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Vol. 10(38), pp. 3731-3739, 17 September, 2015
DOI: 10.5897/AJAR2015.10044
Article Number: 7F93A7955564
ISSN 1991-637X
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African Journal of Agricultural Research

Full Length Research Paper

Alluvial soil quality in agroforestry systems and native forest of the Brazilian semiarid region

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Received 17 June, 2015; Accepted 21 August, 2015

The agroforestry systems consist of techniques appropriate to local conditions, taking into account the coexistence with the semiarid in Brazil. The objective of the research was to evaluate the soil properties in agroforestry management units (SAFs), and native forest, in Bueno community, city of Irauçuba, CE. Treatments were: (1) Agroforestry management unit SAF 1 in the elevated portion of the landscape (interfluve); (2) Agroforestry management unit SAF 2 in the portion of slope (colluvium), and (3) Native forest. Soil samples were collected: 5 composite samples, derived from 15 sub-samples in areas of study in the layers 0.00-0.10; 0.10-0.20; 0.20-0.30 and 0.30-0.40 m. It was a completely randomized design, with 5 repetitions, treatments (SAF 1, SAF 2 and native forest) and the plots being repetitions. The analysis of variance was applied and means submitted to Tukey test at 5%. There were significant differences for properties analyzed, except to CE_{es}, indicating low concentration of soluble salts, without risks of salinity (0.25 a 0.34 dS m^{-1}). The exchangeable sodium (9.51 a 29.88 mg dm^{-3}), with normal values of PST (0.66 a 1.35%), in the SAF 2 differed from the others. The values of exchangeable sodium considered high are not characterized with restriction according to the normal EST. The units of SAF 1 and SAF 2 contributed to the maintenance of soil quality in top condition to MN, featuring high levels of calcium, magnesium and potassium, with restrictions to the exchangeable sodium SAF 1 and SAF 2 to a lesser extent to the native forest.

Key words: Irauçuba-CE, semiarid, caatinga, agroecology.

INTRODUCTION

Agroforestry is an integrated approach to land use that is characterized by deliberate maintenance of trees and other woody perennials in fields and pastures. This system is one of the best known traditional practices for livelihood, suitable land management and sustainable development (Kittur and Bargali 2013; Parihaar et al., 2014, 2015). These indigenous agroforestry systems not only support the livelihood through production of food, fodder and fuel wood, but also mitigate the impact of climate change through carbon sequestration (Arora et

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al., 2011; Singh et al., 2008; Bargali et al., 2009). These include strategies such as crop rotation, consortia, crops associations with animals, which are aimed at inputs obtainment and soil plant cover (Altieri, 1999).

Agricultural production intensification tendency to meet the global demand for food, the pressure on non-renewable natural resources and the need to produce with sustainability emphasizes the importance of understanding agricultural production factors, and especially understand the soil quality study (Gonzaga et al., 2013).

The Brazilian semiarid region is one of the most populous in the world and with rainfalls above the average of others, with spatial and temporal variability, favoring high evaporation rates. In this geographical space, shallow soils that are little weathered and with good chemical characteristics and physical limitations to agricultural cultivation dominate.

In this region, human intervention in the agricultural environment has occurred in order to use natural resources for food obtainment and, with population expansion, in the pursuit of increased productivity and production. Soil intensive preparation for agricultural crops, deforestation and fires have caused several impacts on the agro-ecosystem, such as flora and fauna, water availability and agricultural soils quality reduction, changing the regional climate. Human action in a disorderly way, without observing land agricultural potential, change the physical, chemical and biological attributes, accelerating desertification.

This predominant agricultural production model in the Brazilian semiarid region does not favor its agro-ecosystem genetic and social heritage conservation and protection. This fact contributes to unveil threatening life form degradation scenarios on the planet, thus accelerating the desertification process.

Given the addressed problems, the semiarid region needs an interaction culture that considers the drought phenomenon, the available natural resources and the people who inhabit this plural and diverse geopolitical space. Thus, the development of technologies and research adapted to semiarid geoenvironmental conditions are necessary to achieve an agriculture based on rational water use and natural resources alternative sources.

Sustainable agriculture in the semiarid region can be achieved by means of agricultural production systems design using technologies and management practices that conserve or improve agro-ecosystem physical basis and sustaining capacity (Franco, 2000). Agroforestry systems are recognized by farmers and non-governmental organizations as a semi-arid interaction technology. These redesigns are integral parts of a larger system focusing on the family unit, with external inputs independence and agricultural crops diversity, ensuring food security sovereignty. Therefore, it is a recognized technology by farmers as a sustainable production method with the interaction and local features of the semiarid region.

