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The role of organic matter in the acidification of agricultural soils in Ecuadorian Amazonia

El papel de la materia orgánica en la acidificación de suelos agrícolas de la amazonia ecuatoriana

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Abstract: The research focuses on understanding how agricultural practices and the decomposition of organic matter contribute to changes in soil acidity, a phenomenon critical to soil health and productivity in this area. The study uses scientific methods to analyze soil samples, evaluating the composition of organic matter and its relationship to soil acidity. The influence of organic matter on soil acidity was evaluated, highlighting that Amazonian soils tend to be more acidic and clay soils predominate. The study uses a coefficient of determination of 0.662 to evaluate the relationship between organic matter and soil acidity, indicating that approximately 66.2% of the variability in soil acidity can be explained by organic matter. The researchers conclude that the presence of organic matter plays a significant role in soil acidification, especially in regions such as the Amazon, where higher acidity is observed. They also highlight the predominance of clay soils in these areas, which may influence nutrient retention and the ability to neutralize soil acidity. These findings underscore the importance of considering organic matter and specific soil characteristics when developing agricultural management and conservation strategies in regions with acid soils such as the Amazon.

Keywords: hydrogen potential, organic carbon, organic matter, soil, soil use potential, acidification

Resumen: La investigación se centra en comprender cómo las prácticas agrícolas y la descomposición de la materia orgánica contribuyen a cambios en la acidez del suelo, un fenómeno crítico para la salud y productividad del suelo en esta área. El estudio utiliza métodos científicos para analizar muestras de suelo, evaluando la composición de la materia orgánica y su relación con la acidez del suelo. Se evaluó la influencia de la materia orgánica en la acidez del suelo, destacando que los suelos amazónicos tienden a ser más ácidos y predominan los suelos arcillosos. El estudio utiliza un coeficiente de determinación de 0.662 para evaluar la relación entre la materia orgánica y la acidez del suelo, lo que indica que aproximadamente el 66.2% de la variabilidad en la acidez del suelo puede ser explicada por la materia orgánica. Los investigadores concluyen que la presencia de materia orgánica desempeña un papel significativo en la acidificación de los suelos, especialmente en regiones como la Amazonía, donde se observa una mayor acidez. Además, resaltan la predominancia de suelos arcillosos en estas áreas, lo que puede influir en la retención de nutrientes y en la capacidad de neutralizar la acidez del suelo. Estos hallazgos subrayan la importancia de considerar la materia orgánica y las características específicas del suelo al desarrollar estrategias de manejo agrícola y conservación en regiones con suelos ácidos como la Amazonía.

Palabras clave: Potencial de hidrogeno, carbono orgánico, materia orgánica, suelo, uso potencial, acidificación

Introduction

The Ecuadorian Amazon is home to an exceptional wealth of biodiversity and plays a crucial role in global climate regulation. However, the growth of agricultural activity in this region has raised concerns about environmental impacts, particularly on soil health. Soil acidification, a phenomenon that negatively affects the availability of essential plant nutrients, has emerged as a significant challenge; this decrease in soil pH alters the ability of nutrients to dissolve and be available to plants, leading to nutritional deficiencies and negatively affecting crop growth and yields (Queiroz et al., 2021)..

This study delves into the intricate relationship between organic matter and the acidification of agricultural soils in the Ecuadorian Amazon. Organic matter, consisting of decomposing plant and animal residues, represents an essential component of soil structure and plays a fundamental role in soil fertility. Organic matter, composed of decomposing plant and animal residues, is fundamental to soil structure and fertility; soil organic matter influences moisture retention, improves soil structure and promotes beneficial biological activity. In addition, it serves as a source of plant nutrients, harbors beneficial microorganisms and helps regulate soil pH. Therefore, the presence and maintenance of high levels of soil organic matter are crucial to mitigate the negative effects of soil acidification and ensure the availability of essential plant nutrients. However, processes involving organic matter can also contribute to soil acidification, generating a delicate balance that deserves detailed attention (Lal, 2015).

The objective of this study is to examine in depth the specific role of organic matter in the process of soil acidification in Amazonian agricultural contexts; specifically in the crop area of the Amazonian Research and Production Experimental Center of the Amazon State

University. Through detailed analyses of soil samples and evaluations of local agricultural practices, we seek to provide a clearer understanding of the mechanisms driving this phenomenon. These insights are crucial to inform sustainable management strategies that reconcile agricultural production with the long-term preservation of soil health in this unique region.

