



# Agro-Ecological Aptitude to Produce Cocoa under Rainfed Conditions in Tabasco Mexico

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## Abstract

The main problem of cocoa in Mexico is that it is not competitive due to low productivity related to cultivated areas with low production potential, old and low-yield materials susceptible to diseases and poor use of cultural practices. The state of Tabasco in Mexico is the most important cocoa grower since more of 70% of the country's plantations are located in the state. Faced with a scenario of strengthening the cultivation and renewal of cocoa plantations, it is compulsory to consider the agro-ecological aptitude for cultivation and reclassify the areas according to their potential yields. The agro-climatic requirements of cocoa were compared with the natural agro-climatic condition geographically scattered in the state. A QGIS version 3.6.0 was the Geographic Information System software used to process and analyze the information. There were identified more than 174 thousand hectares of optimal yield potential and more than 32 thousand with suboptimal ones under rainfed conditions.

## Subject Areas

Agricultural Engineering

## Keywords

Geographic Information System, Productivity, Competitive, Potential Areas

## 1. Introduction

Cocoa (*Theobroma cacao* L.) was considered a great value fruit in different political, economic, social and religious spheres in ancient Mesoamerica [1]. In addition, it was the most important perennial crop in the world, commercially ex-

exploited for seed production to be manufactured as fine chocolates and, used in the cosmetic and pharmaceutical industries [2] [3].

*Theobroma cacao* L., is a tree fruit belonging to the *Malvaceae* family, native to the humid tropics of America, its center of origin is believed to be the north-east of South America, in the Amazon area [4] [5]. It was brought to Mesoamerica to be used and domesticated in about 3600 years ago [6]. Due to the scarcity of cultivated areas, its value increased and that was the main reason to be used as exchange money and converted to the most precious tributes and a gift coveted by the great leaders.

Cocoa was offered in high social events of dignitaries and different political and other types of agreements. It was also included in various religious festivals such as marriage ceremonies and funerals when considered that the drink would accompany the deceased dignitary to his transit to the underworld; it also had various medicinal uses [7] [8].

The cocoa was expanded to other regions in the 19th century and currently it is produced in 40 countries of tropical Africa, Asia and America [9]. Ivory Coast, Ghana, Indonesia, Brazil and Nigeria are the main cocoa producers in the world [10]. Cocoa beans are mainly exported to Europe and North America for processing [11]. In the international market, dry beans, residues (shells, barks, husks and cocoa waste), paste, cake, butter, powder and chocolate are commercialized [12]. The largest consumers are the United States (20%), Germany (9%), France (6%), United Kingdom (6%), Brazil (5%), Russia (5%) and Japan (4%) [13] [14].

In Mexico, it is mainly grown in the Soconusco region (Chiapas and Guatemala) and northern Chiapas and the states of Tabasco and Veracruz [1]. Currently, 59,594 ha of cocoa are cultivated at a national level and Tabasco contributes to 66.9% of the total national production volume with 40,857 tons harvested in 41,000 hectares. Chiapas is the second important producer with 32.9% (17,421 tons) and Guerrero third one with only 248 tons representing 0.2% [15]. Tabasco as the first nationwide producer has more than 500 years growing this crop [16].

Despite the hundreds of years managing the crop, Mexico is not a competitive one as compared to other producing countries. And this is related to various factors such as: 1) establishment in unsuitable areas 2) old plantations 3) low-yield materials 4) diseases 5) no cultural practices 6) dependence on rainfed conditions. So facing the scenario of strengthening the cultivation and renewal of cocoa plantations in Tabasco, it was needed to launch this work in order to delimit, geographically, the best areas with high aptitude for cocoa cultivation.

## 2. Materials and Methods

### 2.1. Materials

The study was carried out under cabinet conditions in the Southeast Research Center of the National Institute for Forest, Agriculture and Livestock Research

in Merida Yucatan, Mexico.

