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CMIP6 Projections for Climate Change Impact Assessments in Banana (Musa Paradisiaca) Cultivation

Pedro Lozano-Mendoza[1], Betty González-Osorio[2*], Mariela Díaz Ponce[3], Génesis Mendoza-Rodríguez[4], Byron Oviedo Bayas[5]

Abstract

Valencia is located in the northern part of the province of Los Ríos in the center of the country, Ecuador. It is characterized by a monsoon climate with two distinct seasons; rainy (January-May) and dry (June-December). The study area reports many impacts of hydrometeorological events in the banana distribution zones associated with wet and dry events such as floods and droughts that affect the development of the product. The objective of this research was to determine the geographical distribution of banana cultivation and its potential changes in climate during the 21st century, associated with two types of scenarios; favorable (ssp1) and pessimistic (ssp5) in the canton of Valencia, Ecuador. The "land use coverage" database was used to identify the current geographical distribution zones of banana in the canton of Valencia. Simultaneously, reduced Worlclim simulations from the Climate Model Intercomparison Project 6 (CMIP6) were used to simulate future changes with periods of 2020-2040, 2041-2060 and 2081-2100 with agroclimatic parameters (precipitation (Pr), minimum temperature (Ti) and maximum temperature (Tx)), with spatial resolution expressed as minutes of degree of longitude and latitude of 30 seconds and biophysical (natural drainage, elevation, depth, hydrogen potential, slopes, stoniness, organic matter, soil texture, salinity). Banana cultivation covers an area of 15972.228648 ha in the entire canton, which could be affected by the climate impacts of the CMIP6 scenarios. The results show that a drier future will be characteristic of the climate in the canton of Valencia at the end of the 21st century. It is expected that by the end of the 21st century, the conditions of the SSP5 climate scenario will affect banana geographical distribution zones, human and environmental systems.

Keywords: *Climate change; temperature; precipitation; agroecological zoning.*

INTRODUCTION

Throughout history, the earth has experienced alterations in its climate, precisely in its temperature, considering glacial periods and global warming, those that have produced transformations in the environment. Climate change affects biogeophysical and socioeconomic processes, causing significant positive and negative repercussions on ecosystems and society. (Yazar et al., 2022) (Favier Torres et al., 2019)

[1] Facultad de Ciencia de la ingeniería, Universidad Técnica Estatal de Quevedo (UTEQ), km 1½, Vía Sto. Domingo de los Tsáchilas, Quevedo, Ecuador, 0000-0001-5771-268036

[2] Facultad de Ciencia de la ingeniería, Universidad Técnica Estatal de Quevedo (UTEQ), km 1½, Vía Sto. Domingo de los Tsáchilas, Quevedo, Ecuador, bgonzalez@uteq.edu.ec, 0000-0002-2851-2660

[3] Facultad de Ciencia de la ingeniería, Universidad Técnica Estatal de Quevedo (UTEQ), km 1½, Vía Sto. Domingo de los Tsáchilas, Quevedo, Ecuador

[4] Facultad de Ciencia de la ingeniería, Universidad Técnica Estatal de Quevedo (UTEQ), km 1½, Vía Sto. Domingo de los Tsáchilas, Quevedo, Ecuador, 0000-0002- 8552-7527

[5] Facultad de Ciencia de la ingeniería, Universidad Técnica Estatal de Quevedo (UTEQ), km 1½, Vía Sto. Domingo de los Tsáchilas, Quevedo, Ecuador, 0000-0002-5366-5917

Climate change represents one of the greatest environmental challenges involving all of humanity. This high degree of affectation is related to the vulnerability of the population and the fragility of ecosystems. Agriculture is one of the economic sectors highly vulnerable to the effects of climate change and in particular banana cultivation, whose variation in optimal levels of temperature, precipitation and relative humidity ; alterations that could give rise to problems associated with a higher incidence of pests in banana cultivation, soil degradation and water scarcity, which directly impacts the productivity of the crop, affecting the development of the plant and the fruit. (Sánchez & Reyes, 2015) (Távara Hernández Milbort Paul, 2020) (BananaTecnia , 2017)

Ecuador is among the main producers and exporters of bananas worldwide, the turnover of bananas is 32% of the world trade and 3.84% refers to the gross domestic product; This marketing item generates important income for the country due to its significant volume of commercialization, which places it as the main product and source of foreign exchange that currently exists in the country, after oil. Therefore, Ecuador's banana sector is crucial to the country's national economy, employment, and trade balance. (León Serrano et al., 2020) (Borja, 2016) (Estrada & Maldonado, 2016)

