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Productive Potential of *Vigna unguiculata* L., under Mexican Rainfed Conditions

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Abstract

Vigna unguiculata L., also known as cowpea bean or x'pelon bean (Mayan term), is an important legume mainly consumed as dry grains, although it is also used in the form of immature pods rich in protein, vitamins, fiber, minerals, and antioxidants. It is an excellent source of protein (23% to 25%). It contains all the essential amino acids, carbohydrates, vitamins, and minerals, and a large amount of dietary fiber, low in fat and cholesterol-free. In addition, it is considered a resilient crop due to its great adaptation to high temperatures, excess rainfall, tolerance to drought stress, little demand for high-quality soils, and ability to incorporate nitrogen into the soil because of its capacity to convert atmospheric nitrogen into available one. This work aimed to elaborate maps representing areas with high and medium yield potential under rainfed Mexican conditions. In this paper, the maps were elaborated by using Geographic Information Systems (GIS) through intersections and map algebra. The optimal agro-ecological requirements of the crop were the initial inputs required for the system and the information was processed with ESRI's Arc/View 3.3 Software. It detected more than 13 million hectares with high productive potential under rainfed conditions for cowpea beans. Among the states with the largest areas were identified: Guerrero, Oaxaca, Campeche, Michoacán, Jalisco, Sinaloa, Nayarit, Veracruz, Yucatan, and Quintana Roo.

Subject Areas

Agricultural Engineering

Keywords

Agroclimatic Regions, Legumes, Beans, GIS

1. Introduction

Vigna unguiculata (L.) Walp., is a legume of the Fabaceae family considered one of the most adapted, versatile, and nutritious grain legumes [1]. It is used as human and animal food [2] because of its high-quality protein content for human consumption and for livestock fodder with the additional advantage of fixing nitrogen for the soil [3].

This legume is one of the oldest crops known to man [4]. Cowpea is also known as blackeye pea, southern pea, bean, lubia, feijao caupi, ni'eb'e, carilla, partridge eye bean, careta bean, blackeye bean, castilla bean (Peru), patience bean (Ecuador), chicharillo, wild pea, mung bean, black-headed bean, tape bean (Uruguay), black-mouthed peas (Seville, Spain), espelon or x'pelon (Yucatan, Mexico), cow mackerel, mung bean or yorimón bean (Mexico), there are more names depending on the place to be found [3] [4] [5].

This bean was originally domesticated in Sub-Saharan Africa, probably both west and east, before 2500 BC, and by 400 BC it was already established in all major modern producing regions of the Old World, such as Sub-Saharan Africa, the Mediterranean basin, India, and Southeast Asia. Now, it is grown in all continents except Antarctica. The Columbian Exchange introduced from Africa germplasm into the Caribbean region, the southeastern United States, and South America; and the Mediterranean germplasm was introduced to Cuba, the southwestern United States, and northwestern Mexico [6].

V. unguiculata has been successfully cultivated in a wide range of geographical locations around the world because of its excellent protein quality, fiber, and micronutrient content [6]. The seeds have between 20% and 30% protein by dry weight [7] [8], and the leaves have a similar protein content [9]. Given the advantages of climatic resilience of the species and facing the problems of climate change, this study had the following objectives: 1) to characterize the climatic and edaphic factors that affect the species; 2) to identify high-yield potential areas and their distribution in the Mexican Republic; and 3) to support policies and decision-making for better production programs.

2. Materials and Methods

The study was carried out, in 2022, at the laboratory of Geographic Information Systems (GIS) of the National Institute for Forestry, Agriculture and Livestock Research (INIFAP) located in The Southeast Regional Research Center in Merida Mexico, The delimitation of the production potential was based using the agro-ecological requirements and their respective spatial query on existing maps, taking into account the climatic, topographic and soil variables, in addition to their intersections.

2.1. Agro-Ecological Requirements Determination

Crop distribution is delimited by climate factors worldwide, either by a lack or by an excess of the individuals vital needs and the specific requirements of different biotypes. The plants are submitted to climate components with asynchronous variations, turned into the most determinant factors for the success of any given crop [10]-[15].

The particular needs and requirements are most commonly described in ranges, usually reported for each species or even genotypes.

The result of the diagnosis shall rely on the intervals taken into account; as a result, if optimal values are considered, the resultant potential areas may indeed provide a better yield and crop profitability.

The following criteria were considered to determine the potential areas for *V. unguiculata* under rainfed conditions: 1) when all of the variables interact properly with each other the area was considered as the most suitable for an optimal development; 2) when there are some restricted variables and most of the climatic and soil characteristics interact properly the area was ranked as suboptimal; finally 3) those areas with all variables considered as inadequate for cowpea cultivations were reported as marginal.

Potential areas were determined taking into account only those actual open cultivation areas; as a result, their potential is even higher nationwide [16] [17] [18] [19]. Beside climate, the altitude, soil, temperature, and annual rainfall levels were considered, as defined in **Table 1**.

2.2. Regionalization of Cowpea Potential Areas

The Arc/View version 3.3., software developed by the American company ESRI,

Table 1. *V. unguiculata* agroecological requirements for rainfed conditions.

