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MORPHOPHYSIOLOGICAL DIVERSITY OF RHIZOBIA IN SOILS OF CUANDO CUBANGO AND ITS CORRELATION WITH PHYSICOCHEMICAL PARAMETERS

DIVERSIDADE MORFOFISIOLÓGICA DE RIZÓBIOS EM SOLOS DE CUANDO CUBANGO E SUA CORRELAÇÃO COM PARÂMETROS FÍSICO-QUÍMICOS
DIVERSIDAD MORFOFISIOLÓGICA DE RIZOBIOS EN SUELOS DE CUANDO CUBANGO Y SU CORRELACIÓN CON PARÁMETROS FISICOQUÍMICOS

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Abstract: The diversity and density of rhizobia in the soil directly influence fertility and agricultural productivity, being decisive for the sustainability of agroecological systems. This study, conducted between September 2024 and May 2025, aimed to assess the correlation between physicochemical parameters of the soil (pH, moisture, and electrical conductivity) and the density and morphophysiological diversity of rhizobia in soils from the Cuando Cubango province. Soil samples were collected in the municipalities of Cuchi, Menongue, and Cuito Cuanavale, and subjected to rhizobia isolation in YMA medium. The obtained colonies were morphologically characterized and tested for pH alteration with bromothymol blue and Gram staining. The physicochemical parameters of the soils were also determined. A total of 36 colonies were isolated: 18 from Cuchi, 9 from Menongue, and 9 from Cuito Cuanavale. Based on the analysis of morphological similarity, 33.3% of the isolates resembled the genus Rhizobium, 33.3% Bradyrhizobium, 5.5% Mesorhizobium, 8.3% Azorhizobium, and 8.3% Paenibacillus polymyxa. There was a strong correlation between humidity and electrical conductivity ($r = 0.85$; $p < 0.001$), but microbial density showed weak correlations with pH, humidity, and conductivity. A moderate and negative correlation was observed between the number of colonies and pH ($r = -0.44$; $p = 0.01$). The results suggest that factors such as the presence of host plants, organic matter, and nutrient availability may significantly influence the presence of rhizobia in the soil of the studied region.

Keywords: CFU; Cuando Cubango; Morphophysiological Diversity; Physicochemical Parameters; Rhizobia.

Resumo: A diversidade e a densidade de rizóbios no solo influenciam diretamente a fertilidade e a produtividade agrícola, sendo determinantes para a sustentabilidade dos sistemas agroecológicos. Este estudo, realizado entre setembro de 2024 á maio de 2025, teve como objetivo avaliar a correlação entre parâmetros físico-químicos do solo (pH, humidade e condutividade elétrica) e a densidade e diversidade morfofisiológica de rizóbios em solos da província do Cuando Cubango. Amostras de solo foram coletadas nos municípios de Cuchi, Menongue e Cuito Cuanavale, e submetidas ao isolamento de rizóbios em meio YMA. As

colônias obtidas foram caracterizadas morfologicamente e testadas quanto à alteração de pH com azul de bromotimol e coloração de Gram. Também foram determinados os parâmetros físico-químicos dos solos. Foram isoladas 36 colônias: 18 de Cuchi, 9 de Menongue e 9 de Cuito Cuanavale. Com base na análise de similaridade morfológica, 33,3% dos isolados assemelharam-se ao gênero Rhizobium, 33,3% a Bradyrhizobium, 5,5% a Mesorhizobium, 8,3% a Azorhizobium e 8,3% a Paenibacillus polymyxa. Houve correlação forte entre humidade e condutividade elétrica ($r = 0,85$; $p < 0,001$), mas a densidade microbiana apresentou correlações fracas com pH, humidade e condutividade. Observou-se correlação moderada e negativa entre número de colônias e pH ($r = –0,44$; $p = 0,01$). Os resultados sugerem que factores como presença de plantas hospedeiras, matéria orgânica e disponibilidade de nutrientes podem influenciar mais significativamente a presença de rizóbios no solo da região estudada.

Palavras-chave: Cuando Cubango; Diversidade Morfofisiológica; Parâmetros Físico-Químicos; Rizóbios; UFC.

