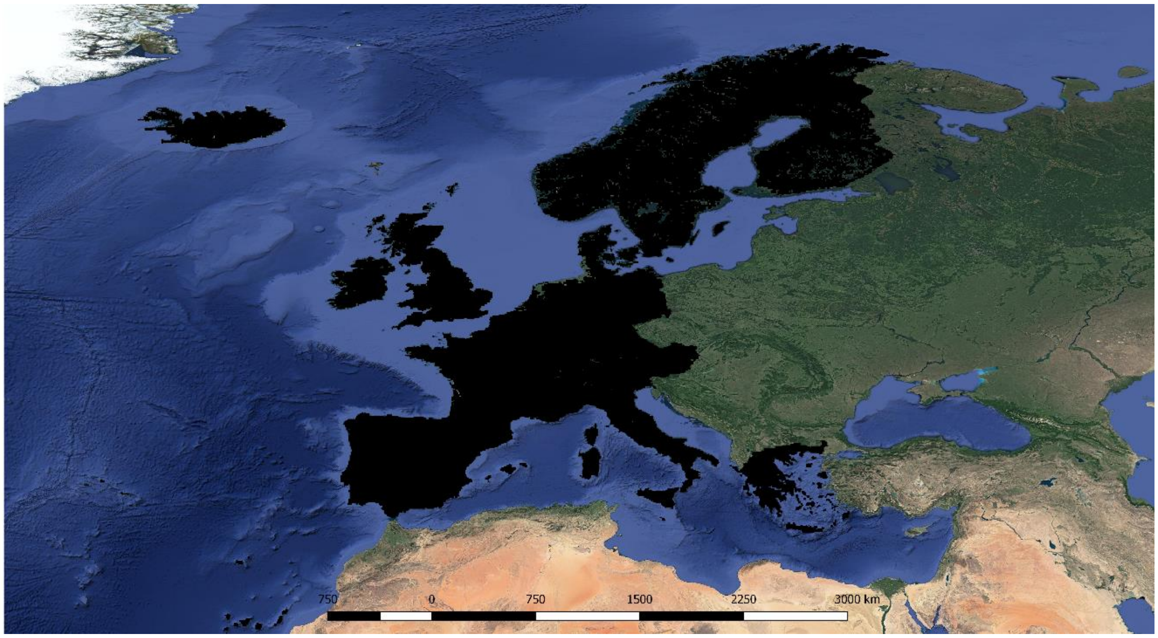

Figure 93 Region 6 map

The calculations were made with the Matlab program and the printing of the maps was made with the QGIS program. These maps will be represented below for the nine different years of the analysis in order to appreciate the evolution over time of these results, which will indicate the spatial distribution between food production and consumption.

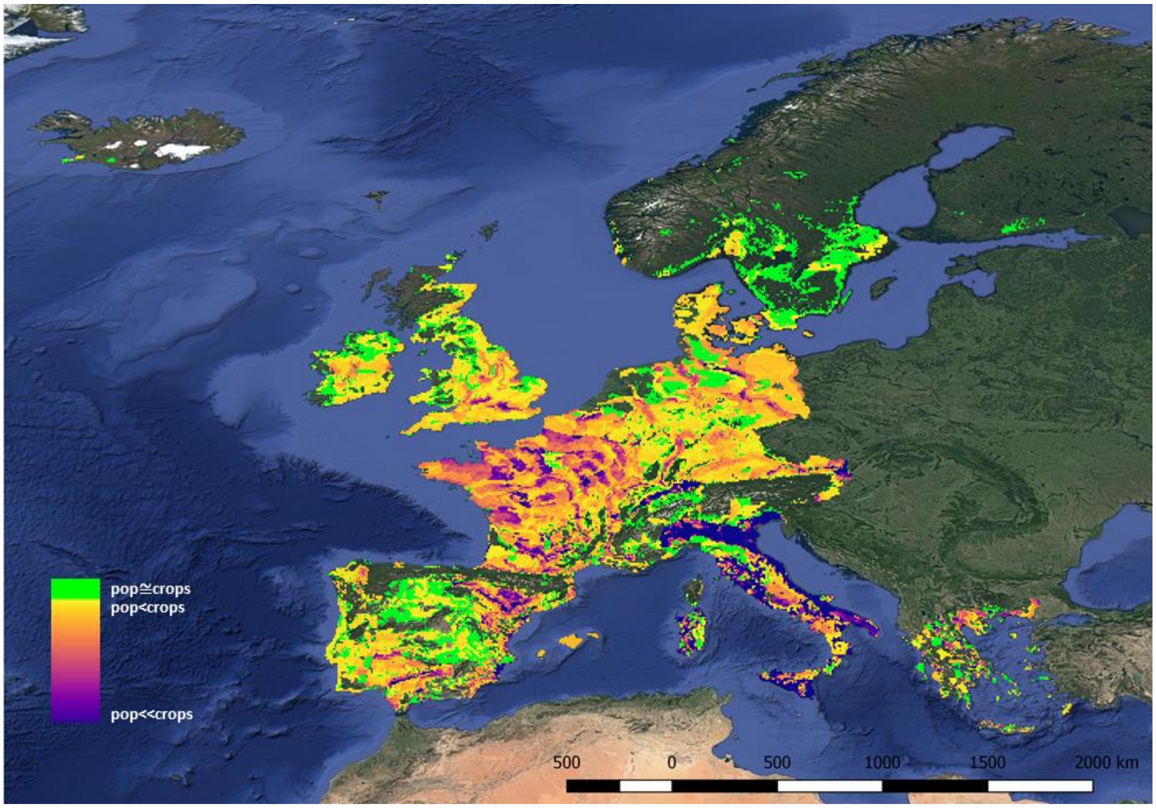

Figure 94 Difference map for Region 6, 0 AD

Starting the analysis of Europe in the year 0 AD, we can see the large amount of ara used, with few places where there is no use compared to today.

We can see that in the vast majority of these habited areas production prevails over consumption, with the exception of some areas where there is a good balance between production and consumption that can be seen to a greater extent in Spain, the United Kingdom and Sweden.

It can be seen that the area where is the most prevalence of production over consumption is the country of Italy, where you can see large violet areas, where production prevails excessively.

A high prevalence of production can also be noticed in France and some parts of Germany.

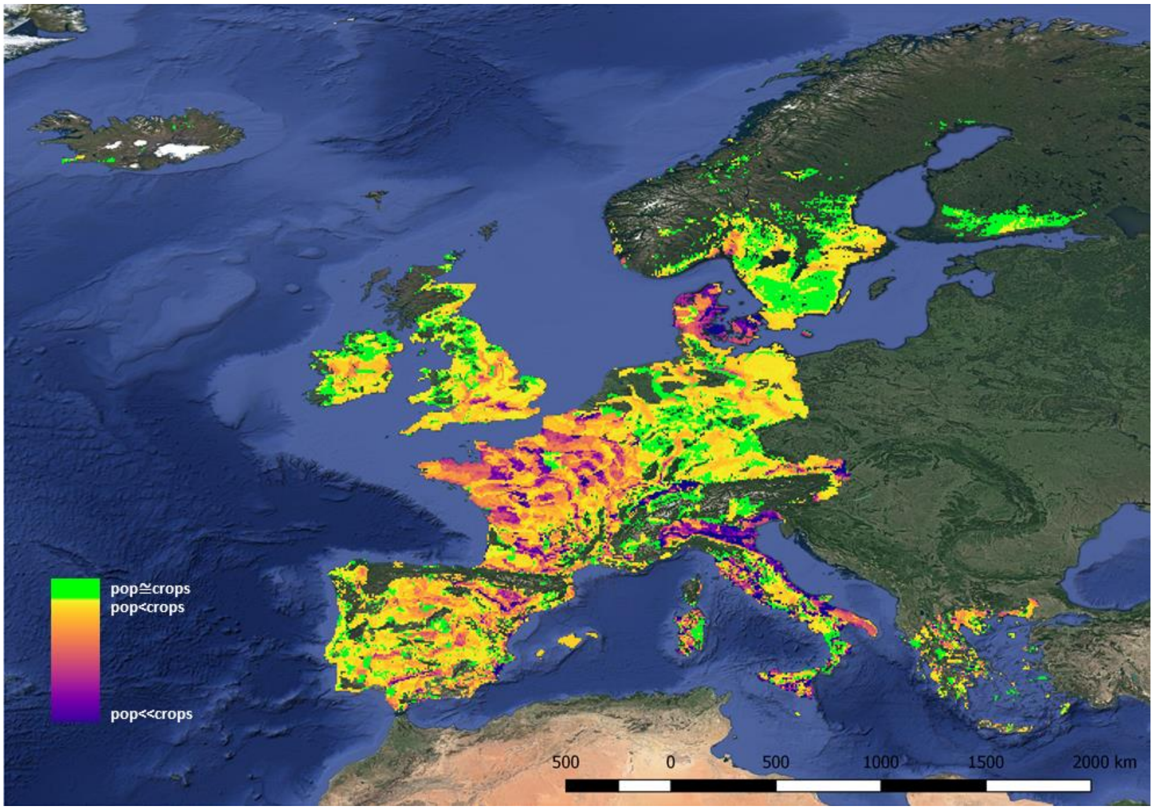

Figure 95 Difference map for Region 6, 500 AD

For 500 AD, compared to 0 AD, the same areas used can be seen, except for an increase in these areas in Sweden and Finland. Where in these countries almost entirely there is a good balance between production and consumption.

We can also notice this year how in Spain now the vast majority of production prevails over consumption. In the case of Germany, a decrease in the prevalence of production is seen with a large appearance of areas where there is a balance between these two variables.

We can also notice an appearance of violet areas, where production prevails excessively over consumption, in Denmark, where production previously prevailed, but not so excessively.

We can see a decrease in the prevalence of production in Italy compared to the previous year, but this prevalence is still great and is present to a great extent.

It can also be notice a disappearance of small areas where before there was a balance between production and consumption in some parts of Italy, Greece and Germany.

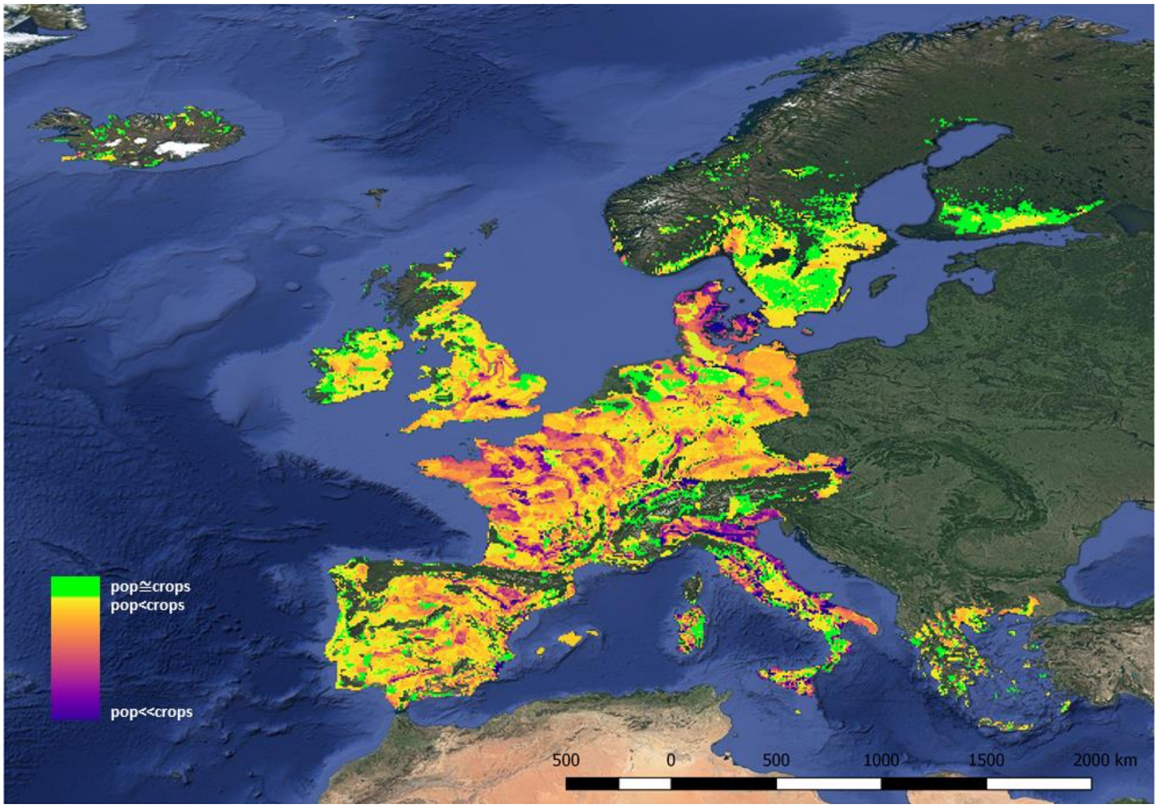

Figure 96 Difference map for Region 6, 1000 AD

By 1000 AD, we can see a brief expansion of area used in both Iceland and Finland compared to 500 years ago.

Things remain quite similar to the year previously analyzed, being able to notice a large increase in the prevalence of production in Germany. There is also a brief decrease in the shade of violet in Italy and an appearance of areas where production prevails, not in a significant number, in an area where before there was a balance between production and consumption in the north of England.

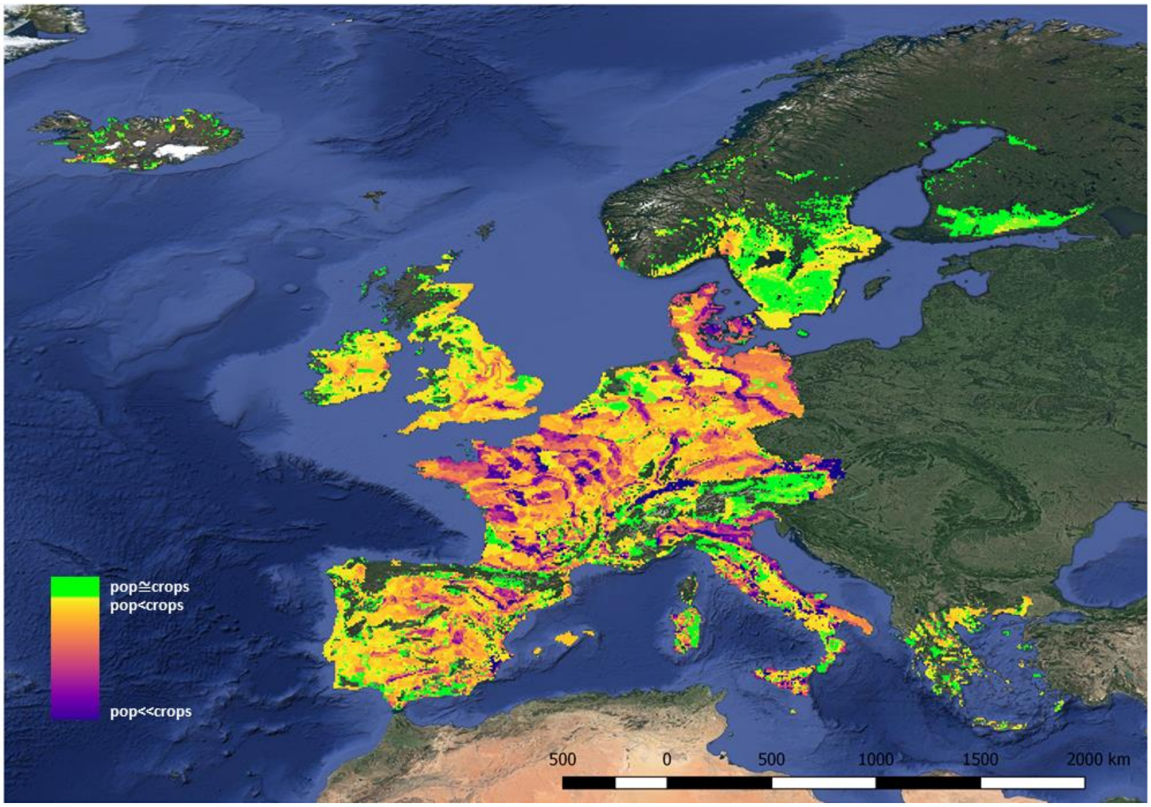

Figure 97 Difference map for Region 6, 1500 AD

Looking now at 1500 AD, compared to 500 years ago, there are no major changes. You can see a new area used in Austria, completing the entire use of this country, where in these areas there is a good balance between production and consumption. In the rest of this country, where before production already prevailed over consumption, now there are violet areas, which means that production continues to prevail, but at this moment it does so in an excessive way.

As for the rest of Europe, everything can be seen very similar with a brief increase in the color tone of the areas where there was a prevalence of production over consumption.

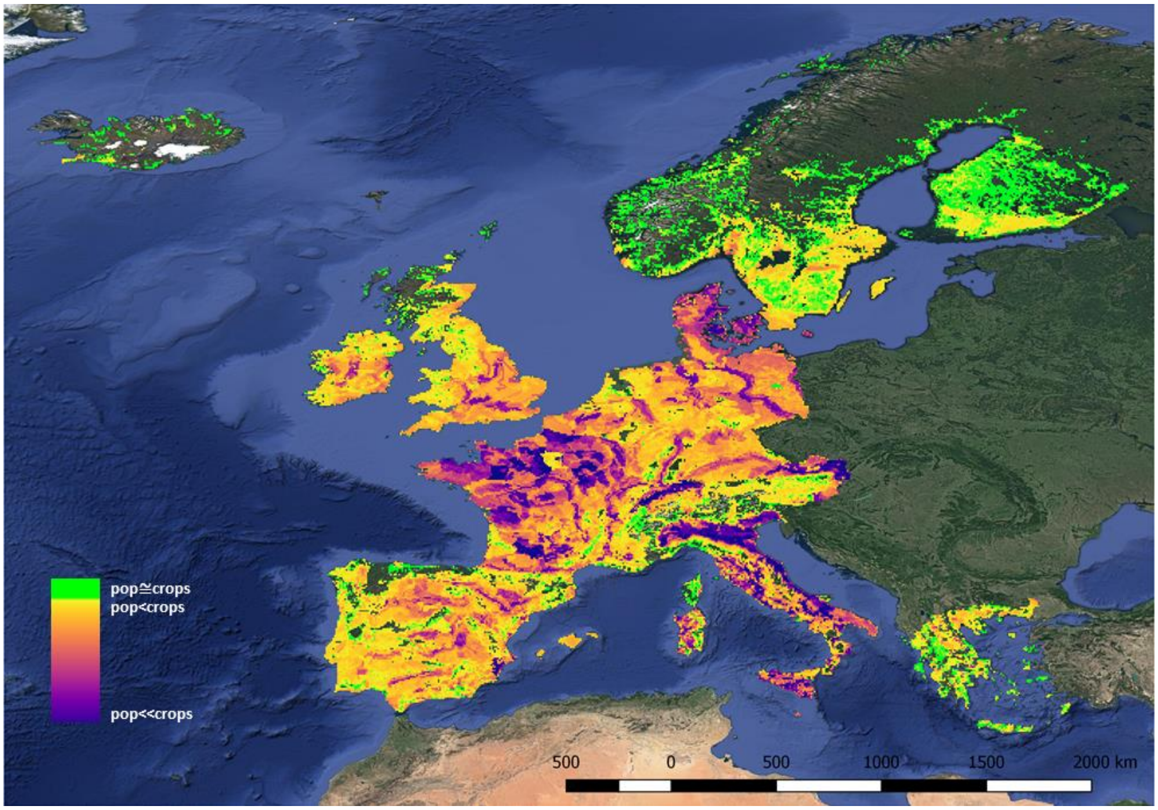

Figure 98 Difference map for Region 6, 1700 AD

For the year 1700 AD, noticeable changes can be seen. Mainly in the vast majority of the areas that were left unused, in this year are used, this can be seen well in Spain. A large increase in the area used can be seen in the Nordic countries of Norway, Sweden and Finland, where there is a good balance between production and consumption, with the exception of Sweden, where a large extension of the area where the production prevails, where before there was balance between production and consumption.

In the area where there was previously a good balance between production and consumption in Austria, production now prevails, but not excessively.