Materials and methods

Specific tools and techniques were used to collect a representative soil sample. A stainless steel shovel, airtight plastic bags, identification tags and disposable gloves were used as key materials. Points within the study area were randomly selected, ensuring an equal distribution. The top layer of vegetation was removed at each point and excavated to a predetermined depth using the shovel. To obtain a three-dimensional representation of the soil, multiple samples were taken at each point, which were combined and homogeneously mixed to form a composite sample. Each sample was accurately labeled, stored in airtight bags, and transported to the laboratory for subsequent analysis, ensuring representative and consistent data collection ((Bismarck et al., 2014).. Samples were taken within the Experimental Center for Amazonian Research and Production (CEIPA); where agricultural practices are implemented with different crops in order to implement a teaching system to students of the Amazon State University.

Determination of pH

For the determination of pH in a soil sample, the following materials and method were implemented according to the FAO proposal. A calibrated glass electrode, buffer solutions of known pH (pH 4.01, 7.00 and 10.01), magnetic stirrer and soil samples were used. Initially, the glass electrode was calibrated using the prepared buffer solutions. Subsequently, a soil suspension was prepared by mixing a measured amount of soil with distilled water. The glass electrode was immersed in the suspension to record the pH of the sample. This procedure was repeated with several samples to obtain representative and accurate results in the evaluation of the soil pH. (Food and Agriculture Organization of the United Nations, 2020).

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Determination of organic matter

In the analysis of organic matter in a soil sample, tools and procedures were used according to the validation of the calcination method. The materials included a muffle furnace, porcelain capsules, a spatula and soil samples. In the method, a known amount of soil was weighed into dry capsules and the initial weight was recorded. Subsequently, the capsules with the soil were placed in the muffle furnace and heated to a constant temperature for a given time. After cooling in a desiccator, they were weighed again to calculate the weight loss as an indicator of the organic matter present in the soil. This procedure was replicated on several samples to obtain a representative assessment (Aguilar and Yuleysi, 2019)..

Organic Carbon Determination

It is possible to estimate soil organic carbon content using the organic matter content as a reference. Soil organic matter consists mainly of carbon, but also includes other elements such as hydrogen, oxygen, nitrogen and small amounts of sulfur and other elements. Although not all components of organic matter are pure carbon, it is common to use an empirical ratio to estimate organic carbon content from organic matter content. The most commonly used ratio is the Van Bemmelen ratio, which states that approximately 58% of the organic matter content in soil is organic carbon. However, this ratio can vary depending on several factors, such as soil type, soil use history, surrounding vegetation, and soil management practices.

Despite these variations, estimating organic carbon content from organic matter content is a common and useful practice in soil quality management and monitoring, especially when specific organic carbon data are not available (Martinez et al., 2017).

Determination of texture

To determine soil texture by bulk density, soil samples are taken from different depths using a cylinder of known volume or a suitable sampling tool. These samples are dried in the laboratory until a dry weight constant is obtained. The bulk density is then calculated by dividing the mass of dry soil by the total volume of the sample.

The relationship between bulk density and soil texture is established through soil theory, where different soil textures, such as clay, silt and sand, have different bulk densities due to their physical and structural properties. For example, clay soils tend to have a higher bulk density due to compaction caused by small particles and high water holding capacity, while sandy soils tend to have a lower bulk density due to their looser structure and the presence of large particles.

Although the determination of soil texture through bulk density provides an indirect and less accurate estimate than other methods of textural analysis, it can be useful in situations where other resources or more advanced techniques are not available. (Ibañez, 2007).

Table 1. *Texture of soils with respect to their bulk density.*

Texture	Bulk density (mg/m)^3
Sandy	1,55 - 1,80
Franco	1,35 - 1,50
Clay loam	1,30 - 1,40
Clayey	1,20 - 1,30

Source: (Ibañez, 2007)

Relationship between pH and organic matter

GeoGebra, with its interactive and visual capabilities, presents itself as a highly effective tool in soil laboratories. It facilitates soil texture analysis by allowing the visualization and evaluation of the relationship between different particle sizes through scatter plots and curve fitting. It is also useful for exploring correlations between various soil parameters, such as the relationship between organic matter content and water holding capacity, taking advantage of dynamic plots to identify trends. GeoGebra is also used to visually model soil permeability and analyze drainage capacity using infiltration rate plots. In spatial variation studies, the tool creates interactive maps that visualize and analyze the distribution of soil properties. In addition, GeoGebra acts as a valuable educational tool, allowing students to interact with models and graphs to improve their understanding of soil phenomena and processes. In addition, it enables the simulation of soil laboratory experiments, providing the opportunity to perform virtual practice before conducting real experiments, which not only streamlines data analysis, but also provides a more intuitive and visual understanding of

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key concepts, thus facilitating informed decision-making in soil management and study.

