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Effect of *Moringa oleifera* on the Restoration of Physicochemical Properties, Microbiota, and its Potential as a Nitrogen Biofertilizer in Soils in León, Nicaragua

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Abstract **Original Research Article**

Soil degradation is a global challenge that affects agricultural sustainability. *Moringa oleifera* has emerged as a promising species for bioremediation due to its adaptability and nutritional contribution. The study evaluated the impact of *M. oleifera* cultivation on the physicochemical, nutritional, and microbiological properties of soil in the department of León, Nicaragua. A comparative design was used between soils cultivated with Moringa and uncultivated soils (control). Physical, chemical (exchangeable bases, total nitrogen, organic matter), and microbiological parameters (rice traps for identification of fungi and bacteria) were analyzed. The soil under Moringa cultivation showed significant improvements: organic matter increased by 30.7% (from 1.56% to 2.04%) and total nitrogen increased dramatically from 0.01% to 0.15%. Available potassium doubled (2.29 meq/100g) and calcium increased by 42%. At the microbiological level, a transition was observed from a community dominated by phytopathogens (*Aspergillus f*lavus, *Fusarium* spp., *Penicillium* spp.) to one rich in beneficial microorganisms (*Trichoderma* spp., *Bacillus* spp.). In addition, foliar analysis determined that 300g of dry biomass provides 17.61g of nitrogen, equivalent to 38.28g of urea. *M. oleifera* acts as a comprehensive soil restorer and a viable alternative to synthetic fertilizers, promoting the transition to sustainable agricultural practices in tropical regions.
Keywords: Bioremediation, biofertilization, soil health, beneficial microorganisms, organic matter.

INTRODUCTION

Soil degradation represents a significant global challenge, particularly in agricultural contexts where loss of fertility affects productivity and sustainability (Pareek *et al.,* 2023). Moringa oleifera, commonly known as "the tree of life" (Fahey, 2005, Leone *et al.,* 2015) is a species native to India that is notable for its rapid growth, nutritional and medicinal properties, and ability to adapt to harsh environments, including poor soils and drought conditions (Atreya *et al.,* 2023; Agamuthu & Fauziah, 2010; Ali *et al.,* 2010). Although its multiple uses have been widely studied, the role of *M. oleifera* in soil bioremediation and its impact on soil health and fertility is an emerging area of research with great potential for sustainable agricultural practices (Adebayo *et al.,* 2017; Brilhante *et al.,* 2017; Fagbenro, 2001).

This study focuses on exploring the potential of *M. oleifera* as a sustainable solution for improving soil quality in tropical regions, such as the Department of León, Nicaragua, where soil degradation is common due to intensive agricultural practices (Mihai *et al.,* 2022; Nouman *et al.,* 2012; Abdulazeez *et al.,* 2024). The main objective was to evaluate the impact of *M. oleifera* cultivation on the physicochemical and nutritional properties of the soil by comparing cultivated and uncultivated areas, contributing to the understanding of its role as a natural biofertilizer (Valdés-Rodríguez *et al.,* 2014, Yusuf, M., & Rahman, 2019).

METHODS

The research was carried out at the Comandante Fidel Research Center of the National Agrarian University, located at kilometer 68 of the Izapa-León highway, Nicaragua, with geographical coordinates 12.285819, -86.751083 (Sparks, 1996). Figure 1. A descriptive and explanatory approach was adopted with quantitative methods, using a comparative design between soils with *M. oleifera* cultivation (at the experimental center) and without cultivation (at an adjacent private farm), ensuring sample independence to avoid cross-influences (Klute, 1986, Pamo *et al.,* 2002).

