SOIL SUITABILITY FOR COFFEE CULTIVATION IN NON-TRADITIONAL AREAS OF PANAMA-HERRERA Province

ABSTRACT

The objective of this research was to determine the suitability of soils for coffee cultivation in the province of Herrera, Republic of Panama. Planting robusta coffee is gaining greater interest among Panamanian farmers as an alternative for soil conservation. On 19 farms in the province of Herrera, samples were taken (0-20 cm) to understand their properties and initiate a sustainable fertilization program that contributes to improving productivity. Digital maps were created using the Q-GIS v.3.32.1 program. The soils of the province of Herrera presented a high percentage of aluminum saturation, with low porosity problems, average pH of 4.9, low levels of organic matter and phosphorus, and low in potassium. Low average calcium content and medium magnesium content. A negative and statistically significant correlation was found between organic matter and % Al saturation, Ca and Mg, indicating that the organic matter was still in the process of mineralization. According to the principal component analysis, the soils of Las Minas district are highly influenced by the percentage of aluminum saturation, Mn, Cu and organic matter. The soils of Los Pozos district by pH, CEC, Ca and Mg. The results of this characterization study and the maps prepared for each soil property are expected to contribute to decision makers, technicians, scientists and producers having a baseline knowledge of the productive coffee soils in the province of Herrera and to allow the development of plans to achieve sustainable coffee production.

Keywords: coffee, digital maps, robusta, soil properties, province of Herrera

1-INTRODUCTION

According to Huamaní and Huauya (1), coffee is currently grown in more than 50 countries, all located in the strip between the Tropic of Cancer and Capricorn, with Brazil, Colombia, Vietnam, Indonesia and Mexico standing out for their production volume. The grain is one of the agricultural products with the greatest commercial dynamism in the world, and it is also the agricultural product with the most volatile international price. In most producing countries, foreign exchange from exports is very important for national economies. Demand is concentrated mainly in the countries of the northern hemisphere, with the United States, Germany and Japan being the main consumers.

Coffee cultivation in Panama is part of one of the agroecosystems that has great biodiversity, helps combat the impact of climate change and is of great economic interest (2). Part of the environmental strategy to protect and expand the forest cover of the Hydrographic Basin of the interoceanic route is to use coffee plantations to contribute to the sustainability of the Panama Canal hydrographic basin, whose lakes supply water to half of the country's population concentrated in the provinces of Panama, Colon and West Panama, as well as to the operation of interoceanic transit (3).

The production of this item is of economic importance for the country, which is estimated to contribute 141.4 million American dollars to the national economy in the acquisition of agricultural goods and services, taking as a reference the planted area by the cost of production. According to the agricultural closing 2022 - 2023, the planted area in Panama is 17,295 hectares (ha) with a total yield of 195,781 quintals (qq) (8,899,136.36 kg) of which the province with the highest contribution is Chiriquí (Occident of Panama), which stands out with 61%. With respect to the five-year period, the planted and harvested area increased by 75 and 71% respectively (4).

One of the main problems faced by coffee producers in the lowlands of the province of Herrera-Panama is the lack of knowledge about soil fertility and nutrition of coffee plants. Monge (5) argues that soils for coffee cultivation must be of medium to high fertility, said fertility being defined by the critical levels of the elements it contains. This is seen as contradictory because studies carried out by Villarreal et al. (6) showed that districts located in the high areas of Azuero peninsula, where the highest annual amount and intensity of rainfall is concentrated, relatively, present the highest levels of acidification and loss of fertility. The degradation of soil properties is greater, especially in properties such as hydrogen potential (pH), aluminum saturation and organic matter content.

Although each crop has its degree of tolerance to acidity, in general terms it can be indicated that almost no crop supports more than 60% acidity saturation and the desirable value for most plants ranges between 10 and 25% (7).

López et al., (7) determined the soil properties of 12,000 ha of coffee grown within the El Triunfo Biosphere Reserve, Chiapas, Mexico, with the purpose of initiating a fertilization program to improve coffee productivity. The results indicated a generalized acidity caused mainly by the hydrogen cation (H+) in the soil solution, with the absence of hydrogen ions (H) and aluminum (Al) in the colloids. The dynamics of the cation exchange capacity (CEC) in the soils is influenced by the pH and the organic matter content. More than 90% of the plots have high levels of potassium (K), calcium (Ca), magnesium (Mg) and low phosphorus (P) content in 50 and 84%, in the latter there could be a response to the application of these nutrients. Excesses of Ca could be limiting the absorption of K and Mg and excesses of molybdenum (Mn) in the soil could be associated with physiological problems for its absorption and storage.

