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Plant Components of Agroforestry System Have Different Contributions to Soil Fertility

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Abstract

The objective was to evaluate soil fertility in agrosilvopastoral system in an area influenced by plant components. The study was carried out in the semi-arid region, in the municipality of Sobral (Ceará State, Brazil). The studied treatments were three plant components: shrub (*Leucaena leucocephala*), tree (*Poincianera pyramidalis*), crop (*Zea mays*) and an area of natural regeneration, all at four soil depths. The main chemical attributes were evaluated in the soil samples. The plant components contribute differently to the chemical attributes, especially the tree component, promoting improvements even without the addition of inputs.

Keywords: agroecosystem, chemical attributes, conservation system, multi-species, plant diversity

1. Introduction

Since the degradation of the soils affects the sustainability of the entire agroecosystem, soil conservation practices emerge as important tools in the agro-environmental planning. In this context, agroforestry systems (AFSs) can be a viable alternative for the different ecosystems of the Brazilian semi-arid tropic (Aguiar et al., 2006).

Agroforestry systems consist in the cultivation of trees, crops and sometimes animals in a combination that interacts and creates land use systems that are structurally and functionally more complex, with higher efficiency of acquisition and use of resources (nutrients, light and water) than the conventional land management (Silva, 2011). These systems require few external inputs, have a high recycling rate and a good integration between trees, crops and animals, which make them good candidates to achieve the objectives referring to the sustainable subsistence and climate changes (Koohafkan et al., 2012).

Since there are different AFS models, they can be grouped considering three basic components of the system: perennial woody species (usually trees), herbaceous species or crops and animals. Hence, three basic types of agroforestry systems can be described: silvoagricultural systems (trees and crops), silvopastoral systems (trees, pasture and animals) and agrosilvopastoral systems (trees, crops, pastures and animals) (Nair et al., 1991).

Agroforests have the potential to improve soil fertility. This is mainly based on the increase in soil organic matter and biological nitrogen fixation by tree leguminous species. Trees also facilitate the cycling of nutrients more than the monocrop system and enrich the soil with nutrients and organic matter (Lehmann et al., 1998). Ketema and Yimer (2014) found improvements in the properties of the soil under agroforestry system in comparison to the conventional system, which is justified by the entry of organic matter and lower soil disturbance.

Given these various benefits, studies have aimed to prove the contribution of AFSs to conservation through soil quality indicators (Brown et al., 2006). Among the main chemical indicators of soil quality, the following ones stand out: pH, organic carbon (OC), effective CEC, nitrogen (N) of the soil and other nutrients available to the plants (potassium-K, calcium-Ca and magnesium-Mg).

Based on the above, we considered the hypothesis that plant components (shrub, tree and crop) have different contributions to soil fertility in agrosilvopastoral system, and the tree component is responsible for promoting higher chemical quality to the soil.

Thus, this study aimed to evaluate the fertility of a Luvisol under agrosilvopastoral system in the influence area of the following plant components: shrub (*Leacaena leucocephala*), tree (*Poincianera pyramidalis*) and crop (*Zea mays*), as well as in area of natural regeneration.

2. Material and Methods

2.1 Location and Characterization of the Region and Study Area

The study was carried out in the Center of Coexistence with the Semi-Arid Region, which belongs to the Embrapa Goats and Sheep, situated in the municipality of Sobral (Ceará State, Brazil). The municipality is found in the semi-arid region of Ceará, at 3º41′ S and 40º20′ W, with altitude of 69 m.

The area of the agrosilvopastoral system in the studied site occupies eight hectares. The system was implemented in 1997, and a native tree vegetation cover of 22% was preserved. Maize (*Zea mays*) and cowpea (*Vigna unguiculata*) were annually planted, since the installation of the AFS, in 3.0-m-wide strips, separated by rows of leguminous plants (*Leucaena leucocephala*), until 2006.

From 2007 on, only maize was cultivated. The species *Leucaena leucocephala* of the agrosilvopastoral system is used as a protein bank for goats and sheep in the dry period.

In 2014, pruning residues of *Leucaena leucocephala* were deposited on the soil, in the spaces between the double rows of the leguminous species, which is the area intended for maize cultivation.

Inside the agrosilvopastoral system, the soil influenced by the following species was evaluated: *Zea mays* (crop component)—characterizes an important food crop in AFSs in the semi-arid region; *Leucaena leucocephala* (Leucaena)—tree-shrub component, exotic and with favorable potential to be introduced in AFSs in the semi-arid region, for being a leguminous species and having importance as forage; *Poincianella pyramidalis* (‘Catingueira’)—tree component native to the semi-arid region, with important contribution to the cycling of nutrients in an agroforestry system, considering not only the high nitrogen content in its leaves and the speed with which they degrade after falling on the soil, but also the fact that it is a symbiont leguminous plant (Araújo Filho, 2013). In addition, the soil of a natural regeneration area under fallow for eight years was also evaluated. This area has already been subjected to fires and the animals (goats and sheep) continued to use it for grazing in the periods of winter and summer. This area is close to the AFS and was chosen in such a way to exhibit similarity with the soil of the AFS. In the natural regeneration area, tree-shrub vegetation prevails.

Soil physical and chemical characterization in the studied sites is presented in Table 1. The soil, both in each studied profile of the AFS and in the natural regeneration area, was classified as typic orthic CHROMIC LUVISOL (Embrapa, 2013).

