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Dynamic organization of two agroforestry systems in the semi-arid region of Paraíba and their contribution to improving the socio-economic conditions of farming families

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ABSTRACT: *The socio-economic vulnerability of family farmers in Brazilian semi-arid regions, combined with the intense degradation of the Caatinga biome, entails the use of alternatives that allow people to remain in the countryside while recovering the environment. Are agroforestry systems (AFS), which are based on the ecological, economic, and social interactions existing in a production system, an alternative? The present study described the structure, organization, and floristic composition of two AFS and analyzed the soil fertility of the two AFSimplanted in the semi-arid region of Paraíba. This study revealed that the farmers consider the AFS to be less harmful to the environment as it provides greater protection to the soil and better-qualityfood. Thegreatest challenges wereobtaining water during drought season and the need foran extra workforce. Nevertheless, the produce from these systemswas sufficient to provide for the families. Several varieties of fruit species were found in both the AFS studied, and Malpighia emarginata (acerola) was the most predominant. The soils of the two AFS presented a practically neutral pH the and high percentage of base saturation,thereby falling under the category of eutrophic soil with high fertility, and are ideal for growingany type of crop.*

Key words: *soil analysis, floristic composition, sustainability.*

Caracterização e organização dinâmica de dois sistemas agroflorestais no semiárido paraibano e sua contribuição para melhoria das condições socioeconômicas de famílias agricultoras

RESUMO: *A vulnerabilidade socioeconômica dos agricultores familiares no semiárido brasileiro aliado à intensa degradação do bioma caatinga requer o emprego de alternativas que propiciem a permanência do homem no campo, ao mesmo tempo em que recupere o meio ambiente. Os Sistemas Agroflorestais (SAFs) que estão fundamentados nas interações ecológicas, econômicas e sociais existentes em um sistema de produção, são alternativas? O presente estudo tem como objetivos descrever a estrutura, a composição florística e a organização de dois SAFs implantados no sertão paraibano, bem como analisar a fertilidade dos solos das propriedades sob estes sistemas. Este trabalho verificou que os agricultores consideram que os SAFs proporcionam menos agressão ao meio ambiente, maior proteção ao solo e alimentação de qualidade, além da manutenção das famílias com a produção. As duas maiores dificuldades são a obtenção de água nos períodos de estiagem e mão de obra auxiliar. Nos dois SAFs estudados, há uma maior quantidade de espécies frutíferas, sendo a Malpighia emarginata (acerola) a de maior predominância. Os solos dos dois SAFs apresentam pH praticamente neutro e elevado percentual de saturação por base, sendo considerados eutróficos, com alto nível de fertilidade e ideal para o estabelecimento de agricultura.*

Palavras-chave: *análise de solos, levantamento florístico, sustentabilidade.*

INTRODUCTION

The semi-arid regions of the Brazilian Northeast are characterized by challenging edaphoclimatic conditions, such ashigh temperatures, irregular rainfall in time and space, soils with low levels of weathering (shallow), and low production of plant mass. Other challenges include the adoption of total extractive systems, and overgrazing with animals above the carrying capacity of the soils in cattle ranching. Furthermore, practices such as agriculture that is based on deforestation and burning and practices such as extraction of firewood and wood to meet the energy demands of families, ceramic industries, and bakeries, which are unfavorable to the local ecological dynamics, contributing enormously to the reduction in the Caatinga vegetation due to the lack of regeneration (AGUIAR et al., 2006).

Within this context, the agroforestry systems (AFS) are a viable alternative for the different ecosystems of the Brazilian semi-arid tropics. Conceptual discussions about agroforestry or

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agroforestry systems (AFS) first started between 1970 and 1980 and have been studied by several researcher (KORTING et al., 2013).

Among the most widely used concepts, the one proposed by MEDRADO (2000) stands out; the author refers to AFS as a sustainable land management system that increases its yield by combining the production of forest plants with crops and/or animal farming, simultaneously or consecutively, in a liberated manner, on the same unit of land, involving management practices in line with the local population.

MICCOLIS et al. (2016) indicated that AFS generate a series of environmental and socio-economic contributions, protecting and nurturing biodiversity, mitigating climate change and increasing adaptive capacity to its effects, regulating hydrological cycle, containing erosion, and helping in the cycling of nutrients and soil fertility. In addition, AFS generates a series of products that can be consumed and traded, improving the income and quality of the life of producers.

Such benefits can have positive impacts on the lives of farming families when they adopt the AFS as a production system on their properties. AGUIAR (2011) emphasized that family farming plays an important role in food production, job creation, and distribution of income and land. The economic and socio-environmental practices employed in the routine of family farmers intend to optimize the production system by diversifying it and making good use of the soil, to meet their primary needs, making family objectives compatible with environmental interaction and production integration.

