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Edaphic recovery of degraded soils with combined use of leucaena (*Leucaena leucocephala*) and vetiver grass (*Chrysopogon zizanioides*) in Vandúzi, Mozambique

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ABSTRACT

Soil recovery is a process aimed at reversing its degradability by incorporating favorable conditions (physical, chemical, and biological) to restructure life so that, through intervention, it can regenerate. This study aimed to analyze the potential combined use of leucaena (*Leucaena leucocephal*a) and vetiver grass (*Chrysopogon zizanioides*) for the recovery of degraded soils in the Nhamurenguera area, Vandúzi District, Mozambique. The experimental method included soil study (physical-chemical analyses), area preparation (field and seedbed), field management, topographic survey, and qualitative and quantitative visual assessment of the developing seedlings. A total of 650 leucaena and 680 vetiver grass seedlings were planted in an area of 0.5 ha, with a spacing of 4 m between rows and 2 m between seedlings of both species in consort. Three months after planting, the survival and adaptability levels of the seedlings were evaluated. The results showed that 17% of the leucaena individuals and 12% of the vetiver grass died due to ant attacks and insufficient moisture, despite the use of mulching. Regarding the seedlings' reaction to soil conditions, 94% of leucaena and 79% of vetiver showed slow development in the first 3 months of planting due to soil compaction and low nutrient availability (leaching). After four years, soil chemical parameters were evaluated and compared with pre-leucaena/vetiver consortium soil data. The pH values, electrical conductivity, NPK contents, calcium, and magnesium increased, improving soil quality and indicating a soil recovery process to prepare it for subsequent agricultural use, especially for cereal and legume crops.

INTRODUCTION

Mozambique is primarily an agricultural country, with 80% of its rural population relying on subsistence farming (HOGUANE, 2007). The low level of agricultural development is one of the main causes of poverty (CARRILHO, 2003), linked to soil degradation, loss of productive areas, and the lack of alternative soil management and recovery techniques. This results in low agricultural productivity, which affects the farmers' quality of life.

In Manica province, particularly in the Beira-Machipanda corridor, notably in the Vandúzi District, soil degradation pressures have been intensifying. Alongside deforestation driven by population growth, insufficient knowledge of conservation techniques and practices (resulting in unsustainable land management), and challenges in diagnosing degradation processes (such as erosion and significant declines in soil productivity) exacerbate soil degradation, threatening food production.

Degraded areas experience adverse environmental effects primarily due to human activities, resulting in negative impacts on native flora and fauna (leading to biodiversity loss), soil fertility (causing soil depletion), seed banks (reducing germination rates), and seedlings (impairing growth capacity) (ALBUQUERQUE, 2007).

The purpose of restoring these degraded areas is to restore the functionality of the damaged soils by providing favorable conditions for the restructuring of plant and animal life, ensuring the ecological restoration of ecosystems (FERREIRA, 2000), by restoring physical, chemical, biological, and productive integrity (ARAÚJO et al., 2021).

An alternative technique to replenish nutrients in degraded soils involves using plants in rotation or intercropping with the target crops, generally resulting in

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improved physical, chemical, and biological soil characteristics. This technique, known as "green manuring" (FERREIRA et al., 2012), employs hardy plants with strong root systems capable of recycling nutrients from deeper soil layers or from the atmosphere, thereby enhancing soil fertility and productivity (ALCÂNTARA, 2016).

Studies have shown that using plants for the recovery of degraded areas, such as *Leucaena leucocephala*, acts as green manure to amend degraded soils, proving effectiveness in nitrogen fixation at rates ranging from 400 to 800 kg ha^{-1}/yr (BARROSO et al., 2021). It also allows for the significant input of biomass, leading to an increase in soil organic matter content over the years (ABRANCHES et al., 2021). Other benefits of using leucaena include weed biomass control and subsequent reduction (MOURA et al., 2009). Another species with soil recovery potential is the vetiver grass (*Chrysopogon zizanioides*), a perennial plant adaptable to a wide range of soil conditions. In addition to its rapid growth, vetiver grass helps reduce erosion caused by surface water runoff (CHAVES; ANDRADE, 2013). It enhances soil filtration, retains moisture, recycles nutrients from deep soil layers to the surface, absorbs and fixes atmospheric nitrogen, and releases nutrients through the decomposition of its litter (CUNHA, 2023).

Given this scenario, this study aims to analyze the effectiveness of the combined use of plant species (leucaena and vetiver) for the recovery of degraded areas. The aim is to assess how these species contribute to restoring the functionality of degraded soils by acting as green manure, providing favorable conditions for soil restructuring.

MATERIAL AND METHODS

Experiment Location

The experiment occurred at the Technology Transfer Center of Zambeze University, in the Vanduzi District located in the central part of Manica Province, with geographic coordinates 18°57'45.68"S, 33°14'31.77"E, and an altitude of 724m. The soil topology in the area selected for the recovery intervention comprised mostly of loamy and moderately loamy clay soils. The predominant vegetation includes grasses (such as *Paniccum maximum*) and shrubs, extending to the outskirts of Vanduzi town and the Belassi community (SERRANI, 2022).

