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Effect of different soil fertilization regimes on soil chemical properties and maize grains yield in humid tropic

Efeito de diferentes regimes de fertilização do solo nas propriedades químicas do solo e na produtividade de grãos de milho em trópico úmido

Efecto de diferentes regímenes de fertilización del suelo sobre las propiedades químicas del suelo y el rendimiento de granos de maíz en el trópico húmedo

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Abstract
Nutrients contained in soil play a fundamental role in plants development. Then, we hypothesize that different soil fertilization regimes modify soil chemical attributes and maize grains yield. This study aimed to evaluate soil chemical attributes in different soil fertilization regimes and their relation to maize grains yield. The experiment was performed in Maranhão state, Brazil. The area was divided into 32 plots of 4x10 m with seven treatments and the control, with four replicates (R) in a randomized block design. The following treatments were performed: *Gliricidia sepium* – gliricidia (G), potassium (K), humic acid (HA), humic acid+potassium (HA+K), potassium+gliricidia (K+G), humic acid+gliricidia (HA+G), humic acid+potassium+gliricidia (HA+K+G) and uncovered soil (US). Each plot was cropped with maize (*Zea mays* L.) and the grains yield was estimated. Soil samples were collected from each plot at depths of 0–5 cm, 5–10 cm and 10–20 cm. Potential acidity, pH, soil organic carbon (SOC), exchangeable K^+, Ca^{2+} and Mg^{2+}, available P, cation exchange capacity (CEC), sum of basic cations (SBC) and base saturation (BS) were determined. One-way ANOVA with Duncan post-test and principal component analysis (PCA) were used. Exchangeable K^+, Ca^{2+} and Mg^{2+}, pH and CEC were related to maize grains yield in upper soil layer especially in plots with gliricidia. Then, this research confirms the hypothesis that different soil fertilization regimes modify soil chemical attributes and maize grains yield.
Keywords: Green manure; Gliricidia; Principal component analyses; Maize yield.

Resumo
Nutrientes contidos no solo desempenham papel fundamental no desenvolvimento das plantas. Então, hipotetizamos que diferentes regimes de fertilização do solo modificam atributos químicos do solo e produtividade de grãos de milho. Este estudo objetivou avaliar atributos químicos do solo em diferentes regimes de fertilização e sua relação com a produtividade de grãos de milho. O experimento foi realizado no estado do Maranhão, Brasil. A área foi dividida em 32 parcelas de 4x10m com sete tratamentos e testemunha, com quatro repetições (R) em delineamento de blocos casualizados. Foram realizados os seguintes tratamentos: *Gliricidia sepium* – gliricídia (G), potássio (K), ácido húmico (HA), ácido húmico+potássio (HA+K), potássio+gliricídia (K+G), ácido húmico+gliricídia (HA +G), ácido húmico+potássio+gliricídia (HA+K+G) e solo descoberto (US). Cada parcela foi cultivada com milho (*Zea mays* L.) e a produtividade de grãos foi estimada. Amostras de solo foram coletadas de cada parcela nas profundidades 0–5 cm,

5–10 cm e 10–20 cm. Acidez potencial, pH, carbono orgânico do solo (COS), K^+ trocável, Ca^{2+} e Mg^{2+}, P disponível, capacidade de troca catiônica (CEC), soma de cátions base (SBC) e saturação por bases (BS) foram determinadas. ANOVA one-way com pós-teste de Duncan e análise de componentes principais (PCA) foram utilizadas. K^+, Ca^{2+} e Mg^{2+} trocáveis, pH e CEC foram associados à produtividade de grãos de milho na camada superior do solo, especialmente em parcelas com gliricídia. Esta pesquisa confirma a hipótese de que diferentes regimes de fertilização do solo modificam os atributos químicos do solo e a produtividade de grãos de milho.
Palavras-chave: Manejo verde; Gliricidia; Análise de components principais; Produtividade do milho.

