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ORIGINAL

Unveiling the soil's potential: a greenhouse case study at AgroBolívar C.A.

Desvelando el potencial del suelo: caso de estudio casa de cultivo en AgroBolívar C.A.

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ABSTRACT

Agriculture is fundamental for economic and social development, with Bolívar state in Venezuela being an important agricultural producer. This research focused on characterizing the agricultural soil in a greenhouse of AgroBolívar C.A. in Ciudad Bolívar, with the objective of understanding its physical and chemical properties and its productive potential. A composite sampling was carried out in Greenhouse #3. The methodology included analyses of bulk density, particle density, porosity, pH, and exchangeable acidity. The results revealed high bulk density (Plot 1: 1,890 g·cm^{-3}; Plot 2: 1,813 g·cm^{-3}; Plot 3: 1,885 g·cm^{-3}), a particle density suggesting a high organic matter content, and low porosity (Plot 1: 17,42 %; Plot 2: 23,28 %; Plot 3: 14,47 %). The pH varied from neutral (Plot 1) to moderately alkaline (Plots 2 and 3). Exchangeable acidity does not represent a limiting factor for the soils. It is concluded that the soil exhibits compaction with variability in pH, which should be considered to optimize management and crop selection.

Keywords: Acidity; Agricultural; Density; Ph; Soil.

RESUMEN

La agricultura es fundamental para el desarrollo económico y social, siendo el estado Bolívar en Venezuela un importante productor agrícola. Esta investigación se centró en caracterizar el suelo agrícola en una casa de cultivo de AgroBolívar C.A. en Ciudad Bolívar, con el objetivo de comprender sus propiedades físicas y químicas y su potencial productivo. Se realizó un muestreo compuesto en la Casa de Cultivo # 3. La metodología incluyó análisis de densidad aparente, densidad real, porosidad, pH y acidez intercambiable. Los resultados revelaron alta densidad aparente (Parcela 1: 1,890 g·cm^{-3}; Parcela 2: 1,813 g·cm^{-3}; Parcela 3: 1,885 g·cm^{-3}), una densidad real que sugiere un elevado contenido de materia orgánica y baja porosidad (Parcela 1: 17,42 %; Parcela 2: 23,28 %; Parcela 3: 14,47 %). El pH varió de neutro (Parcela 1) a moderadamente alcalino (Parcelas 2 y 3). La acidez intercambiable no representa un factor limitante de los suelos. Se concluye que el suelo presenta compactación con variabilidad en el pH, lo que debe considerarse para optimizar el manejo y la selección de cultivos.

Palabras clave: Acidez; Agrícola; Densidad; Ph; Suelo.

INTRODUCTION

Agriculture is the basis of human presence and permanence on Earth. It was the first enterprise created by humans to satisfy their own food needs and use the surplus for bartering to obtain other products necessary for their daily lives.[1,2,3,4] At the national level, Bolívar is recognized as a mining state, but agricultural activity is quite productive and significant. In Ciudad Bolívar, the most abundant crops are corn, yancuic, cassava, beans, and various vegetables, making it a highly productive state in terms of supply.[2] Agriculture is a fundamental factor in the country's development, as it prevents the outflow of foreign currency by allowing us to be self-sufficient and not have to buy agricultural products abroad that can be produced in the country. It also provides a wide range of products, thus contributing to the creation and expansion of a true agri-food industry sector.[1,5,6,7]

Soil is a fundamental natural resource of the country, and knowledge of its productive potential is an indispensable aspect of the technological development of agriculture, which is only possible when there is a complete understanding of the properties and limitations of an essential factor in the agricultural production processes used in different regions of the country.[3] From a farming perspective, soil is the surface layer of the Earth's crust where the seeds of all types of plants germinate, then deepen their roots to anchor themselves and absorb nutrients, ultimately producing food. It consists of a succession of horizons or horizontal layers characterized physically by their color, texture, and type of material, and chemically by the presence of microelements and macroelements.[1,8,9]

This study focuses on the characterization of agricultural soil in a greenhouse belonging to AgroBolívar C.A., a company located in Bolívar state, Venezuela, whose management philosophy is intrinsically linked to the production and marketing of high-quality agricultural food for human and animal consumption. AgroBolívar C.A. is also dedicated to providing technical advice to producers, which underscores the importance of thoroughly understanding the properties of the soil at its own facilities.[4,10,11]

Soil is a natural system of great complexity in terms of physical, chemical, and biological processes. These processes sustain the life of other ecosystems, such as nutrient cycles and the water cycle, and therefore promote human survival.[13,14,15] Although soil is a resource that sustains the development of crops necessary for life, its susceptibility to degradation and the consequent decline in crop productivity have recently been recognized.[1,16,17] In this context, the following question arises, which guides this research: What are the physical and chemical characteristics of the agricultural soil present in the AgroBolívar C.A. greenhouse, and how do these characteristics relate to the company's productive potential?