In this way, climate change is shown as a threat to banana production, due to periods of drought and rainfall that are not constant, this brings the presence of pests and diseases. (Valentín Pérez et al., 2018) In this sense, agroecological zoning methodologies are able to help locate those types of land use that best fit the physical characteristics of a region, these have similar characteristics related to their suitability and production potential. As a result of this process, it is possible to identify the types of land uses that are most in line with the productive capacity of natural resources, while ensuring the balance and conservation of agroecosystems and their future projection. (Gonzalez Gonzalez & Hernández Santana, 2016) (Venero, 2014)

Currently, through the application of more specific methods, we can expand these studies to obtain empirical models that describe and justify the relationships between climatic variables and banana productivity in Ecuador. As well as to apply them with models of the Intergovernmental Panel on Climate Change (IPCC): Coupled Model Intercomparison Project, phase 6 (CMIP6). In this research, the effects on banana cultivation due to climate changes in the Canton of Valencia belonging to the province of Los Ríos will be evaluated, the geographical distribution of the crop will be considered, the most critical future climate scenarios will be indicated, and the characteristics of influence on the development of the plant will be analyzed.

MATERIALS AND METHODS

Localization

The research was carried out in the canton of Valencia, in the northern area of the province of Los Ríos, which has a monsoon climate, with two defined seasons; rainy (January-May) and dry (June-December). Average annual temperature is 24 °C, average annual humidity is 91%, UV index is 5 and average annual precipitation is 2510 mm. (Franco Cedeño, 2017)

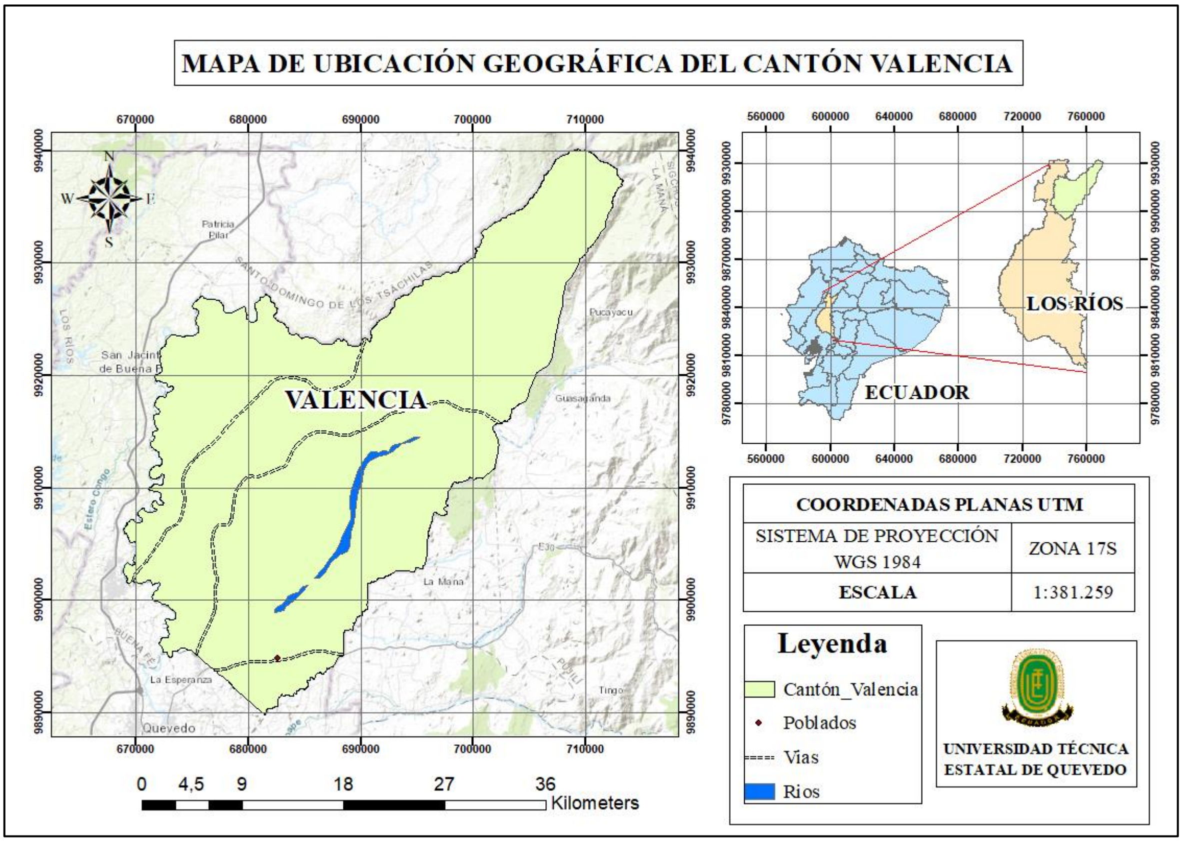

Figure 1. Location map of the canton of Valencia

Figure 1. Location map of the Valencia cantòn

Methodology

Identification of banana cultivation in the territory of the canton of Valencia

The database of the distribution of banana cultivation throughout the territory of the canton of Valencia for the year 2015 was downloaded. Added land use cover layers and used "Clip" for clipping with the studio area. (SNI, 2022)