Resumen

Nutrientes contenidos en el suelo juegan un papel fundamental en el desarrollo de las plantas. Entonces planteamos la hipótesis de que diferentes regímenes de fertilización del suelo modifican los atributos químicos del suelo y el rendimiento de los granos de maíz. Este estudio tuvo como objetivo evaluar los atributos químicos del suelo en diferentes regímenes de fertilización y su relación con el rendimiento de grano de maíz. El experimento se realizó en el estado de Maranhão, Brasil. El área se dividió en 32 parcelas de 4x10m con siete tratamientos y testigo, con cuatro repeticiones (R) en un diseño de bloques al azar. Se realizaron los siguientes tratamientos: *Gliricidia sepium* – gliricidia (G), potasio (K), ácido húmico (HA), ácido húmico+potasio (HA+K), potasio+gliricidia (K+G), ácido húmico+gliricidia (HA+G), ácido húmico+potasio+gliricidia (HA+K+G) y suelo descubierto (US). Cada parcela se sembró con maíz (*Zea mays* L.) y se estimó el rendimiento de granos. Se recolectaron muestras de suelo de cada parcela a profundidades 0–5cm, 5–10cm y 10–20cm. Se determinaron acidez potencial, pH, carbono orgánico del suelo (COS), K^+ intercambiable, Ca^{2+} y Mg^{2+}, P disponible, capacidad de intercambio de cationes (CEC), suma de cationes básicos (SBC) y saturación de bases (BS). ANOVA de una vía con post-test de Duncan e análisis de componentes principales (PCA) se realizaron. K^+ intercambiables, Ca^{2+}, Mg^{2+}, pH y CEC se relacionaron con el rendimiento de granos de maíz en la capa superior del suelo, especialmente en parcelas con gliricidia. Entonces, esta investigación confirma la hipótesis de que diferentes regímenes de fertilización del suelo modifican los atributos químicos del suelo y el rendimiento de los granos de maíz.
Palabras clave: Abono verde; Gliricidia; Análisis de componentes principales; Rendimiento de maíz.

1. Introduction

Soils are considered essential for life on earth (Brady & Weil, 2008; Kopittke et al., 2019), offering diverse ecosystem services. They are result of association between biotic and abiotic factors, and the macro and micronutrients contained in them play a fundamental role in plants development (Morar & Peterlicean, 2014). Ehrenfeld et al. (2005) point out that this influence that soils different cause on agricultural yield was already observed by ancient civilizations such as the Mayans and the Romans and that it is necessary to understand both soils and plants to know better the interactions between them. In this sense, chemical attributes of soil quality need investigations because they are related to soil ability to provide nutrients to plants (Wang & Yang, 2003; Qu et al. 2019).

In this context, the concentration and combination of mineral nutrients into the soil influence plants growth and development, which encounter some difficult to obtain the adequate supply of these nutrients due to their relative immobility. If one of nutrients is not in proper concentration, plant productivity may decrease, leading to decline in crop yield (Morgan & Connolly, 2013).

According to Liu et al. (2010b), soil chemical properties changes are influenced by fertilization practices over time. Bulluck III et al. (2002) and Głąb and Gondek (2014) also point out the relevance of fertilization and they consider that the use of organic or synthetic fertilizer modify macronutrients concentrations. Morar and Peterlicean (2014) affirm that chemical fertilizers are more efficient to increase plant production than organic fertilizers, although the latter enhance soil structure. On the other hand, some research show that organic fertilizers increase the soil nutrients availability and fertility (Ordóñez-Fernández et al., 2015; Zhang et al., 2019a) and that their benefits for soil depend on their addition rates and composition (Arif et al., 2016). A better understanding about which fertilizer should be used to ensure high crop yields is needed, especially in cohesive soil (Moura et al., 2012), with low fertility, such as the soil studied in this research.

Maize (*Zea mays* L.), for example, is a very demanding crop (Ehsanullah et al., 2015). Without an adequate supply of nutrients in low fertility soils as most tropical soils, this specie would not produce high grains yield. According to Srivastava et al. (2018), this crop is one of most important food crops in the world and its yield increases in according to soil fertilization regime, among some other factors.

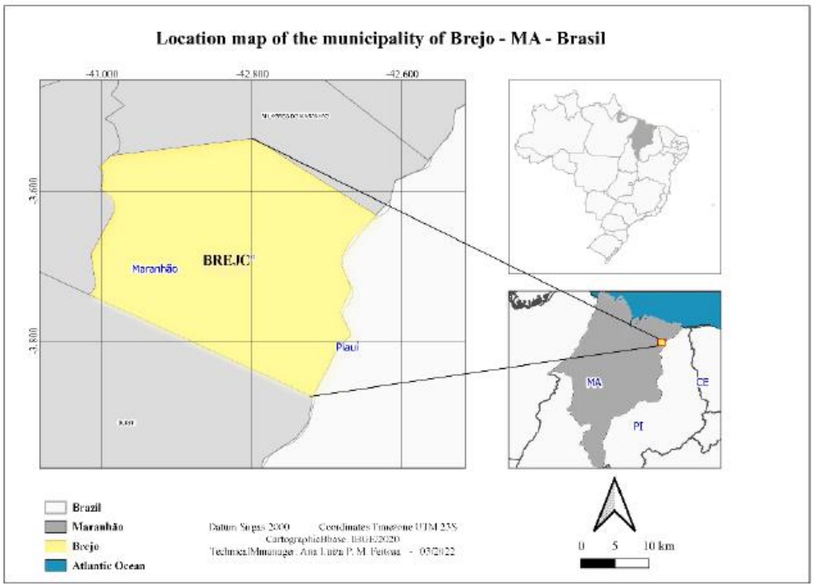
In this context, we hypothesize that different soil fertilization regimes modify soil chemical attributes and maize grains yield. Since that these interactions need further studies because may enhance crop yield, this study aimed to evaluate soil chemical attributes in different soil fertilization regimes and their relation to maize grains yield.

