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Impact of climate change on crop yield of corn (*Zea mays* L.) in the Canton Junín, Province of Manabí

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Abstract---Agriculture provides a significant fraction of the food consumed worldwide. In Ecuador, a large area is dedicated to the production of corn (*Zea mays* L.). However, the progress of current projections in agriculture may be directly affected by climate change and its effects. The present study aims to evaluate the impact of climate change on maize (*Zea mays* L.) crop yields over the last 10 years (2010 - 2020) and to predict future yields under different climate change scenarios proposed by the Intergovernmental Panel on Climate Change (IPCC). Variables such as rainfall, temperatures, heliophany, evapotranspiration, solar radiation, and humidity recorded in the last 10 years on a monthly and annual basis were considered. The data were obtained from two weather stations, and their impact on the yield of this crop on different farms was analyzed by linear regression. The ArcGis program was used to predict the 10-year corn production (yield) under the different IPCC scenarios, through the analysis of the Maxent model for *Zea mays*. The current situation of maize (*Zea mays* L.) in the Junín canton is affected by considerable climatic variations and other serious effects that are detrimental to the local agricultural system. The elaboration of present and future maps through the Maxent software forecast allows concluding that the climatic variables that influence the yield of the maize crop (*Zea mays* L.) are solar radiation and temperature, so it is important to improve the conditions of the population by allowing field support programs that are aligned in conjunction with a good irrigation system planning and an effective improvement of the product.

Keywords---impact, climate change, production, agriculture, maize.

Introduction

Climate change today becomes an issue on a global, economic, and environmental scale, where agricultural productivity is affected by climate variability (Mohammed et al., 2018). Studies recommend adopting conservation farming practices since climate variability threatens food security and production, especially among rural farming households (Samuel et al., 2019). A similar criterion is maintained by (Jiménez 2012), who explains that: In a world subjected to profound transformations, climate change represents a complex threat that in one way or another harms each of the biophysical characteristics of ecosystems, including the efficiency of life of citizens, in turn becoming a natural position of the planet with accounts of natural factors which have altered the structure and dynamics of the atmosphere, causing declines and global expansions in temperature (p. 45).

In Central America, certain crops including maize (*Zea mays* L.) are expected to decrease in production due to the effects of climate change, which would impact regional economies and the livelihoods of smallholder farmers (Viguera et al. 2019). The impact of climate change, in turn, could potentially disrupt progress towards a world without hunger and distinguish a robust and consistent global pattern of impacts on crop productivity that could have consequences for food availability (Wheeler & von Braun 2013).

Considering the criteria of the aforementioned author, Iturbide et al. (2020) state that in order to improve the climatic consistency of regions representing subcontinental areas of greater climatic coherence, different sets of reference climatic regions have been proposed in the literature for the regional synthesis of historical trends and future projections of climate change, where different IPCC assessment reports on the management of risks of external events and disasters have been used to promote climate adaptation.

From the perspective of Morales-Casco and Zúniga-González (2016), these behaviors generate certain unprecedented levels of attention, which becomes an international mobilization to connect proposed actions to mitigate it. Like any ecological problem, climate change has repercussions on various aspects of the life of human beings and species in general. In this sense, Ovares, (2016) explains that in recent years the concern about environmental deterioration is evident, so it seeks great efforts of different Non-Governmental Organizations (NGOs), international forums, regional agreements, and global discussions by the United Nations Organization to create alternatives to climate change.

Sustainable Development Goals 2 and 13 (SDGs) invite to end hunger, achieve food security and nutrition progress. Promoting sustainable agriculture where the agricultural area in which productive agriculture is practiced reflects the three dimensions of production, ensuring the sustainability of food processing systems (Capitán et al., 2019). On the other hand, it takes urgent measures to combat climate change and its impacts, including mitigation, adaptation, and early warning goals to ensure CO₂ emissions are reduced (Cartea 2015). Due to the

close relationship between society, productive activities, and economic development, climate change has become one of the greatest challenges of the present. Agriculture is one of the most sensitive productive activities to this phenomenon that threatens the quality and yield of different crops and, therefore, food security (Torres 2020).

Flores López et al. (2014) state that: The influence of these changes on agriculture is evidenced by the increase in average temperature and atmospheric CO₂ content, which results in higher yields, less precipitation, increased evapotranspiration, and more water in the atmosphere, with serious implications for the global hydrological cycle. Research indicates that agriculture is and continues to be vulnerable to climate change, which causes direct impacts on yields and crop growth due to temperature variation. Climate variables include rainfall, water, light, temperature, relative humidity, air, and wind. There are also abiotic components such as topography and soil (Luna Ayala & Naquiche Yesquen, 2020).