Climate Scenarios

Climate scenarios SSP1 and SSP5 were considered. The SSP1 scenario (Table 1) adopts the principles of sustainable development, while the SSP5 scenario (Table 2) is characterized by rapid development, fueled by fossil fuels, representing a major socioeconomic challenge for mitigation and adaptation (van Vuuren et al., 2017) (Kriegler et al., 2017) .

Table 1. Understanding Story Elements and SSP1 Models

Table 1. Description of story elements and SSP1 models

VARIABLES	SSP1
Generic Element	
Economic growth	High
Population Growth	Low
Governance and institutions	Effective both nationally and internationally.
Technology	Efficiency, renewable technologies and yields

Consumption/Production Preferences	Promoting sustainable development
Energy Demand	
Transport	Lower proportion of revenue spent on transportation
Buildings	Lower overall demand for energy services
Non-energetic	Low Intensity
Power Supply & Conversion	
Fossil fuels	Medium technological development
Bioenergy	Biofuels mostly phased out by 2030
Agriculture and land use	
Regulation of land-use change	Strong – Protected areas are expanded to meet the Aichi target of 17%.
Agricultural productivity (crops)	Strong: increased crop yields.
Environmental Impact of Food Consumption	Low: 30% consumption of animal products.
Commerce	
Trade in agricultural products	Abolition of current import tariffs and export subsidies by 2030
Air Pollution	
Emission Factors	Low

Fountain:. (van Vuuren et al., 2017)

Table 2. Understanding Story Elements and SSP5 Models

Table 2. Description of the elements of the story and the SSP5 model

VARIABLES	SPP5
Indicator	Fossil-fuel-driven development
Demography	
Population Growth	Low (high fertility in high-income countries)
Migration	High
Economy & Lifestyle	
GDP growth (per capita)	High
Inequality	Heavily reduced
Globalization	Strong
Consumption	Materialism, Status Consumption, High Mobility
Technology	
Development	Fast

Changing energy technology	Targeting fossil fuels; Alternative sources not actively sought
Environment & Resources	
Land use	Average regulations lead to a slow decline in the rate of deforestation
Agriculture	Rapid increase in productivity
Policies and institutions	
Environmental (and energy) policy	Focus on the local environment, little concern for global issues

Fountain:. (Kriegler et al., 2017)

Downloading and modelling climate scenarios

The climate models: tn (monthly mean minimum temperature (°C)), tx (monthly mean maximum temperature (°C)) and pr (monthly total precipitation (mm)), were downloaded from Worldclim in 20-year periods (2020-2040, 2041-2060 and 2081-2100), from the atmospheric general circulation (GCM) model laboratory or known as MIROC-ES2L, with spatial resolution expressed as 30-second longitude and latitude degree minutes. (Cheng et al., 2021) (WorldClim, 2022)

The climate models of tn and tx were downscaled in the Saga Gis software by means of "GWR for Grid Downscaling" to improve spatial resolution. Preceded by a trim in the QGIS software with the "buffer" plugin for the study area. (Llúncor, 2016)

Calculation of climate models and agroecological parameters

An algebra procedure was applied to the climate variables tn and tx in the QGIS software with the "Raster calculator" plugin. The equation for averaging (pm) of both temperatures is shown in equation . (Moreno Ortega et al., 2022) (Ruiz Corral et al., 2018)

$Tm = (Tx + Ti)/2$ (Equation 1)

Through the application of "Reclassify" in the QGIS software, the agroecological parameters were reclassified based on the three zoning categories of banana cultivation. Finally, the agroecological zonings of banana cultivation for the Valencia canton were created with the "Weighted Overlay" tool evaluating the weights for each previously reclassified raster (Table 3). (MAGAP, 2020)

