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Technical viability of improving soil chemical characteristics by using biofertilizers

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ABSTRACT: Applying biofertilizers made from wastes from tropical forest agroextrativism to improve the fertility of acidic and nutrient-poor soils is a viable strategy for sustainable development of family farming in Brazil's North region. In this respect, the objective of this study was to evaluate the effect of applying biofertilizers based on locally available organic wastes on the fertility of a Dystrophic Yellow Latosol. The experiment was carried out in the Fazendinha experimental field of the Embrapa Amapá research unit, located in the municipality of Macapá, Amapá. We used a randomized block design with split-plots in space, with five replications. The plots consisted of seven fertilizations, with a control treatment (without fertilization) and six biofertilizers based on fresh cattle manure, shoot of *Cecropia* sp., leaves of *Gliricidia sepium* or *Inga edulis* and leaf sheath of *Euterpe oleracea* or pseudostem of *Musa* sp.; and the subplots were the two soil depths analyzed (0 to 2.5 and 2.5 to 5 cm). The biofertilizers promoted the correction of the soil acidity, increased the contents of organic matter, P, K^+, Ca^{2+}, Mg^{2+}, and raised the sum of bases, cation exchange capacity and base saturation percentage, especially in the surface layer. It was observed a reduction in the chemical limitations on the Dystrophic Yellow Latosol by applying biofertilizers based on locally available organic wastes and the increase in organic matter in the soil positively correlated with the increase in the levels of the beneficial chemical attributes of the Dystrophic Yellow Latosol.

Key words: chemical attributes; *Gliricidia sepium*; *Inga edulis*; organic matter; soil fertility

Viabilidade técnica do uso de biofertilizantes para melhoria das características químicas do solo

RESUMO: Desenvolver biofertilizantes com resíduos do agroextrativismo amazônico capazes de melhorar a fertilidade dos solos ácidos e pobres em nutrientes é uma estratégia viável para o desenvolvimento sustentável da agricultura familiar na Região Norte do Brasil. Nessa perspectiva, o objetivo deste estudo foi avaliar o efeito da aplicação de biofertilizantes, formulados à base de resíduos orgânicos localmente disponíveis, sobre a fertilidade de um LATOSSOLO AMARELO Distrófico. O experimento foi realizado no campo experimental da Fazendinha da Embrapa Amapá, Macapá, AP. Utilizou-se o delineamento em blocos casualizados com parcelas subdivididas no espaço, com cinco repetições. As parcelas foram compostas por sete fertilizações, sendo um tratamento controle (sem fertilização) e seis biofertilizantes formulados a base de esterco bovino fresco, parte aérea de *Cecropia* sp., folhas de *Gliricidia sepium* ou *Inga edulis* e bainha foliar de *Euterpe oleracea* ou pseudocaule de *Musa* sp.; e as subparcelas foram as duas profundidades do solo analisadas (0 a 2,5 e 2,5 a 5 cm). Os biofertilizantes promoveram correção da acidez do solo, incrementos do teor de matéria orgânica, P, K^+, Ca^{2+}, Mg^{2+}, soma de bases e capacidade de troca de cátions e elevação da porcentagem de saturação por bases, sobretudo na camada superficial. Observou-se redução das limitações químicas do LATOSSOLO AMARELO Distrófico pela aplicação de biofertilizantes baseados em resíduos orgânicos localmente disponíveis e o incremento no conteúdo de matéria orgânica correlacionou-se positivamente com o incremento nos níveis dos atributos químicos do LATOSSOLO AMARELO Distrófico.

Palavras-chave: atributos químicos; *Gliricidia sepium*; *Inga edulis*; matéria orgânica; fertilidade do solo

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Introduction

Brazil is one of the main food exporters in the world and this production is significantly dependent on fertilizer imports. The cost of fertilizers in different regions of Brazil is influenced by the demand ladder in each State. In the Brazil's North region due to the production chains geographic isolation and lower demand for fertilizers, high costs are observed, which limits the adoption and agricultural productivity. Alternatively, to improve agricultural productivity in these locations and reduce dependence on chemical fertilizers, highlights the use of organic fertilizers, especially compost and biofertilizer.

