Revista Facultad de Ciencias Básicas
2023 enero - junio
Vol. 19(1) ISSN: 1900-4699 · e-ISSN: 2500-5316 ■ pp. 99-111
Editorial Neogranadina

DOI: https://doi.org/10.18359/rfcb.7364

Tithonia Diversifolia: Promising Species in the Recovery of Cattle Soils; "Santa Isabel" Farm, Sucre - Colombia*

María Fernanda Ruge Rojas[a] ■ Margarita Liliana Contreras Mejía[b] ■ Liliana Figueroa Del Castillo[c]

Abstract: In March 2020, on the "Santa Isabel" farm in Sincelejo, Sucre, with a land use history of over 15 years of cattle ranching, the potential of *Tithonia Diversifolia* was evaluated. Using the Leopold matrix, a value of -460 identified soil as the most impacted resource. Semi-structured interviews revealed significant information gaps within the local community regarding sustainable soil management. A physical and chemical diagnosis was conducted at the IGAC-Bogotá soil laboratory, selecting apparent density (1.65 g/cm^3), real density (2.51 g/cm^3), and porosity (34.05 %) as key soil quality indicators prone to compaction. Based on the results of the multi-criteria matrix, *Tithonia Diversifolia* was chosen as a sustainable alternative to evaluate two treatments over four months in situ: T1 (plant species alone) and T2 (plant species combined with a chemical amendment [lime] and organic fertilizer [stabilized manure]). The study found that in T2, bulk density decreased by 31.33 %, while porosity, field moisture, and PH increased by 53.23 %, 156.35 %, and 21.64 %, respectively. In T1, real density decreased by 8.03 %, and organic carbon content increased by 53.23 %. These results demonstrated the potential of *Tithonia Diversifolia* for rehabilitating soils susceptible to compaction, reducing degradation risks, and contributing to soil recarbonization strategies.

Keywords: Soil Quality Indicators; Compaction; Soil Recovery; Sustainable Livestock Farming; Degradation

Recibido: 2 7/05/2024 **Aceptado:** 07/11/2024 **Disponible en línea:** 26/12/2024

Cómo citar: M. F. Ruge Rojas, M. L. Contreras Mejía, y L. Figueroa Del Castillo, «Tithonia Diversifolia: una especie prometedora en la recuperación de suelos ganaderos. Finca "Santa Isabel", Sucre – Colombia», *Rev. Fac. Cienc. Básicas*, vol. 19, n.º 1, pp. 99–111, dic. 2024.

* Research article.

a Environmental Engineer. Universidad El Bosque, Bogotá, Colombia.
Email: mruger@unbosque.edu.co; ORCID: https://orcid.org/0009-0003-0285-9601

b Environmental Engineer. Universidad El Bosque, Bogotá, Colombia.
Email: mlcontrerasm@unbosque.edu.co; ORCID: https://orcid.org/0009-0007-8520-5388

c Master in Agricultural Sciences with emphasis on Soils and Water. Universidad El Bosque, Bogotá, Colombia.
Email: lfigueroac@unbosque.edu.co; ORCID: https://orcid.org/0000-0003-2326-6904

Tithonia Diversifolia: una especie prometedora en la recuperación de suelos ganaderos. Finca "Santa Isabel", Sucre – Colombia

Resumen: En marzo de 2020, en la finca "Santa Isabel" en Sincelejo, Sucre, con más de 15 años de uso del suelo para la ganadería, se evaluó el potencial de *Tithonia diversifolia*. Utilizando la matriz de Leopold, se identificó un valor de -460, lo que señaló al suelo como el recurso más impactado. Las entrevistas semiestructuradas revelaron importantes brechas de conocimiento en la comunidad local sobre la gestión sostenible del suelo. Se realizó un diagnóstico físico y químico en el laboratorio de suelos del IGAC-BOGOTÁ, seleccionando como indicadores clave de calidad del suelo la densidad aparente (1,65 g/cm^3), la densidad real (2,51 g/cm^3) y la porosidad (34,05 %), todos propensos a la compactación. Basándose en los resultados de la matriz multicriterio, se eligió *Tithonia diversifolia* como una alternativa sostenible para evaluar dos tratamientos durante cuatro meses in situ: T1 (la especie vegetal sola) y T2 (la especie vegetal combinada con una enmienda química [cal] y fertilizante orgánico [estiércol estabilizado]). El estudio encontró que en T2, la densidad aparente disminuyó en un 31,33 %, mientras que la porosidad, la humedad del suelo en campo y el pH aumentaron en un 53,23 %, 156,35 % y 21,64 %, respectivamente. En T1, la densidad real disminuyó un 8,03 % y el contenido de carbono orgánico aumentó en un 53,23 %. Estos resultados demuestran el potencial de *Tithonia Diversifolia* para rehabilitar suelos susceptibles a la compactación, reducir los riesgos de degradación y contribuir a las estrategias de recarbonización del suelo.

