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Agroclimatic Suitability of *Phaseolus vulgaris* L., in the Yucatan Peninsula of Mexico

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Abstract

In the Yucatán Peninsula (**YP**) of Mexico, bean is a staple food playing a fundamental role in the diet of the yucatecan population of the three states conforming the YP (Campeche, Quintana Roo and Yucatán). Three main species, among others, are cultivated in the región: *Phaseolus lunatus* L., *Phaseolus vulgaris* L. and *Vigna unguiculata* L. However, *P. vulgaris* is the main species consumed by Mexicans, as a source of vegetable protein, including those in the **YP**. The main objective of this study was to spatially delimit the areas of high and medium potential for *P. vulgaris* in the **YP**. Climate and soil databases were processed using the Free License Geographic Information Systems QGIS Biatowiza 3.22 based on intersections and map algebra; taking as initial information the optimal agroecological requirements by the crop under rainfed conditions. In the **YP** there are more than 54 thousand hectares of high potential and more than 290 thousand hectares of medium potential.

Subject Areas

Agricultural Engineering

Keywords

Regionalization, Legume, GIS

1. Introduction

Common beans are a strategic product in Mexico, being the second most important agricultural product, just after corn, in terms of cultivated area and number of dedicated farmers. In addition to being a high demanded product, beans contribute as an excellent protein source to enhance health and good nutrition of the population [1].

In Mexico, it is grown in all agricultural regions with 1,690,247, 246.99 hectares, around 88% planted under [2] rainfed conditions. In some specific regions such as the humid tropics and the Northern Pacific, farmers go for small opaque black beans and the Peruvian-type beans respectively.

The most important producer are the states of Zacatecas, Durango, Chihuahua, Sinaloa, Nayarit, Guanajuato, Chiapas, San Luís Potosí and Puebla [3]; the first two ones, being of great relevance due to their soil vocation, surface, number of producers and production volume. However, the rest of the states, with small farmers, are also of considerable importance since they contribute to local supply, reducing the imports.

In the specific case of the **YP**, bean planting is carried out in small areas and generally between August and September, which can last until October. In 2021, the area planted under rainfed was 1346 hectares in Campeche, 475 in Quintana Roo and 356 in Yucatán. Common bean has generally been cultivated as an emerging crop, to support producers who have lost (due to climatic effects) their corn plantings.

Yields are very low (260 to 500 $k \cdot ha^{-1}$), since not all surfaces with good productive potential are used. It is understood that planting in good potential areas the yield can increase by up to 100% to 150%.

Due to the relevance of this crop in the Yucatan Peninsula and the interest of the Federal and State Governments in expanding the surface with areas with high yield potential, it was considered a strategic task to locate and delimit the most suitable areas for produce beans under rainfed conditions in order to improve average crop yields.

2. Materials and Methods

2.1. Materials

The spatial determination of optimal and sub-optimal areas of a crop can be carried out using different methodologies; however, in this case it was done based on the use of map algebra, taking as input variables the agroecological requirements of the crop under Mexico conditions.

The use of Geographic Information Systems (GIS) has been a successful tool to spatially delimit areas of high productive potential [4] of crops.

Through GIS, the agroecological variables, representing the physical environment such as climate, soil and water resources and their spatial distribution, can be welldefined to detect optimal and sub-optimal areas. With the maps the adequate management of resources is facilitated to support public policies in agricultural management and territorial planning [5].

Three fundamental aspects were considered in this work: agroecological requirements, databases of agroclimatic variables and processing.

2.2. Methods

2.2.1. Agroecological Requirements

The agroecological information was integrated based on different bibliographic sources [6] [7]. On the other hand, the experience of some experts was also taken into consideration.

2.2.2. Databases

Several geospatial databases were reviewed. The edaphic information was taken from the World Soil Resource Reference Base, known by its acronym in English as WRB, published by the FAO in 2007, in vector format. Climatic data were taken from the WorldClim version 2.0 database, specifically average temperature and precipitation during the crop cycle. The Digital Elevation Model (DEM) was obtained from the National Institute of Statistics and Geography (INEGI), in raster format with a resolution of 225 m^2 per pixel.

