High Spatial Analysis on the Effects of Climate Change on Cereal Yield in Greece

Ioanna Gkiza[1]*, Stefanos Nastis[1]

Abstract

The aim of this study is to analyze the spatial dimension of economic impacts on cereal yields due to climate change by analyzing data on rainfall as well as soil and geophysical data. We evaluate the effects of climate change on cereal yields using time series data from 1984 to 2014 and future climate A2 emission scenario. The results showed that crop yield is clearly influenced by spatial geophysical, soil and climate variables. Finally, adaptation and mitigation measures that must be taken in order to tackle climate change are discussed.

Keywords: *Spatial Analysis, Cereal Yield, Climate Change*
JEL classification: Q01,Q10,Q51,C21

Introduction

The aim of this study is to collect climatic, soil, geophysical and social data through spatial heterogeneity at any point in Greece, as well as to evaluate the economic impacts of climate changes on cereal yield. High spatial analysis, from 10 x 10 km^2 grid cells allows us to derive more detailed results for more regions of Greece and determining on areas facing particular problems due to climate change. The high spatial resolution of grid cells will be of particular importance in explaining country-wide variation in yields and it is also an appropriate method because of the diversity of even neighboring regions in terms of climate and soil characteristics. It is worth mentioning that spatial analysis of crop yields has not been performed at this high resolution in Greece in the past. Finally, with the above high spatial resolution, we will concentrate on the point source of the problem, without being distracted by some areas that could not possibly affect our results.

In addition to analyzing the data in high spatial resolution, a significant advantage of this research is the type of variables it employs. A large number of surveys use climate models as well as crop yield models (Nelson and Shively 2014, Giannakopoulos et al. 2009, Kapetanakis and Resenzeweig 1997, Tobey et al. 1992, Knox et al. 2012, Schelenker and Lobel 2010, Laux et al. 2010) that do not capture spatial heterogeneity as opposed to the present study that analyzes historical climatic data as well as historical crop yield data on a detailed spatial scale.

A number of studies employ climate models and crop models in combination with statistical models to study the effect of climate change an crop yields for example Adams et al. (1988), Nelson and Shively (2014). In addition, a number of studies employ only statistical models for example Ward et al. (2011), Dasgupta et al. (2013).

[1] Dept. of Agricultural Economics, Aristotle University of Thessaloniki, 541 24, Thessaloniki
Emails: gkiza@agro.auth.com; snastis@auth.gr

There are several studies in the annotated bibliography using simulations to study the effects of climate change on crop productivity for example Nelson and Shively (2014), Giannakopoulos et al. (2009), Tao et al. (2009), Laux et al. (2010). Finally, several researches employed the Ricardian analysis to test the relative importance of value of agriculture land in explaining net agricultural income for example Ajetomobi et al. (2010), Chatzopoulos et al. (2015), Anwar et al. (2007), Molua and Lambi (2007). However, the literature on spatial analysis of climate on crop yields is sparse.

The IPCC (2007) report concludes that climate change may have a negative or also a positive impact on production depending on the region and the type of the crop. Evenson (1999) and Lobell et al. (2008) agree with the above finding. supporting the negative effects of climate change on agricultural production in developing countries, with similar effects on low-income people and agricultural households highly dependent on agriculture (Antle 2008, Hertal and Rosch 2010, Seo et al. 2009 and Parry et al. 2004). These adverse effects are predicted to be more severe in sub-Saharan Africa and other isolated areas of southwestern and southern Asia (Antle 2008).

Furthermore, research conducted in Greece fully agrees with the IPCC (2007) finding (Georgopoulou et al. 2017, Karamanos et al. 2011), arguing that the least negative effects are observed in the northern and eastern regions, emphasizing that the crops of cereals, corn and cotton are the most sensitive to climate change in contrast to tree crops (Kapetanakis and Rosenzweig 1997, Karamanos et al. 2011). Even Ward et al. (2011) Lobell and Burke (2010) and Tao et al. (2009) highlight the negative effects of climate change on rice and wheat yields. In contrast, the Antle 2008 survey estimated that yields would increase and in most cases would double due to different factors.