Criteria	Unit	Optimal	Suboptimal	Inadequate
Average Annual Temperature	˚C	25 - 30	18 - 24 30 - 35	<than 18 >than 35
Annual Rainfall	mm	1000 - 2000	650 to 1000 2000 to 2500	Less than 650 Higher than 2500
Altitude	msnm	0 - 1500	1500 - 2000	Higher than 2000
Soils	Types	Fluvisols Regosols Luvisols Nitisols Andosols Phaeozem Castañozems	Cambisols	Solonchak's Leptosols Vertisols Gleysols Arenosols Calcisols
Texture	Types	Loamy	Sandy	Clay
Depth	m	1	1 to 0.5	<than 0.5
pH	Indicator	5.5 to 6.5	5.0 to 5.4 6.5 to 7.5	<than 5.0 >than 7.5
Light Hours	Hours	Higher than 3000	2500 to 3000	Less than 2500
Drainage	Types	Good	Good	Deficient

was the program used for data processing and analysis. Geo-referenced data was also represented including characteristics and distribution patterns [20]. All of the Arc/View activity considered project parameters, which were a collection of related documents controlled during the Arc/View session.

Projects contained as many as five different views, tables, charts, layouts (or printouts) and scripts. The documents in the Arc/View project were displayed through the Project window; properly organized and stored.

The project decided how and where such documents were meant displayed, keeping the document selection active in window program in a well-defined picture. The information was further stored in an ASCII format file, always with an *. Apr. Extension.

Arc/View was mainly a maps vector generator performed by the Arc/View 3.3, according to Figure 1, in order to take the variables intersection to generate optimal, suboptimal and unsuitable potential areas.

3. Results and Discussion

3.1. Temperature

V. unguiculata, is an annual legume, native from Africa and widely cultivated in Africa, Latin America, Southeast Asia, and the Southern United States. It is relatively well adapted to various agroecosystems, especially semi-arid regions, humid tropics, and temperate zones. It tolerates heat and drought conditions, but does not tolerate frost [21] [22].

The semi-humid and semi-dry climate favors the growth, with temperatures from 19˚C to 34˚C [23]. However, other studies [24], suggests that this crop can survive to temperatures above 45˚C with an adequate level of soil humidity. However, flower abortion occurs and temperatures below 25˚C negatively influence

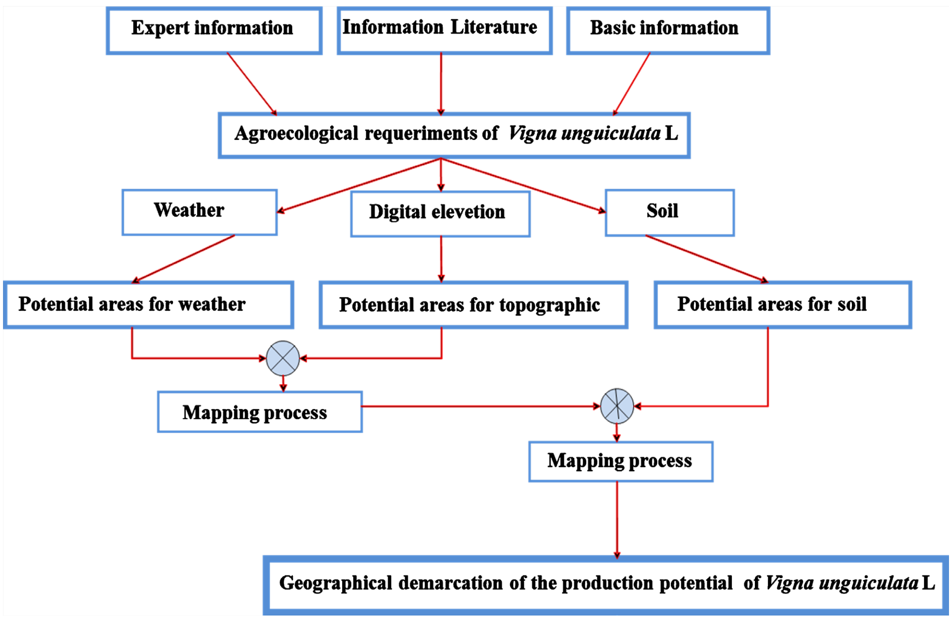

Figure 1. Process methodology used in the delimitation of production potential.

growth.

Ustimenko and BakumovskI (1982) [25], mention that flowering and ripening phase require high temperature, while low temperatures between 15˚C - 18˚C prevent the seed maturation. The optimal temperatures for its cultivation in Mexico are shown in **Table 1**. The temperatures considered optimal are from 25˚C to 35˚C and suboptimal from 18˚C to 24˚C and from 30˚C to 35˚C. The Mexican states that stand out because of their higher yield potential are the next: Tamaulipas, Tabasco, Guerrero, Campeche, Michoacán, Jalisco, Sinaloa, Nayarit, Veracruz, Yucatán and Quintana Roo (**Figure 2**).

