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Chemical properties of soils in agroforestry homegardens and other land use systems in Eastern Amazon, Brazil

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Homegardens are considered as an alternative to preserve and/or restore the fertility and productivity of degraded soils. The assessment of changes in soil chemical properties resulting from land use and management is important to understand these changes and allow a rational intervention to ensure production on a sustainable basis. Thus, the aim of this study was to evaluate the soil chemical properties of homegardens and other systems of land use, as well as to identify the factors that influence fertility in areas of family farming in the municipality of Bonito, Eastern Amazon. Three soil samples were collected from secondary forest, cassava (*Manihot esculenta*) monoculture, silvopastoral systems and homegardens, from the depth range of 0-20 cm, and were evaluated in a completely randomized design with 12 treatments and three replications. The data were subjected to analysis of variance with the Kruskal-Wallis test, correlation analysis and principal component analysis. The variables studied, except Mg and Ca, were influenced by the soil cover. The homegardens, agricultural monoculture and silvopastoral systems were similar to the secondary forest in terms of nutrient cycling, with the exception of one 35-year-old homegarden, where the levels of P and K were higher. The soil fertility was explained by three factors: soil nutrients and salinity (P, K and Na); soil acidity and aluminum toxicity (Ca, Al, Mg, and pH); and by soil organic matter (SOM).

Key words: Soil cover, agroforestry systems, tropical soils, family agriculture, Amazon region.

INTRODUCTION

The sustainable use of natural resources has become an increasingly relevant issue due to the intensification of human activities and the negative impacts they have (Kittur et al., 2014). The removal of natural vegetation and the implementation of agricultural activities disturb the balance of the ecosystem, particularly of the soil,

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since the management influences the physical, chemical and biological processes and consequently, modifies the soil chemical and physical properties (Costa et al., 2008).

Since the soil is the basis for agriculture and forestry production, concerns about the sustainable use and soil quality have increased (Araújo et al., 2007). The degree of alterations caused by human intervention in the natural system can be measured, among other means, by changes in some soil properties. These modifications of soil properties can be positive or negative, depending on the nature of the soil, the plant species, the management system, and period of agricultural exploitation (Salton et al., 2008; Carneiro et al., 2009).

In the case of agricultural crops, resulting from the migrating or shifting cultivation/agriculture, soil fertility can be recovered if the fallow period, in which the secondary forest grows, is long (Bargali et al., 2009; Joshi et al., 1997). Thus, agroforestry systems are recommended as alternatives for sustainable family farming in the Amazon region, for the rehabilitation of degraded areas (Rosa et al., 2009), and for having a number of advantages over the traditional systems of land use.

Homegardens are considered as an alternative to preserve and restore the fertility and productivity of degraded areas (Altieri, 2002; Rosa et al., 2007), since these agroecosystems normally host several perennial food, medicinal and ornamental species, they are considered as repositories of genetic diversity, aside from providing environmental comfort, locations of family aggregation and, above all, food security (Bargali, 2015; Bargali et al., 2015a).

The silvopastoral systems also have a series of advantages, as they raise the productive capacity of pastures and animals, improve fertility, decrease soil compaction, conserve the soil, minimize the environmental stress on livestock, improve the environmental conditions and increase the property value (Oliveira et al., 2003).

When comparing the conditions of the soil under original cover with soil from which it was removed or where a crop was planted, the resulting modifications and damage, especially with regard to fertility are generally visible, with greater or lesser evidence. Thus, the evaluation of fertility is critical for the diagnosis of soil nutrients from which specific recommendations and corrections can then be inferred, according to the crop requirements, or management practices that conserve or restore the soil fertility and productivity can be adopted.

The assessment of changes in soil chemical properties resulting from land use and management is important to understand these changes and allow a rational intervention to ensure production on a sustainable basis. Given the above, the objective of this study was to evaluate the chemical properties of soils of homegardens and different land use systems, and to identify the factors that influence their fertility in areas of subsistence farming in Eastern Amazon, State of Pará, Brazil.

MATERIALS AND METHODS

This study was conducted on seven family farms in four rural communities in the municipality of Bonito (Sumaúma, Cumaruzinho, Pau Amarelo and São Benedito), in the microregion Bragantina, northeast of the State of Pará, Brazil (01° 21' 48" latitude S, 47° 18' 21" longitude W).

Soil samples were collected in four land use systems, namely: secondary forest (capoeira); cultivation of *Manihot esculenta* Crantz - cassava (plantation); silvopastoral system (*Brachiaria* spp. and *Attalaea maripa* (Aubl) Mart.); and homegardens of different ages, not necessarily contiguous areas.