3. Result

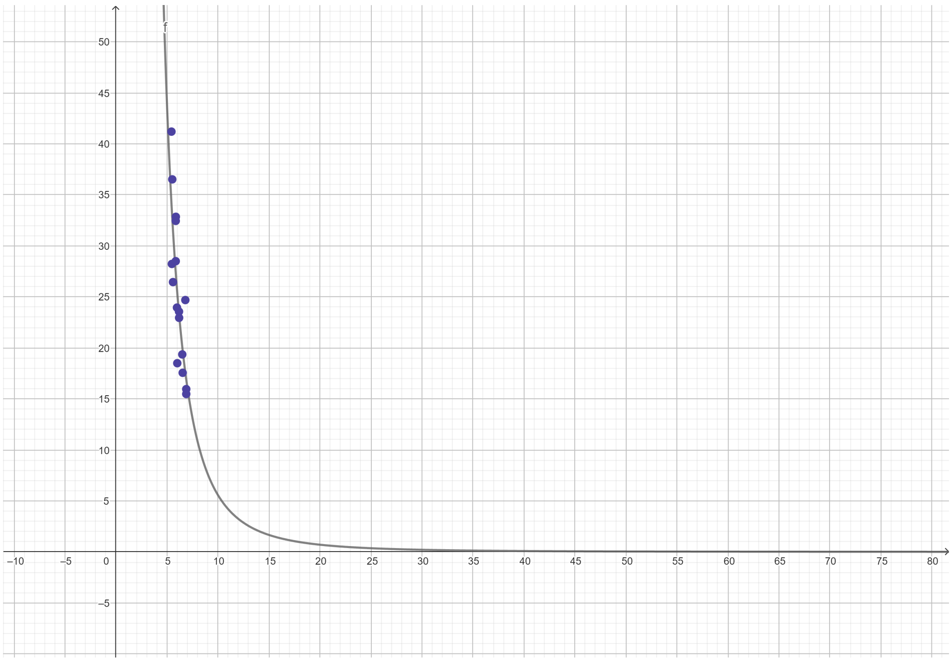
Table 2. *Results of CEIPA agricultural soil parameters*

Soil	PH	Organic Matter (%)	Organic Carbon (%)	Texture
Coffee	6,01	18,50%	17,3884	Clayey
Pastures	5,52	36,52%	15,0684	Clayey
Medicinal Plants PB	6,89	15,96%	24,2846	Clayey
Cocoa	6,18	23,56%	10,962	Clay loam
Bio Fertilizers	6,54	17,56%	11,6	Franco
Citrus	5,59	26,45%	0,2204	Clayey
Forestry program (balsa and guadua)	5,98	23,95%	18,6296	Clayey
Forestry program	6,5	19,36%	13,8562	Clayey
Banana orchard	5,86	32,45%	16,762	Clay loam
Banana study	6,89	15,48%	22,562	Clayey

Old Coffee	5,86	28,50%	8,236	Franco
Grass study	5,48	28,23%	7,4762	Clayey
Medicinal plants PA	6,795	24,69%	23,950	Clayey
Coffee research	6,190	22,95%	8,700	Franco
Sajinos	5,871	32,85%	16,026	Clay loam
Pastures 2	5,441	41,20%	14,852	Clayey

Source: Author

Illustration 1. pH vs. organic matter in CEIPA's agricultural soils**.**



Source: Author

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The results reflect a clear inverse relationship between pH and organic matter in agricultural soils that is mainly due to the buffering capacity of organic matter. Organic matter, composed mainly of decomposing plant and animal residues, contains organic acids that can neutralize the bases in the soil, thus lowering its pH. When there is a greater amount of organic matter present in the soil, microbial activity that decomposes these residues increases, releasing organic acids and other compounds that acidify the soil.

On the other hand, organic matter can also help improve soil structure and nutrient holding capacity, which in turn can influence pH. However, as organic matter decomposes and nutrients are absorbed by plants, pH tends to decrease due to the release of organic acids (Toledo, 2016).

