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ARTIGO CIENTÍFICO

Chemical attributes of soil in agroforestry system of gliricidia intercropped with spineless cactus

Atributos químicos do solo em sistema agroflorestal de gliricídia consorciado com palma forrageira

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Abstract: In this study, we aimed to assess the chemical attributes of a soil fertilized with organic matter, in an agroforestry system. The experiment was carried out at the Miguel Arraes agricultural experiment station of the National Semiarid Institute (INSA), located in Campina Grande, Paraíba, Brazil. Experimental design consisted of a randomized block with four replications. We applied four treatments of organic fertilization: (HS) Humic Substances; (SW) Seaweeds; (B) Bokashi; and (C) control treatment, without fertilization. Soil samples were collected at 0-20 cm depth, placed in plastic bags and taken to laboratory for the following chemical analysis: pH, potassium (K^+), sodium (Na^+), phosphorus (P), calcium (Ca^{2+}), magnesium (Mg^{2+}), soil organic matter (SOM), sum of bases (SB), cation exchange capacity (CEC), base saturation (V%) and Soil Quality Index (SQI). Organic fertilizers applied to the soil did not affected pH, P, K^+, Na^+, Al^{3+} and CEC. Humic substances treatment increased the availability of Mg^{2+}, while seaweeds treatment increased the Ca^{2+}, SB, V% and SOM levels.

Key words: Agroecology; Soil fertility; Resilience; Organic fertilization.

Resumo: Objetivou-se avaliar os atributos químicos de um solo adubado com matéria orgânica, em um sistema agroflorestal. Para isso foi conduzido um experimento na Estação Experimental da Fazenda Miguel Arraes, situada na área sede do Instituto Nacional do Semiárido (INSA), Unidade de Pesquisa do Ministério da Ciência, Tecnologia e Inovação (MCTI), localizada no município de Campina Grande, Paraíba. O delineamento utilizado foi o de blocos casualizados com quatro repetições. Os tratamentos aplicados foram quatro tipos de adubação orgânica: (SH) Substancia Húmicas; (AM) Algas Marinhas; (B) Bokashi; e (T) tratamentos controle, sem adubação. As amostras foram coletadas na profundidade de 0-20 cm, acondicionadas em sacolas plásticas e levadas ao Laboratório de Análise de Solos, Água e Plantas (LASAP) do Instituto Federal de Educação, Ciência e Tecnologia da Paraíba (IFPB) campus Sousa para análises químicas [pH, potássio (K^+), sódio (Na^+), fósforo (P), cálcio (Ca^{2+}), magnésio (Mg^{2+}), matéria orgânica do solo (MOS)], soma de bases (SB), capacidade de troca de cátions (CTC), saturação por bases (V%) e Índice de Qualidade do Solo (IQS). Os adubos orgânicos aplicados no solo não influenciaram no pH, fósforo (P), potássio (K^+), sódio (Na^+), alumínio (Al^{3+}) e CTC. As SH promoveram o aumento na disponibilidade de magnésio (Mg^{2+}) e as AM causaram incremento nos teores de Ca^{2+}, SB, V% e MOS.

Palavras-chave: Agroecologia; Fertilidade do solo; Resiliência; Adubação orgânica.

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INTRODUCTION

Sustainability of family farming systems in Brazilian Semi-arid is a highly discussed topic nowadays. However, improper soil use has led to degradation of its physical, chemical and biological properties, and impairing environmental, social and economic sustainability (MENEZES et al., 2012). Soil degradation spreads all over the world, and extremely affected places have been called “nucleus of desertification or land degradation” in Brazil. In general, they are regions with large areas of bare soils or low vegetation cover and clear signs of soil erosion (PEREZ-MARIN et al., 2012).

These processes usually begin with deforestation and substitution of native vegetation for exotic crops. In Brazilian semi-arid, herbaceous grasses and short cycle crops are replacing the native shrubby arboreal vegetation, called Caatinga. Vegetation removal speeds up erosion process. Continuous cultivation, with extraction of agricultural products without replacement of removed nutrients, leads to the loss of fertility (DUBEUX JUNIOR; SANTOS 2005; PEREZ-MARIN et al., 2006). In irrigated areas, the use of waters with high salt content, poor management of wetting cycles and absence of drainage lead to salinization (CORDEIRO, 1988; FREIRE et al., 2003a; FREIRE et al., 2003b; LEAL et al., 2008). Among these environmental impacts, erosion represents the main factor of soil degradation in semi-arid regions. This comprises a process whereby water or wind displaces and removes the finer and more active particles of soil (in physical, chemical and biological aspects) to other places (GALINDO et al., 2005).

