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Artículo científico

Hydrogen potential and electrical conductivity: two essential parameters in the growth of *Alnus acuminata*

Potencial de hidrógeno y conductividad eléctrica: dos parámetros esenciales en el crecimiento de *Alnus acuminata*

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Abstract

Objective: The study aims to determine whether there are significant differences in pH (hydrogen potential) and electrical conductivity (EC) between rocky and deep soils where *Alnus acuminata* is distributed in the Ilish Pichacoto Private Conservation Area (ACP).**Methodology:** Soil samples were taken near 38 trees using a random linear transect within a 1-meter radius around each tree. Each soil sample was extracted against the slope at a depth of 20 cm using manual probes. The pH was measured with a precision potentiometer, while the EC was recorded with an electrical conductivity meter. For statistical analysis, a Student's t-test for independent samples was used. Additionally, regression equations and coefficients of determination (R^2) were generated. **Results:** The results showed that the average pH of rocky soils was 5.77, significantly higher than the average pH of 4.78 in deep soils. Regarding EC, the mean was 0.15 dS/m in rocky soils and 0.5 dS/m in deep soils, indicating a significant difference between the two soil types. **Conclusion:** There are substantial differences in pH and EC between rocky and deep soils where *Alnus acuminata* grows. This tree species shows better growth in rocky soils than in deep soils within the study area.

Keywords: pH, *Alnus acuminata*, rocky soils, electrical conductivity, Ilish Pichacoto

Resumen

Objetivo: El estudio busca determinar si existen diferencias significativas en el potencial de hidrógeno (pH) y la conductividad eléctrica (CE) entre los suelos pedregosos y profundos en los que se distribuye *Alnus acuminata* en el Área de Conservación Privada (ACP) Ilish Pichacoto. **Metodología:** Se tomaron muestras de suelo cercanas a 38 árboles utilizando un transecto lineal aleatorio en un radio de 1 m alrededor de cada árbol. Cada muestra de suelo se extrajo contra la pendiente del terreno a una profundidad de 20 cm, empleando sondas manuales. El pH se midió con un potenciómetro de precisión, mientras que la CE se registró con un conductímetro eléctrico. Para el análisis estadístico, se utilizó una prueba t de Student para muestras independientes. Adicionalmente, se generaron ecuaciones de regresión y coeficientes de determinación (R^2). **Resultados:** Los resultados mostraron que el pH medio de los suelos pedregosos era de 5,77, significativamente superior al pH medio de 4,78 de los suelos profundos. En cuanto a la CE, la media fue de 0,15 dS/m en los suelos pedregosos y de 0,5 dS/m en los suelos profundos, lo que representa una diferencia significativa entre ambos tipos de suelos. **Conclusión:** Existen diferencias sustanciales en pH y CE entre los suelos pedregosos y profundos en los que crece *Alnus acuminata*. Esta especie arbórea muestra mejor crecimiento en suelos pedregosos que en suelos profundos dentro del área de estudio.

Palabras clave: pH, *Alnus acuminata*, suelos pedregosos, conductividad eléctrica, Ilish Pichacoto.

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Introduction

The chemical properties of the soil are fundamental parameters that determine its quality and function, which were manifested through chemical changes, as well as by the dynamics of the elements and substances that compose it (Mendieta-Mendoza et al., 2023; Sainju & Liptzin, 2022). Anthropogenic activities have significantly altered these properties, affecting the soil-plant interaction by modifying the buffering capacity of the soil (Emadodin & Bork, 2012; Ros et al., 2022), the availability of nutrients, water content and number of microorganisms (Nobis et al., 2022). Soil is an essential component for the development of agroecosystems and forestry systems, and its improper management can cause changes in its chemical properties and, consequently, affect its productive capacity (Ochoa-Hueso et al., 2023).