Nelson (2009) mentions the importance of the rainfall variable since significant effects are observed due to changes in rainfall volumes and periods of aridity, causing short-term crop losses and a reduction in long-term production, which is why it is expected that the effects of climate change will be harmful to agriculture, threatening world food security. Ecuador is not deprived of the difficulties caused by climate change, this statement was dictated in the “Second National Communication on Climate Change”, which mentions that among the possible climatic events are dryness by 20%, the “Southern Oscillation El Niño” phenomenon, decrease of species, increased transmission of tropical diseases, melting of glaciers, among others. The Ministry of Agriculture, Livestock, Aquaculture, and Fisheries -MAGAP, (2017) reveals that given the temperature and rainfall projections, climate variations may be verified, even higher than the total projected planetary average (PRECIS ECHAM Model), which would increase the already high vulnerability of the Ecuadorian economy, of a citizenry in a scenario of poverty and ecosystems rich in biodiversity.

Since agriculture in Manabi is one of the main axes of the economic functioning, its sowing systems generate agroecosystem vulnerability, mainly due to soil degradation, erosion, and nutrient extraction, as well as residue burning, which would imply the sustainability of this production system, which should be based on increasing yields to improve the quality of life of the population without affecting its functions and agroecosystem diversity (Hasang-Moran et al., 2021). It is known that the planet has experienced climatic changes throughout its history, and each of these climate transformations has had natural causes, such as meteoric impacts. These changes do not represent a direct human responsibility since they are part of the climatic stability that the planet has experienced throughout history.

Based on previous studies on the impacts of climate change on the yield of short-cycle crops, the present work aims to determine the impact of climate change on the yield of the maize crop “*Zea mays L.*” in Junin Canton, Province of Manabí, defining adaptation measures in terms of area and yield. Based on the biophysical limit that is described in this study, a description of the different zones of Junin

Canton was established, to determine which are the main areas where the different short-cycle products are cultivated, and focus on the most representative crop (corn), to subsequently take different coordinates in the points where the species is found, evaluating the impact of climate change and its incidence on the crop and predicting the effects of climate change on the corn yield (*Zea mays* L.), creating a personalized approach, based on the need to develop alternative agricultural systems that are aligned with today's society, where there are more sustainable forms of production directed to the need to minimize soil degradation and production and which in turn are less aggressive to the environment, where the management of soil, water and crops is considered and which in turn are socially and economically acceptable. It should be noted that the estimates presented above cannot be considered point forecasts, since they are based on probable scenarios, which could be modified and their results could vary. Such data do offer a broad perspective of what the approximate effects of climate change would be like.

Materials and Methods

The study was carried out in the Junín canton, geographically located at 0° 56' 8" south longitude and 80° 11' 0" west longitude in the Province of Manabí, with a territorial extension of 246.07 km², a locality where at least 40,000 hectares are dedicated to agriculture, livestock and poultry farming. It is made up of 5 zones divided in the cantonal capital called Dry, Intermediate, High, and Low Zone, where annual rainfall ranges from 500 to 1000 mm per year, indicating that its average annual rainfall is 1600 mm, as well as rainy weather from January to April and very dry summer, with high and average temperatures ranging between 25 and 29 °C.

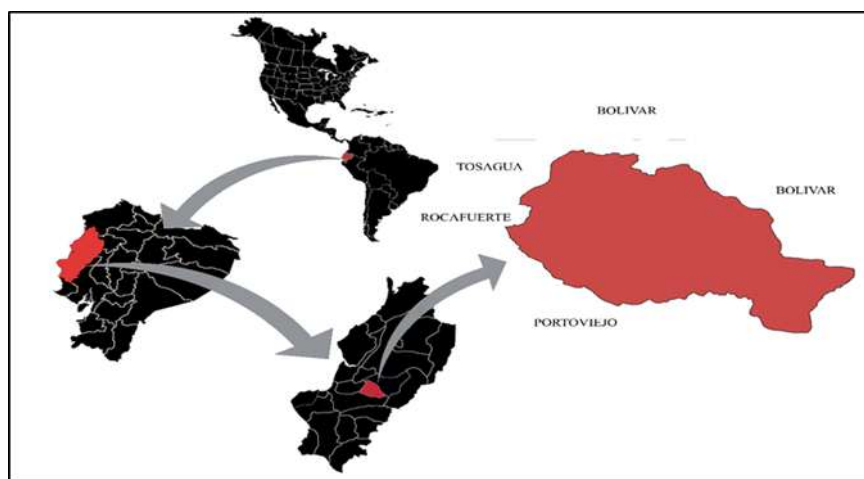


Figure 1. Geographic Location of Junín Canton
Note: The figure shows the study area, Cantón Junín 2022.

According to the National Institute of Statistics and Census (INEC) ESPAC - 2009, the Ministry of Agriculture, Livestock, Aquaculture and Fisheries (MAGAP) states that 54.2% of the territory of the Junín canton is used for cultivated pastures, 21.3% for forests and woodlands, and 12.1% of the land is used for permanent

crops, while the amount of transient crops, natural pastures, rest and other uses is low (PDOT, 2020).