The three cassava fields were manually prepared with slash-burning of the secondary forest and were 5, 6 and 7 years old at the time of the research. The three silvopastoral systems were formed by a consortium of *Brachiaria* spp. with scattered adult *Attalea maripa* (inajá) trees in pastures. The Inajá palms grew spontaneously after burning and cleaning of pasture (natural regeneration), in areas with 10, 15 and 35 years of management. The three homegardens had been managed for 7, 12 and 35 years, for as long as these areas were occupied by the farmer families.

The capoeira areas, targets of this research, were the result of the ecological succession that took place when agricultural fields (farm) were left fallow. These cassava fields had previously been used for an average period of 5 years, and were abandoned after monoculture to regain soil fertility for future reuse and had been left fallow for 10, 12 and 15 years.

The secondary forest was used as a control to demonstrate that homegardens can have satisfactory conditions of environment conservation (Sena et al., 2007), with regard to the chemical properties, aside from serving as comparison with the farm and pasture systems.

The soil was collected as recommended by Silva Jr et al. (2006), using a auger, from the 0-20 cm depth range of each area. Three composite soil samples were collected in each treatments, consisting of 20 simple samples collected in a zig-zag line. The chemical variables soil organic matter (SOM); pH in H_2O; levels of exchangeable Ca^{2+}, Mg^{2+}, K^+, Na^+, Al^{3+} and available P (Mehlich-1) were evaluated as described by Embrapa (1997).

The experimental design was completely randomized, with 12 treatments and three replications. The treatments consisted of four land use systems, which combined with their age resulted in 12 treatments: T1- secondary forest 10 years, T2: secondary forest 12 years, T3- secondary forest 15 years, T4- cassava monoculture 5 years, T5- cassava monoculture 6 years; T6- cassava monoculture 7 years, T7- pasture 10 years; T8- pasture 15 years; T9- pasture 35; T10- homegarden 7 years; T11- homegarden 12 years; T12- homegarden 35 years.

The variables were subjected to the Kolmogorov-Smirnov test to check data normality. Treatment effects on soil chemical properties were determined by analysis of variance (ANOVA), using the program Assistat 7.6 and the averages compared by Tukey's test at 5% for pH, OM, Al, Na, Ca, Mg, with a normal distribution. The variables P and K, with non-normal distribution, were analyzed by the Kruskal- Wallis test at 5%.

Pearson's correlations were established between the chemical properties studied and the data analyzed by multivariate factor analysis to find how the variables are grouped to explain soil fertility. The analysis was carried out with the Statistical Package for Social Sciences (SPSS ® 15.0).

RESULTS AND DISCUSSION

There was a significant difference ($p < 0.05$) between treatments for the variables pH, P, K, Na, Al and SOM.

Table 1. Means of chemical variables of soils (0 - 20cm) under different land use on family farms in Bonito, Eastern Amazon, Brazil.

T	pH $_{H2O}$	SD	P	SD	K	SD	Na	SD	Ca^{2+}	SD	Mg^{2+}	SD	Al^{3+}	SD	SOM	SD
	---------------mg dm^{-3}---------------				--$cmol_c$ dm^{-3}--										g kg^{-1}	
T1	5.53ab	0.12	1.00f	0.00	0.05e	0.00	0.06b	0.01	2.20a	0.30	0.60a	0.10	0.20bc	0.10	9.82ab	1.06
T2	5.43ab	0.15	8.33de	12.70	0.06d	0.00	0.08b	0.01	1.73a	0.21	0.57a	0.12	0.23abc	0.06	10.53ab	0.59
T3	5.40ab	0.40	1.00f	0.00	0.09b	0.01	0.10b	0.01	2.23a	1.23	0.77a	0.15	0.27abc	0.15	12.04ab	2.70
T4	5.17b	0.21	2.00c	0.00	0.07c	0.02	0.08b	0.00	1.47a	0.15	0.53a	0.15	0.53a	0.12	12.55a	0.76
T5	5.30ab	0.20	1.67e	1.15	0.06d	0.00	0.06b	0.01	1.93a	0.32	0.67a	0.12	0.20bc	0.10	8.05ab	1.15
T6	5.33ab	0.06	1.33e	0.58	0.07c	0.01	0.08b	0.01	1.73a	0.25	0.63a	0.06	0.20bc	0.00	8.64ab	0.96
T7	5.40ab	0.17	3.00cd	2.65	0.06d	0.01	0.09b	0.01	1.40a	0.30	0.53a	0.21	0.47ab	0.21	10.46ab	2.13
T8	5.37ab	0.06	1.00f	0.00	0.11b	0.02	0.13ab	0.01	1.63a	0.21	0.63a	0.21	0.37abc	0.06	12.07ab	2.41
T9	5.37ab	0.06	1.33e	0.58	0.06d	0.00	0.08b	0.00	1.53a	0.15	0.53a	0.26	0.37abc	0.06	11.61ab	1.01
T10	5.40ab	0.10	12.00b	1.00	0.07c	0.01	0.08b	0.01	1.57a	0.35	0.40a	0.06	0.30abc	0.00	8.77ab	2.73
T11	5.80ab	0.30	4.33cd	4.93	0.11d	0.11	0.11b	0.04	1.70a	0.36	0.60a	0.12	0.13c	0.06	6.77b	2.06
T12	5.83a	0.38	75.00a	21.52	0.26a	0.04	0.19a	0.01	2.57a	1.04	0.77a	0.12	0.17bc	0.12	10.31ab	3.91
M	5.44		9.33		0.09		0.10		1.81		0.60		0.29		10.13	
CV	3.38		40.29		22.96		10.08		22.48		23.11		29.40		16.85	