In Panama, coffee companies, which are located at altitudes above 1,000 meters above sea level, have carried out various investigations for their own benefit; however, very little is known about lowland coffee plantations or those located below 1,000 meters above sea level. Collantes et al. (8) characterized coffee farms in the province of Colón, Panama. 40 farms were chosen in the districts of Colón, Chagres and Donoso, conducting a structured survey aimed at producers on social, technological and economic aspects related to coffee cultivation. The selected farms total 105.86 ha cultivated with coffee, with 1 ha

plots being frequent. It was shown that 40% of producers receive technical assistance, while 67.5% of producers fertilize with synthetic products or chicken manure, with an average application of 165 grams/plant. On average, the yield obtained is 362.7 kilograms/ha, with 85% of the crop being sold to intermediaries, at an average price of USD 0.96 per kilogram (kg).

According to data from the Ministry of Agriculture of Panama (4), the yield of coffee plantations in the province of Herrera was around 0.273 tons/ha, considered very low since the general yield in coffee plantations in the Republic of Panama is 0.58 tons/ha. It is considered that with good management and balanced fertilization this yield can be improved.

The objective of this work was to determine the suitability of soils for coffee cultivation in the province of Herrera, Republic of Panama.

2-MATERIALS AND METHODS

In 19 plots of the districts of Las Minas, and Los Pozos of the province of Hererra (Table 1 and Fig. 1), soil samples were taken at a depth of 0-20 cm to know the properties of the soils and thus initiate a sustainable fertilization program that contributes to improving productivity.

Table 1. Productive soils sampled in the province of Herrera-Panama

Township	District	Coordinates	Height (m)
1-Las Minas	Las Minas	7° 48´14´´ 80° 45´18´´	343
2-Las Minas	Las Minas	7° 48´14´´ 80° 45´18´´	343
3-Chepo	Las Minas	7° 43´43´´ 80° 48´ 35´´	676
4-Chepo	Las Minas	7° 43´43´´ 80° 48´35´´	676
5-Chepo	Las Minas	7° 43´23´´ 80° 49´31´´	652
6-El Toro	Las Minas	7° 45´13´´ 80° 52´07´´	534
7-El Toro	Las Minas	7° 45´24´´ 80° 52´14´´	493
8-Quebrada del Ciprian	Las Minas	7° 40´ 31´´ 80° 46´47´´	645
9-Quebrada del Ciprian	Las Minas	7° 40´ 20´´ 80° 46´23´´	632
10-Quebrada del Ciprian	Las Minas	7° 40´21´´ 80° 46´35´´	654
11-Leones	Las Minas	7° 44´47´´ 80° 46´58´´	711
12-Quebrada del Rosario	Las Minas	7° 45´09´´ 80° 45´16´´	377
13-El Calabacito	Los Pozos	7° 43´ 54´´ 80° 36´ 03´´	215
14-El Calabacito	Los Pozos	7° 43´ 14´´ 80° 36´ 46´´	255
15-El Calabacito	Los Pozos	7° 43´ 06´´ 80° 36´ 28´´	192
16-El Cedro	Los Pozos	7° 41´ 22´´ 80° 38´ 52´´	237
17-Cerro de Paja	Los Pozos	7° 41´ 47´´ 80° 41´ 35´´	336
18-El Capurí	Los Pozos	7° 43´ 59´´ 80° 40´ 19´´	309
19-El Capurí	Los Pozos	7° 44´25´´ 85° 39´46´´	255