3.2. Annual Rainfall

The water requirements of this crop depend on its stage of development [26]. It is distinguished by its resistance to drought and tolerant to abundant rains, but it does not tolerate waterlogging; however, the lack of water in specific stages of development can affect germination, flowering, formation of pods, stem diameter, leaf area, number of leaves, number of pods per plant, weight of pods, weight of seeds and yield [27]-[32]. Bezerra *et al.* (2003) [33] report that the water deficit during the entire growth period can reduce yield up to 59%. This crop thrives in places with rainfall between 650 to 2000 mm. It is moderately tolerant to

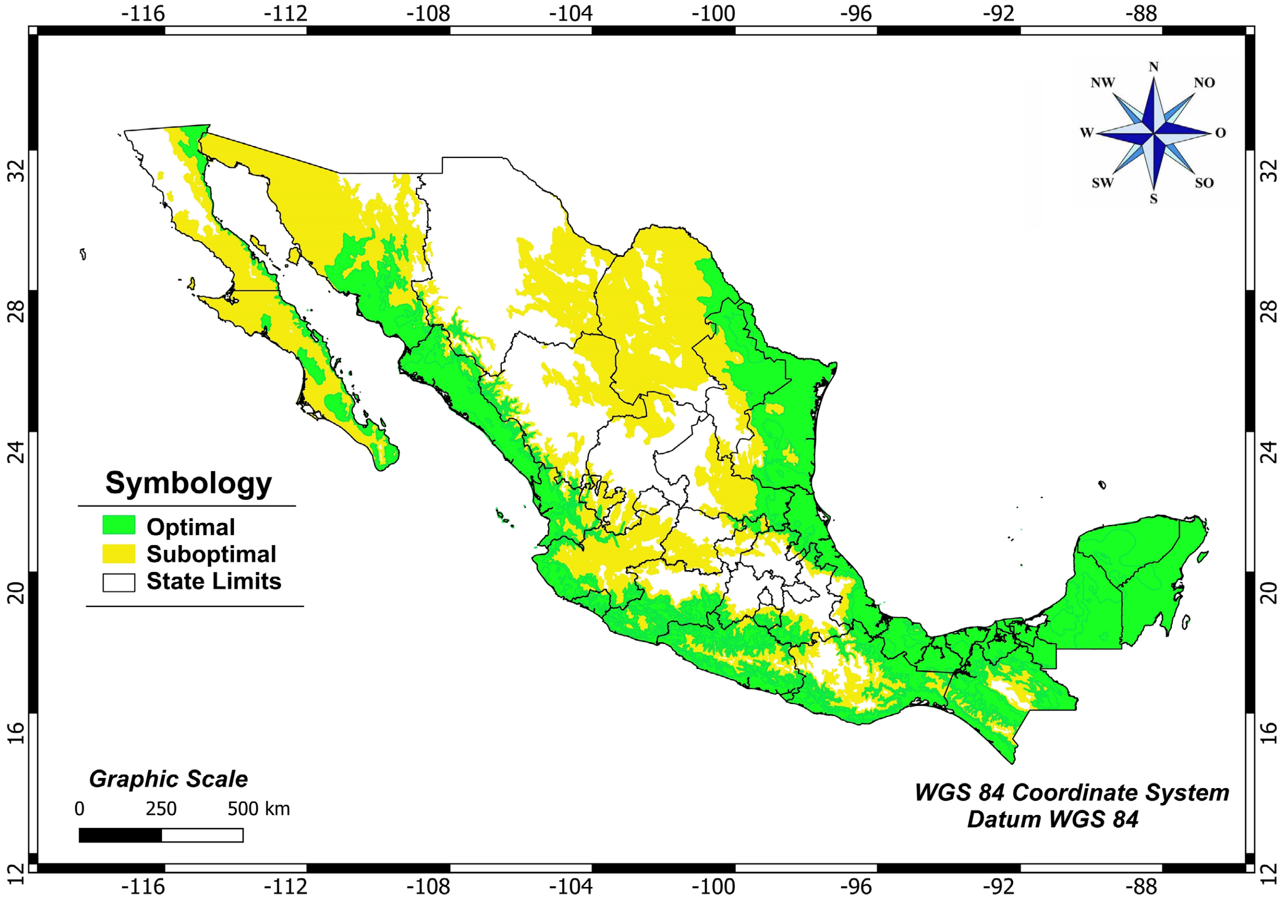

Figure 2. Geographic distribution of suitable average annual temperature in Mexico.

drought, since it can grow with less than 300 mm [34] [35]. For Mexican conditions, the range of 1000 to 2000 mm was considered optimal and, suboptimal two ranges from 650 to 1000 mm and from 2000 to 2500 mm; less than 650 mm and greater than 2500 mm were ranked as not suitable areas (**Figure 3**).

3.3. Soils

Pandey (1990) [36], indicates that cowpea grows in many kinds of soils such as sandy, clayey, in compact soils with low water infiltration capacity, tolerating acid and neutral soil pH's from 4.3 to 7.5 and it is little tolerant to salinity.