Table 1. Granulometry, clay dispersed in water (CDW), flocculation degree (FD), silt/clay ratio, assimilable phosphorus (P) and organic carbon (OC) in the four profiles of study—three in agrosilvopastoral system and one in a natural regeneration area—in the Brazilian semi-arid region of Sobral-CE

Simb. Hor.	Depths	Sand	Silt	Clay	CDW	FD	Silt/Clay	P	OC.
	----- m -----	-------------------- g/kg	--------------------			-- % --		- mg/kg -	- g/kg -
Leucaena leucocephala									
A1	0.00-0.05	736.5	224.9	38.6	24.4	36.79	5.83	116.76	13.01
A2	0.05-0.18	738.5	210.1	51.4	37.4	27.24	4.09	86.74	4.99
Bt1	0.18-0.25	600.0	191.4	208.6	139.2	33.27	0.92	23.35	3.47
Bt2	0.25-0.41	540.0	170.4	289.6	144.8	50.00	0.59	20.02	3.22
Bt3	0.41-0.57	561.0	148.8	290.2	159.6	45.00	0.51	22.40	2.34
BC1	0.57-0.67	565.5	177.3	257.2	138.0	46.35	0.69	21.92	2.21
BC2	0.67-0.90+	577.0	194.2	228.8	135.6	40.73	0.85	18.11	1.33
Poincianera pyramidalis									
A1	0.00-0.05	753.0	171.2	75.8	26.6	64.91	2.26	44.23	13.33
A2	0.05-0.18	746.5	180.9	72.6	41.0	43.53	2.49	10.01	5.12
Bt1	0.18-0.25	699.0	186.4	114.6	61.4	46.42	1.63	4.48	3.73
Bt2	0.25-0.41	622.0	126.6	251.4	145.4	42.16	0.50	4.86	3.35
Bt3	0.41-0.57	595.0	93.6	311.4	160.2	48.55	0.30	4.67	2.91
BC1	0.57-0.67	625.5	136.1	238.4	125.6	47.32	0.57	3.53	2.21
BC2	0.67-0.90+	650.0	131.0	219.0	114.8	47.58	0.60	4.96	1.52
Zea mays									
A1	0.00-0.05	715.5	211.1	73.4	28.2	61.58	2.88	33.46	10.42
A2	0.05-0.18	672.6	210.0	117.4	70.8	39.69	1.79	7.34	5.24
A3	0.18-0.25	676.5	235.3	88.2	57.6	34.69	2.67	10.87	6.63
Bt1	0.25-0.41	501.0	198.0	301.0	169.8	43.59	0.66	2.86	3.47
Bt2	0.41-0.65	593.5	222.7	183.8	126.8	31.01	1.21	5.72	4.61
BC	0.65-0.85+	652.7	210.7	136.6	102.5	24.96	1.54	2.52	2.48
Natural regeneration									
A1	0.00-0.05	726.2	221.9	51.8	34.6	33.20	4.28	40.70	22.17
A2	0.05-0.15	609.4	250.0	51.8	34.6	32.43	1.78	5.72	5.12
Bt1	0.18-0.25	461.6	287.9	140.6	95.0	38.90	1.15	3.24	4.11
Bt2	0.25-0.40	483.1	391.9	250.4	153.0	20.00	3.14	2.10	3.09
BC1	0.41-0.60	620.4	330.0	125.0	100.0	19.35	6.65	3.34	2.08
BC2	0.60-0.75	710.4	258.8	49.6	40.0	20.78	8.40	16.49	1.07
BC3	0.75-0.85+	839.0	138.2	30.8	24.4	18.86	6.06	15.54	0.82

Note. Simb. Horiz.: Symbology of the soil horizons.

2.2 Collection of Soil Samples for Chemical Analyses

The soil samples were collected at a distance of 0.20 m from each studied plant component. The plant components in which the samplings were performed were randomly established in the area. Sampling was performed through mini soil pits for the depths of 0.0-0.05 m and 0.5-0.18 m, and using soil augers for the depths of 0.18-0.25 m and 0.25-0.41 m. The sampling depths were determined according to the separation of the horizons made in the morphological description.

A completely randomized design in split plots was used. The first factor of study was three plant components of the AFS (*Leucaena leucocephala*—shrub component; *Poincianera pyramidalis*—tree component and *Zea mays*—crop component) and the natural regeneration area. The second factor of study consisted of the four sampling depths (0.0-0.05 m, 0.5-0.18 m, 0.18-0.25 m and 0.25-0.41 m). Four replicates were used, totaling 64 soil samples. These samples were stored in plastic bags and sent to the Laboratory of Soil Management of the Federal University of Ceará, where the analyses were made, according to the procedures described below.

2.3 Analyzed Chemical Attributes

The pH was measured in H_2O (1:2.5) through potentiometry; potential acidity was extracted with calcium acetate buffered at pH 7.0 and determined through titration; exchangeable aluminum (Al) was extracted with 1M KCl solution and determined through titration; calcium and magnesium were extracted with 1M KCl solution and determined through atomic absorption spectrometry (Donagema et al., 2011).

The contents of total organic carbon (TOC) were determined as described by Yeomans and Bremner (1988). The contents of total N were determined by the semi-micro Kjeldahl method.