Topography

To assess the slope and geographical location of the field, we carried out a topographic survey by marking points using a level and GPS. Subsequently, the terrain slope was calculated according to the equation proposed by Oliveira et al. (2010).

Field Study

For the field study, soil analyses were conducted at the laboratory of the Higher Polytechnic Institute of Manica (HPIM) during two different periods. The first analysis was carried out in 2018 to assess soil quality before the implementation of the activity. The second analysis took place in 2023 to evaluate nutrient recycling after the establishment of leucaena and vetiver in the field.

The sampling was systematically conducted by collecting soil samples at six different points, following a zigzag pattern, at a depth of 0-40 cm. All samples were combined to form a single composite sample (approximately 300g). Subsequently, the composite sample was homogenized, and an aliquot was taken and sent to the laboratory for analysis.

Figure 1:Mozambique, showing the province of Manica (left) and the district of Vanduzi.

Physicochemical analysis

To determine the pH in water, we used the electrochemical method, measuring the effective concentration of $[H^+]$ ions in the soil solution using a combined glass electrode (potentiometer). The assessment of organic matter content in soils relied on the oxidation of CO_2 by dichromate ions in an acidic medium, using a standardized solution of ammoniacal ferrous sulfate ($Cr_2\ O_7^{-2} + 6\ Fe^{+2}\ 14\ H^+ \leftrightarrows 2Cr_{3+} + 6\ Fe^{+2}\ 7\ H_2O$). For the evaluation of phosphorus (P) concentration available in the soil, we employed the Mehlich-1 extractor method (hydrochloric acid + sulfuric acid) coupled with molecular absorption spectrometry. Potassium (K) concentration was also measured using the Mehlich-1 extractor method, and the analytical reading of the sample was conducted using atomic absorption spectrometry. To measure the Ca^{2+} and Mg^{2+} content, we weighed 0.5 g of corrective and placed it in a 250 ml Erlenmeyer flask. Then, we added 12.5 ml of 1 mol L^{-1} HCl and boiled it on a hot plate until boiling began. We then removed it from the plate to cool, added 50 ml of distilled water, returned it to the hot plate, and boiled for an additional 5 minutes. After cooling again, we filtered the solution and took a 1 ml aliquot for the determination of CaO and MgO content using atomic absorption spectrophotometry, adding 4 ml of lanthanum chloride solution.

Field and seed preparation

In the area preparation for planting, manual cleaning of 0.5 ha was carried out using hoes and sickles. The cut grass was not removed but left in place to serve as mulch, providing protection against weeds (invasive grass) and retaining soil moisture.

During seed collection and selection, we pruned branches with mature fruits containing seeds, which underwent dormancy-breaking treatment by soaking them in a bucket of water for 24 hours. Subsequently, we scarified the seeds to facilitate dormancy breaking and, therefore, germination. The seeds were planted in seedbeds at a depth of about 2 cm, where they germinated after 5 days and remained in the seedbed for another 40 days, totaling 45 days. Once they reached the height of 10 to 12 cm in the seedbed, we transplanted 1,150 seedlings into plastic bags. Throughout these processes, we performed weeding and watering activities regularly.

Around the planting area, we created a 3-meter-wide firebreak by removing dry grass to prevent fires, which are common during the months of July and August each year.

Next, we marked parallel planting rows using a 200-meter plastic line, hoes, and measuring tapes. With the help of gauges, we marked the planting holes with a spacing of 4 meters between rows, 2 meters between leucaena plants, and 1 meter between leucaena and vetiver grass. The planting holes were dug with dimensions of 40 cm in width and 30 cm in depth (Figure 2).