The application of biofertilizers containing microorganisms and biologically active compounds lowers the physical resistance of the soil (Dias et al., 2011) and the toxicity of herbicides (Rêgo et al., 2014), attenuates saline stress (Sousa et al., 2018), increases the biological control of diseases (Yu et al., 2019), reduces the harmful effects of heavy metals and stimulates beneficial microbial consortia (Shen et al., 2018; Wang et al., 2019a). The characteristics of biofertilizers are directly related to the inputs used and the stabilization process employed and the efficiency of biofertilizers varies in function of the physical, chemical and biological characteristics, the form, quantity and frequency of application and the predominant edaphoclimatic factors of the region (Musadji et al., 2020).

In Brazil's North region, the processing of lumber, cassava, açaí, nuts and fish generates large amounts of wastes with potential use as inputs for agriculture. Wastes from industrial processing of cassava in the Southern region of Brazil (Neves et al., 2017), poultry in the Northeast region of Brazil (Dias et al., 2015) and swine in the Southeast region of Brazil (Sediyama et al., 2014) have been used to produce biofertilizers, both aerobically and anaerobically, with positive effects on the growth and productivity of various crops.

In the state of Amapá (Western Amazon), high rainfall and temperature prevail, and the soils are typically weathered and acidic, with the presence of exchangeable aluminum, low availability of phosphorus and low levels of exchangeable bases (Melém Júnior et al., 2008). In this context, increasing the organic matter present in the soil is extremely important to increase the efficiency of applied fertilizers. The objective of this study was to evaluate the effect of applying biofertilizers based on locally available organic wastes on the fertility of a Dystrophic Yellow Latosol (Oxisol).

Materials and Methods

The experiment was conducted in the Fazendinha experimental field (0° 1' 1.5107" S, 51° 6' 35.1888" W) of the Embrapa Amapá research unit, located in Macapá, Amapá, during 2015. We used a randomized block design with split-plots in space, with five replications. The plots consisted of seven fertilization conditions, one a control with application only of water (B0) and six with biofertilizers, and two soil depths, 0 to 2.5 (Z1) and 2.5 to 5 cm (Z2). The biofertilizers were prepared with varied combinations of shoots of *Cecropia* sp. (CS), fresh cattle manure (CM), leaves of *Gliricidia sepium* (GS), leaves of *Inga edulis* (IE), external leaf sheathes of *Euterpe oleracea* (EO) and pseudostems of *Musa* sp. (PM). The compositions, in kilograms, were: B1- CM+EO (20+10); B2- CM+PM (20+10); B3- CM+GS+EO (10+10+10); B4- CM+GS+PM (10+10+10); B5- CM+IE+EO (10+10+10); and B6- CM+IE+PM (10+10+10). All compositions received 10 kg of CS.

The manure was obtained from a local slaughterhouse, the leaf sheathes of the açaí palm were obtained from a plant producing hearts of palm, and the other plant inputs were collected in the Fazendinha experimental field. All the organic wastes were previously ground in a forage grinder. The biofertilizers were produced aerobically, in water tanks with capacity of 310 L during 60 days, using 150 L of water. The mixture was aerated twice a day for 5 minutes. At the end of the biodigestion process, the solid and liquid fractions were separated by sieving through Sombrite screens and the liquid fraction was chemically analyzed to measure the pH and levels of P, K^+, Ca^{2+}, and Mg^{2+} (Table 1).