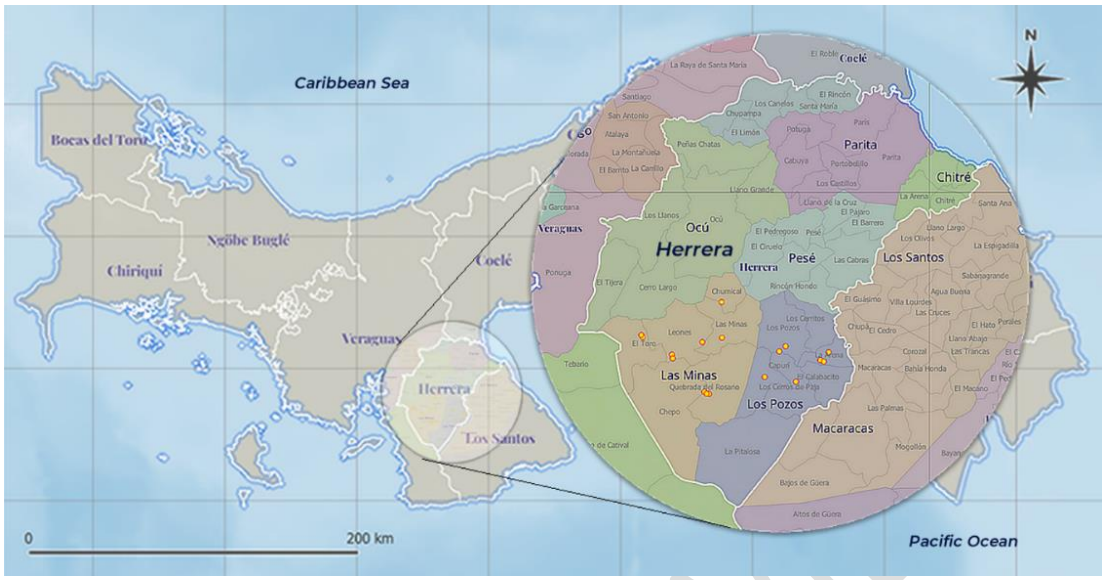

Figure 1. Soils from the sampled locations in the province of Herrera-Panama

The selection of the farms was made considering that they were farms producing coffee under a shade system. Maps of texture levels, pH, organic matter, percentage of aluminum saturation, cationic exchange capacity, macro and micronutrients of the districts where the selected farms are located were prepared, using the Q-Gis v.3.32.1 free program.

In addition, recommended fertilization charts were prepared for each area according to its edaphoclimatic characteristics. Descriptive statistics analysis, Pearson correlation analysis and principal component analysis and box plot data dispersion analysis between pH and % of Aluminum Saturation were carried out to know which elements are influencing the quality of soils for coffee cultivation [9], using the InfoStat program [10].

3-RESULTS AND DISCUSSION

The results of the descriptive statistical analysis of the characterization of the soils of Herrera province can be seen in Table 2.

Table 2. Statistical analysis of the characterization of the soils of Herrera province

Variable	n	Mean	S.D.	Var(n)	E.E.	CV	Min	Max
Sand	19	58.89	10.06	95.65	2.37	17.09	40.00	76.00
Silt	19	14.89	3.58	12.10	0.84	24.04	8.00	20.00
Clay	19	26.22	9.91	92.84	2.34	37.81	8.00	40.00
Bulk Den	19	1.29	0.17	0.03	0.11	0.13	1.18	1.41

%Porosity	19	51.22	6.25	39.12	4.24	0.12	46.98	55.46
% Org Mat	19	1.42	0.87	0.72	0.21	61.41	0.17	2.99
% Org C	19	0.82	0.51	0.24	0.12	61.32	0.10	1.73
pH	19	4.97	0.51	0.25	0.12	10.27	4.20	5.80
P	19	1.00	1.03	0.99	0.24	102.22	0.01	4.00
K	19	40.49	26.78	677.41	6.31	66.14	14.10	118.60
Ca	19	1.93	1.54	2.25	0.36	79.98	0.20	5.80
Mg	19	0.77	0.68	0.44	0.16	88.50	0.01	2.50
Al	19	2.27	2.78	7.31	0.66	122.41	0.30	9.40
% Al Sat.	19	39.32	32.65	1007.06	7.70	83.05	3.73	95.96
CEC	19	5.07	2.41	5.51	0.57	47.61	2.40	9.84
% Bases Sat	19	60.68	32.65	1007.06	7.70	53.81	4.04	96.27
Mn	19	32.88	28.48	766.07	6.71	86.62	1.00	90.90
Fe	19	42.23	36.95	1289.64	8.71	87.51	2.70	151.70
Zn	19	0.61	0.92	0.80	0.22	151.02	0.01	3.90
Cu	19	1.90	0.84	0.67	0.20	44.18	0.70	3.50

In soils under coffee production in Herrera province contain low levels of organic matter (< 3.0 %) and in many soils, also low porosity (<50%). The greater accumulation of organic matter improves the availability of nutrients for plants [9,10]. The soils of Los Pozos district are those that show the best pH levels (>5.5), also favoring the availability of other nutrients. Like the soils of El Cedro and El Capurí, favoring lower levels of aluminum saturation. Miranda et al. (9) found in San Buenaventura-Colombia that in soils sampled at 0.20 m with lower levels of aluminum saturation there was better root development of coffee plantations.