Thus, it is essential to describe, assess the impacts and scientifically validate environmental and social improvement of this successful experience of interaction with the semi-arid, and thus build in a participatory manner a sustainable agricultural production alternative for family farmers.

In this context, the research aimed to evaluate soil chemical and physical properties in agroforestry management units (SAFs), with comparative reference to native forest in Bueno community, municipality of Irauçuba, CE.

MATERIALS AND METHODS

The research was conducted in Bueno community, municipality of Irauçuba, CE, and consisting of 37 families. Latitude: 03° 36 '24 27' S and longitude: 39° 51 '27 59 "W. Main activities are eminently of agricultural nature, where small livestock, beekeeping, rainfed crops of short cycle species such as beans, corn, sesame and sorghum, as well as production yards stand out. From experiences in the SAFs, they expanded their production systems with yards production around their homes.

The areas were defined and agroforestry management units (SAF) were implanted in July 2007. These followed local features criteria regarding landscape and degradation level, besides having a nearby water source for soil moisture use through groundwater upwelling (dam with valley). Therefore, two areas implanted with agroforestry management units (SAFs) were used, conducted with the same implantation criteria, with each one in different locations in the landscape (SAF 1), interfluve (higher land area) and (SAF 2) colluvium (lowland area), totaling 0.5 ha each SAF under study. The soil was classified as Eutrophic Fluvic Neosol (Santos et al., 2013).

The study consisted of the following treatments: (1) Agroforestry management unit, as defined in the previous SAFs design section, being located in the landscape higher portion (interfluve); (2) Agroforestry management unit, located on the lowland portion (colluvium) and 3) native forest as reference (Figure 1A to E).

Differences that distinguish SAF from units 1 and 2 were the position in the landscape, which influences the systems water dynamics. SAF 1 is constituted of good water drainage, with the environment remaining unsaturated, that is, soil pores partially filled with water and air throughout the year. In SAF 2, during the rainy season, is poor soil water drainage happens, providing a saturated environment, that is, all the pore space is filled with water. After the rainy season, soil moisture is higher compared to SAF 1, thus having more stored water in the soil, favoring managed agricultural crops development, a fact favored due to the superficial water table.

Area 3 refers to native forest (NF) and is considered as a reference, comprising a length of 3 ha, without human action for about thirty years. It is located on the opposite portion of SAFs 1 and 2 agroforestry management units, with a distance of approximately 600 m. This vegetation consists of hyperxerophilic caatinga, with predominance of the following main species: thrush, *Caesalpinia pyramidalis*, *Mimosa hostilis*, quince, Brazilian-walnut, *Combretum leprosum*, beach mororó and termite nests in the trees. The soil surface is covered with plant litter in different decomposition stages.

To perform the laboratory analyzes, samples with deformed structure were collected, with five composite samples, originated from 15 sub-samples in each study area in the layers of 0.00 to 0.10; 0.10-0.20; 0.20-0.30 and 0.30-0.40 m depth, using a Dutch

Table 1. Particle size distribution, textural classification and particles density in agroforestry management units (SAF 1 and SAF 1) and native forest, in the layers from 0.00 to 0.10, 0.10 to 0.20, 0.20 to 0.30 and 0.30 to 0.40 m.

Depth (m)	Sand			Silt	Clay	Silt/clay ratio	Textural classification	Particles density
	Coarse	Fine	Total					
			g kg^{-1}					kg dm^{-3}
Agroforestry management unit (SAF 1)								
0.00-0.10	359	244	603	274	123	2.23	Sandy loam	2.35
0.10-0.20	331	305	636	244	120	2.03	Sandy loam	2.40
0.20-0.30	336	281	617	241	142	1.70	Sandy loam	2.41
0.30-0.40	387	240	627	228	145	1.57	Sandy loam	2.41
Agroforestry management unit (SAF 2)								
0.00-0.10	507	205	712	235	53	4.43	Sandy loam	2.40
0.10-0.20	495	204	699	233	68	3.43	Sandy loam	2.43
0.20-0.30	480	198	678	244	78	3.13	Sandy loam	2.42
0.30-0.40	514	206	720	216	64	3.38	Sandy loam	2.46
Native forest (NF)								
0.00-0.10	481	177	658	251	91	2.76	Sandy loam	2.45
0.10-0.20	418	180	598	255	147	1.73	Sandy loam	2.42
0.20-0.30	414	156	570	228	202	1.13	Sandy loam	2.45
0.30-0.40	454	191	645	240	115	2.09	Sandy loam	2.43

type auger, put up in labeled plastic bags and taken to the Soil Analysis Laboratory. Samples were air dried, buffered and passed in sieves with mesh opening of 2.00 mm, thus obtaining the thin air-dried soil (TADS), which were subjected to physical, chemical and soil analysis.