The contents of K^+, Na^+ and P were extracted with Mehlich 1 solution and determined through flame photometry (Donagema et al., 2011).

Cation exchange capacity (CEC), sum of bases (SB), base saturation (V%), aluminum saturation (m%) and exchangeable sodium percentage (ESP) were calculated based on the methods described in Donagema et al. (2011).

2.4 Statistical Analysis

The chemical attributes were analyzed considering a completely randomized experimental design, in split plots in space (4 × 4) with four replicates. Data normality was verified using the Shapiro-Wilk test and, in the absence of normality, the data were transformed. The profiles of each species and depth were compared by the Scott-Knott test, at 0.05 probability level.

3 Results and Discussion

Nitrogen (N) was the only variable with isolated significance for the factor plant component, with values ranging from 0.66 to 1.04 g/kg (Table 2). The highest values were observed for the soil in influence area of the crop (1.04 g/kg) and tree (0.97 g/kg) components, which did not differ. The natural regeneration area resulted in mean value of 0.8 g/kg and did not differ from the shrub component (0.66 g/kg of N).

Table 2. Comparison of means for the variables: pH, aluminum (Al), sodium (Na), base saturation (V%), aluminum saturation (m%), exchangeable sodium percentage (ESP) and nitrogen (N) for the factor plant component

Plant components	pH	Al	Na	V	m	PST	N
	-	--------- $cmol_c$/kg ---------		------------------ % -------------------			-- g/kg --
shrub	6.53 a	0.11 a	0.11 a	72.51 a	1.76 a	1.14 a	0.66 b
Tree	6.71 a	0.15 a	0.08 a	67.03 a	2.53 a	0.83 a	0.97 a
Crop	7.06 a	0.05 a	0.16 a	71.34 a	1.02 a	2.30 a	1.04 a
Natural regeneration	6.57 a	0.11 a	0.11 a	63.60 a	2.11 a	1.34 a	0.80 b

Note. Means followed by the same letter do not differ by Scott-Knott test at 0.05 probability level.

The highest N contents in the soil of the crop component are explained by the goat manure fertilization applied in the AFS along the maize (*Zea mays*) sowing rows. These values of the element are explained by the pruning of leguminous species established in rows of the AFS and the deposition of this pruning residue along the maize planting rows. The application of manure and the cultivation in rows in agricultural areas constitute a good alternative to improve soil fertility, contributing to the increase in production, especially for family farmers (Souza et al., 2014).

For the tree component, the highest N contents are attributed to the contribution of underground tissues for the maintenance of the nutrients in the soil and, consequently, for its fertility (Carranca et al., 2015). There is also contribution of the tree component to the cycling of nutrients through the biological N fixation, for being a leguminous species. Iwata et al. (2012) observed increase in N contents in agroforestry system in the semi-arid region, which was attributed to the supply of organic matter and longer permanence of this material in the soil. Hence, constant supplies of underground and aboveground tissues of the tree component and longer permanence of these tissues in the soil allowed increments in N contents in the AFS.

The mean values of pH did not differ between the studied components (Table 2), so that the pH remained close to alkalinity in the shrub and tree components and natural regeneration area, and was considered as alkaline in the crop component. These mean values of pH are within the range considered as optimal for the development of the crops (Mello et al., 1983) and indicate small participation of the aluminum in soil acidity. It should be mentioned that the mean values of Al^{3+} were statistically equal between the studied components (Table 2). Similarly, the mean values of Na^+, V%, m% and ESP% did not differ between the plant components.

Among the attributes that showed isolated significance for the factor depth, pH decreased with soil depth and its value was statistically equal in the first (0.0-0.05 m) and second (0.05-0.18 m) horizons, being higher than those of the other horizons (Table 3). The organic matter is capable of complexing the free H^+ and Al^{+3} cations and add bases that reduce soil acidity and increase pH (Pavinato & Rosolem, 2008). The higher pH values at the first two soil depths are attributed to the higher contents of organic carbon identified in the soil description (Table 1), and also because, in general, the values of sum of bases were higher in the superficial layer.

Table 3. Comparison of means for the variables: pH, aluminum (Al), sodium (Na), base saturation (V%), aluminum saturation (m%), exchangeable sodium percentage (ESP) and nitrogen (N) for the factor depth

Depth (m)	pH	Al^{3+}	Na^+	V	m	PST	N
	-	---------- $cmol_c/kg$	----------	------------------------	%------------------------		--- g/kg ---
0.0-0.05	6.91 a	0.08 b	0.06 b	73.50 a	1.25 a	0.59 b	1.46 a
0.05-0.18	6.80 a	0.07 b	0.07 b	69.68 b	1.27 a	0.83 b	0.89 b
0.18-0.25	6.68 b	0.13 a	0.11 b	65.73 c	2.31 a	1.66 a	0.57 c
0.25-0.41	6.47 c	0.15 a	0.22 a	65.57 c	2.60 a	2.53 a	0.56 c

Note. Means followed by the same letter do not differ by Scott-Knott test at 0.05 probability level.

The Al^{3+} contents were higher and statistically equal at the depths of 0.18-0.25 m and 0.25-0.41 m, with values of 0.13 $cmol_c/kg$ and 0.15 $cmol_c/kg$, respectively (Table 3). These values indicate small participation of aluminum in soil acidity, which was expected because this cation is not expressive in soils of semi-arid climate, especially for pH values above 5.5 (Richards, 1954), as observed in the present study.