It is a drought-tolerant species with good atmospheric nitrogen fixation capacity, adapted to different cropping systems [37] and to a great diversity of soils but not to akalinity or salinity. It thrives well in light, well-drained, deep soils [27]-[31] [38].

In Mexico, the most appropriate soils, with loam and sandy loam textures, are the Fluvisols, Regosols, Luvisols, Nitisols, Andosols, Phaeozem and Castañozems; the Cambisols (**Figure 4**) represents the suboptimal production potential areas.

3.4. Light Hours (Photoperiod)

When cultivating cowpea, enough light hours for each growth stage are required.

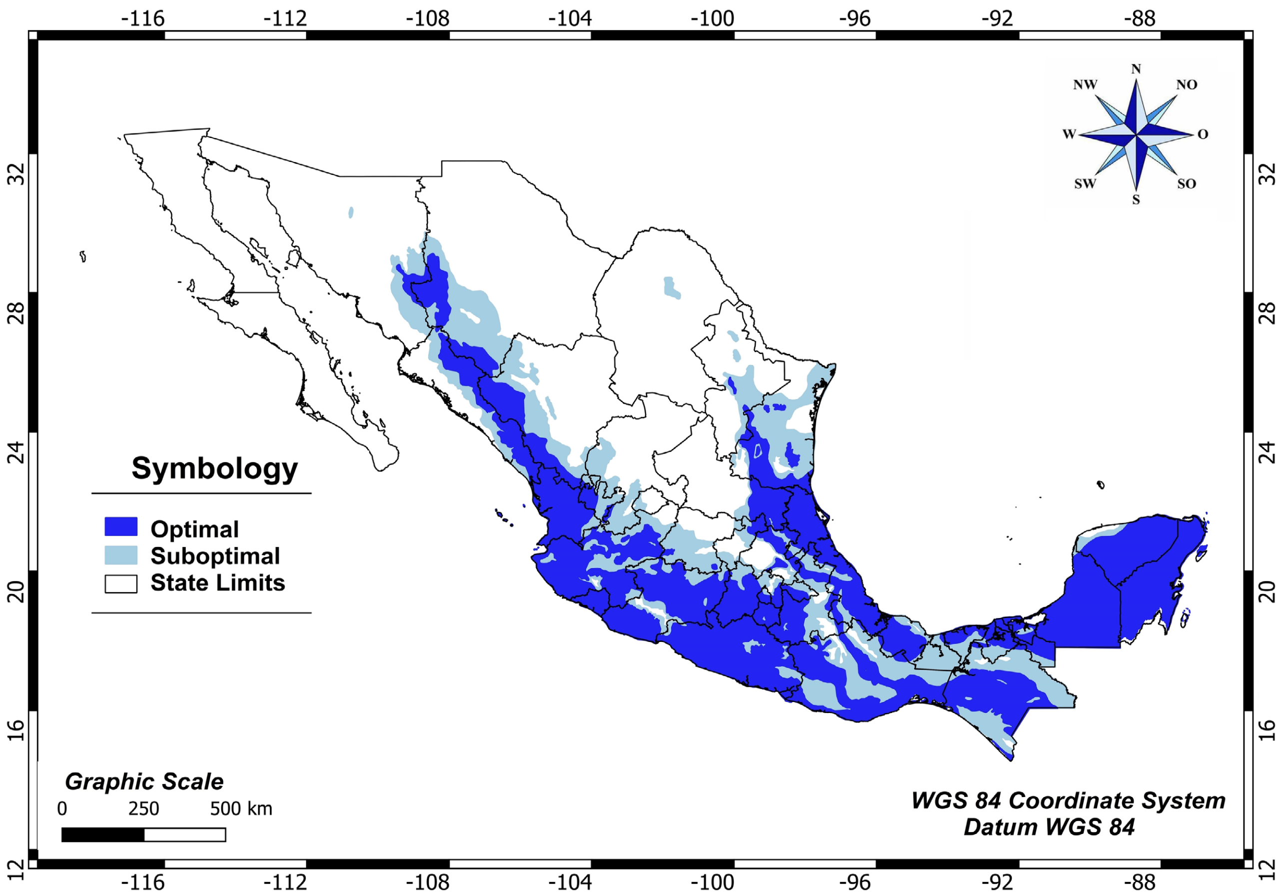

Figure 3. Geographic distribution of suitable average annual precipitation.