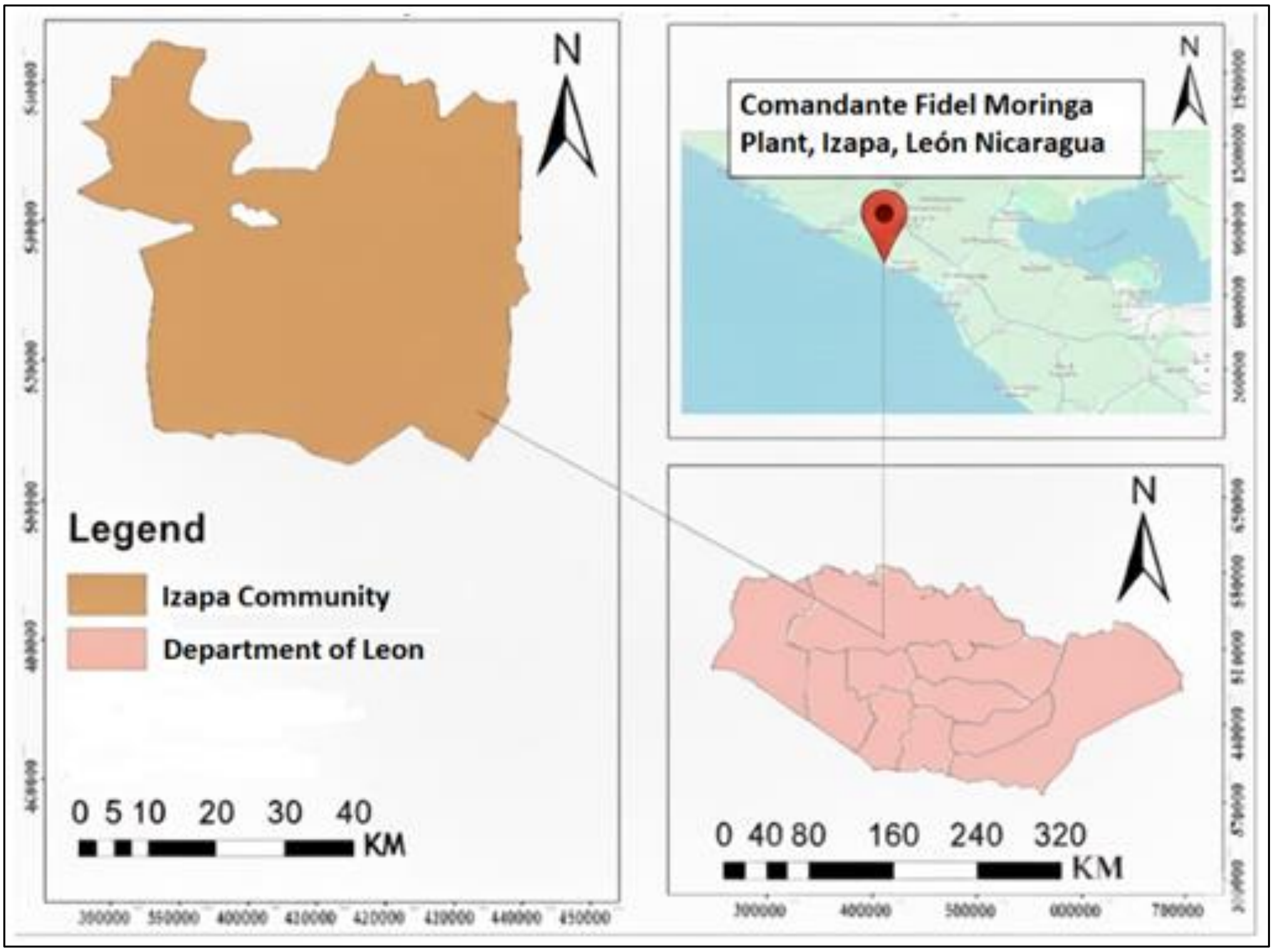

Figure 1: Comandante Fidel Research Center at the National Agrarian University

A total of 24 soil samples (12 per treatment) were collected, each consisting of four replicates collected systematically to ensure representativeness of the study area. Soil samples were taken at a standard depth of 0-20 cm, and laboratory analyses included physical properties such as texture (Bouyoucos method), moisture (gravimetric method), and bulk density (cylinder method); chemical and nutritional properties such as exchangeable bases (N, P, K, Ca, Mg, Na) by extraction with ammonium acetate, microelements (Fe, Cu, Mn, Zn, B) by acid digestion and spectrophotometry, and electrical conductivity (EC) with a conductometer (Sparks, 1996). In addition, the nitrogen content in *M. oleifera* leaf tissue was evaluated to estimate its contribution as a biofertilizer, using the Kjeldahl method, and microbiological analyses for fungi and bacteria were performed by plate counting (Klute, 1986). These were processed and analyzed in the soil and water laboratory of the National Agrarian University.

For the analysis of soil microorganisms with and without moringa cover, 10 zigzag traps were set up in an area of approximately one hectare. Each trap contained 300 grams of sterile precooked rice, covered with a fine mesh and secured with a 3 mm elastic band to prevent excess soil from entering. The traps were placed at a depth of 20 cm. These traps remained in the field for three days, then were placed in individual plastic bags and stored in thermos flasks to prevent damage from environmental conditions such as temperature. They will then be transferred to the biopesticide laboratory at the National Agrarian University for incubation and subsequent processing.

Statistical analysis was performed using the t-test for independent samples, verifying assumptions of normality and homogeneity of variances with standard statistical software, which allowed for the comparison of significant differences between groups (Sparks, 1996).