The spatial determination of productive potential areas for plant species can be carried out using different methodologies. However, in this study, algebraic maps were used considering the specific agro-ecological requirements of cocoa as input variables. The use of Geographical Information Systems (GIS) has been a successful method to determine spatial optimal zones for good crop development [17] [18] [19] [20] [21]. Through GIS, it is possible to manage the agro-ecological variables represented by the physical environment (climate-soil-water) and in that way optimal and sub-optimal areas can be defined.

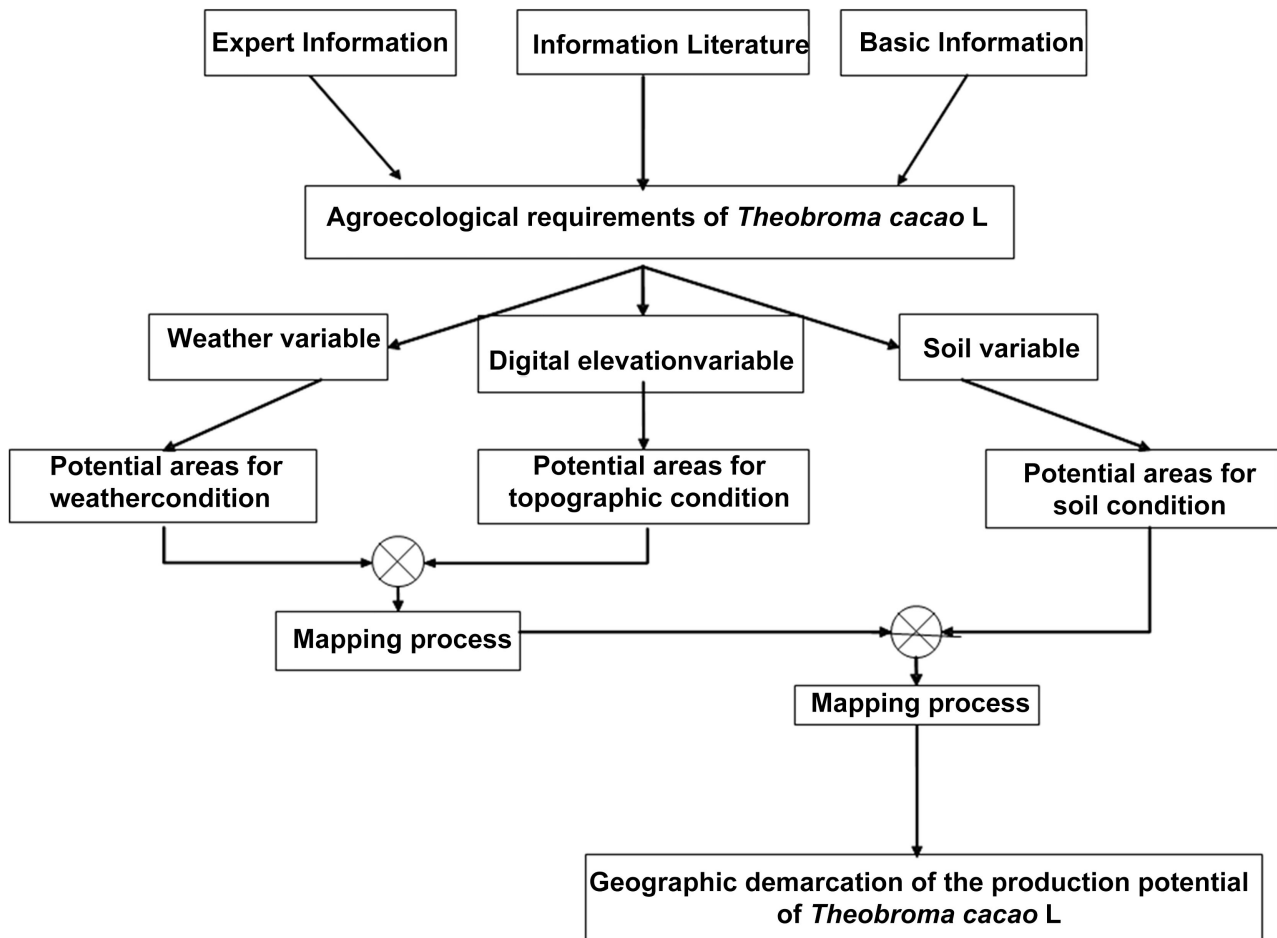
The main contribution of these maps is to facilitate the proper management of resources and it is a basic tool to support agricultural planning policies for future successful crop production.