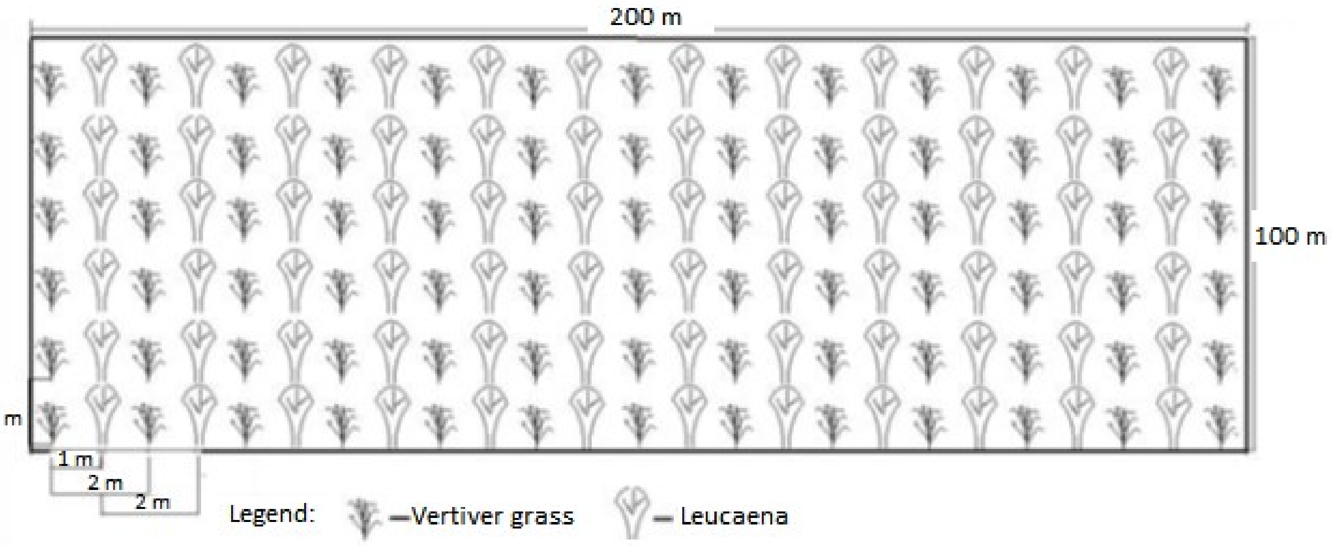

Figure 2: Experimental field layout at UniZambeze in Vandúzi showing the arrangement of the cultivars.

Management of seedlings and field

After the leucaena seedlings reached a height of 10 to 15 cm (approximately 60 days in the nursery), we transplanted them to the field, following the technique of making a cross cut of about 1 cm, removing the bottom part of the container to facilitate removal. Then, we filled the planting holes with soil, forming a small concave "retention basin" to accumulate water. We obtained 680 vetiver seedlings and planted them in association with leucaena in a 0.5 ha area. The planting was done during the dry season, in August. We used the "mulching" technique to cover the small "retention basins," allowing moisture retention.

In the field, management was responsible for controlling weeds and insects. We regularly performed manual weeding within a 50 cm radius of the seedlings and insecticide spraying. Irrigation was carried out three times a week until 210 days after planting, which was necessary due to soil compaction and low concentrations of exchangeable ions to prevent water deficit and stress. This could lead to low plant growth, excessive ion accumulation and toxicity, inhibition of cell division, and protein synthesis (SILVA et al., 2018a). This procedure helped mitigate stress effects on plants, ensuring increased microporosity and aggregate formation for greater water retention in the soil (SOUZA et al., 2018).

Visual assessment of seedlings

The seedlings of leucaena and vetiver were individually evaluated after 3 months of planting in the field through visual diagnosis, assessing: a) seedling growth (cm), b) leaf color (green, yellowish-green, yellow, reddish, and brown), c) leaf loss (none, little, or much), d) leaf characteristics (intact or twisted), e) presence of new leaflets (absent or present, and comparative size), f) stem characteristics (slender or robust), g) bark (smooth or rough), and h) seedling mortality. According to Dantas (2020), the recommended size for new leucaena leaflets is 7-15 mm in length and 3-4 mm in width. Cunha (2023) suggests that the yellowish-green color of the plant's newer leaves is directly related to nutrient deficiency.

RESULTS AND DISCUSSION

Topographic Characteristic

The topographic survey showed that the field had two water drainage directions beginning from two higher points of the terrain, the ridges, with elevations of 20.845 m and 20.454 m. The elevation difference is 0.885 m, horizontal distance 250 m, and the slope of the field is 0.4%, which is less pronounced, requiring planting the seedlings perpendicular to the water flow direction to reduce leaching of inorganic components and humus transport in the soil. According to Oliveira et al. (2010), fields with a slope practically null (0 to 3%), in nearly flat terrain, are not susceptible to water erosion, where surface runoff is slow.

Soil chemical analysis

Before setting up the experiment, the results of the soil chemical analysis showed that the concentration of soluble salts and ionic solution of nutrients in the soil was lower than recommended by Batista et al. (2018) - (Table 1). The soil pH needed for the growth of many cereals, legumes, and vegetables is 6.0 to 7.0 (COSTA, 2018). In this sense, the pH found in this study was below the recommended range for the production of legumes and grasses, and the use of acidifying fertilizers such as ammonium sulfate should be avoided, as they may create conditions of low assimilability of nutrients such as phosphorus, calcium, iron, manganese, and sulfur; especially if there is an excess of aluminum. The levels of nitrogen (N), phosphorus (P), calcium (Ca), and magnesium (Mg) were below the recommended levels, requiring supplementation to increase their concentrations. Potassium (K) levels were high and needed to be reduced. Insufficient salts can result in significant reductions in plant development, morphology, and physiology, due to the reduced osmotic potential of the soil, as well as toxicity caused by excessive ion absorption and nutritional imbalance (ZHU et al., 2019; LIMA et al., 2020).

Table 1: Soil chemical analysis pre-planting (2018) and post-planting (2023) of leucaena and vetiver.

Study Elements	Quantitative Results	Classification Nutrient Contents*	Quantitative Results	Classification Nutrient Contents
	(Pre-green manure - 2018)		(Post-green manure - 2023)	
EC (dS m^{-1})	0.59	Low (leached nutrients)	13.00	Suitable
pH	5.27	Low	6.01	Medium
NO$_3$ (mg /kg)	10.63	Low	27.32	Medium
P (mg /kg)	0.08	Very low	8.02	Medium
K (mg /kg)	31.06 PO$_4$-P	High	26.74 PO$_4$-P	High
Ca (mmolc .dm^{-3})	0.58	Low	4.03	Medium
Mg (mmolc.dm^{-3})	1.00	Low	5.81	Medium

CE (Electrical Conductivity), pH (Hydrogen potential), NO$_3$ (Nitrogen), P (Phosphorus), K (Potassium), Ca (Calcium) e Mg (Magnesium), and the units dS/m^{-1} (decisiemens per meter), mg/kg (milligram per kilogram) e mmolc/dm^{-3} (millimole of charge per cubic decimeter).*Classification of Nutrient Contents in Soil (BATISTA et al., 2018).

