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Tree legumes with fertilizer potential: a multivariate approach[1]

Leguminosas arbóreas com potencial fertilizante: uma abordagem multivariada

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ABSTRACT - The objective of this study was to evaluate, through multivariate data analysis, which tree legume residues have the best fertilizer potential for agricultural crops in the semi-arid region of northeastern Brazil. The experiment was conducted in pots, in a randomized block design, with seven treatments and four replicates. Treatments consisted of residues of Sabiá, Jurema Preta and Gliricidia, besides two parts of the plant: leaves and leaves + branches. The pots were filled with 8.0 dm^3 of soil and the residues were added in the form of green mass, corresponding to 73.0 g of dry mass per pot. Maize seeds were sown and, at 65 days after addition of the residues, soil chemical attributes, growth and nutrient contents in the plants were evaluated. The data were studied through principal component analysis, clustering analysis, canonical discriminant function analysis and means comparison test from canonical variable 1. Gliricidia residues positively influenced soil K and Mg contents, as well as height, stem diameter, number of leaves and leaf contents of P, N and Mg in maize plants. These residues showed greater dissimilarity and separation compared to the control treatment and led to statistically higher means compared to the other treatments. Jurema Preta leaves positively influenced soil Ca, N and TOC, as well as leaf contents of K and Ca and total dry mass of maize. Multivariate statistical analysis made it possible to identify distinct potentials among legume residues for use as fertilizer in maize crop, and Gliricidia is the species with highest potential.

Keywords: Green fertilization. *Mimosa caesalpiniifolia*. *Mimosa tenuiflora*. *Gliricidia sepium*. *Zea mays* L..

RESUMO - Objetivou-se avaliar, por meio de análise multivariada de dados, quais resíduos de leguminosas arbóreas tem melhor potencial fertilizante para culturas agrícolas no semiárido nordestino brasileiro. O experimento foi conduzido em vasos, em delineamento aleatorizado em blocos, com sete tratamentos e quatro repetições. Para constituir os tratamentos utilizaram-se resíduos de sabiá, jurema-preta e gliricídia; além de duas partes da planta: folhas e folhas mais galhos. Os vasos foram preenchidos com 8,0 dm^3 de solo e os resíduos foram adicionados na forma de massa verde, correspondendo a 73,0 g de massa seca por vaso. Sementes de milho foram semeadas e aos 65 dias após adição dos resíduos avaliou-se atributos químicos do solo, crescimento e teores de nutrientes das plantas. Os dados foram estudados por meio das análises de componentes principais, agrupamento, função discriminante canônica e teste de comparação de médias a partir da varável canônica 1. Resíduos de gliricídia influenciaram positivamente K e Mg do solo, bem como altura, diâmetro do caule, número de folhas e teores foliares de P, N e Mg em plantas de milho. Estes resíduos apresentaram maior dissimilaridade e separação em relação ao tratamento controle e proporcionaram médias estatisticamente superiores aos demais tratamentos. Folhas de jurema-preta influenciaram positivamente Ca, N e COT do solo, bem como teores foliares de K e Ca e matéria seca total do milho. A análise estatística multivariada permitiu identificar potenciais distintos entre resíduos de leguminosas para uso como fertilizante na cultura do milho, sendo a espécie gliricídia a que apresenta maior potencial.

Palavras-chave: Adubação verde. *Mimosa caesalpiniifolia*. *Mimosa tenuiflora*. *Gliricidia sepium*. *Zea mays* L..

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INTRODUCTION

Land degradation in northeastern Brazil has increased in the last decade, resulting in the loss of soil fertility. This expansion has occurred mainly in areas of pasture and Caatinga due to the intensive land use, deforestation for the production of firewood and charcoal, in addition to severe droughts that have affected the region, contributing to the increase in the fraction of uncovered soil (TOMASELLA *et al*., 2018).

Techniques that stock organic matter in the soil and improve its fertility, such as the use of crushed plant residues, litter, green manure with tree pruning as occurs in agroforestry systems, among others, assume great importance in agriculture practiced in the semi-arid region, especially for farmers who have low investment capacity, as it is timely to use inputs obtained in rural property (PRIMO *et al*., 2018).