Table 3. Agroecological parameters for banana cultivation

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Agroecological parameters				
Parameters*	Zoning Categories			Pesos
	Optimal (1)	Moderate (2)	Marginal (3)	
Natural drainage	Well	Moderate	Good, moderate	11%
Elevation (m.a.s.l.)	10-300	0-10 / 300-800	800-1200	8%
Depth (cm)	Deep (>100)	Moderately Deep (51-100)	Shallow (21-50)	8%
Hydrogen Potential (pH)	Moderately acidic (5.5-6.0), slightly	Virtually neutral (6.5-7.5), neutral (7)	Acid (4.5-5.5), Slightly	10%

	acidic (6.0-6.5)		Alkaline (7.5-8.0)	
Slopes (%)	Flat (0-2), very soft (2-5), soft (5-12)	Medium (12-25)	Medium to strong (25-40), strong (40-70)	8%
Stoniness (%)	Without, Very Few (< 10)	Few (10-25)	Common (25-50)	7%
Organic matter (%)	Upper Coast (>2), Upper Amazon (6.0)	Mid - Coast (1.0-2.0), Mid - Amazon (3.0-6.0)	Lower - Coast (<1.0), Lower - Amazon (1.5-3.0)	10%
Soil Texture	Loam, silty loam, sandy clay loam, silty clay loam	Silt, clay loam, silty clay, sandy clay, sandy loam, sandy loam	Loamy sand, clay	11%
Salinity (ds/m)	Non-saline (<2.0)	Slightly saline (2.0-4.0)	Saline (4.0-8.0)	6%
Precipitation (mm)	1500-1600	1400-1500 / 1600-1800	1300-1400 / 1800-2000	12%
Temperature (°C)	22-26	21-22	18-21	9%

* °C = centigrade, cm = centimeter, mm = millimeter, < less than, > greater than.

Fountain:. (MAGAP, 2020)

RESULTS AND DISCUSSION

Geographical location of banana cultivation in the canton of Valencia

Banana cultivation is of great importance to the country's economy; both for the producers and the population that uses it. Figure 2 shows the distribution of the product represented by the color red, extending to 15972.228648 hectares throughout the territory of the Canton of Valencia.