Table 3. *Regression data between pH and organic matter.*

Regression model	Power
Formula	$y = a * x^b$
Parameters	a = 5296,844
	b = -2,978
Coefficient of determination	$R^2 = 0.662$

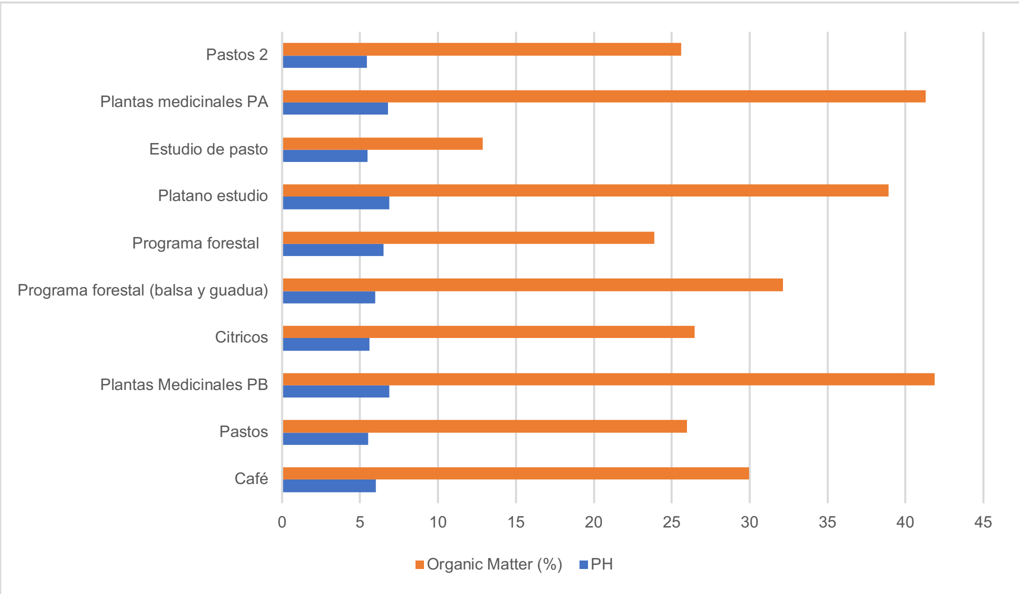
Source: Author

The power regression model is used when the relationship between variables is not linear, but follows an exponential trend. The behavior of this model is such that when X increases, Y also increases, but not in a constant manner. It is important to keep in mind that this type of model can be sensitive to outliers, as small changes in x can result in large changes in y due to the exponential nature of the relationship (Frias et al., 2010).

In a potential model, an inverse relationship, as shown in Figure 1, implies that as an independent variable increases, the dependent variable decreases exponentially. That is, as X increases, Y decreases.

A coefficient of determination of 0.662 can be considered acceptable in many contexts of statistical analysis. This value indicates that approximately 66.2% of the variability in the dependent variable can be explained by the regression model used. Although there is no single criterion for determining the acceptability of a DC, in general, a value of 0.662 suggests a moderately strong relationship between the variables. However, the evaluation of the acceptability of the coefficient of determination should also consider other factors, such as the purpose of the study, the expectations of the investigator, and the nature of the data. In some cases, a CD of 0.662 may be sufficient to support meaningful and useful conclusions, while, in other cases, a higher level of model fit may be required. Ultimately, the decision on the acceptability of a coefficient of determination should be based on a comprehensive assessment of the context and the usefulness of the model for the specific purposes of the research (Novales, 2010).

Table 4. *Inverse relationship of pH and organic matter in clay soils.*



Source: Author

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Table 5. *Inverse relationship between pH and organic matter in loam soils.*

