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MOUNTAIN MASSIF AGROCLIMATIC CHARACTERIZATION OF THE NIPE-SAGUA-BARACOA ACCORDING TO AGROECOLOGICAL ZONING FOR COCOA (*Theobroma cacao* L.)

Caracterización agroclimática del macizo montañoso Nipe-Sagua-Baracoa, en función de la zonificación agroecológica para el cacao (*Theobroma cacao* L.)

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ABSTRACT. An agroclimatic characterization with the aim to establish the correspondence between the behavior of climatic conditions and agroecologys requirements of cocoa, in function to achieve the agroecological zoning of the same one. Precipitations and the temperatures were climatic variables evaluated. The temporary scale considered for registration of data was the monthly one. Meteorological information were used to 1976-2006 period. To precipitations analysis a series data from meteorological stations belong to Meteorology Institute and a total of 253 pluviometers of INRH net were used. For air temperature were carried out correlations of the existent ones with those located near of mountainous massif and different gradient settled down for height. The maps were elaborated with the space distribution of annual media precipitations and temperature. The results allowed recognizing that the behavior of precipitations régime of mountainous region, guarantees high and stabling flooding, during the whole year. It, together to their thermal characteristics, which makes possible the existence of appropriate climatic conditions for cocoa growth and development. The 53 % of total surface of mountainous massif Nipe-Sagua-Baracoa have optimal climatic conditions to cocoa requirements.

Key words: zoning, *Theobroma cocoa*, climate, agroecology

RESUMEN. Se realizó una caracterización agroclimática del macizo montañoso Nipe-Sagua-Baracoa, para determinar la correspondencia entre el comportamiento de las condiciones climáticas y los requerimientos agroecológicos del cacao en función de lograr la zonificación agroecológica del mismo. Las variables climáticas evaluadas fueron las precipitaciones y las temperaturas. La escala temporal considerada para el registro de los datos fue la mensual y la información meteorológica general utilizada correspondió al período 1976-2006. Para el análisis de las precipitaciones se utilizó una serie de datos originados de las estaciones meteorológicas del Instituto de Meteorología y de 253 pluviómetros de la red del INRH. Para la temperatura del aire se realizaron correlaciones de las existentes con las ubicadas en las zonas más llanas y próximas al macizo montañoso, y se establecieron diferentes gradientes por altura. Se elaboraron los mapas con la distribución espacial de las precipitaciones media anual y las temperaturas media anual. Los resultados permitieron reconocer, que el comportamiento del régimen de las precipitaciones en esta región montañosa, garantiza humedecimiento alto y estable durante todo el año. Ello, unido a sus características térmicas, hacen posible la existencia de condiciones climáticas adecuadas para el desarrollo y crecimiento del cultivo del cacao. El 53 % de la superficie total del macizo montañoso Nipe-Sagua-Baracoa, posee condiciones climáticas óptimas, medianamente optimas y aceptables, que responden a los requerimientos del cacao.

Palabras clave: zonificación, *Theobroma cacao*, clima, agroecología

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INTRODUCTION

Cocoa (*Theobroma cacao* L.), is a tree grown in several countries for its food and medicinal qualities. Its byproducts are widely used in the candy industry for the pleasure of its sensorial features, also in cosmetics and the pharmaceutical industry. The greatest importance attached to cocoa is its influence on human health due to its energetic value, the composition of its different byproducts and antioxidant levels (1).

In Cuba, cocoa is mainly grown in the Eastern region at the Nipe-Sagua-Baracoa and Sierra Maestra mountain ranges. Within them, the largest growing area is in the province of Guantanamo, accounting for 76 % of the national planted area and 91 % of production distributed in six municipalities[A]. However, cocoa growing in non-suitable areas[B] and the faulty application of technology in several growing areas that do not meet the agroecological requirements of the crop, are factors influencing in the low yields that do not surpass 0,28 t ha^{-1} (2).

Climate is one of the requirements to consider cocoa growing. The climatic factors most affecting growth and flowering are the quantity and distribution of rainfall in addition to temperatures (3). These factors limit cocoa development areas (4) so it is important to know those climatic factors influencing on the productive potential of the crop which can be achieved through an agroclimatic characterization.