Table 3 shows that the organic matter in these soils is still in the process of mineralization, consequently causing soil acidification. High positive correlations were found between Ca-pH; Mg-pH; Mg-Ca; CEC-pH; CEC with Ca and Mg. Most of the high negative correlations are related to organic matter, indicating that organic matter is still decomposing, releasing acidic substances into the soil, with low base retention. Similar data was obtained by Chinchilla et al. (11), in Costa Rica where a range was maintained between 5-10 $cmol_{(+)}$/kg CEC) in the coffee-growing areas.

Table 3. Pearson correlations between the main variables of the soils cultivated with coffee in Herrera-Panama.

Variables		n	Pearson	p<0.05
pH	% Org matter	19	-0.77	0.00
P	pH	19	0.70	0.00
K	pH	19	0.70	0.00
Ca	% Org matter	19	-0.79	0.00
Ca	pH	19	0.95	0.00
Mg	% Org matter	19	-0.78	0.00

Mg	pH	19	0.89	0.00
Mg	P	19	0.70	0.00
Mg	K	19	0.77	0.00
Mg	Ca	19	0.95	0.00
Al	pH	19	-0.72	0.00
% Al Sat	% Org matter	19	0.79	0.00
% Al Sat	% Org C	19	0.79	0.00
% Al Sat	pH	19	-0.77	0.00
% Al Satl	Ca	19	-0.72	0.00
CEC	% Org matter	19	-0.77	0.00
CEC	% Org C	19	-0.77	0.00
CEC	pH	19	0.91	0.00
CEC	K	19	0.78	0.00
CEC	Ca	19	0.98	0.00
CEC	Mg	19	0.98	0.00
%Base sat	% Org matter	19	-0.79	0.00
%Base sat	% Org C	19	-0.79	0.00
%Base sat	pH	19	0.77	0.00
%Base sat	Ca	19	0.72	0.00
%Base sat	Al	19	-0.84	0.00

Figure 2 shows the principal component analysis for the soils sampled in the province of Herrera. The results show that the soils of the district of La Minas (El Toro, Quebrada del Ciprian, La Minas) are highly influenced by the percentage of aluminum saturation, aluminum content, manganese, copper, and organic matter. However, for the soils of the district of Los Pozos (El Capurí, El Calabacito, El Cedro) the main influence is given by the pH, CEC, potassium, calcium and magnesium content.

Villarreal et al. (12) describe the soils of Las Minas as ultisols, referring to these as degraded soils with low base saturation due to high precipitation and irregular topography tending to base leaching.

Also, Lopez et al., (7) present that in the soils of Los Pozos a high base saturation is observed, which demonstrates the absence of H and Al ions in the colloids. Villarreal et al. (13), they characterized productive soils cultivated with coffee in the Panamanian provinces of Coclé and Veraguas, finding that acidic soils with low organic matter content predominate in the highest areas where a lot of base leaching occurs, increasing acidity with high aluminum saturation.