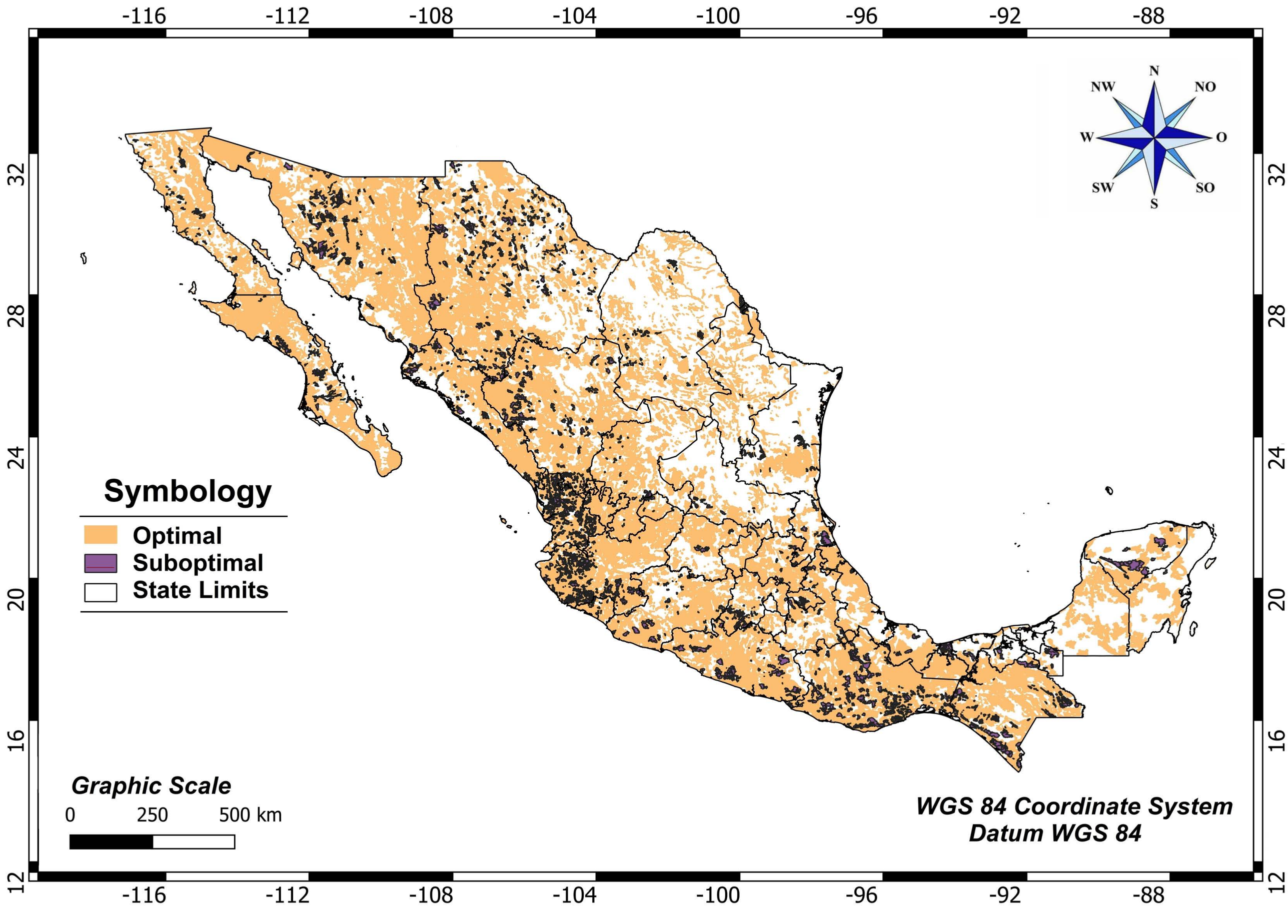

Figure 4. Geographic distribution of suitable soils in Mexico.

The photoperiod can have great effects on reproductive development, although some genotypes are insensitive [39] [40]. ASPROMOR (2012) [41] reports that a good light favors flowering and filling of pods. The optimal photoperiod for flowering induction is 8 - 14 hours. The reduction of light favors a stunted or creeping development of the plant, with a negative effect on yields [42]. On the other hand, White (1999) [43] mentioned the important role of light in regulating plant development, mainly through photoperiod effects; this crop responds better to short days than the long ones, which delays flowering and maturity. For Mexico, the optimal conditions were encountered in areas with more than 3000 light hours; equivalent to 125 days of light during crop development; the suboptimal areas are those receiving from 2500 to 3000 light hours; areas with less than 2500 light hours ranked as not suitable (**Table 1**).

3.5. Altitude

The crop develops favorably from sea level to 1200 meters above, demonstrating a wide range of adaptation [44]. Díaz (1997) [45] mentions that cowpea grows well at altitudes of up to 1500 meters above sea level (masl) while Pandey (1990) [36] reports ranges from 0 to 1500 masl, but optimal from 0 to 800 masl. For Mexico, altitudes of 0 to 1500 masl are recommended as the most optimal planting areas; suboptimal from 1500 to 2000; and those greater than 2000 are not suitable (Figure 5).

3.6. Potential Areas for *V. unguiculata* in Mexico

There were found more than 13 million hectares of high yield potential under rainfed Mexican conditions distributed in 17 states: Guerrero, Oaxaca, Campeche, Michoacán, Jalisco, Sinaloa, Nayarit, Veracruz, Yucatán and Quintana Roo (Figure 6 and Figure 7) being the most important ones, and with lower potential the states of Chiapas, Tamaulipas, Tabasco, Puebla, State of Mexico, Colima and Durango. The loamy and sandy loamy soils are more suitable for cowpea production and for Mexican conditions the Fluvisols, Regosols, Luvisols, Nitisols, Andosols, Phaeozem, Castañozems and Cambisols are considered as optimal ones (Figure 4).