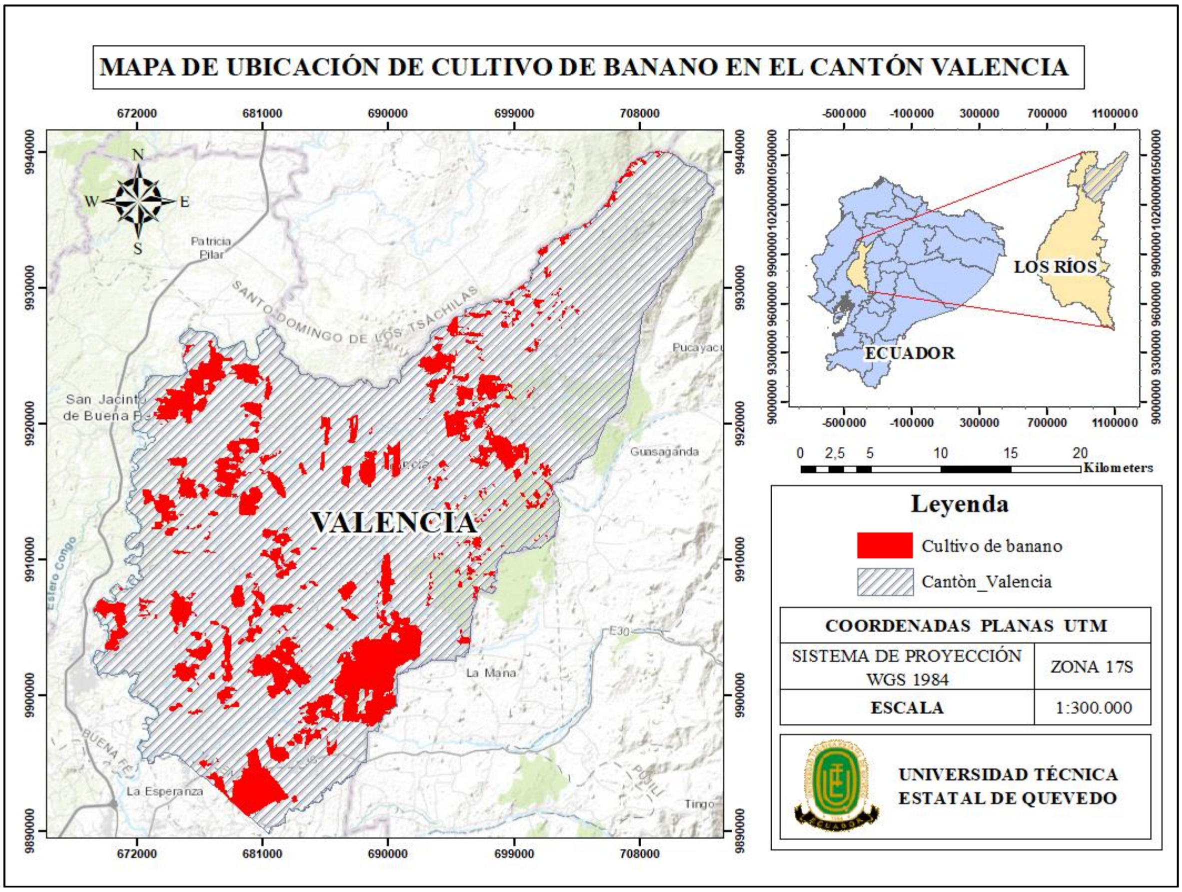

Figure 2. Location map of banana cultivation in the Canton of Valencia

Figure 2. Location map of banana cultivation in Valencia Canton

Agroecological zoning of banana cultivation

The SSP 1 model for land use for banana cultivation has 55,054 hectares of optimal zones and 30,397 hectares of moderate area, for the period 2020-2040 according to the requirements described in Table 3. Data indicate that the future projection in the SSP1 scenario, as long as there is moderate fossil fuel consumption and low population growth, has optimal areas in 64% for banana cultivation with temperatures of 25 °C to 26 °C and rainfall of 1500 mm to 1600 mm. These projected results are beneficial in banana cultivation, bring with them the correct development of the product and at the local, regional, national and international levels would provide constant food and economic security to the population that is directly and indirectly related to this productive activity, considering the pH levels and stable organic matter (Figure 3). For organic matter it can contribute to the decrease of soil pH, it also considers that the application of organic fertilizers in the long term is an option of good environmental practices, the constant use contributes to the mobilization of Fe minerals to the arable soil, this allows a greater conservation of the carbon present in the soil. They also point out the present and future benefits of the use of crop residues (rachis, discarded fruits, pseudostem, leaves, inflorescences), these allow the recovery of the health of the soils cultivated with bananas, in addition to correcting important chemical parameters to improve productivity such as: hydrogen potential (pH,) Cerium (EC), organic matter (M.O); safeguarding the food security of the world's population. (Naranjo Morán et al., 2021) (Zhiminaicela et al., 2020)

The SSP 5 model with respect to banana cultivation has 55 015 ha of optimal zones that represent the green color and 30436 hectares of moderate surface area with the yellow color. This scenario tends towards a strong globalization and an environmental policy with little concern for global problems, agricultural areas are more likely to face devastating ravages that affect climatic conditions, the projection of the period 2020 to 2040 does not present affectations, due to the demonstrated degrees of aptitude from optimal to moderate (Figure 3). In the same way, ; (indicates that the climatic conditions that prevail in the growth and development of the fruit can infer the physical quality of the fruits, they also mention that the ones that have the greatest impact are precipitation and daylight hours. (Vásquez-Castillo et al., 2019) González Osorio et al., 2022)

