



MICROBIOLIZATION AND ROCK DUST IN SOIL QUALITY AND THE DEVELOPMENT OF THE CANOPY

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ABSTRACT

Objective: The objective of this study is to investigate the effect of the combined application of rock powder and growth-promoting microorganisms on soil chemical quality, with emphasis on soil pH value and organic matter content.

Theoretical Framework: The search for sustainable alternatives for soil fertility management has encouraged the combined use of remineralizers and beneficial microorganisms. In this context, the joint application of rock powder and growth-promoting microorganisms may enhance mineral solubilization, resulting in an increase in soil pH value and, consequently, improved agronomic performance of crops.

Method: The experiment was conducted in a greenhouse using pots filled with topsoil (0–20 cm) collected from a non-anthropized area covered with native vegetation. Four doses of rock powder (0, 1.0, 1.5, and 2.0 t ha⁻¹) were evaluated, applied either in the presence or absence of the inoculant, in a randomized block design with four replications. The forest species used was *sombreiro* (*Clitoria fairchildiana* R. A. Howard) and the fungus *Trichoderma* spp.

Results and Discussion: The application of rock powder, alone or in combination with *Trichoderma* spp., increased soil organic matter content and altered soil pH, mainly in treatments without inoculation, without affecting variables related to canopy development.

Research Implications: This study highlights the potential of combining remineralizers with microbiolization, indicating that it is an efficient strategy to improve the fertility and sustainability of tropical soils.

Originality/Value: In this context, this article makes an innovative contribution by presenting evidence of improved soil chemical quality through the combined application of rock powder and *Trichoderma* fungi. Thus, it promotes more sustainable agriculture by incorporating a native plant species in the experimental model, enhancing the regional and low-cost agricultural use of such practices.

Keywords: Remineralizers, Soil Organic Matter, Growth-Promoting Microorganisms, Forest Species.

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MICROBIOLIZAÇÃO E PÓ DE ROCHA NA QUALIDADE DO SOLO E NO DESENVOLVIMENTO DO SOMBREIRO

RESUMO

Objetivo: O objetivo deste estudo foi investigar o efeito da aplicação combinada de pó de rocha e microorganismos promotores do crescimento sobre o valor do pH do solo, teor de matéria orgânica do solo e desenvolvimento de mudas da espécie florestal sombreiro.

Referencial Teórico: A busca por alternativas sustentáveis de manejo da fertilidade do solo tem estimulado o uso combinado de remineralizadores e microrganismos benéficos. A aplicação conjunta do pó de rocha e microrganismos promotores do crescimento pode favorecer a solubilização dos minerais primários da rocha, resultando no aumento do valor do pH do solo e, conseqüentemente, em melhor desempenho das plantas.

Método: O experimento foi conduzido em casa de vegetação, utilizando vasos com solo da camada superficial (0–20 cm) de área não antropizada. Foram avaliadas quatro doses de pó de rocha (0, 1,0, 1,5 e 2,0 t ha⁻¹), aplicadas na presença ou ausência do inoculante produzido com o fungo *Trichoderma* spp., em delineamento experimental em blocos casualizados, com quatro repetições. A espécie florestal utilizada como planta teste foi o sombreiro (*Clitoria fairchildiana* R. A. Howard).

Resultados e Discussão: A aplicação de pó de rocha, isoladamente ou associada ao *Trichoderma* spp., aumentou os teores de matéria orgânica do solo e alterou seu pH, principalmente em tratamentos sem inoculação, sem refletir nas variáveis relacionadas ao desenvolvimento do sombreiro.

Implicações da Pesquisa: Este artigo apresenta resultados sobre o potencial da combinação de remineralizadores e a microbiolização, indicando que pode ser uma estratégia para a produção de mudas de espécies florestais, como o sombreiro.

Originalidade/Valor: A originalidade consiste na utilização de uma espécie florestal nativa, o sombreiro, como planta teste, o que reforça o potencial dessa técnica em contextos de produção sustentável e regionalizada. Ao integrar remineralização e microbiolização, a pesquisa contribui para o desenvolvimento de práticas silviculturais de baixo custo.