2. Methodology

2.1 Study Site

The experiment was performed at Brejo city, located in Maranhão state, Brazil (3º38' S, 42°58' W) (Figure 1). The climate is humid tropical with 1200-1400 mm of average annual precipitation and average annual temperature is above 27° C. The soil is classified as Arenic Hapludult (Soil Survey Staff, 2010), presenting a flat topography (slope < 1%) with the following characteristics: pH 4.4 (0.01 M $CaCl_2$); organic C 15.5 g kg^{-1}; potential acidity 4.7, and CEC 7.9 mmol(c) dm^{-3}; Ca 2.6, Mg 0.5, and K 0.1 mmol(c) dm^{-3}; P 3.7 g dm^{-3} (resin); base saturation 40.2%; and a sandy textural class.

Figure 1. Location of the municipality where the research was carried out.



Source: Authors.

The experimental area was established in 2012 and consists of an alley crop system with Gliricidia (*Gliricidia sepium*), planted with an inter-row spacing of 4 m and an inter-plant spacing of 0.5 m.

In 2015, between the rows of the legume, the area was divided into 32 plots of 4x10 m with seven treatments and the control, with four replicates (R) in a randomized block design. The following treatments were performed: *Gliricidia sepium* – gliricidia (G), potassium (K), humic acid (HA), humic acid+potassium (HA+K), potassium+gliricidia (K+G), humic acid+gliricidia (HA+G), humic acid+potassium+gliricidia (HA+K+G) and uncovered soil (US).

The pruning of the legume was carried out and the green matter was separated to be used in the treatments with gliricidia. In these treatments were applied 15 t ha^{-1} of biomass of the legume. In the treatments that received potassium were applied 78 kg ha^{-1} of KCl, while in treatments with humic acid were applied 500 l ha^{-1} of this substance. All treatments received 120 kg ha^{-1} of P_2O_5, 60 kg ha^{-1} of N e 25 kg ha^{-1} of $ZnSO_4$. These doses were defined according to the result of the soil analysis.

2.2 Maize Grains Yield

Each plot was cropped with maize (*Zea mays* L.), variety QPM BR 473, in March 2015 in a total area of 1,280 m². At physiological maturity, ten cobs were collected from each plot, and their grains were extracted. The grains yield was estimated in Mg ha^{-1} from the total grain mass in each plot and the number of plants per hectare.

2.3 Soil Chemical Attributes

Soil samples were collected with a duty auger, at depths of 0–5 cm, 5–10 cm and 10–20 cm from each plot in July 2015. In the laboratory, each sample was analyzed to determine pH (0.01 M $CaCl_2$ suspension, 1:2.5 soil/solution, v/v), soil organic carbon (SOC) (Walkley-Black), exchangeable K, Ca, Mg (resin) and potential acidity (H + Al) (SMP method) according Raij et al. (2001). For K^+ determination, UV–Vis spectrophotometry was used. Available P was determined by the Mehlich 1. We determined the cation exchange capacity ($CEC = K^+ + Ca^{2+} + Mg^{2+} + H^+ + Al^{3+}$) and the sum of basic cations ($SBC = K^+ + Ca^{2+} + Mg^{2+}$), and these were used to calculate base saturation ($BS = [SBC / CEC] \cdot 100$).

2.4 Statistical analyses

For statistical analysis, the one-way ANOVA was conducted to determine the significance of the difference in means of chemical attributes and maize grains yield. Distributions of all variables were assessed using the Shapiro-wilk test, and they were transformed before analysis where necessary to achieve normal distributions. Duncan test was used to determine which differences are significant. Principal component analysis (PCA) was used, after standardization of data, with the main objective of identify the principal chemical attributes associated with maize yield. Statistica version 7 (Statsoft Inc., 2004) was used in all analyses.