Palabras clave: indicadores de calidad del suelo; compactación; recuperación del suelo; ganadería sostenible; degradación

Tithonia Diversifolia: Uma Espécie Promissora na Recuperação de Solos de Pastagens. Fazenda "Santa Isabel" Sucre – Colômbia

Resumo: Em março de 2020, na fazenda "Santa Isabel" em Sincelejo, Sucre, com mais de 15 anos de uso do solo para pecuária, avaliou-se o potencial da *Tithonia diversifolia*. Utilizando a matriz de Leopold, identificou-se um valor de -460, indicando o solo como o recurso mais impactado. Entrevistas semiestruturadas revelaram lacunas significativas de conhecimento na comunidade local sobre a gestão sustentável do solo. Foi realizado um diagnóstico físico e químico no laboratório de solos do IGAC-Bogotá, selecionando como indicadores-chave de qualidade do solo a densidade aparente (1,65 g/cm^3), a densidade real (2,51 g/cm^3) e a porosidade (34,05 %), todos propensos à compactação. Baseando-se nos resultados da matriz multicritério, escolheu-se a *Tithonia diversifolia* como uma alternativa sustentável para avaliar dois tratamentos ao longo de quatro meses in situ: T1 (a espécie vegetal isolada) e T2 (a espécie vegetal combinada com uma emenda química [cal] e fertilizante orgânico [esterco estabilizado]). O estudo constatou que, no tratamento T2, a densidade aparente reduziu-se em 31,33 %, enquanto a porosidade, a umidade do solo em campo e o pH aumentaram em 53,23 %, 156,35 % e 21,64 %, respectivamente. No tratamento T1, a densidade real diminuiu 8,03 %, e o teor de carbono orgânico aumentou 53,23 %. Esses resultados demonstram o potencial da *Tithonia diversifolia* para reabilitar solos sujeitos à compactação, reduzir os riscos de degradação e contribuir para estratégias de recarbonização do solo.

Palavras-chave: indicadores de qualidade do solo; compactação; recuperação do solo; pecuária sustentável; degradação

Introduction

Livestock farming has been one of the most important economic activities both globally and in Colombia. According to FAO [1], it contributes to food security, nutrition, poverty alleviation, and economic growth. FEDEGAN's 2018–2022 roadmap [2] highlights that the agricultural sector contributes 6% to the national GDP, with livestock accounting for 1.4%. Livestock is the main agricultural activity in Colombia, in terms of annual production value, surpassing other sectors significantly: 2.1 times the poultry sector, 3 times the coffee sector, 3.1 times the flower sector, 4.4 times the pig sector, 5.3 times the banana sector, and 8 times the palm sector. Additionally, it generates 810,000 direct jobs, representing 6% national employment and 19% agricultural employment.

However, as noted by Etter and Zuluaga [3], livestock farming is one of the primary contributors to the environmental footprint. Despite, its socioeconomic benefits, its promotion, restriction, or exclusion must be analyzed within a sociological context. This necessitates exploring initiatives for transitioning towards environmental and productive sustainability, fostering sustainable practices and conserving natural ecosystems within productive landscapes.

Soil, as a vital component of the natural environment, is essential for biogeochemical cycles and biodiversity. Nevertheless, it has become one of the most vulnerable resources globally due to climate change and degradation. These phenomena alter soil quality through changes in its physical and chemical properties, such as organic matter, organic carbon, PH, bulk density, real density, and porosity. These alterations compromise the soil's natural functions and its ability to provide essential ecosystem services, such as carbon storage and retention, given that healthy soil stores more carbon than the atmosphere and vegetation combined [4].

By 2016, FAO and GTIS [5] reported that 33% of global soils were moderately to highly degraded due to erosion, salinization, compaction, acidification, and chemical contamination. These issues result from natural and anthropogenic factors that trigger processes leading to negative dynamics in soil properties [6]. Direct factors include natural elements like climate, water resources, soil characteristics, topography, and vegetation cover, as well as human activities related to land use and management [6].

A report on land degradation assessment [7], estimated that by 2015, 40% of Colombia's continental surface exhibited some degree of soil degradation due to erosion. Departments with over 70% of their area affected by erosion include Cesar, Caldas, Córdoba, Cundinamarca, Santander, La Guajira, Atlántico, Magdalena, Sucre, Tolima, Quindío, Huila, and Boyacá. The study area for this research, the department of Sucre, reflects these conditions. Contributing factors include climatic conditions, topography, and land-use changes, with the region's main economic activities centered around livestock, agriculture, commerce, and other services. Due to the high quality of its cattle, Sincelejo is known as the "Zebu Capital of Colombia," excelling in breeding, raising, and fattening cattle under favorable conditions for regional markets and, to a lesser extent, dairy farming.