In the global context, addressing the problems associated with the chemical properties of the soil is especially relevant, particularly concerning the use of agrochemicals (Cahuana, 2022). According to the Food and Agriculture Organization of the United Nations (FAO), increasing food demand has prompted producers to adopt more efficient methods to maintain the quality of their crops, often resorting to the use of pesticides (Municipalidad distrital de San Pedro de Saños, 2017). However, using compounds carries the risk of altering edaphic chemical properties, which may negatively impact on native species that depend on the ecosystem (Mancini et al., 2019). This reality is not foreign to the San Pedro de Saños district, where the ACP "Illish Pichacoto" is located. According to the master plan of the private area, this includes a multiple-use zone in which agricultural, livestock and agroforestry activities are developed (FAO, 2002).

pH is a key factor in assessing nutrient availability to plants, being influenced by several factors, such as fertilizer use, which impact nutrient retention in the soil (Malakar et al., 2022; Neina, 2019). Most plant species have an optimum pH range between 5.5 and 7.0, so that values outside this range could negatively affect their growth (Bisht et al., 2022). The pH is classified into two categories: acidic, with the release of hydrogen ions or protons (H+), and basic, with the release of hydroxyl ions (OH-), these conditions determine the function of acids and bases in the mineral components of the soil (Wolny-Koladka et al., 2022). In addition to conditioning microbiological activities, pH influences salinity and nutrient availability (Dou et al., 2022; Rosas-Patiño et al., 2017).

Soil acidification reduces plant growth due to a decrease in the availability of essential nutrients such as calcium, magnesium, potassium and phosphorus, which in turn favors the solubility of toxic elements (Prasetyo et al., 2022). Variations in pH can induce morphological modifications in plants as an adaptation mechanism to these changes (Poveda-Díaz et al., 2020). For example, structural alterations caused by the increase in pH of irrigation water have been observed in *Alnus acuminata*, which is evidence of the ability of the species to influence its environment and adapt to edaphic variations (Poucet et al., 2022).

Another relevant parameter in the chemical properties of the soil is the electrical conductivity (EC) (Jung et al., 2005), which refers to the concentration of soluble salts present in the solution of the substrate, this parameter indicates the ability of the material to conduct electric current, so that high EC values imply a higher concentration of salts (Coitiño et al., 2015). It is recommended that substrates have a low EC, ideally less than 1 dS m^{-1}, as this facilitates fertilization management and prevents phytotoxicity problems in plants (Corwin & Lesch, 2005).

In recent years, research on soil chemical properties, such as pH and EC, has provided significant insights into the growth and development of "aliso" (*Alnus acuminata*) as well as other species (Nikodemus et al., 2020; Sroka et al., 2018). These studies have deepened the understanding of how edaphic acidity and its ability to conduct electricity influence this tree species (Lorenc-Plucińska et al., 2013; Rhoades et al., 2001). It has been shown that soil pH affects the availability of nutrients for roots, while EC indicates the presence of dissolved salts, potentially beneficial or harmful, therefore these findings not only benefit the scientific community, but also the local populations that depend on forest resources, by contributing to sustainable forest management, biodiversity conservation and the fulfilment of Sustainable Development Goal 15 (Life of Terrestrial Ecosystems).

Alnus acuminata, commonly known as "aliso" or "ramrash", is a tree species native to the central Andes of Peru (Poveda-Díaz et al., 2020). This species requires humid environments to develop in silty or silty-sandy soils. In the Mantaro Valley, located in the Peruvian Andean region, there are several natural forests of *Alnus acuminata* (Vásquez et al., 2021). One of these forests is located within the ACP "Ilish Pichacoto". Although *Alnus acuminata* establishes and grows in a variety of edaphic conditions, from deep to stony soils, there were soil factors such as pH and EC that could significantly influence its development.

For this reason, the main objective of this study was to determine if there were significant differences in pH and EC between the stony and deep soils where *Alnus acuminata* is distributed within the ACP "Ilish Pichacoto". Understanding how these edaphic parameters vary among different soil types and how they influence the development of this species is crucial to implementing appropriate management and conservation strategies for this important forest species in the Mantaro Valley.