3. Results

3.1 Maize grains yield

The maize grains yield was significantly higher in all treatments that received gliricidia (G, K+G, HA+K+G and HA+G) than in treatments that did not receive it (HA+K, K, HA and US) ($p < 0.05$) (Table 1).

Table 1. Maize grains yield in different treatments.

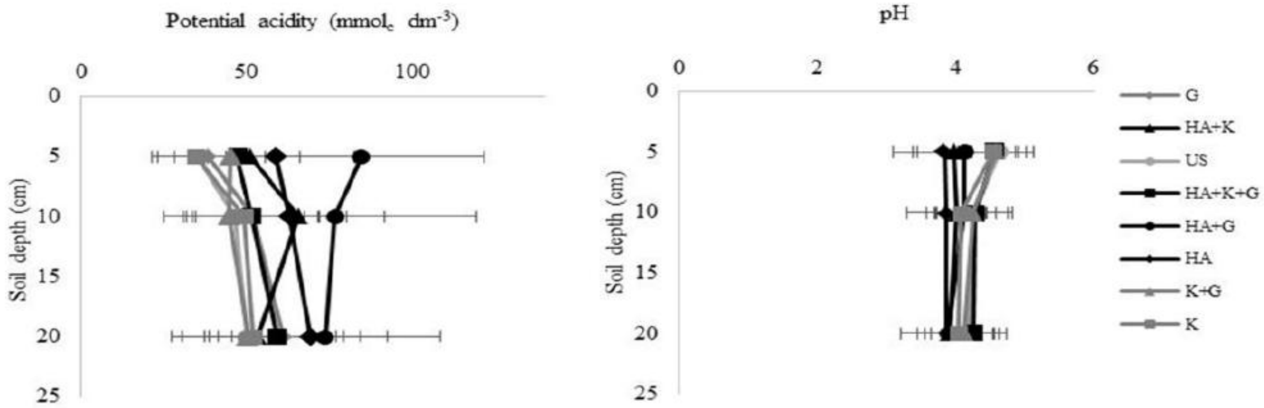
Treatment	Grain yield (Mg ha^{-1})
G	5.21 a
HA+K	3.06 b
K+G	5.17 a
K	2.81 b
HA+K+G	4.61 a
HA+G	4.91 a
HA	1.90 b
US	3.03 b

Distinct letters indicate significant differences (ANOVA with Duncan's test, $p < 0.05$). G: gliricidia, HA+K: humic acid+potassium, K+G: potassium+gliricidia, K: potassium, HA+K+G: humic acid+potassium+gliricidia, HA+G: humic acid+gliricidia, HA: humic acid, US: uncovered soil.
Source: Authors.

3.2 Effect of different soil fertilization regimes on soil chemical properties

Within the 0–20 cm soil layer, potential acidity showed a tendency to increase with increasing soil depth, except at HA+K, K+G and HA+G. The HA+G treatment had significantly greater concentrations in potential acidity than all other treatments ($p < 0.05$) at 0–5 cm soil depth, with increases of 26.1 to 50.1 mmol$_c$ dm^{-3}. There was no significant difference between treatments at 5–20 cm soil layer ($p > 0.05$) (Figure 2).

Figure 2. Effects of different soil fertilization regimes on potential acidity and pH at different soil depths. Horizontal bars indicate standard deviation ($p < 0.05$).

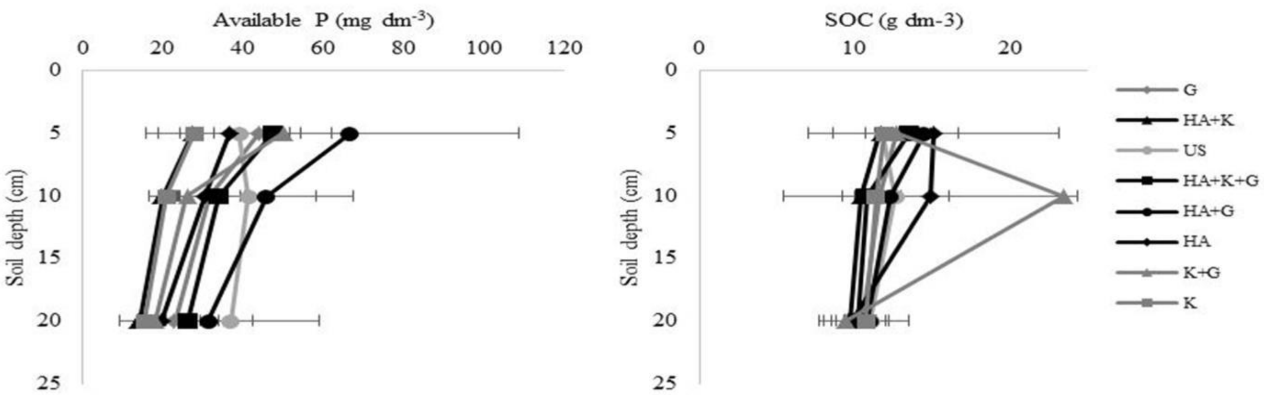


Source: Authors.