Soil analyses can provide farmers with information about the unique characteristics of their soil, enabling them to make data-driven decisions about soil management practices that ultimately improve crop yields and overall soil health.[5,18,19] This is why this research is of utmost importance both for AgroBolívar C.A. and for the agricultural sector in Bolívar state. Understanding the specific properties of the soil in their greenhouses will allow the company to optimize its fertilization, irrigation, and other management practices, which could translate into greater production efficiency and improved quality of its agricultural products. In addition, the results of this study can serve as a basis for future research and the formulation of technical recommendations for other producers in the region, thereby contributing to the strengthening of the local agricultural sector.

METHOD

Geographical Location

Figure 1. Geographic location of the sample collection area (a) AgroBolívar C.A. Botanical Garden Agricultural Center[6]

The soil sample was collected in a 800 m² greenhouse located within the "Jardín Botánico" Agricultural Center of AgroBolívar C.A. This center is strategically located on Avenida 5 de Julio, La Fuente Luminosa sector, Catedral Parish, Angostura del Orinoco Municipality, Bolívar State (figure 1), specifically in Greenhouse No. 3.

Sample collection

The sample was collected using a composite sampling scheme at Cultivation House No. 3, covering an area of approximately 800 m², belonging to AgroBolívar C.A. (figures 2a and 2b). Given the presumed uniformity of the soil in this area, it was decided to obtain a composite sample consisting of twenty individual subsamples. To ensure adequate representation of soil conditions across the entire surface of the greenhouse, a systematic zigzag sampling pattern was implemented, thus guaranteeing the inclusion of spatial variations in the analysis.

a b

Figure 2. Greenhouse diagram. a) Plot 1, b) Plot 3, and c) sampling points

a b c d

Figure 3. Sample collection a) removal of the vegetation layer, b) test pits, c) samples collected in a plastic bucket, d) transferred to a plastic bag

At each sampling point, the vegetation layer was removed to avoid its inclusion (figure 3a). Test pits measuring approximately 20 x 20 x 20 centimeters were dug (figure 3b). The samples were extracted and collected in a plastic bucket (figure 3c). Once sampling was complete, the entire sample was transferred to a sturdy, unused plastic bag, which was hermetically sealed and properly labeled. Finally, the sample was transferred to the laboratory for analysis (figure 3d).

Sample preparation

Once in the laboratory, the sample was carefully spread on a clean plastic sheet (figure 4a). It was homogenized by mixing it manually, after which it was quartered in four successive stages (figure 4b). This process of progressive reduction yielded a representative portion of approximately one kilogram, which was stored in a new plastic bag and properly identified with its corresponding code (figure 4c). This sample was then spread out in a ventilated area and left to air dry for 24 hours. Once sufficiently dry, the sample was sieved using a laboratory sieve with a 1 mm mesh opening, corresponding to number 16 (figure 4d), in order to obtain a uniform particle size for subsequent analysis.