Although, good livestock practices (GLP) were introduced in Colombia, with initial results observed in Sucre in 2009, and the Colombian Agricultural Institute (ICA) certifying the first livestock farm in the region by the end of 2014, no records exist of farms implementing management-focused best practices. This research is therefore pioneering, contributing strategies for optimizing sustainable resource management through soil recharacterization, as promoted by FAO [8].

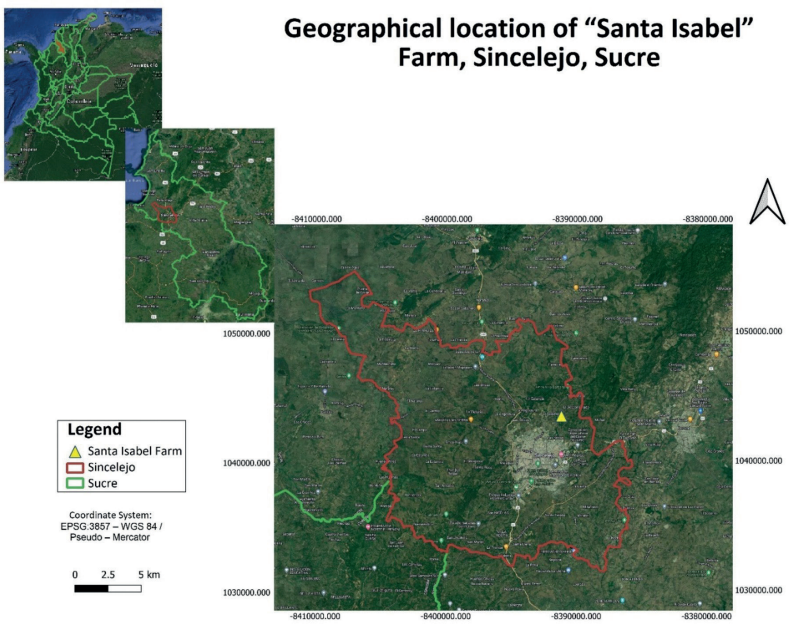
Silvia and Jaramillo [9] propose strategies to mitigate ecosystem damage by applying sustainable models such as the Silvopastoral System (SPS). This combined livestock-agriculture system enhances soil productivity through biological interactions. Contreras-Santos *et al. [*10] confirms that the global trend has been to explore alternatives that reduce soil, water, and air degradation while generating ecosystem services and enhancing the adaptability of agricultural and livestock production systems to climate change. Agroforestry systems (AFS) and silvopastoral systems (SPS), emerge as economically and environmentally viable solutions in the short and long term.

In line with these insights and Colombia's sustainable soil management policy [6], which underscores the importance of research into innovative soil recovery strategies, this study aims to determine the potential of *Tithonia Diversifolia as* a promising plant species for rehabilitating soils susceptible to compaction and subsequent degradation. The research was conducted on the "Santa Isabel" farm, located in the department of Sucre, Colombia, with a history of over 15 years of livestock activity.

Materials and Methods

1.1. Location: According to Figure 1, this study was conducted during the dry season in March 2021 on the "Santa Isabel" farm (indicated by a yellow triangle). The farm is located in Sincelejo (outlined in red), in the department of Sucre (outlined in green), Colombia. The study area spans 11 hectares in the Atenas neighborhood, with coordinates: latitude 9.33118, longitude -75.37915. This region is characterized by a warm, dry climate, with average annual rainfall ranging from 500 to 1200 millimeters. The average annual temperature is approximately 27.15 °C ± 0.4, with a minimum annual average of 19.7 °C and a maximum of 35.3 °C. The area also receives an average of 5 to 6 hours of sunlight per day, according to the Atlas of Solar, Ultraviolet, and Ozone Radiation of Colombia [11][12].

Figure 1. Geo-referencing of the "Santa Isabel" Farm



Source: Own elaboration.

Among the economic activities in the study area, livestock farming has been the most prominent over the past 15 years. This activity has been alternated with cassava and corn cultivation, which continue to be maintained today. The soils in the area predominantly belong to the Inceptisol order and have an agricultural-forestry vocation.

1.2. Diagnosis: Since the central focus of this research was to experimentally assess the potential of *Tithonia Diversifolia* as a promising plant species for recovering soils susceptible to compaction and potential future degradation on the "Santa Isabel" farm, the study considered the following factors: a diagnosis of the economic activities carried out over approximately 15 years, the management practices applied, and the current state of soil quality indicators. Based on these findings, in situ treatments using *Tithonia Diversifolia* were evaluated

through a multicriteria study as an alternative to improve soil conditions on the farm. The sequence of actions undertaken in the study was as follows:

1. **Semi-structured interviews** were conducted to understand how the soil resource has been managed. These interviews explored the history of land use, practices, and resource management, aligning with the knowledge outlined in the Sustainable Soil Management Policy [6].
2. **Evaluation of the Leopold matrix** was carried out to analyze social, economic, and ecological factors, allowing the prioritization of impacts on the resources within the study area.
3. **Soil sampling** was performed based on topographical differences, as shown in Figure 2. The zigzag sampling method was used, following the recommendations provided in the national soil sampling guide by the Agustín Codazzi Geographic Institute (IGAC) [13]. Subsequently, two homogenized soil samples were collected and sent to IGAC's national soil laboratory for analysis. The physical and chemical parameters assessed included texture, bulk density, real density, porosity, field moisture, PH, cation exchange capacity, and organic carbon. These soil properties were evaluated for their susceptibility to compaction, following methodologies proposed by authors such as Opala *et al.* [14].