pH was the largest in the upper soil layer (0–5 cm) and showed a tendency to decrease with increasing soil depth at G, K+G, K and US. pH was significantly greater in G treatment than in HA+K and HA ($p < 0.05$), with increases of 0.6 and 0.8 at 0–5 cm soil depth, respectively. The treatments did not change the pH levels at 5–20 cm soil depth ($p > 0.05$) (Figure 2).

The available P concentrations were the largest in the upper soil layer (0–5 cm) and showed a tendency to decrease with increasing soil depth, except at US, where the depth of 5–10 cm showed the highest content. The HA+G treatment had significantly greater values in available P than HA+K, K, US, HA+K+G and HA ($p < 0.05$), with increases of 39.4, 38.7, 27.5, 19.2 and 30.0 at 0–5 cm soil depth, respectively. The different treatments did not change the available P levels within 5–20 cm soil depth ($p > 0.05$) (Figure 3).

Figure 3. Effects of different soil fertilization regimes on available P and SOC at different soil depths. Horizontal bars indicate standard deviation ($p < 0.05$).



Source: Authors.

The SOC concentrations showed a tendency to decrease with increasing soil depth, except at K+G e US. However, within the 0–20 cm soil layer no significant difference in SOC concentrations was observed between treatments ($p > 0.05$) (Figure 3).

The use of HA+K, K+G and HA+K+G recorded a significantly highest concentration of K^+, leading to increases between 0.4 and 1.0 mmol$_c$ dm^{-3} compared with G, US and HA at 0–5 cm soil depth ($p < 0.05$). The use of G, K+G and K resulted in significantly highest concentrations of Ca^{2+} compared with HA+K and HA, with increases between 2.2 and 7.2 mmol$_c$ dm^{-3} at 0–5 cm soil depth ($p < 0.05$). Compared with HA+K and HA, the Mg^{2+} concentrations resulted in significant increments between 7.5 and 9.8 mmol$_c$ dm^{-3} at K+G and HA+K+G at 0–5 cm soil depth ($p < 0.05$). No significant difference in the K^+, Ca^{2+} and Mg^{2+} concentrations was recorded in the 5–20 cm soil layer ($p > 0.05$) (Table 2).

Compared with HA alone, G, K+G and K treatments showed significant increases of 16.65, 9.36 and 9.65 mmol$_c$ dm^{-3} in SBC at 0–5 cm soil depth, respectively ($p < 0.05$). Compared with K and US, treatments with HA+G and HA resulted in significant increments between 14.30 and 44.48 mmol$_c$ dm^{-3} in CEC at 0–5 cm soil depth ($p < 0.05$). The use of G, K+G, K and HA+K+G recorded a significantly highest BS concentration, leading to increases between 10.43 and 28.19 mmol$_c$ dm^{-3} compared with HA+G and HA at 0–5 cm soil depth ($p < 0.05$). No significant difference in SBC, CEC and BS concentrations was recorded in the 5–20 cm soil layer between all the treatments (Table 2).

Table 2. Effects of different soil fertilization regimes on K^+, Ca^{2+}, Mg^{2+}, SBC, CEC and BS.