We can also notice an increase in the prevalence of color tone in all areas where production prevailed, mainly in Italy, France, Germany and the United Kingdom.

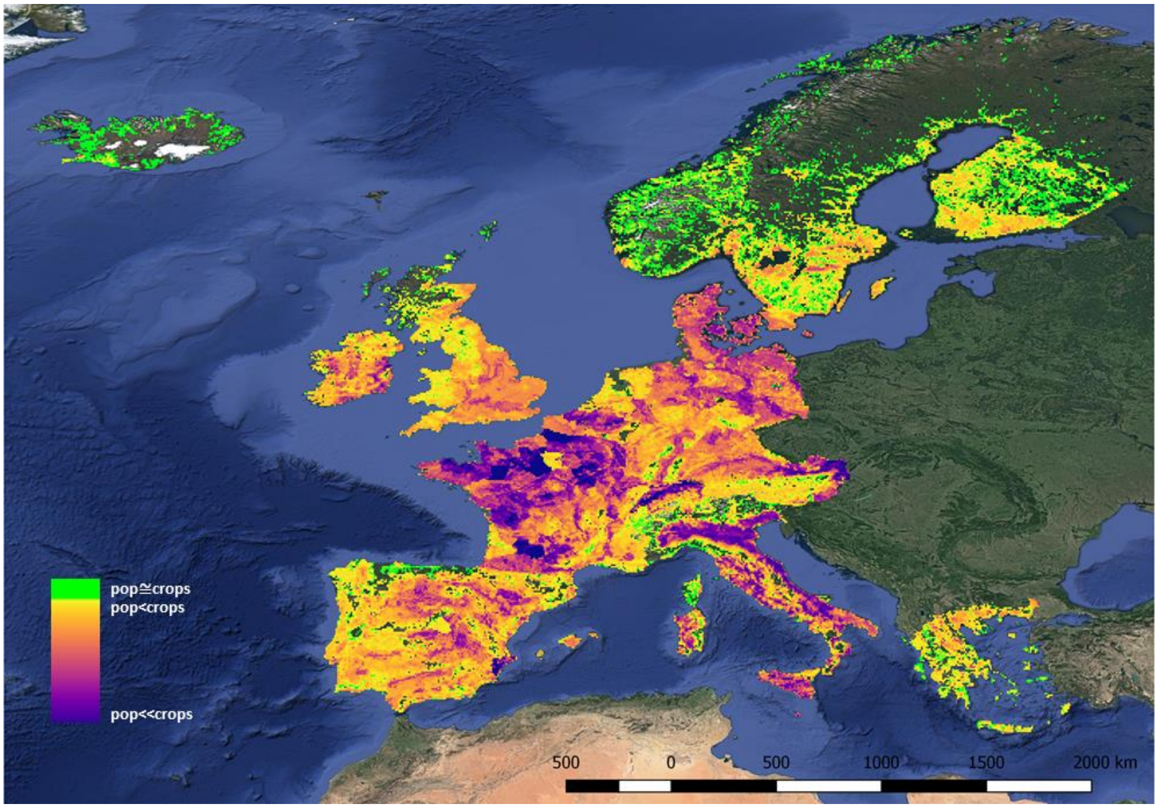

Figure 99 Difference map for Region 6, 1810 AD

For the year 1810 AD, compared to the year previously analyzed, an increase in the area used in Iceland and Norway can be noted, where in these there is a balance between production and consumption.

In the countries of Sweden and Finland, it can now be seen that production prevails in most of these countries, although it does not do so in a very high number.

In the rest of Europe an increase in production prevalence in color tone can be seen, with the exception of Italy, where a brief decrease in color tone is seen in violet areas. This increase can be clearly seen in Germany, France, Ireland and Spain.

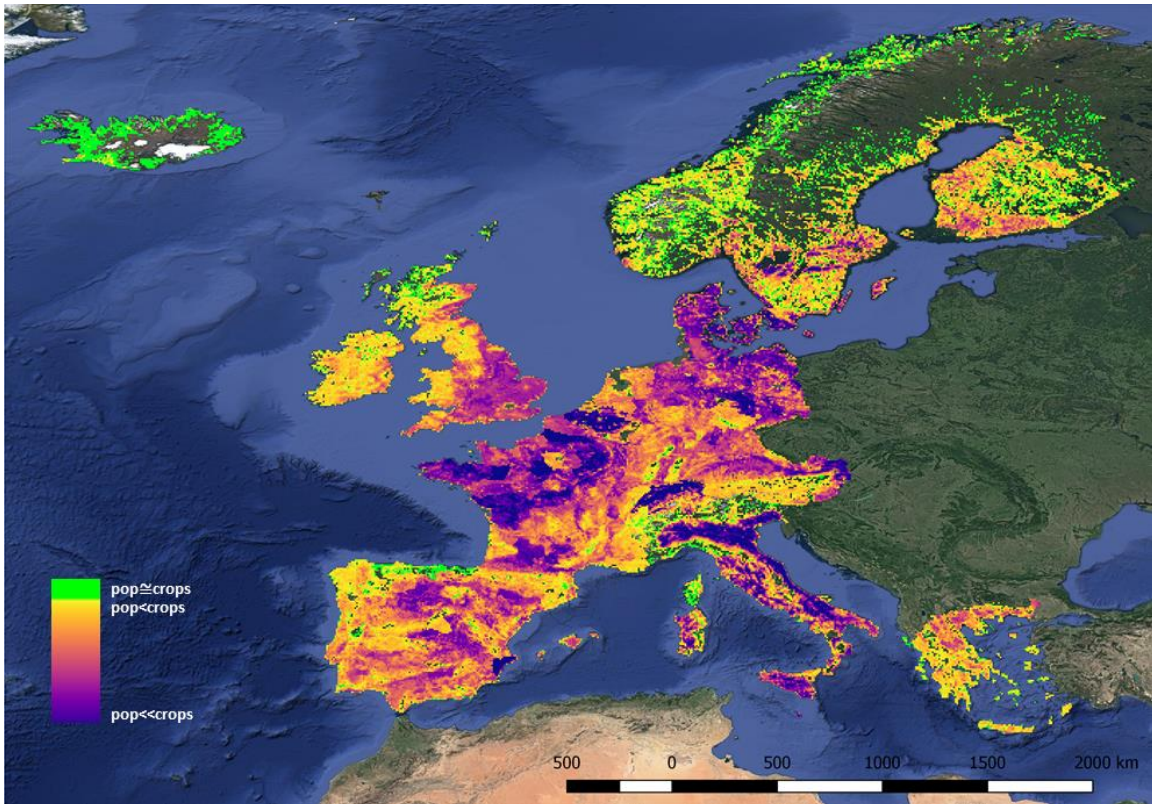

Figure 100 Difference map for Region 6, 1900 AD

In 1900 AD, compared to the year previously analyzed, the extensions of areas used are the same, with a brief extension of these in Iceland and the Nordic countries.

For this year, no major changes can be seen in the areas where production prevails, but an increase in the number of this prevalence can be noted, observing an increase in color tone in almost all of Europe. This can be seen well in the countries of Germany, Spain, Italy, England, Greece, France, Belgium, Denmark and Sweden.

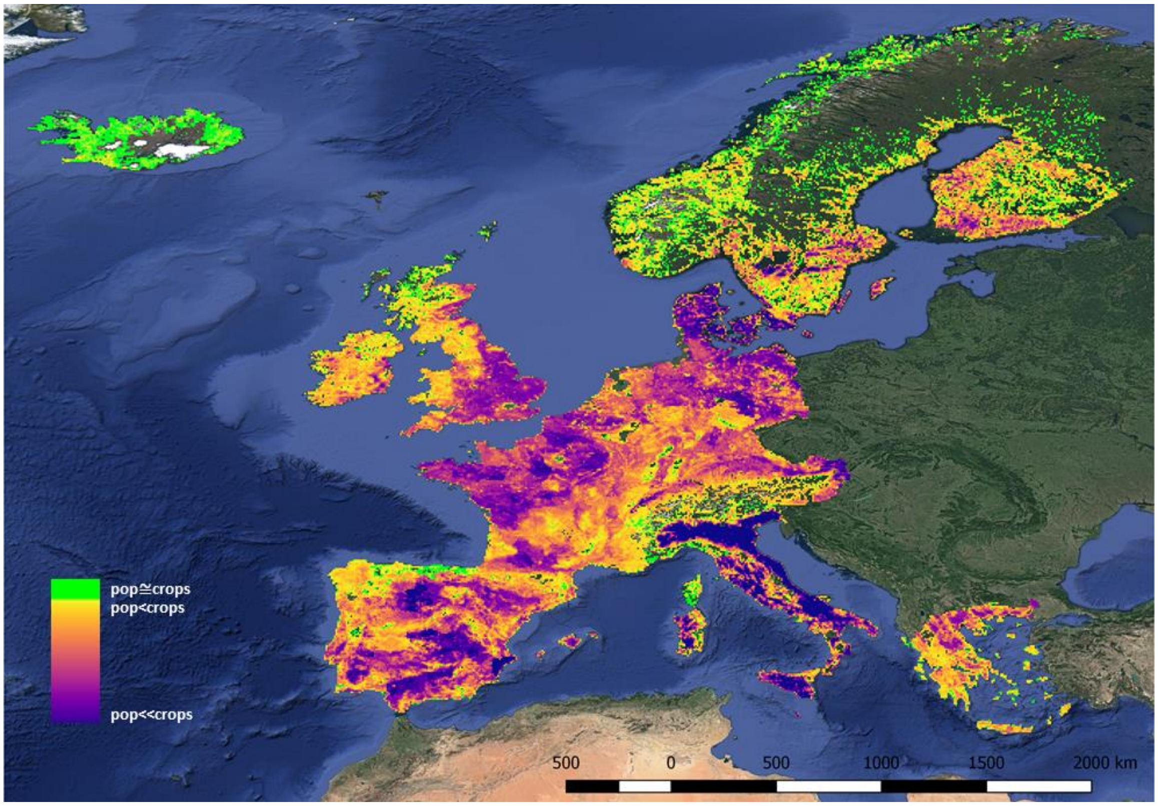

Figure 101 Difference map for Region 6, 1950 AD

Comparing the year 1950 AD, with respect to the year previously analyzed, the areas used throughout Europe are the same, with the exception of an area extension in Iceland, where in this country used in its entirety there is a balance between production and consumption. You can also notice an extension of area to the north of the United Kingdom, where the area in this region is almost completely covered.

Regarding the distribution of production prevalence throughout Europe, it remains the same, but with a relative decrease in the number of production prevalence in the countries of France, Switzerland and Austria. In other countries such as Spain, Italy, Greece and Finland, a relative increase in the color tone of the production prevalence can be noted.

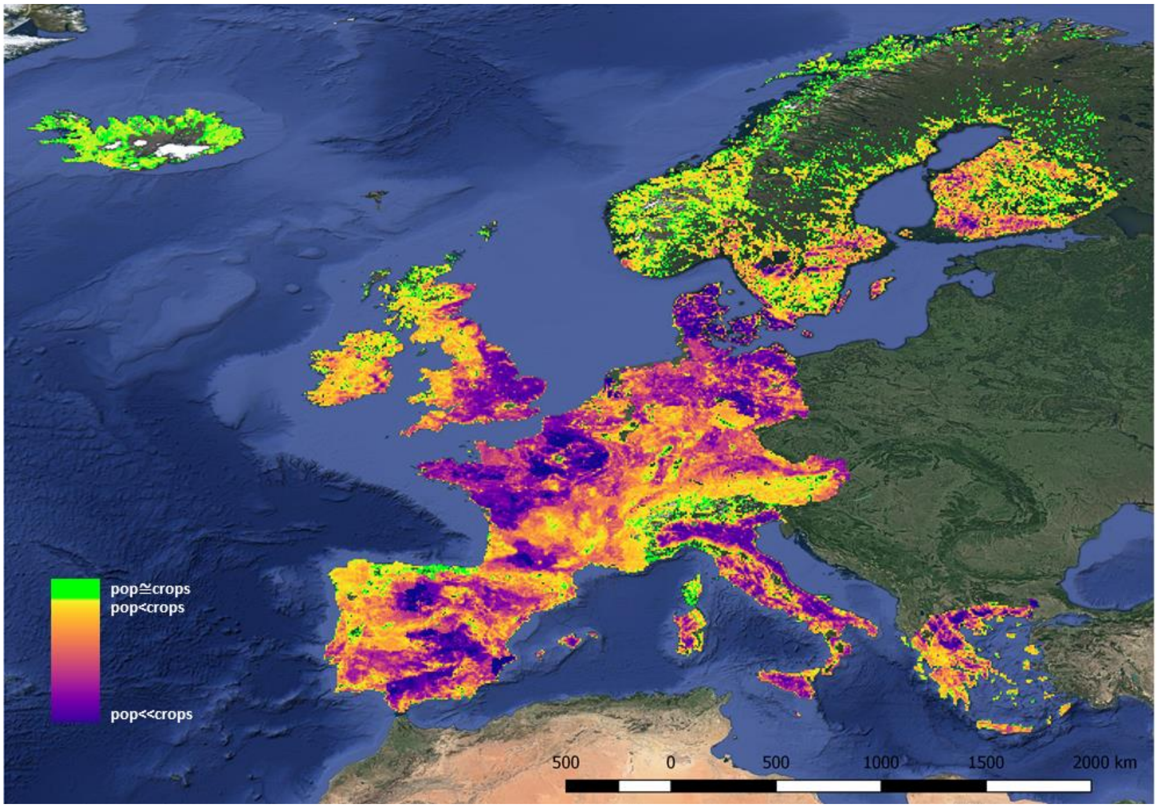

Figure 102 Difference map for Region 6, 2017 AD

We now come to the year 2017 AD, where we can see compared to the year previously analyzed that the areas used are the same, but a small variation in the color tone of some regions can be seen. This can be seen in a relative increase in the prevalence of production in the countries of France, Greece and Iceland, where in the latter it is seen on a small scale and a very light-yellow color, which tells us that production prevails in those areas, but for very small number. A relative decrease in production prevalence can also be seen in Italy. In the rest of the countries they look very similar to the year previously analyzed.

4.2.1.1.7 Northern America

Difference analysis has been done for this area which can be seen on the map below.

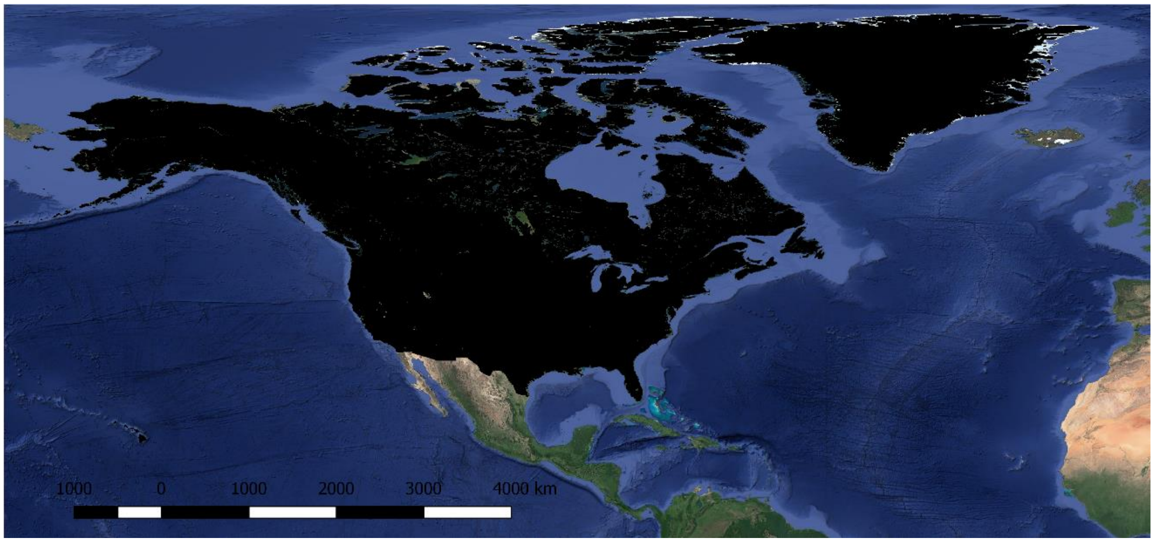

Figure 103 Region 7 map

The calculations were made with the Matlab program and the printing of the maps was made with the QGIS program. These maps will be represented below for the nine different years of the analysis in order to appreciate the evolution over time of these results, which will indicate the spatial distribution between food production and consumption.

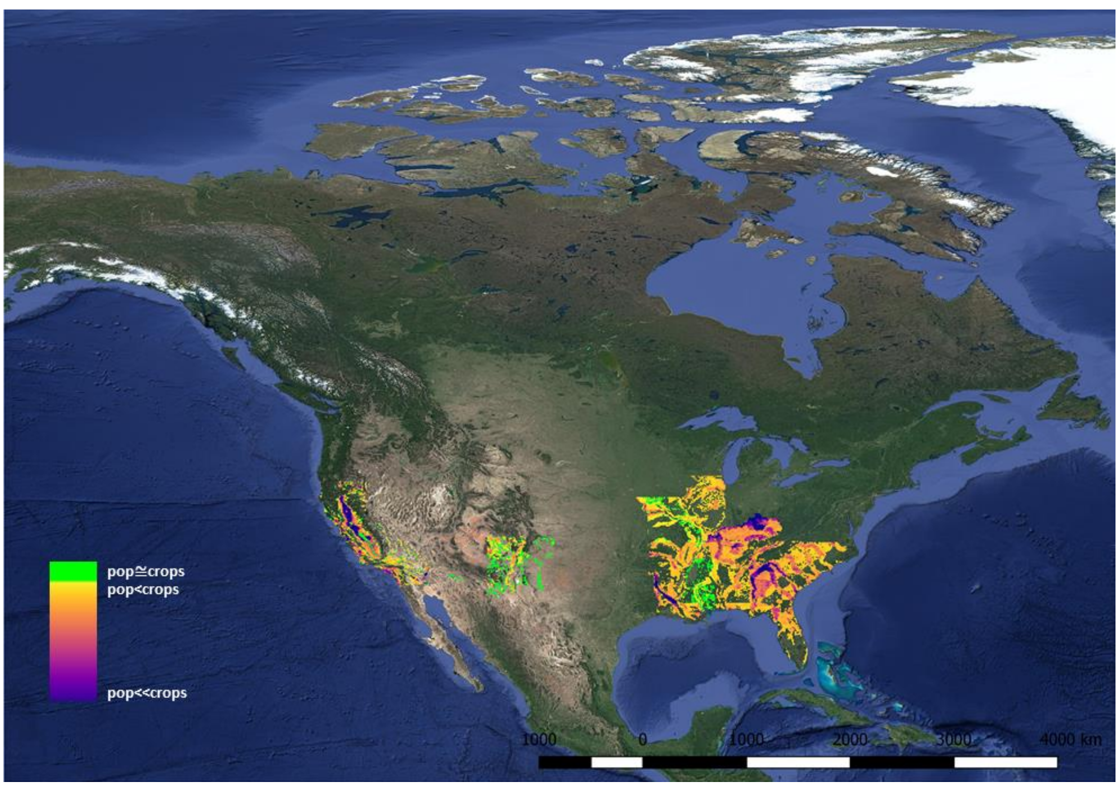

Figure 104 Difference map for Region 7, 0 AD

For the year 0 AD, we can appreciate the large number of habited areas in this region. In most of these areas, production prevails over consumption and you can see small isolated areas where it prevails a lot (violet areas). These habited areas can be seen to a greater extent on the east of what is now the United States and to a lesser extent where today is the state of New Mexico and the state of California.

It can be seen that on west coast of what is now the United States, there is a large central area where production prevails in an excessive way, and that around it has areas where production prevails, but for a number not so high and very small areas where there is a balance between food production and consumption.

In what is now the state of New Mexico, in most of the area in this zone there is a good balance between production and consumption, with small areas where production prevails, but not excessively.

To the east of what is now the United States, where the largest area used in this analyzed region is located, production prevails to a greater extent, with few areas where there is a balance between production and consumption. In this part of the region, four concentrated and isolated areas can be seen in which production prevails excessively, which would indicate the areas of greatest production. These four zones are connected to each other by zones where production prevails, but to a lesser extent.