Figure 2. Topographies of the terrain: hills (orange oval) and flat (yellow oval)

Source: Own elaboration.

1.3. Treatments: The treatments (T) were selected based on the protocols and findings of Opala *et al.* [15], prioritizing those that demonstrated superior results in improving key soil quality indicators to reduce soil susceptibility to compaction. These treatments were implemented in situ on flat terrain over a period of four months, as follows:

T1: *Tithonia diversifolia*

T2: *Tithonia Diversifolia* + decomposed manure + lime.

It is important to note that in T2, the manure used was sourced from cattle on the same farm, following a composting process that lasted four months. A total of 40 kg of composted manure was applied, based on the recommendations of García (pers. comm.). Additionally, the lime dosage was set at 1500 kg of agricultural lime per hectare, in accordance with the guidelines established in the SOPROCAL User Guide [16].

1.4. Final state of the soil resource: After identifying the indicators susceptible to soil compaction, a second physical and chemical analysis was conducted at the Agustín Codazzi Geographic Institute (IGAC) [13]. This analysis evaluated bulk density, real density, porosity, field moisture, PH, cation exchange capacity, and organic carbon, with the aim of assessing the effect of the plant species *Tithonia Diversifolia* on the analyzed soil.

Results, Analysis and Discussion

2.1. Semi-structured interviews and Leopold Matrix

The results of the semi-structured interviews helped identify and explore the underlying causes of soil degradation, rooted in a social reality such as, the lack of information regarding the sustainable management of soil resources.

As shown in Table 1, which corresponds to the analysis of the Leopold matrix, a total impact value of -744 was determined, indicating the unsustainability of all activities and actions on the farm. The abiotic environment was found to be the most affected, with a value of -1014. Additionally, it became clear that the most threatened resource was the soil, and the economic activity that generated the greatest impact was livestock farming, based on the sum of the weighted averages for this activity.

Table 1. Leopold Matrix of "Santa Isabel Farm" activities

| LEOPOLD MATRIX | | |

infiltration, and deep percolation within the farm, and indirectly through surface runoff toward pasture and crop areas [18].

Regarding the impact on the air resource, emissions from manure include odors, gases from anaerobic digestion and aerobic decomposition, and dust [19].

Focusing on the soil resource, it was identified that the tillage method used is traditional mechanized tillage, which led to the selection of certain soil quality indicators, such as moisture content. According to Bravo and *et al.* [20], moisture content is higher in systems that disturb the soil less. Apparent density, is also modified by any form of tillage, remaining unchanged only under a zero-tillage system. This tillage method alters the resistance to penetration, cutting in the arable layer, and soil structure, which in turn affects the growth and development of crops. Furthermore, the history of land use, which involved extensive livestock farming, shows the potential negative changes that can occur when the clay fraction exceeds the proportions of the other granulometric fractions, as seen in Table 2. This situation leads to increased susceptibility to soil compaction and future degradation, particularly with pasture establishment or cattle trampling, which reduces nutrient availability for plants and results in a loss of soil biodiversity.

Additionally, the biotic environment, encompassing both fauna and flora, was assessed, with potential future impacts from practices such as logging, overgrazing, fumigation, burning, and machinery use. These practices affect the habitat, continuity, and diversity of the landscape, and their consequences on the abiotic environment directly influence biodiversity, altering the ecosystem and its food sources [21].

Lastly, socioeconomic factors, including the coverage and quality of public services, were evaluated. It was evident that there is no provision of water supply, sewage, garbage collection, or electricity, and the road communication infrastructure is poor, with no paved roads.

2.2. Selection of land use quality indicators

Table 2 presents the comparative results of the soil samples from Zone 1 (flat topography), and Zone 2 (hilltopography), which were sent to the IGAC laboratory in 2021. The analysis was conducted using the following technique:

Table 2. Initial soil sampling results

Evaluated parameter	Technique	Zone 1	Zone 2
Texture	Bouyoucos-Densimetric Hydrometer	Clayey	Loamy-sandy-clay
Bulk density (g/cm³)	Paraffined lump	1.66	1.65
Real density (g/cm³)	Pycnometer	2.49	2.53
Total porosity (%)	Calculated by IGAC	33.33	34.78
Field humidity qg (%)	Gravimetric	11.96	12.92
pH (pH units)	Potentiometric in soil/water ratio 1:1	6.7	6.8
CIC (cmol/Kg)	Extraction with 1M ammonium acetate pH 7-volumetric, quantification by volumetry	47	27
Organic carbon (%)	Calculated by IGAC	1.59	1.57

Source: Own elaboration.