Resumen: La diversidad y la densidad de rizobios en el suelo influyen directamente en la fertilidad y la productividad agrícola y son determinantes para la sostenibilidad de los sistemas agroecológicos. Este estudio, realizado entre septiembre de 2024 y mayo de 2025, tuvo como objetivo evaluar la correlación entre los parámetros fisicoquímicos del suelo (pH, humedad y conductividad eléctrica) y la densidad y diversidad morfofisiológica de rizobios en suelos de la provincia de Cuando Cubango. Se recolectaron muestras de suelo en los municipios de Cuchi, Menongue y Cuito Cuanavale, y se sometieron al aislamiento de rizobios en medio YMA. Las colonias obtenidas se caracterizaron morfológicamente y se evaluaron en cuanto a la alteración del pH con azul de bromotimol y tinción de Gram. También se determinaron los parámetros fisicoquímicos de los suelos. Se aislaron 36 colonias: 18 de Cuchi, 9 de Menongue y 9 de Cuito Cuanavale. Con base en el análisis de similitud morfológica, el 33,3% de los aislados se asemejó al género Rhizobium, el 33,3% a Bradyrhizobium, el 5,5% a Mesorhizobium, el 8,3% a Azorhizobium y el 8,3% a Paenibacillus polymyxa. Hubo una fuerte correlación entre la humedad y la conductividad eléctrica ($r = 0,85$; $p < 0,001$), pero la densidad microbiana presentó correlaciones débiles con el pH, la humedad y la conductividad. Se observó una correlación moderada y negativa entre el número de colonias y el pH ($r = –0,44$; $p = 0,01$). Los resultados sugieren que factores como la presencia de plantas hospederas, la materia orgánica y la disponibilidad de nutrientes pueden influir más significativamente en la presencia de rizobios en el suelo de la región estudiada.

Palabras clave: Cuando Cubango; Diversidad Morfofisiológica; Parámetros Fisicoquímicos; Rizobios; UFC.

1. Introduction

Biological nitrogen fixation (BNF) plays a crucial role in sustainable agriculture, especially in tropical regions. Rhizobia, symbiotic bacteria of legumes, promote this fixation and contribute to soil fertility. This study investigates the diversity of these microorganisms and their relationship with edaphic variables in Cuando Cubango Province, a region that remains little studied from a microbiological perspective. The growing demand for sustainable alternatives in agriculture has intensified studies on beneficial soil microorganisms, especially

rhizobia, because of their ability to perform biological nitrogen fixation (BNF) in symbiosis with legumes. BNF is considered one of the most relevant ecological processes in terrestrial ecosystems and is mediated mainly by bacteria of the genus Rhizobium and other legume-symbiotic bacteria collectively known as rhizobia. These microorganisms are fundamental to soil sustainability because they convert atmospheric nitrogen (N_2) into forms that plants can assimilate, directly contributing to agricultural productivity, particularly in tropical and subtropical regions (Hungria et al., 2022).

In addition to promoting plant nutrition, rhizobia actively participate in nutrient cycling, help increase soil fertility, and reduce dependence on industrial nitrogen fertilizers, thereby promoting more efficient and less polluting agriculture (Bhattacharjee et al., 2022). The diversity and activity of these microorganisms are influenced by edaphic factors such as pH, texture, organic matter, moisture, and electrical conductivity, as well as by management practices. Therefore, the morphophysiological characterization of rhizobia together with the analysis of soil physicochemical parameters is essential to understand soil–microorganism interactions, identify efficient strains, and develop strategies for their agronomic application (Zilli et al., 2023).

In this context, Cuando Cubango Province, located in southeastern Angola, stands out for its great ecological diversity, soils of varied composition, and dry tropical climate. Despite its environmental importance, the region has been little studied from a microbiological perspective, particularly regarding the diversity of native rhizobia. Investigating these microorganisms in environments with little anthropogenic intervention may reveal strains adapted to local edaphoclimatic conditions, with potential for the development of regional biofertilizers. Thus, the general objective of this work is to evaluate the correlation between soil physicochemical parameters (pH, moisture, and electrical conductivity) and the density and morphophysiological diversity of rhizobia in soils of Cuando Cubango Province.
Research field: Soil microbiology