This agroclimatic characterization has not been done in Cuba yet based on the agroecological requirements of the crop in order to evaluate areas with different potential to develop it. However, the evaluation of lands as part of the agroecological zonification of crops permits finding the most suitable ecological niche for them making a rational use of natural resources (5).

For all the above, this paper looks forward characterizing the Nipe-Sagua-Baracoa mountain range in order to achieve an agroecological zonification for cocoa growing.

MATERIALS AND METHODS

In order to agriclimatically characterize the region, different climatic variables like rainfall and temperatures were evaluated since they are the most influential in the development and growth of cocoa (5).

Recording and processing of meteorological data was done according to standards and procedures of the Climatological Practice Manual of the World Meteorological Organization (6) and data bases created. They were checked through SAROM (Automated System for Checking Meteorological Observations), an official system of the Meteorology Institute in Cuba to measure and validate the quality of meteorological data of each variable.

For rainfall, 30 years old data were used (1976-2006) taken from weather stations of the Meteorology Institute in the studied territories. 253 rain gauges from the network of the National Institute of Hydraulic Resources were used, with an approximate density of one rain gauge per 31 km2, which is considered good according to the Hydrometeorogical Practice Guidelines of the World Meteorological Organization (7).

Monthly and annual rainfall averages were used in addition to those of the less rainy period (November-April) and during the rainy period (May-October). From the recorded information, a rainfall data base was created and isolines maps were drawn showing mean annual rainfall of the less rainy season and of the rainy season as such throught the studied period. According to water demands of the crop, another map was drawn with the space distribution of mean annual rainfall.

For temperatures, data from 20 years were used (1987-2006) including mean, minimum and maximum temperatures of the air, based on data from existing weather stations in the mountain range. Due to the scarce weather stations in the region, correlations of the existing ones were done with those located next to it. Height gradients and temperatures were considered (8).

A data base was set up including maximum, minimum and mean annual temperatures with calculated annual values. From that information, maps were drawn to show maximum, minimum and mean annual air temperature. Based on the thermal demands of the crop a map containing the space distribution of the mean annual temperature was drawn.

From the rainfall and temperature resutling maps, in addition to crop demands as per the parameters of an agroecological zonification, climatic areas for cocoa were determined reaching four suitable categories: optimum climatic area, moderately optimum and non-suitable.

For both variables and determination of climatic areas, a Geographical Information System and the software ArcView ver. 3.2 were used which allowed the representation of those areas in maps of 1: 100 000 scale.

RESULTS AND DISCUSSION

Figure 1 shows mean annual rainfall calculated for 1976-2006 (30 years), in order to characterize its behavior in the studied region.

[A]MINAG. Análisis de la situación productiva del cacao en Cuba. En: II Taller Nacional de Cacao. Informe Grupo Nacional de Agricultura de Montaña. Guantánamo. 2008, 34 pp.

[B]MINAG. Diagnóstico realizado a la actividad de cacao en la provincia de Guantánamo. Grupo Empresarial de Agricultura de Montaña (GEAM). Diciembre 2011. Informe utilizado en investigación. 2011, 41 pp.