The species of the *Fabaceae* family (legumes) are the most used as green manure because they form symbiotic associations with atmospheric nitrogen-fixing bacteria and have a low C/N ratio, favoring the decomposition and release of nutrients in a relatively short time (CHAER *et al*., 2011; CORREA *et al*., 2014; OLIVEIRA *et al*., 2018). The classic pattern for the decomposition of green manure in the soil has higher rates in the first month, which is attributed to the physical process of removal of the water-soluble fraction by rain or irrigation and to the biological decomposition process, even when the residues remain on the soil surface (AITA; GIACOMINI; CERETTA, 2014).

The decomposition and release of nutrients from green manure crops in the state of Ceará were studied by Pereira, Soares and Miranda (2016), who observed half-life times ($t_{1/2}$) of 65, 53 and 54 days for nitrogen (N), phosphorus (P) and potassium (K), respectively, in *Crotalaria spectabilis*. For *Canavalia ensiformes*, the values were 67, 70 and 55 days for N, P and K, respectively.

Although green manuring is an ancient management practice, there are still few studies showing the fertilizer potential of tree legume species in the northeastern semi-arid region that can support the indication of those that most favor the improvement of soil chemical attributes and the development and nutrition of agricultural crops (OLIVEIRA *et al*., 2018; PRIMO *et al*., 2018), especially with multivariate data analysis.

Multivariate analysis is a set of statistical procedures that allow simultaneously evaluating several variables of a sample or population. In studies with soil management, several researchers have used multivariate techniques for data analysis and interpretation because they enable a better understanding of the complex relationships between soil attributes (MOTA *et al*., 2014, 2017). Evaluating the effect of crop residue management systems on soil physical, chemical and biological properties, Melman *et al.* (2019) reported that multivariate techniques indicated a clear effect of the treatments while univariate tests did not reveal significant differences.

The hypothesis of this study is that multivariate techniques, for allowing simultaneous analysis of soil and plant response variables, make it possible to indicate organic residues with better potential for use as fertilizer. Thus, the objective was to evaluate, through multivariate data analysis, which tree legume residues have the best fertilizer potential for agricultural crops in the semi-arid region of the northeastern Brazil.

MATERIAL AND METHODS

The experiment was conducted in a greenhouse in the municipality of Sobral, Ceará, Brazil. The climate of the region is BShw (hot semi-arid) according to Köppen's classification, with rainy season extending from January to June, average annual temperature of 27 ºC and average precipitation of 759 mm year^{-1} (SOUZA *et al.*, 2016).

The experimental design was randomized blocks, with seven treatments and four replicates, and each experimental plot consisted of one pot with capacity of 10 dm^3, containing one plant. To constitute the treatments, plant residues of three legume species were applied to the soil: Sabiá (*Mimosa caesalpiniifolia* Benth), Jurema Preta (*Mimosa tenuiflora* (Willd.) Poir.) and Gliricidia (*Gliricidia sepium* (Jacq.) Kunth), besides two parts of the plant: leaves and leaves + branches. Thus, the treatments were: T1 - No residue (NR); T2 - Sabiá leaves (SL); T3 - Sabiá leaves + branches (SLB); T4 - Jurema leaves (JL); T5 - Jurema leaves + branches (JLB); T6 - Gliricidia leaves (GL); and T7 - Gliricidia leaves + branches (GLB).

The soil used to fill the pots was collected in the 0-0.30 m layer of a *Luvissolo* (Alfisol) (EMBRAPA, 2006) in an area located in the Desertification Hotspot of Irauçuba, CE, in the district of Jaibaras (3º43'30" South; 40º22'30" West) and average altitude of 94 m, at 10 km distance from the Sobral headquarters (Figure 1). The soil was sieved through a 4.0-mm mesh to retain the coarsest material. Physicochemical characterization followed the procedures described in Teixeira *et al*. (2017), and the results are presented in Table 1.

The plant residues that constituted the treatments were collected directly from plants in the agrosilvopastoral system of Embrapa Goats and Sheep. The chemical characterization of plant tissues and moisture content followed the methodology proposed by Silva (2009), and contents of C, N, P, K, Ca and Mg are described in Table 2.