Study rationale

The study of diazotrophic microorganisms is very important, especially in agricultural soils or soils with the potential to improve biological nitrogen fixation, which contributes to increased soil fertility and agricultural sustainability. Understanding how soil physicochemical characteristics (pH, moisture, and electrical conductivity) influence the diversity and distribution of these microorganisms is crucial for developing management strategies adapted

to local conditions. In the provinces of Cuando and Cubango, where agricultural practices are limited by low soil fertility, knowledge about rhizobia may also contribute to selecting more efficient symbiotic legumes adapted to these conditions, promoting soil recovery and productivity. Moreover, this study provides an initial basis for future research, including molecular analyses and agricultural biotechnology strategies aimed at producing biofertilizers.

Objectives

General Objective

- To evaluate the correlation of soil physicochemical parameters (pH, moisture, and electrical conductivity) with the density and morphophysiological diversity of rhizobia in soils from three municipalities of Cuando Cubango Province.

Specific Objectives

1. To isolate rhizobium-type diazotrophic bacteria from soil samples from Cuando Cubango.
2. To identify the possible rhizobial genera found in the soil samples based on the characteristics obtained.
3. To correlate soil physicochemical parameters (pH, electrical conductivity, and moisture) with microbial density (CFU) in the different soil samples.

2. Theoretical Framework

2.1 Biological nitrogen fixation

Biological nitrogen fixation (BNF) is one of the most important ecological processes in terrestrial ecosystems and is mediated mainly by bacteria of the genus Rhizobium and other legume-symbiotic bacteria, collectively known as rhizobia.

Rhizobia are soil bacteria capable of establishing symbiosis with leguminous plants, forming root nodules in which atmospheric nitrogen is biologically fixed into forms that plants can assimilate. This process is essential for nitrogen cycling in natural and agricultural ecosystems, especially in tropical soils characterized by low availability of this nutrient (Hungria & Vargas, 2000).

These microorganisms play an essential role in soil sustainability by converting atmospheric nitrogen (N_2) into forms that plants can assimilate, contributing significantly to agricultural productivity, especially in tropical and subtropical regions (Hungria et al., 2022).

The agronomic importance of BNF is evident in tropical agricultural systems, where soils are naturally poor in nitrogen. The adoption of legume crops inoculated with efficient rhizobial strains can provide productivity gains and improve soil quality by increasing organic matter content and favoring beneficial microbial activity (Moreira and Siqueira, 2021). Thus, BNF is an ally in sustainable soil management.

The contribution of BNF arising from the association of plants and diazotrophic bacteria is the most significant process for adding nitrogen to terrestrial ecosystems, and nitrogen-fixing microorganisms are used in agriculture, especially in soybean cultivation. The inoculation of plants with nitrogen-fixing bacteria has the potential to become a technique applicable to plant systems under water deficit, low fertility, or both conditions.

This may be possible because, in addition to BNF, diazotrophic bacteria can provide other benefits. These microorganisms can act as plant growth-promoting rhizobacteria (PGPR), particularly through the production of plant hormones such as auxins, gibberellins, and cytokinins, and can also act in phosphate solubilization (Bazzicalupo and Okon, 2000).

2.2. Soil physicochemical parameters

Soil physicochemical parameters, such as pH, texture, organic matter content, cation exchange capacity, and nutrient availability, strongly influence the survival, distribution, and diversity of rhizobia. Soil pH, in particular, is considered one of the most decisive factors because it directly affects bacterial growth and nodulation efficiency (Fageria & Baligar, 2008).

2.3. Agronomic applications of rhizobial diversity

Understanding the morphophysiological diversity of rhizobia in relation to soil physicochemical properties is essential for developing bacterial inoculants adapted to local conditions, which may increase nitrogen-fixation efficiency in cultivated legumes.

Strains adapted to local conditions tend to show greater symbiotic efficiency, contributing to increased legume productivity and the sustainability of agricultural systems (Hungria et al., 2013).

In addition to its agronomic importance, conserving rhizobial diversity is environmentally relevant because these microorganisms actively help maintain soil fertility and reduce the environmental impact caused by the excessive use of chemical fertilizers. Therefore, studies of soils from Cuando and Cubango are strategic for developing sustainable agricultural practices adapted to local conditions (Peoples et al., 2009).