Palavras-chave: Remineralizadores, Matéria Orgânica do Solo, Microrganismos Promotores do Crescimento, Espécie Florestal.

MICROBIOLIZACIÓN Y POLVO DE ROCHA EN LA CALIDAD DEL SUELO Y EL DESARROLLO DEL SOMBRERO

RESUMEN

Objetivo: El objetivo de este estudio es investigar el efecto de la aplicación combinada de polvo de roca y microorganismos promotores del crecimiento sobre la calidad química del suelo, con énfasis en el valor del pH y el contenido de materia orgánica del suelo.

Marco Teórico: La búsqueda de alternativas sostenibles para el manejo de la fertilidad del suelo ha estimulado el uso combinado de remineralizadores y microorganismos benéficos. De esta manera, la aplicación conjunta de polvo de roca y microorganismos promotores del crecimiento puede favorecer la solubilización mineral, resultando en un aumento del valor del pH del suelo y, conseqüentemente, en un mejor desempeño agronómico de los cultivos.

Método: El experimento se llevó a cabo en un invernadero, utilizando macetas con suelo de la capa superficial (0–20 cm) proveniente de un área no antropizada, cubierta con vegetación nativa. Se evaluaron cuatro dosis de polvo de roca (0, 1,0, 1,5 y 2,0 t ha⁻¹), aplicadas en presencia o ausencia del inoculante, en un diseño experimental de bloques al azar con cuatro repeticiones. La especie forestal utilizada fue *sombreiro* (*Clitoria fairchildiana* R. A. Howard) y el hongo *Trichoderma* spp.



Resultados y discusión: La aplicación de polvo de roca, solo o asociado con *Trichoderma* spp., aumentó los contenidos de materia orgánica del suelo y alteró su pH, principalmente en tratamientos sin inoculación, sin reflejarse en las variables relacionadas con el desarrollo del follaje.

Implicaciones de la investigación: Este estudio presenta el potencial de la combinación de remineralizadores y la microbiolización, indicando que es una estrategia eficiente para mejorar la fertilidad y la sostenibilidad de los suelos tropicales.

Originalidad/Valor: En este contexto, este artículo contribuye de manera innovadora al presentar evidencia de la mejora de la calidad química del suelo mediante la aplicación conjunta de polvo de roca y hongos *Trichoderma* spp. Asimismo, promueve una agricultura más sostenible al elegir una planta nativa en el modelo experimental, lo que amplía el uso agrícola regional y de bajo costo.

Palabras clave: Remineralizadores, Materia Orgánica Del Suelo, Microorganismos Promotores del Crecimiento, Especie Forestal.

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1 INTRODUCTION

The soils of Maranhão are predominantly characterized by a high degree of weathering, low cation exchange capacity (CEC), and reduced base saturation (Farias Filho *et al.*, 2020). These characteristics reflect the intense leaching process typical of tropical environments and impose significant restrictions on the establishment and development of agricultural and forestry crops of economic interest (Souza, 2006).

Understanding the physical and chemical attributes of soil is fundamental to the proper management and sustainability of agricultural and forestry systems. According to Ronquim (2020), factors such as pH, cation exchange capacity (CEC), base saturation, and organic matter content have a direct influence on soil quality. pH is related to both nutrient availability and the presence of potentially toxic elements. Organic matter acts as an important physical, chemical, and biological conditioner, contributing to increased CEC, improved soil structure, water retention, and gradual nutrient supply to plants (Voltr *et al.*, 2021).

A sustainable alternative for improving soil fertility is rock dusting, a practice that consists of applying finely ground rocks, classified by the Ministry of Agriculture and Livestock (MAPA) as remineralizers. These materials aim to recover low-fertility soils through the gradual supply of nutrients (Castro *et al.*, 2021). The remineralizer slowly releases basic cations and other essential elements, promoting an increase in pH, stimulating microbial activity, and intensifying the decomposition of organic matter, processes that favor the formation of humus



(Hellwig *et al.*, 2018). In addition, this technology reduces dependence on imported fertilizers and lowers production costs (Silva *et al.*, 2023).