Silva et al. (2018b) and Souza et al. (2016) describe that the actual electrical conductivity of the soil depends on the water content, chemical composition, concentration, interaction of non-exchangeable and exchangeable ions, clay percentage, and organic matter content. Sanches et al. (2018) observed that insufficient pH and macronutrient levels (N, P, K, Ca, and Mg) in the soil can be the main cause of reduced electrical conductivity and crop productivity, due to the low concentration of ionic forces in nutrient uptake by plants.

According to Galindo et al. (2018), an increase in nitrogen concentration in the soil solution promotes root system growth and soil exploration area, favoring the recycling of easily leachable elements (such as potassium). As observed, the concentration of soluble salts and ionic nutrients in the soil was low due to nutrient leaching, requiring correction. To increase nitrogen, potassium, phosphorus, calcium, and magnesium, we used a intercropping of leucaena and vetiver as green manure to correct degraded soils (adding organic matter) as an alternative.

The rhizobacteria associated with grasses enhance crop growth and productivity through mechanisms related to the production of phytohormones, nitrogen fixation, phosphorus solubilization, and root development (SANTOS et al., 2020; CARDOZO et al., 2022).

After the installation of the green manure experiment with the consortium of leucaena and vetiver in the field, the analysis results showed an increase in the values of electrical conductivity (EC) and hydrogen potential (pH) in the soil solution, as well as an increase in the concentrations of macronutrients (Table 01).

The data obtained show that nitrogen (N) from the air was fixed and added to the soil through a process involving common *Rhizobium* bacteria found in legumes. This process also involved phosphorus (P) through association with specific fungi, potassium (K) in ionic form, and calcium (Ca) and magnesium (Mg) in mineral form, which contributed to higher nutrient levels in the soil (see Table 1). The nutrients followed this order: N>K>P>Mg>Ca. Although potassium (K) levels were slightly high, they didn't affect the soil recovery process.

According to Schroeder (2017), many crops thrive most effectively when the pH ranges from 6.0 to 7.0, although some crops can grow in acidic soils without affecting their growth. The leucaena/vetiver intercropping contributed to raising the soil pH from 5.27 to 6.01, reaching the ideal pH range for most plants, which has implications for various processes.

Soil acidity affects the solubility, precipitation, mobilization, and availability of nutrients or toxic elements. When soil pH falls below 5.5, microbial activity, especially bacteria, is hindered, impacting essential soil processes like mineralization, nitrification, and nitrogen fixation (GONÇALVES, 2020). This acidity also influences nutrient availability: high acidity restricts the availability of calcium (Ca), magnesium (Mg), and potassium (K) while promoting the availability of aluminum (Al^{3+}), which can be harmful to plants. Additionally, phosphorus availability may decrease under moderately to highly acidic conditions ($pH < 5.5$) or in alkaline conditions ($pH > 7.5$) – (BATISTA et al., 2018).

Soil pH can affect the cation exchange capacity (CEC) and anion exchange capacity (AEC), especially in soils rich in minerals that respond to pH changes. This is common in humid tropical regions and soils with high organic matter content. For healthy plant growth, soil levels of calcium (Ca) and magnesium (Mg) should be high, ideally exceeding 20.1 mmolc.dm^{-3} for Ca and 11.0 mmolc.dm^{-3} for Mg (BATISTA et al., 2018). Before introducing the leucaena/vetiver consortium, these nutrient levels were below the recommended values (Ca: 0.58 mmolc.dm^{-3}, Mg: 1.00 mmolc.dm^{-3}). However, after green manure application, they increased (Ca: 4.03 mmolc.dm^{-3}, Mg: 5.81 mmolc.dm^{-3}), though still insufficient.

Nursery, Experimental Field, and Visual Diagnosis

During the transplanting of 1,150 leucaena seedlings from the bed to the nursery, 3% died due to sensitivity to the transplanting process or failure to adapt to the tubes.

In the field, 650 leucaena and 680 vetiver seedlings were planted, and after 3 months, the results showed 17% mortality for leucaena and 12% mortality for vetiver, mainly due to soil inadaptability (Figure 3 and Figure 4).

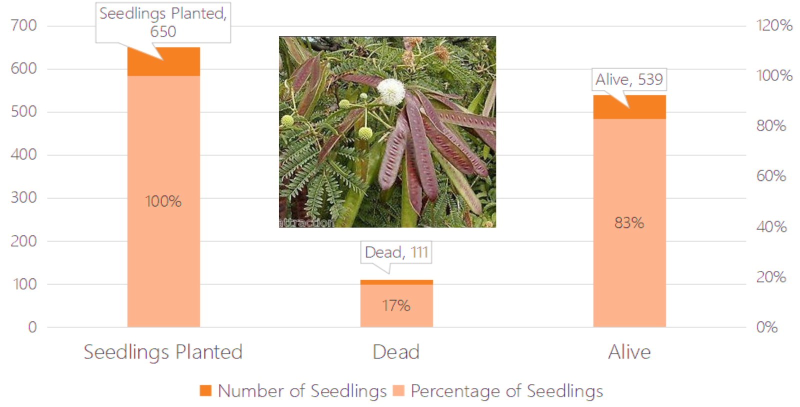

Figure 3. Evaluation of leucaena seedling survival in the field (number of seedlings and percentage).