Based on the above, indicators such as real density, apparent density, and porosity showed a tendency towards soil compaction susceptibility in both types of topography. Apparent density values greater than 1.6 g/cm³ (high) were obtained, along with total porosity values below 40%, which IGAC [22] classifies as low. This impacts field moisture percentages, where values below 5-15% indicate low retention. These results are related to the soil texture, where the flat topography is clayey, which

increases its susceptibility, particularly due to the more than 15 years of livestock activity in the area.

Regarding the caption exchange capacity, there was a significant difference, with a value of 47 cmol/Kg in the flat topography, which was classified as high to very high. This indicates a greater capacity for nutrient retention. This is consistent with the PH values of both areas, which were categorized as neutral, reflecting a high content of Nitrate, Potassium, Phosphorus, Magnesium, Sulfur, Copper, and boron, and a low content of aluminum, calcium, Iron, Manganese, Molybdenum, and Zinc.

Finally, the percentage of organic carbon was classified at a medium level, which aligns with the type of climate. This parameter is important as it serves as an energy source for soil organisms, provides nutrients, stabilizes the structure, regulates gas exchange (Oxygen and CO_2), aeration, and moisture retention. It also helps prevent compaction and erosion [23].

It should be noted that while the study area has an agricultural and forestry vocation, it is currently being used primarily for crop production, with less focus on conservation. This has led to a land use conflict, centered on overexploitation of the resource, which directly impacts the environment. The soil has exceeded its carrying capacity, as evidenced by the apparent density, real density, and porosity values. These indicators were key to monitoring in order to prevent potential soil degradation in the future.

2.3. Plant species selection

Recognizing the potential of green manures, a multi-criteria matrix was developed. This tool includes a set of techniques that enable the evaluation of various alternatives based on multiple criteria and priorities [24]. It was used to consider ecological, economic, and social factors, ensuring a holistic perspective from the environmental engineer. Plant species with potential for recovering soils susceptible to compaction were selected, according to the state of the art (*Table* 3).

According to Ximena Hernández Arboleda's thesis, Master in Agricultural Sciences, UNAL, Palmira, 2023, it was found that buttercup (Ranunculus) promoted greater weight gain in cattle due to its high content of dry matter (30%) and protein (19%), surpassing corn in nutritional quality [25].

The plant species analyzed included Tithonia diversifolia, Canavalia brasiliensis, Brachiaria humidícola, Centrosema pubescens Benth, Dichiantum aristatum, and Pueraria phaseoloides. These were evaluated, and a value of 3 was assigned to those characteristics of the plant species that aligned with the needs and conditions of the study area.

Table 3. Multi-criteria matrix of species.

Description	Plant Species				
	Tithonia diversifolia	*Pueraria phaseoloides*	*Centrosema pubescens benth*	*Brachiaria humidicola*	*Canavalia brasiliensis*
Growing time	2	3	3	1	3
Altitudinal range	3	3	3	3	3
Frequency of irrigation	2	3	3	3	2
Weather	3	3	3	3	3
Soil conditions	3	2	2	3	3

Adaptation	3	2	3	3	3
Susceptibility to pests and diseases	3	2	2	3	2
Greenhouse gas mitigation capacity	3	1	2	2	3
Maintenance cost	3	2	2	2	2
Cost of implementation	2	1	1	3	2
Nutritional quality, digestibility, and palatability	3	2	3	1	3
Subsequent use	3	2	2	2	3
Social knowledge of the species	2	1	1	1	2
Seed availability	**2**	**2**	**2**	**3**	**1**
Total	**37**	**29**	**32**	**33**	**35**

Source: Own elaboration.

According to the results presented in Table 3, the *Tithonia Diversifolia* species scored 37 due to its rapid growth period of 3 months, an altitudinal range of 0 - 2700 meters, an average frequency of irrigation, easy establishment in soils, absence of diseases, and tolerance to pests. Regarding maintenance and implementation costs, it was categorized as average in comparison to the other species.

2.4. Evaluation of *in situ* treatments

The in situ treatments were implemented in the flat topography of the study area due to its high susceptibility to soil compaction, as follows:

T1: *Tithonia Diversifolia*.

T2: *Tithonia Diversifolia* + decomposed manure + lime.

As shown in Table 4, the treatments were evaluated over a total period of 115 days, with height measurements taken on days 17, 31, 51, and 92 (in cm), until the final period was completed. The highest growth was observed in T2, which reached a maximum height of 2 meters, showing a difference of approximately 50 cm compared to T1.

Table 4. Results of treatments with Tithonia Diversifolia in situ at 3 times

T1.	T2.
31 days	

51 days

115 days

Source: Own elaboration.