Thus, the importance of this research refers to the application of the detailed 10x10 km2 spatial analysis, leading to conclusions about the change of yield in very small areas. The structure of this research is presented as follows. First, we briefly present the data used as well as the methodology. The results are presented next and the conclusions are analyzed in the last part of the survey.

Methodological Framework

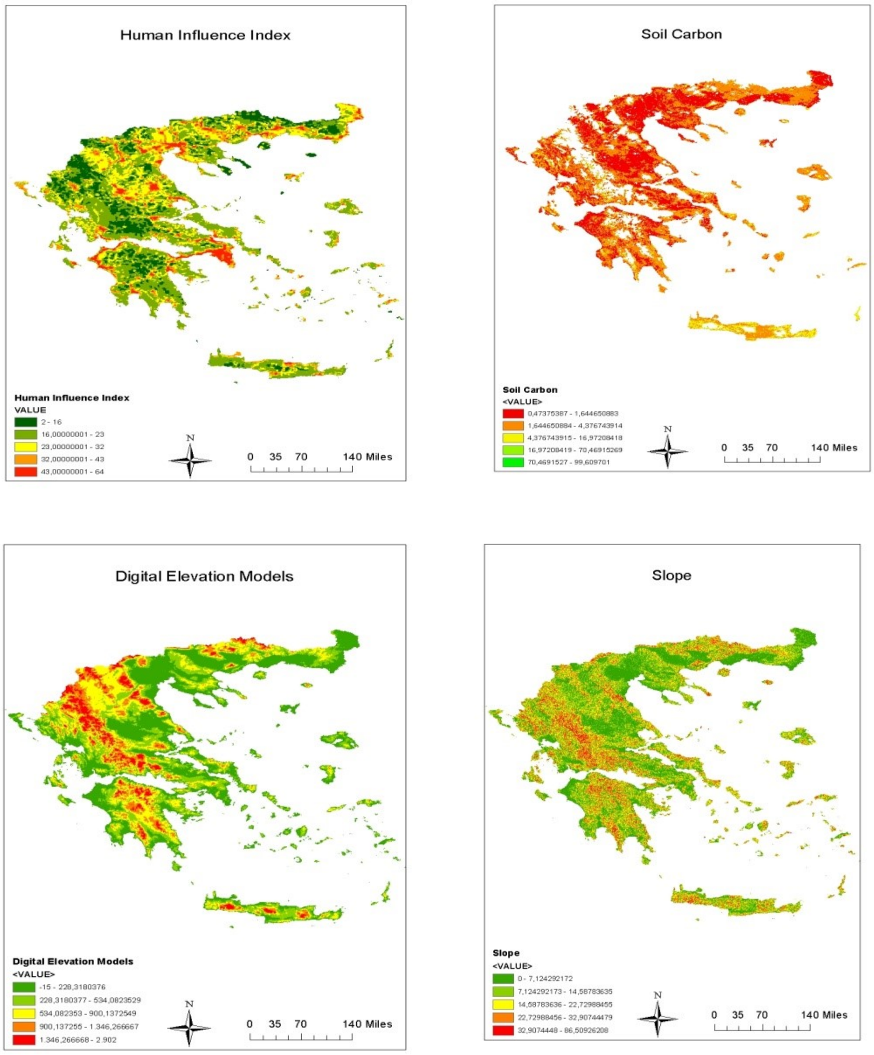
Initially, the total geographical area of Greece was divided into 851 areas, 10 x 10 km^2 grid cells. This grid cell size has been chosen to capture spatial variability between neighboring regions. To capture the spatial dimension of all variables, spatial imagings were selected through ArcGIS commercial software.

The independent variables used in the survey were divided into four categories of geophysical, soil, climatic and social variables, while the dependent variable used was cereal yield. More specifically, geophysical variables employed were the average elevation (m) (Figure 1) within the grid cell, the distance to coast (Km) and the average slope of the grid cell (per cent) (Figure 1). The above geophysical variables were collected by the National Aeronautics and Space Administration (NASA) analyst through the ESRI ArcGIS Spatial Analyst extension software (1 x 1 tiles). These data were collected in 1 * 1 tiles analysis.