Corn yield

According to the Geoportal of Ecuadorian agriculture, geographic and cartographic information for viewing and downloading based on the needs of each thematic area producing spatial information, agricultural production is obtained from the Ministry of Agriculture and Livestock of Manabí (MAG), and the economic and productive department of the Decentralized Autonomous Government of Junín canton. The coordinates of the areas where the species is present were taken by visiting the different communities of the canton, data that were used in the Maxent software for the present and future prediction, identifying its impact on the cultivated zones in each area.

Data analysis

The research was based on the analysis and inference from information that includes climatic variables and the yield of the corn crop in the Junín canton. For this purpose, the information database of the INAMHI Meteorological Station of the Escuela Superior Politécnica Agropecuaria de Manabí Manuel Félix López, located in the El Limo sector, Bolívar canton, geographically located between the coordinates 0° 49' 23" South Latitude, 80° 11' 01" West Longitude and an altitude of 15 meters above sea level, was analyzed. For the last 10 years (2010 to 2020), the records of climatic variables were considered, such as relative humidity (%), maximum and minimum temperature expressed in degrees Celsius (°C), average temperature (°C), evaporation (mm), and precipitation (mm). For the prediction of the future yield of the corn crop from 2021 to 2030, the ArcGis software was applied with geographic localization in the points of presence of the species.

It should be noted that there are other variables in the database that, although not part of this study, are considered: solar radiation, elevation, wind speed, precipitation, and average temperature to predict crop yield and determine the impact of climate change. For the potential modeling of present and future climatic variables of the corn (*Zea mays* L.) crop, the Maxent software was used to determine the environmental variables that influence crop yield.

Statistical analysis

The predictive analysis was carried out using a linear regression model to determine the correlation of the climatological variables: temperature, precipitation, and heliophany between the periods under study and the yield within each climatic scenario. The statistical program GraphPad Prism was used to perform the regressions.

Table 1. Variables used in the production quantity simulations

STUDY VARIABLES	
DEPENDENT	INDEPENDENT
Corn yield	Relative humidity Temperature Precipitation Heliofania

Source: Own elaboration

Results

The results obtained are relevant to what is expressed by Capitan (2019), who argues that the Development Goals (SDGs) call for the promotion of sustainable agriculture that ensures the security and sustainability of the agricultural area where the dimensions of production are reflected under food production systems and agricultural practices that increase productivity based on the maintenance of ecosystems, adaptation to climate change and soil improvements.

Relative humidity

It is the percentage of saturation of the specific volume of air at a specific temperature. (Deras Flofes. 2020) In his research, he indicates that when relative humidity reaches 65%, fungi begin to appear, which are first manifested in dead grains or seeds or with little vitality, or in live grains or seeds that have broken the cover.

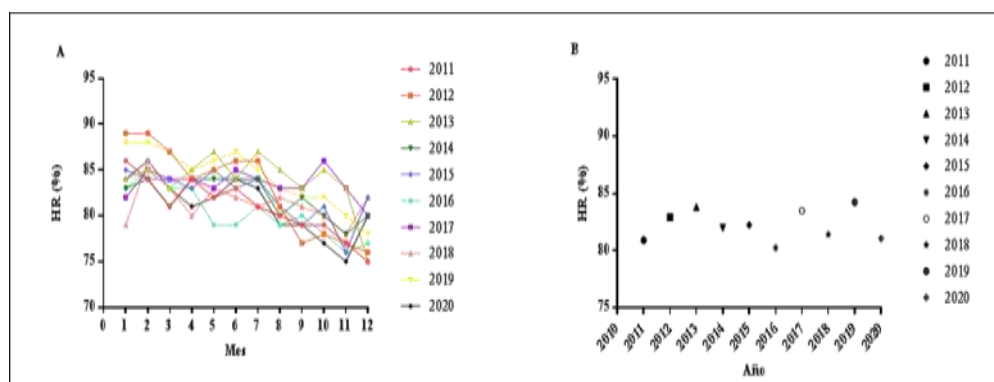


Figure 2. (A) Monthly average of Relative Humidity (%) per year. (B) Average annual Relative Humidity (%).

Source: Meteorological Station of the Escuela Superior Politécnica Agropecuaria de Manabí “Manuel Félix López” (SPAM MFL).

Concerning the behavior of humidity, within the study area, there is a notable variability, the months from January to August are the wettest months where values of up to 89% are recorded while from September to December are the driest months, where humidity can reach levels of up to 71%. Within the study period (2011-2020), the year with the highest humidity is 2019 and the driest is 2016. In other words, the humidity levels in the area are very high for corn

cultivation, so 2016 was the year with the greatest possibilities for increasing productivity levels. These results differ from those expressed by Bollatti (n/d), who indicates that the humidity to trigger the germination process and guarantee the successful planting of corn needs a humidity of around 37-38%.
Temperature

Temperature exerts a decisive predominance in seed germination with great importance in the vegetative processes of plants, being considered in itself one of the main factors that would influence the future yield of maize, affecting its philosophy, and accelerating the development stages of the crop (Cervantes et al. 2014). As stated by Eyherabide (2012), the development of corn depends directly on temperature as long as the physiological evolution of the plants is not modified by the effects of the occurrence of very low or very high values.