For granulometric analysis, the pipette method was used, using the sodium hexametaphosphate chemical dispersant and distilled water in 20 g (TADS), with slow mechanical agitation in a shaker (Wagner 50 rpm) for 16 h. Sand (2.00 to 0.05 mm) was measured by sieving, clay (<0.002 mm) by sediment and silt (0.05 to 0.002 mm) by the difference between sand and clay fractions.

The particle density analysis (ρ_p) was performed through volumetric flask method, using greenhouse dried fine soil (GDFS) at 105°C and ethanol (Donagema et al., 2011).

$$\rho_p = \frac{m_s}{V_p}$$

Where: m_s = dry soil mass at 105°C (kg); and V_p = solids volume (m^3).

pH was obtained in water; Ca, Mg and P content through the Mehlich-1 extractor, and quantified by atomic absorption spectrophotometry (Ca and Mg) and flame photometry (P). Electrolytic conductivity (EC) and Na^+ were determined at 25°C in aqueous extract, at a 1:5 ratio; nitrogen (N) was digested in digester block with sulfuric acid, hydrogen peroxide and digesting mixture at 250°C for 30 min, and at 350°C for 2 h, and quantified by titration with NaOH 0.025 mol L^{-1} after distillation; exchangeable aluminum (Al^{3+}) by extraction with KCl 1 mol L^{-1} and titrated with NaOH 0.025 mol L^{-1}; potential acidity (H + Al) was measured by titration with NaOH 0.025 mol L^{-1} after extraction with calcium acetate 0.5 mol L^{-1}, at 7.0 pH; and soil organic matter (SOM), by titration with ferrous ammonium sulfate 0.005 M after heated in uniform plate with potassium dichromate 0.02 M. From the analyzes, the following indexes were obtained: sum of bases (SB); effective cation exchange capacity (t); cation exchange capacity at pH 7.0 (CEC); bases saturation (V%); exchangeable aluminum saturation (m%) and exchangeable sodium percentage (ESP), according to Donagema et al. (2011).

The design was completely randomized with five replications, with treatments (agroforestry systems and native forest) and plots considered as repetitions. The results were submitted to analysis of variance, and treatment means were submitted to Tukey's test at 5% probability, using the ASSISTAT 7.6 statistical program (Silva et al., 2002).

RESULTS AND DISCUSSION

Table 1 shows particle size distribution results (granulometry), their textural classification and particle density. The studied systems and their respective layers showed no textural range, and it was classified as sandy loam, since studied units had soil class (Fluvic Neosols). It is worth noting that granulometry is a soil physical characteristic of difficult modification, since it is inherent of the source material, not being modified by soil management practices and agricultural crops.

Silt fraction values (Table 1) were high, what is an indicative of young and little weathered soils, and according to the classification and standards adopted by the National Center for Soil Research – CNPS, EMBRAPA, 90% of the municipality area consists of shallow soils characterized by crystalline rocks, corroborating with Silva et al. (2014) and Rebouças et al. (2014). In SAF 2, there was clay decrease and sand increase, what can be explained by agroforestry management units topography (SAF 1 and 2), and SAF 1 is at the highest point in the landscape, thus being

Table 2. Mean squares for soil chemical attributes in agroforestry management units (SAF 1 and SAF 2) and native forest.

VS	DF	MS								
		pH	CE_{es}	N	SOM	P	K^+	Na^+	Ca^{2+}	Mg^{2+}
SAF1, SAF2 and NF	2	7.962**	0.072^{ns}	0.990**	5214.613**	21.898*	39818.175**	3741.200**	72.223**	3.651**
CS Residue	24	0.021	0.025	0.003	30.137	4.314	112.846	2.719	0.037	0.048
Parcelas	26									
Profundidades (P)	3	0.475**	0.199**	0.236**	2314.944**	334.585**	114331.409**	58.638**	50.161**	7.391**
Interação CS x P	6	0.742**	0.274**	0.283**	1013.802**	21.464**	28008.642**	255.259**	4.934**	0.963**
Resíduo P	72	0.024	0.005	0.002	14.666	4.327	113.268	1.715	0.177	0.034
Total	107									
CV% - a		2.45	55.23	29.78	21.32	47.18	9.85	8.27	4.28	17.38
CV% - b		2.6	24.63	23.29	14.87	47.25	9.87	6.57	9.38	14.62