To evaluate the effects of applying the biofertilizers on the soil, PVC tubes with height of 500 mm and diameter of 100 mm were used to form columns of soil with depth of 400 mm. The base of each column was fitted with a polystyrene foam plug with thickness of 100 mm for stabilization. Soil samples (Dystrophic Yellow Latosol) were collected from an area with scrub vegetation at three depths (0-5, 5-20, and 20-40 cm) and were reconstituted in the columns respecting the original depths in the profile. The soil used had the following characteristics: pH in water 4.7, SOM 3.02 dag kg^{-1}, P 7 mg dm^{-3}, K^+ 0.10 $cmol_c$ dm^{-3}, Ca^{+2} + Mg^{+2} 1.8 $cmol_c$ dm^{-3}, H^+ + Al^{+3} 6.7 $cmol_c$ dm^{-3}, Al^{+3} 1.1 $cmol_c$ dm^{-3}, SB 1.9 $cmol_c$ dm^{-3}, CEC 8.6 $cmol_c$ dm^{-3}, clay 380, silt 230, sand 390 g kg^{-1}, at a depth of 0-20 cm. To stabilize the soil in the columns, corn was sown and water was applied for a period of 60 days to mimic the average annual rainfall (2,549 mm) of the municipality of Macapá. After the rain simulation, the corn plants were cut at the soil level without disturbing the soil columns.

Each experimental unit consisted of a soil column. Each column received 6 L of biofertilizer, divided into 0.5 L every seven days. At the end, soil samples were collected at depths Z1 and Z2 and chemically analyzed as described in the Soil

Table 1. Chemical characteristics of the biofertilizers produced with fresh cattle manure, shoot of *Cecropia* sp., leaves of *Gliricidia sepium*, leaves of *Inga edulis*, external leaf sheathes of *Euterpe oleracea* and pseudostems of *Musa* sp.

Treatments	pH	P	K^+	Ca^{2+}	Mg^{2+}
		(mg L^{-1})			
B1	7.00	51.62	640.86	249.77	123.93
B2	6.83	73.69	274.65	146.92	82.62
B3	7.87	49.27	1232.43	178.98	238.14
B4	7.23	65.00	964.81	200.35	278.64
B5	7.30	74.15	880.30	120.21	144.18
B6	7.17	50.21	556.35	142.92	81.81

B1- CM+EO (20+10); B2- CM+PM (20+10); B3- CM+GS+EO (10+10+10); B4- CM+GS+PM (10+10+10); B5- CM+IE+EO (10+10+10); and B6- CM+IE+PM (10+10+10).

Analysis Manual of Embrapa (Teixeira et al., 2017), to measure the following parameters: soil organic matter, SOM (dag kg^{-1}); pH; levels of P (mg dm^{-3}), K^+, Ca^{2+}, Mg^{2+}, H^+, Al^{3+}; sum of bases (SB); cation exchange capacity (CEC) ($cmol_c$ dm^{-3}); and base saturation percentage (BSP) (%).

The data were submitted to analysis of variance (ANOVA) and the Scott-Knott test was used to compare differences between means. Statistically significant differences were determined at the 5% probability level. Statistical analysis was conducted using the Sisvar software (Ferreira, 2014). Access to genetic materials was registered through the Brazilian National System for the Management of Genetic Resources and Associated Traditional Knowledge, of the Ministry of the Environment (SISGEN, MMA), under number AC967D1, according to Law 13,123/2015 and its associated regulations (Brasil, 2015).

Results and Discussion

The soil pH ($\bar{y}_{(B0)}$ = 4.94) was raised to neutrality with the application of biofertilizers ($6.8 \leq pH \leq 7.74$), both between 0 to 2.5 cm (Z1) and between 2.5 to 5 cm of depth (Z2) (Figure 1A). The soil acidity correction occurred because of the significant reduction of H^+ (≤ 3.98 $cmol_c$ dm^{-3}) and the total neutralization of Al^{3+} (Figure 1B), related to the high concentrations of bases and organic matter of the biofertilizers (Table 1). The long-term application of organic fertilizers can mitigate the acidification of an acidic soil, even when constantly exposed to disturbance of fertilization and irrigation, in a crop rotation system with application of organic and chemical fertilizer, alone or combined (Wang et al., 2019b).