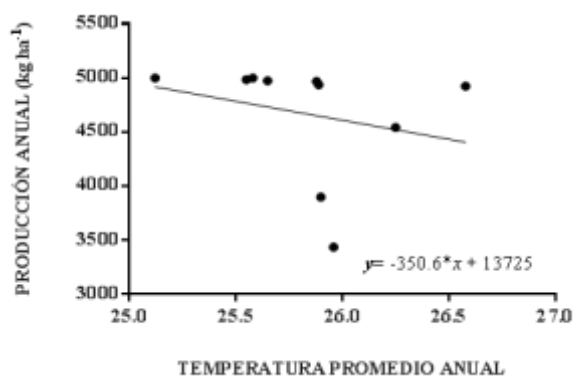


Figure 3. Average annual temperature

Source: Meteorological Station of the Escuela Superior Politécnica Agropecuaria de Manabí “Manuel Félix López”, (SPAM MFL).

The temperature recorded frequency values ranging from 25.0 °C to 27.0 °C. Figure 3 shows the relationship between annual average temperature and annual corn production, indicating that the lower the temperature, the higher the crop production.

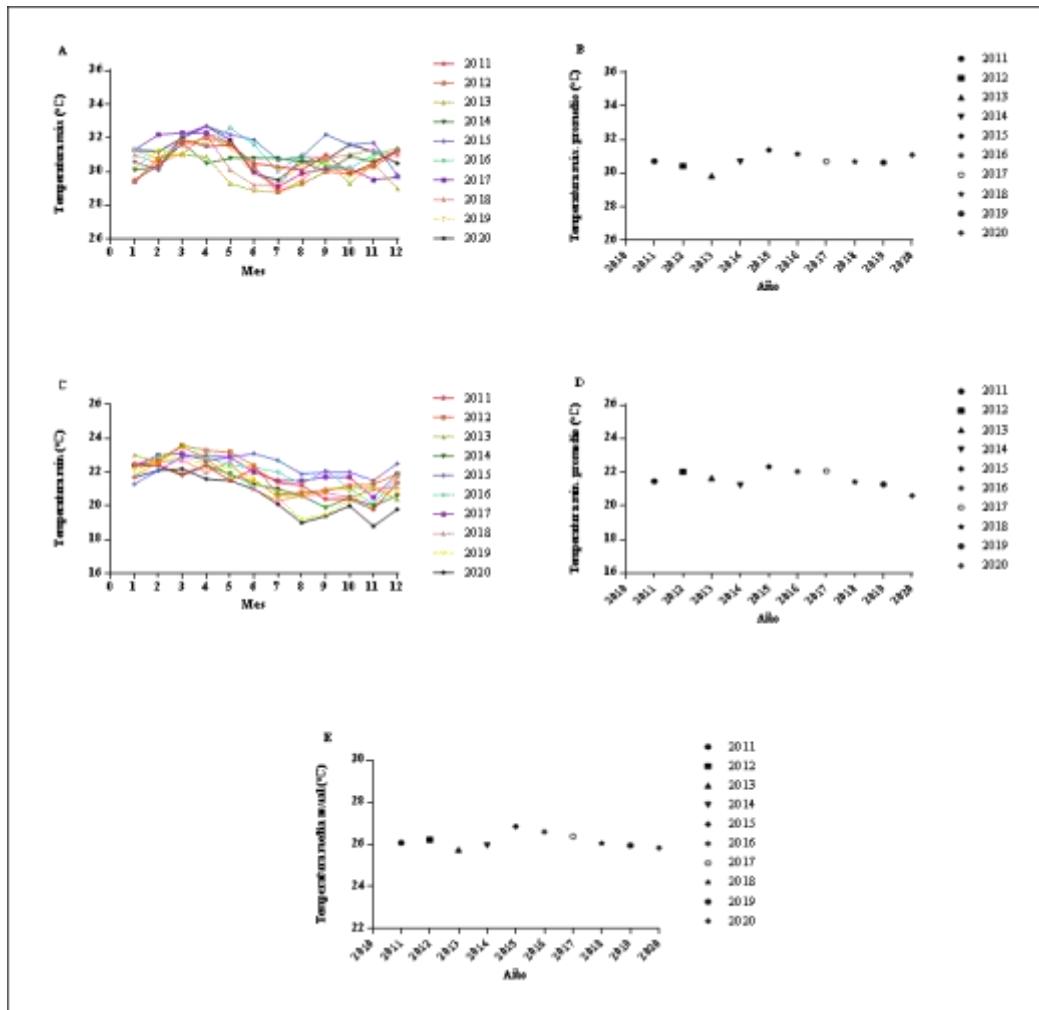


Figure 4. Maximum, minimum and average annual temperature
Source: Meteorological Station of the Escuela Superior Politécnica Agropecuaria de Manabí “Manuel Félix López”, (SPAM MFL)