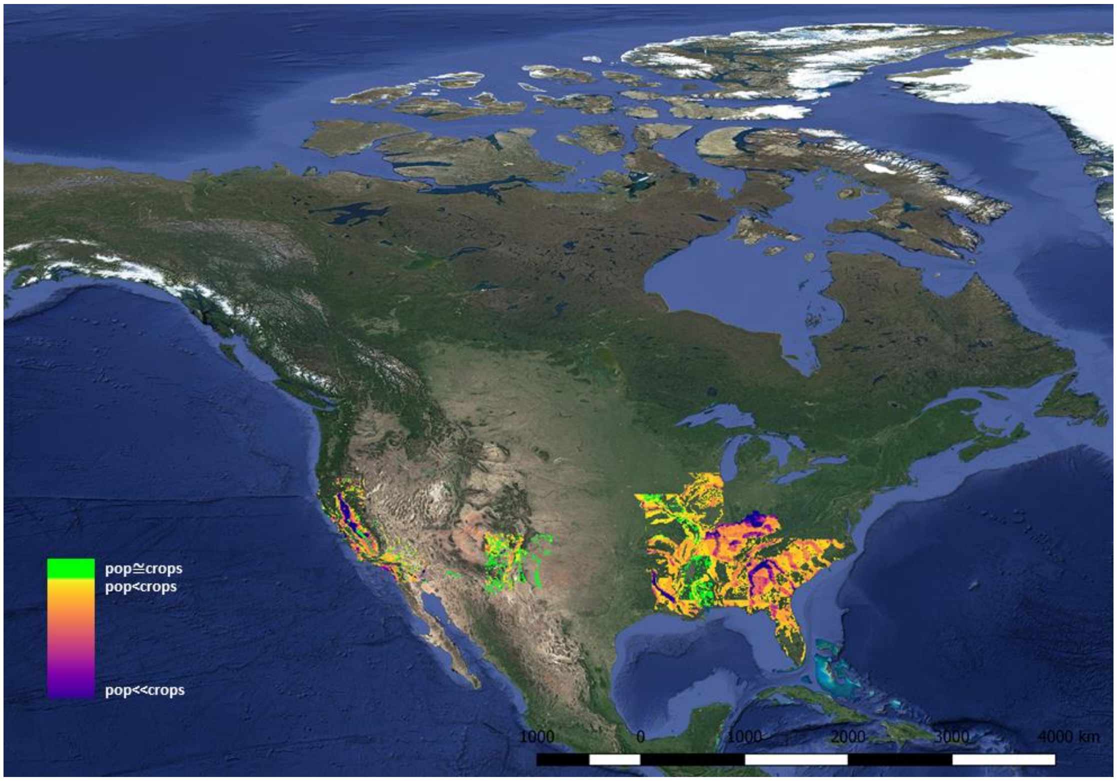

Figure 105 Difference map for Region 7, 500 AD

By the year 500AD, almost no changes can be seen, except for a very small increase in the areas habited in the western zone of what is now the United States in the vicinity of the areas with the highest prevalence of production.

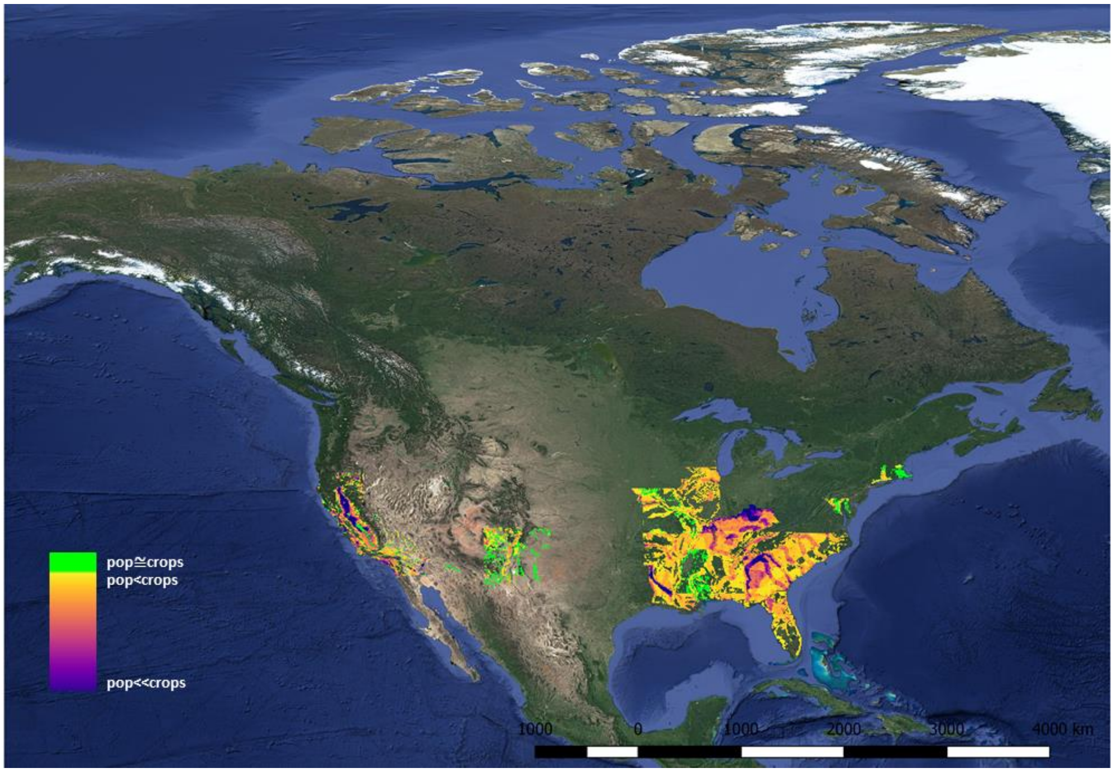

Figure 106 Difference map for Region 7, 1000 AD

For the year 1000AD, almost no changes were seen either, except for another very small increase in the areas habited in the western zone of what is now the United States in proximity to the areas with the highest prevalence of production, covering some of the areas that remained without habit by man. You can also notice an appearance of small habited areas northwest of what is now the United States, where half of these have a good balance between production and consumption and the other half production prevails to a limited extent.

That there have not been many changes in these last 1000 years of history shows how balanced were the civilizations that habited these lands before European colonization.

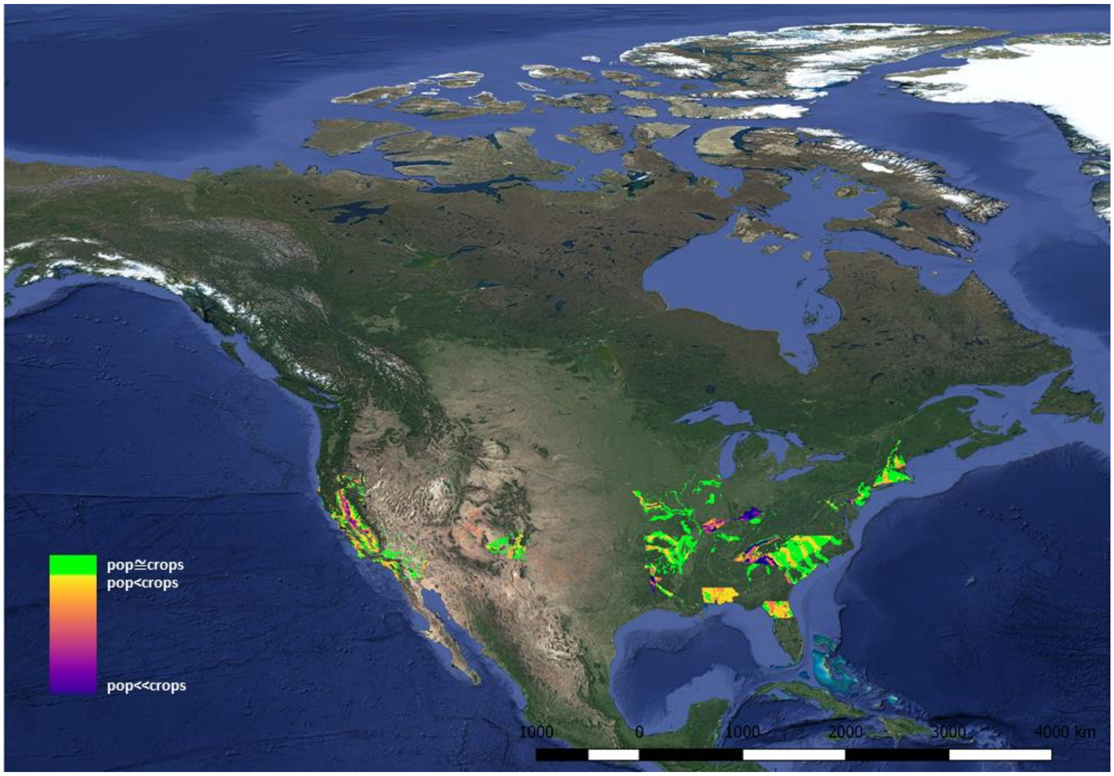

Figure 107 Difference map for Region 7, 1500 AD

By 1500 AD, you can tell a very big difference with what we saw 500 years ago. This difference is seen in the large decrease of habited areas throughout all the region with the exception of the west coast. This decrease of habited areas may be due to the recent start of the European colonization of these lands, since this caused the grouping of this population into smaller areas and also the elimination of it. Although, for this year we saw in the preliminary analysis a number of total population that has grown reasonably with what has grown from 0 AD to 500 AD. In the few areas that still being habited, in the greater area of these there is a balance between production and consumption. You can also see the same regions where production was largely prevalent in the previous year, but still with a much smaller area.

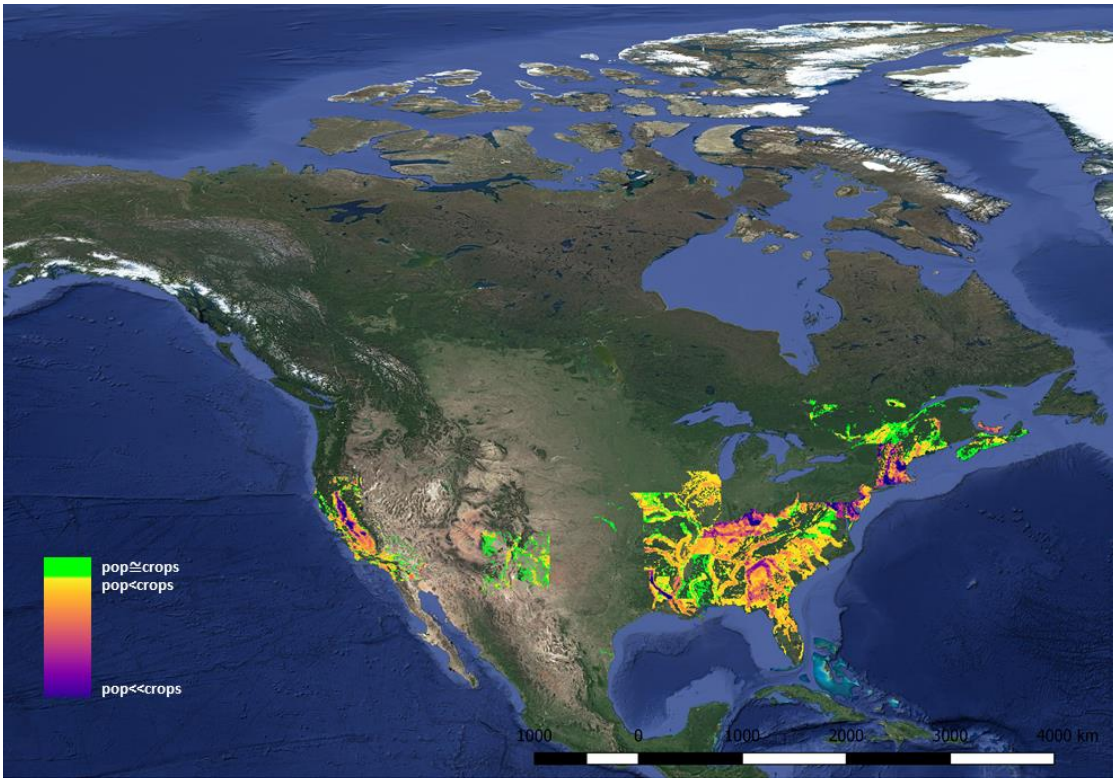

Figure 108 Difference map for Region 7, 1700 AD

By 1700 AD, habited areas continue to differentiate into the 3 large areas mentioned above. A significant increase in the areas used in the western United States can be noticed, with a prevalence of production in most of its extension. On the west coast you can see a brief decrease in the areas where production prevails excessively. In the state of New Mexico, an increase in the area used can be noticed, but they continue to a greater extent in a balance between production and consumption. It is worth clarifying that for this year the number of the population has decreased by almost half, from 2.1 million to 1.1 million inhabitants.

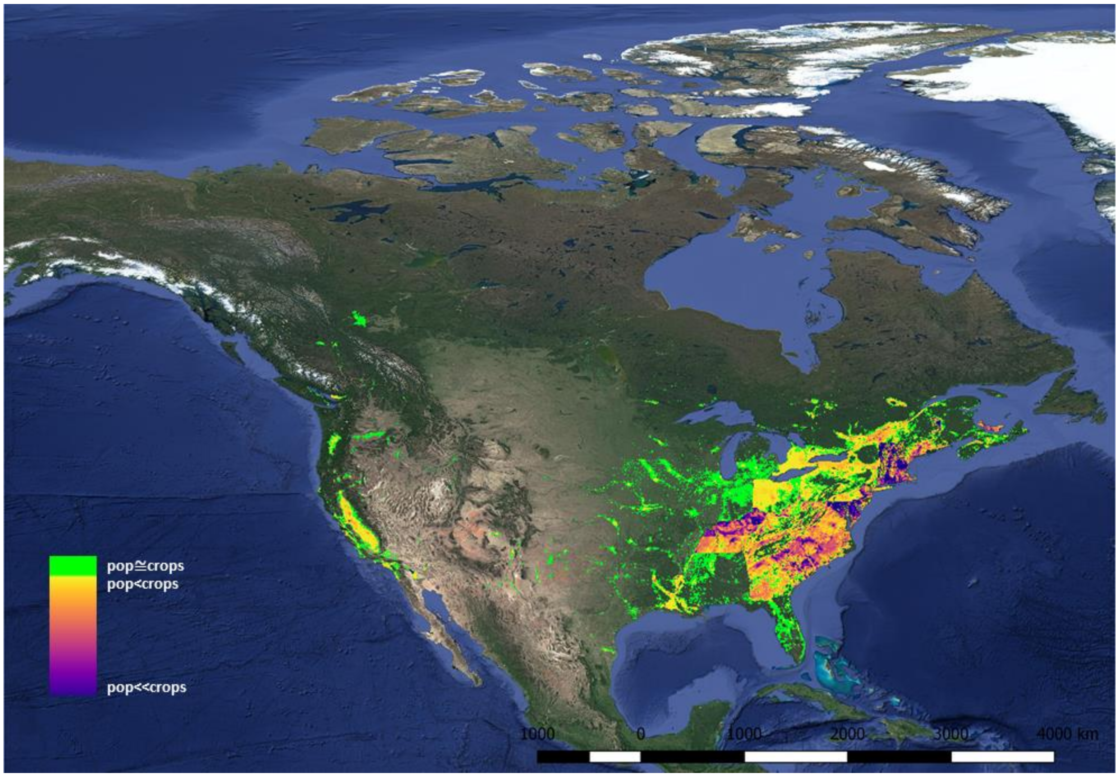

Figure 109 Difference map for Region 7, 1810 AD

For the year 1810 AD, compared to the year previously analyzed, a large increase in the area used in some regions such as Ohaio (USA), New York (USA), Toronto (Canada) and the entire western part of the United States can be seen with a large extension from north to south west of this country. You can also see a disappearance of previously used areas such as the region of the state of New Mexico, Missouri, Alabama and Arkansas. There is also a decrease in the habited areas on the west coast of this country (state of California), which until then still belonged to Mexico. In these areas, production now does not overly prevail relative to the production of the entire region analyzed.

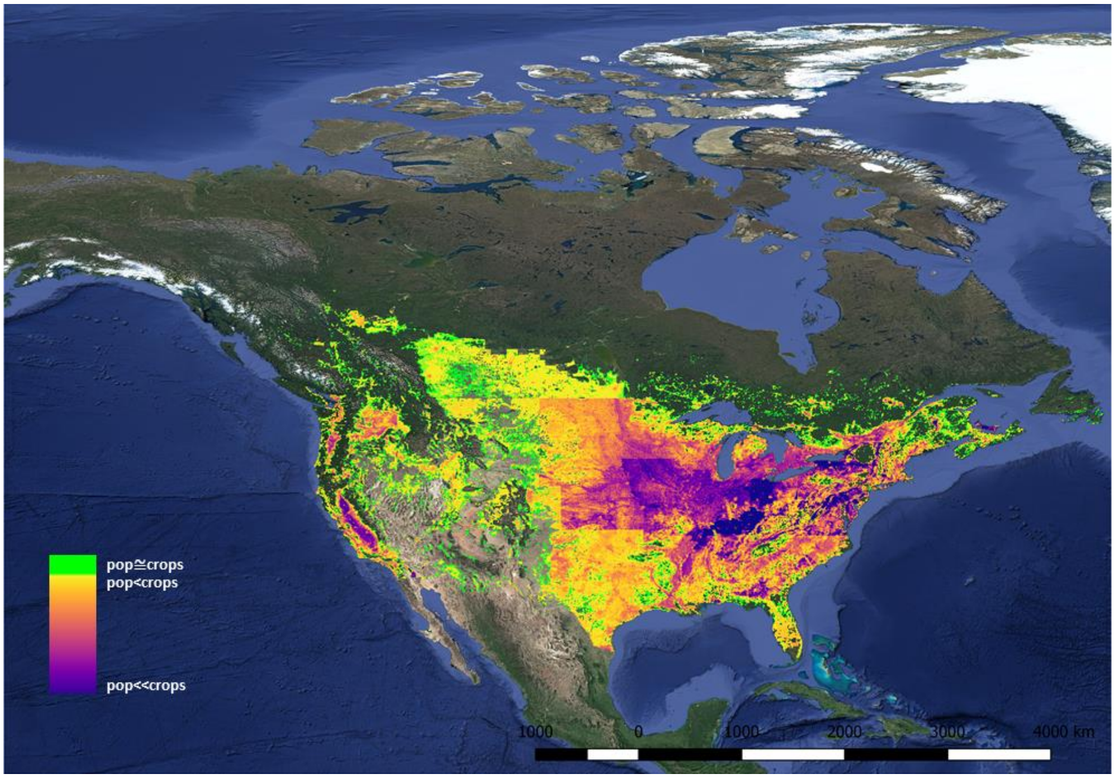

Figure 110 Difference map for Region 7, 1900 AD

For the year 1900 AD, very excessive changes are seen compared to the rest of the analysis.

For this year the western part of this region belonged to the United States after the Treaty of Guadalupe in 1848 AD, which said that Mexico would cede more than half of its territory, which includes all of what are now the states of California, Nevada, Utah, New Mexico, Texas, Colorado and parts of Wyoming, Arizona, Oklahoma and Kansas.

Also for this year, the appearance of industrialized agriculture had begun a few years ago, which in these times the machines replaced the labor force, and this made the possibility of cultivate larger areas with less work.

For this year, the total cultivated area with respect to the previously analyzed year increased 1334%, that is, a little more than 13 times what was produced in the year 1810 AD. The value of square kilometers cultivated in 1810 AD was of 114320. On the other hand, for the year 1900 AD the total production was 1525400 square kilometers.

If we analyze the evolution of the population between these two years, we can see an increase of 952%, 9.5 times the old value. In the year 1810 AD, the population of this region was 9.24

million inhabitants, and in 1900 AD the population was 80.85 million inhabitants. This can be seen very notably in the increase in area used in this region, covering the extension of the United States almost entirely.