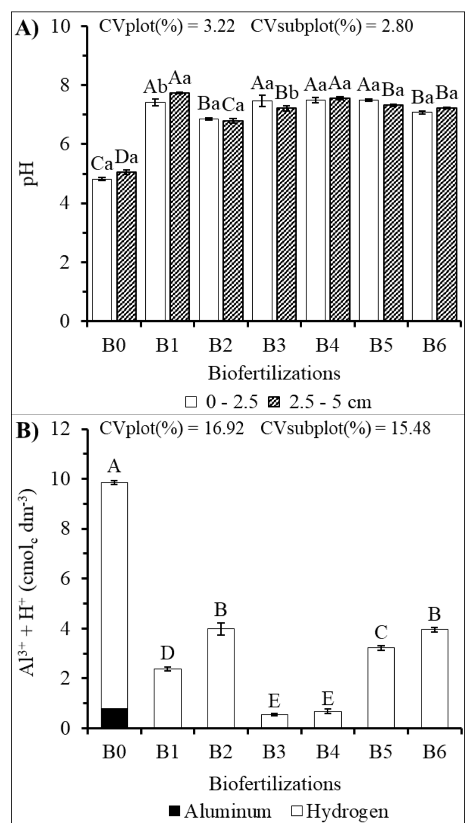
The levels of P were higher in Z1, especially in the treatments with EO ($\bar{y}_{(B1,\ B3\ and\ B5)}$ = 953.07 mg dm^{-3}), which exceeded by 67.3% the average content of P provided by the biofertilizers with PM (Figure 2A). These differences might have been related to the low allocation of dry matter and the high-water content of the PM, causing a low concentration of nutrients in this organ (Moreira & Fageria, 2009). The biofertilizers that received leaves of leguminous plants (B3, B4, B5 and B6) promoted greater leaching of P to Z2, an average of 31.8% of the total incorporated in the soil, in comparison with B1 and B2, which only promoted leaching of 21.6% and did not differ statistically from B0 (Figure 2A).

The low mobility of P is due to the high capacity for adsorption and complexation to the solid particles, especially in acidic soils. Acidic soils exposed to high rainfall, such as the Latosols in the Amazon region, can lose up to 91% of the available P due to surface runoff, even in no-till systems (Zanon et al., 2020), which reinforces the importance of mobilizing the nutrient in the soil profile. The continuous use of liquid biofertilizer can diminish the bond energy of P, reducing its adsorption and mobilizing it to deeper soil layers (Abboud et al., 2018).

The levels of K^+, Ca^{2+} and Mg^{2+} were significantly increased by application of the biofertilizers, with the highest increments occurring in Z1. The greatest increments of K^+ were provided by B3, both in Z1 and Z2, with 9.6 and 5.16 $cmol_c$ of K^+ dm^{-3}, respectively (Figure 2B). The increase of Ca^{2+} in Z1 was more pronounced in the biofertilizers containing *Gliricidia sepium* (B3 = 12.54 and B4 = 12.12 $cmol_c$ dm^{-3}) (Figure 2C), while the interaction of legumes with *Euterpe oleracea* Mart. (B3 and B5) ensured high levels Mg^{2+} in both Z1 and Z2 (Figure 2D).