Et all studied depths, the Na^+ contents were considered as low and do not pose risks of structural damages caused by this monovalent cation. There was higher Na^+ content (0.22 $cmol_c/kg$) at the depth of 0.25-0.41 m, which may be due to the process of washing of the salts from the superficial layer to the deeper layers of the soil. At the other depths, 0.0-0.05 m, 0.5-0.18 m and 0.18-0.25 m, the Na^+ contents were 0.06 cmolc/kg, 0.07 cmolc/kg and 0.11 cmolc/kg, respectively (Table 3).

The ESP values remained below the limit of 15%, which is considered as an indicator of soil sodicity (Richards, 1954). The values found for all depths do not exceed 2.53% (Table 3). Thus, the Na^+ contents remained at acceptable levels, which do not lead to sodification problems. Additionally, there was an increment in the mean values of ESP as soil depth increased, which corresponds to the trend of increment in Na^+ contents with the soil depth.

The values of V% oscillated from 65.57 to 73.50%, with highest value observed at the depth of 0-5 cm (Table 3). However, for all depths, the V% value was higher than 50%, classifying the soil as eutrophic. The release of exchangeable bases superficially, which influenced pH and SB, corroborates this result. According to Prado (2001), the values of base saturation are ideal for maize cultivation, which must be above 65%.

For the shrub component and natural regeneration area, the Ca^{2+} contents were equal at the studied depths (Table 4).

In the natural regeneration area, the contents of this element vary from 4.40 to 5.66 $cmol_c/kg$, which are considered as high according to the table of interpretation of soil analysis results for the Ceará state (Fernandes, 1993). In forest ecosystems, the availability of calcium depends mainly on the weathering of soil minerals (Bedel et al., 2016) and this process is effective in the natural regeneration area of this study, considering the high availability of the nutrient in the soil. In the shrub component, the contents varied from 3.8 to 5.28 cmolc/kg, which are classified as intermediate and high, respectively (Fernandes, 1993), but did not differ.

A similar trend was observed for the Mg^{2+} contents in the natural regeneration area, not differing between depths (Table 4). The absence of soil disturbance in the AFS and in the natural regeneration area led to good conditions for the organisms responsible for the fragmentation of the plant material and cycling of nutrients (Cunha et al., 2012).

At the depth of 0-5 cm, the Ca^{2+} contents did not differ between the plant components, oscillating between 5.28 and 5.93 cmolc/kg, which are classified as high contents in the soil. The Mg^{2+} content, also at the depth of 0-5 cm, was lower (0.93 cmolc/kg) in the natural regeneration area, being classified as intermediate (Fernandes, 1993). There were considerable contents and at adequate proportion for both cations, so that they do not restrict the development of the plant components in the AFS.

Table 4. Contents of Ca^{2+}, Mg^{2+} and K^+ as a function of the plant species and depths

Plant components	Depth (m)			
	0.0-0.05	0.05-0.18	0.18-0.25	0.25-0.41
Ca^{2+} $cmol_c$/kg				
Shrub	5.28 Aa	3.80 Aa	3.44 Aa	5.33 Aa
Tree	5.93 Aa	5.22 Aa	2.92 Ab	3.36 Bb
Crop	5.80 Aa	3.90 Ab	3.44 Ab	3.57 Bb
Natural regeneration	5.66 Aa	4.91 Aa	4.40 Aa	4.55 Aa
Mg^{2+} $cmol_c$/kg				
Shrub	1.29 Ab	1.12 Cb	1.29 Bb	2.04 Aa
Tree	1.38 Aa	1.37 Ba	1.64 Aa	1.46 Ba
Crop	1.50 Aa	1.64 Aa	1.12 Bb	1.13 Cb
Natural regeneration	0.93 Ba	0.93 Ca	0.94 Ca	0.98 Ca
K^+ $cmol_c$/kg				
Shrub	0.87 Ca	0.82 Ba	0.78 Ca	0.78 Ba
Tree	1.04 Aa	0.94 Ab	0.89 Bb	0.88 Ab
Crop	0.97 Ba	0.92 Aa	0.97 Aa	0.94 Aa
Natural regeneration	0.92 Ca	0.82 Bb	0.80 Cb	0.79 Bb

Note. Means followed by the same uppercase letter in the columns do not differ. Means followed by the same lowercase letter do not differ by Scott-Knott test at 0.05 probability level.

The K^+ did not differ between the depths for the shrub and crop components (Table 4), which is attributed to the high mobility of K^+ in the soil. Although there were statistical differences in K^+ contents in the tree component and natural regeneration area, all contents are classified as very high (Fernandes, 1993).

The K^+ at the depth of 0-5 cm was higher in the tree component (1.04 $cmol_c$/kg), followed by the crop component, with 0.97 $cmol_c$/kg. The lowest statistically equal contents of K^+ were found in the shrub component and in the natural regeneration area, with 0.92 and 0.87 $cmol_c$/kg, respectively. In agroforestry systems, Alfaia et al. (2004) mention the possible exportation of this nutrient for successive harvests of products, which can cause reduction in the K^+ contents in the crop component over time. Thus, the K^+ content in the soil influenced by the shrub component was reduced by the pruning management of the *Leucaena leucocephala* and by the removal of plant biomass for the use as feed for goats and sheep. This reinforces the idea that leguminous species introduced in AFSs as fertilizers of food crops or as protein banks for animals deserve special attention in relation to the replacement of nutrients through fertilization.