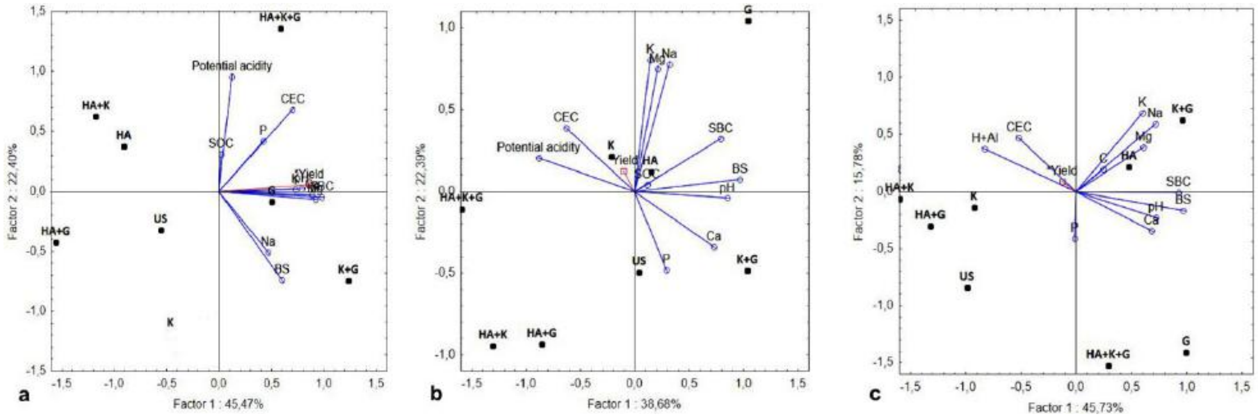
Soil depth	Treatment	K^+	Ca^{2+}	Mg^{2+}	SBC	CEC	BS
		mmol$_c$ dm^{-3}					
0 – 5	G	1,3±0,4b	32,5±5,0a	16,3±6,0b	50,01±7,93a	88,45±5,76ab	57,28±16,41a
	HA+K	2,0±0,5a	25,3±10,3c	6,8±0,8c	37,00±15,08ab	87,88±9,23ab	41,07±14,61ab
	K+G	1,7±0,5a	28,0±0,4a	14,3±0,3a	42,99±6,67a	88,10±6,76ab	49,87±21,74a
	K	1,5±0,3ab	29,0±0,5a	12,5±0,2b	43,01±6,17a	77,64±1,71b	55,53±12,36a
	US	1,0±0,2b	30,8±7,2ab	9,0±2,9bc	40,71±6,79ab	75,55±3,98b	54,30±13,63ab
	HA+K+G	1,7±0,6a	26,0±12,4ab	15,0±1,1a	42,72±9,34ab	89,83±7,85ab	48,63±16,71a
	HA+G	1,9±1,3ab	23,8±17,0ab	9,8±2,8bc	35,35±21,38ab	120,03±29,18a	29,09±13,45b
	HA	1,1±0,5b	25,8±8,1c	6,5±1,5c	33,36±4,20b	91,94±29,42a	38,20±15,29b
5-10	G	1,1±0,5a	26,3±5,7a	12,0±6,6a	39,33±10,76a	91,35±9,80a	44,26±16,04a
	HA+K	1,2±0,8a	16,8±5,6a	19,3±12,6a	37,42±13,66a	102,82±10,97a	36,35±13,14a
	K+G	1,1±0,2a	22,5±11,3a	8,3±5,8a	31,80±5,04a	76,26±17,81a	43,45±11,17a
	K	0,9±0,1a	22,5±6,2a	10,5±8,0a	33,91±8,83a	83,19±9,01a	41,78±13,73a
	US	0,8±0,2a	30,3±10,4a	6,3±8,8a	37,25±10,86a	83,50±12,43a	46,36±18,01a
	HA+K+G	1,2±0,4a	25,5±8,3a	9,0±6,1a	35,72±8,67a	86,95±14,37a	42,90±16,44a
	HA+G	0,9±0,1a	17,8±11,5a	10,0±5,4a	28,67±14,50a	105,15±46,74a	28,16±15,54a
	HA	0,9±0,4a	20,0±5,7a	6,3±5,8a	27,19±8,54a	90,19±22,66a	32,75±16,41a
10-20	G	0,9±0,8a	24,8±12,8a	5,8±5,6a	31,40±15,07a	92,33±9,05a	35,31±19,33a
	HA+K	2,2±1,8a	20,5±5,3a	11,0±7,7a	33,74±15,08a	87,06±14,73a	41,30±25,18a
	K+G	1,2±0,7a	18,0±10,0a	6,0±3,0a	25,17±7,91a	75,62±23,79a	35,11±11,06a
	K	0,9±0,1a	20,8±6,3a	9,5±7,8a	31,17±10,18a	82,94±10,31a	38,64±15,25a
	US	1,2±0,8a	24,3±3,9a	8,0±2,7a	33,46±6,37a	83,35±13,34a	41,90±14,81a
	HA+K+G	1,0±0,4a	19,8±11,6a	10,8±5,1a	31,48±8,81a	90,60±9,09a	35,79±13,86a
	HA+G	0,9±0,8a	15,5±7,9a	7,8±2,7a	24,19±9,48a	97,84±36,09a	26,31±11,58a
	HA	0,8±0,8a	15,8±5,2a	5,3±2,0a	21,81±6,06a	91,02±19,15a	25,44±11,09a

Distinct letters by column in each soil depth indicate significant differences (ANOVA with Duncan test, $p < 0.05$). Abbreviations: G (gliricidia), HA+K (humic acid+potassium), K+G (potassium+gliricidia), K (potassium), US (uncovered soil), HA+K+G (humic acid+potassium+gliricidia), HA+G (humic acid+gliricidia), HA (humic acid). Source: Authors.