Reforestation and use of agroforestry systems arise as alternatives to face the erosion and desertification. Such practices reduce the negative effects of high rainfall variability, increase or stabilize forage availability and improve soil quality. They also maintain of soil fertility and vegetation cover, which ensure a better nutrient flux when compared to those crops fertilized with manure, crop residues and other composts (PEREZ-MARIN et al., 2006; PEREZ-MARIN 2007; MENEZES et al., 2002).

The alley cropping of gliricidia (*Gliricidia Sepium*) stands among agroforestry strategies adopted in Brazilian semi-arid region. This drought resistant arboreal legume is cultivated as a source of fodder and firewood, and is intercropped with spineless cactus (*Opuntia fícus-indica*), which retaining water as an adaptation to dry conditions of semi-arid regions. Such strategy contribute to feeding herds during prolonged droughts (PEREZ-MARIN et al., 2007).

System of alleys comprises planting trees or shrubs, usually legumes, along rows sufficiently spaced to allow planting of agricultural crops between them (SANCHEZ, 2006). The management of this system includes periodic cuts in aerial part of tree species (usually two or three cuts per year), and the use of the biomass to animal feed or for incorporation into soil as green manure.

However, few studies investigated this kind of intercropping strategies in semi-arid Brazil. Thus, the present work aimed to analyze the soil chemical attributes as a function of the implantation of an agroforestry system of gliricidia intercropped with spineless cactus under different organic fertilizations.

MATERIAL AND METHODS

The study was carried out in an agroforestry system at Miguel Arraes agricultural experiment station of the National Semiarid Institute (INSA), Research Unit of the Ministry of Science, Technology and Innovation (MCTI) located in the municipality of Campina Grande (7°14'S-35°57'W), Paraíba, Brazil, with elevation of 491 m. The region has one rainy season, from May to August, and one dry season, from September to April, comprising a dry semi-arid climate. Average annual rainfall is 500 mm with mean annual temperature of 31.5°C and average relative humidity of 78%. Soils in experimental area are natric planosols with sandy texture (EMBRAPA, 2006).

The agroforestry system started in 2010 in an area about 0.5 ha. We planted gliricidia with a spacing of 6 m between rows and 1 m between the plants. Spineless cactus, clone IPA 20, was cultivated between the tree lines, with 1 m x 0.5 m spacing, producing an alley system. After one year of cultivation, four blocks of 240 m^2 (6 m × 40 m) were demarcated. Each block was subdivided into four plots of 60 m^2 (6 m × 10 m), which received four types of organic fertilization: (HS) 40 L ha^{-1} $year^{-1}$ of Humic Substances, of the brand Naturvital-25; (SW) 4 L ha^{-1} $year^{-1}$ of seaweed, of the brand CANADIAN; (B) 5 t ha^{-1} $year^{-1}$ of Bokashi; and (C) the control treatment, without fertilization. The fertilizers were applied to the soil, near the stems of cactus and gliricidia. The experimental design was a randomized block design, with four replications.

For the soil chemical analysis, in May 2016, we collected four simple undisturbed samples in each plot with a soil sampler (cylinder), within 0-20 cm deep, and then we mixed the four simple samples to form one composite sample. The samples were packed in polyethylene bags and identified. After that, the soil was dried in the air, crushed and sifted in a 2 mm sieve at the INSA experimental farm.

Samples were sent to the Laboratory of Analysis of Soil, Water and Plants (LASAP) of the Federal Institute of Education, Science and Technology of Paraíba (IFPB), Sousa Campus. The following soil variables were measured according to EMBRAPA (1997): soil reaction, exchangeable cations, exchangeable aluminum, available phosphorus, potential acidity, sum of bases, cation exchange capacity at pH 7, base saturation and soil organic matter.

To determine Soil Quality Indexes for each treatment, all variables were normalized to a 0-1 scale, representing, respectively, the best and the worst soil quality, independently of the values or absolute levels measured in the laboratory (Cantú et al., 2007).