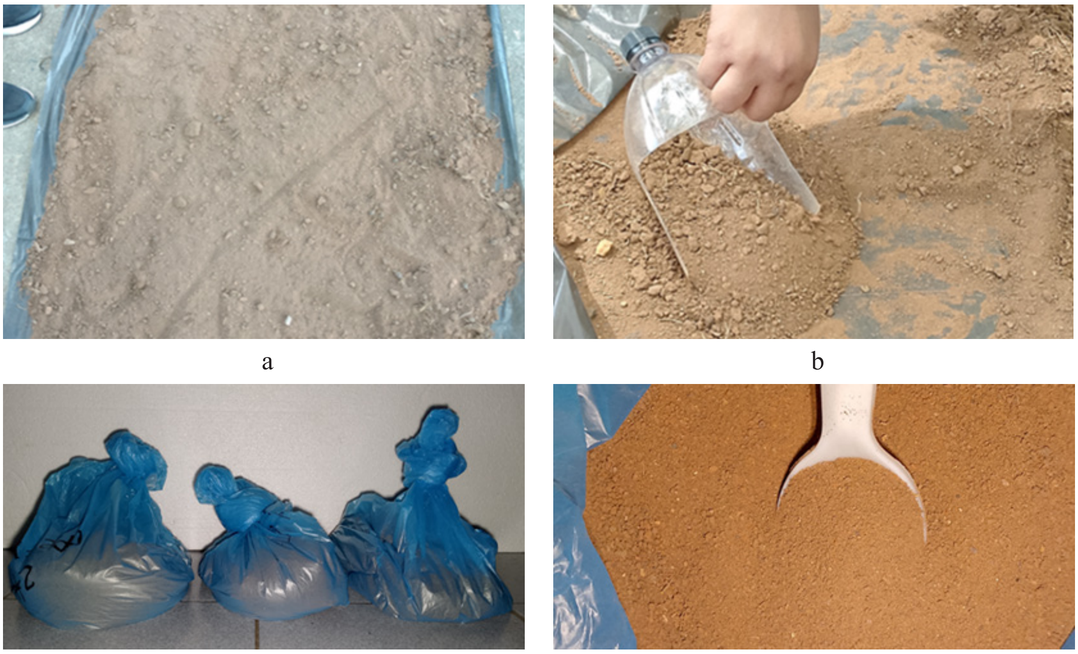

Figure 4. Sample preparation: a) homogenization and quartering, b) discarding of two quartering fractions, c) portion of approximately one kilogram, and d) sieved sample

Soil mass density (ρ)

This is a measure of how compact or dense the soil is, depending on its structure (shape), how many spaces (pores) there are in the sample, how compacted these are, and the composition of the solid material. Soils composed of minerals (sand, silt, and clay) will have a different mass density than soils made of organic matter. In general, soil density can vary from 0,5 g·cm(-3) in soils with many spaces to 2,0 g·cm(-3) or more in very compact horizons. This helps determine how much air or water can be stored or pass through the soil, and also indicates how tightly the particles are bound together and whether it will be difficult or easy for roots to penetrate the horizon. Soil density can be determined in two ways: bulk density (ρ(B))and true density (ρ(T)).[7]

Apparent density (ρ_A) using the paraffin method

This is the mass of a unit volume of dry soil with its pore space. This volume includes both solids and pores, so it reflects the total porosity of the soil. It is a very important parameter for describing soil quality and ecosystem function.[3,8,9] It is given by the expression:

$$\rho_A = P_{ss}/V_t \quad (1)$$

Where:
ρ_A: Apparent density g·cm(-3).
P_{ss}: Dry soil mass (g).
V_t: Total volume (cm^3).

ρ_A varies according to texture. Sandy soils have a higher ρ_A than clayey and loamy soils, due to their lower porosity (sandy soil). It is also affected by soil structure, degree of compaction, expansion and contraction of particles, and moisture content. Mechanization operations that disperse the soil decrease its apparent density, while compaction increases it.[8] In this sense, low ρ(A)values indicate a porous soil condition, while high values express a poor environment for root growth, reduced aeration, and undesirable changes in hydrological function, such as a reduction in water infiltration velocity.[3,9] It should be noted that ρ(A)depends on organic matter, soil texture, the density of soil mineral particles (sand, silt, and clay), and their arrangement. Clay soils have small, narrow pores, while sandy soils have large pores that form continuous channels[9] (table 1).

Table 1. Relationship between bulk density, soil texture, and their influence on plant root development

Texture	Growth		
	Ideal	Affects	Restricts
Sandy - Sandy loam	<1,60	1,69	>1,80
Sandy loam - loam	<1,40	1,63	>1,80
Sandy loam - Clay loam	<1,40	1,60	>1,75
Silt - Silty loam	<1,40	1,60	>1,75
Silty loam	<1,40	1,55	>1,65
Silty clay - Sandy clay	<1,10	1,49	>1,58
Clay	<1,10	1,39	>1,47

Source: [9]

A soil aggregate (undisturbed and dry) was taken (figure 5a) and tied to the end of a string (figure 5b). The assembly (PSS) was weighed on an analytical balance (OHAUS, Adventurer) (figure 5c). Paraffin was heated until it reached the liquid phase. The aggregate was immersed in the paraffin until completely covered, removed, and left to air dry (figure 5d). Once the paraffin was dry, the paraffin-coated aggregate (P(SP))was weighed again (figure 5e). A 250 mL graduated cylinder was filled with distilled water (to 50 % of its capacity) and this volume was noted. The aggregate was immersed in the distilled water in the cylinder and the displaced volume (V(d) was noted (figure 5e).