Figure 1 - Location of the experimental area

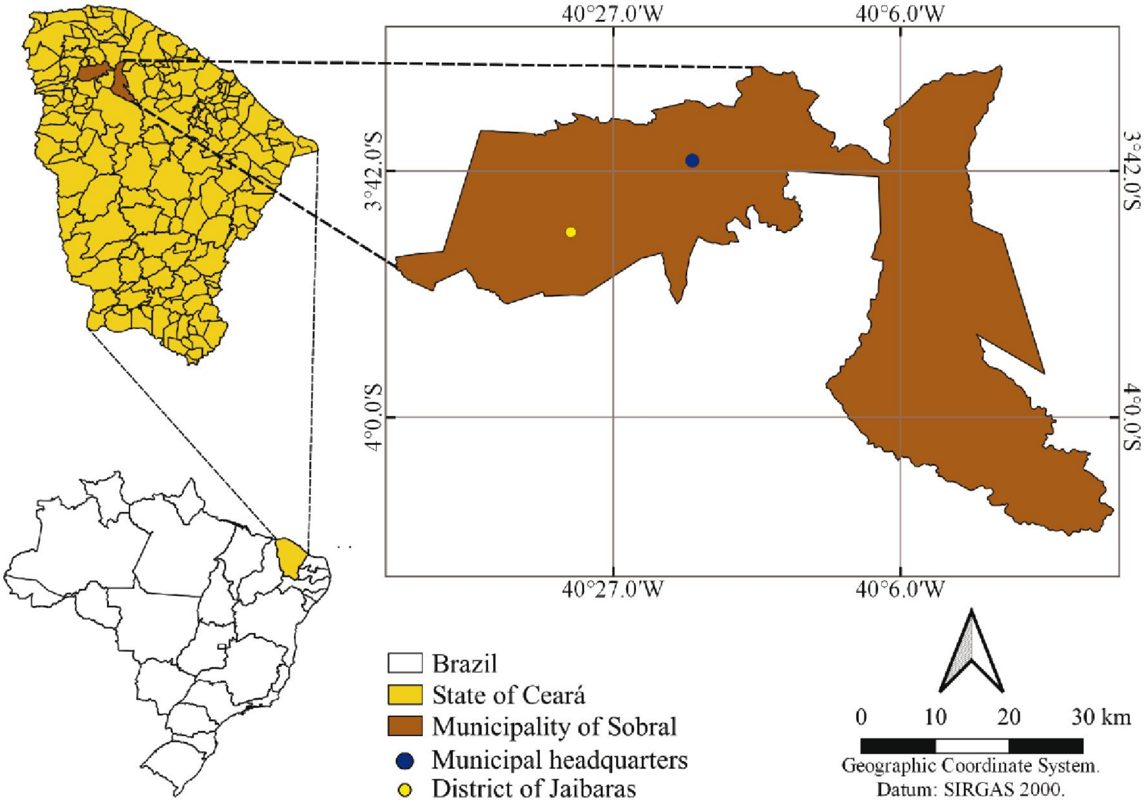


Table 1 - Chemical and physical attributes of the soil used in the experiment

pH	EC	TOC	P*	K	Na	Ca	Mg	Al	(H+Al)
(H_2O)	dS m^{-1}	g kg^{-1}	mg dm^{-3}	----------- mmol$_c$ dm^{-3} -----------					
5.3	0.5	5.0	3.9	2.6	4.2	14.6	5.8	2.0	17.8

BD	Sand	Silt	Clay	Textural class
kg dm^{-3}	----------- g kg^{-1} -----------			
1.5	731.0	192.0	77.0	Sandy loam

*Mehlich 1 extractant, EC - Electrical conductivity; TOC - Total organic carbon; BD - Bulk density

Table 2 - Chemical characterization of residues from legume species used in the study

Species	Plant organ	C	N	P	K	Ca	Mg	C/N
		----------- g kg^{-1} -----------						
Sabiá	Leaf	434.8	14.1	0.8	9.0	7.0	2.5	30.8
	Branch	506.1	6.7	0.8	6.8	6.3	0.9	75.5
Jurema	Leaf	449.8	17.2	0.9	7.4	6.9	2.8	26.2
	Branch	517.3	8.6	1.0	6.0	4.5	0.6	60.2
Gliricídia	Leaf	427.3	22.2	1.4	14.7	8.1	4.3	19.2
	Branch	461.1	11.6	1.7	12.7	6.3	2.2	39.8

The water used for irrigation came from the public supply system of Sobral-CE, and its analysis showed the following chemical characteristics: pH = 7.0; EC = 0.22 dS m^{-1}; Ca^{2+} = 0.50; Mg^{2+} = 0.75; K^+ = 0.20; Na^+ = 0.70; Cl^- = 1.25; HCO_3^- = 1.0 ($mmol_c$ L^{-1}).