In forest plantation efforts to restore degraded areas during the dry season, it's generally deemed acceptable for post-planting mortality to reach up to 20% (MALINOVSKI et al., 2006). Hence, the mortality rates observed in this study fall within acceptable limits. This achievement may be attributed to the use of "mulching", particularly crucial during the initial phase when seedlings rely heavily on water for survival. Typically, forest planting is timed to coincide with the rainy season for this reason.

When evaluating the seedlings' development in the field, it was observed that, regarding the leucaena seedlings, 610 seedlings (94%) showed slow and stunted growth (leaves, leaflets, and stem), and 581 seedlings (89%) exhibited reddish coloration on the lower parts of the older leaves. Additionally, 374 seedlings (58%) had reduced leaflet size, 412 (63%) experienced leaf loss, and 111 (17%) died. As for the vetiver seedlings, it was observed that 538 (79%) had a brownish color and excessive drying of the older leaves, 491 seedlings (72%) showed limited growth and low tillering, 386 (57%) had newer leaves characterized by yellowing of the tips during full growth and twisted margins, and 82 (12%) died. Therefore, most of the seedlings, both leucaena and vetiver, faced development difficulties due to adverse soil conditions (degradation).

The leucaena seedlings exhibited slow growth with yellow-green leaves, indicative of nutrient deficiencies in N, P, K, Ca, and Mg. Nitrogen (N) deficiency was characterized by the replacement of green color with yellow-green color in the leaves and reduction in leaflet size. Signs of phosphorus (P) deficiency included reddish coloration on the lower parts of the older foliage and leaf loss. Regarding the effects of potassium (K) excess, they were not noticeable, as they should have caused rusting on the leaves and fruits, which was not observed. Low levels of calcium (Ca) were manifested by stunted growth and dying plants. Along with other nutrients, magnesium (Mg) exhibits similar attributes, and in this study, its deficiency was noticeable with the appearance of coloration and shedding of lower leaves in leucaena (Figure 5A).

Vetiver grass is recommended for low-fertility soils, with a response to fertilization similar to legumes (GRACIANO et al., 2021). Symptoms of nutrient deficiency in vetiver, such as nitrogen (N), began in the older leaves, which dried excessively, while the newer ones remained green for a longer period. Reduced seedling development and low tiller numbers were noticeable symptoms of phosphorus (P) and potassium (K) deficiency. The first signs of deficiency in the leaves appeared in the older ones, which showed a brownish coloration. Reduced calcium (Ca) resulted in yellowing of the tips of the newer leaves (upper leaves in full growth) and leaves with twisted margins. Since magnesium (Mg) is involved in chlorophyll formation, its deficiency in vetiver grass was characterized by yellow-green coloration (chlorosis) in the older leaves (Figure 5B).

During the study, the soil nutrients recovered their functionalities, becoming suitable for agricultural cultivation or forest restoration development, thus, soil recovery was achieved. The data from this experiment support the effectiveness of the combined use of leucaena and vetiver as green manure (Figure 6A and B) in degraded soils, offering an alternative solution to the acquisition of chemical fertilizers and aeration pumps.

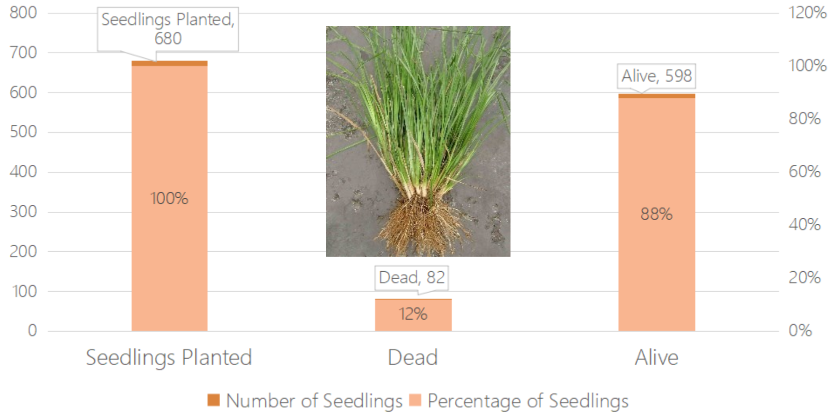

Figure 4. Evaluation of vetiver seedling survival in the field (number of seedlings and percentage).

It is important to highlight that the potential use of the leucaena and vetiver consortium as green manure in this experiment was not fully achieved. To maximize its benefits, we recommend thinning the leaves and branches throughout the development of the seedlings. This fastens the incorporation of organic matter into the soil, covering it and creating a shaded micro-habitat with lower temperatures and reduced soil water loss, which promotes accelerated green cover growth with subsequent nutrient release, improving soil environmental quality.