3. Materials and Methods

The investigation was carried out in the Department of Plant Production and Protection of the Faculty of Agricultural Sciences (FCA), José Eduardo dos Santos University (UJES), and comprised two main phases: a field stage dedicated to collecting soil samples and a laboratory stage focused on sample processing and analysis.

Soil samples were collected in the municipalities of Menongue, Cuchi, and Cuito Cuanavale, which previously belonged to Cuando Cubango and, after the territorial restructuring of January 2025, were redistributed between the new provinces of Cuando and Cubango. Area selection followed the objectives of the SASSCAL 2.0 Project, which prioritizes the study of Ferralsols and Arenosols, both widely represented in the region. Local edaphic variability, associated with different environmental conditions, favors an integrated analysis of the soil microbiota and its correlation with physical and chemical attributes.

The sampling points were georeferenced using GPS and the WGS 84 reference system (EPSG:4326). The coordinates obtained made it possible to prepare the location map of the study area. The region's edaphoclimatic conditions—a dry to subhumid tropical climate, average temperatures between 20 °C and 25 °C, and annual rainfall ranging from 600 mm to 1,200 mm—directly influence microbiota composition. The region's soils, predominantly Oxisols and Quartz Sands, are characterized by low natural fertility, high acidity, and sandy texture (FAO, 2004; Instituto Geográfico e Cadastral de Angola, 2013).

Sample collection followed the protocol of Silva et al. (2020), with soil removed from the 0–20 cm layer in areas with a history of legume cultivation. The soil was placed in sterile plastic bags, stored in coolers with ice, and maintained at 4–8 °C until it reached the laboratory, thereby ensuring microbial viability.

At the FCA/UJES Soil Microbiology Laboratory, samples underwent physicochemical and microbiological analyses. The physicochemical analyses followed the methods described by Teixeira et al. (2017) and Embrapa (2017), covering pH (1:2 suspension in distilled water, measured with a digital pH meter), electrical conductivity (the same suspension, measured with

a digital conductivity meter), and moisture content (gravimetric method according to Gee and Bauder, 1986).

Gravimetric moisture content (U) was calculated using the following formula:

$$U\% = ((Ww - Wd) / Wd) \times 100$$

Where:

U% = Soil moisture percentage;

Ww = Wet weight of the soil sample (g);

Wd = Dry weight of the soil sample (g).



Figure 1: Equipment used to obtain the physicochemical parameter results: pH meter, oven, and conductivity meter.

Source: Prepared by the authors (2024).

Microbiological analyses included the selective isolation of rhizobia on YMA medium with Congo red, according to Vincent (1970). Samples underwent serial dilutions (10^{-1} to 10^{-8}) in sterile saline solution (0.85% NaCl), and 0.1 mL aliquots were spread onto Petri dishes and incubated at 28 ± 2 °C for 3 to 5 days. Colonies with typical morphology were selected and subcultured to obtain pure cultures.

Bacteria were quantified as Colony-Forming Units per gram of dry soil ($CFU.g^{-1}$), considering plates containing 30 to 300 colonies. Values were $\log_{10}$-transformed and used in statistical analyses. Morphophysiological characterization followed the Embrapa (2011) protocol, evaluating shape, color, elevation, consistency, brightness, and acid/alkaline metabolism in medium containing bromothymol blue. Gram staining was used as a preliminary identification criterion, considering that rhizobia are Gram-negative.



Figure 2: Selective isolation of rhizobia from soil in the laboratory under aseptic conditions.
Source: Prepared by the authors (2024).

Preliminary assignment of the bacterial genus was carried out according to Brenner et al. (2005), integrating morphology, physiology, and Gram staining. The data obtained were organized in individual evaluation forms and subjected to statistical analysis. The relative frequency of genus occurrence was calculated, and Pearson's correlation test (5% significance level) was applied to verify relationships between physicochemical parameters (pH, electrical conductivity, and moisture) and rhizobial density ($CFU.g^{-1}$, $\log_{10}$), using IBM SPSS Statistics version 25.0.