In association with rock dusting, the use of growth-promoting fungi can enhance the effects on soil quality, accelerating the availability of essential elements. Carvalho *et al.* (2020) highlight that nitrogen-fixing strains increase the solubilization of minerals, influencing the pH and organic matter content of the soil. This interaction favors nutrition, but also plant resistance to biotic and abiotic stresses (Lima *et al.*, 2018). The mechanisms of action include the production of organic acids such as citric, malic, and oxalic acids and the release of enzymes that dissolve minerals present in rock dust, releasing nutrients present in the mineralogical composition of the rock (Adesemoye *et al.*, 2009).

In this context, the objective of this study is to evaluate the effect of the combined application of rock dust and growth-promoting microorganisms on soil chemical quality, focusing on variations in pH and organic matter content, as well as on the development of the forest species *Clitoria fairchildiana* R. A. Howard. The hypothesis is that the combined use of these inputs enhances mineral solubilization, promoting an increase in soil pH and, consequently, improving the performance of the species studied.

2 METHODOLOGY

The study was conducted in a greenhouse at the Agricultural Sciences Center of the State University of the Tocantina Region of Maranhão (CCA/UEMASUL), located in the municipality of Imperatriz, MA. The experiment was set up in a randomized block design, in a 4×2 factorial scheme, with four replicates, totaling eight treatments and 32 experimental units. Factor 1 corresponded to the doses of rock powder (0; 1.0; 1.5, and 2.0 t ha^{-1}) and factor 2 to the application of the inoculant, considered in two conditions: presence and absence.

The rock powder used was obtained from the São Francisco Quarry, located in the municipality of Porto Franco, MA. Chemical analysis of the material indicated the following contents: 51% silicon, 1.2% potassium oxide, 7.9% calcium oxide, 3.69% magnesium oxide, 0.005% cobalt, nickel, and molybdenum, 0.1% manganese, 0.17% chlorine, 7.37% iron, 0.1% zinc, and 0.1% boron.

The soil used was collected from an area of native, unaltered vegetation located at coordinates $5^{\circ}33'36.09'' \text{ S}$ and $47^{\circ}27'15.47'' \text{ W}$, at a depth of 0–20 cm. After homogenization, a 500 g subsample was sent to the laboratory for chemical analysis and tion (Table 1). The soil



was air-dried, crushed, and sieved through a 2 mm mesh, obtaining air-dried fine soil (TFSA). Each experimental unit received 1.0 dm³ of TFSA.

Table 1

Results of the chemical analysis of the soil used in the experiment.

pH	MO	P	Ca	Mg	K	Al	(H+Al)	SB	T	V
CaCl ₂	%	mg/dm ³	-----	-----	-----	cmol/dm ³	-----	-----	-----	%
4.7	1.42	2.0	1.84	1.34	0.17	0.0	3.40	3.35	6.75	49.6

*Collection depth between 0 and 20 cm. *The method used to extract available P was determined by the Mehlich 1 method. *The method used to determine organic matter was oxidation via potassium dichromate.

Source: Authors, 2024.

The doses of rock powder (0; 1.0; 1.5, and 2.0 t ha⁻¹) were applied according to the treatments, combined or not with the inoculant. After homogenization in plastic bags, the soil was moistened to maximum water retention capacity and incubated for 30 days in a greenhouse.

The inoculant used was the fungus *Trichoderma* spp., isolated and multiplied in a laminar flow chamber to avoid contamination. Small fractions were transferred to Erlenmeyer flasks containing rice as a substrate. After the fungus grew, the colonized material was suspended in distilled water at a ratio of 100 g of colonized rice to 2 L of distilled water, resulting in the suspension used in the microbiolization of the seeds.

The forest species *Clitoria fairchildiana* R. A. Howard (sombreiro), a pioneer species with rapid growth, was used as a test plant. The choice of species is justified by its ability to produce abundant fine and secondary roots, contributing to biomass accumulation and improving soil biological quality. The seeds were immersed in the suspension containing the *Trichoderma* spp. isolate for 24 hours before sowing. Subsequently, sowing was carried out in pots, kept under controlled greenhouse conditions, both in the presence and absence of the inoculant.