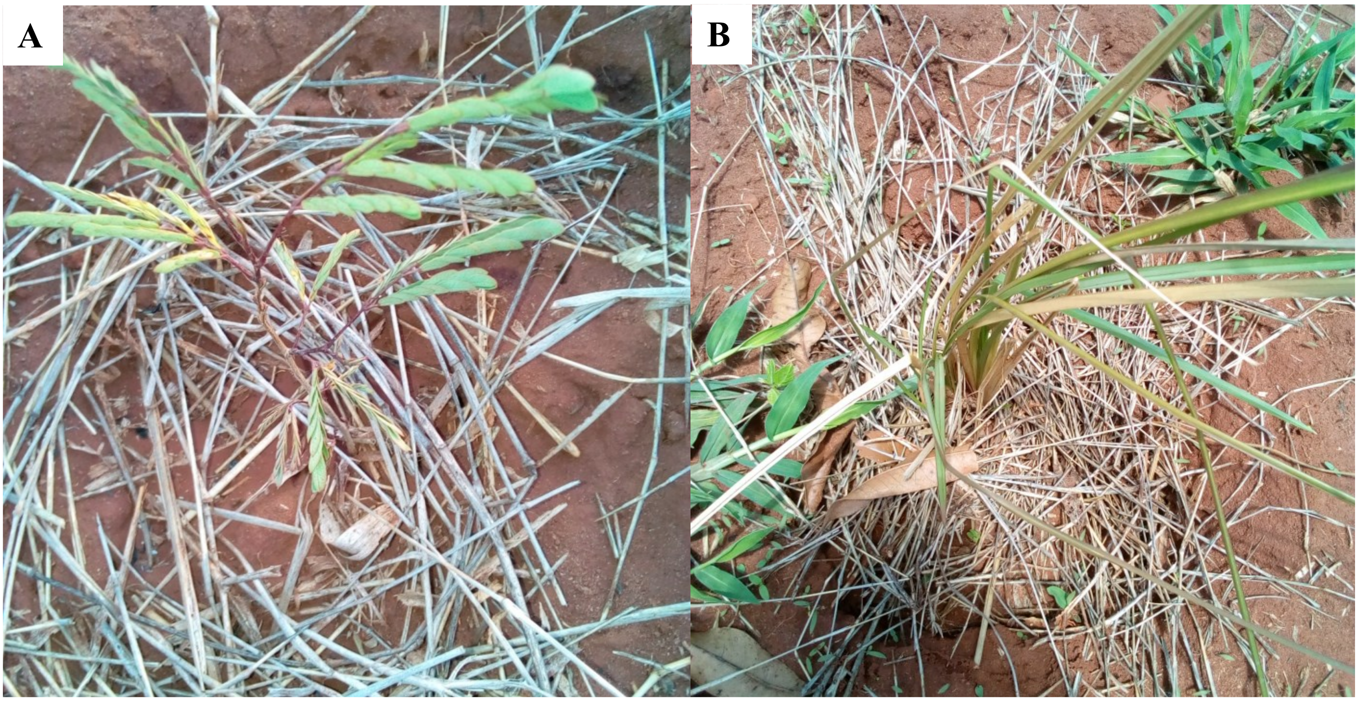

Figure 5. Development of leucaena (A) and vetiver (B) seedlings 90 days after planting.

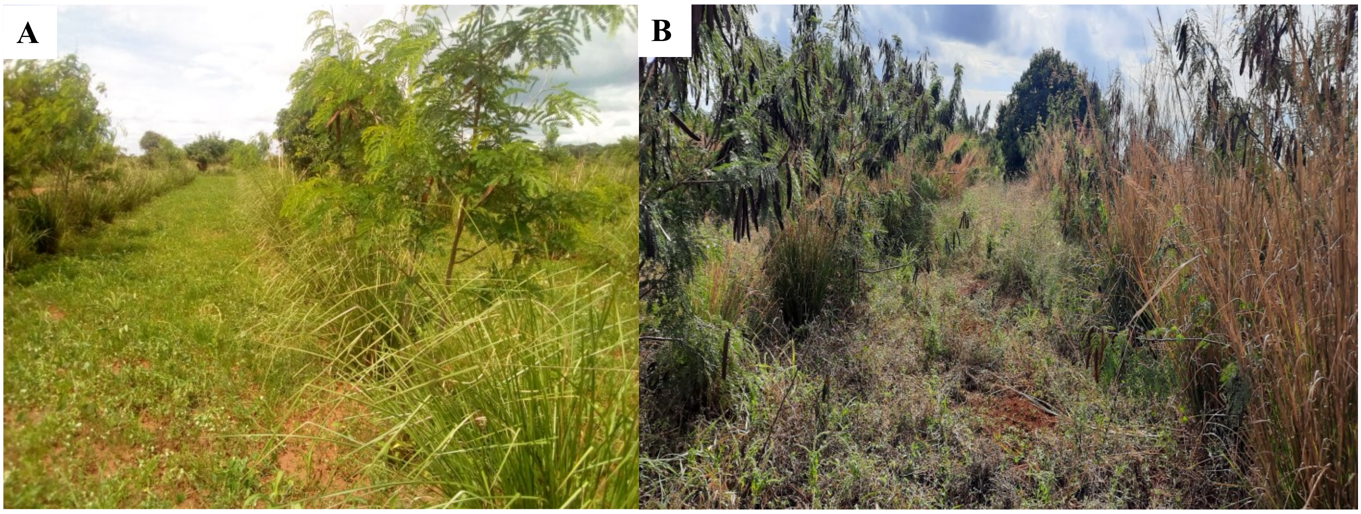

Figure 6. Development of leucaena (A) and vetiver (B) five years after planting (2023).