Based on the agro-ecological requirements, a large surface presents favorable altitudes for cowpea production and, only those regions (central and north-central Mexico) with more than 2000 masl were considered unsuitable. Regarding the number of light hours per year, only small areas of the states of Veracruz, Puebla and Oaxaca, with less than 2500 light hours per year were not suitable (Figure 8).

On the other hand, and based on the average annual temperature, the optimal and suboptimal conditions are mainly found in the states closed to the Pacific

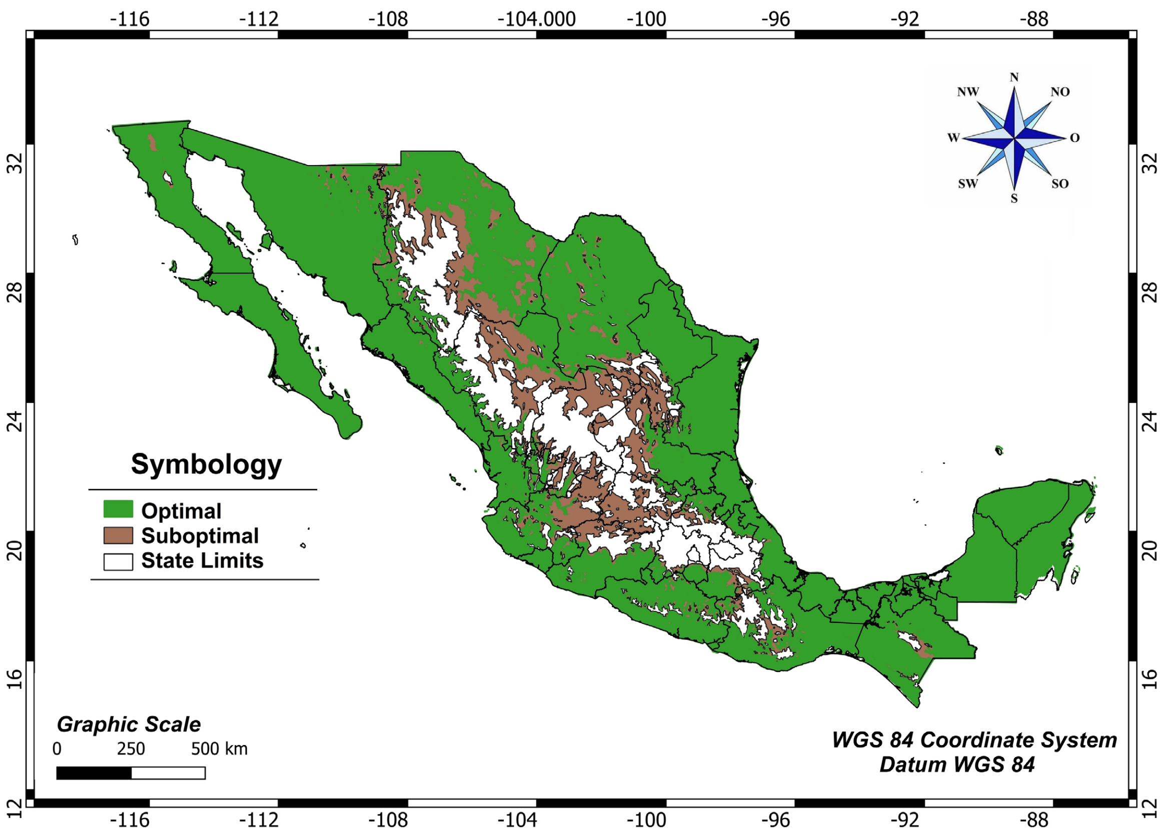

Figure 5. Geographic distribution of suitable altitudes for cowpea production in Mexico.