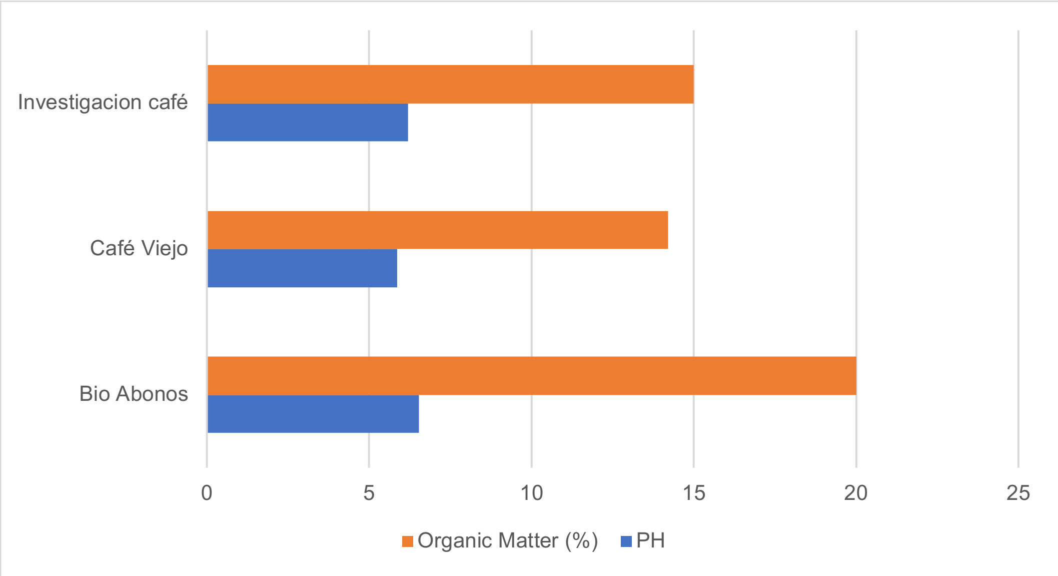
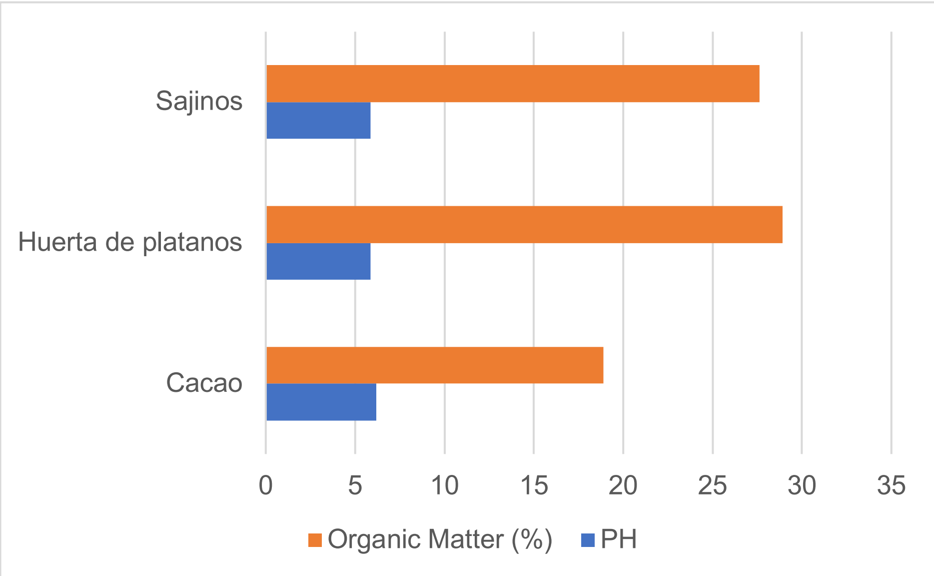


Table 6. *Inverse relationship between pH and organic matter in sandy loam soils.*



Source: Author

The great part of soils according to their topography turned out to be clayey; according to Astorga (2018): in Ecuadorian Amazonian soils, a clay texture predominates. This texture is characterized by having a high proportion of clay particles compared to sand and silt particles. Clay is a mineral fraction of the soil with extremely small particles and a high water and nutrient retention capacity. In Amazonian soils, the presence of clay contributes to the high fertility of the soil and its ability to retain moisture, which is fundamental to the diversity and lush vegetation of the region (Astorga et al., 2018)..

Naturally, organic matter (OM) is integrated into the soil through the decomposition of organic plant residues, concentrating predominantly in the surface layers and decreasing in depth. Scientific literature indicates that the presence of high levels of OM is associated with a more acidic soil pH, although this behavior may vary depending on the original soil material. MO and pH are crucial indicators of soil fertility and health, underscoring the importance of ensuring that these attributes are at adequate levels and at the optimum depth to support plant growth. This study focused on determining the MO content and pH in a specific agricultural soil. The results revealed a high concentration of OM throughout the soil and a neutral pH, which is beneficial for a wide variety of crops. An inverse relationship was observed between these properties, where higher levels of OM were associated with lower pH, especially in Amazonian soils, due to the anion richness of the original soil material (Mora et al., 2016).

4. Conclusions

This study has provided significant evidence of the influence of organic matter on the pH of Amazonian soils. With a coefficient of determination of 0.662, we have shown that approximately 66.2% of the variability in soil pH can be explained by organic matter. Furthermore, we have found that the relationship between these parameters is inversely proportional, suggesting that as organic matter increases, soil pH tends to decrease, following a potential regression. This relationship is especially relevant in the context of Amazonian soils, where a clay texture predominates. The presence of clay in these soils not only influences water and nutrient retention, but can also modulate the influence of organic matter on pH. These findings underscore the importance of considering the interaction between organic matter, soil pH and soil texture in the management and conservation of Amazonian soils, highlighting the need for management strategies that promote an adequate balance of these

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factors to maintain ecosystem health and agricultural productivity in the region.

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