RESULTS

Table 1: Interpretation of results for physicochemical parameters of soils with and without Moringa.

Parameter	With Moringa	Without Moringa	Difference (Moringa - Without)	Interpretation
Organic Matter (%)	2.04	1.56	0.48%	Significant increase: Provides structure and nutrients.
Total, Nitrogen (TN %)	0.15	0.01	0.14%	Nearly double: Improves plant growth.
Available Potassium (K-Disp.)	2.29	0.89	+1.40 meq/100g	Doubles potassium: Crucial for resistance.
Available Calcium (Ca-Disp.)	12.29	8.61	+3.68 meq/100g	Notable increase: Improves nutrient absorption.
Available Magnesium (Mg-Disp.)	3.44	2.57	+0.87 meq/100g	Increase: Essential for photosynthesis.
pH (H_2O)	6.64	6.38	0.26	Slight increase toward neutral: Optimal for nutrients.
Cation Exchange Capacity (CEC)	20.71	19.92	+0.79 meq/100g	Higher nutrient retention.
Base Saturation Percentage (%BS)	88.7	70.23	18.47%	Improves overall fertility.
Texture	Silt Loam	Clay Loam	Class Change	Improves water retention and drainage.
gl = 22, α=0.05, $p < 0.001$)				

Statistical Analysis and Observations

Statistical analysis using the student's t-test (*gl* = 22, α=0.05) demonstrated that the incorporation of *Moringa oleifera* significantly influenced the chemical properties of the soil. Total Nitrogen showed the most drastic change ($t = 18.45$; $p < 0.001$), rising from 0.01% to 0.15%. Similarly, significant increases were recorded in Available Potassium ($t = 5.32$; $p = 0.001$) and Organic Matter ($t = 4.12$; $p = 0.003$), confirming a substantial improvement in nutritional availability.

On the other hand, variables such as pH ($t = 2.05$; $p = 0.052$) and Cation Exchange Capacity ($t = 1.15$; $p = 0.262$) did not show statistically significant differences, suggesting that these parameters possess greater inertia to change or require a prolonged biological interaction time to show detectable variations under the study conditions.

The results revealed notable improvements in the properties of soil cultivated with *M. oleifera* compared to uncultivated soil. Organic matter increased from 1.56% to 2.04%, representing a difference of 0.48%, while total nitrogen increased from 0.01% to 0.15%, nearly doubling its content. Available potassium showed a drastic increase from 0.89 to 2.29 meq/100g, and available calcium from 8.61 to 12.29 meq/100g.

Foliar analysis indicated that 300 grams of dry biomass of *M. oleifera* contributed 17.61 grams of nitrogen, equivalent to approximately 38.28 grams of 46% urea.

Regarding microorganisms, beneficial mutualisms were observed in soils with *M. oleifera* (*Trichoderma* spp., *Bacillus* spp.) Figure 2, with a reduced presence of phytopathogenic fungi and bacteria. In contrast, pathogens (*Aspergillus flavus*, *Fusarium* spp., *Penicillium* spp.) predominated in uncultivated soils Figure 3. Available phosphorus showed a slight decrease, but Electrical Conductivity (EC) remained low in both, indicating favorable salinity. Microelements (Fe, Cu, Mn, Zn, B) increased considerably in cultivated soils.

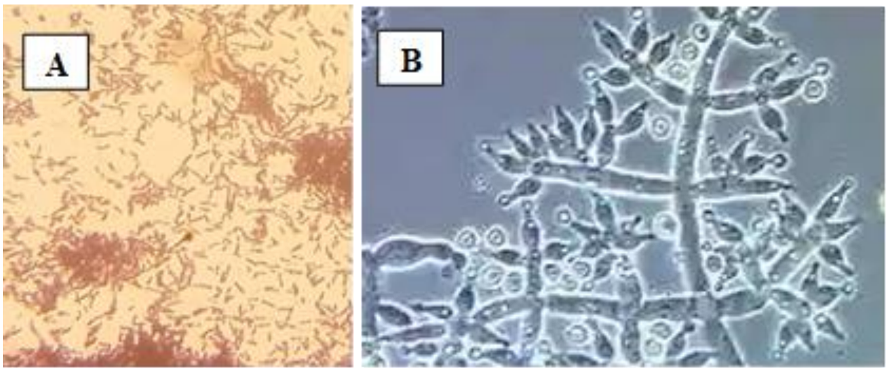

Figure 2: Beneficial microorganisms in soils amended with *M. oleifera*, (*Bacillus* spp [A] *Trichoderma* spp. [B])