The sum of bases (Ca^{2+} + Mg^{2+} + K^+ + Na^+) and CEC showed similar results because of the low acidity of the soil (Figure 1). For the shrub component, the SB was higher at the depth of 0.25-0.41 m, being attributed to the higher contents of Na^+, Ca^{2+} and K^+ found at this depth. On the other hand, for the tree component and natural regeneration area, the sum of bases and CEC did not vary with the depths. The deep root systems and thin roots of the trees can be responsible for this balance between SB and CEC along all depths, through root contributions.

The trees facilitate the cycling of nutrients and enrich the soil with nutrients and organic matter (Lehmann et al., 1998), which leads to improvements in soil properties, including increase of CEC. According to Paciullo et al. (2011), in agrosilvopastoral system there is the influence of the tree component on most characteristics of the pasture. Additionally, Pezzoni et al. (2012) observed that the accumulation of litter under the trees can favor soil chemical attributes, interfering with the development of other plants.

For the crop component, the sum of bases and CEC were higher in surface (0-5 and 5-18 cm), which is caused by the management of the crops employed in the AFS, with organic fertilization and deposition of the material from the pruning of leguminous species. Additionally, the roots in the crop component concentrate more in surface, compared with the tree and shrub components. The organic matter, with higher contents in surface, caused higher values of soil CEC. For the other plant components, the superficial CEC did not differ statistically from the underlying depth.

The content of organic carbon in the soil under natural regeneration was expected to be superior to that in the AFS, because soils under fallow tend to be less disturbed than in cultivated systems, allowing greater accumulation of organic matter. However, the differences between these contents were not significant. This can be attributed to the short fallow period to which the regeneration area has been subjected, which probably was not sufficient to increase the carbon contents of the soil, and to the grazing of litter by goats and sheep, which continue to access the area. However, the resilience established in the AFS is not ruled out, which allows the maintenance of the organic matter at similar levels to those of native forest areas (Dias, 2002).

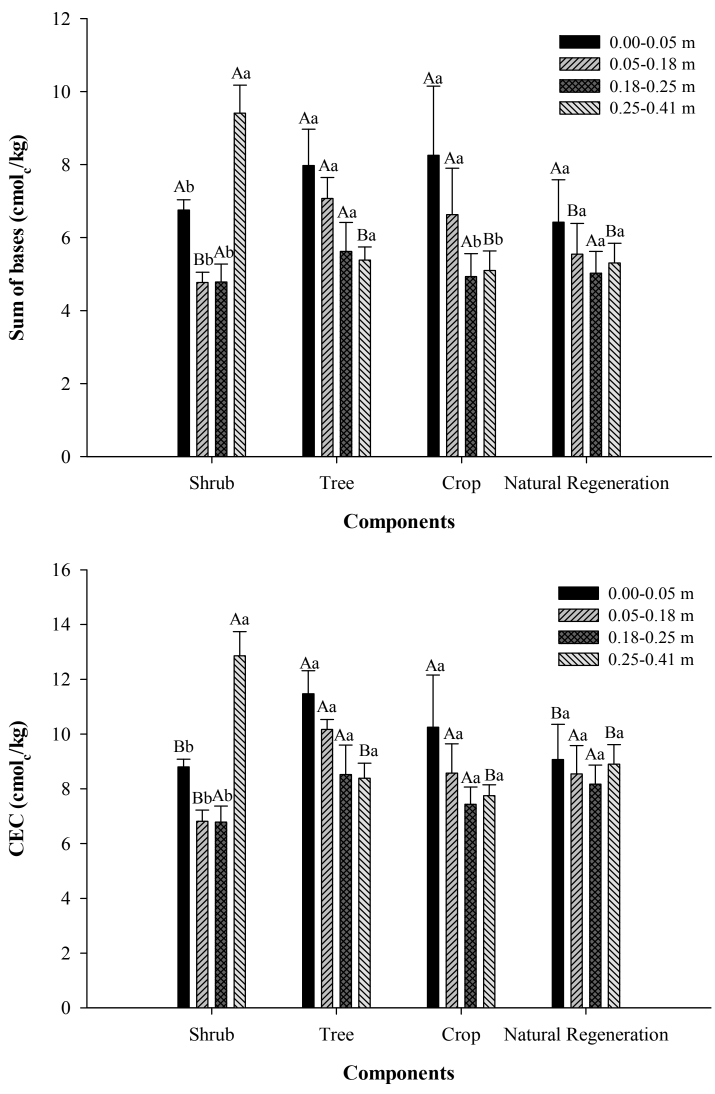

Figure 1. Sum of bases and CEC as a function of the plant species and depths. Means followed by the same uppercase letter between the plant components do not differ. Means followed by the same lowercase letter in the same plant component do not differ by Scott-Knott test at 0.05 probability level

The observed P contents, in general, were higher in surface, which is associated with the low mobility of this nutrient and the biocycling promoted by the plants, in which P is absorbed in deeper layers by the roots and deposited on the surface by the plant residues (Araújo et al., 2004). There was high variability in the P contents (2.52 to 211.14 mg/kg) between the plant components and depths (Table 5). Likewise, Silveira et al. (2006), evaluating P contents in soils of Paraíba and Pernambuco, observed that the results of the Mehlich-1 extractions in soil samples showed high variation (1 to 202 mg/kg). The P content in the soil is mainly affected by factors such as parent material, climate, organisms and biogeochemical processes in the soil, and its distribution has great spatial heterogeneity (Lane et al., 2011).