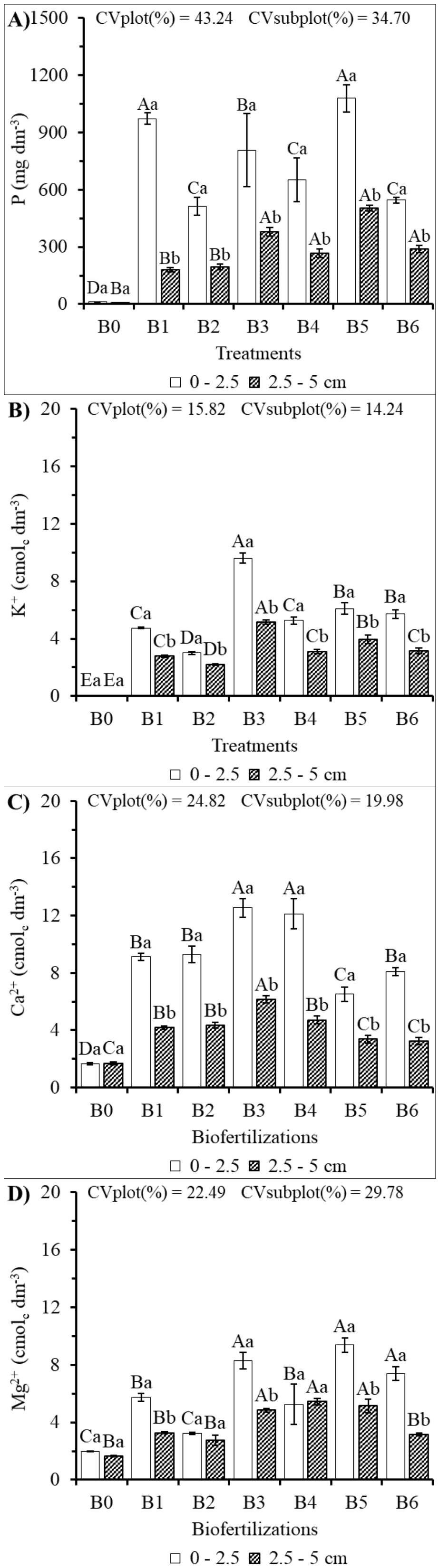
The application of the biofertilizers increased the values of SB and CEC more in Z1 than in Z2 ($p < 0.001$), with the highest increments being promoted by biofertilizer B3 (Figures 3A and 3B). The SB of the biofertilized soils exceeded that of B0 at both depths, while the CEC tended to be equal among the different treatments due to the high concentration of Al^{3+} + H^+ in the control, but without statistical differences in Z2, except for B3 and B5.

The BSP of the control treatment was 26.6%, while the fertilized soils exceeded 70% of saturation up to 5 cm in depth (Figure 3C). BSP promoted by biofertilizers in a Dystrophic Yellow Latosol are extremely relevant for the state of Amapá, where Latosols with BSP below 25%, high acidity, presence of Al3 + and low SB predominate (Melém Júnior et al., 2008). This recurring condition of the Latosols in the Amazon region restricts their use for agriculture, so the development of inexpensive inputs can positively affect the production systems adopted.



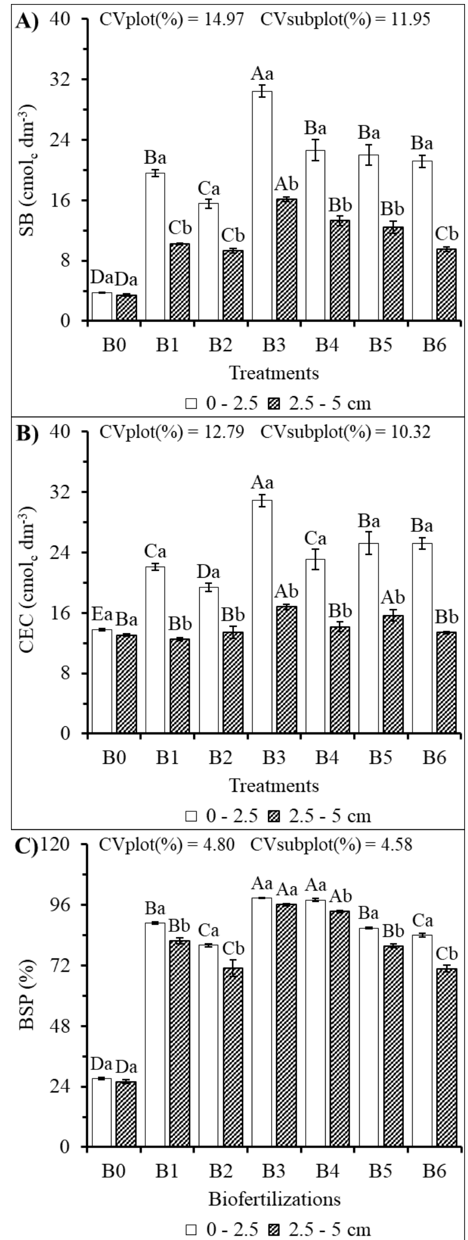
B0 - Without fertilization, B1- CM+EO (20+10); B2- CM+PM (20+10); B3- CM+GS+EO (10+10+10); B4- CM+GS+PM (10+10+10); B5- CM+IE+EO (10+10+10); and B6- CM+IE+PM (10+10+10). Different uppercase letters in the same fertilization differ statistically by the Scott-Knott test at 5% probability. CV - Coefficient of variation. Vertical bars represent the standard error (n=10).