The experiment was irrigated according to water requirements. Fifty-five days after emergence, the plants were cut at the collar height, and the soil in each pot was turned over for the second stage of the experiment.

In the second stage, the shade tree seeds were replanted, following the same sowing and inoculation protocol adopted initially. The pots contained the same previously turned soil, allowing the evaluation of the persistence of the effects of rock powder and inoculant on plant development and soil chemical quality.



The variables evaluated in the seedlings were: collar diameter (D, in mm), measured with a caliper; height (H, in cm), measured with a 30 cm ruler; dry weight, obtained after drying in a forced-air oven at 35 °C for 72 h; number of leaves, determined by manual counting.

After cutting the aerial part, soil samples were collected and analyzed. The hydrogen ion potential (pH) was determined in a 0.01 mol L⁻¹ CaCl₂ solution, and organic matter was determined by the dry method in a muffle furnace, both according to Teixeira *et al.* (2017).

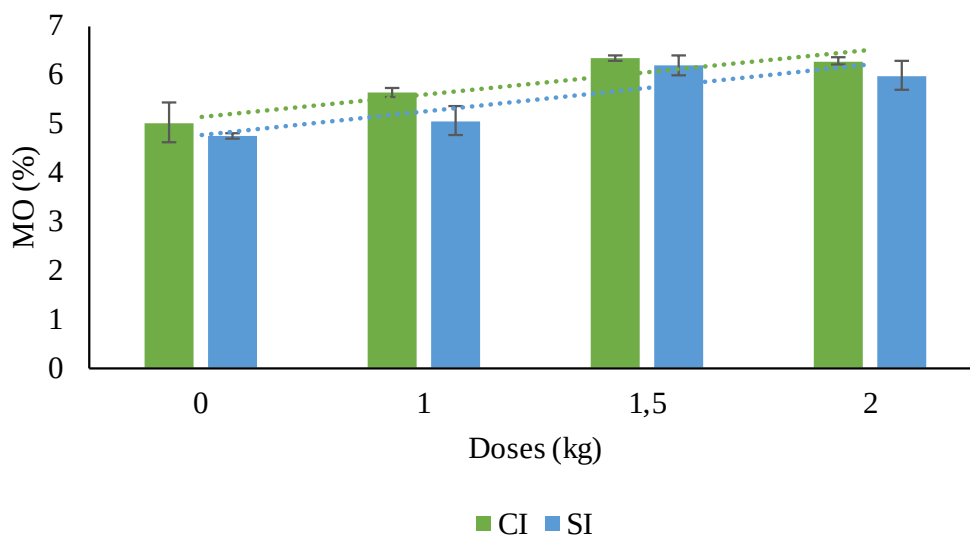
The results obtained were submitted to analysis of variance (ANOVA) in a factorial design (4 × 2), considering the treatments with and without inoculant (CI and SI) and the different doses of rock powder (0; 1.0; 1.5, and 2.0 t ha⁻¹). When significant effects were identified, the treatment means were compared using the F test ($p < 0.05$). The effect of the doses was evaluated by linear regression. The error bars in the graphs represent the standard error of the mean, calculated from the replicates. Statistical analyses were performed using SISVAR software.

3 RESULTS AND DISCUSSIONS

The results showed that the soil organic matter content increased after the cultivation of the shade tree species in all experimental units, ranging from 4.76% at the lowest dose of rock powder to 6.35% at the highest dose applied (Figure 1). Regression analysis indicated a positive linear trend for both inoculation treatments (CI), described by the equation $y = 0.499x + 4.7$ ($R^2 = 0.8653$), and non-inoculation treatments (SI), adjusted by $y = 0.479x + 4.3$ ($R^2 = 0.7924$), suggesting that the increase in OM content is associated with the doses of powder. No statistically significant differences were found between the treatments with inoculation (CI) and without inoculation (SI), regardless of the doses of rock powder that were applied (Figure 1).

**Figure 1**

Mean values of soil organic matter content (%) as a function of rock powder doses in treatments with inoculation (CI) and without inoculation (SI).



Source: Authors, 2025.