Each pot received 8.0 dm^3 of soil measured with a 1.0 L graduated cylinder. Based on the results of the chemical characterization analysis, the soil received 108.8 mg dm^{-3} of triple superphosphate, which corresponded to 90 kg ha^{-1} of P_2O_5 (FERNANDES *et al.*, 1993).

After fertilization, the pots were irrigated until saturation and subsequently planted with maize (*Zea mays* L.) using the variety BRS Gorutuba. Four seeds were sown in each pot at a depth of 2.0 cm. After sowing, residues from the legume species were applied to the pots in the form of green mass.

In addition, each pot received 73.0 g of dry mas, which corresponded to 17.3 t ha^{-1}. This amount was obtained considering the average production of dry biomass (leaves + thin branches) among the three species studied, in kg $plant^{-1}$ $year^{-1}$. The equivalence for dry mass was obtained from the moisture contents in the leaves and branches of each species. In the treatments composed of leaves + branches, the proportion was 50% for each part of the plant. The fraction "branches" was obtained by selecting branches with diameters ≤ 1.0 cm and cutting them into pieces approximately 2.0 cm long.

The amounts of N, P, K, Ca and Mg contained in the residues applied to the pots are presented in Table 3.

Irrigation was performed daily, initially applying a sufficient volume of water to increase soil moisture up to 80% of field capacity. From the second day on, the volume of water to be applied was determined by weighing each pot and calculating the mass difference in comparison to the previous day. Seedlings were thinned 15 days after sowing (DAS), leaving the most vigorous plant in each pot.

Plants were collected at 65 days after sowing (DAS), when 80% had already produced the female inflorescence. Maize growth was evaluated by measurements of plant height (PH), number of leaves (NL), stem diameter (SD), and total dry mass (TDM). PH, SD and NL were determined at the experiment site. To obtain TDM (roots, stem, leaves and inflorescences), the plants were cut close to the soil; their shoots were dried in an air circulation and renewal oven at 65 °C (±1), and their roots were collected, washed and dried following the same procedure of the shoots. After drying, root and shoot samples were weighed on a precision scale and the values were summed to obtain the TDM. Shoot dry mass samples were crushed in a Wiley-type mill and used to determine the contents of nitrogen (N_p), phosphorus (P_p), potassium (K_p), calcium (Ca_p) and magnesium (Mg_p) (SILVA, 2009).

Soil sampling was performed after plant collection at a depth of 0.0-0.10 m. A sample was collected for the analyses of hydrogen potential (pH_s), total organic carbon (TOC_s), phosphorus (P_s), sodium (Na_s), potassium (K_s), calcium (Ca_s), magnesium (Mg_s) and potential acidity (H+Al_s); and another sample was used for the analysis of inorganic nitrogen (IN_s), obtained from the concentrations of NO_3^--N and NH_4^+-N, determined by steam drag distillation (TEIXEIRA *et al.*, 2017).

Data were analyzed with multivariate methods using the statistical package SAS (SAS INSTITUTE, 2012). Initially, the data were subjected to principal component analysis, an exploratory technique that aims to reduce the number of variables that need to be considered to a smaller number of indices (principal components), which are linear combinations of the original variables (MANLY; ALBERTO, 2019). One of the main uses of this technique is when the variables originate from

Table 3 - Amounts of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg) from tree legume residues added to the soil

Treatments	N	P	K	Ca	Mg
	mg pot^{-1}				
Sabiá leaves of (SL)	1029.3	60.5	657.0	511.7	182.5
Sabiá leaves + branches (SLB)	759.2	60.9	576.7	486.1	124.1
Jurema leaves (JL)	1255.6	62.0	540.2	503.7	204.4
Jurema leaves + branches (JLB)	941.7	68.6	489.1	417.1	124.1
Gliricidia leaves (GL)	1620.6	103.6	1073.1	593.4	313.9
Gliricidia leaves + branches (GLB)	1233.7	114.6	1000.1	527.7	237.2

processes in which several characteristics must be observed simultaneously and there is a link between them, determined by correlation (VICINI *et al*., 2018), as occurs in the present study. Thus, with this analysis, it was sought to characterize the influence of treatments through the linear combinations that most explain the total variance of the original data. The set of data composed of the means of the variables of each treatment were standardized ($\mu = 0$; $\sigma^2 = 1$), aiming to eliminate the influence of the different units of measurement of the variables on the final result. The criterion for choosing the number of components was to select those that had eigenvalues greater than one (MANLY; ALBERTO, 2019).