Figure 1. Potential of hydrogen - pH (A) in soil depths from 0 to 2.5 (Z1) and 2.5 to 5 cm (Z2), and hydrogen - H^+ + Aluminum - Al^{3+} content (B) in soil depths from 0 to 5 cm under biofertilization.



B0 - Without fertilization, B1- CM+EO (20+10); B2- CM+PM (20+10); B3- CM+GS+EO (10+10+10); B4- CM+GS+PM (10+10+10); B5- CM+IE+EO (10+10+10); and B6- CM+IE+PM (10+10+10). Different uppercase letters in the same depth, and lowercase letters in the same fertilization, differ statistically by the Scott-Knott test at 5% probability. CV - Coefficient of variation. Vertical bars represent the standard error (n=5).

Figure 2. Phosphorus - P (A), potassium - K^+ (B), calcium - Ca^{2+} (C) and magnesium - Mg^{2+} (D) in soil depths from 0 to 2.5 (Z1) and 2.5 to 5 cm (Z2) under biofertilization.



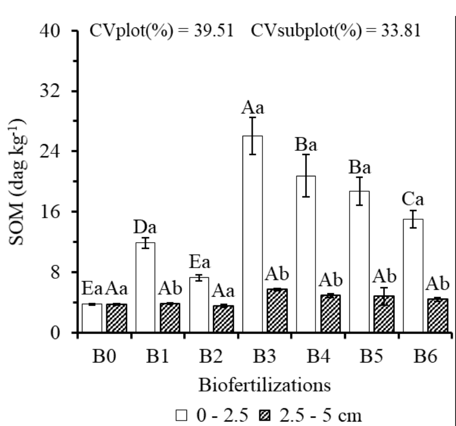
B0 - Without fertilization, B1- CM+EO (20+10); B2- CM+PM (20+10); B3- CM+GS+EO (10+10+10); B4- CM+GS+PM (10+10+10); B5- CM+IE+EO (10+10+10); and B6- CM+IE+PM (10+10+10). Different uppercase letters in the same depth, and lowercase letters in the same fertilization, differ statistically by the Scott-Knott test at 5% probability. CV - Coefficient of variation. Vertical bars represent the standard error (n=5).

Figure 3. Sum of bases - SB (A), cation exchange capacity - CEC (B) and base saturation percentage - BSP (C) in soil depths from 0 to 2.5 (Z1) and 2.5 to 5 cm (Z2) under biofertilization.

Gliricidia sepium was the common component in the composition of the biofertilizers that promoted the highest BSP. The agronomic efficacy of using *Gliricidia sepium* to formulate biofertilizers was reported by Alakhyar et al. (2019), since these formulations are able to supply the needs of different crops and maintain the soil fertility, especially when associated with cattle manure (Garrido et al., 2017). Since this species is a leguminous plant able to fix atmospheric nitrogen in symbiosis with rhizobia, besides being tolerant to water stress and easy to propagate, it is considered an important alternative to provide greater autonomy to and reduce the costs of family farmers (Primo et al., 2018).

The SOM in the Z1 layer increased significantly with application of the biofertilizers, except for B2 (Figure 4). At this depth, B3 promoted the highest level of SOM (26 dag kg^{-1}), exceeding by 24, 39, 73, 118, 256, and 590% the levels obtained by B4, B5, B6, B1, B2, and B0, respectively. In turn, at the Z2 depth, the SOM did not differ significantly among the treatments, with an average value of 4.4 dag kg^{-1}. The fact the difference between the treatments with and without biofertilization was only significant in the surface layer (Z1) indicates a limitation of the mobilization of SOM in the soil profile. Naturally, the surface layer of yellow latosol in the Amazon has the highest concentration of SOM, both in native forest areas (Tognon et al., 1998) and in no-till systems (Martins et al., 2012). This concentration is directly impacted by the annual rainfall and the type of vegetation in the area and reduces as the depth of the soil increases. Therefore, strategies to manage organic fertilization that enable mobilization of the SOM to deeper layers, such as the long-term use of biofertilizers, are important, especially because at the surface the material is highly subject to destabilization by the intense dynamics of the biosphere processes (Cagnarini et al., 2019).

