The Relationship between Climatic Patterns and Staple Crop Yields in USA, China, and India

Nirma Golder, Nabill Huq, Ariel Avgi, Ehsan Najafi, Reza Khanbilvardi

Abstract

As our global population grows, so does the demand for food and by 2050, the world population is projected to reach 9.7 billion. Nevertheless, many countries, especially in Africa, are already suffering from food shortages resulting in starvation. Most of the countries that are experiencing food shortages are also facing crop failure due to extreme weather events including drought making them unable to farm and produce food for themselves. Therefore, the effects of climate change should be taken into account and monitored when looking for a solution to food insecurity. In this project, data was collected from 1961 to 2013 in three countries: China, India, and the United States of America. This study focuses on the area harvested, and the weighted yield of six different crops including barley, maize, rice, sorghum, soybean and wheat. The climatic variables looked at includes drought and El Nino Southern Oscillation (ENSO). Droughts were measured using the Palmer Drought Severity Index (PDSI). Additionally, the effects of carbon dioxide (CO2) levels were also taken into consideration. Lastly, using multiple linear regression, the impacts of these variables on crop yield were identified. Results showed the positive correlations between these variables and weighted crop yield in these countries from 1961 to 2013.

Introduction

As the World Food Summit defines, "Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life". Today, about one billion people in the world are undernourished suffering endless food shortages. When looking for a solution to the problem of global food insecurity, climate change is a very important factor to take into account as most crop failure is due to extreme climatic events like drought.

In this project, data was collected from the years 1961 to 2013. The study also focused on three countries: China, India, and the United States of America as they are some of the most populated and highly agricultural, as well as being some of the biggest exporters providing food to the rest of the world. Lastly, the harvested area and yield for six different crops including barley, maize, rice, sorghum, soybean and wheat was collected from the Food and Agriculture Organizations of the United Nations website. These six crops were chosen because they are the most nutritious and provide most of the calories taken by most of the world, humans and animals. The climatic variables looked at were the El Niño Southern Oscillation (ENSO) and droughts. ENSO is a natural cycle in the Pacific Ocean in terms of winds, temperatures, and clouds and swings between La Niña, Neutral, and El Niño. El Niño is unpredictable and can bring extreme weather of different types to different parts of the world. Droughts were measured using the Palmer Drought Severity Index (PDSI). PDSI is a negative to positive scale where the more negative a number is, the correlating area is dryer, compared to an area corresponding to a higher number meaning it's more wet and the closer the number is to zero, the conditions are considered normal. (Dai et.al) Lastly, the effects of carbon dioxide (CO2) levels were also taken into consideration because crops tend to grow more efficiently when there's more CO2 but the increasing CO2 emissions from burning fossil fuels is one of the biggest causes of climate change and global warming.

Methodology

This project looks at climatic factors and sees how these aspects affect the crop yields of barley, maize, rice, sorghum, soybeans and wheat in the countries of China, India, and the United States. The weighted crop yields are calculated in Excel using data from FAO and the following equation.

$$Y_{it} = \frac{\sum_{k=1}^{Ne} y_{it}^{k} a_{it}^{k}}{\sum_{k=1}^{Ne} a_{it}^{k}}$$

From the years 1961 to 2013, using data from NOAA and from our mentor, the relationship between ENSO, CO2, and PDSI data versus the weighted crop yield of each country was studied using a multiple linear regression model. A multiple linear regression equation models, mathematically, the relationship between one dependent variable and many independent variables using algebra. The equation is as follows.

$$Log(yield_{it}) = \alpha + \beta_1 ENSO_{it} + \beta_2 CO2_t + \beta_3 PDSI_t$$

This known data made it possible to calculate the coefficients in the equation that relate to each of the climatic factors to predict the outcome of crop yield. Once the coefficients were determined, maps were created using ArcMap to show the difference in coefficients for a particular climatic factor among the three countries.