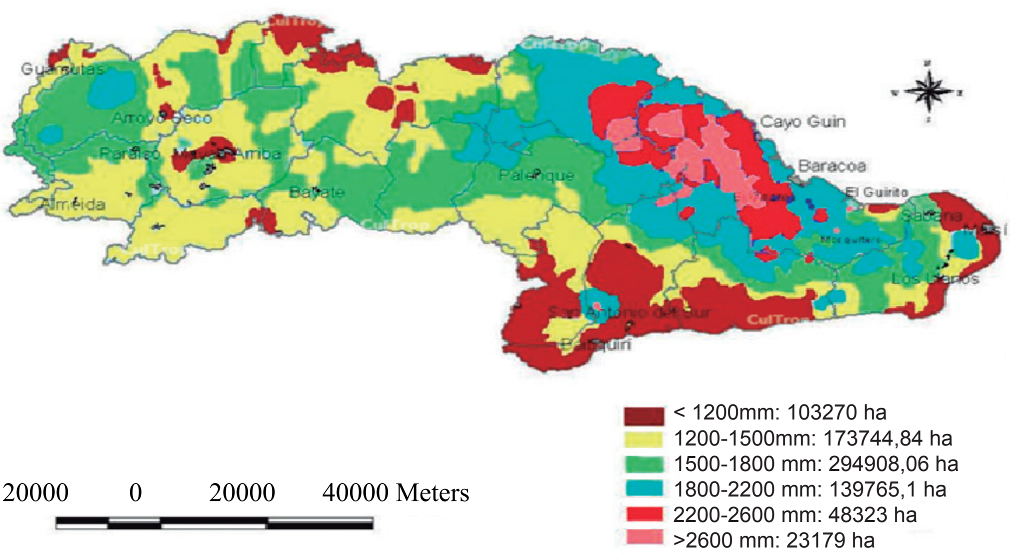

Figure 1. Mean annual rainfall in the Nipe-Sagua-Baracoa mountain massif

Mean annual rainfall in this territory ranged from 400 to 3 800 mm, most of them from 1 200 to 2 200 mm with an annual average of 1 800 mm. This pattern is within the limits considered suitable for the crop, since cocoa needs rainfall above 1 200 mm per year.

In the lower part of the coastal terraced plain of Maisí, rainfall went down up to 800 mm or less in specific spots, while in the Southern coast of the range (semi-desert coastal plain of Guantánamo), rainfall decreased below 600 mm per year. However, in the Moa-Toa Ridge, rainfall exceeded 3 400 mm annual average with a yearly maximum in May and November, with two minimum in March and July.

This feature of rainy tropical climate (9), is homogeneous in the whole mountain range of the Nipe-Cristal-Baracoa, where rainfall exceeds 2 000 mm per year.

The Northeast of this mountain range has low altitude mointains and it is the rainiest region of the country. In the scarce rainy season, important rains fell (November-April) of around 1 500 mm and 1 800 mm, and in some years rains have exceeded values of the rainy period (May-October). The above indicated that in this part of the mountain range, rainfall does not behave like in the rest of the region and other mountainous areas of the country.

Presumably, it is due to the geographical location of this territory since the North slope directly receives the effects of trade winds from the Northeast and from the Northwest full of humidity. When they collide with this orographic system, in the North part rainfall are higher than in the South (10).

Rainfall behavior in this territory is associated to landscape (vertical gradient), so there is a gradual rainfall increase as height is higher. Therefore, the great variations in the altitude of the region create very special conditions in the changes and distribution of climatic elements. Hence, the characteristics and variation of climate in this orographic group are determined by landscape and the altitude over the sea level (11).

It was confirmed that in the lower part of the mountains till a height of 400 m a. s. l., the vertical gradient is 122 mm per every 100 m height; however, it is reduced at higher heights with values of 39 mm per every 100 m height in mountains above 400 m a. s. l.

Cocoa growing in Cuba is preferably developed up to 700 m a. s. l., with a higher planted area from 200 to 600 m a. s. l. According to the digital landscape model, data bases associated to rainfall and the vertical gradient, showed that these conditions coincide with rainfall till 2 200 mm, considered optimum for the main physiological processes of the crop (vegetative growth, flowering and fruiting).

The general rainfall behavior in this mountain range provided adequate soil moisture throughout the year and so water needs of the crop. This territory distinguishes from the rest of the country for its high humidity values that coincide with the highest rainfall annual totals in Cuba.

According to rainfall distribution and the water requirements of cocoa, this territory has a planted area of 608 418 ha (77,6 % of the total surface), that meet water requirements of the crop (1 200-2 200 mm year^{-1}). However, there also lands with severe restrictions due to low rainfall values (103 270 ha) or abundant rainfall that cause a moisture excess (71 502 ha), equivalent to 13,18 and 9,15 % respectively.

Such restrictions can influence on different physiological processes of the crop like vegetative growth that can suffer from stress under excess of moisture.

At the second day soils are flooded, cocoa shows reduced nutrition and growth delay, stomatic opening is also reduced. If this situation lasts a long time, the crop dies. These conditions also create a favorable moisture environment for fungal disease development (12).

Also related to moisture excess there are reports that add a poor soil aeration and growth delay of the crop. When rainfall exceeds 2 600 mm in sites with poor drainage, cocoa production is affected (13, 14), water flooding or ponding cause root suffocation and death in a relatively short time[C].

On the other hand, cocoa trees are very sensitive to lack of moisture on the soil. In areas where rains do not meet water nedds of the crop in dry or scarce rains, flowering will be low and consequently fruit production. Moreover, vegetative growth suffers an important reduction as well as flushing that is usually favored by rains (13).