2.2.3. Data Processing

The procedure basically consisted on classifying the climatic and edaphic attributes for rainfed conditions.

Vector data are entities associated with each attribute, have their own spatial characteristics, and the geometry that defines each attribute serves on its own to carry out numerous analyzes, such as cuts and intersections. These geometric operations on vector data consisted of intercepting the edaphic and climatic layers, to subsequently eliminate areas of mangroves, protected areas, and urban and rural settlements. All information was processed and reclassified using the QGIS 3.22.14 Biatowieza 2022 [8] software.

High potential areas are those where all agroclimatic variables interact for optimal crop conditions. Medium potential areas are those where some of the agroclimatic variables present some suboptimal or unsuitable condition for the crop to develop with the fewest possible limitations and the unsuitable ones are those where all the limiting conditions interact for crop production.

3. Results

In this work only areas open to cultivation (areas used for agricultural, livestock or forest plantation purposes) were considered.

3.1. Potential Areas for Rainfed Beans in the Yucatan Peninsula

The growth, development and production of *Phaseolus vulgaris* L are closely related to the climate and soil conditions. Climatic factors such as thermal and humidity conditions must be satisfactory during the vegetative period. The environment regulates time of flowering, budding, fruiting and harvest.

Table 1 shows the Optimal, Suboptimal and Unsuitable agroecological conditions for the development of *Phaseolus vulgaris* L. This information was prepared with consultation with experts in cultivation and bibliographic review on the requirements of the species.

In **Figure 1**, the areas of high and medium potential are represented in green and orange colors. These areas have good environmental conditions suggesting that bean yields can be higher than the regional average. On the other hand, the blank areas are not suitable for bean cultivation. This is due to limiting factors such as lack of precipitation and shallow or flood soils, mainly.

Table 1. Agroecological requeriments of *Phaseolus vulgaris* L.

Variable	Unit	Optimal	Suboptimal	Not suitable
Average Annual Temperature	˚C	20 - 26	18 - 20 26 - 35	Less than 18 Over 35
Altitude	*masl*	0 - 1500	1500 - 2000	Over 2000
Average Annual Precepitetion	*mm*	1600 - 2500	1000 - 1600 2500 - 300	Less than 1000 Over 3000
Soil	*Type*	Fluvisoles Luvisoles Nitisoles	Cambisoles Regosoles Phaeozems	Solonchaks Leptosoles Vertisoles Gleysoles Arenosoles Calcisoles
Texture	*Type*	Medium	Ligth y Medium	Very ligth y heavy
Depth	*m*	Over 1	1 a 0.5	de 50
pH	*Indicator*	6.5 a 7.0	5.5 a 6.5	<de 5.5 >de 7.5
Ligth hours per year	*Hours*	Over 3000	2500 a 3000	Less than 2500
Drainage	*Type*	Good	Medium	poor