## 2.2. Methods

To determine areas with agro-climatic aptitude, three fundamental aspects were considered: 1) specific agro-ecological requirements for cocoa (Table 1), 2) databases of agro-climatic variables and 3) processing the information (Figure 1). The soil-edaphic information was taken from the World Reference Base for Soil Resources (WRB) published by FAO (2007) in vector format. The climatic data were taken from the base of World-Clim version 2.0, specifically temperature and average precipitation during the crop cycle. The Digital Elevation Model (MDE) was obtained from the National Institute of Statistics and Geography (INEGI), in raster format with a 500 m<sup>2</sup> resolution. The slope map, bodies of water, mangroves, urban and rural areas of Mexico, as well as protected natural

**Table 1.** Agro-ecological requirements of cocoa (*Theobroma cacao* L.).

Variable	Condition			
	Unit	Optimal	Suboptimal	No suitable
Average Annual Temperature	°C	25 - 32	20 - 25 32 - 35	<20 >35
Altitude	M	0 - 1000	1000 - 1400	>1400
Average Annual Precipitation	mm	1400 - 2500	800 - 1200 2500 - 3000	<800 >3000
Soil	Type	Gleysols Vertisols Fluvisols Luvisols Nitisols	Andosols Cambisols Regosols	Solonchaks Leptosols Arenosols Calcisols
Soil Texture	Type	Loamy-Clayey	Loamy-Clayey-Sandy	Sandy and Clayey
Soil Depth	M	>1	1 - 0.5	<0.50
Soil pH	Level	5 to 6	4.0 - 5.0 6.0 - 7.5	<4.0 >7.5
Soil Drainage	Type	Good	Regular	Deficient



**Figure 1.** Methodological model used to determine the production potential areas of Tabasco, Mexico.

areas, were collected from the Geoportal of the National Information System for Biodiversity of the National Commission for the Knowledge and Use of Biodiversity of Mexico (CONABIO).

The climatic and edaphic attributes were established and classified according to the edaphic and climatic ranges for rainfed conditions. Each attribute was linked to the Vector data giving specific spatial geometrical characteristics which were cut and intersected. Once the geometric operation ended with the edaphic and climatic layers, the areas dedicated to mangroves, protected areas, and urban and rural settlements were eliminated. The information was processed and reclassified using the QGIS 3.6.0 Noosa software [22].

### 3. Results

The growth and production of cocoa are closely related to climate and soil conditions. Therefore, thermal and humidity conditions must be satisfactory for flowering, budding, fruiting and harvesting time [23].

The agro-ecological information for this study was gathered from different bibliographic sources [18] [24] [25] [26] [27] and, the experience of some cocoa

experts were also considered to have the following results.

### 3.1. Photoperiod for Cocoa in Tabasco

The length of the day in the state of Tabasco varies throughout the year. In 2020, the shortest day was December 21, with 10 hours and 48 minutes and the longest one was June 20, with 13 hours and 28 minutes of natural light. The cocoa needs an average of 11.5 h/day of light [28].

In Tabasco, cultivation under natural shade is practiced. This is a traditional cultivation system used in tropical areas where temperatures show little variability and there is abundant precipitation and low light intensity [29]. However, it has been observed that under intense shade the cocoa's leaf regrowth diminished and it is less frequent than under sparse shade (little shade) or in full sun light. When shade is an excessive one yield decreases due to low photosynthetic process of cocoa [30]. The permanence of the leaves in cocoa trees is greater under shade conditions (up to 450 days in the tree) than when they are exposed directly to the sun (up to 250 days in the tree) [31]. This means more photosynthesis activity and more fruits to be harvested.