3.3 Relations between different soil fertilization regimes, soil chemical attributes and maize grains yield

K^+, pH, Ca^{2+}, Mg^{2+}, SBC and CEC showed positive correlations with maize grains yield only in the 0–5 cm soil depth, especially in treatments with gliricidia (Figure 4a). Available P, potential acidity, SOC and BS did not show any correlation with maize grains yield in the soil profile (0–20 cm) (Figures 4a, 4b and 4c).

Figure 4. Results of principal components analysis at 0–5 cm (a), 5–10 (b) and 10–20 (c) soil depth in different soil fertilization regimes.



Source: Authors.

The following attributes showed a positive correlation in soil profile (0–20 cm): potential acidity and CEC; pH and SBC; Ca, SBC and BS; and Mg^{2+} and SBC. Available P and SOC did not show any correlation with other attributes in the soil profile (0–20 cm) (Figures 4a, 4b and 4c).

4. Discussion

4.1 Maize grain yield

The maize grains yield was significantly higher in treatments that received gliricidia than in those that did not receive it ($p < 0.05$). According to Kamara et al. (2000), the increased maize yield is attributed to the presence of gliricidia because this legume has high nitrogen content and is fast decomposing, favouring crop development. Rao and Mathuva (2000) also showed that green manuring with gliricidia increased maize yield in an experiment conducted in Kenya. For Sakala and Mhang (2003), green manures may increase not only maize yield but also soil fertility. Zhong et al. (2018) emphasize the importance of green manure using legumes, which alter soil bacterial community structure, enhancing soil fertility. Afolayan & Oyetunji (2018) point out that besides improving soil structure, organic materials increase the soil organic carbon content, then enhancing crop yield.

4.2 Effect of different soil fertilization regimes on soil chemical properties

According to Liu et al. (2010b), soil chemical properties are very influenced by soil management practices such as fertilization. This happens because fertilization alters soil composition. In the present study we also find these results.

In general, while pH showed a tendency to decrease with increasing soil depth, potential acidity increased. Potential acidity considers hydrogen ions of various chemical combinations and adsorbed on the solid particles surfaces, but pH only considers hydrogen ions (Allaway, 1957). Then, the values are usually inversely proportional. As well as in research made by Davenport et al. (2003), we obtained significant differences in pH between treatments in upper soil layer. The significantly higher pH levels found at G treatment ($p < 0.05$) are in agreement with Awodun et al. (2007) and Mweta et al. (2007), which showed that gliricidia residues reduced soil acidity by increasing in pH. In highly weathered soils, as the soil researched in present study, Sakala et al. (2004) affirm that this effect caused by leguminous is much more evident. For them, the possibility of these plants improve soil acidity is influenced by their potential alkalinity and potential to release N minerals.

The available P concentrations tended to decrease with increasing soil depth, as was recorded by Milić et al. (2019), for which available P receive a great human influence at agricultural systems. Furthermore, plants composition influences nutrients redistribution through the soil, and this may be exemplified by phosphorus presence in high concentrations in vegetable tissues and also in upper soil layer (Ehrenfeld et al., 2005), since this layer serves as a nutrient deposition site (Milić et al., 2019). For Maharjan et al. (2018), land alterations greatly influence the phosphorus concentration in soil. We recorded this result in present study, in which HA+G treatment had significantly greater concentrations in available P in upper soil layer ($p < 0.05$). According Mweta et al. (2007), green manure may increase available P since it decreases the P sorption capacity of the soils, which increases the available P concentration in surface. For Awodun et al. (2007), it is possible that gliricidia manure can improve available P, but Mweta et al. (2007) point out that there is little information on the effect of gliricidia manure on P sorption capacity in the soils. When gliricidia mulch is added to soil, the soil organic matter (SOM) increases, then increasing the supply of nutrients (Awodun et al., 2007) due to increase in quantity of decomposing microorganisms in the soil (Parnas, 1975). Humic matter can also increase soil microorganism populations (Visser, 1985; Saruhan et al., 2011). For Comte et al. (2012), the recycling made by these microorganisms increase the availability of P in the soils.