4. Results and Discussion

Thirty-six viable rhizobial colonies were isolated from soil samples collected in the three municipalities studied: 18 isolates from Cuchi, 9 from Menongue, and 9 from Cuito Cuanavale. The predominance of isolates in Cuchi may be related to edaphic conditions that are more favorable to bacterial survival and proliferation, such as a pH close to neutrality and lower salinity, which favor microbial activity (Moreira & Siqueira, 2006; Alcobia, 2024).

Morphophysiological characterization revealed broad phenotypic diversity among the isolates. Colonies showed different shapes, elevations, opacities, mucus production, and growth times, with consistent variations among municipalities. In Cuchi, predominantly translucent and mucoid colonies with rapid growth were observed, whereas opaque, slow-growing colonies with lower mucus production stood out in Menongue and Cuito Cuanavale. These differences may be associated with the diversity of soil microenvironments and local adaptation of bacterial populations (Zilli et al., 2023; Silva, 2023).

Gram staining indicated that 92% of the isolates were Gram-negative, as expected for typical rhizobia, whereas 8% were Gram-positive, especially Paenibacillus polymyxa, which is recognized for its potential as a plant growth-promoting bacterium (PGPB) despite not forming symbiotic nodules (Cunha, 2023; Bhattacharjee, 2022).

Metabolic assessment on YMA medium with bromothymol blue revealed that 58.2% of the isolates acidified the medium, changing it to the characteristic yellow color associated with the production of organic acids by Rhizobium and Mesorhizobium strains (Cardoso, 2022). The remaining isolates maintained the blue coloration, indicating an alkaline reaction associated with Bradyrhizobium and Azorhizobium, which produce basic nitrogen compounds (Oliveira, 2021).

Genus assignment based on morphological and physiological characteristics and Gram staining identified 28% of isolates as belonging to the genus Rhizobium, 61% to Bradyrhizobium, and 11% to P. polymyxa. The others could not be classified accurately, suggesting the presence of undescribed strains or strains with atypical profiles (Silva, 2023; Brenner, 2005). The predominance of Bradyrhizobium in Cuito Cuanavale confirms its adaptation to more acidic soils, as reported by Oliveira (2021) and Santos (2023).

Colony-forming unit counts ($CFU.g^{-1}$) ranged from 3.778 to 8.623 (log_{10}), indicating high microbial density in Figure 1. The highest values were observed in Cuchi, consistent with its lower acidity and low electrical conductivity. These results reflect soils with biological potential favorable to rhizobial activity (Moreira & Siqueira, 2006; Silva, M.C. et al., 2020).

The physicochemical parameters of the soils showed pH values between 5.77 and 6.8, with values closer to neutrality in Cuchi. Electrical conductivity (EC) was highest in Cuito Cuanavale (1.114 dS/m), indicating higher salinity, whereas values in Menongue and Cuchi remained below 0.1 dS/m. Moisture varied widely among municipalities: Cuito showed extreme values (up to 66.6%), while Cuchi and Menongue recorded levels between 2% and 8%. The high acidity and salinity in Cuito may explain the lower density of rhizobia in that municipality (Cunha, 2023; Santos, 2023).

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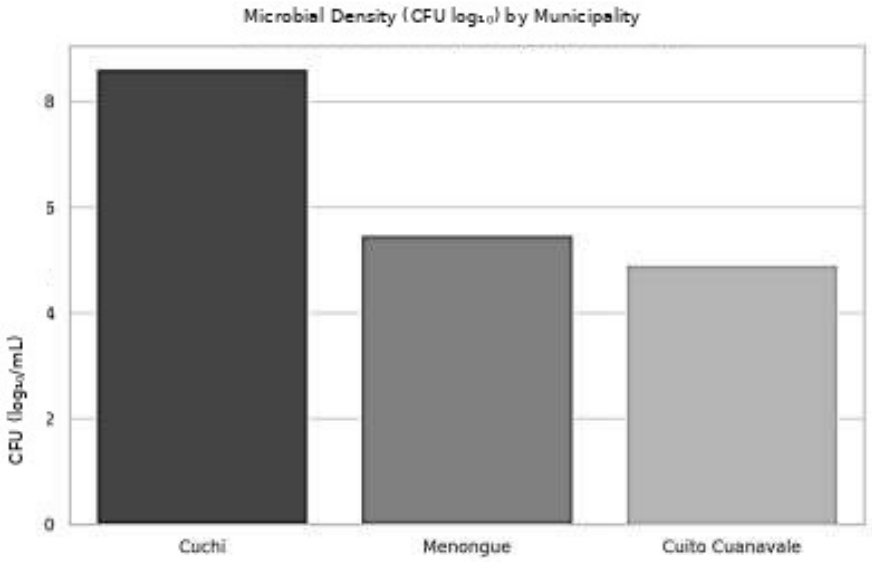