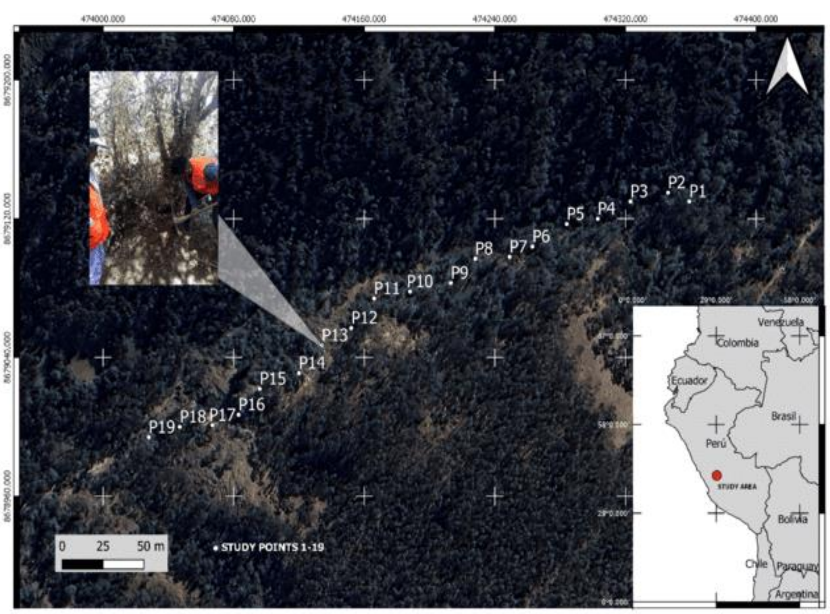
Methodology

Location and sampling of raw material

The study was conducted in the ACP "Ilish Pichacoto", located in the district of San Pedro de Saño, Huancayo province, Junin department and Peru country (Figure 1). The *Alnus acuminata* forests are located at an altitude of 3286 m.a.s.l. at coordinates 473475 E and 8678911 N UTM WGS84 Zone 18S. The average annual maximum temperature ranges between 17°C while the minimum temperature was 4°C; average annual precipitation was 775.4 mm and average monthly relative humidity was 83 % (Perú, 2005).

Figure 1

Location map of ACP "Ilish Pichacoto".



Soil sampling

Soil samples were collected near 38 *Alnus acuminata* trees, 19 in deep soils and 19 in shallow (stony) soils by simple random sampling in a 1 m radius around the tree according to MINAM's Soil Sampling Guide (Ministerio del Ambiente, 2014). Both samples were taken against the slope and with manual probing at a depth of 15 cm. For the collection, ziplock bags were used which were filled with 500 g of soil sample, labelled and implemented a chain of custody according to Annex 3 of the MINAM Soil Sampling Guide (Ministerio del Ambiente, 2014) to identify pH and EC as a substantial factor, (Figure 2).

Figure 2

Stony and deep soil samples.

pH and electrical conductivity analysis

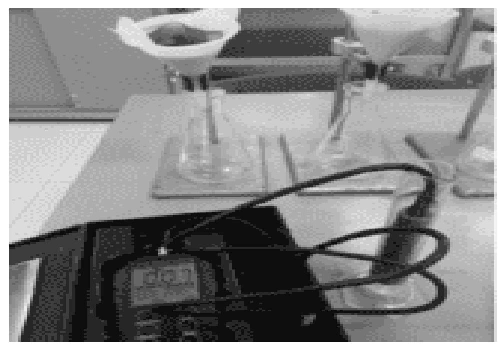
The collected soil samples were taken to the Universidad Continental laboratory, where they underwent a sieving process to homogenize and eliminate coarse particles. Subsequently, mixtures of soil and distilled water were prepared in a ratio of 1: 2.5 (soil: water), following the guidelines established in the "Guía de Análisis de Suelo, Metodología e Interpretación" of the Instituto Nacional de Innovación Agraria (INIA, 2017).

This dilution ratio was commonly used in soil analysis, as it allows adequate dissolution of salts and other soluble compounds presented in the sample. For the determination of pH, quantitative measurements were taken directly in the mixtures using a potentiometer, an instrument that measures the activity of hydrogen ions (H+) in an aqueous solution. As for EC (Figure 3), an initial filtration process of the previously prepared water-soil solution was carried out. This filtration was necessary to remove solid particles that may interfere with the accurate measurement of EC.

Subsequently, measurements of the filtered solution were taken using a conductivity meter, model HI8734 which is a Total Dissolved Solids (TDS) brand HANNA, an instrument specifically designed to measure the ability of a solution to conduct electric current.

Figure 3

Electrical conductivity data acquisition.



Statistical analysis

For the statistical analysis of the data, two different tests were used. First, the Fisher's F-test was performed to evaluate the homogeneity of variances and to determine whether the data collected complied with the homoscedasticity assumption. Subsequently, the main analysis was carried out using Student's t-test for independent samples to determine if there were significant differences in pH and EC between deep and stony soils. Both tests were performed using R Studio statistical software.

In addition, in order to effectively visualize the possible significant differences found, box plots were prepared. This graphical representation allowed a clear appreciation of data distribution, dispersion and the presence of outliers, thus facilitating the interpretation of the results obtained.