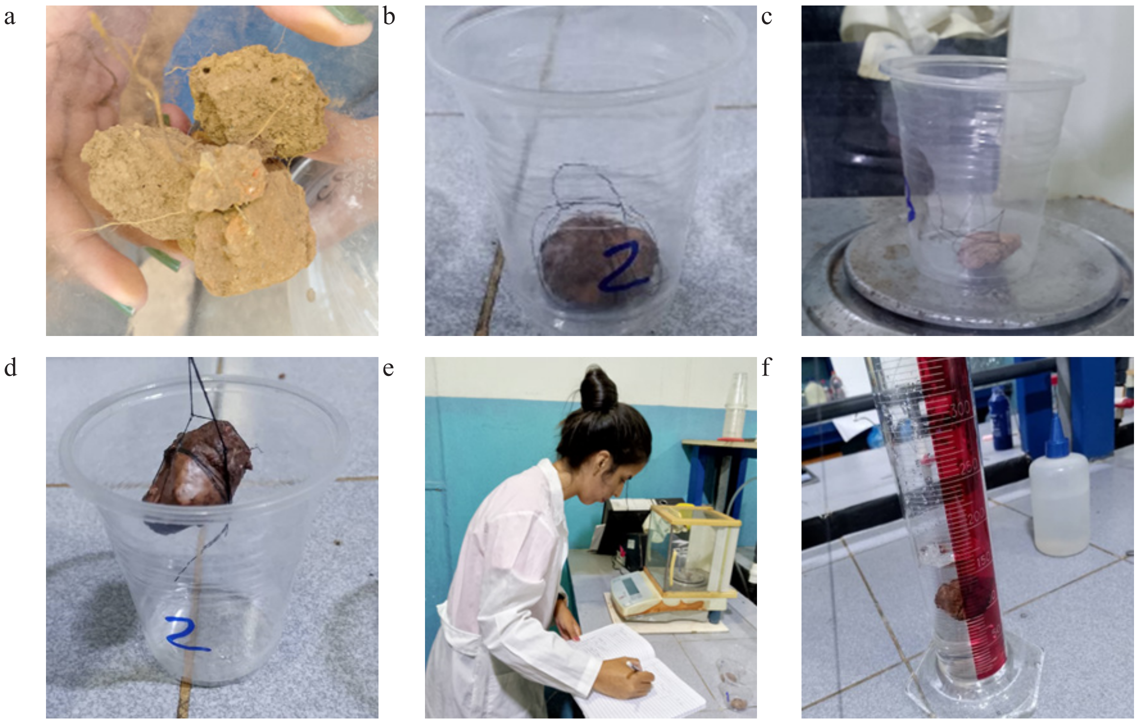

Figure 5. Apparent density (ρA) using the paraffin method, a) soil aggregate (undisturbed and dry), b) soil aggregate tied to a thread, c) weighing of the assembly (PSS). d) coating the aggregate in paraffin, c) weighing the assembly (P(SP))and e) determining the volume of the paraffin-coated aggregate (V(d)

Calculations

$$\rho_A = \frac{P_{SS}}{V_d - \left[\frac{P_{SP} - P_{SS}}{0,9}\right]} \qquad (2)$$

Where:
ρ_A: Apparent density.
P_{SS}: Weight of the uncoated soil aggregate.
P_{SP}: Weight of the waxed soil aggregate.
V_d: Displaced volume.
0,9: Density of paraffin.

Real density (ρ_R) using the pycnometer method

This is the ratio between the unit of mass and the unit of volume of the soil, which is relatively constant, as it is determined by the chemical and mineralogical composition of the solid phase. ρR expresses the density of the soil particles excluding the pore space. Most soil components (aluminosilicates, silica) have a density between 2,6–2,7 g·cm(-3), with an average value of 2,65 g·cm(-3). The possible variation in the ρ(R) of the soil is due to the amount of organic matter.[9] If ρ(R) is< 2,65 g·cm(-3), it can be assumed that the soil has a high content of gypsum or organic matter; if ρ (R)> 2,65 g·cm(-3), a high content of iron oxides or ferromagnesian minerals can be inferred.[8]

A clean, dry pycnometer (Wa) was weighed on an analytical balance (OHAUS, Adventurer). Next, approximately 10 g of dry soil was weighed and placed in the pycnometer (Ws). Distilled carbon dioxide (CO_2) water was added very carefully until the pycnometer was full, avoiding the formation of bubbles. After replacing the lid, the outer surface of the pycnometer was dried and then weighed again W(sw). The contents of the pycnometer were discarded, and it was refilled with distilled water free of CO_2 (2), and a final weighing was performed (W(w)). This protocol was repeated three times. Finally, the water temperature during the experiment was recorded for density calculations (figure 6).