Figure 3: Microbial density (CFU $\log_{10}$) by municipality.
Source: Prepared by the authors (2024).

Table 1 presents Pearson's correlation coefficients between soil physicochemical parameters and rhizobial density. The analysis revealed a moderate negative correlation between pH and number of colonies ($r = –0.44$; $p = 0.01$), as illustrated in Figure 2. This result agrees with studies indicating greater rhizobial activity in slightly acidic soils (Oliveira et al., 2021).

Table 1: Pearson correlation matrix between edaphic variables and rhizobial density (CFU/$\log_{10}$CFU).

Variables	**No. of colonies**	**Log_{10}(CFU/mL)**	**pH**	**Conductivity**	**Moisture**
No. of colonies	1.00	0.06	0.01	0.94	0.68
Log_{10}(CFU/mL)	–0.32	1.00	0.72	0.59	0.52
pH	–0.44	–0.06	1.00	0.05	0.01
Conductivity	0.01	0.09	–0.33	1.00	8.2×10^{-11}
Moisture	0.07	0.11	–0.44	0.85	1.00

Source: Prepared by the authors (2024).

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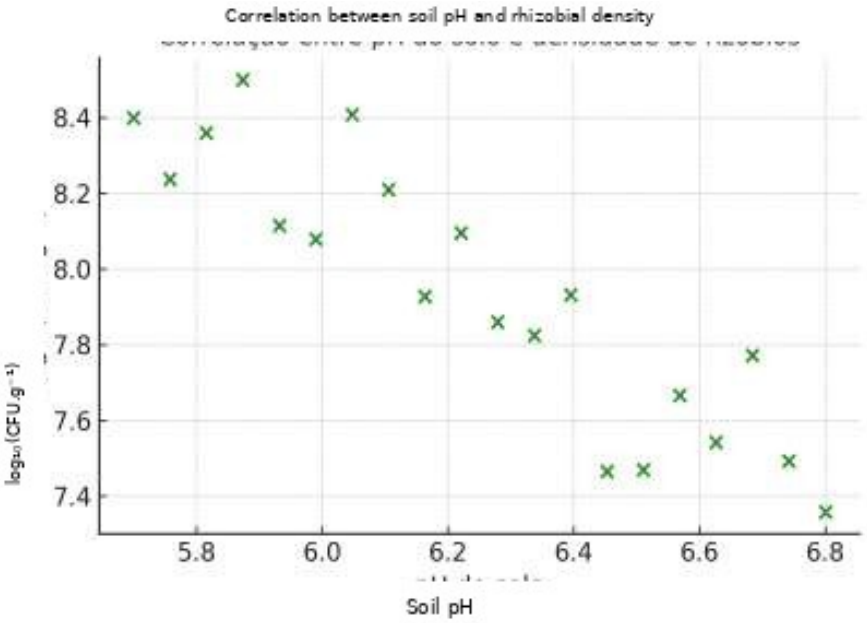

Figure 4: Correlation between soil pH and rhizobial density, expressed as $\log_{10}(CFU.g^{-1})$. A negative trend is observed between the variables, with r = –0.44 (p = 0.01), indicating that slightly more acidic soils favor the presence of rhizobia.

Source: Prepared by the authors (2024).

Correlations between CFU and EC or moisture were weak, suggesting that these factors alone do not explain the variability in microbial density. This result reinforces the idea that rhizobial density is influenced by a combination of factors, including not only soil physicochemical parameters but also biotic aspects, such as the presence of host plants, the quality of organic matter, and interactions with other microbial populations (Silva, 2022; Alcobia, 2024). In addition, spatial and temporal variations in the soil microenvironment can significantly affect the distribution and activity of these microorganisms, making it difficult to attribute direct causality to a single edaphic factor.