Results

The pH of stony soils ranges from 4.78 to 6.89 and the average pH value was 5.77, which means that they were slightly acidic due to their greater availability.

The EC was in a range of 0.13 to 0.18 (dS/m) and average values of 0.16 dS/m.

Table 1

pH and electrical conductivity measurements by soil types.

Stony Soil (SS)			Deep soil (DS)		
Sample number	pH	EC (dS/m)	Sample number	pH	EC (dS/m)
1	5.28	0.14	1	5.34	0.09
2	6.37	0.15	2	4.53	0.04
3	6.89	0.16	3	4.68	0.05
4	6.63	0.16	4	4.51	0.05
5	4.98	0.14	5	5.17	0.07
6	4.78	0.15	6	5.19	0.07
7	6.28	0.15	7	4.91	0.06
8	5.31	0.14	8	4.48	0.04
9	6.83	0.18	9	4.23	0.03
10	6.22	0.16	10	4.01	0.03
11	6.44	0.17	11	4.83	0.05
12	5.14	0.16	12	3.94	0.02
13	5.72	0.16	13	5.23	0.08
14	5.43	0.15	14	5.01	0.06
15	5.44	0.15	15	5.06	0.06
16	5.35	0.14	16	5.19	0.07
17	5.43	0.14	17	4.79	0.04
18	6.1	0.14	18	4.43	0.03
19	4.93	0.13	19	5.34	0.09
Average	5.77	0.16	Average	4.78	0.05

The pH of the deep soils was in a range of 4.01 to 5.34 and an average value of 4.78 pH.
The EC was in a range of 0.02 - 0.09 (dS/m), and an average value of 0.05 dS/m. These data were presented due to their availability.

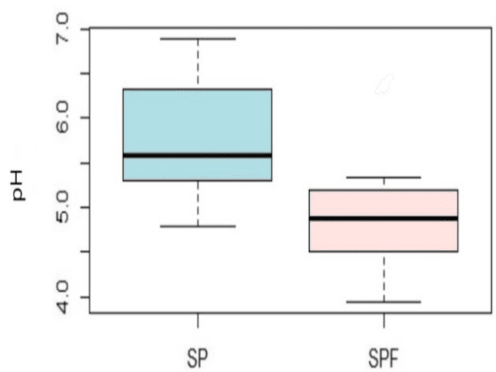
pH Analysis

In the analysis of pH data, 50% of the samples from stony soils (SP) presented greater variability

compared to deep soils (SPF) (t=5.34 and p=3.46e-).
On the other hand, the pH of the stony and deep soils showed significant differences at a 95% confidence level (t=5.34 and p=3.46e-), these differences were due to the variability of the samples obtained (Figure 4).

Figure 4

pH values in stony and deep soils.



Analysis Electrical Conductivity

The electrical conductivity (EC) of stony and deep soils showed significant differences, with a confidence level of 95% (t = 17.53, p = 2.2e-). In this context, the data indicate that 50% of the samples from stony soils (SP) presented lower variability compared to deep soils (SPF), suggesting that the structure and composition of the stony soils influence their electrical behavior (t = 17.53, p = 2.2e-) (Figure 5).

Figure 5

Electrical conductivity values in stone and deep soils.

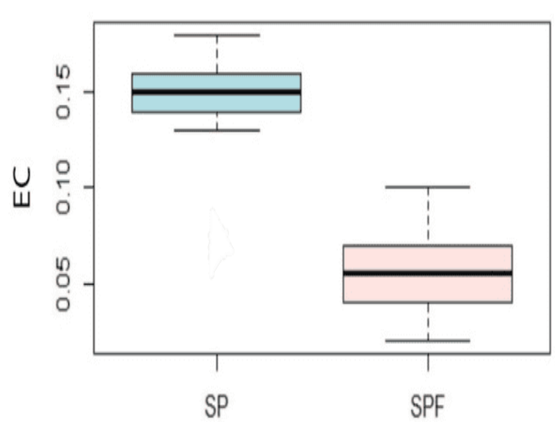


Figure 6 shows the relationship between electrical conductivity (EC) and pH of deep soil. A clear positive trend was observed in the relationship between both variables: as electrical conductivity increases, so does the pH of the soil. This suggests that soil with higher electrical conductivity tends to be less acidic, which may have implications for soil quality and agricultural use.