Table 5. Contents of P as a function of the depths

Plant components	Depht (m)			
	0.0-0.05	0.05-0.18	0.18-0.25	0.25-0.41
	P (mg/kg)			
Shrub	22.25 Ca	11.92 Bb	6.08 Ab	3.02 Bb
Tree	41.80 Ba	15.92 Bb	14.12 Ab	13.25 Ab
Crop	209.21 Aa	211.14 Aa	3.80 Ab	15.10 Ab
Natural regeneration	16.61 Ca	3.87 Ba	2.52 Aa	2.81 Ba

Note. Means followed by the same lowercase letter do not differ by Scott-Knott test at 0.05 probability level.

The highest P contents were found in the A horizon, referring to the crop component, which is explained by the application of large amounts of sheep manure from the pens and fertilization with pruning residues. Higher contents of organic matter in surface contribute to the higher P contents.

With the use of the biomass from the shrub component, the soil of this area showed reduction in P contents, which can be intensified over time. The use of Leucaena as fertilizer and as protein bank causes reduction in the P contents of the soil in its influence area. An important recommendation to guarantee the sustainability of the AFS is the supply of P to the fertilizer leguminous species.

In the natural regeneration area, there were lower contents of P in surface, together with the shrub component, confirming that the available P contents in soils of the semi-arid region are generally low, thus requiring strategies that maximize the cycling of the native P. The use of organic manures, when they are available, should be highlighted. In addition, mechanisms of acquisition of P from the litter and soil, such as modifications of roots and mycorrhizal fungi, can be alternatives to acquire P in systems of low-fertility soils (Mendes-Filho et al., 2009).

The mean content of organic carbon was higher in surface (17.64 g/kg), followed by the depths of 5-18 cm (10.02 g/kg), and 18-25 and 25-41 cm, with contents of 7.74 and 6.52 g/kg, respectively (Figure 2).

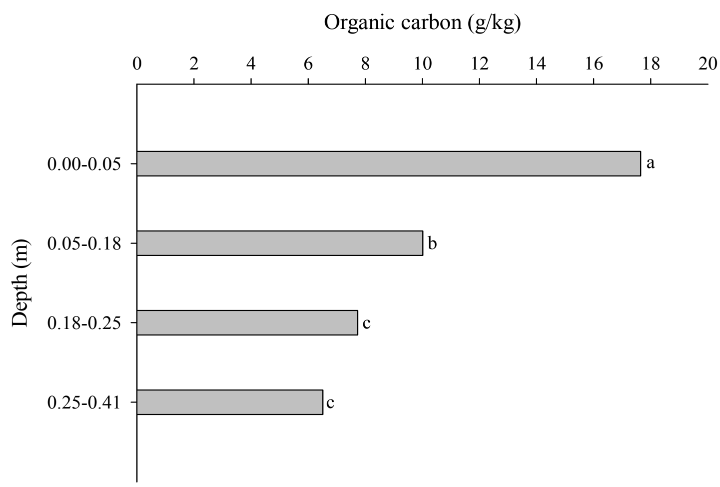

Figure 2. Mean contents of total organic carbon of the soil (g/kg) at the depths of 0.0-0.05, 0.05-0.18, 0.18-0.25 and 0.25-0.41 m. Bars followed by the same lowercase letter do not differ by Scott-Knott test at 0.05 probability level

In agroforestry systems, the vegetal residues are supplied to the soil as crop residues, residues from tree pruning and litter. These vegetal residues are sources of nutrients and organic matter and, when decompose, they can contribute to the maintenance of soil fertility (Zeng et al., 2010). Considering that 58% of the organic matter is carbon and multiplying the mean values of organic carbon by the factor 1.724 (100/58), the mean values of organic matter for the depths of 0-5, 5-18, 18-25 and 25-41 cm were 30.41, 17.27, 13.34 and 11.23 g/kg, respectively. In a study conducted by Menezes et al. (2012), based on the above-mentioned assumption, the mean value of organic matter in the Caatinga biome was 16.03 g/kg in surface. The contents of organic matter found at the first two soil depths in the present study were higher than those reported by Menezes et al. (2012), which is explained by the application of manures and incorporation of residues from leguminous plants in the AFS.

Thus, it is proven that the AFSs increase the organic matter contents of the soil, with reduced disturbance and with supply of organic materials of distinct quality. Hence, they contribute to improving the contents of organic carbon and nutrients in the soil, culminating in improvements for the microbial diversity and fertility of the soil (Bini et al., 2013).

4. Conclusions

The plant components contribute differently to soil chemical attributes.

Agrosilvopastoral systems have positive impacts on soil chemical quality attributes, especially the tree component, which promotes improvements in attributes such as CEC, even without the addition of inputs.

There are benefits in the soil chemical attributes in the influence area of the crop component, due to the addition of pruning residues of the shrub component and the manures from the animals of the agrosilvopastoral system.

