INFLUENCE OF RAINFALL ON THE YIELD OF Coffea canephora Pierre ex Froehner CULTIVATED IN CAMBISOL SOILS OF THE EASTERN REGION OF CUBA

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ABSTRACT. In order to evaluate the effect of rainfall on the yield of the species Coffea canephora Pierre ex Froehner cultivated in brown soils in two coffee areas of eastern part of Cuba (Cruce de los Baños site, located in the municipality Tercer Frente, Sierra Maestra hills and Alcarraza site, located in the municipality of Sagua Tánamo, Nipe-Sagua-Baracoa hills). Data from two production cycles of this species were used in an experiment of study of nitrogen fertilizer dose, planted in 1996 and pruned in 2003. Regressions between yields and annual rainfall were established. Different mathematical models were used, selecting the highest coefficient of determination (R²). A strong relationship between annual rainfall and maximum stable yields at both sites and cycles (R² > 90%) was found. With rainfall in the range of 1 400 mm – 1 600 mm in "Tercer Frente" and "La Alcarraza", were not obtained more than 1,30 t ha⁻¹ green coffee year⁻¹, while annual rainfall values from 1 750 mm to 1 900 mm allowed yields from 1,4 t ha⁻¹ to 1,8 t ha⁻¹ of green coffee. When rainfall amounted to 2 000 mm at both sites, 2 t ha⁻¹ green coffee year⁻¹ were obtained.

Key words: Coffea canephora, clime, rainfall, yield, correlation

INTRODUCTION

Due to the wide geographical distribution of coffee plots, the response to different management systems among countries and regions within one country is different. The dissimilar of ecology in world coffee growing areas suggests this crop is not identical everywhere, and therefore, frequent experimental results do not match amongst themselves or are diametrically opposed (1).
It has been stated that the ecological requirements are better studied in the region of origin of the specie, other authors express that sometimes is more useful to study plant growth in areas where the specie has been distributed, particularly if the plants show good growth in those sites (1). Out of the Coffea species cropped in Cuba, canephora has been less studied, hence why it is essential to conduct investigations with this specie in the pre-mountainous areas where it is grown in the country.

The climatic characteristics expressed through temperature, rainfall and rainy days in addition to those relative to landscape and soil properties, interact and decisively influence on growth and yield of the plot and therefore, on the nutritional requirements (2, 3). Thus, it has been established that climate in subtropical regions has a greater importance on the growth and fruting of coffee trees than in the warm areas of the tropics, regardless the studied varieties (4).

Coffee trees productivity depends on a complex system of interrelated environmental and social factors. Temperature and rainfall distribution are two of those factors affecting crop phenology, yield and quality, and even the composition of the organic compounds of the beverage (5, 6, 7). At the same time, when estimating the climatic impact over production, the fertilization effect on increased CO₂ in the atmosphere should be considered4.

At present, there studies on the threats of climate change on crops have boomed and governments are creating scenarios to mitigate its effects. As to coffee trees are concerned, studies have focussed on the agroforestry management as an adaptation strategy against microclimate extremes (8). There are reports from Brazil on the relationship between coffee planted areas and climatic vulnerability and also for the climatic context of 2080, the displacement of suitable coffee growing areas to the South and Southeast states is being thought of (4), and even increased areas of the specie canephora (9).

In Camerun (10) a relationship was found between the increased severity of Coffee Berry Disease and the fall of temperatures (minimum or maximum). Likewise, a strong relationship was found between the attack of the disease and the quantity of rainy days, however, no correlation was found with the total rainfall of the years under study. Authors suggest the use of both indicators to establish predictive models to optimize the effective control of the disease.

Out of the environmental elements associated to climate system, the commonly recognized critical variable for the plants is water availability, because it is the determining factor for growth (11). Rainfall, temperature and sun radiation are climatic elements of major importance in coffee production. Water deficits are necessary for flowering, but if it lasts too much, flower opening does not take place, vegetative growth and fruit filling are limited. On the other hand, water excesses reduce flower induction (12) and the formation of reproductive structures, favor the presence of diseases, promote soil nutrients leaching and losses by erosion (13).

Coffee from the arabica specie responds with sensitivity to temperature increase and it occurs with a higher intensity during flowering and fruiting. Much less information is available regarding temperature impact and rainfall distribution in plants of the Robusta cultivar, which could be related to a lesser interest on climate change impact over this specie, but it can also be related to the lower volume of this variety in the world market (30 %) compared to arabica (70 %) (4).