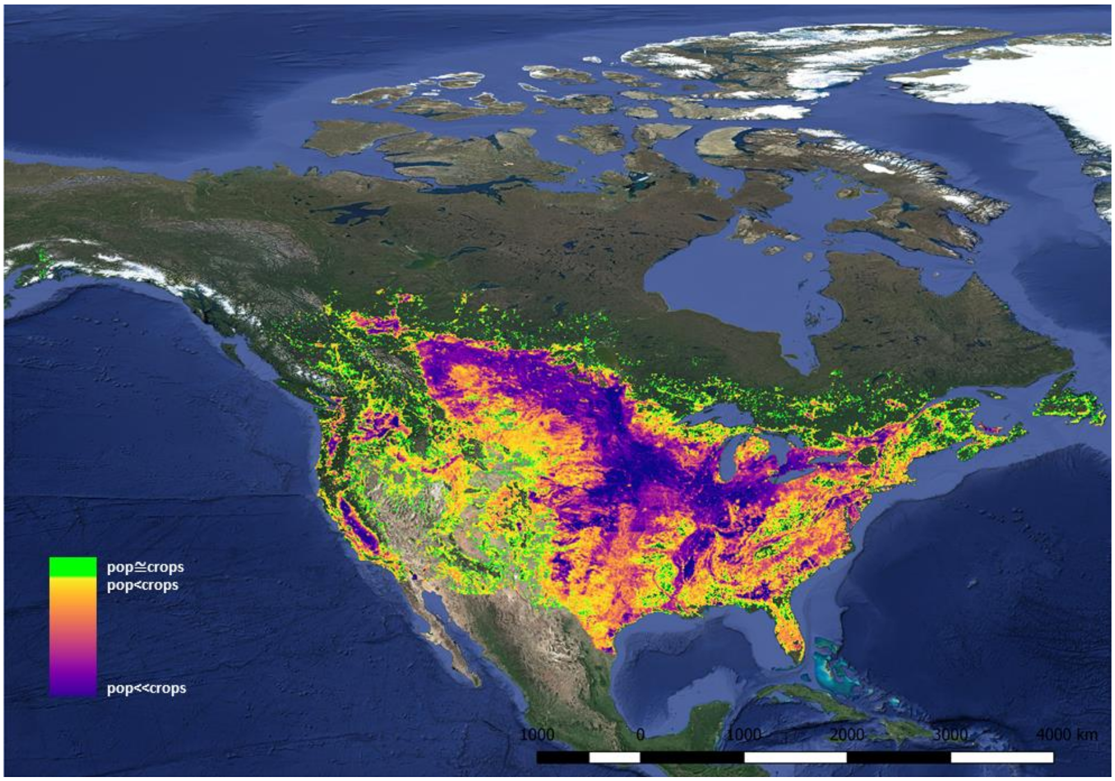

Figure 111 Difference map for Region 7, 1950 AD

For the year 1950 AD the extent of land used is very similar with increases in small areas that were unused. You can also notice an appearance of small areas in what is now Alaska with a balance between production and consumption. Increase in areas used can be noticed to the north in what is Canada and in states like New Mexico.

Although the extensions of areas used are similar, the amount of production and consumption continued to increase during these 50 years. In this case the population increase was 200%, that is to say, it increased twice, from 80.85 to 168.58 million habitants. As for the increase in cultivated area, it was 52% and this is seen in the increase in violet areas with a much higher prevalence of production than of consumption throughout the region.

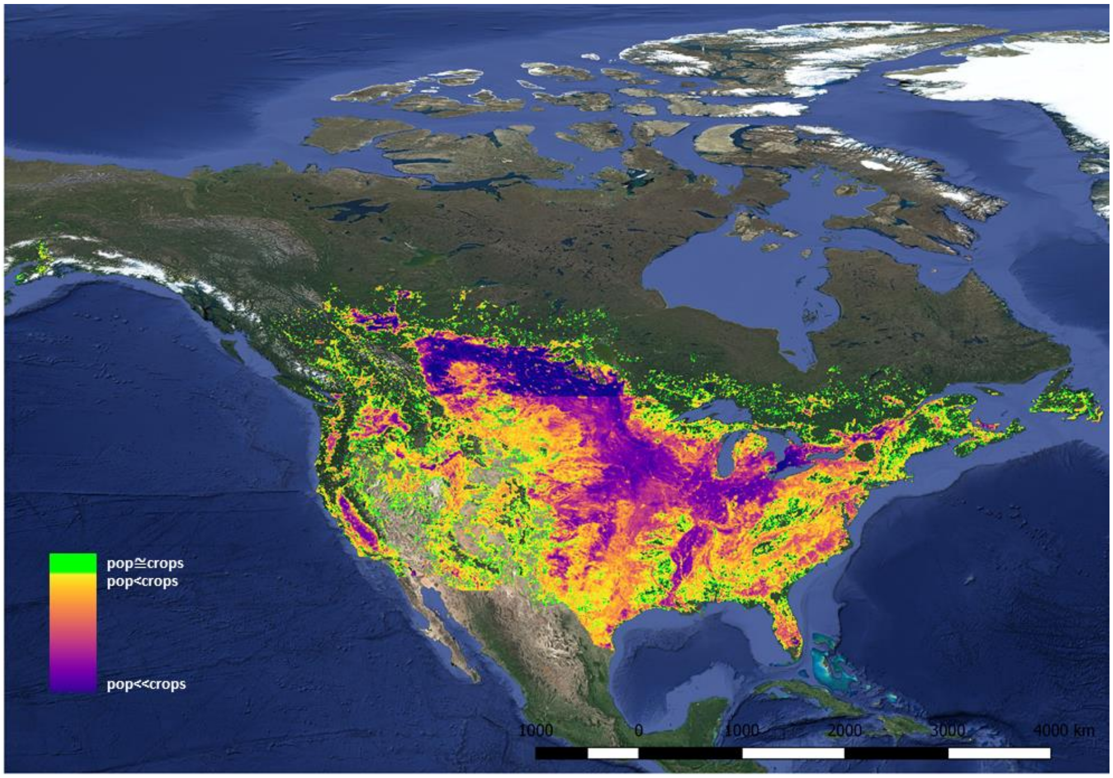

Figure 112 Difference map for Region 7, 2017 AD

Arriving at the most current year of our analysis, 2017 AD, with respect to the previous year analyzed, there are no noticeable changes in spatial distribution between the places where consumption prevails and where production prevails. But you can notice a change in the tone of violets between the amount of production prevalence in the areas that produce most between Canada and the United States. This is due to the fact that the areas that produce the most in Canada have fewer habitants, than the areas that produce the most in the United States, since both areas are areas of use of almost the entire area of the cell under cultivation.

4.2.1.1.8 Latin America and Carribean

Difference analysis has been done for this area which can be seen on the map below.

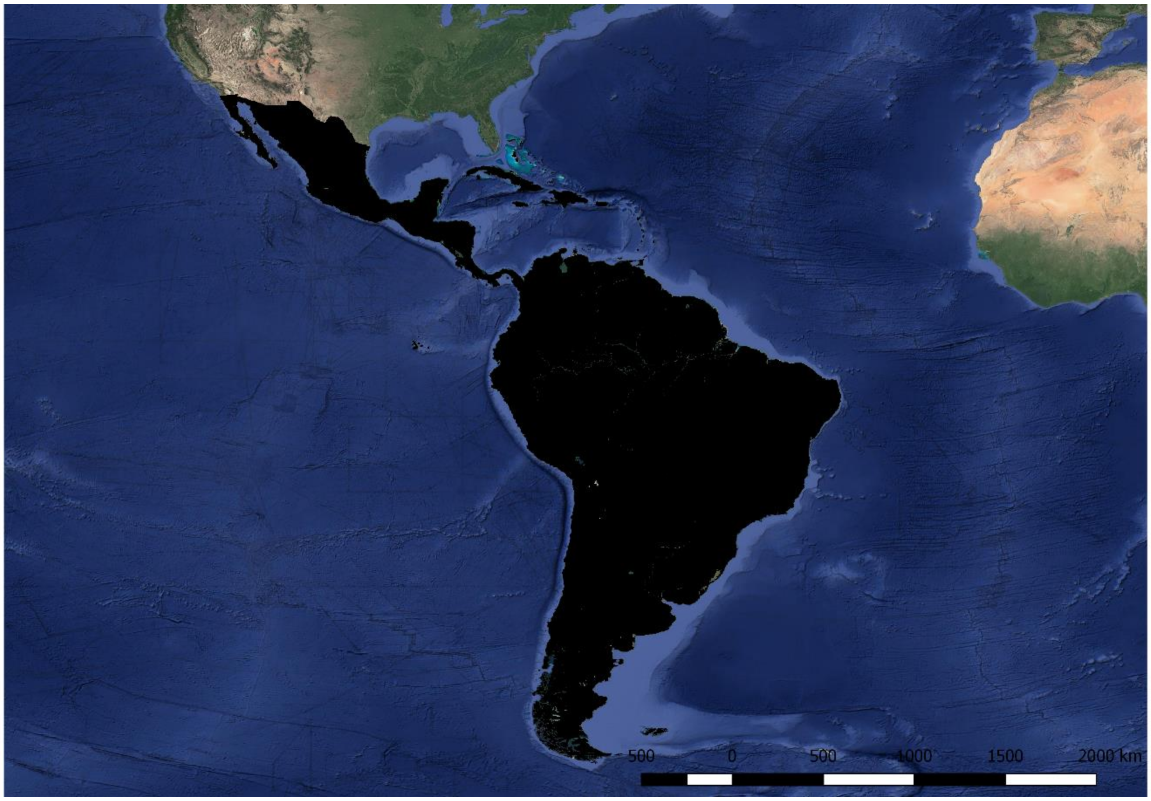

Figure 113 Region 8 map

The calculations were made with the Matlab program and the printing of the maps was made with the QGIS program. These maps will be represented below for the nine different years of the analysis in order to appreciate the evolution over time of these results, which will indicate the spatial distribution between food production and consumption.

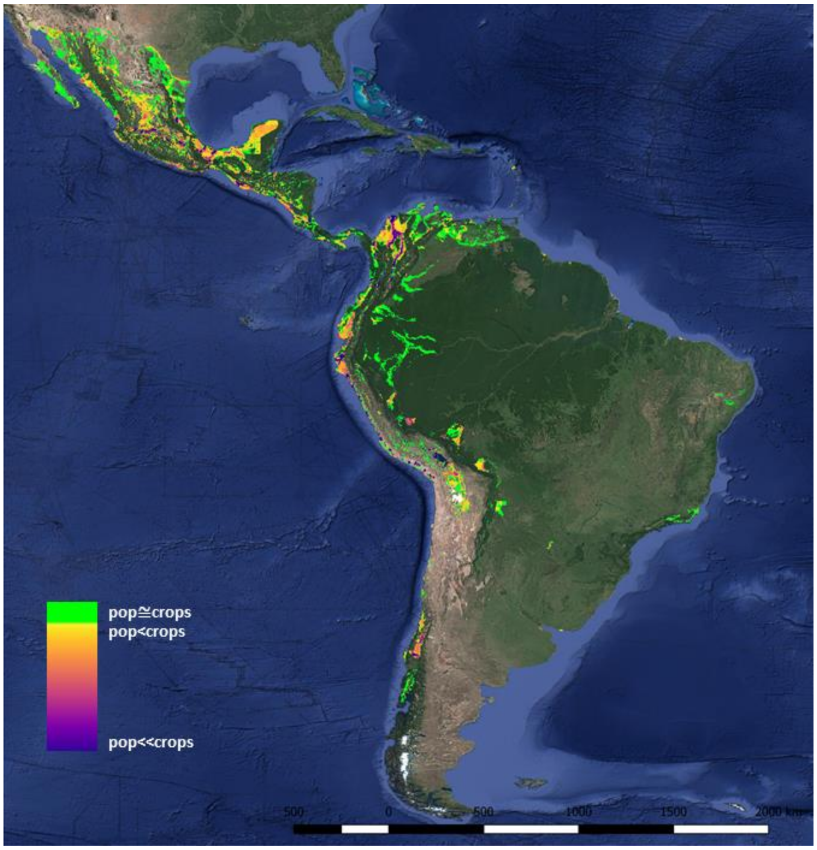

Figure 114 Difference map for Region 8, 0 AD

If we start to see starting in year 0 AD, in these years the area was habited by what we now call aborigines of mainly the Mayan, Aztec and Inca tribes, who habited these areas, those of Central America and some of North America. In this year no negative data are found, so consumption never takes prevalence over production. You can see few habited areas which in most of them production prevails, but for very little. There are also areas where there is a balance, which indicates that they produce and consume in the same place. These equilibrium zones are seen more in areas far from the rest of the habited areas, and they can be seen most in the north of Peru, Venezuela, south Chile and north Mexico. Also, you can see balanced areas not too much big very far away for the rest of them in the east of Brazil. There are also areas where production is much higher but these areas are very small and can be found mostly near the most populated areas, in the north of where now is Colombia, in the on the coasts of Peru, in Nicaragua and you can see a thin and long strip in Mexico between the cities that are today Guadalajara and Mexico city.

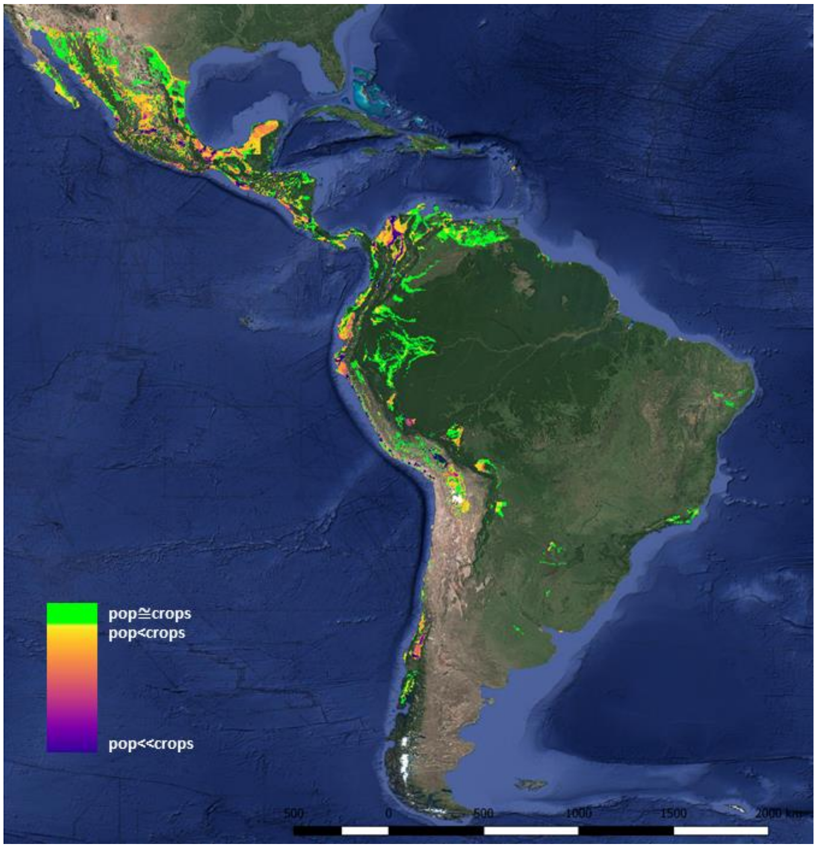

Figure 115 Difference map for Region 8, 500 AD

For the year 500 AD, this didn't change too much. The same data can be noticed, but with a brief extension of the areas of the previous results. These brief extensions of areas can be seen most in the places of what is today Venezuela, north of Peru. You can also see news areas habited, and you can find one very small for first time in where today is Argentina.

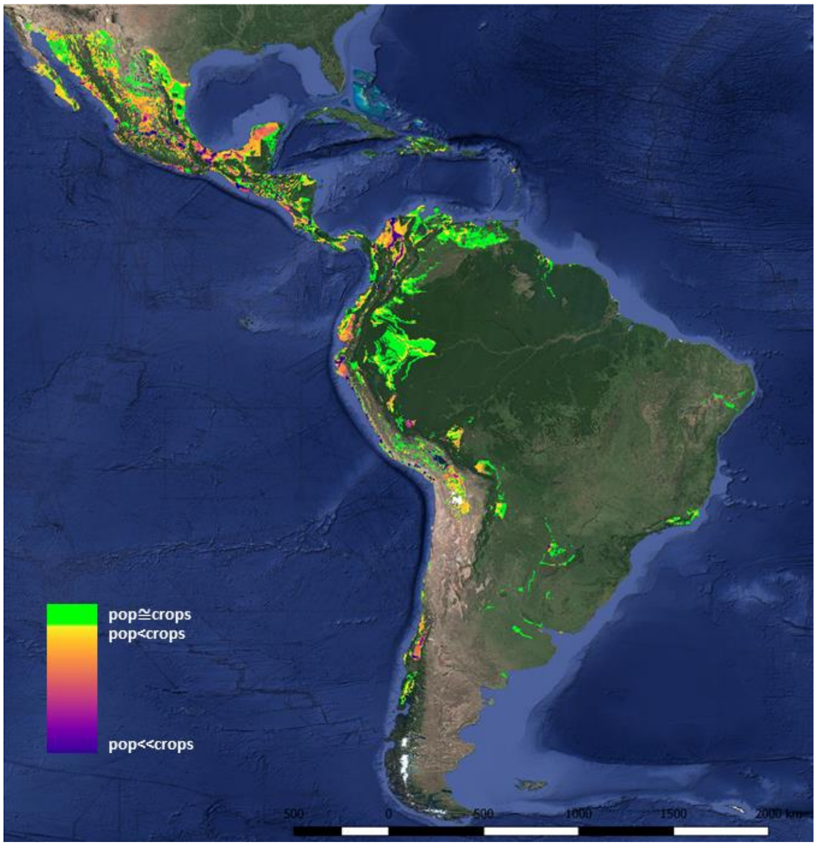

Figure 116 Difference map for Region 8, 1000 AD

In the year 1000 AD, it shows that it did not change much either. The zones briefly extended in area and you can also notice an appearance of large area of balance between production and consumption in the area where today is northern Peru. In this year you can also see new habited areas with a balance between production and consumption in what is now Paraguay, Argentina. Also new areas where there is balance between production an consumption on the island of Haiti and Dominican Republic.

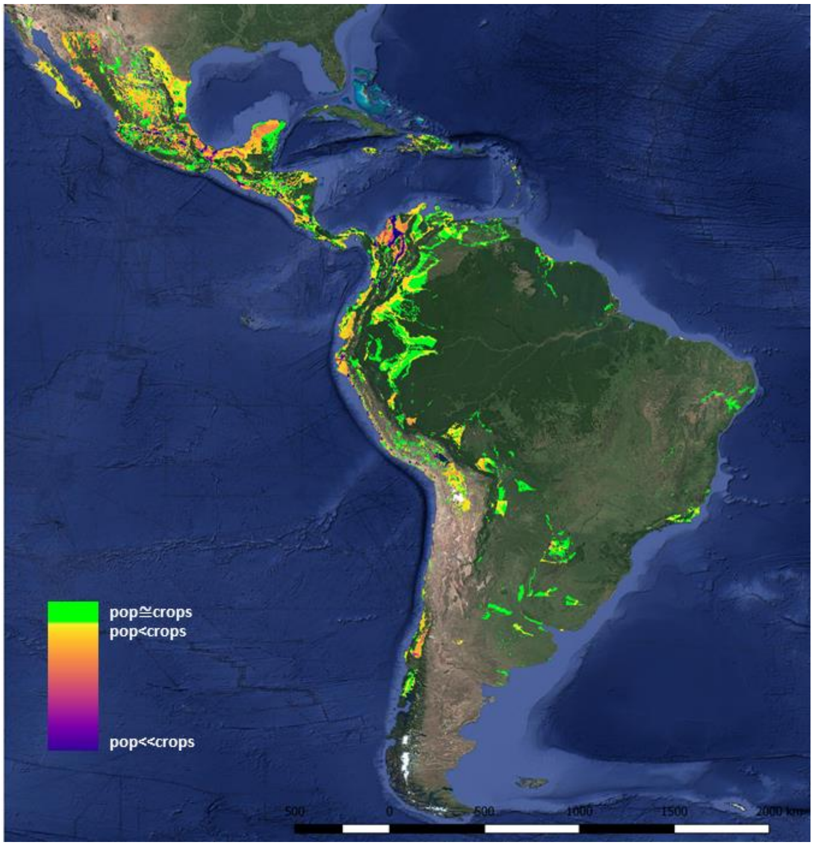

Figure 117 Difference map for Region 8, 1500 AD

For the year 1500 AD, everything is very similar to how it was 500 years ago. It can be noted that in the area where there was previously a balance in northern Peru, it became an area where production now prevails. Habited areas continue to expand but it is almost imperceptible, there are no very large changes. It can be seen a very extent of area in the island that today is Jamaica. In this year the European colonization in America was just beginning, so there are still no major changes in this regard.