The shrub component, for suffering exportation of nutrients due to the use as fertilizer leguminous plant and protein bank for animal feed, must be complemented with nutrients through fertilization.

The shrub, tree and crop components equally contribute to the organic matter contents of the soil in the agrosilvopastoral system and these contents are similar to those of the natural regeneration area.

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References

Aguiar, M. I. D., Malta Ferreira Maia, S., Senna de Oliveira, T., Sá Mendonça, E., & Araujo Filho, J. A. (2006). Perdas de solo, água e nutrientes em sistemas agroflorestais no município de Sobral, CE. *Revista Ciência Agronômica, 37*(3), 270-278.

Alfaia, S. S., Ribeiro, G. A., Nobre, A. D., Luizão, R. C., & Luizão, F. J. (2004). Evaluation of soil fertility in smallholder agroforestry systems and pastures in western Amazonia. *Agriculture, Ecosystems & Environment, 102*(3), 409-414. https://doi.org/10.1016/j.agee.2003.08.011

Araújo Filho, J. (2013). *Manejo pastoril sustentável da caatinga* (No. IICA L01-52). IICA, Brasilia (Brasil) Projeto Dom Helder Camara, Recife (Brasil) Projeto SEMEAR, Brasilia (Brasil) Associação Brasileira de Agroecologia, Rio Grande do Sul (Brasil).

Araújo, M. A., Tormena, C. A., & Silva, A. D. (2004). Propriedades físicas de um Latossolo Vermelho distrófico cultivado e sob mata nativa. *Revista Brasileira de Ciência do Solo, 28*(2), 337-345. https://doi.org/10.1590/S0100-06832004000200012

Bedel, L., Poszwa, A., van der Heijden, G., Legout, A., Aquilina, L., & Ranger, J. (2016). Unexpected calcium sources in deep soil layers in low-fertility forest soils identified by strontium isotopes (Lorraine plateau, eastern France). *Geoderma, 264*, 103-116. https://doi.org/10.1016/j.geoderma.2015.09.020

Bini, D., dos Santos, C. A., do Carmo, K. B., Kishino, N., Andrade, G., Zangaro, W., & Nogueira, M. A. (2013). Effects of land use on soil organic carbon and microbial processes associated with soil health in southern Brazil. *European Journal of Soil Biology, 55*, 117-123. https://doi.org/10.1016/j.ejsobi.2012.12.010

Brown, G. G., Römbke, J., Höfer, H., Verhaagh, M. A. N. E. R. E. D., Sautter, K. D., & Santana, D. L. Q. (2006). Biodiversity and function of soil animals in Brazilian agroforestry systems. *Sistemas Agroflorestais: Bases Cientıficas para o desenvolvimento sustentável* (pp. 217-242). UENF, Campos dos Goytacazes.

Carranca, C., Torres, M. O., & Madeira, M. (2015). Underestimated role of legume roots for soil N fertility. *Agronomy for Sustainable Development, 35*(3), 1095-1102. https://doi.org/10.1007/s13593-015-0297-y

Cunha, Q., Stone, L. F., de B, F., Enderson, P., Didonet, A. D., & Moreira, J. A. (2012). Atributos físicos, químicos e biológicos de solo sob produção orgânica impactados por sistemas de cultivo. *Revista Brasileira de Engenharia Agricola e Ambiental, 16*(1), 56-63. https://doi.org/10.1590/S1415-43662012000100008

Dias Teixeira, H. C., Figueira Dias, M., Silveira, V., Fontes Leite, M. A., Filho Oliveira, A. T. D., & Scolforo, S. J. R. (2002). Variação temporal de nutrientes na serapilheira de um fragmento de floresta estacional semidecidual montana em Lavras, MG. *Cerne, 8*(2), 1-16.

Donagema, G. K., de Campos, D. B., Calderano, S. B., Teixeira, W. G., & Viana, J. M. (2011). *Manual de métodos de análise de solo*. Embrapa Solos-Documentos (INFOTECA-E).

EMBRAPA. (2013). Empresa Brasileira de Pesquisa Agropecuária. *Sistema brasileiro de classificação de solos* (3rd ed., p. 353). Rio de Janeiro: Embrapa Solos.

Fernandes, V. L. B. (1993). *Recomendações de adubação e calagem para o Estado do Ceará*. Fortaleza: UFC.

Iwata, B. D. F., Leite, L. F., Araújo, A. S., Nunes, L. A., Gehring, C., & Campos, L. P. (2012). Sistemas agroflorestais e seus efeitos sobre os atributos químicos em Argissolo Vermelho-Amarelo do Cerrado piauiense. *Revista Brasileira de Engenharia Agrícola e Ambiental, 16*(7), 730-738. https://doi.org/10.1590/S1415-43662012000700005

Ketema, H., & Yimer, F. (2014). Soil property variation under agroforestry based conservation tillage and maize based conventional tillage in Southern Ethiopia. *Soil and Tillage Research, 141*, 25-31. https://doi.org/10.1016/j.still.2014.03.011

Koohafkan, P., Altieri, M. A., & Gimenez, E. H. (2012). Green Agriculture: foundations for biodiverse, resilient and productive agricultural systems. *International Journal of Agricultural Sustainability, 10*(1), 61-75. https://doi.org/10.1080/14735903.2011.610206

Lane, P. N., Noske, P. J., & Sheridan, G. J. (2011). Phosphorus enrichment from point to catchment scale following fire in eucalypt forests. *Catena, 87*(1), 157-162. https://doi.org/10.1016/j.catena.2011.05.024

Lehmann, J., Peter, I., Steglich, C., Gebauer, G., Huwe, B., & Zech, W. (1998). Below-ground interactions in dryland agroforestry. *Forest Ecology and Management, 111*(2), 157-169. https://doi.org/10.1016/S0378-1127(98)00322-3

Mello, F. D., Brasil Sobrinho, M. D., Arzolla, S., Silveira, R. I., Cobra Netto, A., & Kiehl, J. D. C. (1983). *Fertilidade do solo*. São Paulo: Nobel.