In order to control for soil heterogeneity we use data on pH (1x1 km) from European Soil Data Center (ESDAC), Reuter et al. (2008), the soil carbon density (2x2 grid cell Km^2) (Figure 1) (European Soil Data Center (ESDAC), de Brogniez et al. 2015) and soil erosion in tons per hectare (100mx100m grid cell) (European Soil Data Center (ESDAC), Panagos et al. (2015)). According to research carried out by Sanderson et al. (2002), the ecosystems and the atmosphere are greatly influenced by human activities.

As a social variable, the Human influence Index was used (30 arcs second x 30 arc-second grid cell level) (Figure 1). Index values were collected from the Socioeconomic Data and Applications Center (SEDAC). The Human influence Index (HII) measures the impact of humans on terrestrial ecosystems, using data such as population density, land use / land cover, residential areas, access to roads, railway stations, rivers and infrastructure in electricity (night lighting). Sanderson et al. (2002) claims that 83% of the soil surface is affected by a combination of the above factors. Based on all the above, human is the main factor that affects the disorder of ecosystems, affecting both the cultivated area and the quantity produced. Thus, higher human density leads to higher levels of ecosystem change (Sanderson et al. 2002). Index values range from 2-64. Higher values exhibit greater human influence while lower values have less human impact. Because all of the above variables showed a more detailed analysis than the analysis applied in the present study (10x10 km^2 grid cells), the average for each grid cell was calculated.

Figure 1: Analysis - Presentation of the most important independent variables of the research (Human influence Index, soil carbon, elevation, slope).

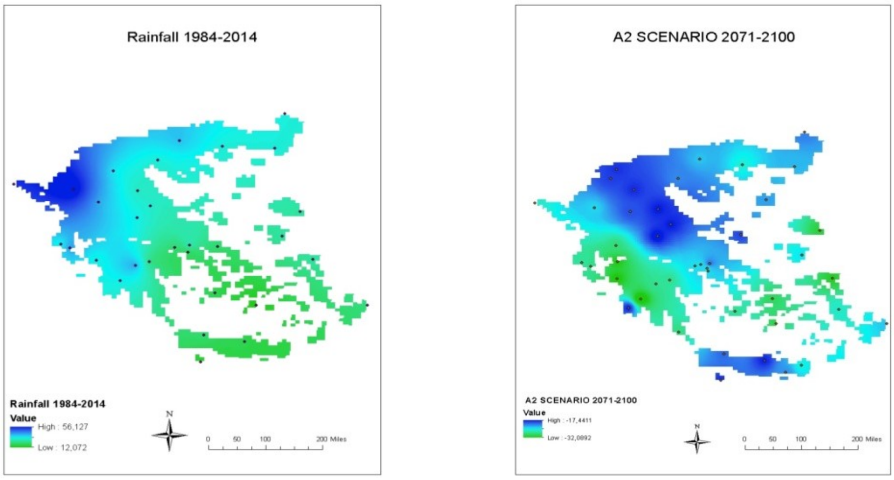


Another variable employed is irrigated land. Wang et al. (2014), Dasgupta et al. (2013) and Laux et al. (2010) stress that climate change should be evaluated differently in dryland and in irrigated crops. Finally, the average cereal yields for the years 2000-2010 were used. The yield variable was chosen because it is a determinant of rural prosperity and development of a country (Daskupta et al. 2013) and is directly linked to the variables investigated by other researchers. Also, agricultural yields are important for determining socio-economic results. The cereal yield and irrigation crops data were aggregated to 10x10 km^2 grid cell in order for them to be spatially joined and were selected from the Hellenic Statistical Authority. The cereal yield is directly linked to the producers' income. Also, agricultural yields are important for determining socio-economic results. The yield and irrigation crops data were aggregated to 10x10 km^2 grid cell in order for them to be spatially joined.

Because of the differences in cereal yields and climate events across Greece, it is also of interest to use Spatial Analyses. Spatial Analysis require the mapping of the climatic data on the map and to extract data in the required format.