The regression line fitted to the data was represented by the equation 1

$$y = 3.7 + 19.9x \quad (1)$$

In this equation, the coefficient 19.9 indicates that for every increase of 0.01 in electrical conductivity, the pH of the soil increases by approximately 0.199 units. This highlights a significant and direct relationship between the two variables. Additionally, the intercept of the line, which was 3.7, indicates the estimated value of pH when EC was zero, establishing a reference point for interpreting the data.

The grey band surrounding the regression line represents the confidence interval of the pH estimates based on the EC values, suggesting inherent variability in the predictions. The dispersion of the black data points, which represent individual observations, was relatively low in relation to the regression line, indicating that the observed relationship was strong and consistent.

The coefficient of determination (R^2) calculated for the relationship between electrical conductivity (EC) and soil pH was 0.530.

This indicates that approximately 53% of the variability in pH can be explained by the variability in electrical conductivity. This value suggests that the relationship was weak, meaning that there were other factors influencing soil pH that were not being captured by the linear regression model.

Figure 6

Linear regression of deep soil samples

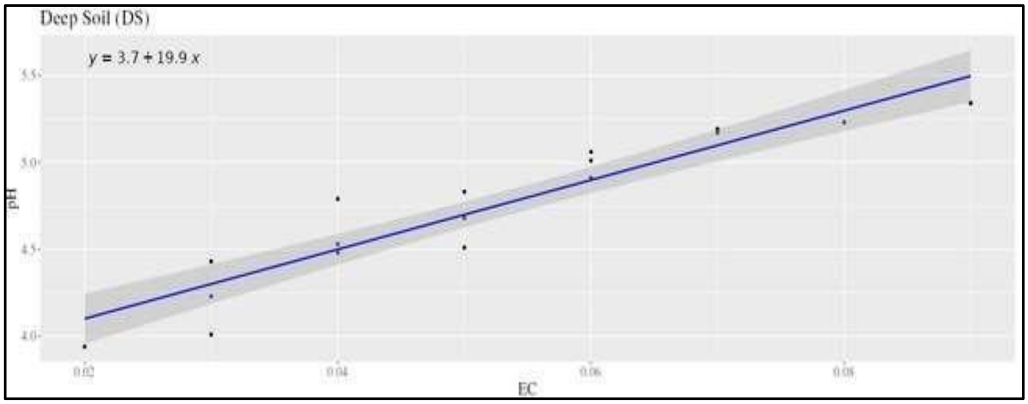


Figure 7 represents a linear relationship between the electrical conductivity (EC) of stony soil and its pH. This arrangement allows for the observation of how pH varies in response to changes in electrical conductivity.

The regression line, represented in blue, illustrates the general trend of the data and was described by the equation 2.

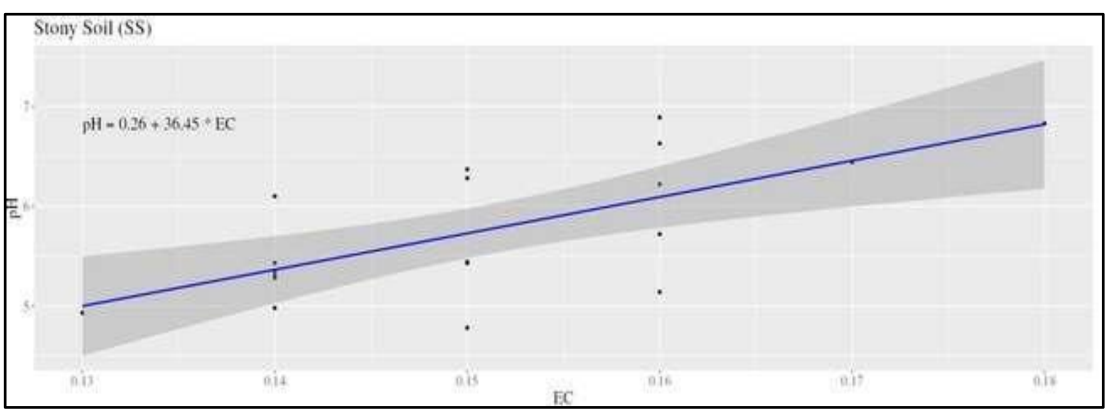
$$y = 0.26 + 36.45x \quad (2)$$

As electrical conductivity increases; the pH of the soil also increases. This suggests that soil with higher electrical conductivity could be associated with more alkaline conditions, which was an important factor to consider in soil management and agriculture.