The SOM level was positively correlated with the increases of pH and macronutrients (P, K^+, Ca^{2+}, and Mg^{2+}), and negatively with Al^{3+} + H^+, explaining the positive correlations with SB, CEC and BSP. The spatial dependence degree in the Z1 layer was high ($r = \geq 0.7$) while in Z2 it was moderate to strong ($0.5 \leq r \leq 0.7$) (Dancey & Reidy, 2019). There was a significant effect for all the parameters except pH in Z2 (Table 2). Because of the chemical diversity of the components, which promotes dissociation of the functional groups of the organic compounds and the capacity to alter the soil pH, increases in the levels of SOM cause greater stability of the organomineral complex and contribute most of the CEC of the surface layer of soils, in particular weathered tropical soils with low levels of clay and variable loads. Besides this, the decomposition of SOM is the main source in the soil solution of ionic forms of P available to plants (Troeh & Thompson, 2007).



B1- CM+EO (20+10); B2- CM+PM (20+10); B3- CM+GS+EO (10+10+10); B4- CM+GS+PM (10+10+10); B5- CM+IE+EO (10+10+10); and B6- CM+IE+PM (10+10+10). Different uppercase letters in the same depth, and lowercase letters in the same fertilization, differ statistically by the Scott-Knott test at 5% probability. CV - Coefficient of variation. Vertical bars represent the standard error (n=5).

Figure 4. Soil organic matter - SOM in soil depths from 0 to 2.5 (Z1) and 2.5 to 5 cm (Z2) under biofertilization.

According to Lehmann & Kleber (2015) the progressive evolution of soil quality is related to management of the turnover of SOM through the use of water-soluble organic compounds, associated with the continuous decomposition of residues in the soil. They further stated that increasing the knowledge about the soluble organic fractions, rather than just the stocks of stable humus, is essential to develop the ability to manage soil fertility.

Conclusions

The application of the liquid biofertilizers significantly raises the levels of SOM, P, K^+, Ca^{2+}, and Mg^{2+}, corrects the acidity and neutralizes the exchangeable aluminum of the Dystrophic Yellow Latosol, especially the surface layer.

The partial substitution of cattle manure by *Gliricidia sepium* or *Inga edulis*, together with leaf sheathes of *Euterpe oleracea* Mart., an important source of P, in the formulation of the biofertilizers promotes higher increases of K^+, Ca^{2+}, Mg^{2+}, SB, CEC, BSP, and SOM in the soil surface layer.

The SOM is positively correlated with the beneficial chemical attributes for fertility of the Dystrophic Yellow Latosol with application of the biofertilizers and can be used as an indicator of quality.

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Compliance with Ethical Standards

Author contributions: Funding acquisition: WLB, FSC; Investigation: WLB, FSC, ASM, NSF; Methodology: WLB, FSC; Supervision: WLB; Writing – review & editing: WLB, FSC, ASM, NSF.

Conflict of interest: The authors declare that they have no conflict of interest.

Table 2. Pearson's linear correlation between SOM and chemical attributes: pH, P, K^+, Ca^{2+}, Mg^{2+}, H^+ + Al^{3+}, SB, CEC, and BSP, at depths 0 to 2.5 (Z1) and 2.5 to 5 cm (Z2).

Z (cm)	pH H_2O (1:2.5)	P	K^+	Ca^{2+}	Mg^{2+}	Ca^{2+}+Mg^{2+}	Al^{3+}+ H^+	SB	CEC	BSP (%)
		($cmol_c$ dm^{-3})								
0-2.5	0.7**	0.5**	0.9**	0.7**	0.7**	0.8**	-0.7**	0.9**	0.9**	0.7**
2.5-5	0.3ns	0.7**	0.7**	0.6**	0.6**	0.7**	-0.5**	0.7**	0.7**	0.5**

ns and **, respectively, non-significant and significant at 1% probability.

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