For the collection of climatic data, 32 stations were selected from the Hellenic National Weather Meteorological Service climate database, which records a large number of climatic data, for the time period 1984-2014. More specifically, the average monthly temperature in ° C and the average monthly rainfall in mm for the cereal growing season (March - September) were analyzed. In order to predict the temperatures and rainfall for the whole study area, the geographic method of kriging was chosen. Figure 2 shows that there is heavy rainfall in western Greece and the islands, and as we go north, rainfall is decreasing.

Figure 2: Average rainfall for years 1984-2014 and scenario A2.



Spatial Ordinary Least Squares (OLS) was then used to determine the variables affecting average cereal yields. A summary of the variables employed are presented in Table 1

Table 1: Summary statistics

Variable	Explanation of variable	Mean	St. Dev.
Y	Cereal yield (tons per hectare)	3,95	2,51
HII	Human Influence Index	26,31	7,30
T	Average growing season monthly temperature (°C)	20,31	0,53
P	Average growing season monthly precipitation (mm)	31,13	6,93
Di	Distance to coast (km)	28110,47	28054,71
Sl	Average slope (percent)	26,53	13,11
El	Elevation (m)	436,59	359,74
IRR	Irrigated area (ha)	294,86	7356,66
Ph	Soil pH index	6,50	0,42
Ca	Soil carbon density (percent)	2,53	1,47
Er	Soil erosion (tons per hectare)	5,25	8,71

Finally, the simulation system will be implemented with the Intergovernmental Panelon Climate Change (IPCC) A2 scenario for years 2071-2100. Initially the IPCC in 2000 analyzed scenarios for achieving Climate Change Simulation Special Report on Emission Scenarios (SRES) and then in 2014 an upgrade of these scenarios Representative Concentration Pathways (RCP) was carried out. The scenario A2 used in this study approximates the upgraded RCP 8.5 scenario (Georgakopoulos 2017). The collection of future climate data was carried out from the geo-ellinikos-eagean.gr website. The format of the data was 50x50 km (spatial resolution) and a more detailed 10x10 km^2 resolution was conducted with the help of the kriging method.

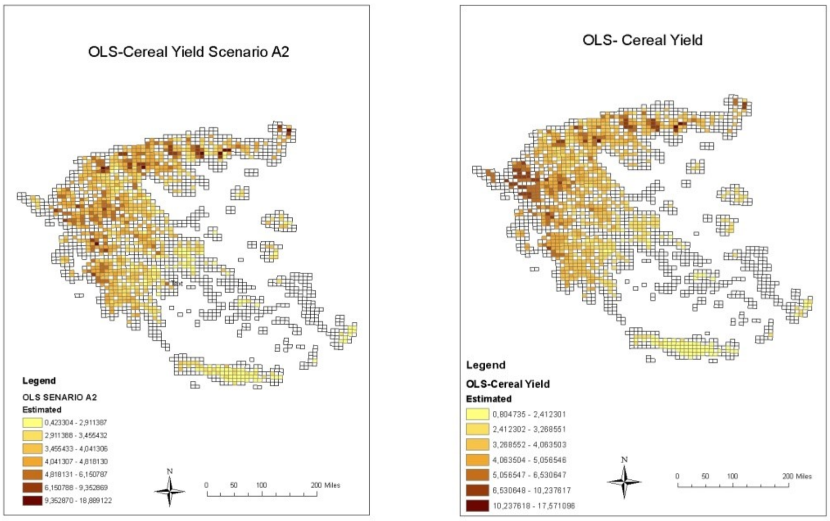
The results of all climate models are subjected to the problem of bias correction. To deal with this problem, several bias correction methods have been recently developed. The simplest method that can be used in order to approach the actual results is by using the correction factor. In bibliography correction factor is defined as the ratio of the mean value of observational data to the mean value of simulation data. The results reveal that the actual data are similar to the simulated data.