The higher coefficient of determination (R^2) observed in the inoculated treatments suggests an interaction between the remineralizer and the fungus. This interaction may be related to the ability of *Trichoderma* spp. to stimulate root growth, intensify microbial activity, and promote the solubilization of rock minerals and make nutrients available, resulting in greater supply and cycling of root biomass in the soil. Similar results were reported by Carvalho *et al.* (2020), Lima *et al.* (2018), and Adesemoye *et al.* (2009), who highlight the contribution of the fungus to improving soil fertility.

The increase in organic matter observed may be associated with the high production of fine and secondary roots of the forest species used. This biomass input favors root decomposition, releasing organic compounds that stimulate microbial activity and accelerate the formation of new organic matter stocks, as described by Staszal-Szlachta *et al.* (2024) and Ribeiro (2023).

However, the increase in OM content values in the experiment cannot be compared to the OM value expressed in Table 1, which corresponds to the content in the soil before the application of the treatments (1.4%), as the methodology for determining OM content was different. The method used to determine OM content in this experiment, muffle furnace combustion (dry method), considers the total loss of mass of the organic fraction present. For this reason, the values tend to be higher, since, in addition to structural water from minerals,

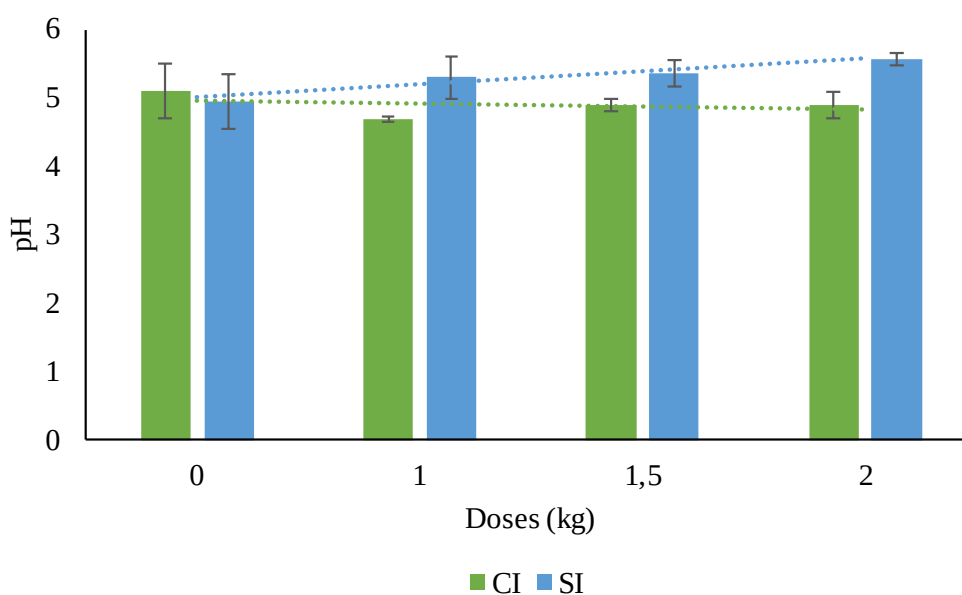


carbonates, and hydrated oxides can also be eliminated. The initial organic matter was determined using the wet oxidation method.

As for soil pH values, the results showed different behaviors between the CI and SI treatments (Figure 2). In the treatments with inoculation, the values decreased from 5.0 at the zero dose to 4.9 at the highest dose applied, adjusted by the equation $y = -0.04x + 5$ ($R^2 = 0.9299$). In the treatments without inoculation (SI), there was an increase in the pH value from 4.82 at the zero dose to 5.57 at the 2 t ha^{-1} dose, described by the equation $y = 0.189x + 4.825$ ($R^2 = 0.9299$). The results show that rock powder contributed to the neutralization of acidity in the treatments without inoculation, while microbial activity may have intensified acidification in the inoculated treatments.

Figure 2

Mean soil pH values as a function of rock powder doses in treatments with inoculation (CI) and without inoculation (SI).



Source: Authors, 2025.

The results can be explained by the gradual release of essential elements during the solubilization process of the minerals in the applied remineralizer. This process may have promoted partial acidity neutralization, as also observed by Melo *et al.* (2012) and Ribeiro (2010).