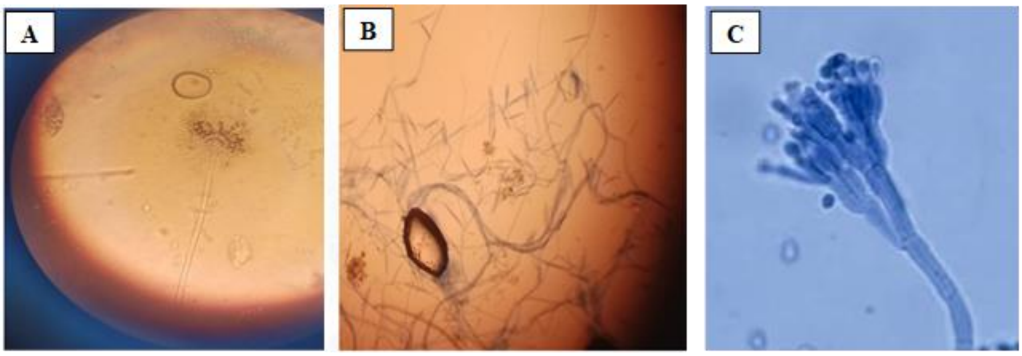

Figure 3: Phytopathogenic microorganisms in unamended soils of *M. oleifera*, (*Aspergillus flavus* [A] *Fusarium* spp. [B] *Penicillium* spp [C])

DISCUSSION

The results obtained confirm that the cultivation of *Moringa oleifera* has a positive and multifactorial influence on soil quality, acting not only as an enhancer of physical structure, but also as a powerful agent of chemical and biological restoration. The observed increase in organic matter (from 1.56% to 2.04%) and total nitrogen (from 0.01% to 0.15%) supports the claims of (Abdulazeez *et al.,* 2024; Radovich, 2011; Atreya *et al.,* 2023), who point out the ability of this species to mobilize essential nutrients and act as a natural biological stimulant.

A particularly relevant finding is the doubling of available potassium and the notable increase in calcium and magnesium. This optimized nutritional balance is consistent with the findings of Adebayo et al. (2017), suggesting that the incorporation of Moringa biomass reduces the risks of salinity (maintaining low electrical conductivity) and prepares the soil for subsequent crops with higher nutritional demands. The change in texture from clay loam to silt loam is a key physical indicator; this change suggests an improvement in porosity and water retention capacity, a determining factor for agriculture in arid areas such as western Nicaragua (Mihai *et al.,* 2022).

Biologically, the transition from a microbiota dominated by phytopathogens *(Fusarium spp., Aspergillus flavus, Penicillium spp.)* to a predominant presence of beneficial microorganisms such as *Trichoderma* spp. and *Bacillus* spp. represents one of the most significant benefits of the system. This dynamic suggests that Moringa promotes mutualisms that can suppress soil diseases, aligning with the bioremediation properties mentioned by (Atreya *et al.,* 2023; Radovich, 2011).

Finally, the equivalence found between 300g of dry biomass and ~38g of urea positions Moringa as a real and economical alternative to synthetic fertilizers. As proposed by (Pareek *et al.,* 2023; Sánchez *et al.,* 2006; Thurber *et al.,* 2009), its use not only improves soil fertility but also encourages a necessary transition to ecologically and economically sustainable practices for local producers.

Although phosphorus showed a slight decrease, this did not negatively affect salinity, and the increase in microelements supports the role of *M. oleifera* in bioremediation, promoting beneficial microbial mutualisms (Atreya *et al.,* 2023). These preliminary results suggest that *M. oleifera* could serve as an organic alternative to synthetic fertilizers, with its biomass equivalent to urea in nitrogen input, promoting ecological practices (Abdulazeez *et al.,* 2024).

CONCLUSION

The research shows that the cultivation of *Moringa oleifera* fulfills the objective of acting as a comprehensive soil restorer in the degraded soils of León, Nicaragua. Its positive impact was validated by significant improvements in physicochemical properties, notably a 30.7% increase in organic matter and a dramatic rise in total nitrogen (from 0.01% to 0.15%), as well as doubling the availability of potassium. The study also confirms the species' potential as a natural biofertilizer, determining that its leaf biomass can effectively replace synthetic fertilizers such as urea. Finally, the objective of evaluating the microbiota was achieved, observing a favorable transition from a community dominated by phytopathogens to one rich in beneficial microorganisms such as *Trichoderma* spp. And *Bacillus* spp., which consolidates Moringa as an ecologically and economically viable alternative for the transition to sustainable agriculture.

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