For scenario A2, a maximum increase in temperature of 4.48 ° C is predicted and rainfall decreases by 30.09 mm (IPCC 2007). A2 scenario was chosen because it is the most widely accepted scenario (Nastis et al. 2012), but at the same time the most extreme. This allows us to draw conclusions about the extreme changes in production. This scenario is characterized by a heterogeneous world with a large increase in the world population, but with an average increase in world per capita income. Technological development and economic growth are more limited than in other scenarios. Finally, CO_2 in the atmosphere will reach 850 ppm in 2100, which is much higher than CO_2 levels compared to other scenarios (Karamanos et al. 2011).

Results

At first, the multicollinearity of the variables is checked. Variables with large VIF values (above 7.5, for example) are redundant. Thus, controlling for multicollinearity the pH measurements and the temperature were dropped.

Figure 3: Change in cereal yields by the method OLS and A2 scenario



Based on the results of the analysis, rainfall, elevation, irrigation area and slope are statistically significant at a significance level of 0.05. More specifically, the rainfall elasticity is 0.132, implying an increase in rainfall which leads to an average increase in cereal yields in the whole of Greece. Ward et al. (2011), Lobell and Burke (2010) also agree with the above result, highlighting the increasing production due to the increase in rainfall.

Table 2. Results of spatial OLS

	1985-2014		**A2 2071-2100**	
	Estimation	**Std Error**	**Estimation**	**Std Error**
Constant	-0.799620	0.605137	2,724291	0,517741
Human influence Index	-0.000923	0.011576	-0,015661	0,012149
Rainfall	0.132044	0.012938*	0,010327	0,003902*
Distance to Shore	-0.000003	0.000003	0,000010	0,000003*
Slope	0.026164	0.009858*	0,043522	0,010255*
Elevation	-0.001452	0.000392*	-0,001474	0,000414*
Irrigated area	0.000145	0.000010*	0,000158	0,000011*
Soil Carbon	0.067450	0.067450	0,102976	0,059358**
Soil Erosion	0.015531	0.008410	0,033650	0,008686*
	R2= 0.35 N=851 * Significance level of 0.10 ** Significance level of 0.05		R2= 0.27 N=851 * Significance level of 0.10 ** Significance level of 0.05	

Another important variable that presents a positive correlation is crop irrigation. Adams et al. (1988) and Ward et al. (2011) agree by highlighting the importance of growing crops in irrigated fields. Statistically significant factor that has a negative correlation with cereal production is average elevation. An increase in elevation by one meter will lead to a reduction in production of 0.00145 t/ha. This is due to the fact that the conditions for the development of cereals are not favorable at high altitudes.

For the A2 scenario, variables that are statistically significant at a significance level of 0.05 are rainfall, distance to shore, slope, elevation, irrigation crops and soil erosion. While organic carbon is statistically significant at a significance level of 0.10. In this simulation, the variables changing were the climate variable. All others remained the same.

The variables to be thoroughly analyzed are rainfall, distance to shore and organic carbon (Table 2), as they show an obvious variation in the average cereal yield, from today to 2100, as for rainfall, a positive correlation is observed. Comparing results it is observed that average cereal yield will decrease from 0.13 t / ha to 0.01 t / ha. Thus, by 2100, there will be a significant reduction in the average cereal yield to reach 0.12 t / ha. This is due to the extreme weather phenomena that will be intense in the future and as a result production will be negatively affected. Recent studies point to an increase of extreme events and expect to affect volatility of yields (Powell and Reinhard 2016). Extreme events are expected to affect the volatility of yields and are seen as the principle immediate threat to global crop production (Powell and Reinhard 2016, van der Velde et al. 2012, Moriondo et al. 2011).

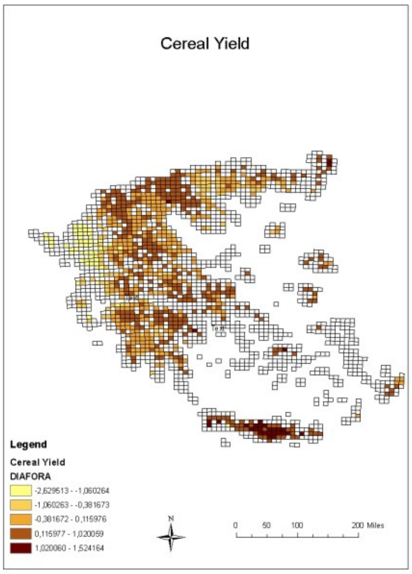
It is also observed that as the distance to shore increases, the average cereal yield is higher. This means that the seaside areas do not favor the cultivation of cereals. Many researchers argue that climate change will increase sea levels by 0.4 to 2 meters, resulting in shifting cereal yield to more remote areas off the coast.