We showed that SOC concentrations tended to decrease with increasing soil depth. These decreasing can be associated with crop root system, since that its decomposition is slower in soil deeper layers (Li et al., 2013a, 2019). According Kaur et al. (2005), Li et al. (2019) and Zhang et al. (2015), different managements greatly influences organic carbon content in upper soil layer. For Liu et al. (2010b), accumulation of SOC enhances with organic and inorganic fertilizers combined. However, we did not find any significant differences in SOC concentrations between the treatments ($p > 0.05$).

Nutrient concentrations showed some differences between treatments. Bulluck III et al. (2002) found higher concentrations of calcium, potassium and magnesium in soils that received organic amendments, but not in soils receiving synthetic fertilizers. According Ordóñez-Fernández et al. (2015), organic residues of leguminous enrich the soil with nutrients. For Lupwayi and Haque (1998), they are a source both nitrogen and other nutrients such as magnesium, potassium and calcium, since they lead to the accumulation of organic matter (Carvalho et al., 2014). Awodun et al. (2007) found that mulch with gliricidia increased these nutrients content in soil. However, we did not find these results at gliricidia alone, but highest concentrations in K^+, Ca^{2+} and Mg^{2+} occurred at gliricidia added to potassium in upper soil layer ($p < 0.05$). Kaur et al. (2005) found higher concentrations in potassium in chemically fertilized soils than in soils with chemical fertilizers and organic manures combined, but we did not find these results.

HA+G and HA alone recorded significant increments in CEC in upper soil layer ($p < 0.05$). One of the indirect effects of humic compounds on soil is the increase in the CEC (Saruhan et al., 2011). Nascente et al. (2015) recorded that the decomposition of cover crops provided a significant increase in organic matter and, consequently, in CEC. For Harada & Inoko (1975), the CEC of soils is mainly influenced by organic matter, and according Crusciol et al. (2010), this organic matter is greatly accumulated in the soil surface due to crop residue. This accumulation increases soil negative charges, leading to the increase in CEC (Carvalho et al., 2014). G and K+G showed significant increases in SBC and BS at upper soil layer ($p < 0.05$). Legumes used as green manures can increase soil organic matter and, consequently, SBC (Delarmelinda et al., 2010) and BS (Crusciol et al., 2010). Nascente et al. (2015) also recorded this increase in BS influenced by cover crops.

4.3 Relations between different soil fertilization regimes, soil chemical attributes and maize grains yield

K^+, Ca^{2+} and Mg^{2+} were positively associated with maize grains yield in upper soil layer, especially in treatments with gliricidia. For Salvagiotti et al. (2017), nutrients availability in soil increases maize yield since they collaborate with crop growth during grains number formation. According Zörb et al. (2014), potassium is very important to yield in all crops and Kang (1981) points out its importance due to the increase in maize yield. For Cakmak (2001) some macronutrients as calcium and magnesium collaborate to crop development and metabolism and for Cronk and Fennessy (2001), they fabricate some essential plants constituents. Martins et al. (2015) clarifies that magnesium still plays an important role in photosynthesis. Thus, the functions performed by these nutrients contribute to agricultural yield. pH and CEC were also positively associated with maize grains yield in upper soil layer, especially in treatments with gliricidia. Nascimento et al. (2003) points out that legumes act on soil fertility and increase pH and CEC. Furthermore, gliricidia releases mineral elements to the soil, which are available to the plants, also collaborating to crop yield (Afolayan & Oyetunji, 2018). The specific use of gliricidia pruning, according Mweta et al. (2007), enhances maize production since increases organic matter in soil. Higher concentrations in organic matter provide more negative charges to the soil, leading to higher CEC and less possibility of nutrient leaching.

Parameters related to acidity showed some associations. Potential acidity is used to estimate the value of CEC, which may have led to the association between these attributes in all layers. pH was positively associated to SBC in all layers, as Abreu Jr. et al. (2003) also recorded at intemperized Brazilian soils.

5. Conclusion

Our study showed that gliricidia manures increase maize grains yield and changed chemical properties in upper soil layer, such as pH, available P, exchangeable K^+, Ca^{2+} and Mg^{2+}, CEC, SBC and BS due mainly to the increase in organic matter content. The association between potassium, calcium, magnesium, pH and CEC and maize grains yield in upper soil layer is related to the legume presence. Then, this research confirms the hypothesis that different soil fertilization regimes modify soil chemical attributes and maize grains yield.

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