(A) Average monthly maximum temperature per year; (B) Average annual maximum temperature; (C) Monthly average of minimum temperature per year; (D) Average annual minimum temperature; (E) Average annual temperature. Figure 4 represents the historical behavior of the maximum, minimum, and average temperatures recorded during the evaluation period. It can be observed that the average maximum temperature ranged between 28.80 and 32.70°C; the highest average monthly maximum temperature was recorded between 2015 and 2020, being April the month with the highest average temperature of 32.7°C. Likewise, it can be observed for this variable that the lowest average temperature was recorded during the years 2012 and 2013, with July being the month in which the temperature reached 28.80°C.

Regarding the annual average minimum temperature (C), the lowest value recorded was 18.8°C in November 2020, and the highest was 23.6°C in March

2012. In general, the year with the lowest minimum temperature was 2020, which recorded 20.60°C. When evaluating the average annual temperature, it was observed that these ranged between 25.12 and 26.58 °C; 2013 was the year with the lowest average temperature, while the highest average temperature was recorded in 2015. When evaluating the average yield achieved during each year concerning the average temperature, a negative relationship is observed, since it shows that as there is an increase in the average temperature there is a slight decrease in crop yield Figure 5.

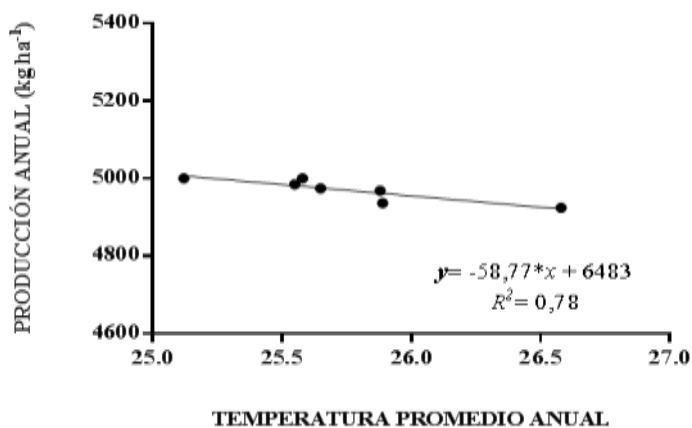


Figure 5. Average annual temperature

Source: Meteorological Station of the Escuela Superior Politécnica Agropecuaria de Manabí “Manuel Félix López”, (SPAM MFL).

Relationship between the observed data obtained for the variable production per hectare (kg/ha) and the average annual temperature recorded in the Junín canton. These results are in line with those of Luna and Naquiche (2020), who explain that the optimum temperature for germination is between 20°C to 25°C, a minimum of 10°C and a maximum of 40°C since high temperatures (above 30°C) can cause the appearance of the male inflorescence, which means that corn needs more water in its early stages of growth.

Precipitation

Used in meteorology to refer to all phenomena such as that liquid or solid water formed in the atmosphere that returns to the earth's surface in the form of rain (Granados Ramírez and Sarabia Rodríguez, 2013). In his research, they argue that the increase in precipitation in some cases affects certain periods of life of cultivated plants, a situation that affects productivity, which would generate negative outcomes in the phenological development of corn, mainly affecting flowering, which can significantly reduce production.

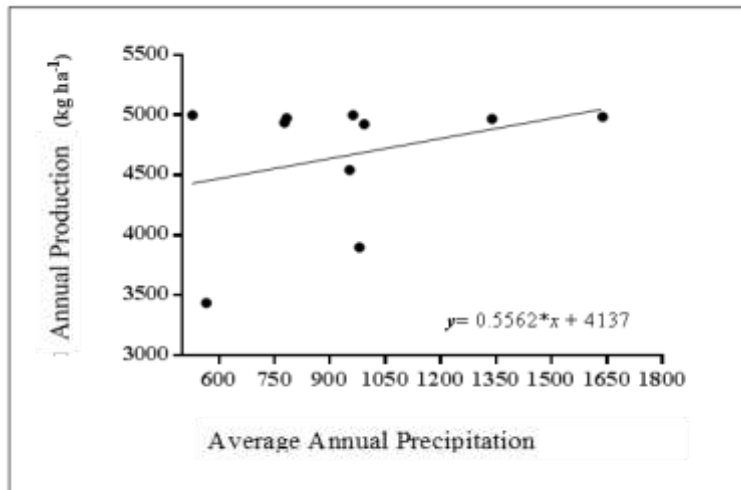


Figure 6. Average annual precipitation

Source: Meteorological Station of the Escuela Superior Politécnica Agropecuaria de Manabí “Manuel Félix López”, (SPAM MFL).