Soil organic carbon has a positive correlation with production. In particular, an increase of 1% in soil organic carbon will result in an increase in production of 6.7 t / ha and by 2100 will reach 10.3 t / ha (Table 2).

It is noted that as the erosion and the slope of the soil increase, cereal yield is also increasing. In particular, if we have a 1% rise in soil erosion and slope, we will see a slight increase in yield of 0.033 and 0.043 t / ha respectively. This increase in crop yield is mainly due to the relocation of fertile soils to lower soils where cereals may be grown. Soils characterized by a large slope are usually not cultivated with large amounts of organic matter. As the soils are eroded, they move fertile soil with a strong organic substance at lower levels where cereals are grown and their productivity increases. Finally, elevation will not greatly affect the cereal yield until 2100.

Based on the analysis of the survey, some aggregate results were obtained for the whole of Greece. However, the purpose of the survey is the high spatial analysis of the results, so it would be important to refer to specific areas experiencing a large reduction or increase in production. So we will focus on individual areas that are in need of adaptation effects urgently.

Figure 4: Change in average cereal yields by 2100



Based on figure 4, a sharp increase in production in Crete ranges from 1.05 to 1.22 t / ha. More specifically, in the region of Bonn, the highest increase in average cereal yield reaches 1.22 t / ha, whereas at the same time in neighboring areas there is a decrease in production. Also, a significant increase is seen in the eastern Peloponnese in the region of Taktikoupolis by 1.34 t / ha. On the contrary, a significant decrease occurs in the central Peloponnese and more specifically in the region of Magoula reaching 1.00 t / ha and in the eastern Peloponnese in the region of Sageika there is a decrease of 1.09 t / ha. Generally, in Western Greece, we can say that there is a significant reduction in the cereal yields and more specifically in the area of Balahogianni by 2,62 t / ha. This decrease is due to the significant reduced rainfall in this area and the A2 climate scenario (Figure 3). In general, as seen from Figure 3, an increase in production in the Orestiada region and in the area of Nea Vrisi is observed by 1.11 and 1.21 respectively. Finally, a significant increase in cereal yield is observed in the Halastra region by 1.31 t / ha.

Conclusions

The aim of this paper was to spatially analyze the effect of climate change on cereal yield and to predict change in cereal yields by 2100 due to climate change using the A2 climate change scenario. Through the results of the analyses, we will seek to propose some measures to adapt and mitigate climate change. In this way, the decline in average cereal yield in Greece will be reduced, aiming at the stability or even increase of producers' income, as well as the self-sufficiency of Greece in cereals. The variation in the income of producers is largely due to the change in the average yield of cereals.

Based on the above there will be a shift in cereal yield from west to north and south. So, the Western regions turn to other crops that are more profitable and the Northern and the Southern regions, which are favored by climate change, increase the area of irrigated cereal while also increasing their income. The increase in irrigated areas can be achieved through policy measures aimed at better disposing of irrigation resources in these areas. Therefore, investments must be made so as to install new irrigation infrastructure and improve the existing ones, and measures must also be taken to reduce the price of irrigation water and the agricultural electricity you use for irrigation purposes. Finally, economic support is needed for farmers to turn to the appropriate crops that are favored by the climatic conditions that exist in each area.

This paper presents some novelties. As the results of the analysis show in neighboring areas there is a significant change in production, more specifically some areas may show increase while their neighboring areas show a significant reduction in production. This result entirely justifies the detailed spatial analysis (10x10 km^2) used in the methodology, which is important to extend and for other cultivations.

In conclusion, we must stress that climate change will have a significant impact on cereal yields if no adaptation and mitigation measures are taken. So there must be cooperation of nature, ecosystems and anthropogenic activities to adapt to and mitigate climate change.