Jaimez *et al.* (2008) [32] indicate that light intensity in cocoa plantations is regulated by the natural trees canopy and affects other microclimatic factors such as: temperature, relative humidity, evaporation and water availability in the soil. All this factors have an influence on soil fertility when modifying the rates of litter incorporation and the sum of these factors affects both the growth and production of cocoa [29].

### 3.2. Altitude for Cacao in Tabasco

Tabasco is mainly a flat territory with few elevations of no more than 30 meters high. To the south, in the municipalities of Huimanguillo, Tenosique, Tacotalpa and Teapa there are some elevations that are part of the central plateau of Chiapas. Among the most important hills are El Madrigal (1000 masl aprox.), La Campana, La Corona and Poaná, in Tacotalpa; Cocona in Teapa, Mono Pelado in Huimanguillo and El Tortuguero in Macuspana. Cocoa grows best in tropical areas in altitudes ranging from 0 to 800 meters above sea level (masl). However, at latitudes close to the equator, plantings normally develop at higher altitudes from 1000 to 1400 [33] [34]. The crop is well adapted from 4 to 800 masl but ranges between 10 and 400 masl is the most suitable [35].

### 3.3. Climate Conditions in Tabasco

The annual mean temperature for cocoa must range between 21°C and 26°C and the difference between the monthly minimum and maximum temperature must not exceed 9°C, since this difference directly affects the flowering, fruiting and ripening time [36]. In Tabasco, the predominant climate is warm humid with abundant rains in Summer [37], temperatures range from 15°C in the coldest months (January and December) to 42°C in the hottest ones; the average tem-

perature is 26°C [37].

### 3.4. Humidity Conditions in Tabasco

For optimal cocoa production, the humidity must remain between 50% to 70% [33] but the crop can be better adapted to 75% - 86% relative humidity at 09.0 hours, and 51% - 72% at 15.0 hours. Above those humidity levels the incidence of diseases is of highly risk [38].

### 3.5. Average Rainfall in Tabasco

The amount of rain required for cocoa ranges from 1500 to 2500 mm in the humid tropic areas and from 1000 to 1500 mm in the more temperate areas or in the higher valleys. Adequate precipitation varies between 1200 mm and 2500 mm in a well distribution pattern throughout the year. It requires a minimum monthly precipitation of 100 mm [39].

Tabasco is one of the states with the highest average annual rainfall; ranging from 1200 mm to more than 3500 mm. The availability of water is based on the basins formed by the Usumacinta and Grijalva rivers which flow to innumerable streams and are discharged to the sea. The average annual volume is 125 billion cubic meters representing 30% of that of the total country. Wide channels are formed, reaching maximum water levels during September and November causing important floods [40].

### 3.6. Type of Soils for Cocoa in Tabasco

Soil texture is of great importance for agriculture. Loamy and clay-loamy are the best soil textures for cocoa [41] [42] due to both good moisture retention and drainage. Deep alluvial soils with loamy-clay, loamy-silty and loamy-sandy texture are so loose that main roots can penetrate 80 to 150 centimeters, considered as optimal conditions [43]. In the case of Tabasco, the cocoa-producing region is located in the Chontalpa Region with eutric Fluvisols [44] considered as high production potential soils for cocoa. **Table 1** shows the main agro-ecological requirements for cocoa.

Another important factor to be considered is the grade of alkalinity or acidity in the soil as indicated by the pH. The optimum pH should be in the range of 6.0 to 7.5 in the topsoil whilst in the one-meter-deep subsoil should not be extremely acid (pH less than 4.0) nor highly alkaline (pH greater than 8.0) [42].

## 4. Discussion

The optimum annual mean temperature for cocoa ranges from 25°C to 32°C; therefore, the state of Tabasco presents no limitation for the development of cocoa since the temperatures oscillate between 25°C and 27°C.

Regarding the altitude, it is considered that 0 to 1000 meters above sea level are the optimal conditions for cocoa, and since Tabasco is mostly a flat surface with no more than 30 meters above sea level, as the temperature, does not

represent a difficulty for the crop development.