Next, the data were subjected to cluster analysis, a numerical exploratory technique that aims to identify similar objects, individuals or treatments, and the groups formed show homogeneity within groups and heterogeneity between groups (VICINI *et al*., 2018). Thus, it was sought to identify which residues show the greatest dissimilarity with the control treatment (without residue application), thus suggesting greater fertilizer potential. The hierarchical method of mean linkage between groups (UPGMA) was used with data standardization and Euclidean distance as a measure of dissimilarity.

Finally, the canonical discriminant function analysis was performed using the data set with repetitions. This technique offers the possibility of separating different groups based on the available measures (MANLY; ALBERTO, 2019), making it possible to verify if there are significant differences between the groups, in addition to identifying the variables that discriminate treatments in different groups (VICINI *et al*., 2018). Thus, it was sought to show the greatest separation between treatments (groups), with the two best dimensions being analyzed by canonical variables 1 and 2 (CAN1 and CAN2). Additionally, to test the hypothesis that the means are not equal and verify the statistical difference between the treatments, the means were compared by Tukey test, at 5% significance level, using the canonical variable 1 (CAN1). For this, the data were subjected to the Shapiro-Wilk, Levene's and Student's t-tests to verify the multivariate normality, homogeneity of variances and discrepant points, respectively.

RESULT AND DISCUSSION

Principal component analysis showed that the two selected components explained 63.21% of the total data variance, of which 45.17% was explained by component 1 (PC1) and 18.04% by component 2 (PC2), as presented in Table 4. The third principal component, despite having eigenvalue greater than one, was not considered because it did not add important information. Regarding the correlation between the variables and the principal components, those with weight coefficients greater than 0.30 were considered relevant (Table 4).

The treatments Gliricidia leaves and Gliricidia leaves + branches led to higher values of K and Mg in soil, plant growth (PH, SD and NL), leaf contents of P, N and Mg, and low values of Na and P in soil (Figure 2).

It is evident that Gliricidia residues stand out from the others, being the only ones located in the first quadrant of the graph, with positive weights for the variables mentioned, considering the two components analyzed. This result can be explained by the fact that Gliricidia is the species that had the lowest C/N ratio, both in leaves and branches (Table 2). In addition, Gliricidia residues influenced higher K contents in soil, which favors the development of maize plants due to the greater influx of water in root cells, increasing the efficiency in the absorption of water and nutrients (GUO *et al.*, 2017).

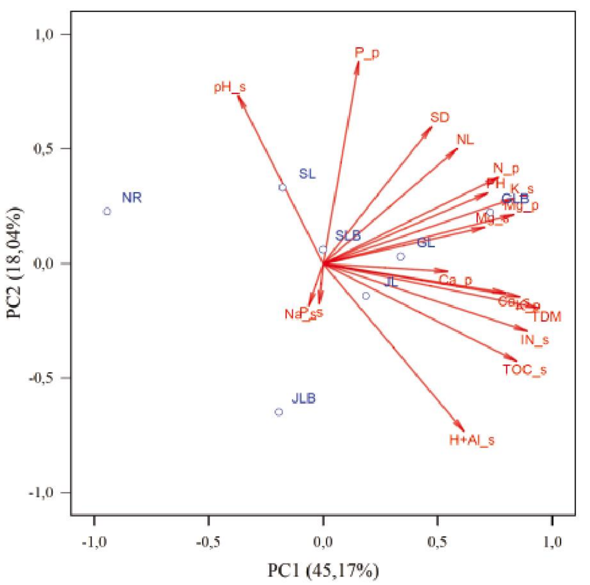
The residues of Jurema leaves led to higher values of Ca, IN and TOC in soil, leaf contents of K and Ca, and total dry mass (Figure 2). In this case, Jurema leaves, besides having a relatively low C/N ratio (Table 2), also have a larger contact surface (tiny leaflets), which facilitates their decomposition and, consequently, the availability of nutrients (OLIVEIRA *et al*., 2018). It is also observed that the residues of Jurema leaves influenced higher values of potential acidity and lower values of pH. It is worth pointing out that the decomposition of organic residues initially contemplates the release of organic acids, which, within the studied period (65 days), may have favored the increase in potential acidity and, consequently, the decrease in pH. Despite the high values for the variables mentioned, such temporary condition of lower pH associated with Jurema Preta leaves certainly negatively affected the absorption of nutrients by maize plants, which shows lower potential of the leaves of this species compared to Gliricidia residues in the time studied.