On the other hand, a strong positive correlation was observed between EC and moisture ($r = 0.85$; $p < 0.001$), demonstrating the combined influence of these parameters on the soil microenvironment. These results indicate that soil electrical conductivity, often associated with the concentration of soluble salts, is closely linked to water availability in the edaphic environment. Studies of tropical soils have shown that apparent EC (ECa) tends to increase together with moisture content because of ion mobility in the presence of water (Costa et al., 2014). This mechanism suggests that wetter soils show greater solubilization of nutrients and salts, creating favorable conditions for microbial activity in general, although this does not necessarily translate into increased rhizobial density. Therefore, the strong correlation observed between EC and moisture reinforces the importance of considering the joint dynamics of these

factors when evaluating soil microbiological fertility and its potential to sustain functional rhizobial communities.

5. Final Considerations

The results of this study demonstrated significant rhizobial diversity in the soils of Cuando Cubango Province, with a predominance of the genera Rhizobium and Bradyrhizobium, as well as the presence of strains of Paenibacillus polymyxa. The identification of isolates not assigned to known genera indicates the possible occurrence of native strains that remain little explored and have biotechnological potential.

Statistical analysis revealed that the physicochemical parameters evaluated (pH, electrical conductivity, and moisture) showed weak or moderate correlation with rhizobial density, suggesting that these factors alone do not determine the distribution and abundance of these bacteria in the soil. The negative correlation between pH and CFU reinforces the sensitivity of rhizobia to variations in soil acidity, although not exclusively.

It is therefore concluded that biotic factors, such as the presence of host plants, organic matter composition, and local microbial interactions, play a more relevant role in structuring rhizobial communities. These findings reinforce the importance of considering soil ecology in an integrated manner, especially when selecting promising strains for inoculation programs and use in sustainable agricultural systems adapted to local conditions in Angola.

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References

ALCOBIA, V. F. Relação da qualidade química e biológica do solo com a produtividade do milho: sementeira direta vs. mobilização convencional. 2024. Dissertação (Mestrado em Agronomia) – Instituto Superior de Agronomia, Universidade de Lisboa, Lisboa, 2024. Disponível em: http://hdl.handle.net/10400.5/98643. Acesso em: 20 abr. 2024.

ANGOLA PRESS (ANGOP). Notícias sobre desenvolvimento socioeconômico no Cuando Cubango. Luanda, 2021–2022. Disponível em: https://www.angop.ao. Acesso em: 20 abr. 2024.

BAZZICALUPO, M.; OKON, Y. Associative and endophytic symbiosis. In: PEDROSA, F. O. et al. (ed.). Nitrogen fixation: from molecules to crop productivity. Dordrecht: Kluwer Academic Publishers, 2000.

BHATTACHARJEE, R. B. Biological nitrogen fixation and its relevance to sustainable agriculture. In: Environmental Sustainability. [S.l.]: Springer, 2022. p. 85–96. DOI: https://doi.org/10.1007/s42398-021-00197-9.

BRENNER, D. J.; KRIEG, N. R.; STALEY, J. T. (ed.). Bergey's manual of systematic bacteriology. 2. ed. New York: Springer, 2005. v. 2: The Proteobacteria, Part C: The Alpha-, Beta-, Delta-, and Epsilonproteobacteria. DOI: https://doi.org/10.1007/0-387-29298-5.

COSTA, F. G.; SOUZA, E. R.; SILVA, J. B. da. Relação entre condutividade elétrica aparente e umidade do solo em diferentes sistemas de cultivo. Revista Brasileira de Ciência do Solo, v. 38, n. 5, p. 1485–1494, 2014. DOI: https://doi.org/10.1590/S0100-06832014000500023.

CUNHA, A. L. da. Efeitos de fatores edáficos na distribuição de rizóbios em solos tropicais. 2023. Dissertação (Mestrado) – Universidade Federal de Lavras, Lavras, 2023.

CUNHA, F. F. Rizobactérias promotoras de crescimento vegetal em ambientes de estresse hídrico e salino: potencial e aplicações. Revista de Ciências Agrárias, p. 341–352, 2023.

EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA (EMBRAPA). Protocolo de caracterização morfofisiológica de estirpes de rizóbios. Brasília, DF: Embrapa, 2011. Disponível em: https://www.embrapa.br. Acesso em: 20 abr. 2024.

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS (FAO). Agro-ecological zoning guidelines. Rome: FAO, 2004.

FAGERIA, N. K.; BALIGAR, V. C. Ameliorating soil acidity of tropical oxisols by liming for sustainable crop production. Advances in Agronomy, v. 99, p. 345–399, 2008. DOI: https://doi.org/10.1016/S0065-2113(08)00407-0.

GEE, G. W.; BAUDER, J. W. Particle-size analysis. In: KLUTE, A. (ed.). Methods of soil analysis. Part 1: Physical and mineralogical methods. 2. ed. Madison: American Society of Agronomy; Soil Science Society of America, 1986. p. 383–411. DOI: https://doi.org/10.2136/sssabookser5.1.2ed.c15.

HUNGRIA, M. et al. Biological nitrogen fixation: recent advances and future challenges in the context of climate change. Soil Biology and Biochemistry, 2022. Art. 104594.

HUNGRIA, M.; VARGAS, M. A. T. Environmental factors affecting N_2 fixation in grain legumes in the tropics. Field Crops Research, v. 65, n. 2–3, p. 151–164, 2000. DOI: https://doi.org/10.1016/S0378-4290(99)00084-2.

INSTITUTO GEOGRÁFICO E CADASTRAL DE ANGOLA (IGCA). Atlas geográfico de Angola. Luanda: IGCA, 2013.

KLOEPPER, J. W.; SCHROTH, M. N. Plant growth-promoting rhizobacteria on radishes. In: PROCEEDINGS OF THE 4TH INTERNATIONAL CONFERENCE ON PLANT PATHOGENIC BACTERIA. [S.l.], 1981.

MOREIRA, F. M. S.; SIQUEIRA, J. O. Microbiologia e bioquímica do solo. 2. ed. Lavras: UFLA, 2006.

MOREIRA, F. M. S.; SIQUEIRA, J. O. Microbiologia e bioquímica do solo. 3. ed. Lavras: UFLA, 2021.

OLIVEIRA, C. S. Functional and taxonomic diversity of rhizobial communities under different pH soil conditions. Applied Soil Ecology, v. 164, 2021.

PEOPLES, M. B. et al. The contributions of nitrogen-fixing crop legumes to the productivity of agricultural systems. Symbiosis, v. 48, p. 1–17, 2009. DOI: https://doi.org/10.1007/BF03179980.

SANTOS, M. R. dos. Caracterização de comunidades microbianas em ambientes com diferentes níveis de acidez. 2023. Tese (Doutorado) – Universidade Federal do Ceará, Fortaleza, 2023.

SILVA, A. P. Rizobactérias e sua influência na disponibilidade de nutrientes e sustentabilidade agrícola. Revista Verde de Agroecologia e Desenvolvimento Sustentável, 2022.

SILVA, J. F. Unidentified rhizobial strains in tropical soils: a reservoir of novel symbiotic genes. Archives of Microbiology, v. 205, 2023.

SILVA, M. C.; PEREIRA, M. G.; SOUZA, I. F. Coleta e preparo de amostras de solo para análise microbiológica. Revista Brasileira de Ciência do Solo, 2020. DOI: https://doi.org/10.36783/18069657rbcs20190187.

TEIXEIRA, P. C.; DONAGEMMA, G. K.; FONTANA, A.; TEIXEIRA, W. G. Manual de métodos de análise de solo. 3. ed. Brasília, DF: Embrapa, 2017.

VINCENT, J. M. A manual for the practical study of root-nodule bacteria. Oxford: Blackwell Scientific Publications, 1970. (International Biological Programme Handbook, n. 15).

ZILLI, J. E. Rhizobia-legume symbiosis under changing environmental conditions: a Brazilian perspective. Agriculture, Ecosystems & Environment, v. 355, art. 108550, 2023. DOI: https://doi.org/10.1016/j.agee.2023.108550.