T= Treatments; SD=standard deviation; M=mean; CV= coefficient of variation (%). Means followed by the same letter in columns are statistically not different by Tukey's test at $p < 0.05$ (pH_{H2O}; Na^+; Ca^{2+}; Mg^{2+}; Al^{3+}; SOM- soil organic matter) and by the Kruskal-Wallis test at $p < 0.05$ (P and K). (T1- secondary forest 10 years ; T2: secondary forest 12 years ; T3- secondary forest 15 years ; T4- cassava monoculture 5 years ; T5- cassava monoculture 6 years; T6- cassava monoculture 7 years; T7- pasture 10 years; T8- pasture 15 years; T9- pasture 35 years; T10- homegarden 7 years; T11- homegarden 12 years; T12- homegarden 35 years).

Regarding pH, the soils studied were moderately acid (Table 1). Only T4 and T12 differed, the soil in T4 had a lower pH than in T12. This can be explained by the higher SOM content in T4, which increases the active acidity of the soil, favoring the development of active H^+ ions in the soil solution.

The average pH values observed in this study were higher than those found by Sena et al. (2007) in different systems of land use in Marituba (Brazil), including capoeira, agroforestry and açaí (*Euterpe oleracea* Mart.) monoculture. Oliveira et al. (2008) found high acidity levels in soils under forest plantations and degraded grassland in the State of Espírito Santo (Brazil). In T12, nutrient cycling was more efficient (Table 1), with higher mean values of soil P (75.00 mg dm^{-1}) and K (0.26 $cmol_c$ dm^{-3}) than in the other agroecosystems. Phosphorus is fundamental for the plant physiology. According to Fraga and Salcedo (2004), soils with low levels of available P, together with the water limitations, can be a serious combination that would severely restrict the recovery rate of degraded soils or may even impair their recovery, due to the drawback in plant growth.

The values of available P can be explained not only by the high weathering degree of these soils, culminating in the predominance of Fe and Al oxides in the clay fraction of Oxisols, but also by the high soil moisture, which increases the redox potential, leading to a probable reduction of ferric compounds and higher levels of available P to plants (Fernandez et al., 2008; Pandey and Srivastava, 2009). For being elements of low mobility in soil, the P highest level measured in the layer can be explained by the accumulation resulting from cycling promoted by the roots, which absorb it from deeper layers and after metabolism are deposited on the soil surface through the deposition of plant residues. Another factor that could justify the highest level of available P in T12 is the lower value of exchangeable acidity. Therefore, less Al^{3+} is available to adsorb the P in the soil solution.

In T12, the highest content and concentration of

Table 2. Correlation matrix of chemical variables of soils under different land use systems on family farms, Eastern Amazon, Pará, Brazil.

	pH	Ca	Mg	Al	P	K	Na	SOM
pH	1							
Ca	0.620	1						
Mg	0.456	0.726	1					
Al	-0.712	-0.624	-0.455	1				
P	0.518	0.468	0.348	-0.285	1			
K	0.608	0.344	0.316	-0.310	0.839	1		
Na	0.577	0.286	0.341	-0.233	0.732	0.931	1	
SOM	-0.003	0.349	0.257	0.272	0.079	0.113	0.216	1

P and K (75.00 mg dm^{-1} and 0.26 $cmol_c$ dm^{-3}, respectively) in the soil can be explained by the release of these nutrients from the manure of pigs reared in a semi-confined system in this area. According to Merten and Minella (2002), pig feces are rich in N, P and K, and a high P supply can cause serious impacts on ecosystems. The residue management should take the soil nutrient uptake capacity in waste into consideration to prevent the contamination of water resources.