VS	DF	MS							
		Al^{3+}	(H+Al)	SB	t	T	V	m	PST
SAF1, SAF2 and NF	2	1.290**	859.527**	108.985**	120.685**	987.592**	4600.952**	260.823**	4.961**
CS Residue	24	0.015	1.584	0.063	0.124	11.859	407.273	10.529	0.11
Parcelas	26								
Profundidades (P)	3	0.184**	6.657*	110.366**	102.853**	228.978**	494.299*	41.716**	2.406**
Interação CS x P	6	0.179**	20.807**	12.128**	10.246**	53.458**	386.602*	53.939**	0.832**
Resíduo P	72	0.016	1.779	0.209	0.233	5.547	159.459	4.922	0.048
Total	107								
CV% - a		106.63	22.86	4.12	5.68	31.25	32.36	188.16	35.84
CV% - b		112.4	24.23	7.49	7.78	21.37	20.25	128.65	23.64

Agroforestry Management Units (SAF 1 and SAF 2); NF, native forest; VS, variation sources; DF, degrees of freedom; MS, mean squares; pH, hydrogenionic potential; CE_{es}, electrical conductivity in the saturation extract; N nitrogen; SOM, soil organic matter; P, phosphorus; K^+, potassium; Na^+, sodium; CS, cropping systems.

considered a sediment loss area. And SAF 2 is the more easily transported and deposited particles deposition area (clay, silt and organic matter), besides being also favorable for these sediments loss due to the surface groundwater saturation, thus forming a stream at a dam downstream. This is fueled by dam valley water and rainfall. It is worth noting that the decrease in clay has not influenced in the sandy loam textural classification.

Particles density, as well as granulometry, has not showed large amplitude variation in the values due to little texture variation, since particles diameter is closely related to its density, and they are, therefore, strongly correlated attributes. Values varied (2.35 to 2.46 kg dm^{-3}), what was characterized as mineral soil, conditioned by the source material and its mineralogical composition and silt/clay ratio (1.13 to 4.43).

In Table 2, SAFs 1 and 2 agroforestry management units and native forest soil chemical attributes mean squares are shown. Significant differences were found at 5% probability level for chemical attributes, except for phosphorus and electrical conductivity in the saturation extract.

Significant differences were found in the analyzed attributes, except for CE_{es}, indicating soluble salts low concentration, without salinity potential risks (0.25 to 0.34 dS m^{-1}) for SAF 1 and 2 agroforestry management units and native forest (Table 2). This fact can be explained by exchangeable sodium increase (from 9.51 to 29.88 mg dm^{-3}), and PST normal values (0.66 to

Table 3. Soil chemical attributes means in agroforestry management units (SAF 1 and SAF 2) and native forest.

Study unit	pH	CE_{es}	N	SOM	P	K^{+}	Na^{+}	Ca^{2+}	Mg^{2+}
	(water)	dS m^{-1}	g kg^{-1}		mg dm^{-3}			$cmol_c$ dm^{-3}	
SAF 1	5.693^{b}	0.254^{a}	0.385^{a}	39.014^{a}	4.946^{a}	130.379^{a}	20.440^{b}	5.258^{a}	1.400^{a}
SAF2	6.524^{a}	0.273^{a}	0.117^{b}	22.708^{b}	3.509^{b}	69.630^{c}	29.885^{a}	5.342^{a}	1.491^{a}
NF	5.727^{b}	0.339^{a}	0.082^{c}	15.527^{c}	4.753^{a}	123.464^{b}	9.514^{c}	2.848^{b}	0.900^{b}
	Al^{3+}	**(H+Al)**	**SB**	**t**	**T**	**V**	**m**	**PST**	
			cmolc dm^{-3}				**%**		
SAF 1	0.333^{a}	11.034^{a}	7.081^{a}	7.372^{a}	16.334^{a}	49.431^{b}	4.832^{a}	0.665^{b}	
SAF2	0.008^{b}	3.719^{b}	7.141^{a}	7.150^{b}	10.861^{b}	67.278^{a}	0.135^{b}	1.351^{a}	
NF	0.003^{b}	1.765^{c}	4.098^{b}	4.096^{c}	5.863^{c}	70.376^{a}	0.206^{b}	0.762^{b}	

Agroforestry management units (SAF 1 and SAF 2); NF, native forest; pH, hydrogenionic potential; CE_{es}, electrical conductivity in the saturation extract; N nitrogen; SOM, soil organic matter; P, phosphorus; K^{+}, potassium; Na^{+}, sodium. Ca^{2+}, Calcium; Mg^{2+}, magnesium; Al^{3+}, aluminum; (H+Al), potential acidity; SB, sum of bases; t, effective cation exchange capacity; T, cation exchange capacity at pH 7.0; V, base saturation; m, aluminum saturation; PST, exchangeable sodium percentage.