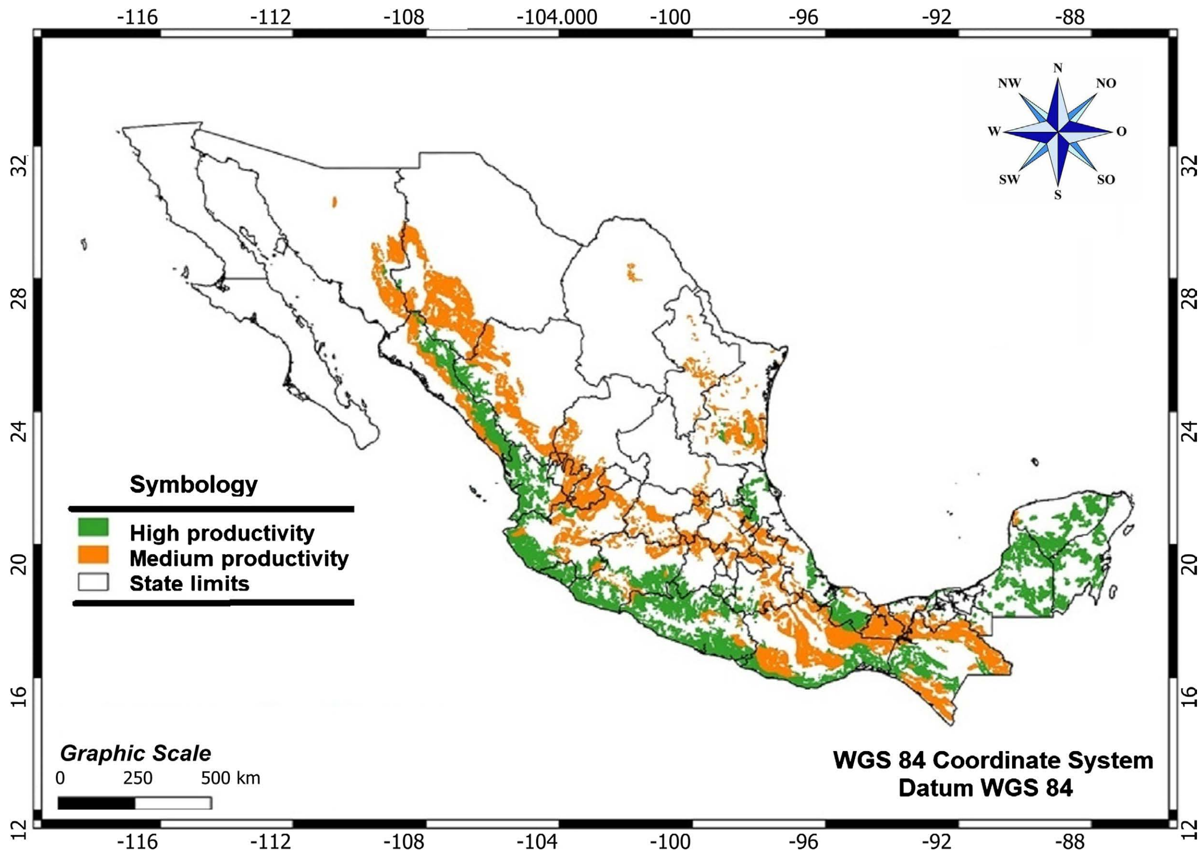

Figure 6. Geographic distribution of potential areas for cowpea beans in Mexico.

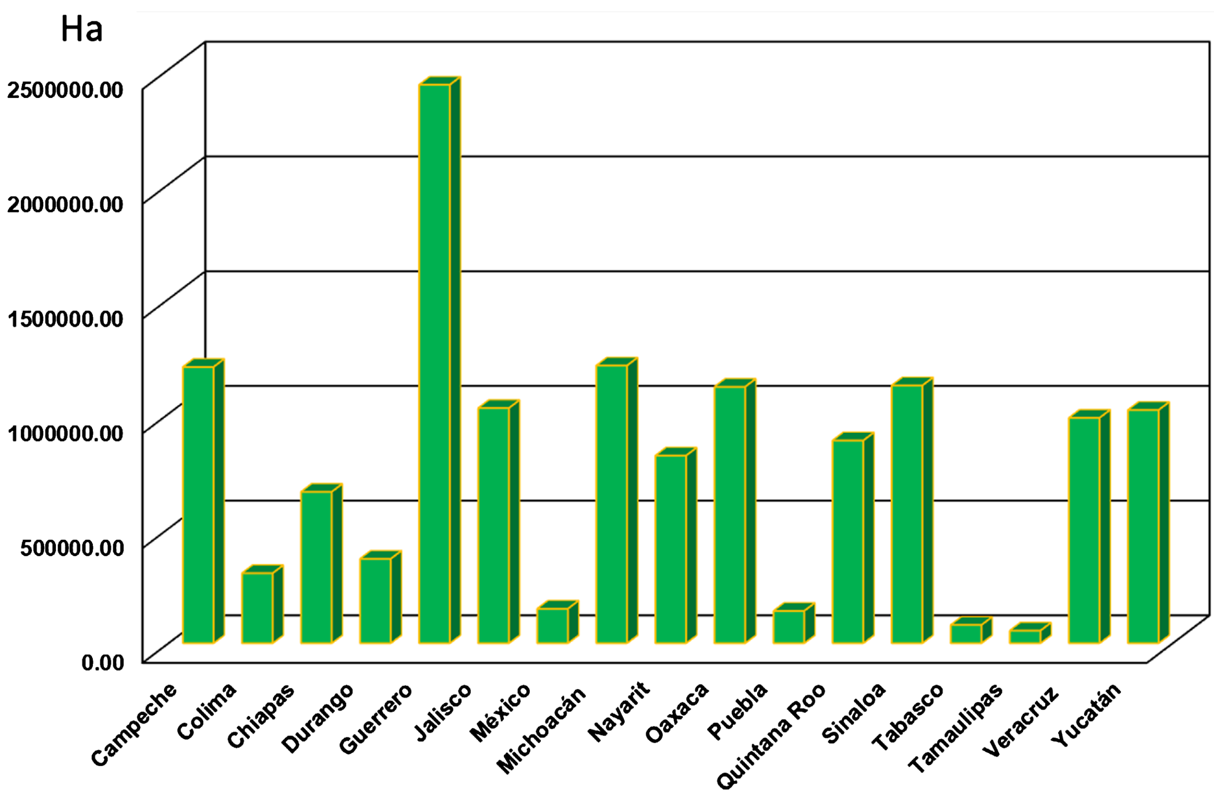

Figure 7. Surface with high yield potential for *Vigna unguiculata* in Mexico.