Depending on the edaphic conditions and the annual rainfall distribution, for those areas with moisture deficit, additional irrigation might be needed in areas adapted to plain landscape or measures to preserve soil moisture could be implemented.

Temperature

This territory has a mean annual temperature from 19 to 27 ºC in most of the region, between 22 y 24 ºC that coincide with altitudes of 400 and 600 m a. s. l. and a monthly average of 25,6 ºC (Figure 2).

In general, the behavior of this climatic variable in the region meets crop requirements since it needs an an optimum average temperature of 25 °C.

[C]Tezara, W. /*et al.*/. Plasticidad ecofisiológica de árboles de cacao (*Theobroma cacao* L.) en diferentes ambientes de Venezuela. III CLAE e IXCEB, 10 a 17 de septiembre de 2009, São Lourenço – MG.

[D]Márquez, J. Comunicación personal. Instituto de Investigaciones Forestales. MINAG, C. Habana, Cuba. 2008.

These values are representatives of the different cocoa growing areas of the world.

In this regard, there are reports confirming that the general average temperature range on a monthly basis for the crop, includes a minimum of 15 °C and a maximum of 30 °C, with an average of 25,5 °C, which coincides with the behavior of this variable in the region under study[D].

Temperature behavior in this territory is also associated to landscape conditions (vertical gradient), so temperature goes down as height is higher. Therefore, lower values were recorded on higher mountains above 600 m a. s. l. and the highest values in the valleys of the nearby regions to this mountain range.

Annual average minimum temperatures in this mountain range moves from 17,5 to 23,5 ºC, and maximum from 21 to 29 ºC. According to the vertical gradient of temperature regarding height, extreme temperatures behavior is a limitation for the crop only in regions with high mountains with minimum in the valleys and maximum in coastal areas.

The general temperature behavior in this mountain range encourages physiological processes like flowering, fruiting and stem growth.

Under these conditions, flowering occurs at 21 ºC with an optimum of 25,5 ºC. These are optimum temperatures to guarantee an average growth of the tree with abundant flower and fruit formation, an adequate distribution of bud sprouting and new leaves throughout the year (5, 13).

In most of the territory under study (72,10 % of the total surface), there are no temperature limitations to grow cocoa (22-26 ºC); however, lands with restrictions were found, either for low temperatures (137 476,4 ha) or high temperatures (81 107,8 ha), equivalent to 17,55 and 10,35 % respectively.

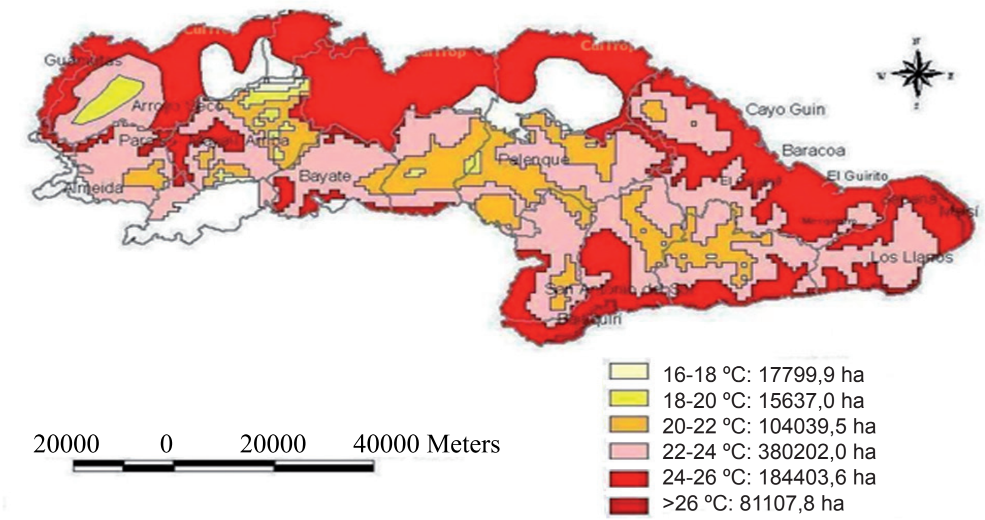

Figura 2. Map showing mean annual temperatures at the Nipe-Sagua-Baracoa mountain massif

Low temperatures and increased relative humidity cause the emergence of diseases. Nevertheless, in areas with high temperatures, the crop is exposed to a higher level of damages by insects (13).