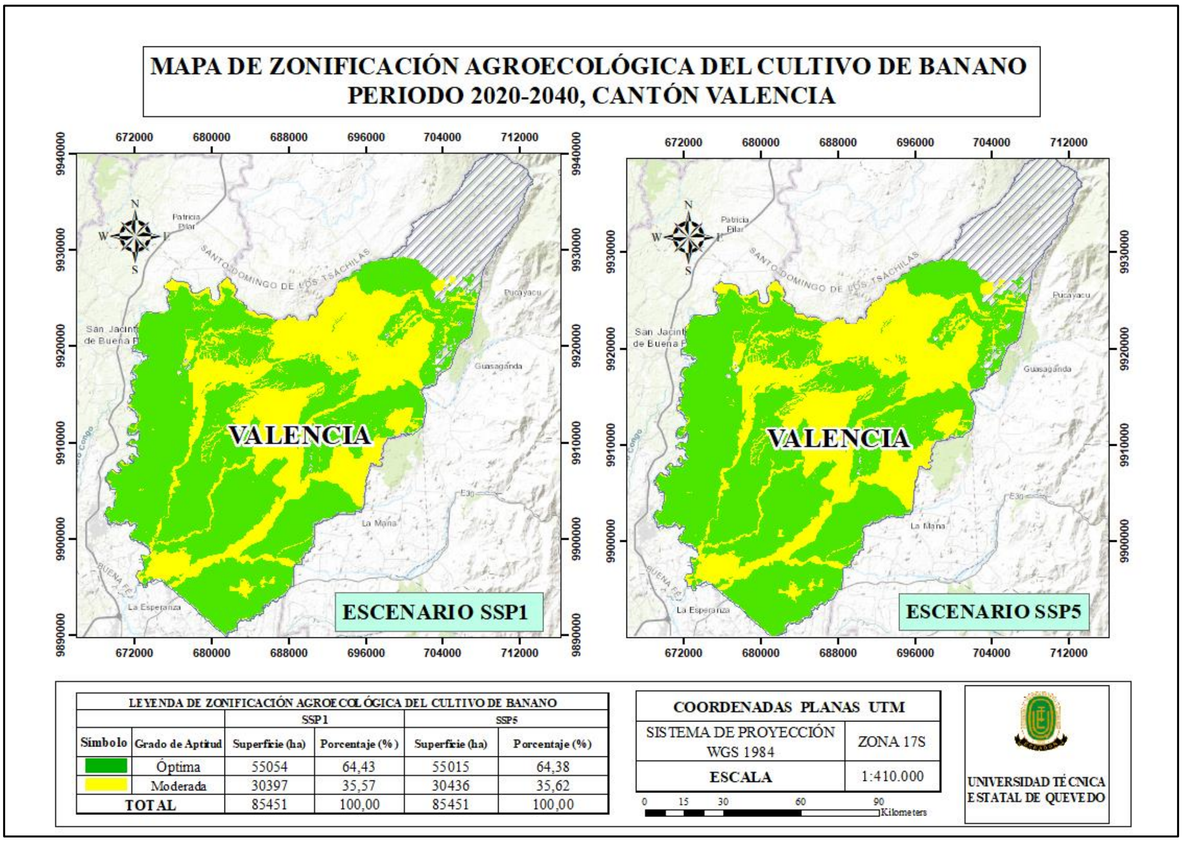

Figure 3. Agroecological zoning map period 2020-2041, climate scenario SSP1-SSP5

Figure 3. Agroecological zoning map for the period 2020-2041, climate scenario SSP1-SSP5

The SSP 1 soil use model for banana cultivation has 70 409 ha of optimal zones, 12 402 ha of moderate area and 2 640 ha of marginal area according to the requirements described in Table 3. However, after the procedures to be followed for the zoning and verifying the aptitudes in the study area for this period, it is concluded that the projection to 20 years more than Figures 4 and 5, already denotes significant changes. The optimal area is still larger in the SSP 1 scenario, reflecting the outcome of good environmental practices and regulations, with the good use of fossil fuels that the model represents (Figure 4). Banana growers already use a variety of technologies to overcome temperature and water constraints, including annual planting, protective structures and, most commonly, irrigation to cool plants during periods of excessively high temperatures. For Ecuador it is the (Van Den Bergh et al., 2012) (Machovina & Feeley, 2013) number one exporter of bananas in Latin America with an ideal area of 5.7%, however the results presented in this article differ, due to the fact that in its Projections for 2060 it is expected that Ecuador will experience an increase in the extension of the adequate area in its production, such a conclusion was reached considering that the global average annual temperature will increase from 26.2 to 28.9 °C (+10.2%) in the next 50 years.

The SSP 5 model with respect to banana cultivation has 23 178 ha of optimal areas representing the green color, 36 139 ha of moderate surface area with the yellow color and 6 134 ha with the orange color. These future results already reflect a concern about the scarcity of optimal areas for the proper development of banana cultivation, bringing with it more problems that are not only aimed at production, but are also socioeconomic considerations (Figure 4). They also (Varma & Bebber, 2019) claim that the increase in temperature due to climate change will reduce banana production by at least a third in the main banana producing countries by 2050 and that Ecuador is a country classified as "at risk" in which its yield will decrease due to climate change. On the other hand, they estimate that the highest temperature anomalies with the absolute maximum differences with the historical baselines for the Tmax., Tmed. and Tmin. will be +2.89, +2.80 and +2.33 °C, respectively, and will occur between June and mid-September, while the lowest will be in February by 2060. (Pérez & Porras, 2015)