In Cuba, growing areas of Coffea canephora Pierre ex Froehner, have been increased mainly in the Eastern region of the country. For this reason, this research has aimed at evaluating rainfall effect over the yield of this specie grown on Brown soils of two coffee growing areas in this region.

MATERIALS AND METHODS

In order to establish a relationship between rainfall and yields, this research was done from 1995-2007 in two sites of the Sierra Maestra and Sagua-Nipe- Baracoa Mountain ranges, in which increasing nitrogen fertilizer rates were studied.

The location of Tercer Frente (site Cruce de los Baños): located in the municipality Tercer Frente, Sierra Maestra Mountain Range, at 20°09’ N lat and 76°16’ O long, and at 135 km North West of Santiago de Cuba city, at a height of 150 m a. s. l., with an annual mean temperature of (13 years- average) of 24,5 °C, minimum temperature of 15,5 °C, maximum temperature 31 °C, rainfall of 1 654 mm in 112 days with rains and relative humidity of 79,8 %. Landscape: Pre-mountain. Predominant shade: Samanea saman (Jacq) Merrill. Soil type: Oric brown without carbonates

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4 Hagger, J. y Schepp, K. Coffee and Climate Change Impacts and options for adaption in Brazil, Guatemala, Tanzania and Vietnam [en linea], [Climate Change, Agriculture and Natural Resources, 4], Natural Resources Institute, University of Greenwich, 2012, p. 47, [Consultado: 5 mayo 2015], Disponible en: <http://www.nri.org/images/documents/promotional_material/D5930-11_NRI_Coffee_Climate_Change_WEB.pdf>.
(14) with a slightly acid pH (6.3), low contents of assimilable phosphorus (8.7 mg 100 g⁻¹ of soil) and a high capacity of cationic exchange 44.6 cmol kg⁻¹.

*The location La Alcarraza:* located in the municipality Sagua de Tánamo, Nipe-Sagua-Baracoa Mountain Range, at 20°35’ N lat and 75°15’ West long, at 118 km to the south East of Holguín city. With a height of 300 m a.s.l. The main climatic variables are: annual mean temperature (13 years-average): 24.1 °C. Rainfall (13 years-average): 1 773 mm and 120 days of rain. Landscape: Pre-mountain. Predominant shade: *Gliricidia sepium* (Jacq) Walp. Soil type: Glay brown without carbonates (14) with a slightly acid pH (5.8), low contents of assimilable phosphorus (9.72 mg 100 g⁻¹ of soil) and a high capacity of cationic exchange 34.7 cmol kg⁻¹.

During 12 years, the response to five nitrogen fertilization systems was studied (Table I), using a random block design with four replicates. The first productive cycle extended from planting till low pruning and the second one included three harvests after pruning coffee trees. The agronomical effects of this experiment are detailed in Vol 38 No. 4 of C Centro Agrícola magazine, the results of the first productive cycle (15) and the results of the second one can be found in Vol 46, No. 8 of the Pesquisa Agropecuaria Brasileira magazine (16).

All treatments included a bottom fertilization with P₂O₅ and K₂O. Simple superphosphate and potassium chloride were used as carriers. The 100 % of phosphorus was applied together with 50 % of the potassium in May, and the rest of the latter one in September, both around the trunk following a half moon pattern.

The behavior of climatic variables like rainfall, mean temperature and monthly rainy days are shown in Figure 1. Rain values are within the range of 1 400 mm to 2 900 mm excluding values considered as threats for the crop under Colombia’s conditions (17).

### Table I. Nitrogen rates (kg ha⁻¹) used under the two fertilization studied systems

<table>
<thead>
<tr>
<th>Treatments</th>
<th>First productive cycle</th>
<th>Second productive cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>N₀</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>N₁</td>
<td>30</td>
<td>45</td>
</tr>
<tr>
<td>N₂</td>
<td>60</td>
<td>90</td>
</tr>
<tr>
<td>N₃</td>
<td>90</td>
<td>135</td>
</tr>
<tr>
<td>N₄</td>
<td>120</td>
<td>180</td>
</tr>
</tbody>
</table>

N carrier: urea. Splitted nitrogen fertilizer at 50 %, first application between March and June, second application: September-November