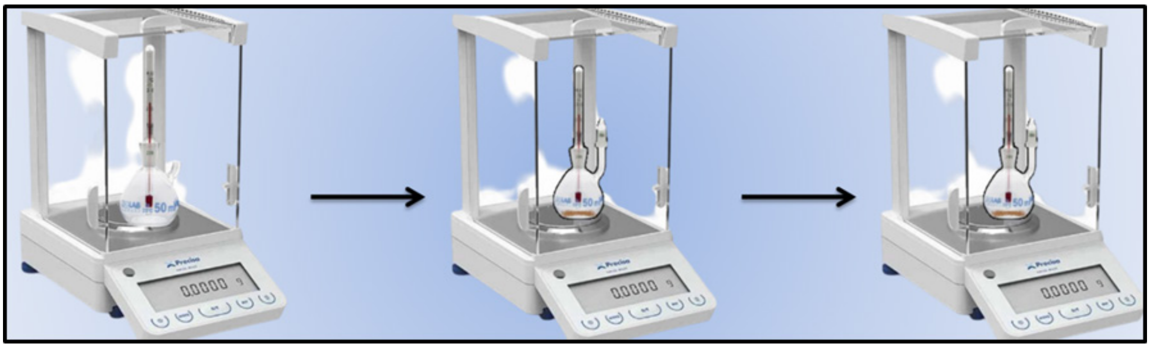

Figure 6. Procedure for determining actual density using the pycnometer method[7]

Table 2. Water densities as a function of temperature

T (˚C)	ρ (g·cm(-3)	T (˚C)	ρ (g·cm(-3)	T (˚C)	ρ (g·cm(-3)
19,0	0,99843	23,0	0,99757	27,0	0,99652
20,0	0,99823	24,0	0,99733	28,0	0,99624
21,0	0,99802	25,0	0,99705	29,0	0,99595
22,0	0,99780	26,0	0,99683	30,0	0,99567

Source: [8]

Calculations

$$\rho_R = \frac{d_w(W_s - W_a)}{(W_s - W_a) - (W_{sw} - W_w)} \qquad (3)$$

Where:
ρR: Actual density.
dw: Density of water as a function of temperature (table 2).

Ws: Weight of the pycnometer plus soil.
Wa: Weight of empty pycnometer.
Wsw: Weight of the pycnometer plus soil plus water.
Ww: Weight of the pycnometer plus water.

Calculations of the percentage of porosity[9]

Porosity is important for gas exchange between the soil and the atmosphere, root growth, water movement, and water storage. It is the percentage of soil volume occupied by porous space. Porous space is formed by the pores between soil particles and aggregates, which is why soil texture and structure are the main factors that determine soil porosity.[8]

Calculations

$$\%_P = 100 - \left(\frac{\rho_A}{\rho_R} \times 100\right) \quad (4)$$

Where:
%P: Percentage of porosity.
ρA: Apparent density.
ρR: Real density.

Acidity by potentiometric analysis[10]

pH is one of the most common and important measurements in routine soil chemical analysis, as it controls chemical and biological reactions.[10] Hydrogen potential (pH) is a chemical property of soil that has an important effect on the development of living organisms (including microorganisms and plants). The pH reading refers to the concentration of active hydrogen ions (H+) that occurs at the liquid interface of the soil, due to the interaction of solid and liquid components (figure 7).[11]