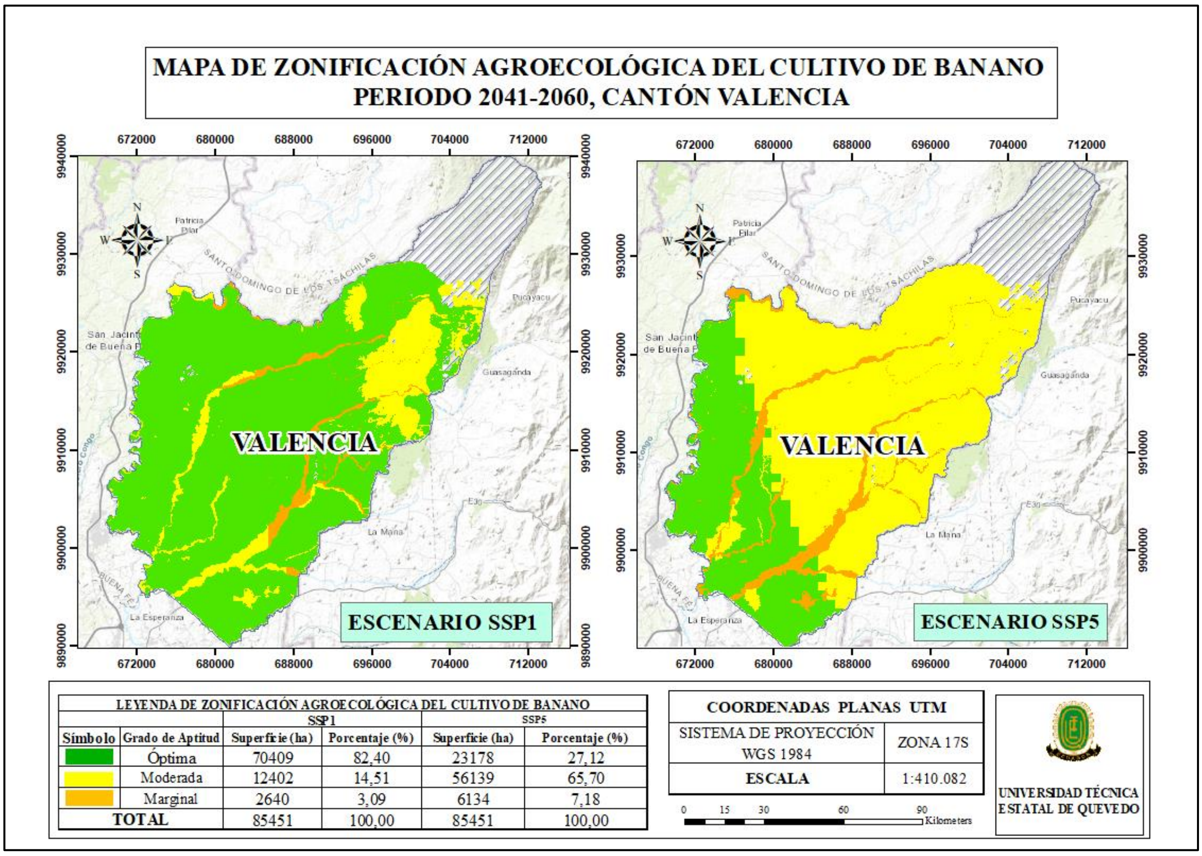

Figure 4. Agroecological zoning map period 2041-2060, climate scenario SSP1-SSP5

Figure 4. Agroecological zoning map for the period 2041-2060, climate scenario SSP1-SSP5

The SSP 1 model land use for banana cultivation has 31 876 ha of optimal areas for banana cultivation with the color green, the yellow color represents 47 441 ha of moderate area and with the orange color 6 139 ha of marginal area. The model reflects a projection similar to Figure 4, with the yellow areas being the largest areas of moderate format for banana cultivation with the SSP 1 model, this indicates that temperatures tend from 21°C to 22°C with rainfall ranging from 1400 mm to 1800 mm. Results that resemble what is described by the author mentions that bananas cannot grow with minimum monthly temperatures below 0°C, stop growing below 12°C (Tmin) or above 33°C (Tmax), and have optimal growth between 17.5 and 26.3°C (Tmin and Tmax, respectively). On the other hand, they demonstrate the importance of subjecting the different irrigation methods in banana cultivation to a constant hydraulic evaluation, because the lack of water in the flowering period limits the development of the leaves and the number of fruits, in the same way in the period of formation of the bunch. It affects the size of the fruits and their commercial quality is reduced, in contrast to the SSP 1 model, good environmental practices contribute to the good development of the crop. (Van Den Bergh et al., 2012) (Santacruz de León & Santacruz de León, 2020)

The SSP 5 model with respect to banana cultivation has 79 317 ha of moderate yellow surface area and 6 134 ha of orange marginal area. The projection with the characteristics of the SSP 5 model are the most worrying, this will close a productive cycle of great reception and fundamental in food sovereignty. Households that receive or engage in this productive activity will be affected as production decreases. The conditions are unfavorable for this model in the period from 2081 to 2100, this is due to the (González B. et al., 2020) (Yela Piedrahita et al., 2016) fact that there is little information on the effects of climate change on producers, due to the lack of technical assistance and a forceful State policy that is capable of recognizing two important aspects: the productive-economic and social-environmental value. A situation that he complements with his affirmation that the daily practices carried out by people in their daily spaces lead to the same end: the dispossession of the land, the erosion of the social fabric and the emergence of new forms of poverty and exclusion. (Suárez, 2019)