We considered the following two situations: first, when the maximum nutrient value (Nmax) matches the best nutrient status in the soil (normalized nutrient value - Vn = 1). In this case, the quality calculation was done with the equation 1.

$$Vn = \frac{Nm - Nmin}{Nmax - Nmin} \quad \text{(Eq. 1)}$$

On what: Vn = normalized value; Nm = Nutrient measured in laboratory; Nmax = Maximum value of nutrient in soil; and Nmin = Minimum value of nutrient in soil.

Second, when the maximum nutrient value (Nmax) matches the worst nutrient availability in soil (normalized nutrient value - Vn = 0). In this case, the calculation of Vn was done with the equation 2.

$$Vn = 1 - \left(\frac{Nm - Nmin}{Nmax - Nmin}\right) \qquad \text{(Eq. 2)}$$

Maximum and minimum values were set using as reference the values described by Alvarez et al. (1999) and by Cavalcante (2008). Finally, one Soil Quality Index was assigned to each treatment using the average values of all variables. For its interpretation, we applied the scale of transformation in five classes of soil quality (Table 1).

Table 1. Fertility classes for the interpretation of soil analyzes.

Soil Quality Index	Scale	Class
Very Good Quality	0.80 - 1.00	1
High quality	0.60 - 0.79	2
Moderate quality	0.40 - 0.59	3
Low quality	0.20 - 0.39	4
Very Low Quality	0.00 - 0.19	5

To interpret results, data were analyzed with the statistical software ASSISTAT version 7.7 beta (pt) using Tukey test at 5% probability.

RESULTS AND DISCUSSION

Treatments with organic fertilization did not influence significantly the values of pH, P, K^+ and Na^+ of the soil. The pH of the soil was acid, that is, a soil with acid conditions, with values below the pH suitable for most crops, which ranges from 6.0 to 7.0 (LUZ et al., 2002). On the other hand, the available P values ranged from 3 to 4 mg kg^{-1} of soil, and those of K^+ remained constant at 0.2 cmo_c kg^{-1} of soil. The levels of P, under any type of management, were very low when compared to soils with ideal available nutrient values. The low effect of organic fertilizers on availability of P perhaps was caused by natural low P levels in the soil, or by degradation processes that the area has undergone in the past. These results suggest that, under conditions studied, the fertilizer doses as well as the time of cultivation of the agroforestry system were insufficient to improve the availability of these elements in the soil.

Sodium values did not differed among treatments (Table 2). All soils had normal values of Na^+ and may be considered arable, that is, the addition of fertilizers did not cause any problem of soil sodicity. Holland et al. (2001), studying methods to recover salinized areas, showed that some cultural practices and green manure may help to reduce soil Na^+ through deposition of mulch and incorporation of organic matter to the soil.

Values of Calcium (Ca^{+2}) differed significantly among treatments ($p \leq 0.01$). The treatments were assessed in the Ca^{+3} content suitable range. The soil fertilized with HS and SW stood out from other treatments, showing high concentrations (2 $cmol_c$ dm^{-3}). Similar results were observed by Santos et al. (2008), whom considered that the application of organic fertilizer may increase availability of Ca^{+2}. Magnesium (Mg^{+2}) concentrations also differed among treatments ($p \leq 0.05$), with the lowest content in soil fertilized with Bokashi, which is a natural characteristic of acid soils.

Table 2. Average values of pH, Phosphorus (P), Potassium (K^+) and Sodium (Na^+) of soil fertilized with organic matter in an agroforestry system with gliricidia and spineless cactus at depth of 0-20 cm, in the experimental area of INSA, Campina Grande, Paraíba.

Treatments	pH	P	K^+	Na^+
	H_2O	mg dm^{-1}	------$cmol_c$ dm^{-3}------	
HS	5.7 a	4 a	0.2 a	0.03 a
SW	5.8 a	3 a	0.2 a	0.03 a
B	5.7 a	3 a	0.2 a	0.02 a
C	5.6 a	4 a	0.2 a	0.03 a
CV%	1.67	21.49	12.74	36.93
F	ns	ns	ns	ns
MSD	0.21	1.58	0.06	0.02

HS = Humic Substances; SW = Seaweed; B = Bokashi; C = No fertilization; CV = Coefficient of Variation; MSD = Minimum Significant Difference. Means followed by the same letter, in columns, do not differ from each other by the Tukey test. ns = not significant.