1.35%) differed from the other units under study at SAF 2. It is noteworthy that although exchangeable sodium values were considered high, they were not characterized with restrictions in function of the normal PST. Exchangeable sodium may be conditioned to characteristic soils formation source material consisting of crystalline rocks, relief conditions, soil and agricultural crops management. SAF 1 and SAF 2 study units had soil and caatinga degradation history in advanced stage due to deforestation, burning and overgrazing (Montenegro et al., 2004). Although high sodium values were found (Table 2), they are not characterized as solodic due to high CEC, with very good calcium, magnesium and potassium levels, according to recommendations for lime and fertilizer use by Minas Gerais Soil Fertility Commission (1999).

For studied systems, SAF2 pH average values differed from SAF1 and native forest (Table 3). It is noteworthy that pH values have no restrictions for crop development, although potential acidity differed between studied units, with an average value higher than others for SAF1 (11.03 $cmol_c$ dm^{-3}), with restrictions also to the high exchangeable calcium content, probably coming from the source material (crystalline rocks).

Calcium, magnesium, potassium and soil organic matter chemical attributes at SAF 1 and SAF 2 agroforestry management units were higher than native forest conditions. These results can be attributed to the constant organic compounds input in several decomposition stages derived from implanted plant species diversity in combination with caatinga (local biome) during seven years from its implementation. This indicates that plants management with crop residues thinning, pruning and raking shows SAFs potential in soil organic matter increase. These results corroborate with those found by Xavier et al. (2004), and is considered a good indicator of changes in soil organic matter as a function of soil management and agricultural crops.

It was found that nitrogen (N) and soil organic matter (SOM) values, followed the same tendency, with statistical difference between studied units, being higher in the SAF 1, followed by SAF 2 and NF, where N needs SOM mineralization According to Frazão et al. (2008), N levels are strongly correlated with those of organic matter.

SAFs agroforestry systems can be a viable alternative for agriculture development in the Brazilian semiarid to the extent that arable species introduction contributes to soil properties maintenance and improvement (Table 2). Other assessed attributes qualitatively contributed through observation and experience at SAF 1 and SAF 2 study units, such as bee pasture, thermal comfort, humidity control, residue inputs at several decomposition stages, food availability and diversity for permanent food and nutritional security. Studies evaluating agroforestry systems should take into account local conditions, such as weather pattern, sampling time, soil type and landscape position. Adopted methods for soil attributes assessment are dynamic and can be modified in time and space (Marchiori Junior et al., 2000). For phosphorus (P) content, there was SAF 2 statistical difference compared to the others, but with lower values.

For calcium (Ca^{2+}) and potassium (Mg^{2+}) ions, there were significant differences between studied units, with decreasing values in the following order: SAF2> SAF 1> native forest to (Ca^{2+}) (5.34, 5.25 and 2.85 $cmol_c$ dm^{-3}) and (Mg^{2+}) (1.49, 1.40 and 0.90 $cmol_c$ dm^{-3}), with relatively high values. Potassium (K^{+}) had significant differences between studied units, with decreasing values in the following order: SAF1> native forest> SAF 2 (130.35; 123.46 and 69.63 mg dm^{-3}). These high values reflect the sum of bases (SB), effective CEC (t) and base saturation (V>50%), being considered eutrophic in the studied units. When assessing studied units chemical quality, it is noteworthy to be careful with sodium, and subsequently PST, which had no limitations on studied

Table 4. Soil chemical attributes means in layers from 0.00 to 0.10, 0.10 to 0.20, 0.20 to 0.30 and 0.30 to 0.40 m.