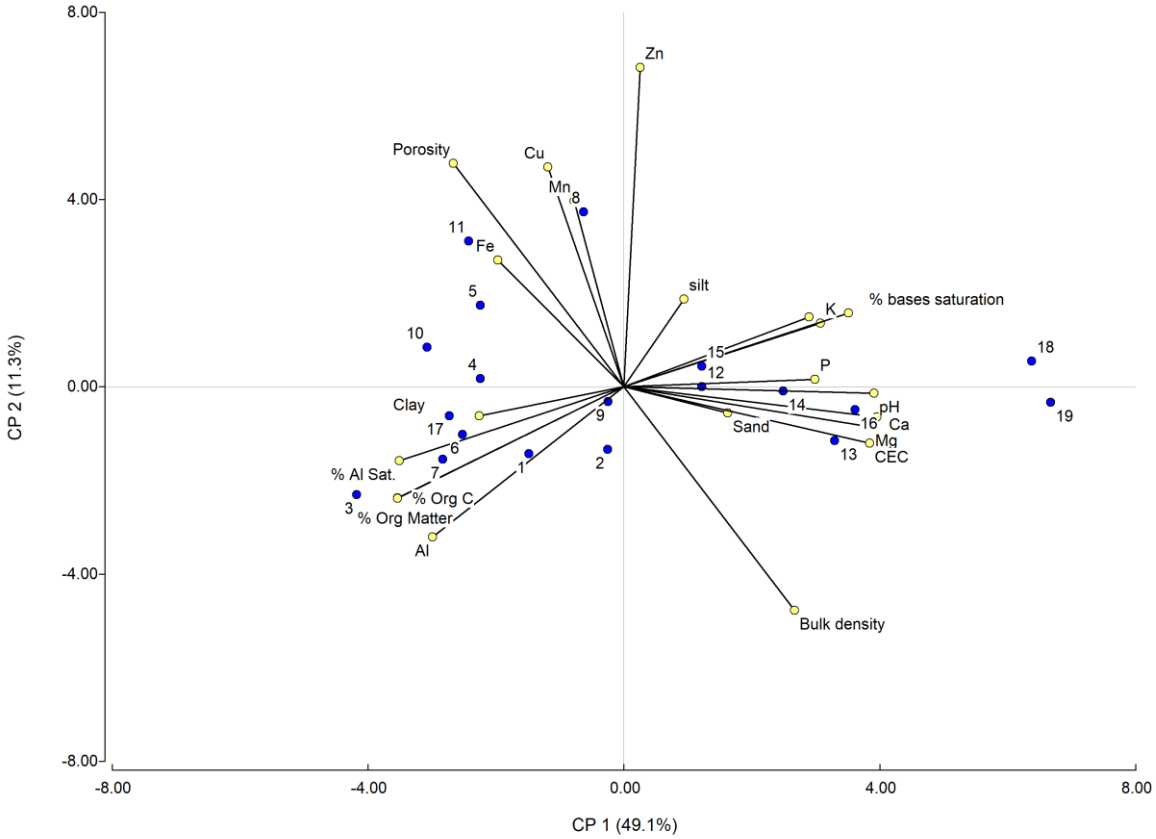

Figure 2. Principal component analysis for soils from province of Herrera-Panama.

Figure 3 shows the results of the dispersion analysis (box plot) where it can be observed that the most acidic soils (Las Minas) present a greater dispersion with the average percentage of aluminum saturation between 40% and 70%. As the pH increases (Los Pozos soils), the dispersion is less between the soils and the average percentage of aluminum saturation decreases (<10%).

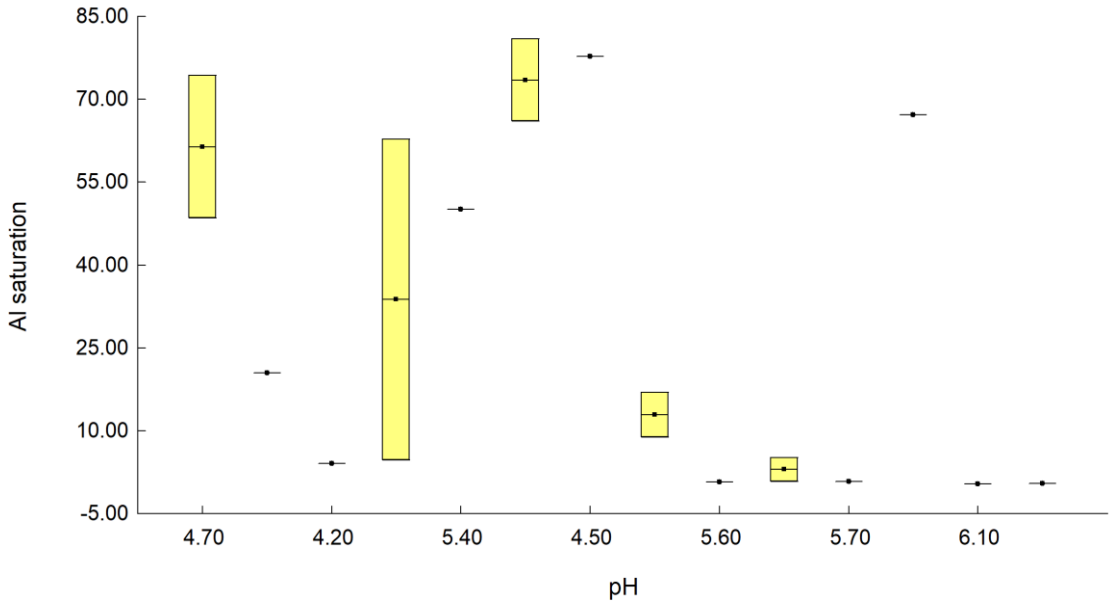

Figure 3. Dispersion analysis (box plot) for soils cultivated with coffee in the province of Herrera-Panama.