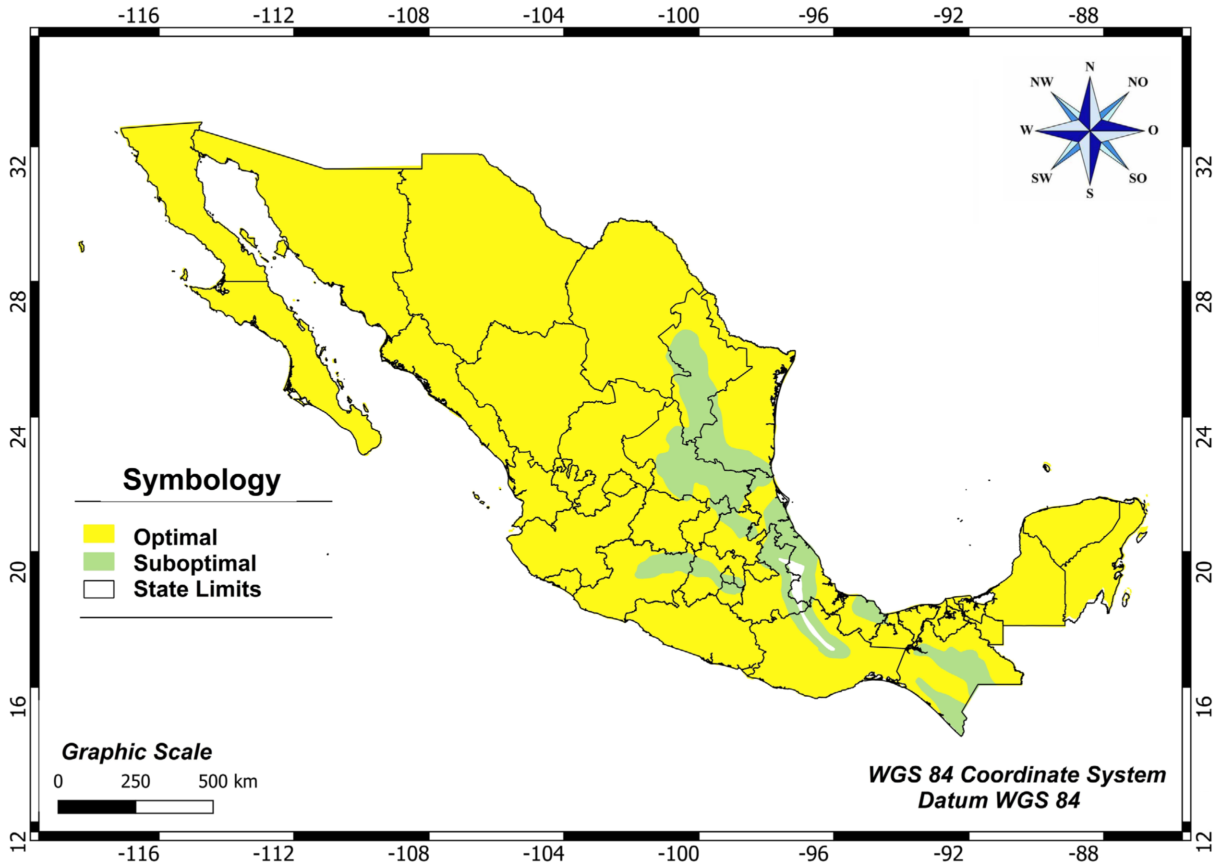

Figure 8. Geographic distribution of suitable daylight hours per year in Mexico.

Sea, the Caribbean Sea, and the Gulf of Mexico, with tropical and subtropical climates and an average annual temperature between 25˚C and 30˚C. Regarding to the soils, practically all the states have optimal conditions, but the states bordering the Pacific Sea, from Baja California to Chiapas stand out for their quantity.

The average annual rainfall is one of the most influential variables to delimit the high and medium potential areas so the outstanding states are: Yucatán, Campeche, Quintana Roo, Veracruz, Guerrero, Oaxaca, Jalisco, Michoacán, Nayarit, and Sinaloa.

4. Conclusion

There are optimal agro-ecological conditions to produce *V. unguiculata* under rainfed conditions in Mexico. The most appropriate areas are located in 17 states: overhanging for surface Guerrero, Oaxaca, Campeche, Michoacán, Jalisco, Sinaloa, Nayarit, Veracruz, Yucatan, and Quintana Roo. The soil types, precipitation, and altitude are determining factors to properly define the optimal and suboptimal potential areas. The high potential areas detected in this work far exceed the areas of *V. unguiculata* currently planted in the country.

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Conflicts of Interest

The authors declare no conflicts of interest.

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