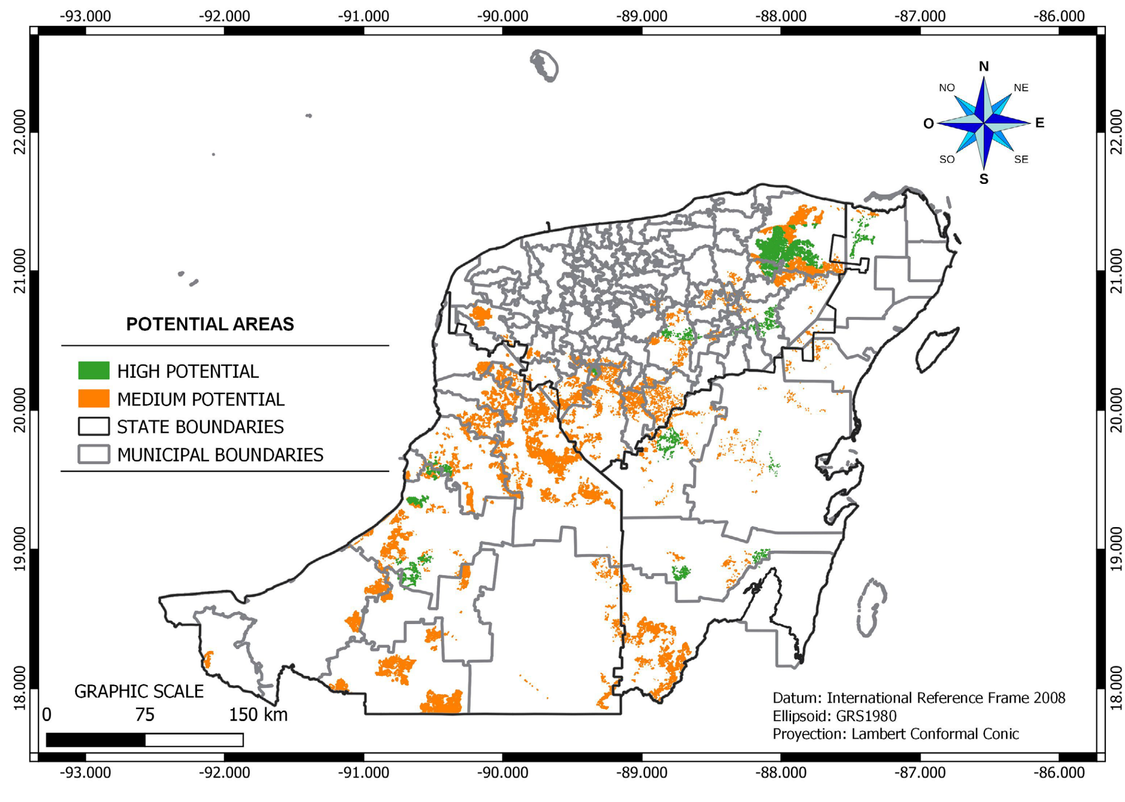

Figure 1. Distribution of areas with productive potential for *Phaseolus vulgaris* L.

The high potential area detected was of 54,992.00 hectares with 12,850.00 in the state of Campeche, 4878.00 in Quintana Roo and 37,264.00 in Yucatan. Regarding the areas of medium potential, 290,993.00 hectares were found of which 188,819.00 correspond to Campeche, 27,115.00 to Quintana Roo and 75,059.00 to Yucatán.

3.2. Soil and Climate

The most favorable soils for growing beans in the YP are those known as the Nitisols and Luvisols (regionally known with the Mayan names of Ya'ax hom and K'ankab) located mainly in the northeast and central part. This is the south and east of Yucatán, the north-central part of Campeche and the south-central part of Quintana Roo (**Figure 2**). In the state of Campeche, the main municipalities of: Calkini, Hecelchakán, Tenabo and Campeche; in Quintana Roo in the municipalities of: Morelos, Bacalar and Lázaro Cárdenas; in Yucatán in the municipalities of Tizimín, Espita, Calatmul, Maxcanu, opichen, Muna, Santa Elena, Oxkutzcab, Ticul and Tekax.

The average annual temperature is practically optimal in most of the territory of the peninsula with the exception of small areas of suboptimal condition in the municipalities of Campeche, Champotón and Calakmul. in the state of Campeche (**Figure 3**). In general, the average annual temperature is in the range of 24˚ to 26˚C, although in some small areas, bordering the Gulf of Mexico, the stlill optimal temparatures range from 26˚ to 28˚C. There are some specific areas, mainly in the state of Campeche, with suboptimal temperatures from 22˚ to 24˚C.