The average annual precipitation recorded values ranging from 510 to 1650 mm, which indicates that production varies depending on the precipitation ranges that occur in Figure 6.

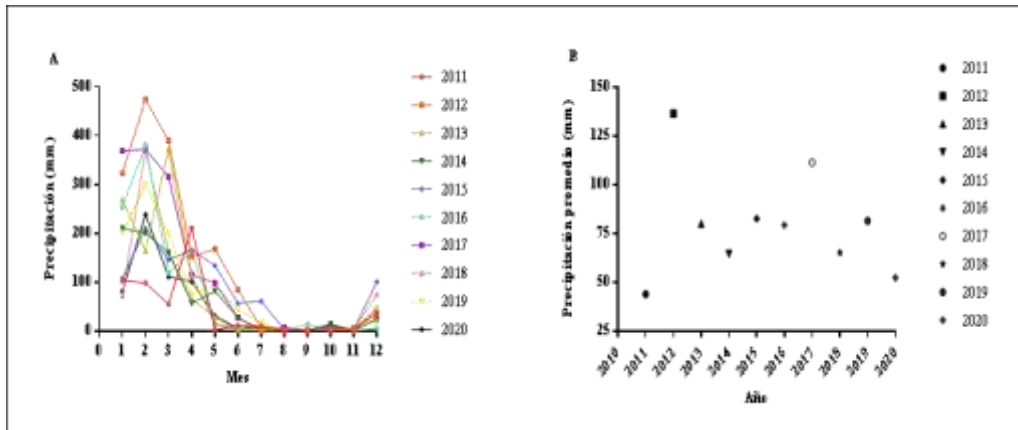


Figure 7. (A) Average monthly precipitation per year. (B) Average annual precipitation

Source: Meteorological Station of the Escuela Superior Politécnica Agropecuaria de Manabí “Manuel Félix López”, (SPAM MFL).

The behavior of the average monthly precipitation (A) shows the temporal variability of rainfall in the study area, as it can be seen that January through April are months of abundant precipitation, with February being the rainiest month with a record of 490 mm, while May through December are drier months. Regarding the average annual precipitation (B), as shown in the graph, the rainiest year was 2012 with 140 mm, while the driest years were 2011 and 2020 with 49 mm and 52 mm, respectively. This is similar to Nelson’s opinion (2009),

which states that climate change is harmful to agriculture since rainfall presents artifacts caused by alterations in rainfall volumes and aridity periods, causing constant crop losses in the short term, as well as a significant reduction in production in the long term.

Heliophany

Defined as the duration of solar brightness reflected in hours of sunshine, as a natural and fundamental resource in terms of the sustenance and production of the plant, is directly influenced by external factors that intervene in the operation and productivity of the crop. (Guzmán Buñay 2017).

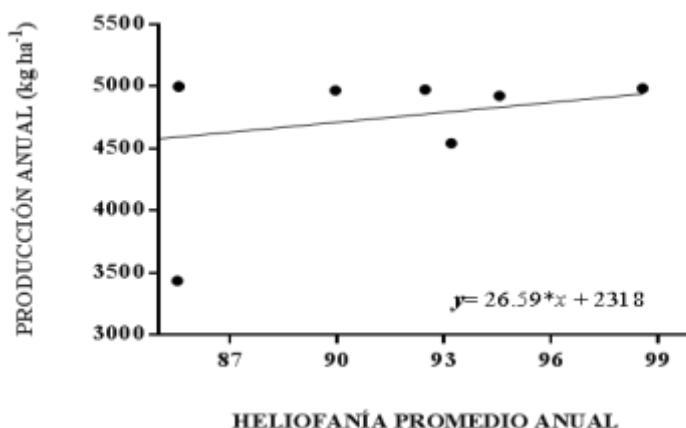


Figure 8. Relationship between heliophany and production

Source: Meteorological Station of the Escuela Superior Politécnica Agropecuaria de Manabí “Manuel Félix López” (SPAM MFL).

The relationship between heliophany and corn production is observed, where the annual average ranges from 75 to 98%, which shows that production is not affected by the hours of sunshine.