In treatments with inoculation, a reduction in pH from 5.0 to 4.9 was observed in the highest dose. This behavior may be associated with the high microbial activity promoted by the inoculant, which intensifies respiration and CO_2 release. According to Madeira & Ricardo



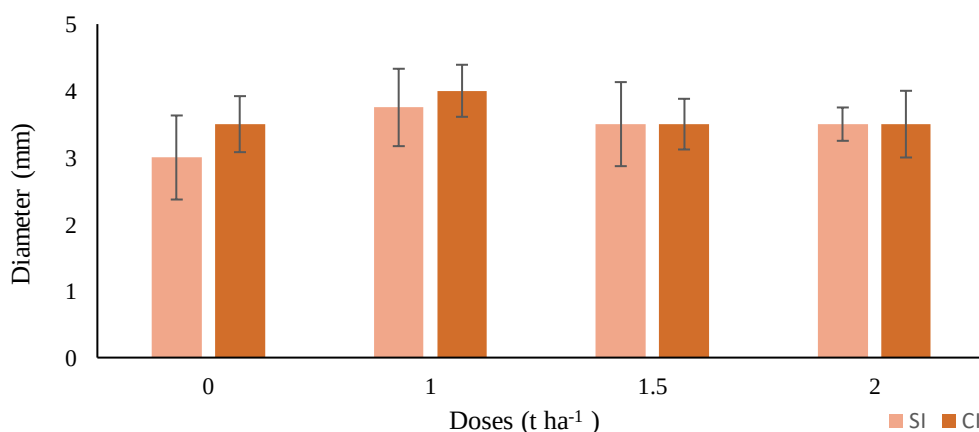
(2017), in the soil solution, this gas forms carbonic acid, increasing the concentration of H^+ and contributing to soil acidification.

When evaluating the effect of the combination of microbiolization and remineralizers on the shade tree species, no statistically significant differences were observed in the variables related to development, collar diameter, height, dry weight, and number of leaves.

The mean diameters ranged from 3.0 to 3.75 mm in the SI treatments and from 3.5 to 4.0 mm in the CI treatments (Figure 3). An increase in the average collar diameter was observed with the application of rock powder doses, compared to the control (0 t ha^{-1}); however, it was not possible to adjust an equation that described the response of the seedlings to the applied doses. These results are consistent with studies showing that the effects of *Trichoderma* spp. and remineralizers may be more evident in later stages of development or under prolonged cultivation conditions (Florentino *et al.*, 2017; Seidel *et al.*, 2022).

Figure 3

Mean values of the collar diameter of shade tree seedlings as a function of doses of rock powder with inoculation (CI) and without inoculation (SI) with *Trichoderma* spp.