2.5. Evaluation of soil indicators susceptible to compaction

After the in-situ evaluation of treatments 1 and 2, the soil samples were sent to IGAC for analysis (*Table* 5). The dynamic indicators were selected and reported to assess any changes in the parameters susceptible to compaction, such as apparent density, real density, porosity, field moisture, PH, and organic carbon, in order to determine the biomass contribution of the implemented treatments:

Table 5. Comparison of results

Parameter	Diagnosis	T1	T2
Bulk density (g/cm^3)	1.66	1.27	1.14
Real density (g/cm^3)	2.49	2.29	2.33
Porosity (%)	33.33	44.54	51.07
Field humidity Θg (%)	11.96	29.09	30.66
PH	6.7	6.97	8.15
Organic Carbon (%)	1.59	2.26	1.9

Source: Own elaboration.

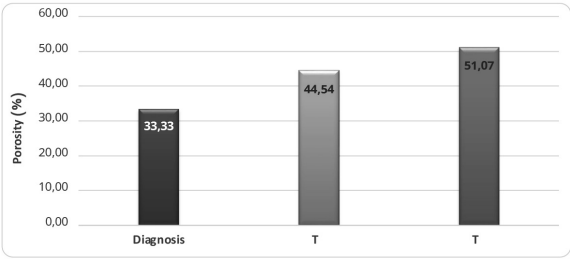
According to the above, it is evident that for the first indicator to be analyzed, bulk density, and based on the categorization degree of IGAC [22], a transition from high classification to medium classification was obtained for treatment 1 and a low classification for treatment 2. This result is consistent with previous studies; however, it is worth mentioning that better results were obtained with the sole implementation of the plant species, without amendments, with values ranging from 9% to 30% [15][26][27].

This is supported by several authors, who assert that agricultural lime and organic manure improve the infiltration rate and water holding capacity of the soil, thereby decreasing bulk density [28], while positively impacting aggregate stability, soil fertility, and biological properties.

On the other hand, parameters such as porosity, field moisture, PH, and organic carbon increased significantly in comparison to the initial values. Porosity was classified as low and medium for treatments 1 and 2, respectively, a result supported by authors like Hafifah *et al.* [26]. However, the percentages ranged from 5.6% to 7.02%, and in

this study, there was an increase of 33.63% for T1 and 53.23% for T2 (Figure 3). A similar situation was observed with field moisture, which, according to Anaya [29] for a medium texture, in the case of this project, should be at 25%. According to IGAC [23], it is at a critical level when its value is between 5-15%. The field moisture increased significantly, exceeding the established ranges for both treatments, a fact reported by authors such as Opala [15], Atayese and Liasu [30], Agbede *et al.* [31], with increases of exactly 143.23% for T1 and 156.35% for T2.

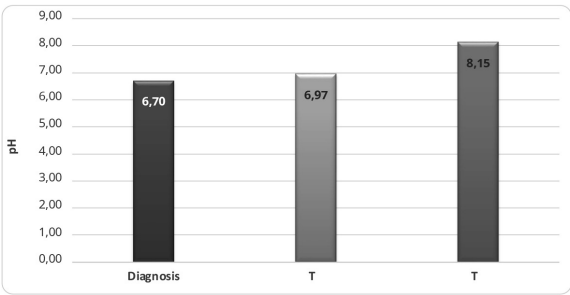
Figure 3. Comparison of the porosity (%) values in the treatments



Source: Own elaboration.

The PH showed an upward trend (*Figure* 4), highlighting that the use of the plant species without amendments also demonstrated the capacity to increase this parameter, reaching an optimal range. This raises the question of whether chemical amendments (lime) are truly required, a result widely documented by Carvajal and Gomez [32] and Whalen *et al.* [33].

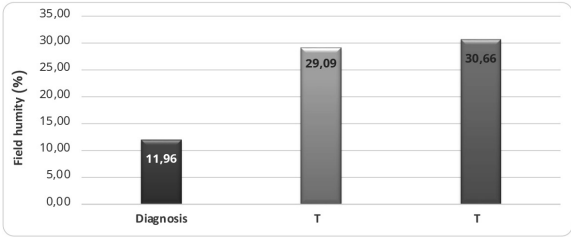
Figure 4. Comparison of the PH values in the treatments.



Source: Own elaboration.

As for field moisture (Figure 5), which, according to Anaya [29], for a medium texture, as in the case of this project, should be 25%, and according to IGAC [23], is at a critical level when its value is between 5-15%, it significantly increased and exceeded the established ranges for both treatments. This fact was also reported by authors such as Opala [15], Atayese and Liasu [30], Agbede et al. [31], and Hafifah *et al.* [26], with the values obtained being 44.54% and 51.07%, respectively, highlighting a considerable increase.