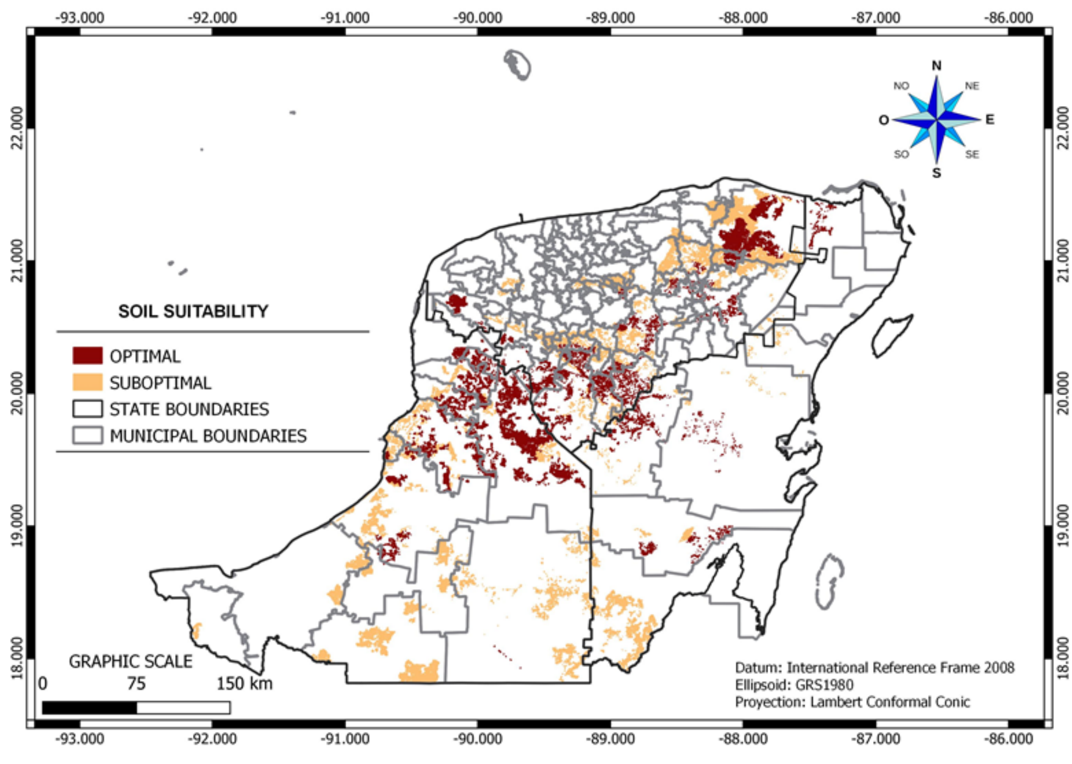

Figure 2. Distribution of areas optimal and suboptimal soils for beans in the Peninsula of Yucatan.