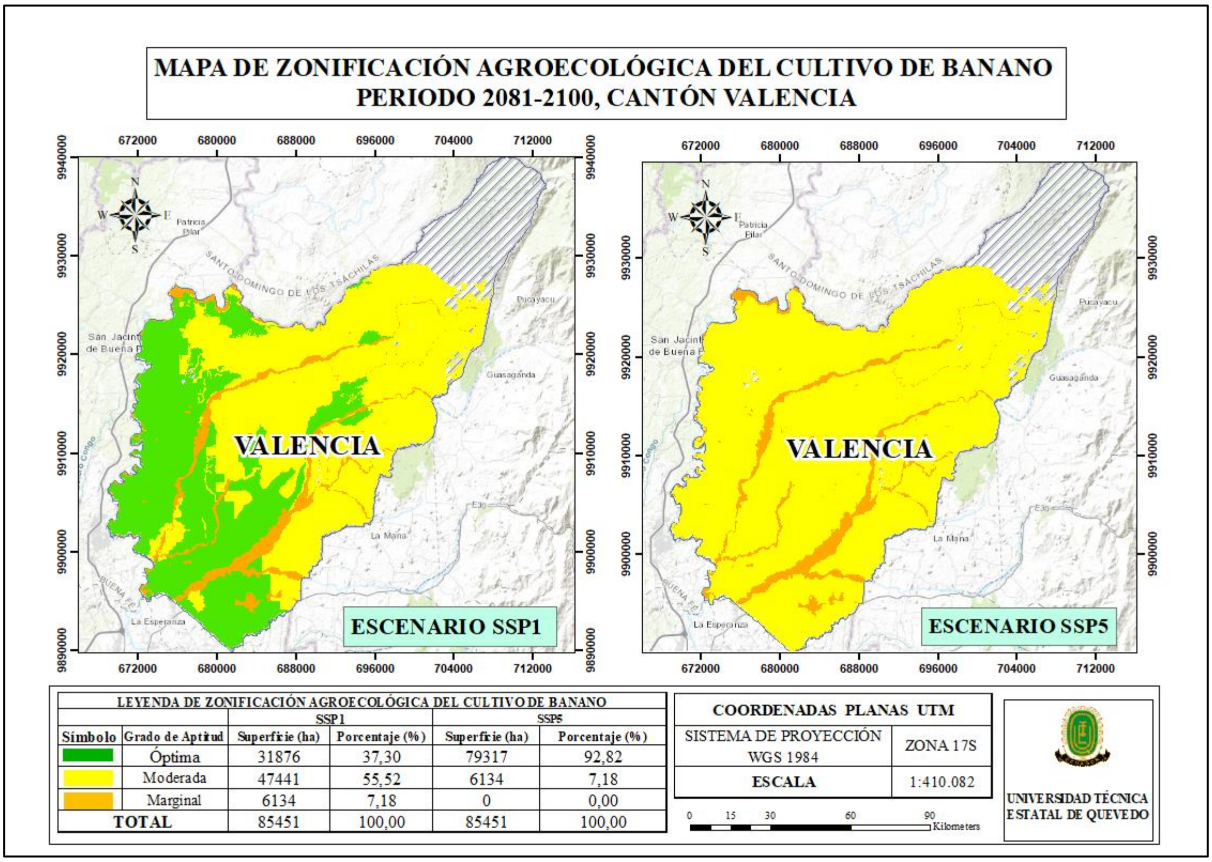

Figure 5. Agroecological zoning map period 2081-2100, climate scenario SSP1-SSP5

Figure 5. Map of agroecological zoning period 2081-2100, climate scenario SSP1-SSP5

CONCLUSIONS

The thematic maps showed the distribution areas of banana cultivation in the canton of Valencia, indicating which areas of this are optimal for its cultivation and development. Among the scenarios, SSP1 and SSP5 models were selected for the aforementioned periods ranging from 2020 to 2040, 2041 to 2060, and 2081 to 2100. In which it was possible to identify that in the latest SSP5 model for the future period from 2081 to 2100 it will no longer have three zones with categories of use, thus indicating that in the future the areas with geographical distribution and optimal conditions for banana cultivation will decrease. Demonstrating that if there is a quick act, the categories will remain as Moderately or Marginal, a worrying case for food security and the country's economy.

GRATITUDE

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