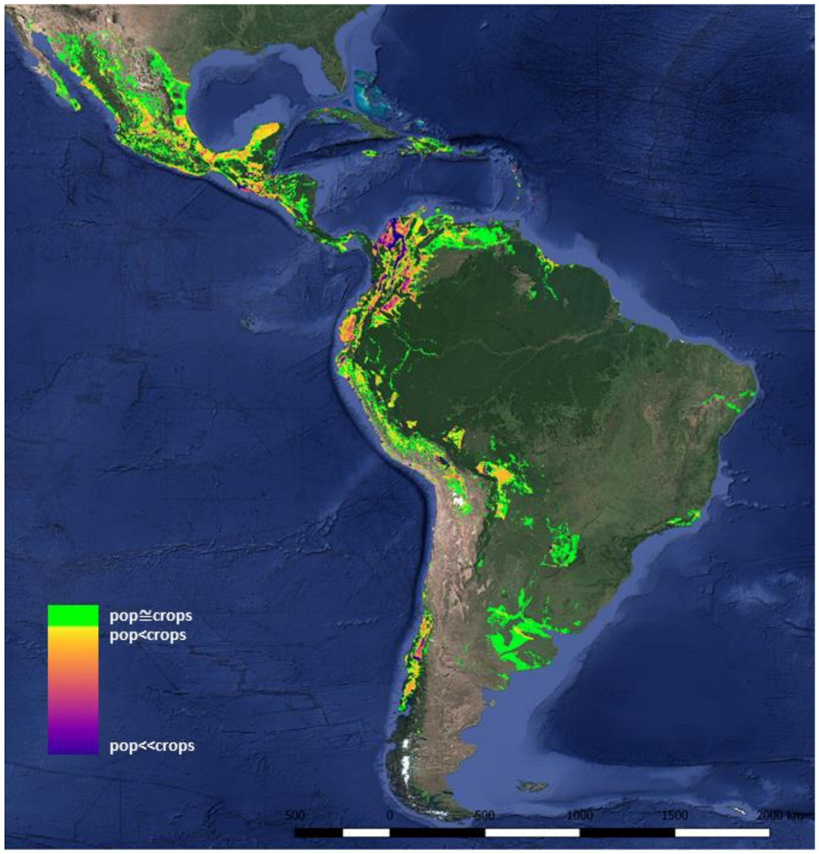

Figure 118 Difference map for Region 8, 1700 AD

In 1700 AD, America had already been colonized by Europe and new settlements were beginning on their part in the area where Argentina is today, showing a large increase in the area where there is a balance between production and consumption. This also can be shown on eastern Brazil, where had been disappeared large areas. It could be because it was eliminated by the great massacre by the colonizers, which at this time in these areas you can see small areas where there is a balance between production and population. This can be seen very well also in the area we had talked about in northern Peru, as it disappears almost completely. There is a noted diminution of area habited in Mexico also, and in this country there are not more areas with excessive prevalence of production.

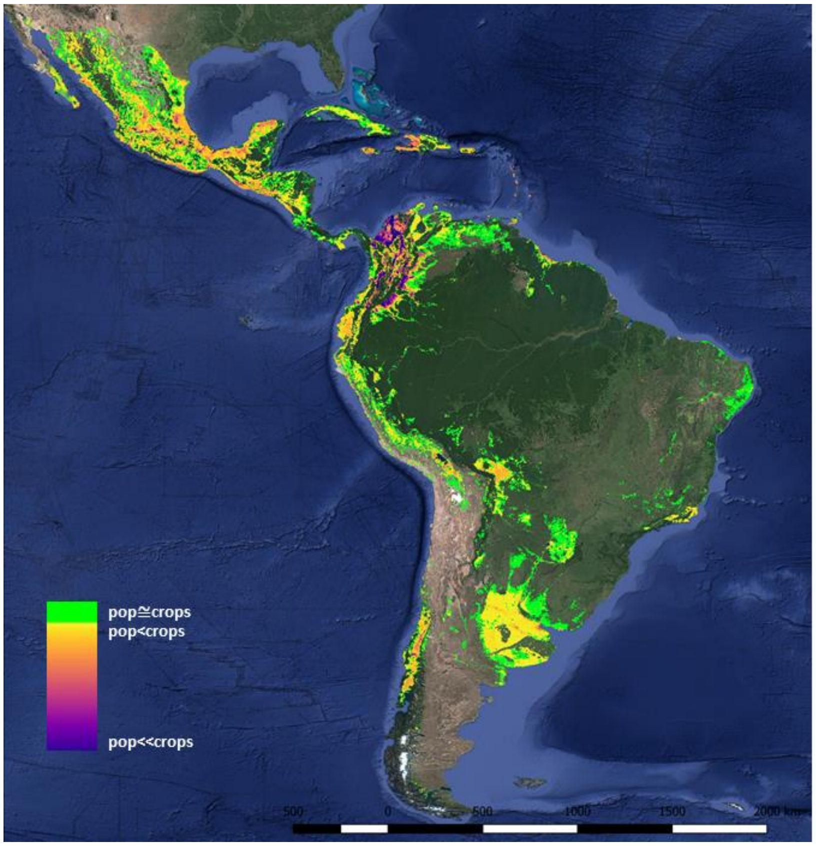

Figure 119 Difference map for Region 8, 1810 AD

For the year 1810 AD, there is a large increase in habited area, mostly in Argentina, where in most of it, production already prevails over consumption. And this production was consumed in other continents such as Europe. Still this year it is not possible to see a large increase in Brazil, although there is a brief increase. There is also a significant increase in its area this year in areas where there was much more production than consumption in the area of Colombia. You can also see a large increase in inhabited areas in what is Mexico, Cuba, Haiti and the Dominican Republic, where in almost all of them production prevails in terms of consumption, but not in large numbers.

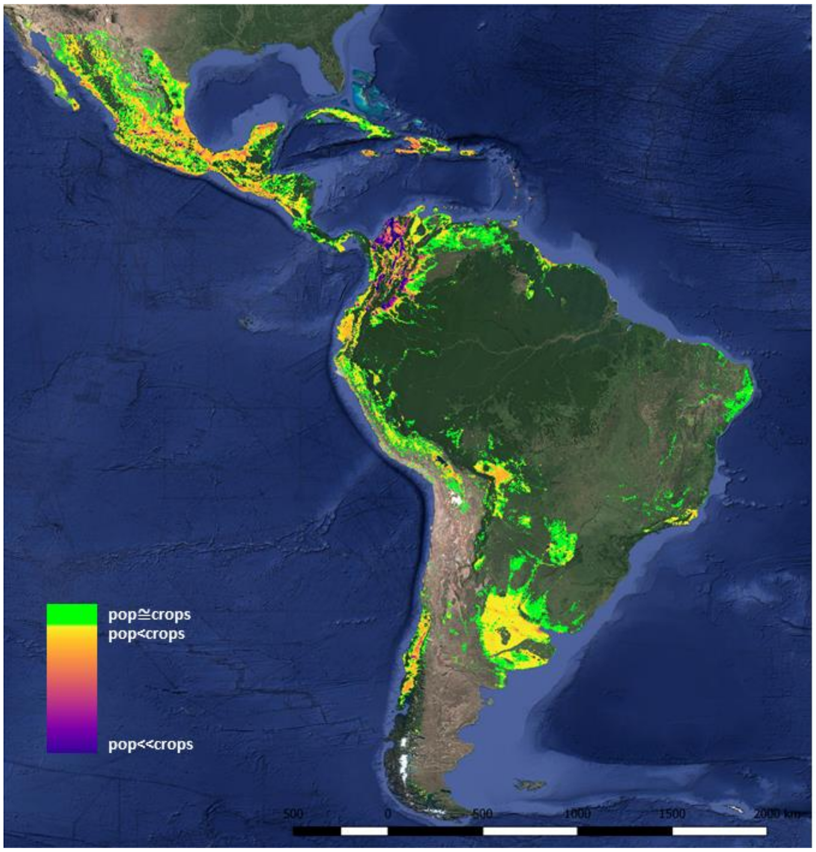

Figure 120 Difference map for Region 8, 1900 AD

For the year 1900 AD, already all the South American countries were independent of Europe, and recently the industrialization of agriculture had begun where innovations in machinery and chemical fertilizers were introduced to the world. Already for this year you can notice the increase in areas where production prevails over consumption in Argentina. You can also notice the great expansion in the area of cultivated areas in Brazil, where mostly there was a balance between consumption and production, but in areas where there were already cultivated areas, which had a balance between production and consumption, now prevails the production. Throughout the western part of Peru, you can also notice how the balance between production and consumption prevailed before, and now there are almost no areas where production does not prevail. The same thing that happened in the western part of Peru can be seen in Venezuela and Mexico.

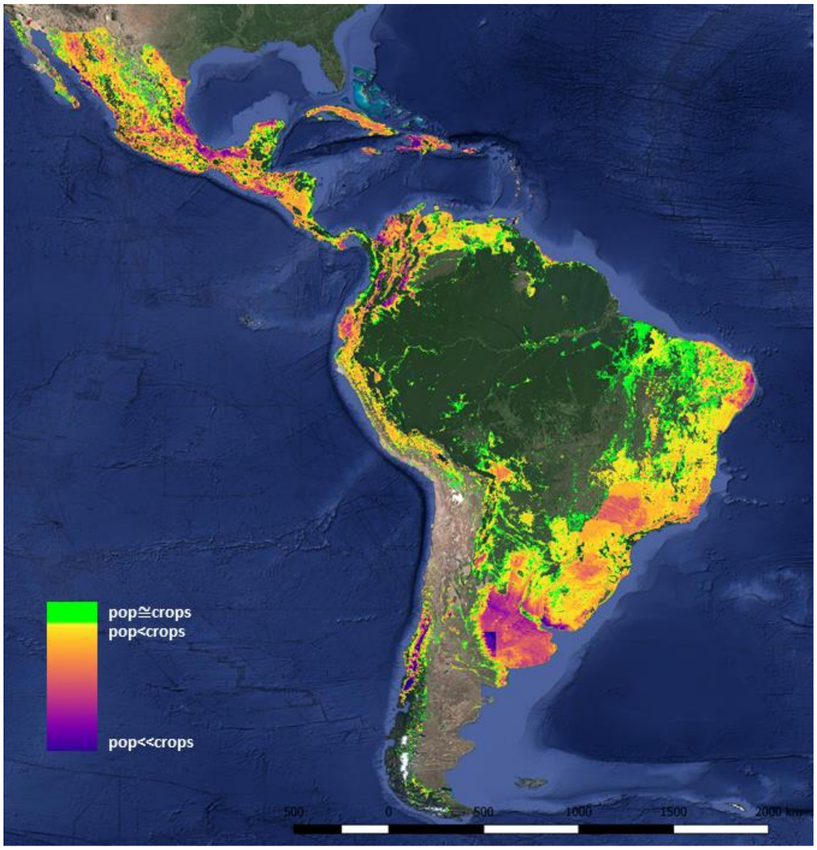

Figure 121 Difference map for Region 8, 1950 AD

The next year analyzed is the year 1950 AD, where you can see an incredible increase in the total area of cultivated areas and all these areas with a high prevalence of production over consumption. This large increase occurred throughout eastern South America and is very noticeable and may be due to the large population increase of around two and a half times more. You can also notice the increase in area where production (violet areas) prevails in Chile.

for this time Central America is almost fully inhabited and in most of its coverage production prevails significantly in terms of consumption.

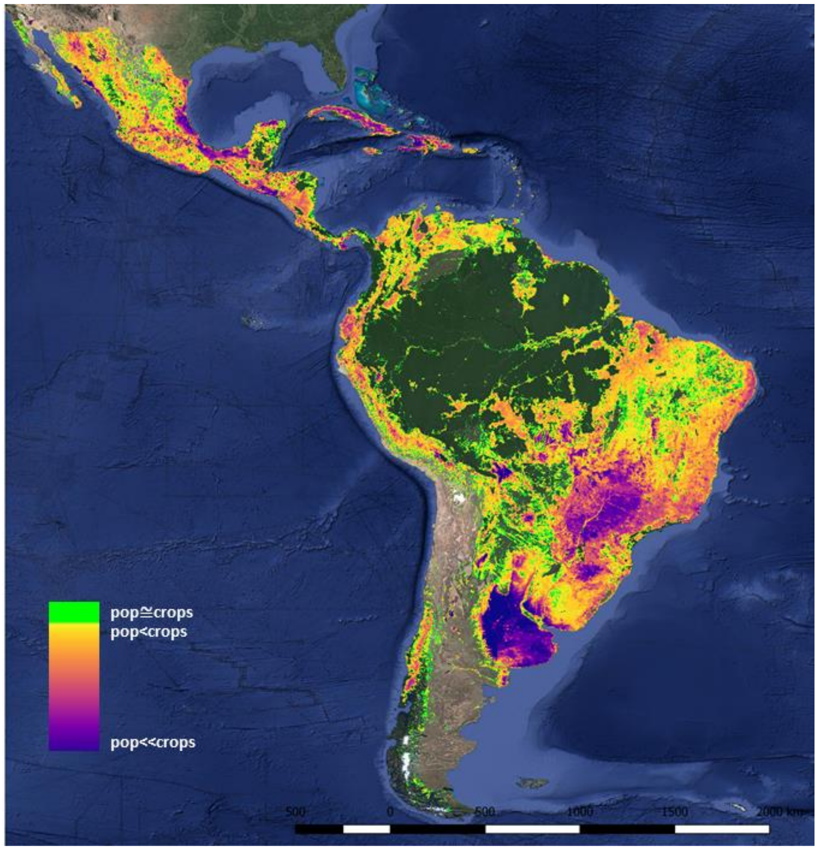

Figure 122 Difference map for Region 8, 2017 AD

After all these years we reach the most current year of our analysis, 2017 AD, that with respect to the year analyzed above, the world population increased by almost 360%. This is notoriously seen in the incredible increase not only of cultivated areas, but in these areas, production prevails markedly in terms of consumption. The increase in cultivated areas with respect to the year previously analyzed is 2.4 times. It can be seen how at present almost all the available areas are cultivated, with the exception of the Amazon jungle and places where the climate is not suitable for it, such as north and south of Chile and west and south of Argentina.

4.2.2 Distribution of alpha, gamma and diff

To see what values our results are approaching, a probabilistic analysis has been done to see the probabilities that a cell has a certain value.

This has been done with the help of the Matlab program and the Exel program, which helped us calculate and interpret the data. The Matlab codes for the calculation can be found in the annex.

In the following, a probabilistic example of the most current year of the analysis will be shown, which will help us to understand the probable values that our data may have. This analysis will be evaluated for the result of the differences, which is the one of our interest. This will be done by looking at the probability of the gamma, alpha, and difference values. The alpha value, varies between zero and one, and represents the relative population of that cell. The gamma value, also varies between zero and one, and represents the relative cultivation of that cell. The difference value is the subtraction of gamma minus alpha, making it a value between -1 and 1. If this value is positive, it indicates that food production prevails. If it is negative, it indicates that food consumption prevails. If this value is zero, it indicates a good balance between food production and consumption in that cell.

We have these values in matrices representing the world map divided into cells. These cells are likely to have a certain value.

The following results were reached for a particular year, in this case, 2017 AD. These results can be found in annex tabulated.

To better appreciate and understand of the probabilistic results, this data was plotted with the probability that this value range will appear on the vertical axis, and the range of values on the horizontal axis.

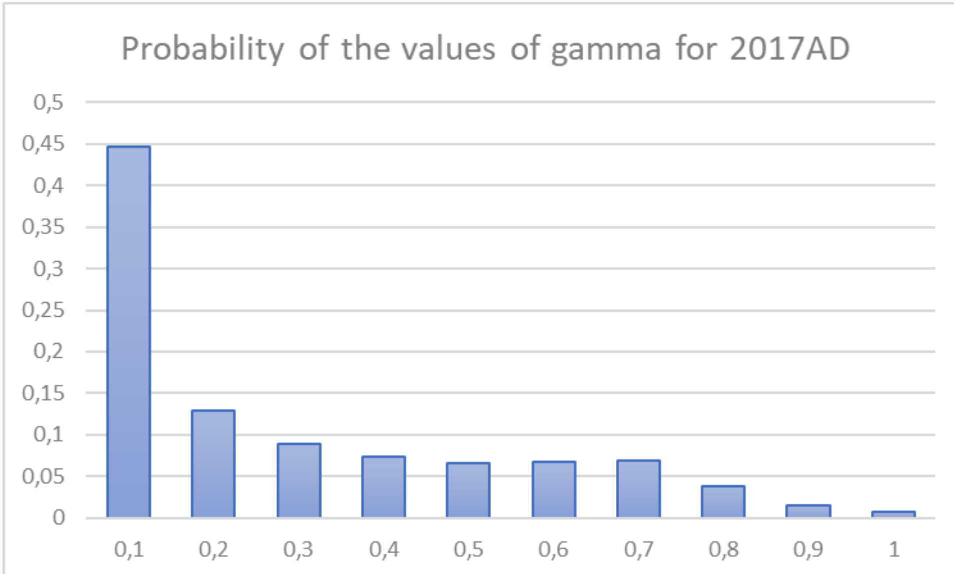

Figure 123 Probability of the values of gamma for 2017AD

The graph on figure 124 indicates that there is a 44.6% chance that the gamma value is between 0 and 0,1.

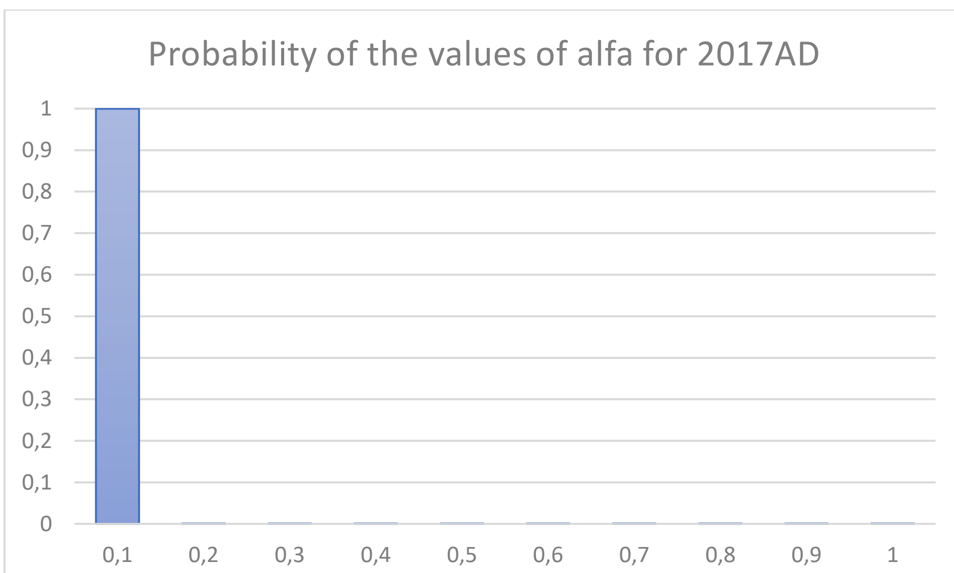

Figure 124 Probability of the values of alpha for 2017AD

The graph on figure 125 indicates that there is a 99.98% chance that the alfa value is between 0 and 0,1.