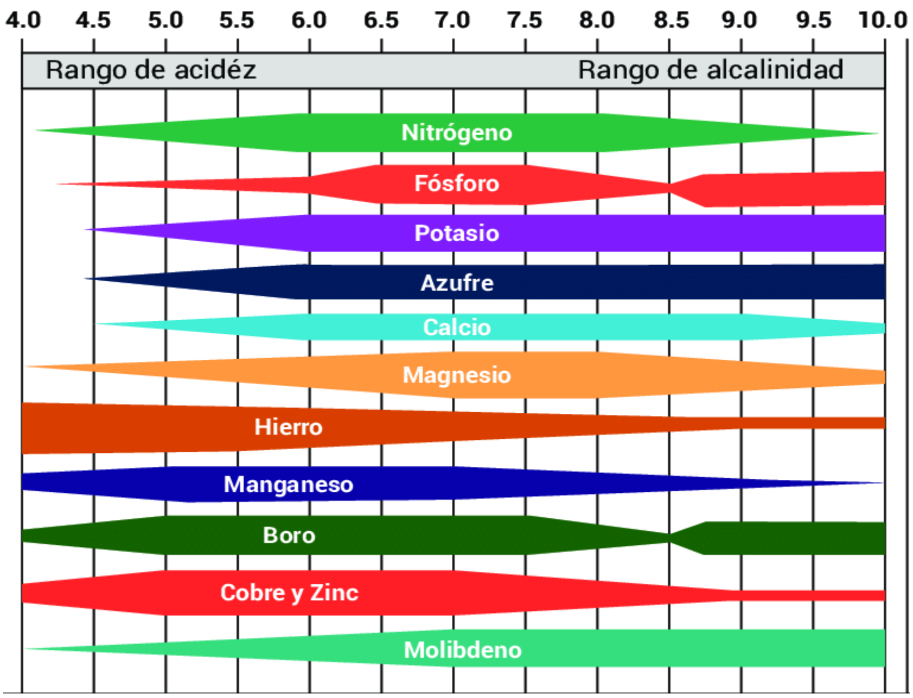

Figure 7. Nutrient availability according to pH[12]

Soil pH is a chemical property that influences the regulation of nutrient availability and many other processes. Each nutrient is available for plant uptake at different soil pH levels, which is why different crops grow well at different pH values. Values between 5,5 and 7,5 are suitable for most crops, as a wider variety of nutrients would be available[13] (table 3).

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Table 3. Criteria for evaluating soil with respect to its pH	
Category	**pH value**
Strongly acidic	< 5,0
Moderately acidic	5,1 – 6,5
Neutral	6,6 – 7,3
Moderately alkaline	7,4–8,5
Strongly alkaline	> 8,5
Source:[10]	

Ten grams of soil were weighed on an analytical balance (*OHAUS, Adventurer*) and placed in a 50 mL beaker. Twenty mL of distilled water were then added to the beaker containing the soil sample, and the mixture was stirred with a glass rod at five-minute intervals for thirty minutes. The pH of the suspension was measured immediately after stirring, the reading was allowed to stabilize, and finally the reading was recorded. The procedure was performed in triplicate (figure 8).

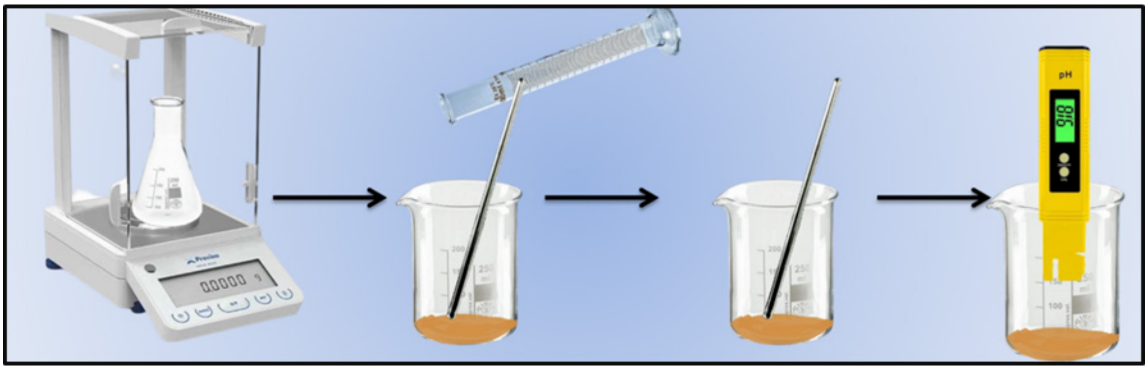

Figure 8. Diagram of the procedure for determining pH[7]

Exchangeable acidity (Al^{3}+ H^{+})

In agricultural soils, the pH value typically ranges from 4 to 10. However, the lower the soil pH, the higher the concentration of aluminum, and high concentrations of exchangeable aluminum are toxic to plants. The populations of microorganisms involved in the nitrogen and sulfur cycles are also altered. Furthermore, phosphorus availability is reduced, as it forms insoluble compounds with iron and aluminum, leading to deficiencies in soil quality.[11] Acidic soil can contain high concentrations of elements such as aluminum (Al), iron (Fe), and manganese (Mn), which are toxic to the vast majority of plants.[1]

On the other hand, the amount of nutrients available to plants is related to soil acidity. Exchangeable acidity occurs through the hydrolysis of aluminum (Al) in solution and by the exchangeable hydrogen ion (H+). The latter has a minimal value at the pH found in soil; therefore, what is determined is exchangeable aluminum.[1]