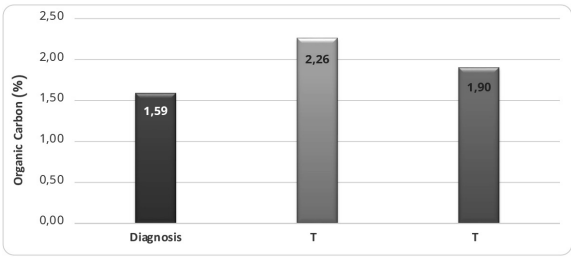
Figure 5. Comparison of the field humity (%) values in the treatments



Source: Own elaboration.

On the other hand, organic carbon unexpectedly presented a better result in treatment 1 (*Figure* 5). *Tithonia Diversifolia* demonstrated a higher capacity compared to the amendments used, a result supported by Hafifah *et al.* [26]. This is important because organic carbon is a source of energy for the organisms that inhabit the soil, a contributor of nutrients, with the capacity to provide stability to the soil structure; regulate the exchange of gases (oxygen and CO2), aeration, and retention of moisture and nutrients; and prevent compaction and erosion [23].

Figure 6. Comparison of the organic carbon (%) values in the treatments



Source: Own elaboration.

Conclusions

This research demonstrated the capacity of the plant species *Tithonia Diversifolia* to recover indicators of soils susceptible to compaction, such as bulk density, with a decrease of 31.33%, and an increase in porosity, field moisture, PH, and organic carbon by 53.23%, 156.35%, 21.64%, and 42.12%, respectively.

It was also determined that livestock activity plays an important role in the traditional economy of the population, reflecting cultural identity, which cannot be excluded. However, through environmental engineering and in collaboration with local communities, initiatives can be developed to promote its sustainability. These initiatives integrate academic knowledge and practical experience, ensuring a balance between social, ecological, and economic components.

This research can be replicated in contexts with similar characteristics in the region and provides a benchmark for future studies proposing sustainable alternatives to mitigate the impacts of inadequate land use and management practices. It focuses on reducing susceptibility to future soil compaction, degradation, and promoting the recarbonization of soil resources.

Acknowledgements

We would like to thank the collaborators of the farm for sharing their valuable knowledge, their willingness and support, and for always being open to listening, with respect, to our contributions from academia.

References

[1] FAO, La ganadería y el medio ambiente. [En línea]. Disponible en: https://www.fao.org/livestock-environment/es (consultado el 17 de octubre de 2024).

[2] FEDEGAN, Cifras de referencia del sector ganadero colombiano, 2017. [En línea]. Disponible en: https://estadisticas.fedegan.org.co

[3] Etter y A. F. Zuluaga, "Áreas aptas para la actividad ganadera en Colombia: análisis espacial de los impactos ambientales y niveles de productividad de la ganadería," 2018. [En línea]. Disponible en: http://reporte.humboldt.org.co/biodiversidad/2017/cap4/403/#seccion9

[4] C. Lefévre, F. Rekik, V. Alcantara, y L. Wiese, Carbono orgánico del suelo: potencial oculto, 2017.

[5] FAO y GTIS, Estado Mundial del Recurso Suelo, vol. I, 2015. [En línea]. Disponible en: http://www.fao.org/3/a-i5126s.pdf

[6] Ministerio de Ambiente y Desarrollo Sostenible, Política Nacional para la Gestión Integral Ambiental del Suelo (GIAS), 2016.

[7] Instituto de Hidrología, Meteorología y Estudios Ambientales-IDEAM y Universidad de Ciencias Aplicadas y Ambientales- U.D.C.A. Síntesis del estudio nacional de la degradación de suelos por erosión en Colombia - 62 Pp. (2015).

[8] FAO, Recarbonización de los suelos del mundo, Alianza Mundial por el Suelo, 2020.

[9] L. Silva Ruiz y D. A. Jaramillo Peralta, "Manejo Sostenible de la ganadería en Latinoamérica: Revisión Sistemática 2018-2021," Ambiente, Comportamiento y Sociedad, vol. 5, no. 1, pp. 1-18, 2022. DOI: 10.51343/racs.v5i1.969

[10] J. L. Contreras-Santos, J. Martínez-Atencia, y C. K. Falla-Guzman, "Carbono acumulado en raíces de especies vegetales en sistemas silvopastoriles en el Norte de Colombia," Revista de Ciencias Ambientales, vol. 55, no. 1, pp. 52-69, 2021. DOI: https://doi.org/10.15359/rca.55-1.3

[11] IDEAM, Atlas de Radiación Solar, Ultravioleta y Ozono de Colombia, 2021. [En línea]. Disponible en: http://atlas.ideam.gov.co/visorAtlasRadiacion.html

[12] Alcaldía de Sincelejo, Plan de Desarrollo Municipal 2020-2023, 2020. [En línea]. Disponible en: https://www.asocapitales.co/nueva/wp-content/uploads/2020/11/Sincelejo_Plan-de-DesarrolloMunicipal_2020-2023.pdf

[13] IGAC, Guía, recomendaciones para la toma de muestras para análisis del laboratorio nacional de suelos, 2017.