Data and Analysis

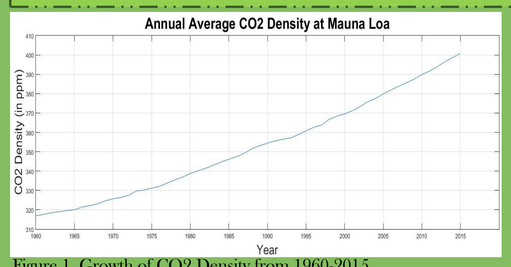

Figure 1. Growth of CO2 Density from 1960-2015

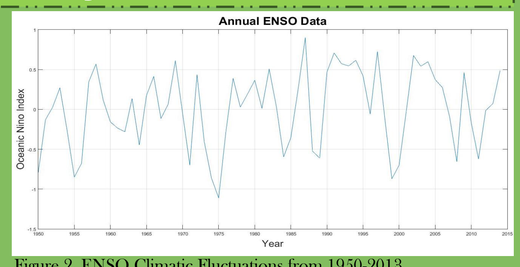

Figure 2. ENSO Climatic Fluctuations from 1950-2013

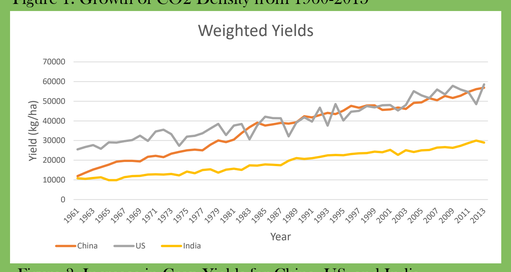

Figure 3. Increase in Crop Yields for China, US, and India

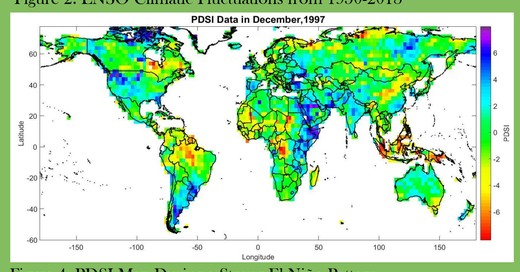

Figure 4. PDSI Map During a Strong El Niño Pattern

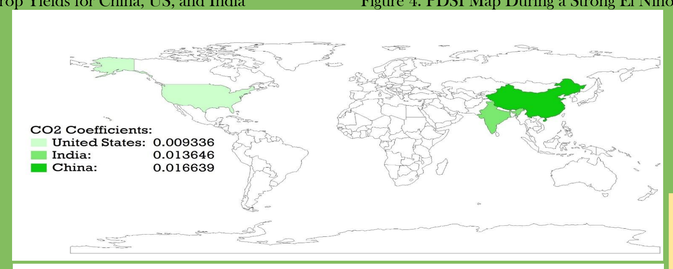

Figure 5.
CO2 Coefficient Value Comparison

Figure 6.
ENSO Coefficient Value Comparison

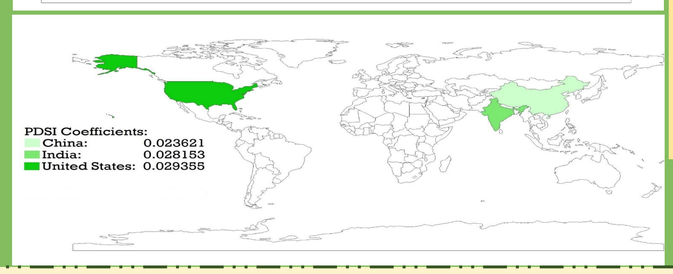

Figure 7.
PDSI Coefficient Value Comparison

The calculations for the coefficients for every climatic factor resulted in a positive value. In particular, China's crop yields are affected the most by CO2 and ENSO compared to India and the United States, while the United States' crop yields are most affected by the PDSI index.

Conclusion

The different climatic variables observed, ENSO, PDSI, and CO2, show a positive impact on yield, in which the coefficients obtained from multiple linear regression are all positive. High PDSI numbers show wet conditions and vice versa . The positive PDSI coefficient values demonstrates that when we have wetter conditions, crop yields responds positively and when PDSI numbers are small and we have drought conditions, yield decreases. The positive CO2 coefficient numbers represents the positive impact of atmospheric carbon dioxide enriched in these countries on six crop yields. However, El Niño and La Niña episode create climatic anomalies, wetter and drier conditions in many parts of the word, the positive ENSO coefficient values show that this large scale climatic pattern in average was beneficial for crop yields of these countries.

More research needs to be done to show if the negative impacts of climate change on food security outweigh the positive impacts it has on crop yield and vice-versa. Additionally, it also needs to be taken into consideration that the three countries focused on, China, India, and the U.S. are all developed or developing countries with advanced tools, fertilizers, and seeds to help adapt to the farming conditions in order to produce enough crops for food. But this does not mean that certain places in these countries aren't facing food shortages due to climate change. The ever changing climate is what makes this topic of food security forever relevant.

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