Organic fertilizations with humic substances, seaweeds, Bokashi and the control did not affected aluminum content (Al^{+3}), showing average variation of Al^{+3} and lower values than the soil before fertilization. Levels of Al^{+3} in all treatments can be considered as toxic to plants. Cerreta et al. (2003), when analyzing soil chemical characteristics under application of organic fertilizers, verified that contents of exchangeable Al^{+3} in soils decreased with application of manure and this was reflected in a decrease of Al^{+3} saturation.

Potential acidity ($H^+ + Al^{+3}$) differed significantly between treatments with and without organic fertilization ($p \leq 0.01$; Table 3). Control treatment overlapped all other treatments. Teixeira et al. (2003) verified that the addition of organic matter to the soil promotes neutralization of potential acidity through increasing of negative charges in soil that become available to adsorption of basic cations.

Table 3. Average values of Calcium (Ca^{+2}), Magnesium (Mg^{+2}), Aluminum (Al^{+3}) and Potential Acidity ($H^+ + Al^{+3}$) of soils fertilized with organic matter in an agroforestry system with gliricidia and spineless cactus at depth of 0-20 cm, in the experimental area of INSA, Campina Grande, Paraíba.

Treatments	Ca^{+2}	Mg^{+2}	Al^{+3}	$H^+ + Al^{+3}$
	-----------------$cmol_c$ dm^{-3}-------------			
HS	2.3 ab	1.5 a	0.5 a	3.8 b
SW	2.8 a	1.0 ab	0.5 a	3.4 b
B	1.7 b	0.7 b	0.5 a	3.2 b
C	1.6 b	1.0 ab	0.6 a	5.0 a
CV%	18.74	28.25	22.76	14.37
F	**	*	ns	**
MSD	0.86	0.67	0.26	1.20

HS = Humic Substances; SW = Seaweed; B = Bokashi; C = No fertilization; CV = Coefficient of Variation; MSD = Minimum Significant Difference. Means followed by the same letter, in columns, do not differ from each other by the Tukey test. * = $p \leq 0.05$; ** = $p \leq 0.01$; ns = not significant.

The sum of bases (SB) showed significant differences ($p \leq 0.01$), with average values in treatments with Bokashi (B) and the control (C), and high values in treatments with Humic Substances (HS) and Seaweed (SW). Damatto Junior et al. (2006), studying the changes in soil properties, concluded that SB was influenced by treatments with organic fertilization, presenting a linear increase with the doses of compounds, the control showing the lowest values and the highest values obtained with the largest amount of organic fertilizer.

Although cation exchange capacity (CEC) levels were good, they did not differ statistically among treatments. These results are mainly due to the sandy soils found in the studied region, which generally have low CEC and are more susceptible to nutrient loss due to leaching (PIRES et al., 2008).

Scherer, Baldissera and Nesi (2007), studying chemical properties of a Latosol under organic fertilization, found that CEC was unaffected by organic fertilization and remained with relatively high values, between 17 and 20 $cmol_c$ dm^{-3}. These values may be caused by high organic matter content in the superficial layers and high clay content in the deepest layers of the profile, which are responsible for the presence of negative charges in soil.

Organic Matter (OM) presented low values (Table 4) but with significant differences among treatments ($p \leq 0.05$), ranging from 7.7 to 10.0 g kg^{-1}. This result may be caused mainly by the increase of microbial activity in soil, since OM tends to decompose faster under high humidity. Benites and Mendonça (1998), studying the electrochemical properties of a soil fertilized with organic sources, state that from management point of view, organic matter can present dispersive or aggregating effect, depending on quantity and quality of fertilizer.

Table 4. Average values of Sum of Bases (SB), Cation Exchange Capacity (CEC), Organic Matter (OM) and Base Saturation (V%) of a soil fertilized with organic matter in an agroforestry system with gliricidia and spineless at depth of 0-20 cm, in the experimental area of INSA, Campina Grande, Paraíba.