The determination of exchangeable acidity is based on the use of a neutral salt, potassium chloride (KCl) 1,0 mol L-1, with a displacing ion (K+), which causes the aluminum ions (Al3+) and hydrogen ions (H+) to pass into the solution. In this way, the filtered sample (soil, sediment, or organic fertilizer) is acidic. It can be titrated with a basic solution, so that the amount of acidity will be equal to the amount of base used between the neutralization points. Titration is carried out to the alkaline extreme using phenolphthalein (pH 8,2) as an indicator. Aluminum complexes with KCl, releasing an equivalent amount of H+, which are titrated with 0,01N sodium hydroxide (NaOH).[12]

Approximately 2,5 g of the dried, sieved soil sample (particles <2 mm) was weighed on an analytical balance (OHAUS, Adventurer) and transferred to a beaker of appropriate size. Next, 25 mL of 1,0 mol L-1potassium chloride (KCl) was added to the sample (ratio: 1 to 10) was added to the sample. The mixture was subjected to magnetic stirring using a heating and stirring plate (Lab. Companión, HP-3000) for 30 minutes to ensure the extraction of Al(+3)and H+ ions were exchanged for potassium ions (K+). Once stirring was complete, the mixture was left to stand for 20 minutes. It was filtered by gravity, and a 25 mL aliquot of the filtrate obtained (containing Al(+3)and H+ ions) was taken, followed by the addition of 25 mL of distilled water and a few drops of 3 % phenolphthalein indicator. The titration was initiated with 0,01 N NaOH until a persistent pale pink color was achieved. The procedure was performed in triplicate. Finally, a blank was performed (figure 9).

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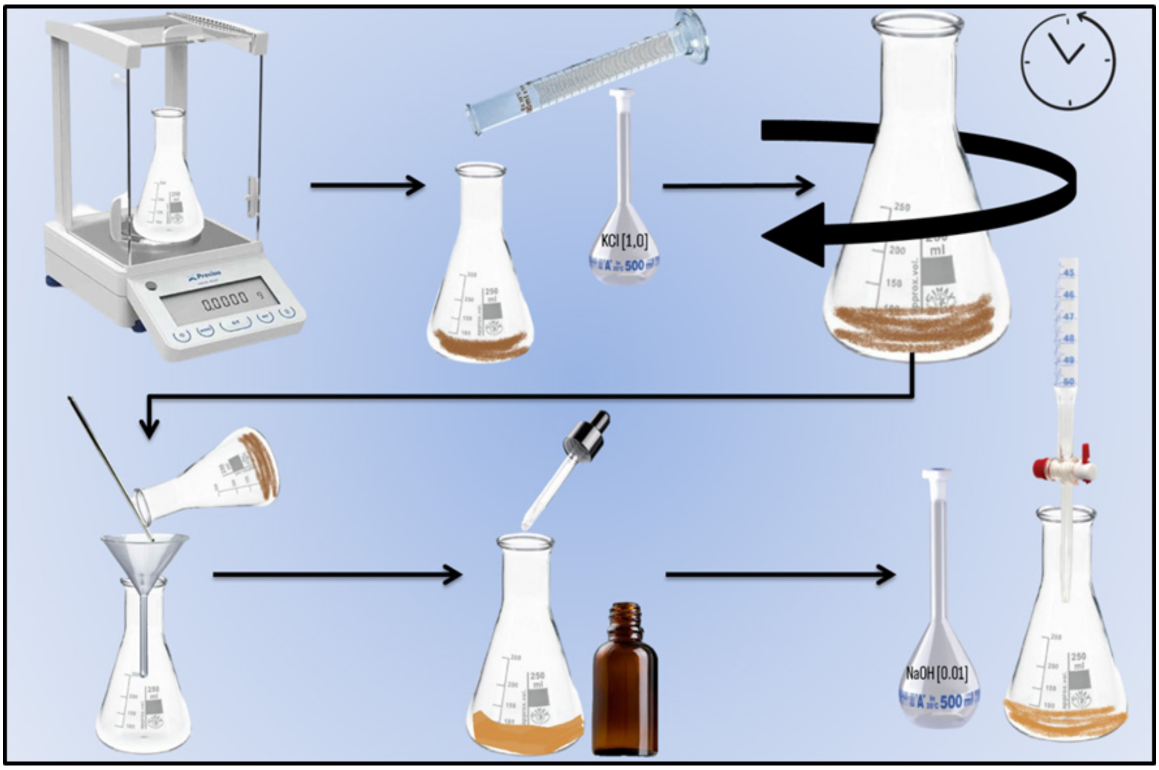

Figure 9. Diagram of the soil exchangeable acidity procedure[7]

Calculations

$$AI\ (meq/100\ g) = \frac{(V_m - V_b) \times N_{NaOH} \times 100}{m_s\ (g)} \qquad \textbf{(5)}$$

Where:
Vm: Volume of NaOH used in the titration of the sample (in mL).
Vm: Volume of NaOH used in the titration of the blank (in mL).
M: Molarity of the NaOH solution.
100: Conversion factor to express the result in meq/100 g.
ms: Weight of the soil sample (in grams).