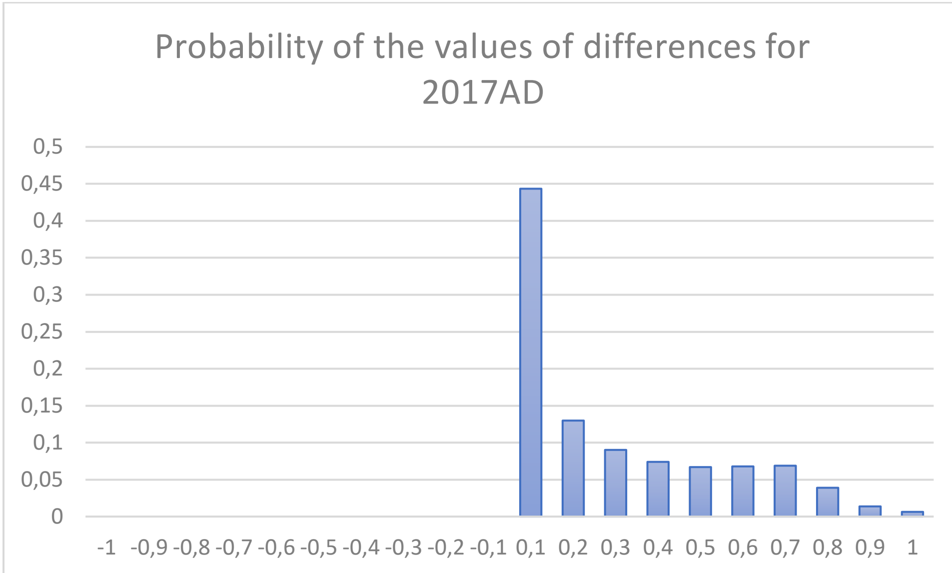

Figure 125 Probability of the values of differences for 2017AD

The graph on figure 126 indicates that there are no negative values of differences and that there is 44.3% chance that the value is between 0 and 0,1.

It is necessary to clarify that for this analysis the data equal to zero have been eliminated to avoid the no-data cells.

Because the ranges used do not give a good representation of the difference's possible values, where more than 90% of the data fall in the same range, the probability of values for other ranges of values has been made, these will be shown below.

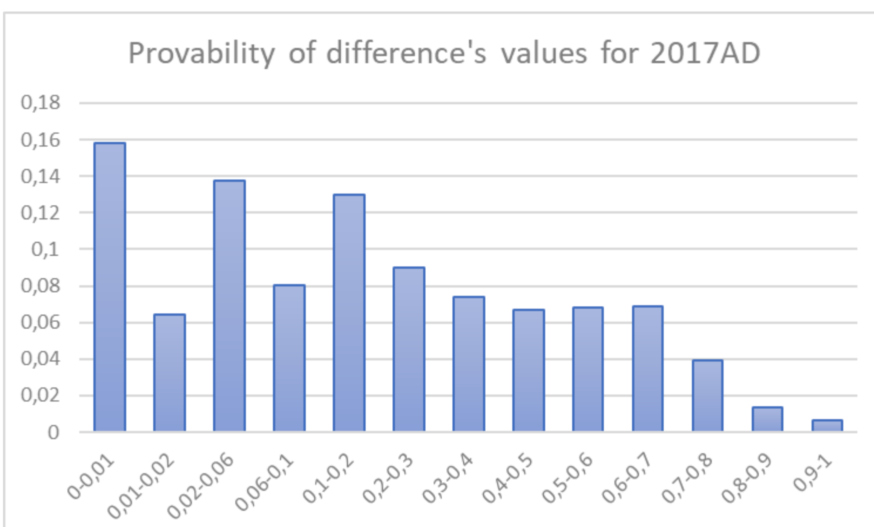

Figure 126 Probability of difference's values for 2017AD

The graph on figure 127 represents what is the probability of the difference's values for 2017 AD in the different ranges of values. A series of ranges of values have been chosen, that best represent the different probabilities that we have of finding a differences data of a certain value. These ranges of values are not constant. The ranges of values can be observed on the horizontal axis of the graph and the probability that a value belongs to this range can be found on the vertical axis.

In other words, the graph represents that 15.8% of the values are between 0 and 0.01, the 6.4% of the values are between 0.01 and 0.02, the 13.75% are between 0.02 and 0.06, the 8% are between 0.06 and 0.1, the 13% are between 0.1 and 0.2, the 9% are between 0.2 and 0.3, the 7.4% are between 0.3 and 0.4, the 6.7% are between 0.4 and 0.5, the 6.8% they are between 0.5 and 0.6, the 6.9% are between 0.6 and 0.7, the 3.9% are between 0.7 and 0.8, the 1.4% are between 0.8 and 0.9 and the 0.6% are between 0.6 and 1.

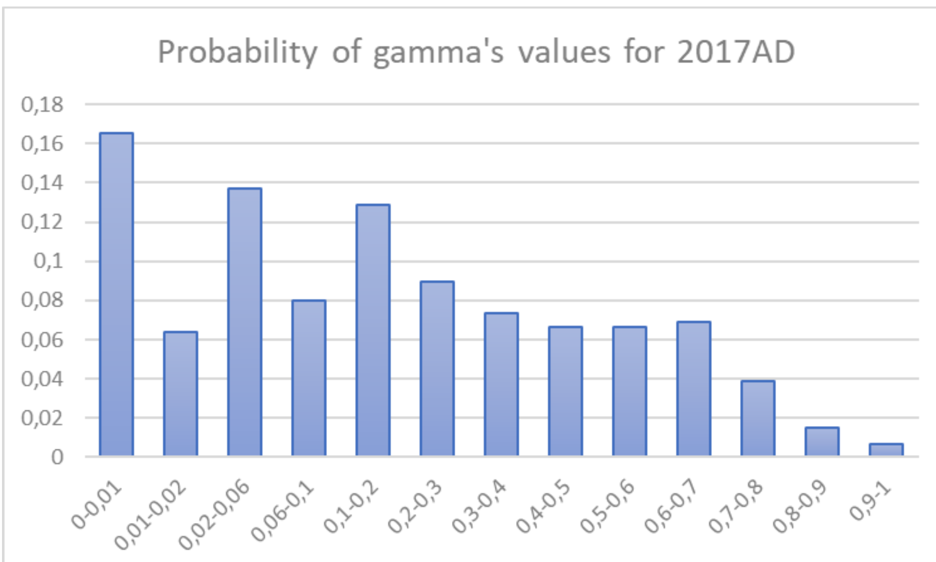

Figure 127 Probability of gamma's values for 2017AD

The graph on figure 128 represents what is the probability of the gamma values for 2017 AD in the different ranges of values. A series of ranges of values have been chosen, that best represent the different probabilities that we have of finding a gamma data of a certain value. These ranges of values are not constant. The ranges of values can be observed on the horizontal axis of the graph and the probability that a value belongs to this range can be found on the vertical axis. This graph is similar to the graph above, because the gamma value is generally much larger than the alpha value.

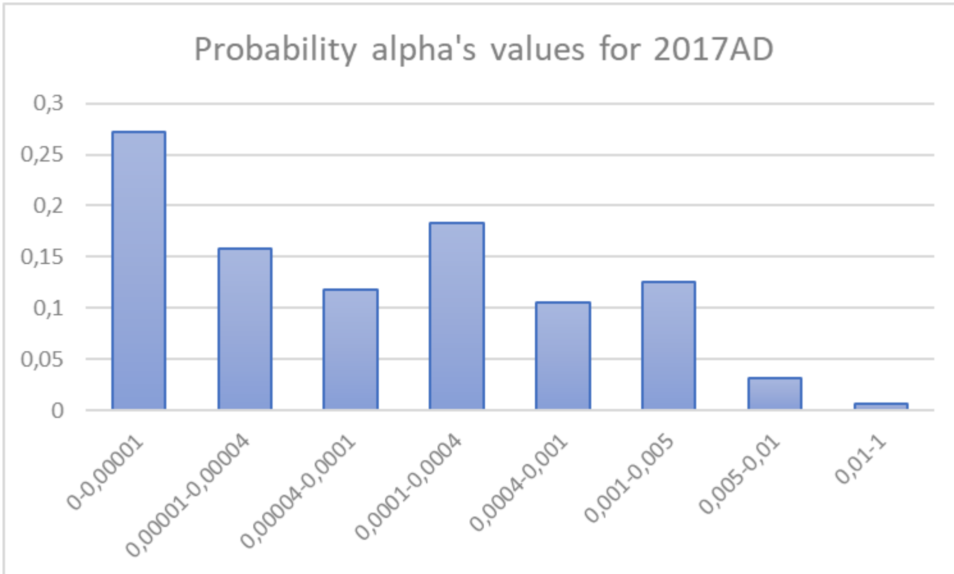

Figure 128 Probability of alpha's values for 2017AD

The graph on figure 129 represents what is the probability of the alpha values for 2017 AD in the different ranges of values. A series of ranges of values have been chosen, that best represent the different probabilities that we have of finding an alpha data of a certain value. These ranges of values are not constant. The ranges of values can be observed on the horizontal axis of the graph and the probability that a value belongs to this range can be found on the vertical axis. This graph has different ranges of values than the graphs previously analyzed, because alpha values have different probability than gamma and differences data.

In other words, the graph represents that 27.2% of the values are between 0 and 0.00001, the 15.8% of the values are between 0.00001 and 0.00004, the 11.8% are between 0.00004 and 0.0001, the 18.3% are between 0.0001 and 0.0004, the 10.5% are between 0.0004 and 0.001, the 12.5% are between 0.001 and 0.005, the 3.1% are between 0.005 and 0.01 and the 0.6% are between 0.01 and 1.

4.2.3 Data dispersion

Like we explained before, parallel to the calculation of the differences, the dispersion of these data represented through the standard deviation has been calculated for each year, and then it was evaluated as it was changing over time. With this ability, the variability of the distribution of these data is shown, indicating by means of a number, if the data obtained from the calculation of the differences are very far from the average[2]. The higher that value, the greater the variability. The smaller it is, the more homogeneous it will be on average. Thus, it is known if all cases are similar or vary greatly between them.

This value is calculated for each particular year and is obtained from the following formula:

$$\sigma = \sqrt{\sum_{1}^{n} \frac{(diff_i - \overline{diff})^2}{n}}$$

Where:

σ = standard deviation of the difference data of a particular difference matrix

$diff_i$ = difference value of the i-cell of the matrix

$\overline{diff}$ = average difference value of all cells in that particular year

n = total number of cells in the difference matrix analyzed (2160x4320 = 9,331,200)

In order to calculate the value of the standard deviation for each year, the Matlab program has been used as a tool, using the standard deviation calculation function applied to the matrix of differences. This calculation was made both for the matrix of differences of cultivated area without artificial irrigation, and for the matrix of differences of cultivated area with artificial irrigation. The codes used in the Matlab program can be found in the annex.

The results obtained were calculated and tabulated for each year, both for matrices differences calculated with cultivated area without artificial irrigation, and for matrices

[2] In colloquial language, an average is a single number taken as representative of a list of numbers. Often "average" refers to the arithmetic mean, the sum of the numbers divided by how many numbers are being averaged. In statistics, mean, median, and mode are all known as measures of central tendency, and in colloquial usage any of these might be called an average value

differences calculated with cultivated area with artificial irrigation. These tabulated of results can be found in annex.

The results obtained, to be able to better appreciate how this varies over time, have been plotted, putting the value of the standard deviation on the vertical axis and the time in years on the horizontal axis. This graph is shown and analyzed below on figure 130.

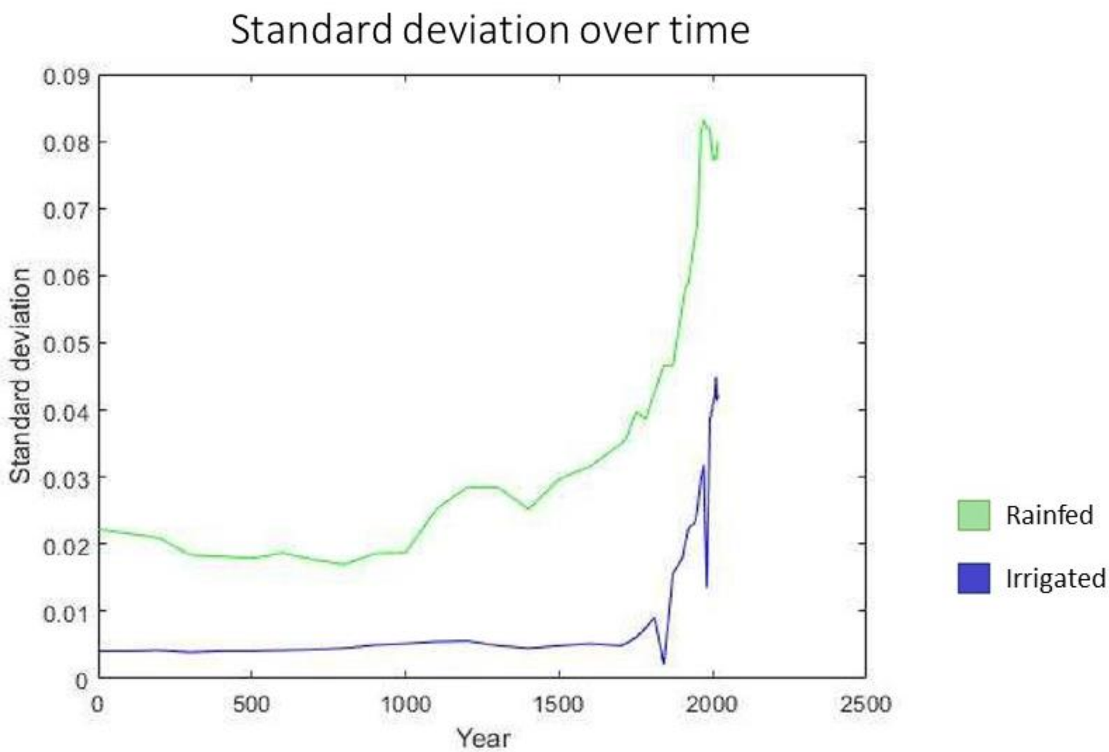

Figure 129 Standard deviation over time of the difference's values

In the case of data from the rainfed cultivated area until the year 1000 AD they are quite homogeneous and as of this year the value of the standard deviation begins to rise and passing the 1800s begins to rise with greater increase. Increasing this value means that the homogeneity of the data decreases, that is, that the data differ more between them and with respect to the average. In the case of data on irrigated area, homogeneity is maintained over time, until approximately year 1800 AD, and then the value begins to increase, thus increasing the dispersion of the data with respect to the average.

This dispersion of data is greatly affected from the beginning of the 19th century and mostly in the final part of this century. This may be due to the fact that in the period between the second half of the 18th century and the beginning of the 19th century, there was a historical event in the world remembered as the Industrial Revolution, in which labor was replaced by machines. The industrialization of agriculture began in the final part of the 19th century. The great changes began in about 1870 AD, when industrial innovations aimed at the agricultural sector began to appear. These innovations were developed in two large planes: machinery and chemical fertilizers.

Efforts have been developed since the beginning of the 20th century to produce hybrid varieties of the main crops in order to increase their yields. This resulted in Industrialized Agriculture, which focuses on the mass production of a single product, but carries a high level of technification and needs a high investment of capital, energy and other resources. This technological change was widely encouraged by public investments in developed countries.

There was an accelerated increase in productivity, this favored the increase in differences between big and small farmers. This also generated a significant negative environmental impact.

The consequences of industrial agriculture were, among others:

- Depletion and contamination of land, water, seeds and animals
- Elimination of work in the countryside and forced emigration to cities
- Concentration of land ownership in fewer owners

The standard deviation of the difference value with the total cultivated area, the standard deviation of the alpha values and the standard deviation of the gamma values were also calculated. These three values were calculated for each year and plotted over time together to compare their values. This graph can be seen below in figure 131.

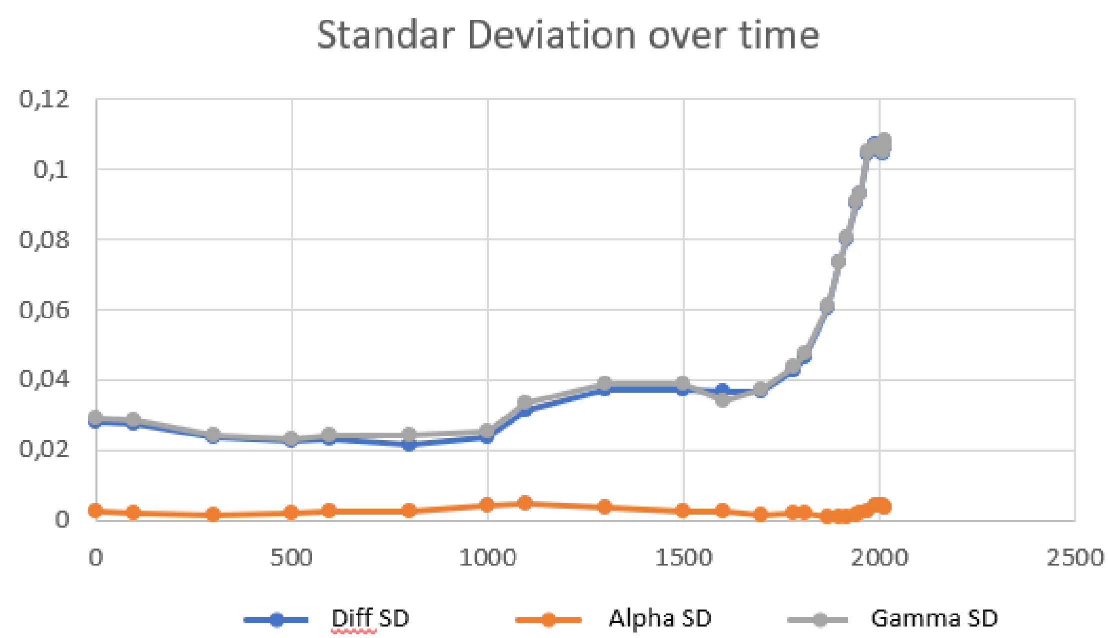

Figure 130 Standard deviation over time of the difference's, alpha's and gamma's values

The mean of these three variables was also calculated for each year. These values were plotted over time on the same graph to be able to compare them with each other. This graph can be seen below in figure 132.

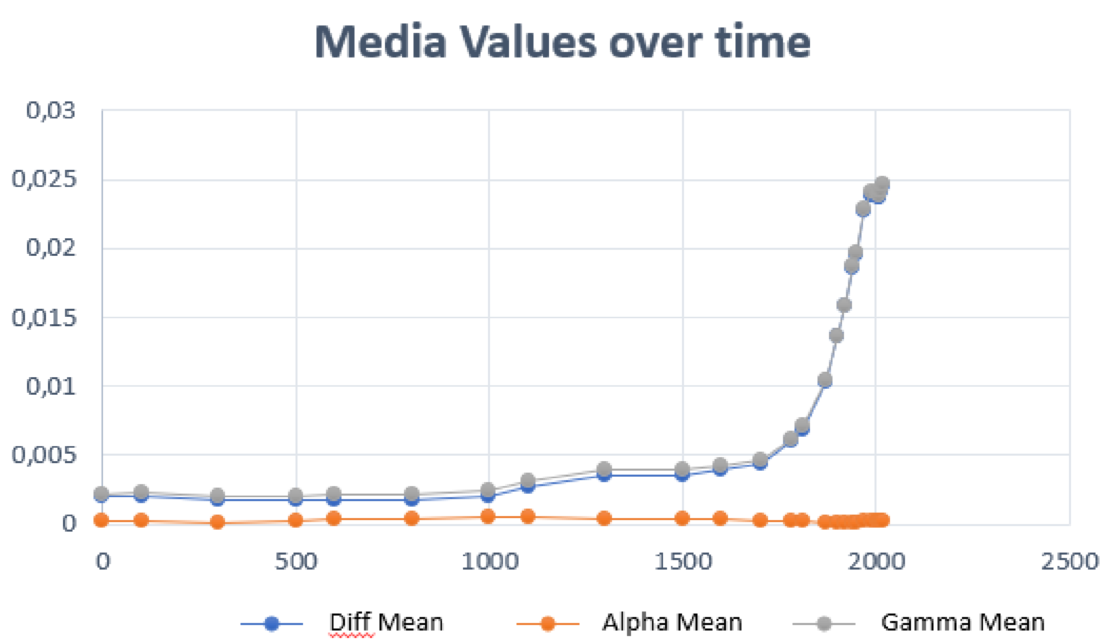

Figure 131 Mean over time of the difference's, alpha's and gamma's values

It can be clearly seen from this graph that the alpha values are always below the gamma values by a large difference. This coincides that the difference values in our analysis at no time give us negative values.