In Bonito, Eastern Amazon, P levels were higher than the value reported by Gama-Rodrigues et al. (2008), in soils of forest monoculture, pasture and capoeira, and by Sena et al. (2007) in an agroforestry system and capoeira.

Menezes et al. (2008) studied the soil chemical properties of different agroforestry systems and forest fragments in Rondônia and found similar mean levels of available P as in Bonito, Eastern Amazon. However, the soils of the homegardens in Pará had higher levels of available P than in Rondonia (Brazil), due to the soil management (organic fertilization with pig manure).

The K values in the different land use systems in Bonito were generally low. Statistical differences were found only for T12, with 0.26 $cmol_c$ dm^{-3} K. This value was similar to that found by Gama-Rodrigues et al. (2008) for planted forests and higher than in the capoeira area in this study. Portugal et al. (2010) found K concentrations (0.061 $cmol_c$ dm^{-3}) in the Zona da Mata of Minas Gerais (Brazil), that were very close to those observed in this study in the secondary forest areas in Bonito, Eastern Amazon (0.065 $cmol_c$ dm^{-3}). The values of K were lower than those of other nutrients because K is actively leachable (Bargali et al., 1993, 2015b).

The Ca and Mg levels did not differ between the agroecosystems (Table 1). With regard to the Al^{3+} contents, most treatments were not statistically different; only T4 and T11 showed highly significant differences at 5% probability.

The Al^{3+} contents found in the agroecosystems under different land uses were low as compared to those reported by Portugal et al. (2010) and Sena et al. (2007). The latter authors found an average level of 1.44 $cmol_c$ dm^{-3} in land use systems evaluated in Marituba (Brazil), and inferred that, regardless of the systems, the Al^{3+} soil concentrations were high and toxic to plants.

The SOM level was lower in the 12-year-old homegarden than in the field cultivated for 5 years, showing that the practice of removing the litter from these systems tends to reduce sustainability. The values for organic matter in the evaluated systems and secondary forest areas were about 10.1 g, and 10.8 g kg^{-1}, respectively.. According to Gliessman (2005), SOM levels in the A horizon of natural ecosystems can reach 150-200 g kg^{-1}, but the content of this variable is on average around 10-50 g kg^{-1}.

In a comparative study of the chemical properties of native forest soils with an orange (*Citrus sinensis* (L.) Osbech) orchard and pasture in the Zona da Mata, Minas Gerais (Brazil), Portugal et al. (2010) identified significant SOM values. However, the values obtained by these authors were lower than those found in Bonito, Eastern Amazon. In contrast, Silva et al. (2006) reported higher SOM values in secondary forests (24.1 g kg^{-1}) and degraded pastures (33.7 g kg^{-1}) in Marituba, Pará. They stated that the high SOM levels in degraded pastures are due to the soil regeneration and death of grass root system.

The correlation matrix of the chemical variables analyzed in the soil under different agrosystems (Table 2) showed that the pH was positively but moderately correlated with the variables Ca, Na and K. This indicates that the removal of the basic cations, particularly of Ca^{2+} and K^+ led to a decrease in the pH of the system and that their addition, mainly by liming or fertilization, induced Ph increase. In regions with high rainfall, the tendency for soil acidification by displacement of basic cations, such as Ca, Mg, K, and Na, from the exchange complex is greater (Sousa et al., 2007).

The degree of association between pH and Al^{3+} was negative and relatively high (-0.712), indicating that the lower the pH, the greater the amount of Al^{3+} in the soil, which according to Fernandéz et al. (2008) may occur due to the higher solubility of Al complexes in these pH ranges.

The pH reduction favored an increase of the Al^{3+}

Table 3. Results of the eigenvalues for the extraction of factors and the total variance explained by the factors.

Component	Eigenvalues (λ) and initial variances			Variance after rotation		
	Total variance	Variance (%)	Total variance	Variance (%)	Total variance	Variance (%)
1	4.12	51.50	51.50	2.91	36.42	36.42
2	1.48	18.47	69.97	2.66	33.31	69.74
3	1.30	16.29	86.26	1.32	16.53	86.26
4	0.45	5.69	91.95			
5	0.35	4.43	96.39			
6	0.18	2.21	98.60			
7	0.07	0.85	99.45			
8	0.04	0.54	100			

Table 4. Matrix of factor loadings (α) after orthogonal rotation by the Varimax method for the chemical properties of soils of different land use systems in Eastern Amazon, Pará, Brazil.