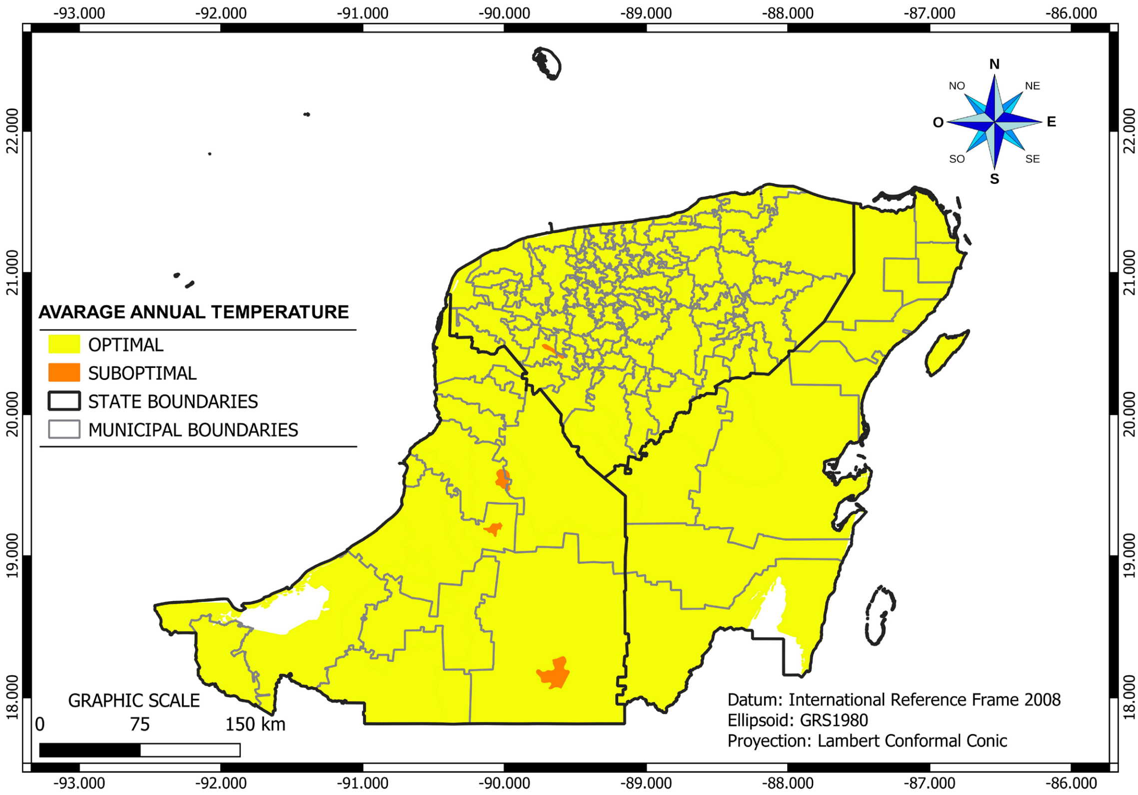

Figure 3. Distribution of optimal and suboptimal average anual temperature for beans in the Peninsula of Yucatan.

Regarding the distribution of precipitation, the optimal area is located in the east of the YP and south of the state of Campeche. The suboptimal zone is in the central part and the unsuitable one in the coast of the state of Yucatán (**Figure 4**). The average annual precipitation ranges from 500 mm to 2000 mm with the driest zone located in the northern part in the state of Yucatán.

The highest average annual precipitation is in the south and east of the region, mainly in the state of Campeche and Quintana Roo.

Bean can grow in various climates such as the subhumid ones (Awo, AW, Af, Am and Aw2) and dry tropics (BS and BW) with rainfall ranging between 100 to 1150 mm according to the National Seed Inspection and Certification Service (SNICS) [9] [10].

3.3. Opened Lands for Beans Cultivation

According to the map (**Figure 5**) of areas open to cultivation, most of the **YP** are covered by grasslands for livestock activity.

These areas were previously used for Sisal-Henequen cultivation to industrialize the fiber mainly in the state of Yucatán and rice in the state of Campeche. Sugarcane is nowadays an important crop in the state of Quintana Roo. The potential zones were determined considering the total area open to cultivation but special consideration must be given to those soils that are underutilized, with low-profitability crops and of little interest to producer