Treatments	**SB**	**CEC**	**OM**	**V**
	-----$cmol_c$ dm^{-3}-----		g kg^{-1}	%
HS	4,0 ab	7,8 a	9,9 ab	51,9 a
SW	4,1 a	7,4 a	10,0 a	54,5 a
B	2,8 c	6,0 a	8,2 ab	45,2 b
C	2,8 bc	7,7 a	7,7 b	36,3 c
CV%	16,28	13,98	11,66	5,79
F	**	ns	*	**
MSD	1,22	2,23	2,30	6,02

HS = Humic Substances; SW = Seaweed; B = Bokashi; C = No fertilization; CV = Coefficient of Variation; MSD = Minimum Significant Difference. Means followed by the same letter, in columns, do not differ from each other by the Tukey test. * = $p \leq 0.05$; ** = $p \leq 0.01$; ns = not significant.

Base Saturation (V%) showed a significant difference among kind of fertilizations ($p \leq 0.01$). Treatments B and C had V less than 50%, which are considered dystrophic soils, that is, little fertile. The treatments fertilized with Humic Substances (HS) and Seaweed (SW) showed average results of Base Saturation, which are considered eutrophic soils (V > 50%). Damatto Junior et al. (2006), studying changes in properties of soils fertilized with organic compound obtained similar results, noting the influence of treatments on SB. In their results control treatment showed the lowest index (69%), but this high value of SB was caused by organic matter applied as a compound, which raised the pH due to addition of organic residues and because it adsorbed hydrogen and aluminum in the surface of organic material.

In Table 5, we show normalized values of indicators calculations and the indexes of soil quality by treatment of organic fertilization. In general, the indicators that showed the lowest values of soil quality in all treatments of organic fertilization were P, OM, V and CEC at pH 7, indicating that these factors were critical in studied soils. Highest values of soil quality in all treatments were pH, Al^{3+}, $H^+ + Al^{3+}$ and Na^+ indicators, while K^+ values were intermediate in all treatments. The value of Ca^{2+} decreased strongly in treatments B and C, showing intermediate to high values in treatments SW (0.86) and HS (0.50). On the other hand, values of Mg^{2+} were high in the HS treatments, average in SW and C and low in the treatment B.

Table 5. Indicators and Soil Quality Index as a function of organic fertilization applied in an agroforestry management system - cultivation of gliricidia with spineless cactus.

Indicator	**Organic fertilization treatments**			
	HS	**SW**	**B**	**C**
pH	0.87	0.80	0.87	0.93
P	-1.73	-1.80	-1.80	-1.73
K^+	0.60	0.60	0.60	0.60
Na^+	0.90	0.90	0.93	0.90
Ca^{+2}	0.50	0.86	0.07	0.00
Mg^{+2}	1.00	0.63	0.41	0.63
Al^{+3}	1.00	1.00	1.00	0.90
$H^+ + Al^{+3}$	0.80	0.86	0.89	0.62
SB	0.62	0.67	0.05	0.05
CTC	0.32	0.25	0.00	0.31
MO	0.21	0.21	0.12	0.09
V	0.04	0.09	-0.10	-0.27
IQS	0.43	0.42	0.25	0.25

HS = Humic Substances; SW = Seaweed; B = Bokashi; C = No fertilization; SQI = Soil Quality Index.

Soil Quality Index (SQI) for HS and SW treatments showed moderate quality, where the SQI was strongly influenced by the P>V>OM>CEC indicators. Treatments B and T were classified as low quality, being strongly influenced by the indicators P>V>OM>SB>CEC. Iwata et al. (2012), assessing the effects of agroforestry systems on chemical attributes of the soil, verified an improve in soil chemical indicators as a result of the increase in pH, nutrient content, decrease in saturation by aluminum and larger stability of soil chemical quality under effect of seasonality in northern mesoregion of the state of Piauí. These changes in chemical attributes affect soil fertility conditions as a source of nutrients for crops.

CONCLUSIONS

Organic fertilizers applied to soil did not influence pH, Phosphorus (P), Potassium (K^+), Sodium (Na^+), Aluminum (Al^{+3}) and Cation Exchange Capacity (CEC).

Humic Substances (SH) increased availability of Magnesium (Mg^{+2}), while Seaweeds (SW) increased Calcium, Sum of Bases (SB), Base Saturation (V) and Organic Matter (OM) in the soil.

Duration of fertilization was insufficient to cause alteration, mainly in the contents of P and OM.

Only HS and SW treatments were classified as class 3 in Soil Quality Index, which are considered as moderate quality.

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