The treatments Sabiá leaves, Sabiá leaves + branches and control were characterized by having high values only for soil pH (Figure 2). On the other hand, they led to lower values of Ca, IN, TOC and H+Al in soil, leaf contents of K and Ca, and total dry mass of maize plants. Studies involving Sabiá show that this species has high levels of lignin, polyphenols and cellulose in both 'leaf' and 'branch' fractions (COSTA *et al.*, 2014), compromising the release of nutrients. In addition, Ca is the main constituent of the middle lamella of the cell wall, constituting the most recalcitrant component of plant

Table 4 - Weight coefficients (eigenvectors), eigenvalues and variance explained by each principal component (PC1 and PC2), from the variables studied

Variable	PC1	PC2
Plant height (PH)	0.30	0.20
Number of leaves (NL)	0.20	0.30
Stem diameter (SD)	0.20	0.33
Total dry mass (TDM)	0.33	-0.01
Nitrogen in plant (N_p)	0.30	0.21
Phosphorus in plant (P_p)	0.10	0.50
Potassium in plant (K_p)	0.30	-0.10
Calcium in plant (Ca_p)	0.20	-0.02
Magnesium in plant (Mg_p)	0.30	0.20
Inorganic nitrogen in soil (IN_s)	0.31	-0.02
pH in soil (pH_s)	-0.01	0.41
Total organic carbon in soil (TOC_s)	0.30	-0.02
Phosphorus in soil (P_s)	-0.01	-0.10
Potassium in soil (K_s)	0.30	0.20
Sodium in soil (Na_s)	-0.02	-0.01
Calcium in soil (Ca_s)	0.30	-0.07
Magnesium in soil (Mg_s)	0.30	0.09
Potential acidity in soil (H+Al_s)	0.22	-0.04
Eigenvalues	8.13	3.24
Explained variance (%)	45.17	18.04
Accumulated explained variance (%)	45.17	63.21

Figure 2 - Biplot showing the relation between variables and treatments for the first two principal components (PC1 and PC2)



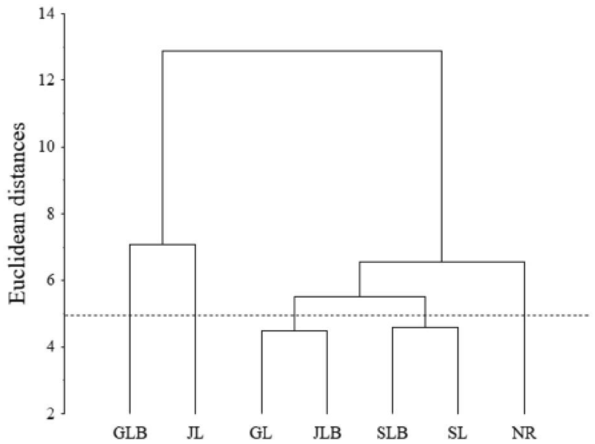
NR - No residue; SL - Sabiá leaves; SLB - Sabiá leaves + branches; JL - Jurema leaves; JLB - Jurema leaves + branches; GL - Gliricidia leaves; GLB - Gliricidia leaves + branches

tissue (PAULA *et al*., 2015), which makes its release little significant in the studied time, justifying the lower values of Ca contents in the soil and in the plant. For pH and potential acidity, as the decomposition of these residues was slower, considering lower values for TOC, the release of organic acids was not enough to influence these soil attributes.

Jurema leaves + branches influenced only the contents of Na and P in the soil (Figure 2), but these two variables were not considered relevant for the principal components 1 and 2 as they had low weight coefficients (Table 4). This can be justified by the fact that the mixture with the branches fraction, which has a higher C/N ratio, reduce the speed of decomposition of the residues and mineralization of nutrients. It is also hypothesized that Jurema residues containing branches, for having high tannin contents, cause negative allelopathic effects, affecting the development of maize plants. Silveira, Maia and Coelho (2012) report that aqueous extracts of Jurema Preta bark have a phytotoxic effect on the development of the test crop and, at the highest concentrations, drastically affect the lengths of roots and shoots.