The coefficient of determination (R^2) obtained for the association between electrical conductivity (EC) and soil pH was 0.573. This indicated that approximately 57% of the pH variations could be attributed to changes in electrical conductivity. This figure implies a low correlation, suggesting that other variables affecting soil pH were not accounted for in the linear regression model.

Figure 7

Linear regression of stony soil samples



Discussion

pH Analysis

The results obtained suggest that stony soils have a more optimal pH for the growth of *Alnus acuminata* compared to deep soils. The average pH value of 5.77 recorded in the stony soils was classified as moderately acidic, which was within the favourable range for this species. According to previous reports, *Alnus acuminata* requires a pH higher than 5.0 for its adequate development (Alzamora, 2015).

A slightly acid soil pH was beneficial for plants, as it facilitates the solubilization and availability of several essential nutrients. In this context, the stony soils analyzed in the present study could offer better access to key nutrients compared to deep soils, whose pH values were farther away from the optimal range (Russo, 1994).

In addition, it was relevant to consider that soil pH influences microbial activity and the presence of beneficial microorganisms, such as nitrogen-fixing bacteria that establish symbiosis with the roots of *Alnus acuminata*. A moderately acid pH could promote the proliferation of these microorganisms, which in turn would enhance growth and nitrogen fixation by *Alnus acuminata* (Mberwa et al., 2022).

Stony soils, having a slightly more acidic pH, could provide more favorable conditions for the availability of nutrients and the development of beneficial microorganisms associated with the roots of *Alnus acuminata*, as mentioned by (Toscano et al., 2022). These edaphic conditions could explain, in part, the better development of this tree species in stony soils compared to deep soils within the study area.

Electrical Conductivity analysis

Soil exhibits a diversity of mineral, organic and biological elements, all subject to the influence of their physical, chemical and biochemical properties, as well as rock residues that generate new mineral components (Corwin & Lesch, 2005). This variety gives the soil an extensive surface area and significant electrical charges, allowing it to absorb and exchange cations. Organic and biological elements were intrinsically related to these characteristics, such as surface area, electrical charge and ion exchange capacity (Poucet et al., 2022).

In line with our findings, stony soils, with an EC 0.15 dS/m, exhibit higherEC values compared to deep soils (0.05 dS/m). This disparity could be attributed to the samples extracted from stony soils, specifically from silty soil, which contains a higher concentration of rock and mineral debris (Vásquez et al., 2021). In the same way, the distance to the river should be taken into account in a range of 18 to 20 m compared to the deep soils (Yu et al., 2021).

Based on our results, we can affirm that *Alnus acuminata* grows better in stony soils, because they have a pH ranging between 5.0 and EC (0.16 ds/m) as opposed to deep soils (Russo, 1994), However, the conditions given by the deep soils do not prevent the development of this species but limit its optimal development, therefore, when the *Alnus acuminata* was closer to the river, it presents a higher EC due to the presence of salinity in the mineral substrates. These findings were relevant not only for alder but also for other trees that coexist in these forests. Given that these ecosystems harbor a diversity of tree species, each with different soil requirements, the results could have important implications for understanding how salinity affects the health and growth of other trees present in the same environment. It was crucial to consider the specific needs of each tree species and how variations in soil salinity may influence their development and survival.

Although the observed relationship was not ideal concerning the regression equations, the dispersion of the data and the confidence band suggest moderate variability in the predictions, highlighting the complexity of the factors influencing soil pH. To improve accuracy, future studies should include more variables and explore multivariate models. This EC-pH relationship can be useful for agricultural management, allowing for indirect estimates of soil pH and optimizing management practices.

Conclusion

pH and electrical conductivity (EC) were key factors for the growth of *Alnus acuminata*, as they influenced the availability of nutrients in the soil. The results showed that the species developed better in rocky soils, with an average pH of 5.77, within the optimal slightly acidic range, which promoted the solubilization of essential minerals. Likewise, electrical conductivity (EC) was identified as a relevant factor for the growth of Alnus *acuminata*, with an average value of 0.15 dS/m in the stony soils analyzed, which facilitates fertilization management and prevents phytotoxicity problems; being closer to the river, *Alnus acuminata* presented higher EC values, possibly due to the salinity in the mineral substrates of these areas, although these values remain within the recommended range for the development of the plant.

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