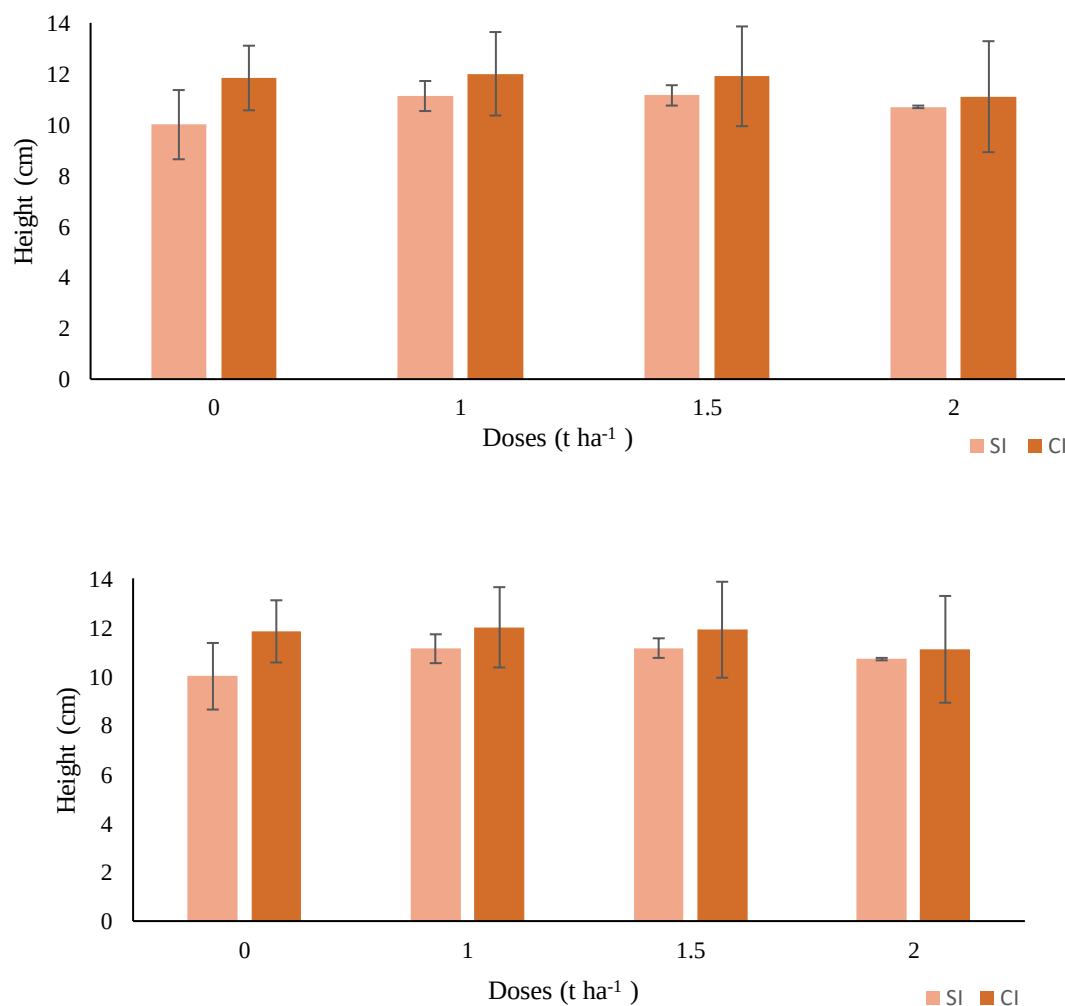


Source: Authors, 2025.

The average height of the seedlings also did not show significant differences between the CI and SI treatments at any of the doses. In the SI treatments, the averages ranged from 10.0 to 11.1 cm, while in the CI treatments they ranged from 11.1 to 12.0 cm (Figure 4). The absence of adjustment to mathematical models indicates that, under the conditions evaluated, the doses of rock powder associated with the inoculant had no effect on height growth. The result can be explained by the short evaluation period, as the 30-day post-germination stage corresponds to the beginning of plant establishment (Carvalho *et al.*, 2023).

**Figure 4**

Average heights of shade tree seedlings as a function of doses of rock powder with inoculation (CI) and without inoculation (SI) with *Trichoderma* spp.

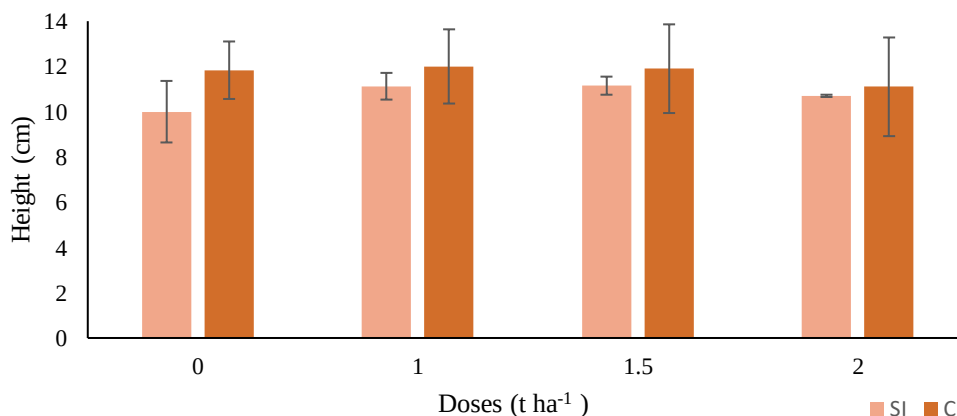


Source: Authors, 2025.