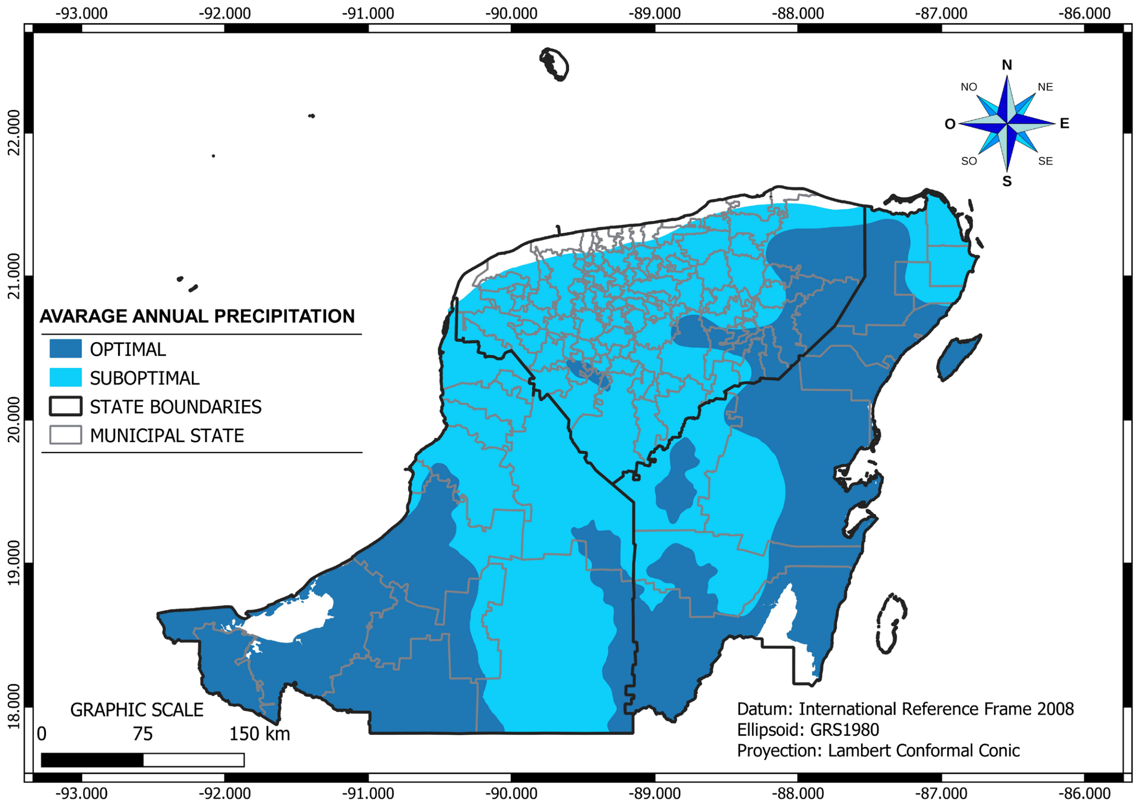

Figure 4. Distribution of optimal and suboptimal precipitation for beans in the Peninsula of Yucatan.

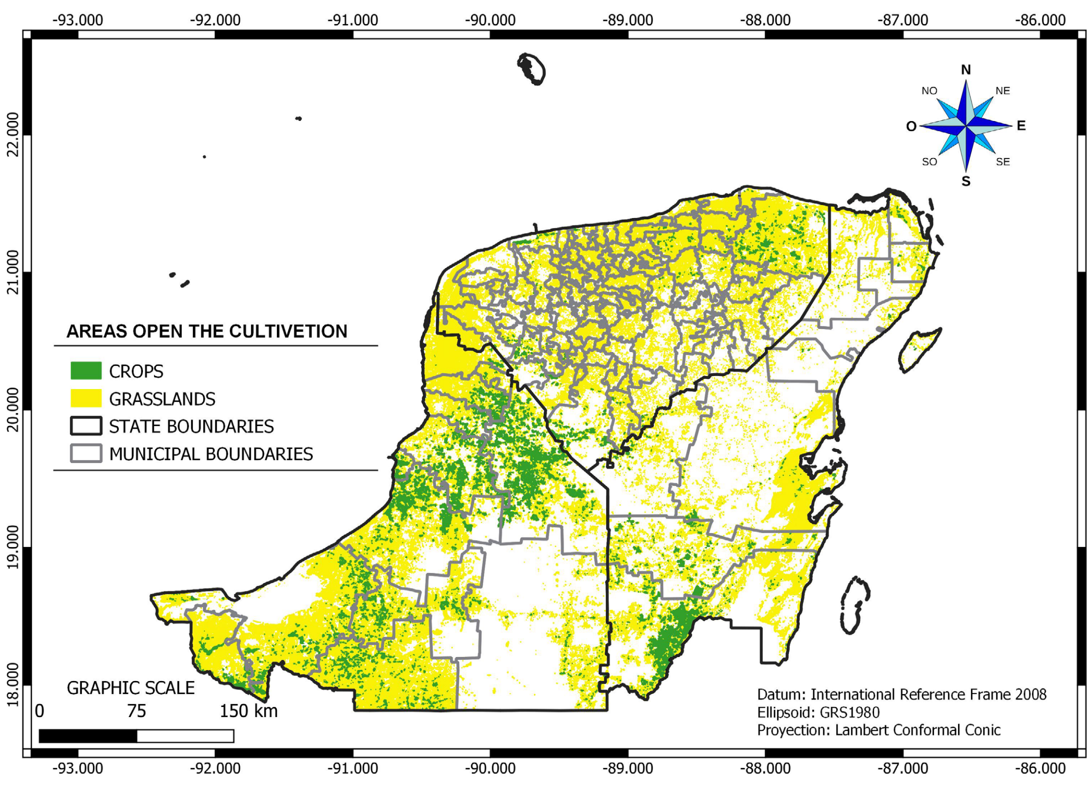

Figure 5. Areas open the cultivetion in the Yucatan Peninsula.