Depth	pH	CE_{es}	N	MOS	P	K^{+}	Na^{+}	Ca^{2+}	Mg^{2+}
(m)	(water)	$dS\ m^{-1}$	$g\ kg^{-1}$		$mg\ dm^{-3}$			$cmol_c\ dm^{-3}$	
0.00-0.10	6.070^{a}	0.236^{bc}	0.288^{a}	37.082^{a}	9.539^{a}	201.022^{a}	18.962^{c}	6.513^{a}	2.007^{a}
0.10-0.20	6.074^{a}	0.281^{b}	0.106^{b}	25.277^{b}	2.117^{c}	100.906^{b}	20.646^{b}	3.862^{bc}	0.964^{c}
0.20-0.30	5.990^{a}	0.226^{c}	0.122^{b}	26.220^{b}	2.110^{c}	75.817^{c}	21.673^{a}	3.585^{c}	0.841^{c}
0.30-0.40	5.791^{b}	0.413^{a}	0.262^{a}	14.421^{c}	3.844^{b}	53.553^{d}	18.505^{c}	3.970^{b}	1.244^{b}
	Al^{3+}	(H+Al)	SB	t	T	V	m	PST	
			$^{c}mol^{c}\ ^{d}m^{-3}$			%			
0.00-0.10	0.004^{b}	5.989^{a}	9.106^{a}	9.105^{a}	15.096^{a}	64.210^{ab}	0.275^{b}	0.523^{c}	
0.10-0.20	0.100^{a}	5.845^{ab}	5.174^{b}	5.279^{b}	11.019^{b}	55.983^{b}	1.515^{b}	0.974^{b}	
0.20-0.30	0.178^{a}	4.932^{b}	4.714^{c}	4.890^{c}	8.472^{c}	64.097^{ab}	3.301^{a}	1.245^{a}	
0.30-0.40	0.178^{a}	5.259^{ab}	5.432^{b}	5.554^{b}	9.490^{bc}	65.156^{a}	1.807^{ab}	0.962^{b}	

pH, hydrogenionic potential; CE_{es}, electrical conductivity in the saturation extract; N nitrogen; SOM, soil organic matter; P, phosphorus; K^{+}, potassium; Na^{+}, sodium. Ca^{2+}, Calcium; Mg^{2+}, magnesium; Al^{3+}, aluminum; (H+Al), potential acidity; SB, sum of bases; t, effective cation exchange capacity; T, cation exchange capacity at pH 7.0; V, base saturation; m, aluminum saturation; PST, exchangeable sodium percentage.

units, although sodium had masked the sum of base values, since sodium content were high in all units under study, SAF 1, SAF 2 and native forest (Table 3).

Mean values for soil chemical attributes in layers from 0.00 to 0.10; 0.10 to 0.20; 0.20 to 0.30 and 0.30 to 0.40 m are shown in Table 4. Significant differences were verified in the 0.30-0.40 layer, with higher value for CE_{es}, indicating soluble salts low concentration, without salinity potential risks (from 0.226 to 0.413 dS m^{-1}). This fact may have occurred due to increased exchangeable sodium in the 0.10-0.20 and 0.20-0.30 layers (20.65 to 21.67) mg dm^{-3}), differing from the other layers, with the same tendency for PST (0.97 to 1.25%). They were not characterized with restrictions.

The high sodium content in all layers (Table 4), were not characterized as solodic, with high CEC levels, statistically differing in the layers from 0.00 to 0.10 and from 0.10 to 0.20, with (15.10 to 11.02 $cmol_c\ dm^{-3}$). Calcium differed statistically on 0.00 to 0.10 and 0.30 to 0.30 layers, (6.51 and 3.97 $cmol_c\ dm^{-3}$), with magnesium having the same tendency (2.01 and 1.24 $cmol_c\ dm^{-3}$), and potassium differing in all layers. These are considered high levels.

The pH varied in the 0.30-0.40 layer, with lower value (Table 4) without restrictions. Potential acidity has not differed between layers, and these were considered high values.

It was found that nitrogen (N) and soil organic matter (SOM) values in the layers follow the same tendency, except for soil matter at a depth of 0.30-0.40, with lower value than the others, with decrease in depth. The others, however, had lower values, which are considered low.

Soil chemical attributes interactions in agroforestry management units SAF 1, SAF 2 and native forest at layers from 0.00 to 0.10, 0.10 to 0.20, 0.20 to 0.30 and 0.30 to 0.40 m are shown in (Table 5).

The pH was statistically different in the native forest, which had lower value compared to SAF 1 and SAF 2, at the 0.00 to 0.10 layer (Table 5). Potential acidity and exchangeable aluminum differed between studied units, with higher average value (9.43 $cmol_c\ dm^{-3}$) in the other studied units, besides not differing between layers. Assessing CE_{es}, SAF 1 differed statistically from other units under study in the layers of 0.20-0.30 and 0.30-0.40. Significant differences in pH value for natural forests replaced by plantations were also reported by Bargali et al (1993) and Joshi et al (1997).