From the eco-physiological point of view, flowering, the number of leaves per shoot, the average leaf surface and their longevity, reduced with increased temperature (3). However, the same author indicated that the number of foliar shoots increased with high temperatures.

Usually, when air temperature is higher than 30-35 °C most of the crops closes stomas because the plant is unable to absorb and replace the water lost through transpiration. It also happens for the accumulation of CO_2 caused by a reduction of the photosynthesis and increased respiration due to a rise in temperature (15).

Climatic Zonification

Considering the guidelines of the agroecological zonification for cocoa growing (16) and combining rain and temperature maps, four climatic areas were identified in the Nipe-Sagua-Baracoa mountain range (Figure 3) which were:

Optimum climatic area: land with an optimum climatic behavior for cocoa growing and development. It covers an area of 91 835.75 ha, whose annual rainfall ranges from 1 800 to 2 200 mm and the mean temperature from 22 to 26 °C.

Moderately optimum climatic area: land with a moderately optimum climatic behavior for cocoa growing and development. It covers an area of 128 592,75 ha, whose annual rainfall ranges from 1 500 to 1 800 mm and the mean temperature from 22 a 26 °C.

Acceptable climatic area: land with an acceptable climatic behavior for cocoa growing and development. It covers an area of 195 803,25 ha, whose annual rainfall ranges from 1 200 to 1 500 mm and the mean temperature 22 a 26 °C.

Non-suitable climatic area: land with a non-suitable climatic behavior for cocoa growing and development. It covers an area of 366 958.25 ha, whose annual rainfall are below 1 200 mm or above 2 200 mm and temperature below 21 °C or above 26 °C.

Most of the mountain massif (53.15) shows adequate climatic conditions to grow cocoa in one or another category in order to achieve its productive potencial.

CONCLUSIONS

- The behavior of the rainfall pattern in this mountain range guarantees a high and stable moisture level throughout the year which, together with its thermal features, creates adequate climatic conditions for cocoa growing.
- Fifty three percent of the area covered by the Nipe-Sagua-Baracoa mountain range, has optimum, moderately optimum and acceptable climatic conditions to grow cocoa.

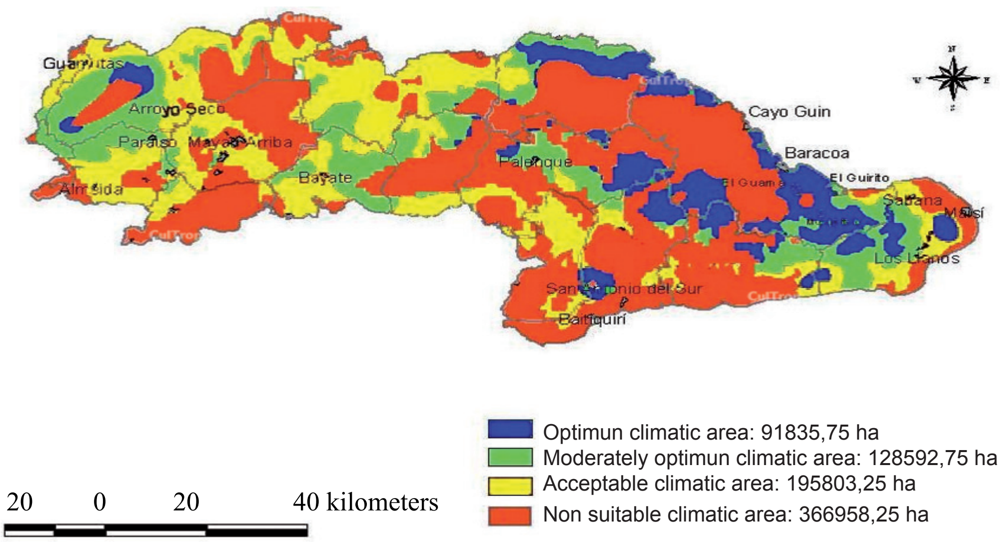

Figura 3. Map with climatic regions to grow cocoa in the Nipe-Sagua-Baracoa mountain massif

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