4. Discussion

The bean (*Phaseolus vulgaris* L.) plays a fundamental role in feeding the world's population. It has been cultivated and domesticated since pre-Hispanic times in various environments of America, including tropical and temperate regions [11] [12]. In Mexico, bean cultivation occupies third place in terms of cultivated area, although its production varies annually due to the various climatic conditions according to Aguilar-Benítez *et al.* (2019) [13].

This study determined that the Yucatan Peninsula has 54,992.00 hectares of high potential and 290,993.00 hectares of medium ones.

According to de Ron *et al.* (2015) [14], *P. vulgaris* can grow in different soil-climatic conditions; on the other hand, Acosta-Gallegos *et al.*, (2004) [15] mention that loam soils, with good drainage, provide the best conditions for the crop. In the case of the YP, the best soils for beans are *Luvisols* and *Nitisols*, which are clayey, with a *Kaolinite* type of clay with good drainage.

However, the YP is mainly covered by very thin (less than 30 cm deep) stony soils such as *Leptosols* but are the *Lithic Leptosols* the Not Suitable ones for beans. The contrasting soils are the deeper soils such as the *Gleysols*, *Vertisols* and *Solonchaks* [16], also considered as Not Suitable but due to the type of clay that induces water accumulation.

In spite of this constraints, is in the northeast and center part of the Peninsula that are located the best and optimal soils such as the *rhodic Nitisols* and *ferric Luvisols* (regionally known with the Mayan names of *Ya' ax hom* and *K' ankab*).

Related to the temperature, the ideal period for beans is from August to October. However, if the temperature rises above 35˚C flowering and grain filling can be affected. Anyway, beans adapted to tropical climate must be considered for cultivation. Tropical beans are less sensitive to high temperatures than the temperate types. The response of the plant would depend mainly on varietal genetics [17].

However, it is important to consider that 25˚C is the optimal temperature [18]. Higher temperatures than 30˚C during the day or 20˚C during the night can stress the plant and reduce production [19]. There is an inhibition of pollen fertility, flower abortion and yield and quality of grain is reduced [20].

Maqueira-López *et al.* (2021) [21] suggest that the environment can impact positive and negative, depending on climatic conditions. So, another crucial factor to be considered is the average annual precipitation during the crop cycle. This despite the fact that this crop has been cultivated since pre-Hispanic times in different environments in America under [22] rainfed conditions.

For example, in central and northern Mexico, beans are grown in the spring-summer-cycle, under rainfed conditions with 250 to 400 mm of precipitation [23]; while in the **YP**, the sowing date is from August to September and harvesting from November to December receiving from 500 to 700 mm of rainfall durin the cycle. Lack of humidity at any stage of the growing cycle can be affected by drought. Germination being one of the most important stages, since it determines the efficient use of nutrients and water [24]. Varieties with good germination power, under water stress, should receive special attention. By instance, Light-Color cultivars are more sensitive to water stress than the Black-Color ones [12].

5. Conclusions

Common beans are a strategic product in Mexico, being the second most important agricultural product, just after corn, in terms of cultivated area and number of dedicated farmers. Knowing the areas where this legume can be produced with the least agroecological restrictions and with the best yield potential is of strategic importance for agricultural planning.

In this work the important findings related to the foregoing were:

1) There are optimal and suboptimal agroecological conditions for producing *Phaseolus vulgaris* L. under rainfed conditions in the Yucatan Peninsula (YP).

2) It is feasible to produce with high and medium potential in the three states of the YP.

3) The type of soil, the average annual temperature, the average annual rainfall and the crop cycle are determining factors to properly define areas of high and medium potential.

4) Yields of beans can be increased by more than 100% by using high and medium potential areas.

Conflicts of Interest

The authors declare no conflicts of interest.

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