[14] P. A. Opala, J. R. Okalebo, y C. Othieno, "Effects of organic and inorganic materials on soil acidity and phosphorus availability in a soil incubation study," ISRN Agronomy, 2012. DOI: 10.542/2012/597216

[15] P. A. Opala, "Recent Advances in the Use of *Tithonia Diversifolia* Green Manure for Soil Fertility Management in Africa: A Review," Agricultural Reviews, pp. 256-263, 2020. DOI: https://doi.org/10.18805/ag.R-141

[16] SOPROCAL, Guía de uso de cal agrícola, 2021. [En línea]. Disponible en: https://puntoganadero.cl/imagenes/upload/_5cdc5dda3aa85.pdf

[17] FAO, Las repercusiones del ganado en el medio ambiente, 2006.

[18] **EPA**, Global warming - Methane, 2005. [En línea]. Disponible en: http://www.epa.gov/methane

[19] J. R. Miner, F. J. Humenik, y M. R. Overchash, Managing Livestock Wastes to Preserve Environmental Quality, Iowa State University Press, Ames, IA, USA, 2000.

[20] N. Bravo, B. F. Sandoval, V. M. O. Chaparro, y F. V. G. Cossio, "Efecto de la labranza sobre la estructura del suelo, la germinación y el desarrollo del maíz y frijol," Terra Latinoamericana, vol. 18, no. 1, pp. 61-69, 2000.

[21] M. A. M. Marín, L. R. Pescador, L. R. Ramos, y J. L. A. Charry, "Impacto de la actividad ganadera sobre el suelo en Colombia," Ingeniería y Región, vol. 17, pp. 1-12, 2017. DOI: https://doi.org/10.25054/22161325.1212

[22] IGAC, Informe de gestión del Sector Estadístico, 2016. [En línea]. Disponible en: https://www.dane.gov.co/files/control_participacion/rendicion_cuentas/informe_congreso_IGAC_2015_2016.pdf

[23] IGAC, Manejo de suelos colombianos, Bogotá, Colombia: Imprenta Nacional, 2014.

[24] Barba-Romero y Pomerol, Multicriteria decisions, theoretical foundations and practical use, University of Alcala, 1997.

[25] Al día UNAL. Botón de oro, un "alimento" revolucionario para bovinos que promete mejorar la productividad ganadera. Recuperado de https://aldiaunal.palmira.unal.edu.co/detalle/boton-de-oro-un-alimento-revolucionario-para-bovinos-que-promete-mejorar-la-productividad-ganadera 12 de noviembre de 2024

[26] S. Hafifah, M. D. Maghfoer, y B. Prasetya, "The potential of *Tithonia Diversifolia* green manure for improving soil quality for cauliflower (Brassica oleracea var. Brotrytis L.)," Journal of Degraded and Mining Lands Management, vol. 3, pp. 499-506, 2016. DOI: https://doi.org/10.15243/jdmlm.2016.032.499

[27] G. Crespo, T. E. Ruiz, y J. Álvarez, "Efecto del abono verde de Tithonia (T. diversifolia) en el establecimiento y producción de forraje de P. purpureum vc. Cuba CT-169 y en algunas propiedades del suelo," Revista Cubana de Ciencia Agrícola, vol. 45, no. 1, pp. 79-82, 2011.

[28] U. R. Sangakkar, "Root dynamics and nutrient uptake efficiencies of Mung Bean as affected by organic matter and effective microorganisms," en 5th International Conference on Kyuse Nature Farming, Bangkok, Tailandia, 1997.

[29] M. Anaya, Captación in situ del agua de lluvia para la agricultura de temporal, México, 1994.

[30] M. O. Atayese y M. O. Liasu, "Arbuscular mycorrhizal fungi, weeds and earthworm interactions in restoration of soil fertility in Guinea Savanna region of Nigeria," Moor Journal of Agriculture Research, vol. 3, pp. 104-109, 2001.

[31] T. M. Agbede, A. O. Adekiya, y J. S. Ogeh, "Response of soil properties and yam yield to Chromolaena odorata and *Tithonia Diversifolia* mulches," Archives of Agronomy and Soil Science, vol. 60, pp. 209-224, 2014. DOI: https://doi.org/10.1080/03650340.2013.780127

[32] K. G. Carvajal y C. A. Gómez, "Efecto de la aplicación de cal dolomita sobre el PH del suelo y rendimiento de sorgo sureño en suelos de uso agrícola, Zamorano, Honduras," 2016.

[33] J. K. Whalen, C. Chang, G. W. Clayton, y J. P. Carefoot, "Cattle manure amendments can increase the PH of acid soils," Soil Science Society of America Journal, vol. 64, no. 3, pp. 962-966, 2000. DOI: https://doi.org/10.2136/sssaj2000.643962x