Cluster analysis shows the dissimilarity between treatments from the joint analysis of soil and plant variables (Figure 3). With a cut at 5.0 of Euclidean distance, five groups were formed. By analyzing the dendrogram from left to right, it can be verified that the first two groups are formed by Gliricidia leaves + branches and Jurema leaves. The third group is formed by the treatments Gliricidia leaves and Jurema leaves + branches. The fourth group is formed by the treatments Sabiá leaves + branches and Sabiá leaves, is the one with the lowest dissimilarity with the control treatment (fifth group). This result mainly suggests the potential of Gliricidia residues and Jurema leaves to improve soil chemical attributes, growth and nutrient contents in maize, since they are the ones with the greatest dissimilarity in relation to the control treatment (No residue).

Figure 3 - Dendrogram of dissimilarity between treatments established by Euclidean distance from the soil and plant variables studied



NR - No residue; SL - Sabiá leaves; SLB - Sabiá leaves + branches; JL - Jurema leaves; JLB - Jurema leaves + branches; GL - Gliricidia leaves; GLB - Gliricidia leaves + branches

The discriminant function analysis, using canonical variables 1 and 2 (CAN1 and CAN2), shows the separation between treatments, with canonical correlation of 0.99 in CAN1 and 0.96 in CAN2 (Table 5). Additionally, it can be observed that 89.68% of the total variation of the data is explained by the first two canonical variables, with 74.70% explained by CAN1 and 14.98% by CAN2.

The separation between treatments from the joint analysis of soil and plant variables is evident in Figure 4. It can be verified that the treatments that most distance themselves from the control (NR - no residue) form two groups. The farthest one is formed by the treatment of Gliricidia leaves, followed by the treatment consisting of Gliricidia leaves + branches. The other treatments constituted three groups, the first formed by the treatments Jurema leaves, Jurema leaves + branches and Sabiá leaves + branches, and it was not possible to identify separation; close to it was the treatment of Sabiá leaves. These two groups were the ones that least distanced themselves from the control treatment, which in turn grouped separately.

From the raw canonical coefficients of CAN1 (Table 5), it was verified that the treatments were separated because they resulted in high coefficients for phosphorus in the plant, inorganic nitrogen and potassium in the soil, and low coefficients for phosphorus in the soil [$CAN1 = 7.29(P\_p) + 2.56(IN\_s) + 5.98(K\_s) - 4.64(P\_s)$].

In relation to phosphorus, it is important to highlight that the plants received phosphate fertilization; however, as the same amount was applied for all treatments, it probably did not influence the separation of treatments by the discriminant function analysis. Thus, the high contribution of P in the plant may be related to the rapid release of this nutrient in the initial period of decomposition of the residues, since most of the P in the plant tissue is in the vacuole of the cells, in the mineral form of inorganic phosphorus (Pi), highly soluble in water (AITA; GIACOMINI; CERETTA, 2014; MARSCHNER, 1995). Moreover, the stock of organic residues with low C/N ratio may have stimulated mineralization, turning organic P into inorganic P, which was absorbed by maize plants. On the other hand, the low concentration in the soil at the end of cultivation can be explained by the export of P by maize crop coupled with phosphate adsorption to soil constituents, which can occur in tropical regions even in poorly weathered soils (NOVAIS; SMYTH; NUNES, 2007).

The contribution of soil nitrogen to the separation of groups confirms the potential of tree legumes to supply this nutrient to the system, especially species with lower C/N ratio (CHAER *et al*., 2011; CORREA *et al*., 2014), as is the case of Gliricidia and Jurema Preta leaves (Table 2). The importance of potassium for the separation of groups is explained by the fact that this nutrient is not part of structural components of plant cells, being found in the ionic form in the vacuole of these cells (MARSCHNER, 1995). For this reason, K is the nutrient most rapidly released from plant residues and can be washed from the organic material soon after the death of the cells (AITA; GIACOMINI; CERETTA, 2014; ERNANI; ALMEIDA; SANTOS, 2007).