CONCLUSION

The intercropping of leucaena and vetiver grass as green manure technique in the experimental area proved to be efficient, as indicated by the physical and chemical variables. These variables showed nitrogen fixation, improved vegetation cover aiding in erosion control and moisture retention, as well as an increase in macronutrient content. The enhancement of degraded soil quality indicates its recovery and regeneration, enabling future agricultural use or forest restoration in the area.

REFERENCES

ABRANCHES, M. O.; SILVA, G. A. M.; SANTOS, L. C.; PEREIRA, L. F.; FREITAS, G. B. Contribuição da adubação verde nas características químicas, físicas e biológicas do solo e sua influência na nutrição de hortaliças. Research Society and Development. v.10, n. 7, e7410716351, 2021. 10.33448/rsd-v10i7.16351

ALCÂNTARA, F. A.; FURTINI NETO, A. E.; PAULA, M.; MESQUITA, H. A.; MUNIZ, J. A. Adubação verde na recuperação da fertilidade de um Latossolo Vermelho-Escuro degradado. Pesquisa Agropecuária Brasileira. v. 35, n. 2, p. 277-288, 2000. 10.1590/S0100-204X2000000200006

ARAÚJO, A. V. L. S.; RODRIGUES, J. I. DE M.; VIEIRA, L. R.; MARTINS, W. B. R OLIVEIRA.; FRANCISCO, DE A. Efeitos da Aplicação de *Trichoderma spp* no Crescimento de Mudas de Ipê Roxo (*Handroanthus impetiginosus* Mart), Anais do II Congresso Brasileiro Interdisciplinar em Ciência e Tecnologia, 2021.

BARROSO, G. R. P., CARVALHO, J. O. M., DOS SANTOS, M. R. A., FERREIRA, M. D. G. R., & MARCOLAN, A. L. Teor de macronutrientes em plantas utilizadas como adubo verde. Saber Científico*,* v. 2, n. 1, p. 37-42, 2021.

BATISTA, M. A.; INOUE, T. T.; ESPER NETO, M.; MUNIZ, A. S. Princípios de fertilidade do solo, adubação e nutrição mineral. In: BRANDÃO FILHO, J. U. T.; FREITAS, P. S. L.; BERIAN, L. O. S.; GOTO, R., Comps. Hortaliças-fruto. Maringá: EDUEM, 2018. 113-162p. 10.7476/9786586383010.0006

CARDOZO, P.; DI PALMA, A.; MARTIN, S.; CERLIANI, C.; ESPOSITO, G.; REINOSO H.; TRAVAGLIA, C. Improvement of maize yield by foliar application of *Azospirillum brasilense* Az39. Journal of Plant Growth Regulation, v. 41, pages 1032–1040, 2022. 10.1007/s00344-021-10356-9

CARRILHO, J.; BENFICA, R.; TSCHIRLEY, D. L.; BOUGHTON, D. Qual o Papel da Agricultura Familiar Comercial no Desenvolvimento Rural e Reduço da Pobreza em Moçambique? Agricultural & Applied Economics Digital Library*,* Ministério da Agricultura e Desenvolvimento Rural, Direcção de Economia, Departamento de Análise de Políticas, Relatório, p. 33-35, 2003. 10.22004/ag.econ.56057 .

CHAVES, T. A.; ANDRADE, A. G. Capim vetiver: produção de mudas e uso no controle da erosão e na recuperação de áreas degradadas. Secretaria de Estado de Agricultura e Pecuária Superintendência de Desenvolvimento Sustentável, Programa Rio Rural, Manual Técnico N°39, 16 p., Niterói/RJ. 2013.

COSTA, J. B. Caracterização e Constituição do Solo. Fundação Calouste Gulbenkian, 9ª edição. Lisboa, Portugal, 2018.

CUNHA, F. L.; ALMEIDA, R. S.; DINIZ, P. C.; PAULA, S. H. A.; CAMPOS, V. A.; VENTURIN, N. Crescimento inicial e nutrição mineral de espécies florestais com potencial econômico sob omissão de nutrientes. Advances in Forestry Science. v.10, n. 1, p.1949-1957, 2023. 10.34062/afs.v10i1.12937

DANTAS, S. M. Calibração e validação do modelo AquaCrop para a cultura leucena (*Leucaena leucocephala* (Lam.) de Wit) cultivada no semiárido do Nordeste Brasileiro. Universidade Federal de Campina Grande, 2020. 53p.

FERREIRA, C. A. G. Recuperação de áreas degradadas. Informe Agropecuário, v. 21, n. 202, p. 127-130, 2000.