Variables	Factors			Commonalities
	F1	F2	F3	
pH	0.528	0.679	-0.217	0.787
SOM	0.088	0.112	0.941	0.906
P	0.855	0.247	0.033	0.794
K	0.965	0.182	0.009	0.964
Na	0.936	0.143	0.116	0.910
Ca	0.190	0.894	0.257	0.902
Mg	0.166	0.787	0.295	0.734
Al	-0.158	-0.811	0.470	0.904

concentration in the medium, raising P fixation, mainly by the formation of insoluble Al-P compounds, which explains the higher level of available P by the pH increase.

After the analysis of linear correlation, the variables were grouped by the method of principal component analysis and reduced to factors that can help explain soil fertility in the studied agroecosystems (Table 3). The factor extraction was performed from the eight variables in the soil analysis.

Three components (factors) with Eigenvalues greater than 1 were extracted. The value of the Kaiser-Meyer-Olkin (KMO) test was 0.641. According to Hair Jr. et al. (2009), KMO values above 0.50 allow the use of this tool to explain a phenomenon.

The data of the initial solution are rotated for the three possible factors and the explanatory power expressed by the Eigenvalues obtained from the spectral decomposition of the correlation matrix is shown in Table 3. The three factors together explain 86.26% of the data cloud related to the chemical properties of different land use systems in Bonito. In order of importance, Factor 1 explained most of the variance (36.42%), Factor 2 explained 33.31% of the variance and Factor 3 accounted for 16.53%.

According to Santana (2007), a meaning must be assigned to the factor solution. This author suggests that the significant factor loadings should be used in the process of interpretation and also recommends that the selection of names or labels to represent the factors be based on the variables with highest load. Thus, the appointment of factors, from the factor loadings, is presented in Table 4, which also shows the values of commonalities. According to Santana (2007), these values indicate the degree to which each variable can be explained by factors.

The variables P, K and Na were grouped in Factor 1. The combination of these variables generated the factor nutrients and soil salinity. The source variables had positive and high factor load, which shows a strong inter-relationship between them. In soils with predominance of variable loads, the K content in the solution is influenced mainly by the electrostatic adsorption of K to negative charges (Neves et al., 2009). Potassium reserves are very important for agricultural systems with low input (Rangel, 2008) and a dynamic element, with high mobility, which can move Na by the cation exchange capacity of the soil

(Melo et al., 2000).

Factor 2 was formed by the inter-relationship between pH, Ca, Mg and Al. This factor was named soil acidity and aluminum toxicity, since the variables that compose it are related to soil acidity. The Al^{3+} content had a negative factor loading, showing that higher values of pH, Ca and Mg tend to produce smaller amounts of Al^{3+}. This result is in agreement with Leite et al. (2010), who studied the characteristics of soils under *Eucalyptus* sp. and found a reduction in the exchangeable Ca, Mg and K levels. Moreover, Lopes et al. (1991) stated that the removal of basic elements such as K, Ca, Mg and Na can lead to soil acidity.

Factor 3 was named soil organic matter, and consists only of the variable organic matter, showing the great importance of this compartment for soil fertility in the systems evaluated in Bonito, influencing the soil physical, chemical as well as biological properties. The mineralization of organic matter leads to, primarily, release of nitrogen to plants. According to Gliessman (2005), SOM has a close relationship with the soil N content and can influence the levels of this nutrient in the soil by up to 80%.

The soil organic matter supplies N to plants, and therefore its presence constitutes a great benefit to the soil. However, this required processes of microbial decomposition, accompanied by mineralization and humification of their constituents (Silva, 2008). It is considered to be a major soil component for maintaining the chemical, physical and biological quality. According to Silva and Mendonça (2007), its growth and maintenance in tropical soils has proved more difficult than in subtropical soils. For the authors, the adoption of conservation practices (no tillage, green manure, rotation, etc.) has achieved better results, indicating the importance of higher residue inputs and organic N in the maintenance of this property.

Conclusions

The variables studied, with the exception of Mg and Ca, are influenced by the soil cover. The homegardens, except for the 35-year-old in which P and K levels were higher, and the monoculture, agricultural and silvopastoral systems were similar to the secondary forest in terms of nutrient cycling.

The homegardens preserved some soil chemical properties, with similar values as the secondary forest, and shows that these systems conserve the fertility of tropical soils. The soil fertility in the four land use systems was explained by three factors: soil salinity and nutrients (P, K and Na), soil acidity and aluminum toxicity (Ca, Al, Mg and pH), and soil organic matter (SOM).

Conflict of interests

The authors have not declared any conflict of interest.

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