SAF 1 PST differed from other studied units in all layers, with higher value. (PST = 0.57%), with normal values in the studied units and layers, being influenced by calcium, magnesium and potassium high levels. Because of these exchangeable cations high levels, it was not constituted as solodic.

Exchangeable sodium results were high, differing between studied units, with SAF 1 having higher value than others and the same tendency in layers, with restrictions on agricultural crops. CEC has not differed between studied units nor between layers, but the values were considered high, thereby giving cultivation good chemical characteristics. Calcium, magnesium and potassium chemical attributes were high and have not differed between studied units, except between layers with variations.

Organic matter in the native forest had lower value and differed from SAF 1 and SAF 2 agroforestry units, differing in 0.20-0.30 and 0.30-0.40 subsurface layers. SAF 1 Nitrogen (N) showed higher value and differed from SAF 2 and native forest, with no statistical differences between layers.

The sum of bases (SB), effective CEC (t) and base saturation have not differed between studied units, with statistical variation between layers. It is noteworthy that

Table 5. Chemical attributes interaction in Agroforestry Management Units (SAF 1 and SAF 2) and Native Forest in layers from 0.00 to 0.10, 0.10 to 0.20, 0.20 to 0.30 and 0.30 to 0 40 m for pH, CE, PST, N, MOS, P, Al^{3+}, (H+Al), t, T, V, m, K^{+}, Na^{+}, ca^{2+}, Mg^{2+} and SB.

Cropping systems	**Depth (m)**			
	0.00-0.10	**0.10-0.20**	**0.20-0.30**	**0.30-0.40**
pH (água)				
SAF 1	6.157^{bA}	5.640^{cB}	5.530^{cBC}	5.447^{cC}
SAF2	6.683^{aA}	6.663^{aA}	6.563^{aA}	6.187^{aB}
NF	5.370^{cB}	5.920^{bA}	5.878^{bA}	5.740^{bA}
CE$_{es}$ (dS m^{-1})				
SAF 1	0.077^{bC}	0.210^{bB}	0.220^{aB}	0.510^{aA}
SAF2	0.293^{aB}	0.107^{bC}	0.180^{aC}	0.513^{aA}
NF	0.339^{aB}	0.527^{aA}	0.277^{aBC}	0.214^{bC}
PST (%)				
SAF 1	0.577^{aB}	0.431^{bB}	0.963^{bA}	0.690^{bB}
SAF2	0.623^{aC}	1.848^{aA}	1.681^{aA}	1.251^{aB}
NF	0.369^{aC}	0.643^{bB}	1.090^{bA}	0.945^{bA}
N (g kg^{-1})				
SAF 1	0.723^{aA}	0.163^{aC}	0.117^{abC}	0.537^{aB}
SAF2	0.070^{bB}	0.070^{bB}	0.163^{aA}	0.163^{bA}
NF	0.070^{bB}	0.086^{bA}	0.087^{bA}	0.086^{cA}
MOS (g kg^{-1})				
SAF 1	56.663^{aA}	39.077^{aC}	45.833^{aB}	14.483^{abD}
SAF2	37.563^{bB}	24.747^{bB}	10.287^{cD}	18.237^{aC}
NF	17.020^{cC}	12.007^{cC}	22.539^{bA}	10.542^{bC}
P (mg dm^{-3})				
SAF 1	8.137^{bA}	2.132^{aB}	3.014^{aB}	6.501^{aA}
SAF2	9.127^{abA}	1.242^{aB}	1.608^{aB}	2.060^{bB}
NF	11.355^{aA}	2.978^{aB}	1.709^{aB}	2.971^{bB}
Al^{3+} (cmol$_{c}$ dm^{-3})				
SAF 1	0.000^{aC}	0.300^{aB}	0.533^{aA}	0.500^{aA}
SAF2	0.000^{aA}	0.000^{bA}	0.000^{bA}	0.033^{bA}
NF	0.011^{aA}	0.000^{bA}	0.000^{bA}	0.000^{bA}
(H+Al) (cmol$_{c}$ dm^{-3})				
SAF 1	9.433^{aB}	13.118^{aA}	10.533^{aB}	11.055^{aB}
SAF2	6.188^{bA}	2.640^{bB}	2.723^{bB}	3.328^{bB}
NF	2.348^{cA}	1.778^{bA}	1.540^{bA}	1.393^{cA}
t (cmol$_{c}$ dm^{-3})				
SAF 1	11.370^{aA}	6.553^{aB}	5.019^{bC}	6.548^{aB}
SAF2	10.580^{bA}	5.529^{bC}	6.167^{aB}	6.323^{aB}
NF	5.365^{cA}	3.739^{cB}	3.485^{cB}	3.792^{bB}
T (cmol$_{c}$ dm^{-3})				
SAF 1	20.802^{aA}	19.370^{aA}	11.498^{aB}	13.667^{aB}
SAF2	16.767^{bA}	8.169^{bB}	8.890^{aB}	9.617^{bB}
NF	7.718^{cA}	5.518^{bA}	5.030^{bA}	5.186^{cA}