4.3 Lorenz curve and Gini Index

Like we said before, in addition to the calculation of the differences, to interpret from another point of view the historical evolution of the relationship between production and consumption of the food, the Lorenz curve has been made for these two variables and then calculated the respective Gini index for each year analyzed.

This index indicates the inequality between two parameters analyzed, in our case production and consumption of the food. This index varies between 0 and 1. If this index is equal to zero it means that there is no inequality, so it is produced in the same place it is consumed, or rather the same population produces what they consume. And if this index is equal to one, it means that the inequality is total and that only one person produces and the rest consumes.

4.3.1 Gini Index

To calculate the Gini index, I have to calculate the area between the Lorenz curve and a line F (x) = 1, that is, the line at 45° because the Lorenz curve goes between 0 and 1 value, both in accidents and in abscissa.

To perform these calculations, the Matlab program has been used as a tool. That's necessary because in our case we have matrices of 2160x4320 data. The codes used are attached in the annex.

The calculation of the Lorenz curve and Gini index were made for both irrigated cultivated area and rainfed cultivated area, the latter two used as food production variables. And as the other variable we use the population data, which would come to represent consumption.

These calculations were made for all the years of our data, from 0 AD. The table of results of Gini index for all these years can be found in annex.

In order to appreciate its variation in time, these data were plotted by placing the Gini index on the vertical axis and time on years on the horizontal axis, using blue for the irrigated data and orange for the rainfed data. It can be seen these results on figure 131 below.

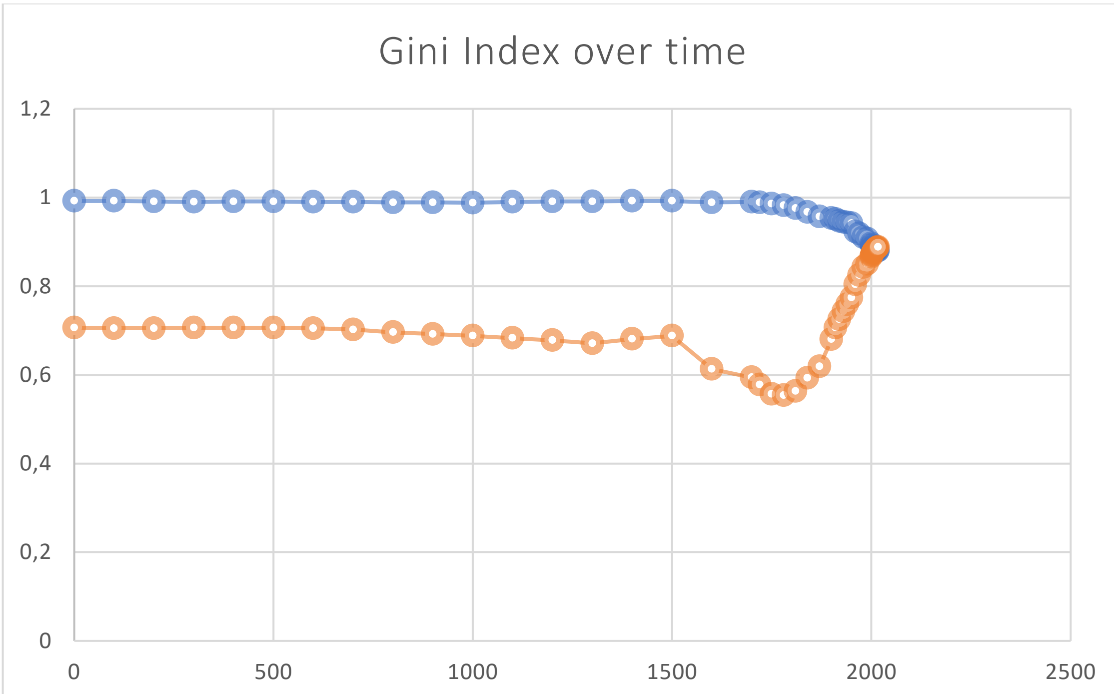

Figure 132 Gini Index over time

With the help of the graph and table 2.1 it can be seen how this index for the case of irrigated is almost equal to one until the year 1750 AD, which means that the inequality is almost total and that a few people produce with irrigated and the rest consumes it. After that, this index begins to decrease, which means that more people started producing with irrigation from that year.

If we analyze now the index for rainfed cultivated area, it can be seen that until the year 1500 AD this index is constant and is around the value of 0.7, which means that inequality exists, but not completely, but 30 percent of the population lives where food is produced and the other 70 where consumption prevails. You can see that this index decreases from this year until it reaches a lower peak in the year 1780 AD where it reaches a value of 0.554. After this year the index begins to increase and at the end of the 19th century this increase begins to be much greater, which makes sense because of the appearance of industrialized agriculture, which in these times not only the machines replaced the labor force, but also because small producers cannot compete with big producers and many people stopped living in agrarian areas to move on to live in cities. This index does not stop increasing until now that a value of 0.88 was reached, equaling the index calculated for cultivated area with irrigated land, which means that only 12% of people live in areas where food is produced and 88% are more concentrated in areas where consumption prevails.

4.3.2 Lorenz Curves

The Lorenz curves will be represented below in the graph where the rapport between the accumulated cultivated area and the total sum of the cultivated area on the vertical axis and the rapport between the accumulated population and the total sum of population on the horizontal axis.

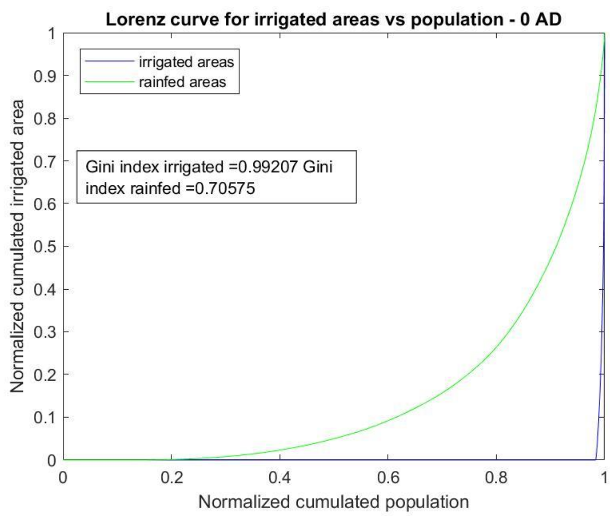

Figure 133 Lorenz Curve for year 0 AD

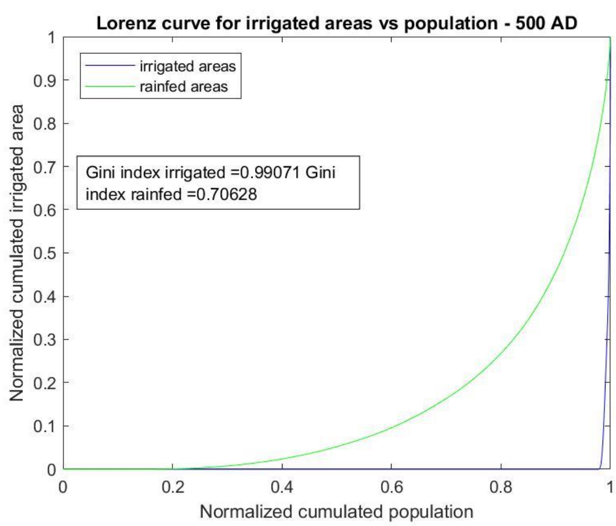

Figure 134 Lorenz Curve for year 500 AD

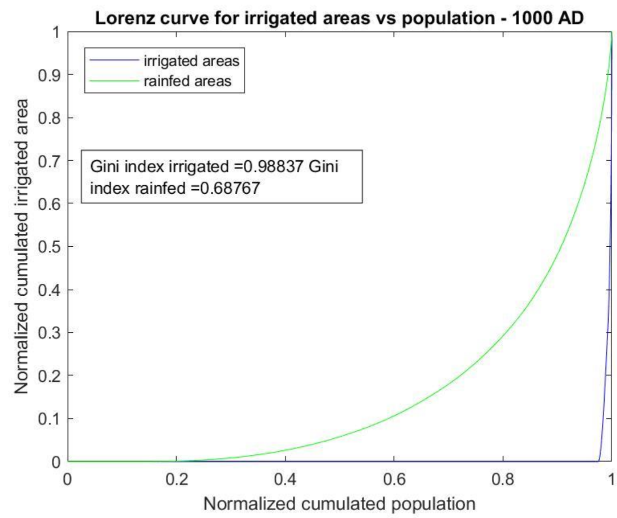

Figure 135 Lorenz Curve for year 1000 AD

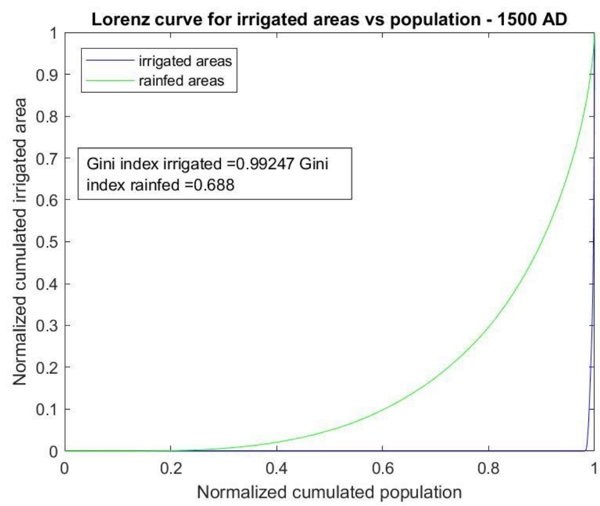

Figure 136 Lorenz Curve for year 1500 AD

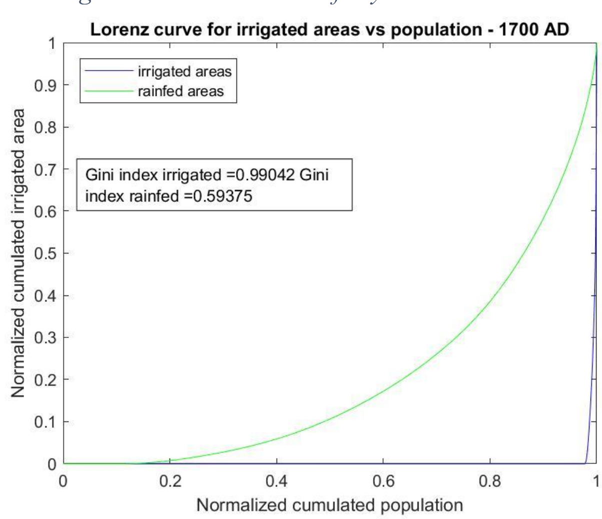

Figure 137 Lorenz Curve for year 1700 AD

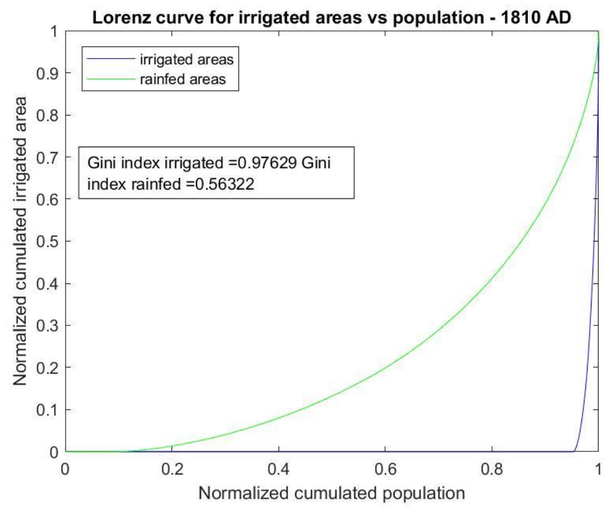

Figure 138 Lorenz Curve for year 1810 AD

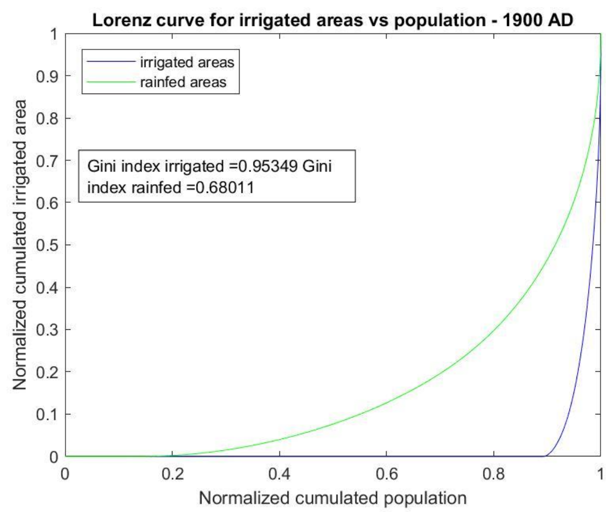

Figure 139 Lorenz Curve for year 1900 AD

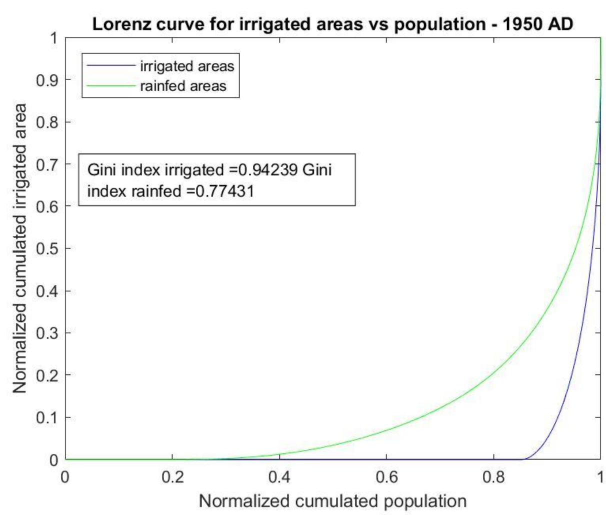

Figure 140 Lorenz Curve for year 1950 AD

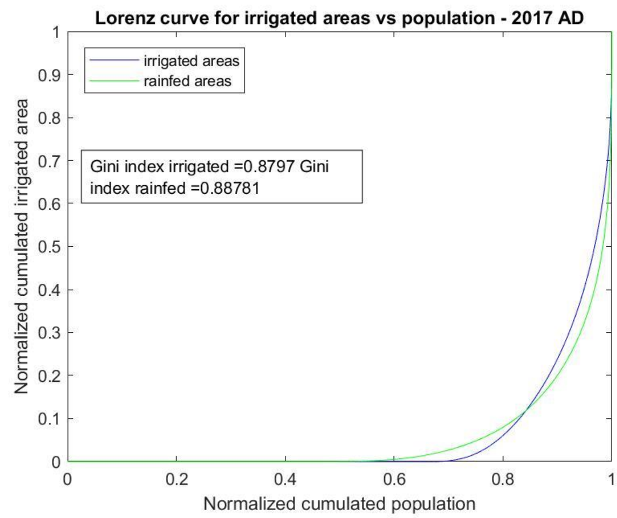

Figure 141 Lorenz Curve for year 2017 AD

5. Conclusion

As a conclusion it can be said that having all positive data in our analysis of differences, indicates that the world produces much more food than we really need. This may be because it is produced only for economic purposes and not only to feed the population.

The spatial distribution of where food is produced and consumed could have been better studied if in our analysis we obtained some negative data. With negative data, it would be well known where people concentrations are and where food is produced. In the closest case, the difference between the value that was equivalent to consumption and the value that was equivalent to production in an area is close to zero, but no negative data was obtained. Reviewing the calculations, it was found that in the most populated areas, there were generally also data on hectares cultivated with irrigation, which made us think that the production added up enough to balance consumption. Before analyzing the results of this thesis, the difference calculations had been made with only the data on hectares cultivated without artificial irrigation, which are always greater than 90% of the total crops, and the maps obtained was very different from the maps of the thesis, because there were negative results. Having negatives results we could interpret where there was more population than cultivated area without irrigation and that showed us clearly the spatial distribution of where it is consumed and where it is produced. This led us to similar results to the Gini index. That says that 80% of people live concentrated in a place of consumption, and that 20% of the population lives in production areas or in settlements with smalls population.

I want to comment from this, that in order to better appreciate the spatial distribution between where food is produced and where it is consumed, to this data could be given a weight value, through a coefficient, to the alpha value in the difference equation. This alpha value is the value that represents consumption in that cell, and is seen as the ratio between the population in that place and the maximum number of population that it could have according to the data. As this alpha value subtracts, it can been increase with a weight in the equation, and thus be able to notice more where it is consumed.

As a conclusion we can say that the spatial distribution of where is the production is very noticeable and looks very extensive compared to populated areas. Man cultivate crops throughout the planet, using everything within his reach. An excessive area for food production can be seen in all countries of the world. The use of soil that we are generating and the little effectiveness that we are applying to what is consumed are worrying. In effectiveness, I mean the amount that is produced more for economic purposes only, which would bring very negative results if we do not start to regulate production with consumption. This excessive use of land on the planet is bringing us very negative environmental results, not only in fertilizers and excessive demands on the soil, but also in the change of the water cycle. This is due to the excessive consumption of water transformed to produce food. In this analysis you can notice how excessive is the distribution of the area where food is produced. It could be said that it covers every land we know today that is suitable for crops, with a few exceptions.

It can be observed in this analysis the excessive evolution of the extension of land used for food production, which has increased by 1000% from our first year of analysis to the present. This increase occurred mostly and very quickly in a period of less than two hundred years between the year 1700AD and 1970AD. This evolution was very fast and came to cover almost all of the land that we know today suitable for cultivation, which is worrying considering the future, if things continue the same way.

It is already very difficult to take a brake measure to this use of land by our race, but it is never too late to take any regulatory measure. Let it return in some way to nature, at least a little of everything it gives us. We could start by raising awareness of the amount of food that is produced and the amount of land that this requires. Since, according to this analysis, in all parts of the world, including large settlements, production is higher than consumption.