Table 5 - Raw canonical coefficients of the canonical variables 1 and 2 (CAN1 and CAN2)

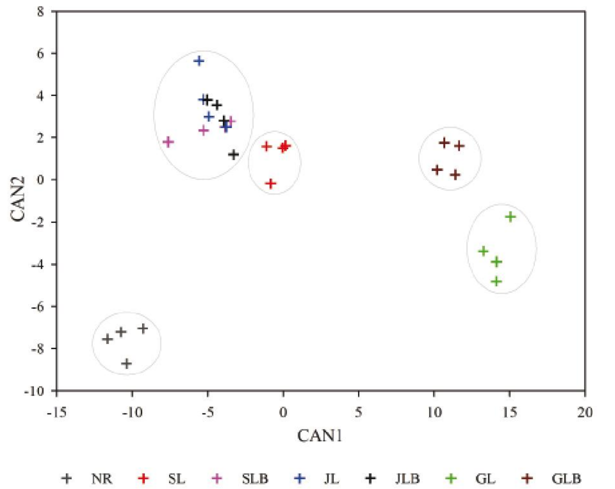
Variable	CAN1	CAN2
Plant height (PH)	-0.18	0.13
Number of leaves (NL)	1.23	-0.64
Stem diameter (SD)	-1.25	1.71
Total dry mass (TDM)	-0.76	1.70
Nitrogen in plant (N_p)	0.48	0.57
Phosphorus in plant (P_p)	7.79	-5.6
Potassium in plant (K_p)	1.31	-0.83
Calcium in plant (Ca_p)	-1.25	0.84
Magnesium in plant (Mg_p)	-0.04	0.34
Inorganic nitrogen in soil (IN_s)	2.56	-0.10
pH in soil (pH_s)	1.89	-6.32
Total organic carbon in soil (TOC_s)	0.47	-0.15
Phosphorus in soil (P_s)	-4.64	1.98
Potassium in soil (K_s)	5.98	-0.63
Sodium in soil (Na_s)	-0.28	-0.98
Calcium in soil (Ca_s)	-1.15	0.18
Magnesium in soil (Mg_s)	1.16	-1.82
Potential acidity (H+Al_s)	-1.96	2.32
Canonical correlation	0.99	0.96
Total variance (%)	74.70	14.98
Accumulated variance (%)	74.70	89.68
Pr > F	<0.00	0.13

Finally, in order to confirm the difference between the treatments, Tukey test ($p<0.05$) was performed from the canonical variable 1 (CAN1) (Table 6).

It worth pointing out that the H_0 hypotheses of normality of CAN1 residuals ($p=0.35$) and homogeneity of treatment variances ($p=0.08$) were not rejected, and no discrepant points were verified ($p>0.05$). In general, it was verified that all residues applied led to statistically higher means than those observed in the control treatment. However, Gliricidia residues stand out for resulting in positive means and statistical superiority compared to other residues added.

The techniques used showed coherent results, as a whole, making it possible to identify which residues of the studied legume species have the greatest potential for use as fertilizer, unlike the result observed by Oliveira *et al.* (2018), who adopted univariate techniques for analyzing data of a similar study and did not find responses that allowed them to indicate the best species or part of the plant for this purpose.

Figure 4 - Dispersion of treatments according to the canonical variables 1 and 2 (CAN1 and CAN2) from soil and plant variables



NR - No residue; SL - Sabiá leaves; SLB - Sabiá leaves + branches; JL - Jurema leaves; JLB - Jurema leaves + branches; GL - Gliricidia leaves; GLB - Gliricidia leaves + branches

Table 6 - Comparison of treatment means from the canonical variable 1 (CAN1)

Treatments	NR	SL	SLB	JL	JLB	GL	GLB
Means	-105.27 e	-0.47 c	-50.64 d	-49.03 d	-41.72 d	141.49 a	109.85 b

Means followed by the same letter do not differ by Tukey test at 0.05 probability level. NR - No residue; SL - Sabiá leaves; SLB - Sabiá leaves + branches; JL - Jurema leaves; JLB - Jurema leaves + branches; GL - Gliricidia leaves; GLB - Gliricidia leaves + branches

CONCLUSIONS

1. Multivariate statistical analysis made it possible to identify distinct potentials among residues of legume species to be used as fertilizer for maize crop;
2. Among the residues of the tree legumes studied, the ones with the highest potential for fertilizer are Gliricidia leaves and Gliricidia leaves + branches;
3. Jurema Preta leaves have potential for fertilizer, but to a lesser extent than Gliricidia residues;
4. Jurema Preta leaves + branches, Sabiá leaves + branches and Sabiá leaves have low potential for fertilizer when the intent is to obtain results up to 65 days.

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