Mendes Filho, P. F., Vasconcellos, R. L. F., De Paula, A. M., & Cardoso, E. J. B. N. (2010). Evaluating the potential of forest species under "microbial management" for the restoration of degraded mining areas. *Water, Air, and Soil Pollution, 208*(1-4), 79-89. https://doi.org/10.1007/s11270-009-0150-5

Menezes, R. S. C., Sampaio, E. V. S. B., Giongo, V., & Pérez-Marin, A. M. (2012). Biogeochemical cycling in terrestrial ecosystems of the Caatinga Biome. *Brazilian Journal of Biology, 72*(3), 643-653. https://doi.org/10.1590/S1519-69842012000400004

Nair, M. G., Safir, G. R., & Siqueira, J. O. (1991). Isolation and identification of vesicular-arbuscular mycorrhiza-stimulatory compounds from clover (*Trifolium repens*) roots. *Applied and Environmental Microbiology, 57*(2), 434-439.

Oliveira, F. C., Mattiazzo, M. E., Marciano, C. R., & Rossetto, R. (2002). Efeitos de aplicações sucessivas de lodo de esgoto em um Latossolo Amarelo distrófico cultivado com cana-de-açúcar: Carbono orgânico, condutividade elétrica, pH e CTC. *Revista Brasileira de Ciência do Solo, 26*(2), 505-519. https://doi.org/10.1590/S0100-06832002000200025

Paciullo, D. S. C., de Miranda Gomide, C. A., de Castro, C. R. T., Fernandes, P. B., Müller, M. D., Pires, M. D. F. Á., ... & Xavier, D. F. (2012). Características produtivas e nutricionais do pasto em sistema agrossilvipastoril, conforme a distância das árvores. *Pesquisa Agropecuária Brasileira, 46*(10), 1176-1183. https://doi.org/10.1590/S0100-204X2011001000009

Pavinato, P. S., & Rosolem, C. A. (2008). Disponibilidade de nutrientes no solo-decomposição e liberação de compostos orgânicos de resíduos vegetais. *Revista Brasileira de Ciência do Solo, 32*(3), 911-920. https://doi.org/10.1590/S0100-06832008000300001

Pezzoni, T., Vitorino, A. C. T., Daniel, O., & Lempp, B. (2012). Influência de *Pterodon emarginatus* Vogel sobre atributos físicos e químicos do solo e valor nutritivo de *Brachiaria decumbens* Stapf em sistema silvipastoril. *Cerne, 18*(2), 293-301. https://doi.org/10.1590/S0104-77602012000200014

Prado, R. D. M. (2001). Saturação por bases e híbridos de milho sob sistema plantio direto. *Scientia Agricola, 58*(2), 391-394. https://doi.org/10.1590/S0103-90162001000200024

Richards, L. A. (1969). *Diagnosis and improvement of saline and alkali soils*. United States Department of Agriculture; Washington.

Silva, G. L., Lima, H. V., Campanha, M. M., Gilkes, R. J., & Oliveira, T. S. (2011). Soil physical quality of Luvisols under agroforestry, natural vegetation and conventional crop management systems in the Brazilian semi-arid region. *Geoderma, 167*, 61-70. https://doi.org/10.1016/j.geoderma.2011.09.009

Silveira, M. M. L. D., Bezerra Araújo, M. D. S., & de Sá Barretto Sampaio, E. V. (2006). Distribuição de fósforo em diferentes ordens de solo do semi-árido da Paraíba e de Pernambuco. *Revista Brasileira de Ciência do Solo, 30*(2), 281-291. https://doi.org/10.1590/S0100-06832006000200009

Souza, H. A., Cavalcante, A. C., Tonucci, R. G., Pompeu, R. C. F. F., Souza, M. C. R., & Maia, C. E. (2014). Níveis críticos para atributos do solo pela distribuição normal reduzida em culturas anuais de subsistência. *Revista Brasileira de Engenharia Agrícola e Ambiental, 18*(4), 425-430. https://doi.org/10.1590/S1415-43662014000400010

Yeomans, J. C., & Bremner, J. M. (1988). A rapid and precise method for routine determination of organic carbon in soil. *Communications in Soil Science and Plant Analysis, 19*(13), 1467-1476. https://doi.org/10.1080/00103628809368027

Zeng, D. H., Mao, R., Chang, S. X., Li, L. J., & Yang, D. (2010). Carbon mineralization of tree leaf litter and crop residues from poplar-based agroforestry systems in Northeast China: A laboratory study. *Applied Soil Ecology, 44*(2), 133-137. https://doi.org/10.1016/j.apsoil.2009.11.002

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