Figures 4, 5 and 6 show the pH maps, percentage of aluminum saturation and organic matter content, respectively. These maps reflect the results found in the characterization of each soil in the different sampled farms. It is observed that for the highest zones (Las Minas district) the pH is more acidic, coinciding with a higher percentage of aluminum saturation in that zone. In the case of the organic matter content map in the entire region, the soils show a low organic matter content for coffee cultivation, therefore, no differences are observed in the map.

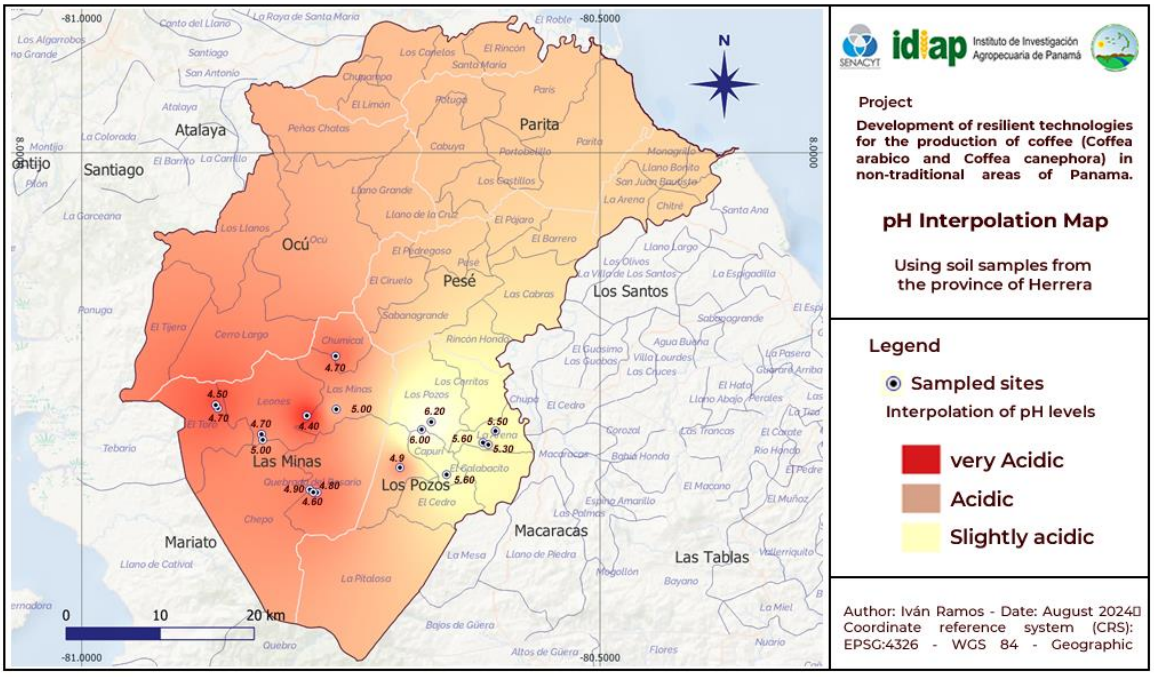

Figure 5. Map of pH in soils cultivated with coffee in the province of Herrera-Panama