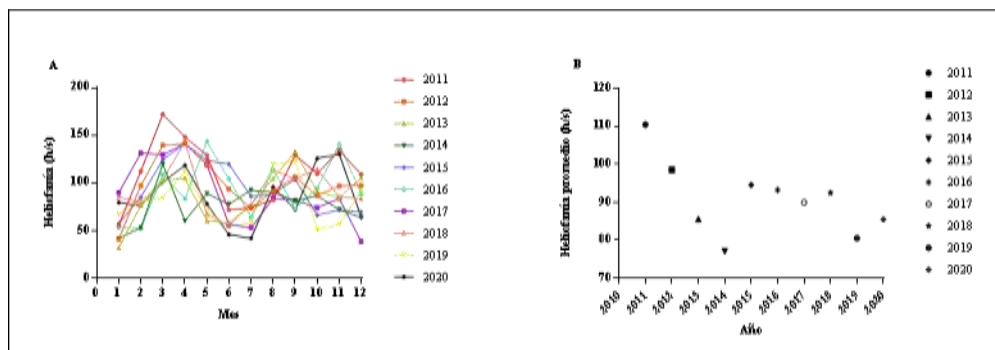


Figure 9. (A) Monthly average of Heliophania per year. (B) Annual average of Heliophania

Source: Meteorological Station of the Escuela Superior Politécnica Agropecuaria de Manabí “Manuel Félix López”, (SPAM MFL).

Figure 9 shows the monthly behavior of heliophany (A), and it can be observed that the months with the highest solar brightness are: March, April, May, September, and November where values from 147 to 160 h/g are reached while July and December reach lower heliophany with 46 and 48h/g respectively. On annual average, the year with the highest solar brightness was 2011 reaching an average of 110h/g while the years 2014 and 2019 obtained averages of 78 and 80h/g respectively. That is, the hours of light exceed the required values with the corn crop.

This differs from what is indicated by León Torres (2012), who indicates that sunlight is indispensable for the life of plants since the formation of organic matter takes place outside of the light since corn cultivation requires at least 12 hours of light as the optimum level of production.



Figure 10. Map Present geographic distribution of maize species (*Zea mays L.*)

Once the areas have been georeferenced and the necessary procedures have been applied for modeling the present and future climatic variables of the maize crop (*Zea mays L.*), the current distribution of the crop within the study area can be seen. Figure 10 shows the current spatial distribution of maize (*Zea mays L.*) cultivation in the Junín cantón, data that would allow the potential modeling process of the crop with the help of Maxent software.

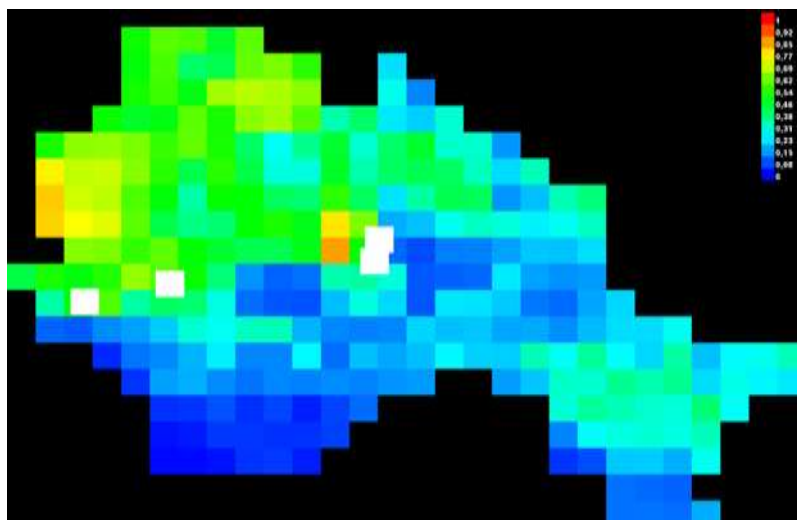


Figure 11. Modeling of potential distribution versus environmental impact generated in corn (*Zea mays* L.) cultivation using Maxent software

Figure 11 shows the representation of the potential distribution model of the species under study and with the help of Maxent software; the color ranges of each pixel from 0 to 1 can be observed, where 0 represents the non-existence of corn cultivation in the future and 1 the continuity of the species, considering within the research environmental variables such as wind speed, average temperature, solar radiation, precipitation and another factor such as the elevation at which each cultivated area is distributed.

Analyzing the research by Ballesteros-Barrera (2011) on the geographical representation of the species under climate change scenarios, it is observed that the sites suitable for corn cultivation show different responses to global warming, where probably over the next 40 years there will be a gradual loss of sites suitable for cultivation, which would generate a decrease in its production.