FERREIRA, L. E.; SOUZA, E. P.; CHAVES, A. F. Adubação verde e seu efeito sobre os atributos do solo. Revista Verde de Agroecologia e Desenvolvimento Sustentável, v. 7, n. 1, p. 5, 2012.

GALINDO, F. S.; BUZETTI, S.; TEIXEIRA FILHO, M. C. M.; DUPAS, E.; LUDKIEWICZ, M. G. Z. Acúmulo de matéria seca e nutrientes no capim-mombaça em função do manejo da adubação nitrogenada. Revista de Agricultura Neotropical. Revista de Agricultura Neotropical. v. 5, n. 3, p. 1-9, 2018.

GONÇALVES, M. C. Imobilização de frutosiltransferase microbiana em gel de alginato e sua caracterização para a produção de frutoligossacarideos, Universidade Federal de Alfenas, 2020. 139 p.

HOGUANE, A. M. Perfil diagnóstico da zona costeira de Moçambique. Revista de Gestão Costeira Integrada-Journal of Integrated Coastal Zone Management, v. 7, n. 1, p. 69-82, 2007.

LIMA, G. S.; SILVA, J. B.; SOUZA, L. P.; NOBRE, R. G.; SOARES, L. A. A.; GHEYI, H. R. Tolerance of precocious dwarf cashew clones to salt stress during rootstock formation stage. Revista Brasileira de Engenharia Agrícola e Ambiental. v. 24, p. 474-481, 2020.

MALINOVSKI, R. A.; BERGER, R.; SILVA, I. C.; MALINOVSKI, R. A.; BARREIROS, R. M. Viabilidade econômica de reflorestamentos em áreas limítrofes de pequenas propriedades rurais no município de São José dos Pinhais-PR. Floresta, v. 36, n. 2, 2006.

MOURA, E. G.; AGUIAR, A. D. C. F.; JÚNIOR, A. S. D. L. F.; COSTA, M. G.; SOUSA, J. T. R.; SILVA JUNIOR, E. M.; GEHRING, C. Incidência de ervas daninhas e atributos do solo em um agrossistema da pré-amazônia, sob efeito da cobertura morta de diferentes combinações de leguminosas em aléias. Scientia Agraria, v.10, n.1, p.7-14, 2009.

OLIVEIRA, J. B. Práticas de manejo e conservação de solo e água no semiárido do Ceará. Cartilhas temáticas tecnologias e práticas hidroambientais para convivência com o Semiárido*,* v. 4, 2010.

SANCHES, G. M.; MAGALHÃES, P. S.; REMACRE, A. Z.; FRANCO, H. C. Potential of apparent soil electrical conductivity to describe the soil pH and improve lime application in clayey soil, Soil and Tillage Research, v. 175, p. 217-225, 2018. 10.1016/j.still.2017.09.010

SANTOS, R. M.; DIAZ, P. A. E.; LOBO, L. L. B.; RIGOBELO, E. C. Use of plant growth-promoting rhizobacteria in maize and sugarcane: characteristics and applications. Frontiers in Sustainable Food Systems, Frontiers in Sustainable Food Systems, v. 4, p. 136, 2020.

SCHROEDER, D. Solos: Fatos e Conceitos. ANDA: São Paulo, 2017, 178 p.

SERRANI, D.; COCCO, S.; CARDELLI, V.; D'OTTAVIO, P.; RAFAEL, R. B. A.; FENIASSE, D.; VILANCULOS, A.; FERNÁNDEZ-MARCOS, M. L.; GIOSUÉ, C.; TITTARELLI, F.; CORTI, G. Soil fertility in slash and burn agricultural systems in central Mozambique. Journal of Environmental Management, v. 322, p. 116031, 2022. 10.1016/j.jenvman.2022.116031

SOUZA, L. P.; LIMA. G. S.; CHEYI, R.; NOBRE, R. G.; SOARES, L. A. D. A. Emergence, growth, and production of colored cotton subjected to salt stress and organic fertilization. Revista Caatinga, v. 31, p. 719-729, 2018. 10.1590/1983-21252018v31n322rc.

SOUZA, E. A. Atributos do solo, crescimento e produção da bananeira sob fertilização com e sem cobertura morta. Universidade Federal do Recôncavo da Bahia, 2016.

SILVA, E. M.; LIMA, G. S.; GHEYI, H. R.; NOBRE, R. G.; SÁ, F. V. S.; SOUZA, L. P. Growth and gas exchanges in soursop under irrigation with saline water and nitrogen sources. Revista Brasileira de Engenharia Agrícola e Ambiental, v. 22, p. 776-781, 2018a.

SILVA, A. J. P.; COELHO, E. F.; COELHO FILHO, M. A.; SOUZA, J. L. Water extraction and implications on soil moisture sensor placement in the root zone of banana, Scientia Agricola, v. 75, p. 95-101, 2018b. 10.1590/1678-992X-2016-0339

ZHU, G.; AN, L.; JIAO, X.; CHEN.; ZHOU, G.; MCLAUGHLIN, N. Effects of gibberellic acid on water uptake and germination of sweet sorghum seeds under salinity stress. Chilean Journal of Agricultural Research, v. 79, n. 3, p. 415-424, 2019. 10.4067/S0718-58392019000300415 .