References

Adams, R. M., McCarl, B. A., Dudek, D. J., & Glyer, J. D. (1988). Implications of global climate change for western agriculture. Western Journal of Agricultural Economics, 348-356.

Antle, J. M. (2008). Climate change and agriculture: economic impacts. Choices, 23(1), 9-11.

Anwar, M. R., O'Leary, G., McNeil, D., Hossain, H., & Nelson, R. (2007). Climate change impact on rainfed wheat in south-eastern Australia. Field Crops Research, 104(1-3), 139-147.

Ajetomobi, J. O., Abiodun, A. J. I. B. O. Y. E., & Hassan, R. A. S. H. I. D. (2010). Economic impact of climate change on irrigated rice agriculture in Nigeria. In Contributed paper presented at the Joint 3rd African Association of Agricultural Economists (AAAE) and 48th Agricultural Economists Association of South Africa (AEASA) Conference, Cape Town, S. Africa, Sept (pp. 19-23).

Chatzopoulos, T., & Lippert, C. (2015). Endogenous farm-type selection, endogenous irrigation, and spatial effects in Ricardian models of climate change. European Review of Agricultural Economics, 43(2), 217-235.

Dasgupta, P., Bhattacharjee, D., & Kumari, A. (2013). Socio-economic analysis of climate change impacts on foodgrain production in Indian states. Environmental Development, 8, 5-21.

De Brogniez, D., Ballabio, C., Stevens, A., Jones, R. J. A., Montanarella, L., & van Wesemael, B. (2015). A map of the topsoil organic carbon content of Europe generated by a generalized additive model. European Journal of Soil Science, 66(1), 121-134.

European Soil Data Center (ESDAC), Date of access: 21/12/2017, https://esdac.jrc.ec.europa.eu/content/soil-atlas-europe

Evenson, R. E. (1999). Global and local implications of biotechnology and climate change for future food supplies. Proceedings of the National Academy of Sciences, 96(11), 5921-5928.

Geoclima, https://geoclima.aegean.gr/el/, Date of access: 21/12/2017

Georgakopoulos Th., (2017) The Impact of Climate Change on the Greek Economy Research and Policy Institute

Georgopoulou, E., Mirasgedis, S., Sarafidis, Y., Vitaliotou, M., Lalas, D. P., Theloudis, I., & Zavras, V. (2017). Climate change impacts and adaptation options for the Greek agriculture in 2021–2050: A monetary assessment. Climate Risk Management, 16, 164-182.

Giannakopoulos, C., Le Sager, P., Bindi, M., Moriondo, M., Kostopoulou, E., & Goodess, C. M. (2009). Climatic changes and associated impacts in the Mediterranean resulting from a 2 C global warming. Global and Planetary Change, 68(3), 209-224.

Hellenic National Weather Meteorological, Date of access: 21/11/2017, http://www.hnms.gr/emy/el/

Hellenic Statistical Authority, Date of access: 21/09/2017, http://www.statistics.gr/en/home/

Hertel, T. W., & Rosch, S. D. (2010). Climate change, agriculture and poverty. The World Bank.

IPCC 2007: Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland, 104 pp.

Kapetanaki, G., & Rosenzweig, C. (1997). Impact of climate change on maize yield in central and northern Greece: A simulation study with CERES-Maize. *Mitigation and Adaptation Strategies for Global Change*, *1*(3), 251-271.

Karamanos A., Skourtos M.,Boloudakis D.,Kontogianni A.,Maxleras A., (2011), Environmental, Economic and Social Impact of climate change in Greece, Bank of Greece.

Knox, J., Hess, T., Daccache, A., & Wheeler, T. (2012). Climate change impacts on crop productivity in Africa and South Asia. *Environmental Research Letters*, *7*(3), 034032.

Laux, P., Jäckel, G., Tingem, R. M., & Kunstmann, H. (2010). Impact of climate change on agricultural productivity under rainfed conditions in Cameroon—A method to improve attainable crop yields by planting date adaptations. Agricultural and Forest Meteorology, 150(9), 1258-1271.