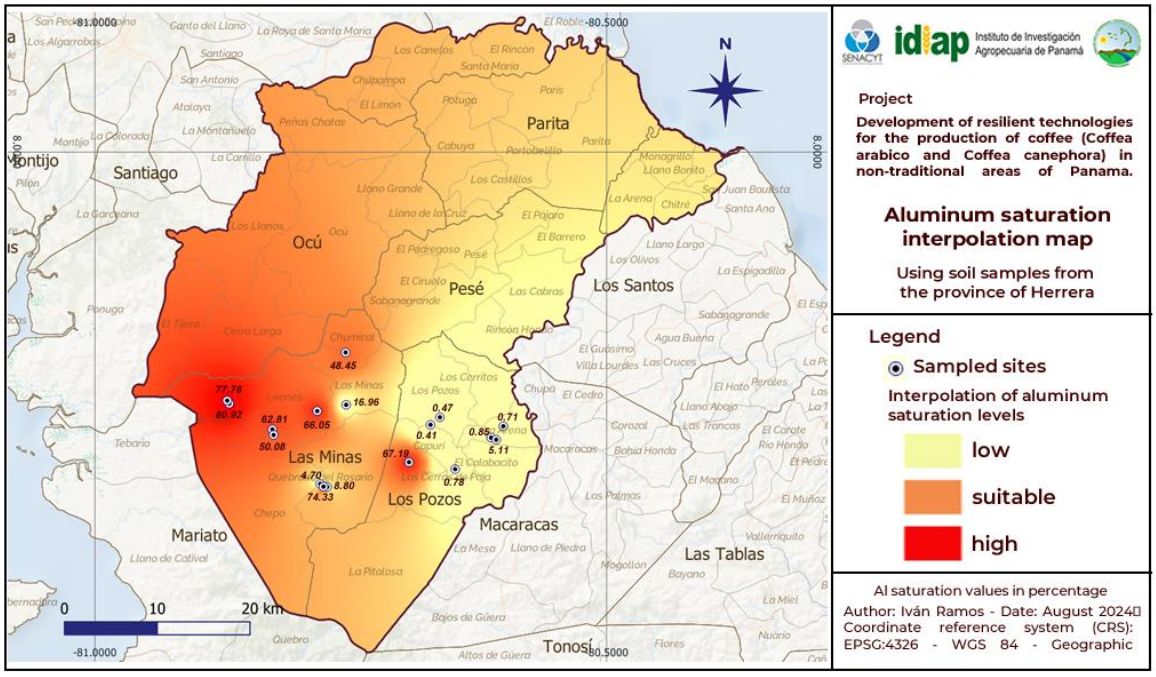

Figure 6. Map of aluminum saturation percentage in soils cultivated with coffee in the province of Herrera-Panama

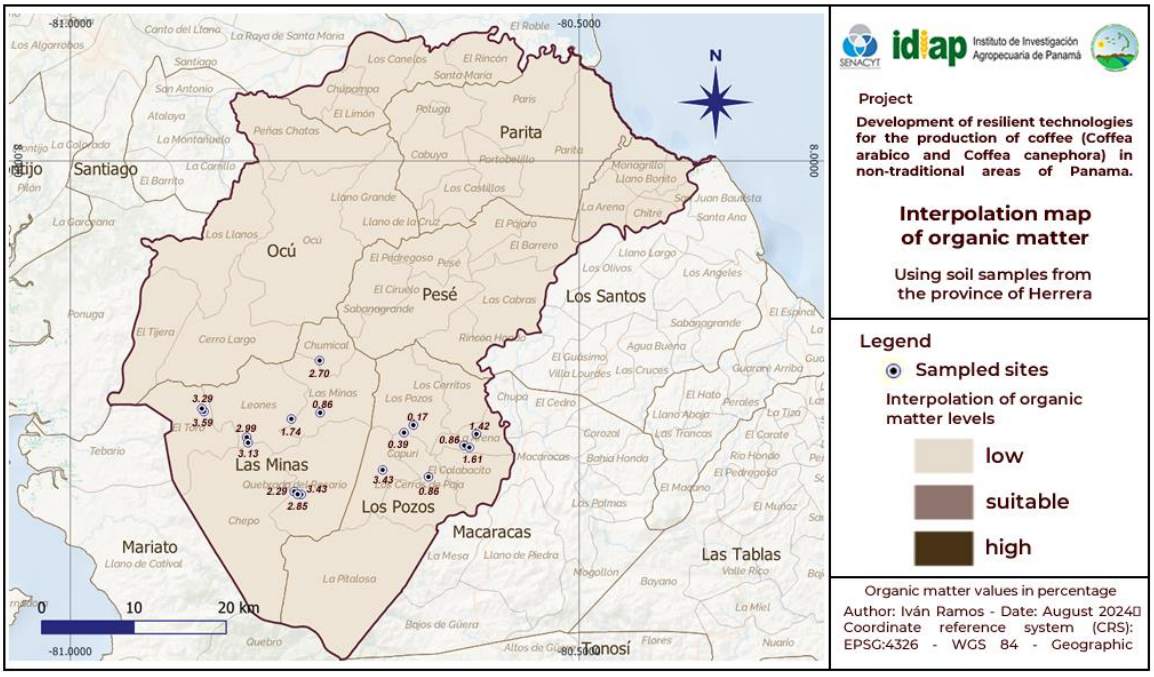

Figure 7. Map of content of organic matter in soils cultivated of coffee in the province of Herrera-Panama

4-CONCLUSION

Much of the soil in the province of Herrera used for coffee cultivation is very acidic with a high aluminum content and little organic matter. These conditions are present, above all, in the highest regions of the province, where there are also problems of deforestation and soil with low vegetation cover, which favors problems of erosion and leaching of soil bases. In areas with lower altitudes, the pH is more favorable and there is also a better nutrient content. Robusta coffee adapts very well to these areas, producing high-quality coffee. All these soils can be productive by improving their management and cultivation techniques. The best soils for cultivation are around El Cedro, El Capurí in Los Pozos.