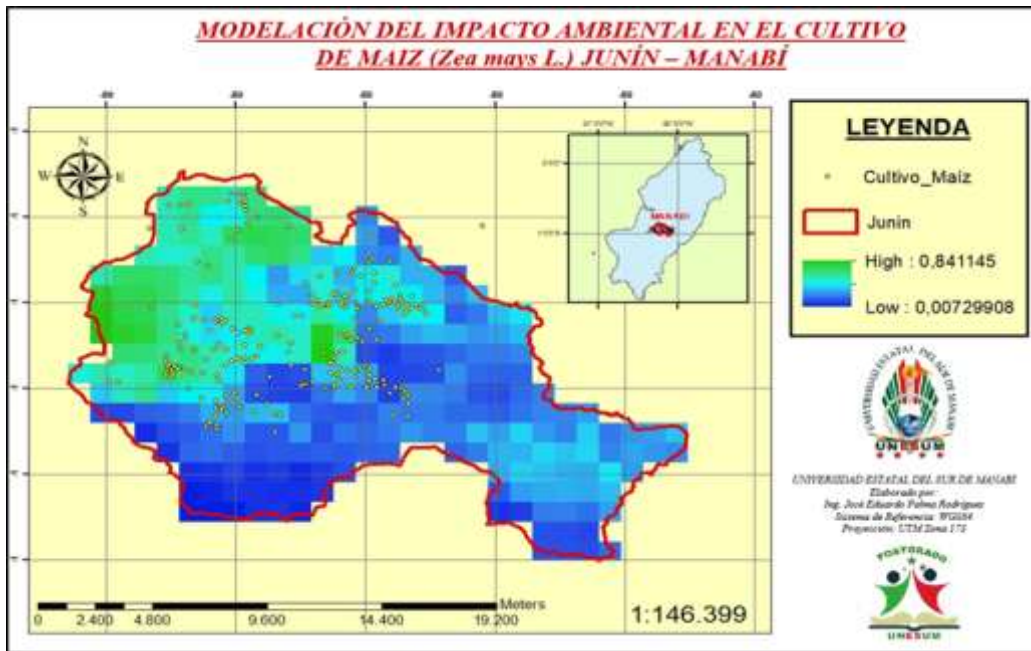


Figure 12. ArcGis map of the future forecast of the maize (*Zea mays* L.) crop in the Junín canton

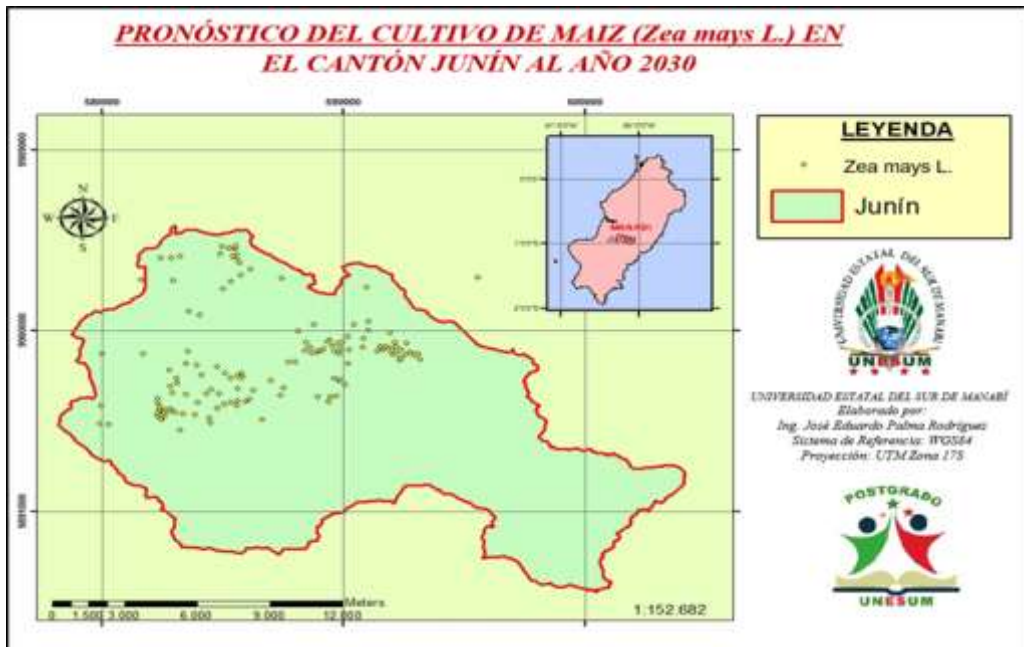


Figure 13. Future forecast map for maize (*Zea mays* L.)

According to the results obtained by applying the modeling with Maxent software, Figures 12 and 13 show, with the help of a thematic map designed in ArcGis, the areas in which corn cultivation will gradually disappear by the year 2030. For this potential distribution, the analysis of future changes identifies the area or site

that presents a loss of the species (Estrada-Contreras et al., 2022). The research indicates that modeling maps of potential species distribution are fundamental for decision makers and civil society in terms of generating policies to improve crop adaptation to climate change.

Conclusions

- The climate impact affects corn (*Zea mays* L.) crops in the Junín canton as a result of changes in the production process and the inadequate use of chemical inputs; therefore, it is necessary to implement sustainable processes to ensure food sovereignty and guarantee climate change mitigation.
- When evaluating the average yield achieved in Junín Canton during each year, the study shows a negative relationship, indicating that as there is an increase in the average temperature there is a slight decrease in the yield of the corn crop (*Zea mays* L.).
- Climate variations in the coming years could jeopardize crop production, so it is important to improve the conditions of the population by allowing field support programs that are aligned in conjunction with good irrigation system planning and effective product improvement.

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