Lobell, D. B., Burke, M. B., Tebaldi, C., Mastrandrea, M. D., Falcon, W. P., & Naylor, R. L. (2008). Prioritizing climate change adaptation needs for food security in 2030. Science, 319(5863), 607-610.

Lobell, D. B., & Burke, M. B. (2010). On the use of statistical models to predict crop yield responses to climate change. Agricultural and forest meteorology, 150(11), 1443-1452.

Molua, E. L., & Lambi, C. M. (2007). The Economic Impact Of Climate Change On Agriculture In Cameroon, Volume 1of 1. The World Bank.

Moriondo, M., Giannakopoulos, C., & Bindi, M. (2011). Climate change impact assessment: the role of climate extremes in crop yield simulation. Climatic Change, 104(3-4), 679-701.

Nastis, S. A., Michailidis, A., & Chatzitheodoridis, F. (2012). Climate change and agricultural productivity. African Journal of Agricultural Research, 7(35), 4885-4893.

National Aeronautics and Space Administration (NASA), Date of access: 21/11/2017, https://www.nasa.gov/.

Nelson, G. C., & Shively, G. E. (2014) a. Modeling climate change and agriculture: an introduction to the special issue. Agricultural Economics, 45(1), 1-2.

Panagos, P., Borrelli, P., Poesen, J., Ballabio, C., Lugato, E., Meusburger, K., & Alewell, C. (2015). The new assessment of soil loss by water erosion in Europe. Environmental science & policy, 54, 438-447.

Parry, M. L., Rosenzweig, C., Iglesias, A., Livermore, M., & Fischer, G. (2004). Effects of climate change on global food production under SRES emissions and socio-economic scenarios. Global environmental change, 14(1), 53-67.

Powell, J. P., & Reinhard, S. (2016). Measuring the effects of extreme weather events on yields. Weather and Climate Extremes, 12, 69-79.

Reuter, H. I., Lado, L. R., Hengl, T., & Montanarella, L. (2008). Continental-scale digital soil mapping using European soil profile data: soil pH. Hamburger Beiträge zur Physischen Geographie und Landschaftsökologie, 19, 91-102.

Sanderson, E. W., Jaiteh, M., Levy, M. A., Redford, K. H., Wannebo, A. V., & Woolmer, G. (2002). The human footprint and the last of the wild: the human footprint is a global map of human influence on the land surface, which suggests that human beings are stewards of nature, whether we like it or not. AIBS Bulletin, 52(10), 891-904.

Schlenker, W., & Lobell, D. B. (2010). Robust negative impacts of climate change on African agriculture. Environmental Research Letters, 5(1), 014010.

Seo, S. N., Mendelsohn, R., Dinar, A., Hassan, R., & Kurukulasuriya, P. (2008). *A Ricardian analysis of the distribution of climate change impacts on agriculture across agro-ecological zones in Africa*. The World Bank.

Socioeconomic Data and Applications Center (SEDAC), Date of access: 21/11/2017, http://sedac.ciesin.columbia.edu/data/set/wildareas-v2-human-footprint-geographic/metadata

Tao, F., Yokozawa, M., & Zhang, Z. (2009). Modelling the impacts of weather and climate variability on crop productivity over a large area: a new process-based model development, optimization, and uncertainties analysis. agricultural and forest meteorology, 149(5), 831-850

Tobey, J., Reilly, J., & Kane, S. (1992). Economic implications of global climate change for world agriculture. Journal of Agricultural and Resource Economics, 195-204.

Van der Velde, M., Tubiello, F. N., Vrieling, A., & Bouraoui, F. (2012). Impacts of extreme weather on wheat and maize in France: evaluating regional crop simulations against observed data. Climatic Change, 113(3-4), 751-765.

Wang, J. X., Huang, J. K., & Jun, Y. A. N. G. (2014). Overview of impacts of climate change and adaptation in China's agriculture. Journal of Integrative Agriculture, 13(1), 1-17.

Ward P., Raymond F., and Flores-Lagunes A. (2011). Climate change and agricultural productivity in sub-Saharan Africa: a spatial sample selection model, Dept. of Agricultural Economics. Purdue University Working.Paper: 11-4.