The average number of leaves ranged from 6.6 to 7.3 leaves per plant in the SI treatments and from 8 to 9.25 leaves in the CI treatments (Figure 5). Although not significant, the results suggest a trend toward increased leaf production with inoculation, possibly related to the biostimulating action of *Trichoderma* spp., which may favor the absorption of nutrients that are not readily available in remineralizers (Floram *et al.*, 2018; Silva *et al.*, 2023).

**Figure 5**

Mean values of the number of leaves of shade tree seedlings as a function of rock powder doses with inoculation (CI) and without inoculation (SI) with *Trichoderma* spp.

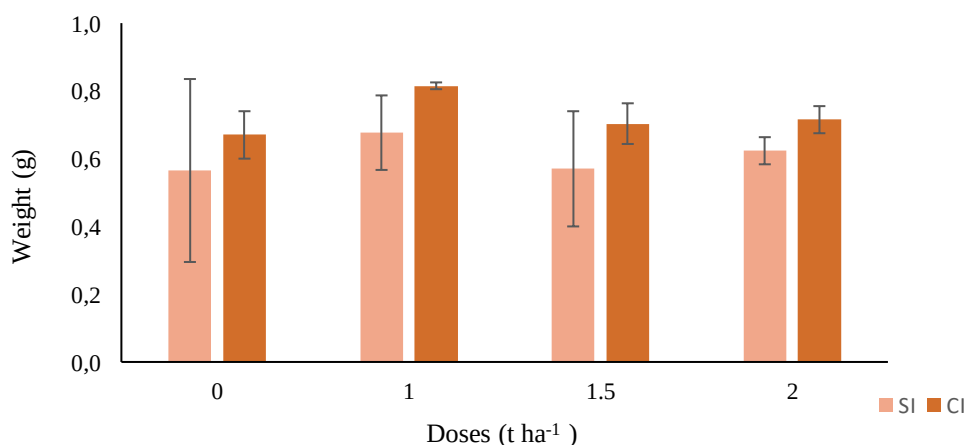


Source: Authors, 2025.

The weight of the aerial part of the seedlings also showed a tendency for higher dry mass in CI seedlings, indicating that the interaction between rock powder and *Trichoderma* spp. may have an initial effect on stimulating biomass (Figure 6). This behavior is consistent with the literature, in which native forest species showed greater growth and biomass accumulation after prolonged periods of cultivation with bio-inputs and remineralizers (Brito *et al.*, 2019; Floram *et al.*, 2018).

Figure 6

Mean dry weight values of the aerial part of shade tree seedlings as a function of rock powder doses with inoculation (CI) and without inoculation (SI) with *Trichoderma* spp.



Source: Authors, 2025.



The shade tree species, being a pioneer, has rapid initial growth, high plasticity, and biological nitrogen fixation capacity, characteristics that can enhance the response to the combination of rock dust and growth-promoting microorganisms (Souza *et al.*, 2007). Although the statistical effects were not significant, the trend toward an increase in the number of leaves and dry mass in inoculated seedlings suggests that the treatment may favor the initial development of the plant, especially under prolonged cultivation or field conditions.

Although there were no statistically significant differences in the development variables—height, collar diameter, number of leaves, and dry mass—the inoculated seedlings had slightly higher averages than the non-inoculated ones, which demonstrates the importance of the interaction between soil quality and plant performance in the early stages of growth (Floram *et al.*, 2018; Silva *et al.*, 2023).

5 CONCLUSION

The application of rock powder, alone or combined with the *Trichoderma* spp. inoculant, promoted changes in soil pH and soil organic matter without affecting the initial canopy development variables, including height, collar diameter, number of leaves, and dry mass. However, a tendency toward an increase in the parameters evaluated in the inoculated seedlings was observed, suggesting that the microbial activity stimulated by the inoculant may create soil chemical conditions more favorable to plant growth. These results indicate that the combination of rock powder and *Trichoderma* spp. represents an alternative for improving soil fertility and enhancing the development of forest seedlings.



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