The results of this characterization study and the maps prepared for each soil property are expected to contribute to decision makers, technicians, scientists and producers having a baseline knowledge of the productive coffee soils in the province of Herrera and to allow the development of plans to achieve sustainable coffee production.

COMPETING INTERESTS DISCLAIMER:

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declares that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

REFERENCES

1- Huamaní, H., y Huauya, M. (2011). Evaluation of soil and foliar nutritional condition in organic coffee cultivation in Tingo María, Peru. ***Revista Investigación y Amazonía*, *1*(1), 29-33.** https://n9.cl/gpwr4d. Consult: 09/12/2024.

2- Arraúz, C. (2022). Determination of the biodiversity of entomofauna in the coffee agroecosystem in Boquete and Renacimiento, Chiriquí Province [Doctoral Thesis, University of Panama]. http://up-rid.up.ac.pa/6700/1/carlos_arauz.pdf. Consult: 14/12/2024

3- Autoridad del Canal de Panamá (ACP). (2020). Panama Canal to receive 150,000 coffee seedlings for reforestation in the Basin. https://n9.cl/08srb. Consult: 26/12/2024.

4- Ministerio de Desarrollo Agropecuario (MIDA). (2023). Panamanian coffee continues to grow and taste good.https://mida.gob.pa/el-cafe-de-panama-mantiene-su-crecimiento-y-su-buen-sabor/. Consult: 07/12/2024.

5- Monge, L. (1999). Nutrition and Fertilization Management of Organic Coffee Crops in Costa Rica. In XI National Agronomic Congress/III National Soil Congress (pp. 175-191). http://www.mag.go.cr/bibliotecavirtual/a50-6907-III-p175.pdf. Consult: 03/12/2024.

6- Villarreal, J.; Name, B and García, R. (2012). Monitoring changes in soil fertility through laboratory analysis. ***Agronomía Mesoamericana*, 23(2), 301-309**. https://www.scielo.sa.cr/scielo.php?script=sci_arttext&pid=S1659-13212012000200009

7- López, W., Castro, I., Salinas, E., Reynoso, R., and López, J. (2016). Properties of coffee soils in the El Triunfo Biosphere Reserve, Chiapas, Mexico. ***Revista Mexicana de ciencias agrícolas*, *7*(3),607-618.** https://www.scielo.org.mx/scielo.php?script=sci_arttext&pid=S2007-09342016000300607

8- Collantes RD, Lezcano JA., Marquínez L and Ibarra A. Characterization of robusta coffee producing farms in the Province of Colón, Panamá. **Ciencia Agropecuaria. 2020; 31: 156-168.** Available:http://200.46.165.126/index.php/ciencia-agropecuaria/article/view/307

9- Silva-Parra A, Colmenares-Parra C and Alvarez-Alarcón J. Multivariate analysis of soil fertility in organic coffee systems in Puente Abadía, Villavicencio. U.D.C.A **Magazine News & Scientific Dissemination. 2017; 20(2):289–298.**

10-Di Rienzo JA, Casanoves F, Balzarini – Italy MG, González L, Tablada M, Robledo CW. InfoStad Version (2008). Transfer Center InoStad, FCA, National University of Córdoba, Argentina; 2015.

11- Chinchilla, M., Alvarado, A y Mata, R. (2011). Capacity of land for agricultural use in the middle-upper sub-basin of the Pirrís River, Los Santos, Costa Rica. **AgronomíaCostarricense, *35*(1),109-130.** https://www.scielo.sa.cr/scielo.php?pid=S037794242011000100006&script=sci_arttext.

12-Villarreal JE, Name B. García RA. Fertility maps like tools for soils zoning in Panama. **Revista Informaciones Agronómicas de Hispanoamérica. (2018); 31:32–39.**

13-Villarreal, JE; Ramos, IA and Riquelme, MR. (2024). Characterization of soil in coffee productive areas in the provinces of Cocle and Veraguas-Republic of Panama. ***International Journal of Plant & Soil Science. Volume 36, Issue 6, Page 371-381, 2024; Article no.IJPSS.116129***