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Data from the Meteorological Stations of Cruce de los Baños, Tercer Frente municipality and Sagua de Tánamo, municipality of Sagua de Tánamo

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**Figure 1.** Annual behavior of meteorological variables rainfall, rainy days and mean temperatures in both sites of the Tercer Frente (A) and La Alcarraza (B) during the execution of the experiments

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A study of the relationship between rainfall and yield of Coffea canephora Pierre ex Froehner was conducted. In so doing, maximum stable yields in each cycle and location were considered (15, 16) and regression equations were established taking as independent variables rainfall values. The equation of the highest coefficient was determined ($R^2$) and the one of the least standard error of estimation ($E_{sy}$). From this analysis, model of better adjustment was selected. The whole statistical procedure was done using the software Statgraphics Centurión XV, version 15.2.14.

RESULTS AND DISCUSSION

In order to adequately understand the relationship between annual maximum yield, nitrogen fertilization and rainfall, it should be known that coffee yield depends on the variety, the quantity of new shoots at flowering, planting density, rainfall level, intensity of the previous harvest, soil type and landscape in such a way that these variables predetermine the yield level.

In relation to the above, the rainfall effect was evaluated over the yield of C. canephora plots with an adequate nutrients supply and it was found that with rainfall of 1 400 mm –1 600 mm in both locations, more than 1,30 t ha⁻¹ of green coffee per year was harvested; while with rainfall of 1 750 –1 900 mm allowed to reach annual yields of 1,4 t ha⁻¹ to 1,8 t ha⁻¹ of green coffee (Figure 2).

However, when rainfall increased to 2 000 mm in both sites, 2 t ha⁻¹ of green coffee per year were reached. The above led to stand out the importance of the annual rainfall level over the yield.

This is a frequent characteristic of the site La Alcarraza, historical records show that in 52 % of the years, rainfall of around 2 000 mm were recorded, unlike Tercer Frente, where only 20 % of those years recorded such annual rainfall values⁹.

Table II shows the comparison of different mathematical models to establish the regression analysis between total annual rainfall (independent variable) and the yield reached in both experimental sites.

The integration of the results from different harvests into the productive stages of the two cycles in both sites, showed a strong positive relationship between annual rainfall and maximum stable yields, with a high association between variables ($R^2>90\%$), which explains, to a great extent, the differences found in annual yields between the sites (Figure 3).

This analysis determined that the existence of favorable conditions of humidity make possible for Coffea canephora to show a good growth and productivity in any of the productive cycles.

The evaluation of climatic variability in Eastern Cuba showed that total annual rainfall is the variable determining most of yield variations which confirms that rainfall is the climatic element of greatest variability in the country. The same is not true with tempperature due to the predominating warm nature of the climate. Figure 1 show that mean temperature showed little variations in its monthly values in years.

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⁹ Rivera, R. Nutrición, fertilización y balance del fertilizante nitrogenado (15N) para el cafeto en un suelo Ferralítico Rojo compactado [Tesis de Doctorado], Instituto Nacional de Ciencias Agrícolas, Mayabeque, Cuba, 1988, 110 p.

⁸ Palacios, J.R. y Palacios, A.V. “Evaluación de la variabilidad climática interanual en el oriente cubano con el uso de la clasificación climática de Köppen”, Resúmenes Convención Trópico. II Congreso de Meteorología Tropical, 2008, 337 p.
The fact of obtaining a high relation between the annual precipitations and the maximum yields stable, as well as that the species canephora in Cuba is harvested from October, suggests that the growth of the fruit is going to extend from May to December and therefore can take advantage of both the annual rainfall and the fertilizer that was applied at the beginning of October.

These results coincide with those obtained in research carried out in Mexico, where it was found that the rainfall included in the period from May to December, ensure the growth of Coffea fruit. Canephora Pierre ex Froehner, beginning the harvest from the month of January, with the beginning of the maturing phase of the grain.

It is worth noting that the yield - precipitation ratio is not so simple and here the rainfall distribution depends on the phenological stage of the crop, the number of rainy days, and the crop’s alternation (18). Investigations in Colombia showed that in the shade coffee plantations there is a double interception of rainfall, a smaller proportion due to the aerial part of the vegetation and the other by the superficial rasping layer in which a high proportion of water is retained (19). An example of this positive interaction occurs in the conditions of Pinares de Mayarí, province of Holguín on Ferritic Soils (Rhodic - Ferric Ferralsols), where plantations of Coffea arabica L. are obtained with an adequate supply of nutrients, related to an adequate Temperature, rainfall (1 650 mm annually), with 180 days of rain.year⁻¹ and in a plateau relief, all of which conditions an adequate water supply for coffee⁶.