Table 5. Contd.

V (%)				
SAF 1	54.657^{bA}	32.289^{bB}	53.460^{aA}	57.317^{aA}
SAF2	66.463^{abA}	67.782^{aA}	69.432^{aA}	65.434^{aA}
NF	71.511^{aA}	67.878^{aA}	69.398^{aA}	72.719^{aA}
m (%)				
SAF 1	0.000^{aC}	4.544^{aB}	9.902^{aA}	4.883^{aB}
SAF2	0.000^{aA}	0.000^{bA}	0.000^{bA}	0.539^{bA}
NF	0.826^{aA}	0.000^{bA}	0.000^{bA}	0.000^{bA}
K^+ (mg dm^{-3})				
SAF 1	319.194^{aA}	92.399^{bB}	67.560^{bC}	42.360^{bD}
SAF2	122.279^{cA}	69.720^{cB}	59.280^{bB}	27.241^{cC}
NF	161.592^{bA}	140.598^{aB}	100.610^{aC}	91.057^{aC}
Na^+ ((mg dm^{-3})				
SAF 1	27.611^{aA}	19.215^{bB}	18.166^{bBC}	16.767^{bC}
SAF2	23.063^{bC}	34.608^{aA}	34.258^{aA}	27.611^{aB}
NF	6.211^{cC}	8.115^{cB}	12.594^{cA}	11.138^{cA}
Ca^{2+} ($cmol_c$ dm^{-3})				
SAF 1	7.933^{aA}	4.833^{aB}	3.500^{bC}	4.767^{aB}
SAF2	7.767^{aA}	4.200^{bC}	4.800^{aB}	4.600^{aBC}
NF	3.838^{bA}	2.553^{cB}	2.456^{cB}	2.544^{bB}
Mg^{2+} ($cmol_c$ dm^{-3})				
SAF 1	2.500^{aA}	1.100^{aB}	0.733^{bC}	1.267^{bB}
SAF2	2.400^{aA}	1.000^{abC}	1.067^{aC}	1.500^{aB}
NF	1.120^{bA}	0.791^{bBC}	0.722^{bC}	0.967^{cAB}
SB ($cmol_c$ dm^{-3})				
SAF 1	11.370^{aA}	6.253^{aB}	4.485^{bC}	6.215^{aB}
SAF2	10.580^{bA}	5.529^{bC}	6.167^{aB}	6.290^{aB}
NF	5.370^{cA}	3.739^{cB}	3.490^{cB}	3.792^{bB}

Agroforestry Management Units (SAF 1 and SAF 2); NF: native forest; pH: hydrogenionic potential; CE_{es}: electrical conductivity in the saturation extract; PST: exchangeable sodium percentage; N nitrogen; SOM: soil organic matter; P: phosphorus; $Al3^+$: aluminum; (H+Al): potential acidity; t: effective cation exchange capacity; T: cation exchange capacity at pH 7.0; V: base saturation; m: aluminum saturation; potassium; Na^+: sodium; Ca^{2+}: calcium; Mg^{2+}: magnesium; SB: sum of bases. Lowercase letters refer to depths and capital letters to cropping systems.

(V>50%) was higher than 50% in studied units, and is considered eutrophic (Table 5).

Conclusions

SAF 1 and SAF 2 agroforestry management units contributed to soil quality maintenance in higher conditions than native forest. SAF 1 and SAF 2 agroforestry management units and native forest showed favorable chemical attributes to soil fertility concerning calcium, magnesium and potassium content, with restrictions regarding SAF 1 and SAF 2 exchangeable sodium levels, and in a lower extent to native forest. SAF 1 and SAF 2 agroforestry management units provided higher soil organic matter intakes compared to Forest.

Conflict of Interest

The authors have not declared any conflict of interest.

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