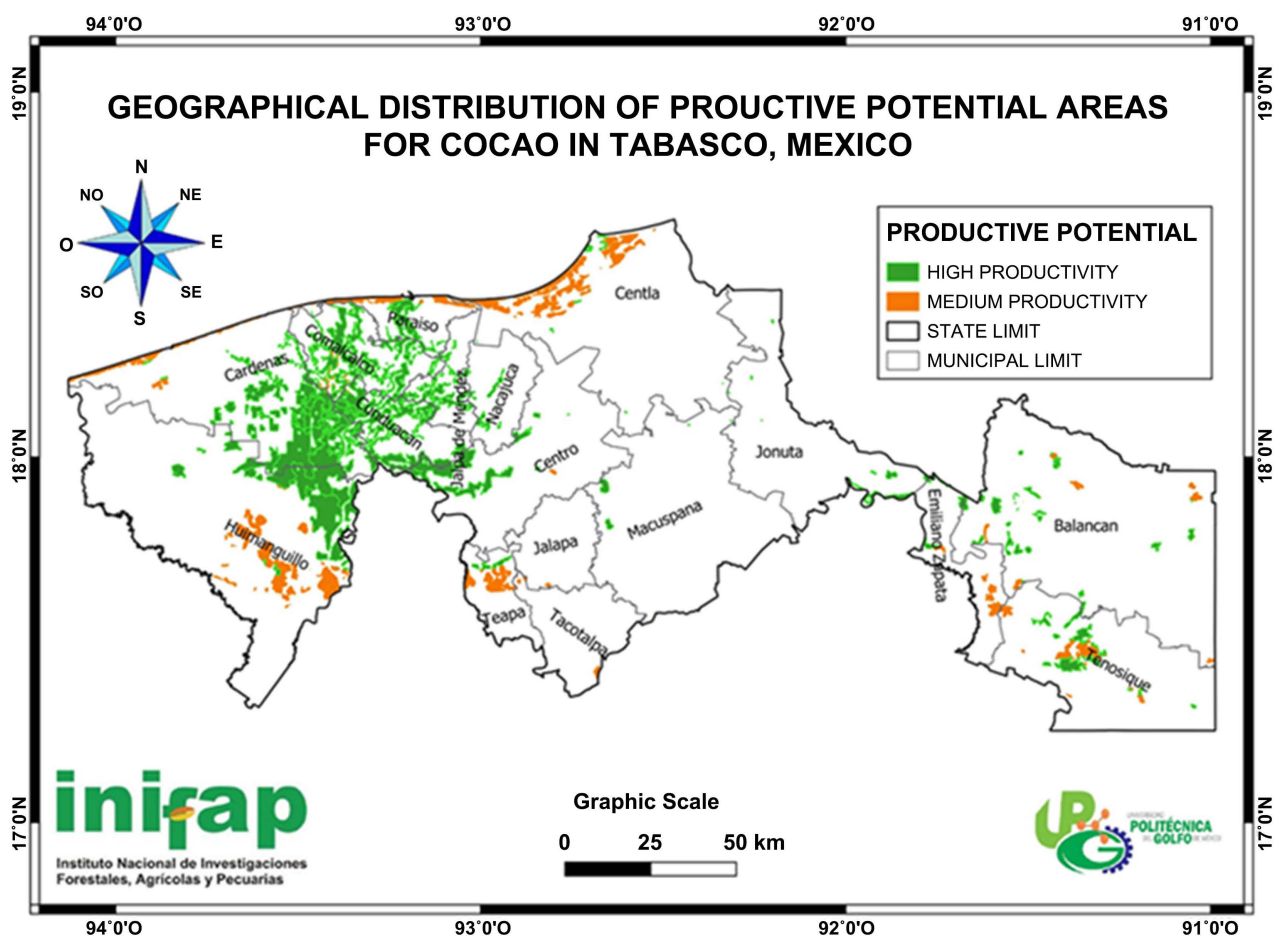
On the other hand, the high rainfall, exceeding more than 2500 mm per year, it is not a limiting factor and it is considered as optimal. Although, the farmers can face fungal diseases problems they can handle it properly.