### Table II. Comparison of Alternate Models for the relationship between yields and total annual rainfall in both experimental sites

<table>
<thead>
<tr>
<th>Model</th>
<th>Correlation</th>
<th>R²</th>
<th>Esŷ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inverse double</td>
<td>0.9516</td>
<td>90.55 %</td>
<td>0.04</td>
</tr>
<tr>
<td>Inverse of X</td>
<td>-0.9487</td>
<td>90.00 %</td>
<td>0.12</td>
</tr>
<tr>
<td>Logarithm of X</td>
<td>0.9430</td>
<td>88.93 %</td>
<td>0.12</td>
</tr>
<tr>
<td>Multiplicative</td>
<td>0.9421</td>
<td>88.75 %</td>
<td>0.08</td>
</tr>
<tr>
<td>Square root of X</td>
<td>0.9376</td>
<td>87.90 %</td>
<td>0.13</td>
</tr>
<tr>
<td>Double square root</td>
<td>0.9364</td>
<td>87.68 %</td>
<td>0.05</td>
</tr>
<tr>
<td>Square of Y</td>
<td>0.9330</td>
<td>87.05 %</td>
<td>0.45</td>
</tr>
<tr>
<td>Linear</td>
<td>0.9302</td>
<td>86.53 %</td>
<td>0.14</td>
</tr>
<tr>
<td>Square root of Y</td>
<td>0.9281</td>
<td>86.13 %</td>
<td>0.05</td>
</tr>
<tr>
<td>Exponential</td>
<td>0.9254</td>
<td>85.64 %</td>
<td>0.09</td>
</tr>
<tr>
<td>Inverse of Y</td>
<td>-0.9188</td>
<td>84.42 %</td>
<td>0.06</td>
</tr>
<tr>
<td>Double Square</td>
<td>0.9170</td>
<td>84.09 %</td>
<td>0.50</td>
</tr>
<tr>
<td>X square</td>
<td>0.9100</td>
<td>82.81 %</td>
<td>0.16</td>
</tr>
</tbody>
</table>

Figure 3. Relationship between maximum stable yields (y) found and annual rainfall (x) in both experimental sites

y = 1/(-0.0242012 + 1194.68/x) R² = 90.55 % Esŷ = 0.04

⁶ Ochoa, M. Nutrición y fertilización fósforica del cafeto (Coffea arabica L.) cultivado sobre suelo Ferrítico Rojo oscuro [Tesis de Maestría], Instituto Nacional de Ciencias Agrícolas, Mayabeque, Cuba, 2000, 80 p.
In these conditions of Ferritic soils and for 18 years, with total lower pruning every four harvests, annual yields were obtained between 1.5 and 2.5 t ha$^{-1}$ of gold coffee, with doses varying between 164 kg ha$^{-1}$.year$^{-1}$ and 240 kg ha$^{-1}$ year$^{-1}$ N, depending on the level of yield, precipitation and fractionation used.

Under Veracruz’s conditions in Mexico, it is said that rainfall and temperature related to the subperiods of the phenological stages, affect differently coffee production cycles and for those conditions it is explained that excess rains do not allow the optimum development of flowers and fruting causing early wilt$^6$.

The situation found in these experimental sites lead to state that *Canephora* specie, can reach yields from 1.5 t ha$^{-1}$ of green coffee to 2 t ha$^{-1}$ when favored with rains, regardless the location and soil type.

**CONCLUSIONS**

A strong relationship between annual rainfall and maximum stable yields was found in both sites and cycles (R$^2$>90 %); and due to the eminent predominating nature of the annual variation of rainfall, it is necessary to consider this variable in the harvest estimates to guarantee stability in coffee production in addition to an adequate nutrients supply and good cultural practices.

**BIBLIOGRAPHY**


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$^6$ Rosales, G.T. *Evaluación de los impactos potenciales de la variabilidad y cambio climáticos en la producción de café (Coffea arabica L.) en Coatepec, Veracruz* [Tesis de Maestría], UNAM, 2013, 111 p.


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