Presentation, analysis, and interpretation of results

Apparent density (ρA)

The high values of bulk density (ρA) in the three plots are significantly high for all types of damaged soil texture in the relationship between bulk density, soil texture,[9] suggesting reduced pore space. This could imply unfavorable conditions for aeration, water infiltration, and root growth (table 4).

Table 4. Bulk density (ρA)

Plot	ρA (g·cm(-3)	s (g·cm(-3)
1	1,890	0,111
2	1,813	0,561
3	1,885	0,320

Real density (ρR)

The actual density values (ρR) are lower than the value of 2,65 g·cm^3 expected for most mineral components of soil, such as aluminosilicates and silica.[13] The results suggest the presence of components with lower density; consequently, the soil could have a high organic matter content (table 5).

Table 5. Real density (ρR)		
Plot	ρR(g·cm(-3)	s (g·cm(-3)
1	2,288	0,053
2	2,364	0,010
3	2,204	0,056

Percentage of porosity

Considering the results obtained, the porosity percentage is significantly low (table 6) if we think that agricultural soil generally has a porosity between 40 % and 60 %.(14) Such low porosity confirms the inference obtained from the high apparent density, which suggested limited porous space. The low porosity observed can have several negative implications for the soil, including difficulty in aerating the soil, which is essential for plant root respiration and the activity of beneficial microorganisms. In addition, it limits water infiltration and storage, causing water availability problems, especially in dry periods. Root growth may also be restricted in soils with low porosity due to the lack of space for development.

Table 6. Percentage of porosity	
Plot	Porosity (%)
1	17,42
2	23,28
3	14,47

Hydrogen potential (pH)

Plot 1 has a pH of 7,2. This value falls within the range of 6,6–7,3, indicating that the soil in this plot is considered neutral. It is therefore regarded as suitable for most crops, as the availability of a wide range of nutrients for plants is optimal in this range. Plot 2 has a pH of 7,8, and Plot 3 has a pH of 7,9 (table 7). This value falls within the range of 7,4 to 8,5, indicating that the soil in this plot is considered moderately alkaline. While some crops can tolerate or even prefer slightly alkaline conditions, for others, it can affect the availability of specific nutrients such as iron, manganese, copper, and zinc, which are essential for plant growth, potentially limiting the absorption of important microelements, which tend to be less soluble at high pH levels.

Table 7. Hydrogen potential (pH)		
Plot	pH	s
1	7,2	<0,1
2	7,8	<0,1
3	7,9	0,1

In general, the results indicate that the soil in Plot 1 has an optimal pH for a wide variety of crops. However, Plots 2 and 3 show moderate alkalinity and moderate pH, which could have implications for the availability of specific nutrients. Although most macronutrients are not usually significantly affected by this level of alkalinity, it is essential to consider the specific requirements of the crops planned for these plots, as some may be more sensitive to alkalinity than others. If species that prefer neutral or slightly acidic soils are to be grown, soil management strategies to reduce the pH in Plots 2 and 3 could be considered.

Exchangeable Acidity (Al^{3+}+ H^{+})

Interchangeable acidity analysis is usually performed on soils with a pH below 5,5 because in these acidic soils, the presence of aluminum ions (Al^{3}) increases significantly, reaching levels that are toxic to most plants.(21) Given that the three plots had pH values above 7,0, indicating alkaline conditions, the determination of exchangeable acidity was not considered necessary. The presence of exchangeable aluminum is considered minimal and does not represent a concern for crop development, with other parameters such as alkalinity and the presence of carbonates being the most relevant factors to evaluate.

CONCLUSIONS

The greenhouses of AgroBolívar C.A. have soils with contrasting physical characteristics. Although the high bulk density and low porosity suggest compaction, which could limit aeration and water infiltration, the actual density indicates a high organic matter content that could mitigate these effects. Chemically, the pH varies between neutral (Plot 1) and moderately alkaline (Plots 2 and 3), which could influence the availability of microelements in the latter. Exchangeable acidity is not a limiting factor given the alkaline pH of the soils. In general, variability in soil properties is observed and should be considered to optimize management practices and crop selection in different growing areas.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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