In the case of soils, the clayey texture ones, with logging problems, mainly distributed in the north part of the state are not appropriate for proper cocoa cultivation. The most adequate soils for cocoa are the Luvisols, Nitisols and Fluvisols with natural good drainage and, those soils with high clay content such as the Gleysols and Vertisols can be good prospects for cocoa if located in areas with incline slopes to drain excess moisture.

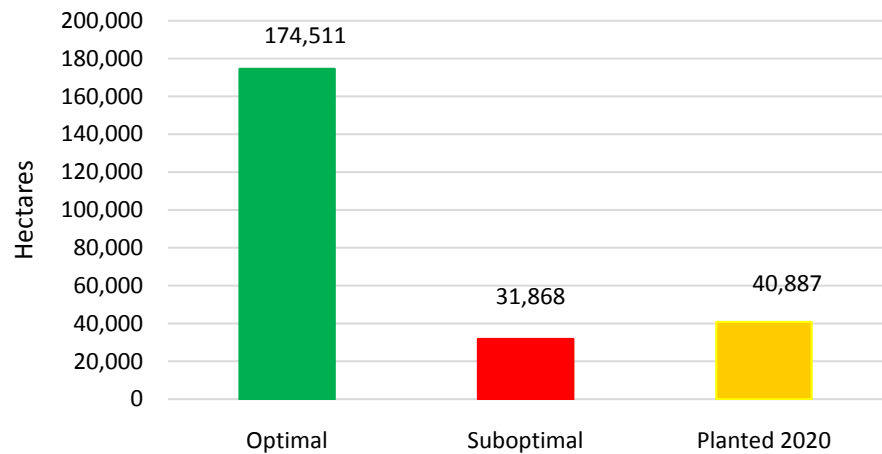
The actual surface of cocoa in Tabasco is of 40,887 hectares [45], which can be increased with the expansion of high productive potential areas identified in this work and indicated below.

### Agro-Ecological Aptitude of Cacao in Tabasco

**Productive Potential of *Theobroma cacao* (L).** Regarding to the regionalization, in **Figure 2** is being shown the Map of Potential Cocoa Production Areas pointing out the Optimal Potential Zones (OPZ) and Sub-Optimal Potential



**Figure 2.** Distribution of potential areas for the cultivation of rainfed cocoa in Tabasco, Mexico.



**Figure 3.** Potential areas for growing *Theobroma cacao* L., under rainfed conditions in Tabasco, Mexico.

Zones (SOPZ). The OPZ were registered with more than 174,000 hectares where all agro-climatic variables interacted properly to favor cocoa production in a competitive way. In the SOPZ, with more than 31,000 hectares, some agro-climatic variables were suboptimal for cocoa and it was considered as Medium Potential Area.

Taking into account all agro-ecological cocoa requirements, the main high potential areas were located in the municipalities of Comalcalco, Cunduacán, Cárdenas, Huimanguillo, Jalpa de Méndez and Paraíso. The municipalities with less high potential areas were: Nacajuca, Centro, Teapa, Jonuta, Emiliano, Zapata, Balancán and Tenosique (Figure 2).

As it is shown in Figure 3 the optimal potential areas (174,511 has) exceed more than 4 times the actual cultivated area (40,887 has) in Tabasco.

## 5. Conclusion

The more extension high potential areas to produce rainfed cocoa are located mainly in the municipalities of Cárdenas, Huimanguillo, Comalcalco and Cunduacán, and the municipalities with less extension areas are: Nacajuca, Jalpa de Méndez, Centro, Paraíso, Teapa, Balancán and Tenosique. The type of soil, relief and precipitation are determining factors in order to properly define optimal and suboptimal cocoa potential areas under rainfed conditions. There are optimal agro-ecological conditions to produce rainfed cocoa and improve its productivity in Tabasco, Mexico. It's feasible to increase the yields of cocoa, under rainfed conditions if the crop is located in the high production potential regions and the currently innovative generated technology is to be applied properly.

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### Conflicts of Interest

The authors declare no conflicts of interest.

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