6. Bibliography

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7. Annex

7.1 Matlab Codes

7.1.1 Matlab code for the differences calculation for worldwide data

The following Matlab code was used to calculate the difference's arrays for each year analized for the worldwide data.

```
if exist('tot_irri2017AD_1.txt')
    irr=dlmread('tot_irri2017AD_1.txt');
    rf=dlmread('tot_rainfed2017AD_1.txt');
    pop=dlmread('popc_2017AD_1.txt');
    Area=dlmread('cell_area_ha_05mn.txt');
        %Trasformo no data in 0
irr_zero=zeros(size(irr));
for i=1:numel(irr_zero)
    if irr(i)==-9999
        irr_zero(i)=0;
    else
        irr_zero(i)=irr(i);
    end
end
pop_zero=zeros(size(pop));
for i=1:numel(pop)
    if pop(i)==-9999 || pop(i)==0
        pop_zero(i)=0.000000001;
    else
        pop_zero(i)=pop(i);
    end
end
rf_zero=zeros(size(rf));
for i=1:numel(rf_zero)
    if rf(i)==-9999
        rf_zero(i)=0;
    else
        rf_zero(i)=rf(i);
    end
end
Acultivated=zeros(size(rf));
for i=1:numel(rf);
    Acultivated(i)=irr_zero(i)+rf_zero(i);
end
max_Area=max(Area(:));
cp=zeros(size(irr_zero));
for i=1:numel(rf);
    cp(i)=(max_Area)/Area(i);
end
max_pop=max(pop_zero(:));
alfa=zeros(size(rf));
for i=1:numel(rf);
    alfa(i)=(1*pop_zero(i)/max_pop)*cp(i);%Coeficiente C = 1
end
beta=zeros(size(rf));
for i=1:numel(rf);
```

```
    beta(i)=(100*Acultivated(i))/Area(i);%*100 because Area_zero is in ha
and Acultivated is in Km2
end
max_beta=max(beta(:));
gamma=zeros(size(rf));
for i=1:numel(rf);
    gamma(i)=beta(i)/max_beta;
end
diff_Ac_pop=zeros(size(rf));
for i=1:numel(rf);
    diff_Ac_pop(i)=gamma(i)-alfa(i);
end
for i=1:numel(rf);
    if isnan(diff_Ac_pop(i))==1
        diff_Ac_pop(i)=0;
    end
end
max_Acultivated=max(Acultivated(:));
save('diff_Ac_pop_0AD.txt','diff_Ac_pop');
txt_per_QGis(diff_Ac_pop,'diff_Ac_pop_0AD','0','0.0833333','2')
end
```

7.1.2 Matlab code for the differences calculation for specific region

For each year and each region, the following Matlab code was used to calculate the specific difference's arrays. This code was used also for the calculation of specifics maps of population, cultivated area with artificial irrigation and cultivated area without artificial irrigation.

```
regions=importdata('regionsMatlab.txt');
irr=dlmread('tot_irri2017AD_1.txt');
rf=dlmread('tot_rainfed2017AD_1.txt');
pop=dlmread('popc_2017AD_1.txt');
Area=dlmread('cell_area_ha_05mn.txt');
%Trasformo no data in 0
irr_zero=zeros(size(irr));
for i=1:numel(irr_zero)
    if regions(i)==1
        if irr(i)>0
            irr_zero(i)=irr(i);
        end
    else
        irr_zero(i)=0;
    end
end
pop_zero=zeros(size(pop));
for i=1:numel(pop)
    if regions(i)==1
        if pop(i)>0
            pop_zero(i)= pop(i);
        end
    else
        pop_zero(i)=0;
    end
end
rf_zero=zeros(size(rf));
for i=1:numel(rf_zero)
    if regions(i)==1
        if irr(i)>0
            rf_zero(i)=rf(i);
        end
    else
        rf_zero(i)=0;
    end
end
Area_zero=zeros(size(Area));
for i=1:numel(Area)
    if regions(i)==1
        Area_zero(i)=Area(i);
    else
        Area_zero(i)=0;
    end
end
max_irr=max(irr_zero(:));
max_pop=max(pop_zero(:));
max_rf=max(rf_zero(:));
```

```
Acultivated=zeros(size(rf));
for i=1:numel(rf)
    Acultivated(i)=irr_zero(i)+rf_zero(i);
end
max_Acultivated=max(Acultivated(:));
cp=zeros(size(irr_zero));
for i=1:numel(rf)
    cp(i)=(max_Acultivated)/Area_zero(i);
end
cpirr=zeros(size(rf));
for i=1:numel(rf)
    cpirr(i)=max_irr/Area_zero(i);
end
cprf=zeros(size(rf));
for i=1:numel(rf)
    cprf(i)=max_rf/Area_zero(i);
end
alfa=zeros(size(rf));
for i=1:numel(rf)
    alfa(i)=(pop_zero(i)/max_pop)*cp(i);
end
beta=zeros(size(rf));
for i=1:numel(rf)
    beta(i)=Acultivated(i)/Area_zero(i);
end
betairr=zeros(size(rf));
for i=1:numel(rf)
    betairr(i)=irr_zero(i)/Area_zero(i);
end
betarf=zeros(size(rf));
for i=1:numel(rf)
    betarf(i)=rf_zero(i)/Area_zero(i);
end
max_beta=max(beta(:));
max_betairr=max(betairr(:));
max_betarf=max(betarf(:));
gamma=zeros(size(rf));
for i=1:numel(rf)
    gamma(i)=beta(i)/max_beta;
end
gammairr=zeros(size(rf));
for i=1:numel(rf)
    gammairr(i)=betairr(i)/max_betairr;
end
gammarf=zeros(size(rf));
for i=1:numel(rf)
    gammarf(i)=betarf(i)/max_betarf;
end
diff_Ac_pop=zeros(size(rf));
for i=1:numel(rf)
    diff_Ac_pop(i)=gamma(i)-alfa(i);
end
diff_irr_pop=zeros(size(rf));
for i=1:numel(rf)
    diff_irr_pop(i)=gammairr(i)-alfa(i);
end
diff_rf_pop=zeros(size(rf));
```

```
for i=1:numel(rf)
    diff_rf_pop(i)=gammarf(i)-alfa(i);
end
save('diff_Ac_1_pop_2017AD.txt','diff_Ac_pop');
save('diff_irr_1_pop_2017AD.txt','diff_irr_pop');
save('diff_rf_1_pop_2017AD.txt','diff_rf_pop');
save('irr_1_2017AD.txt','irr_zero');
save('rf_1_2017AD.txt','rf_zero');
save('pop_1_2017AD.txt','pop_zero');
txt_per_QGis(diff_Ac_pop,'diff_Ac_1_pop_2017AD','0','0.0833333','2')
txt_per_QGis(diff_irr_pop,'diff_irr_1_pop_2017AD','0','0.0833333','2')
txt_per_QGis(diff_rf_pop,'diff_rf_1_pop_2017AD','0','0.0833333','2')
txt_per_QGis(irr_zero,'irr_1_2017AD','0','0.0833333','2');
txt_per_QGis(rf_zero,'rf_1_2017AD','0','0.0833333','2');
txt_per_QGis(pop_zero,'pop_1_2017AD','0','0.0833333','2');
```

7.1.3 Matlab code for the Standar Deviation calculation:

```
if exist('diff_Ac_pop_2017ADmod.txt')
    diff=dlmread('diff_Ac_pop_2017ADmod.txt');
%Trasformo no data in 0
diff_zero=zeros(size(diff));
for i=1:numel(diff_zero)
    if diff(i)==-9999
        diff_zero(i)=0;
    else
        diff_zero(i)=diff(i);
    end
end
%transforming to array
diff_A=diff_zero(:);
var=std(diff_A);
print var
var
end
```

7.1.4 Matlab code for the Lorenz Curve and Gini Index calculation

It has been calculated all the Lorenz Curve for all the years of our data with the following Matlab code.

```
for j=0:10000

cd('C:\Users\CLIENTE\Desktop\Tesis_Final\T\TESIS\TesisGer\DatosParaLlegar
ALorenz\land_use_txt\tot_irri')
    if exist(['tot_irri2000',num2str(j),'AD_1.txt'])

irr=dlmread(['C:\Users\CLIENTE\Desktop\Tesis_Final\T\TESIS\TesisGer\Datos
ParaLlegarALorenz\land_use_txt\tot_irri\tot_irri2000AD_1',num2str(j),'AD_
1.txt']);

rf=dlmread(['C:\Users\CLIENTE\Desktop\Tesis_Final\T\TESIS\TesisGer\DatosP
araLlegarALorenz\land_use_txt\tot_rainfed\tot_rainfed2000AD_1',num2str(j)
,'AD_1.txt']);

pop=dlmread(['C:\Users\CLIENTE\Desktop\Tesis_Final\T\TESIS\TesisGer\Datos
ParaLlegarALorenz\Pop_txt\popc_2000AD_1',num2str(j),'BC_1.txt']);

        %Trasformo no data in 0
        irr_zero=zeros(size(irr));
        for i=1:numel(irr_zero)
            if irr(i)==-9999
                irr_zero(i)=0;
            else
                irr_zero(i)=irr(i);
            end
        end
        pop_zero=zeros(size(pop));
        for i=1:numel(pop)
            if pop(i)==-9999 || pop(i)==0
                pop_zero(i)=0.000000001;
            else
                pop_zero(i)=pop(i);
            end
        end
        rf_zero=zeros(size(rf));
        for i=1:numel(rf_zero)
            if rf(i)==-9999
                rf_zero(i)=0;
            else
                rf_zero(i)=rf(i);
            end
        end
        %transforming to array
        irr_A=irr_zero(:);
        pop_A=pop_zero(:);
        rf_A=rf_zero(:);
        %ordino sulla base del rapporto irr/pop
        ratio_irr=irr_A./pop_A;
        irr_A=[irr_A ratio_irr];
        pop_A_irr=[pop_A ratio_irr];
```

```
        irr_ord=sortrows(irr_A,2);
        pop_ord_ir=sortrows(pop_A_irr,2);

        %ordino sulla base del rapporto rf/pop
        ratio_rf=rf_A./pop_A;
        rf_A=[rf_A ratio_rf];
        pop_A_rf=[pop_A ratio_rf];
        rf_ord=sortrows(rf_A,2);
        pop_ord_rf=sortrows(pop_A_rf,2);

        %cumulo
        irr_cum=cumsum(irr_ord(:,1))/sum(irr_ord(:,1));
        pop_cum_ir=cumsum(pop_ord_ir(:,1))/sum(pop_ord_ir(:,1));

        rf_cum=cumsum(rf_ord(:,1))/sum(rf_ord(:,1));
        pop_cum_rf=cumsum(pop_ord_rf(:,1))/sum(pop_ord_rf(:,1));

        %Gini
        elements=length(irr_cum);
        gini_temp_irr=zeros((length(elements)-1),1);
        gini_temp_rf=zeros((length(elements)-1),1);
                   for y=1:(elements-1)
              g_temp_irr=(irr_cum(y,1)+irr_cum(y+1,1)).*(pop_cum_ir(y+1)-
pop_cum_ir(y));

g_temp_rf=(rf_cum(y,1)+rf_cum(y+1,1)).*(pop_cum_rf(y+1)-pop_cum_rf(y));
                       gini_temp_irr(y)=g_temp_irr;
                       gini_temp_rf(y)=g_temp_rf;
                   end
        Gini_irr=(1-sum(gini_temp_irr));
        Gini_rf=(1-sum(gini_temp_rf));
        %Curva di Lorentz
        plot(pop_cum_ir,irr_cum,'b')
        hold on
        plot(pop_cum_rf,rf_cum,'g')
        hold off
        axis([0 1 0 inf]);
        title(['Lorenz curve for irrigated areas vs population -
',num2str(j),' BC']);
        xlabel('Normalized cumulated population');
        ylabel('Normalized cumulated irrigated area');
        str=['Gini index irrigated =',num2str(Gini_irr),' Gini index
rainfed =',num2str(Gini_rf)];
        dim=[0.15,0.6,0.4, 0.1];
        annotation('textbox',dim,'String',str,'Tag','254_palmoil');
        legend({'irrigated areas','rainfed
areas'},'Location','northwest');

saveas(gcf,['Lorentz_areas_for_15crops_2000AD_1',num2str(j),'BC_world.jpg
']);
        delete(findall(gcf,'Tag','254_palmoil'));
    else
       continue
    end
end
```

7.1.5 Matlab code for the Regions matrix calculation

In order to mathematically recognize the regions of our interest, from a matrix with specific values for each country, and knowing the data of which region number belongs to each country identification number, the Regions matrix has been calculated. This matrix has data from numbers 1 to 9 to identify which region from 1 to 9 each cell belongs to. This calculation was made with the following Matlab code.

```
if exist('gridded_country_FAO_correct.mat')
    region=importdata('gridded_country_FAO_correct.mat');
    WBcode=importdata('WBcode.mat');
A =
[2,3,4,5,6,7,258,30,8,9,1,22,10,11,52,12,13,16,14,57,255,15,23,53,17,18,1
9,80,20,31,21,24,239,26,27,233,29,115,32,33,34,35,36,37,39,40,351,357,96,
128,41,214,42,43,44,45,46,250,47,48,107,98,49,50,167,51,54,72,55,56,58,59
,60,61,178,63,238,62,261,65,64,66,67,68,69,70,71,74,75,76,73,79,78,77,81,
82,84,85,86,87,88,89,90,175,91,93,92,94,95,97,99,100,101,102,103,104,105,
106,109,110,111,112,108,114,83,116,117,118,113,120,119,121,122,123,124,12
5,126,256,154,129,130,131,132,133,134,127,135,136,137,270,138,145,139,146
,140,141,273,142,143,144,28,147,148,149,150,151,152,153,156,157,158,159,1
60,161,163,162,299,221,164,165,180,166,168,169,170,171,172,173,174,177,17
9,182,183,185,184,187,188,189,190,191,244,192,193,194,195,272,186,196,197
,200,199,198,25,201,202,271,203,38,206,207,260,209,210,211,212,208,215,21
6,176,217,218,219,220,222,223,213,224,227,226,230,225,229,232,231,240,252
,234,228,235,155,236,237,242,243,245,205,249,246,247,248,251,181];
B =
[1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,
28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,0,0,47,48,49,50,
51,52,53,54,55,56,57,58,59,60,61,62,63,64,65,66,67,68,69,70,71,72,73,74,7
5,0,0,76,77,78,79,80,81,82,83,84,85,0,86,87,88,89,90,91,92,93,94,95,96,97
,98,99,100,101,102,103,104,105,106,107,108,109,110,111,112,113,114,115,11
6,117,118,119,120,121,122,123,124,125,126,127,128,129,130,131,132,133,134
,135,136,137,138,139,140,141,142,143,144,145,146,147,148,149,150,151,152,
153,154,155,156,157,158,159,160,161,0,162,163,164,165,166,167,168,169,170
,171,172,173,174,175,176,177,178,179,180,181,182,183,184,185,186,187,188,
189,190,191,192,193,194,195,196,197,198,199,200,201,202,203,204,205,206,2
07,208,209,210,211,212,213,214,215,216,217,218,219,220,221,222,223,224,22
5,226,227,228,229,230,231,232,233,234,235,236,237,238,239,240,241,242,243
,244,245,246,247,248,0,249,250,251,252,253,254,255];

sz=size(region);
m=sz(1,1);
n=sz(1,2);
region_zero=zeros(size(region));
for i=1:numel(region_zero)
    if region(i)==-9999
        region_zero(i)=0;
    else
        region_zero(i)=region(i);
    end
end
regio=zeros(size(region));
```

```
for i=1:m
    for j=1:n
        if region_zero(i,j) == 0
            regio(i,j)=0;
        else
            temp=region_zero(i,j);
            for l = 1:262
                if A(l)== temp
                    posizione = B(l);
                    reg=0;
                    if posizione > 0
                        reg=WBcode(posizione);
                    end
                    regio(i,j)=reg;
                end
            end
        end
    end
end
% %region_zero(550,2250)
% regio(550,2250)
save('regions.txt','regio');
txt_per_QGis(regio,'regions','0','0.0833333','2')
```

7.2 Tables

7.2.1 Table of probabylities

The following table have the probability of differences, gamma and alpha values for 2017 AD.

Table 11 Probability of differences, gamma and alpha values

Values	diff(i)	p(diff(i))	gamma(i)	p(gamma(i))	alfa(i)	p(alfa(i))
-1<v<-0,9	0	0	-	-	-	-
-0,9<v<-0,8	0	0	-	-	-	-
-0,8<v<-0,7	0	0	-	-	-	-
-0,7<v<-0,6	0	0	-	-	-	-
-0,6<v<-0,5	0	0	-	-	-	-
-0,5<v<-0,4	0	0	-	-	-	-
-0,4<v<-0,3	0	0	-	-	-	-
-0,3<v<-0,2	0	0	-	-	-	-
-0,2<v<-0,1	0	0	-	-	-	-
-0,1<v<0	0	0	-	-	-	-
0<v<0,1	425123	0,4434203	431420	0,44600803	1350007	0,998723859
0,1<v<0,2	124470	0,12982719	124652	0,12886698	1179	0,000872214
0,2<v<0,3	86447	0,09016768	86570	0,08949728	303	0,000224157
0,3<v<0,4	70922	0,07397448	70925	0,07332326	120	8,8775E-05
0,4<v<0,5	64159	0,0669204	64026	0,06619097	57	4,21681E-05
0,5<v<0,6	65048	0,06784767	64510	0,06669134	29	2,1454E-05
0,6<v<0,7	65960	0,06879892	66584	0,06883547	19	1,4056E-05
0,7<v<0,8	37340	0,03894711	37511	0,0387794	7	5,17854E-06
0,8<v<0,9	13176	0,0137431	14823	0,01532422	7	5,17854E-06
0,9<v<1	6091	0,00635316	6271	0,00648305	4	2,95917E-06
tot	958736	1	967292	1	1351732	1

Where:

- values, is the range of values.
- diff(i), is the amount of differences data that fall in each range of values.
- p(diff(i)), it is the probability that a difference data is from that range of values.
- gamma(i), is the amount of gamma data that fall in each range of values.
- p(gamma(i)), it is the probability that a gamma data is from that range of values.
- alfa(i), is the amount of alfa data that fall in each range of values.
- p(alfa(i)), it is the probability that a alfa data is from that range of values.
- tot, refers to the total sum of all ranges of values.

7.2.2 Table of standard deviation

Standard deviation values for all the years of our data, from 0 AD, of the difference's values calculated with cultivated area with and without irrigation are in the table below.

Table 12 Standar deviation for all years with data of cultivated area rainfed and irrigated

Year	irrigated_σ	rainfed_σ
0	0,0041	0,0222
100	0,0041	0,0216
200	0,0042	0,0209
300	0,0039	0,0184
400	0,0041	0,0182
500	0,0041	0,0179
600	0,0042	0,0187
700	0,0043	0,0177
800	0,0045	0,0170
900	0,0050	0,0186
1000	0,0052	0,0187
1100	0,0055	0,0252
1200	0,0056	0,0285
1300	0,0049	0,0285
1400	0,0045	0,0252

1500	0,0049	0,0297
1600	0,0052	0,0316
1700	0,0049	0,0349
1720	0,0053	0,0359
1750	0,0061	0,0398
1780	0,0075	0,0386
1810	0,0091	0,0426
1840	0,0021	0,0466
1870	0,0156	0,0466
1900	0,0179	0,0552
1910	0,0202	0,0582
1920	0,0223	0,0589
1930	0,0228	0,0619
1940	0,0230	0,0652
1950	0,0252	0,0676
1960	0,0295	0,0812
1970	0,0318	0,0832
1980	0,0135	0,0819
1990	0,0386	0,0818
2000	0,0405	0,0772
2001	0,0411	0,0774
2002	0,0413	0,0770
2003	0,0416	0,0773
2004	0,0417	0,0775
2005	0,0419	0,0778
2006	0,0418	0,0774
2007	0,0420	0,0775
2008	0,0431	0,0776
2009	0,0437	0,0774
2010	0,0449	0,0772

2011	0,0447	0,0779
2012	0,0413	0,0790
2013	0,0415	0,0788
2014	0,0417	0,0790
2015	0,0418	0,0795
2016	0,0420	0,0797
2017	0,0422	0,0799

7.2.3 Table of Gini index

The table below shows the Gini indices calculated for all the years of our data from 0 AD:

Table 13 Gini Index for all years for cultivated area rainfed and irrigated

YEAR	Irrigated GINI	Rainfed GINI
0	0,992	0,706
100	0,992	0,705
200	0,991	0,705
300	0,990	0,706
400	0,991	0,706
500	0,991	0,706
600	0,990	0,705
700	0,990	0,702
800	0,989	0,696
900	0,989	0,692
1000	0,988	0,688
1100	0,990	0,683
1200	0,991	0,678
1300	0,991	0,671
1400	0,992	0,681

1500	0,992	0,688
1600	0,989	0,613
1700	0,990	0,594
1720	0,989	0,578
1750	0,986	0,557
1780	0,982	0,554
1810	0,976	0,563
1840	0,967	0,593
1870	0,957	0,619
1900	0,953	0,680
1910	0,951	0,706
1920	0,947	0,725
1930	0,945	0,743
1940	0,943	0,759
1950	0,942	0,774
1960	0,923	0,804
1970	0,919	0,825
1980	0,910	0,843
1990	0,907	0,850
2000	0,896	0,866
2001	0,893	0,869
2002	0,891	0,871
2003	0,888	0,874
2004	0,887	0,875
2005	0,886	0,877
2006	0,885	0,878
2007	0,884	0,879
2008	0,884	0,880
2009	0,884	0,881
2010	0,883	0,882

2011	0,882	0,884
2012	0,882	0,885
2013	0,882	0,885
2014	0,881	0,886
2015	0,881	0,887
2016	0,880	0,887
2017	0,880	0,888