In this context, it is necessary to understand how agricultural production models based on agroforestry systems practiced by family farmers can contribute to the improvement of socio-economic and environmental conditions in the semi-arid region of Paraíba, given the intensification of the environmental degradation process in the region. This consequently results in loss of the productive capacity of the soil and the creation of social problems, such as rural exodus. The causes of this process come from a long history of removing native vegetation for monocultures, coupled with extensive use of soil without proper management, in addition to the uncontrolled use of chemical inputs, depleting the land and rendering it unproductive.

Given this situation, it is important to develop research that presents the particularities of productive systems based on agroforestry systems and understand how they interact with the surrounding environment and improve environmental conditions of the semi-arid region, and the quality of life, and income of the farmers.

A detailed study on the subject is necessary for effective improvement in the techniques adopted by farmers, identifying the measures adopted through their knowledge and practices to interact with the environment while coping with the adversities in a sustainable manner. The intention is to combine it with academic scientific knowledge, with similar objectives such as minimizing the anthropic impacts in the semi-arid region, especially to the Caatinga biome, and contributing to the socio-economic and environmental development of the region.

Thus, the present study described the structure, floristic composition, and organization of two agroforestry systems in the semi-arid region of Paraíba and analyze the fertility and properties of the soils under the systems.

MATERIALS AND METHODS

This qualy-quantitative research comprised a survey of shrub/arboreal species, evaluation of soil fertility, and application of questionnaires to gain knowledge about the experiences of family farmers with the agroforestry system.

Characterization of the study areas

The present study evaluated two experiences with agroforestry systems (AFS) implemented and developed by family farmers in the semi-arid region of the state of Paraíba. One is located in the municipality of Patos, in the Trincheiras farm (6°58′10″S, 37°16′34″W; AFS 1), and the other in the municipality of São José do Sabugi, in the Nova Conquista farm (6°46′35″S, 36°51′59″W; AFS 2). The selection of family units for the research was based on the experience of successful implementation of agroforestry systems.

The two municipalities are characterized by a Bsh climate, classified as hot and dry, with two well-defined seasons, one rainy and the other dry, with average annual precipitation of 600 mm, an average temperature of 30 °C, and relative air humidity of approximately 55% (ALVARES et al., 2013). Table 1 shows the monthly rainfall data of the two regions during the research period. In these areas, the predominant vegetation formation is called open hyper xerophilous shrub-arboreal Caatinga, which is dense in small isolated areas and has been intensively exploited by cotton cultivation and extensive livestock (EMBRAPA, 2002).

Data collection and analysis

Data collection began with the delimitation of the two areas and their topographic

Table 1 - Accumulated monthly precipitation during the research period (2018) in the regions of Patos-PB (AFS1) and São José do Sabugi-PB (AFS2).

Monthly precipitation/2018	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Set	Oct	Nov	Dec
AFS1	133.1	202	164	156.4	12	0	0	0	0	0	0	1.5
AFS2	45.4	212	72.7	132.1	20.3	0	0	0	0	15.2	15	30.5

Source: AESA-PB (2018).

characterization. This procedure was performed using a GPS, GARMIM ETREEX 30, with a precision of 1 to 2 m at each point. After this procedure, the floristic composition of the fruit tree and shrub species was surveyed to identify their uses within the production chain of the two properties.

The degree of soil fertility in the two studied areas where the AFS were developed was verified using the composite sampling method described by CAVALCANTI (1998). At each area site, a zigzag walking was used to obtain 20 simple samples per area at a depth of 0–0.20m. Then, the simple samples were homogenized into a soil composite for each site. The composite samples were identified and sent to the Soil and Water Laboratory (LASAG) of the Federal University of Campina Grande (UFCG), Campus of Patos-PB, where the following soil chemical attributes were analyzed: pH, organic matter, available phosphorus and potassium; exchangeable aluminum, calcium, and magnesium.

Qualitative data were collected using a semi-structured questionnaire to describe each experience and evaluate the contribution of the AFS to improve the income of the families involved in the productive systems. The data collected were tabulated and inserted into electronic spreadsheets, presented in tables, and discussed according to the results found by other authors in studies related to semi-arid region.

RESULTS AND DISCUSSION

Establishment and management of agroforestry systems (AFS)

The first agroforestry system (AFS1) was implemented in 2016. The family that practiced it said that before they used agroforestry on their property, their livelihood came from hiring third-party properties, and they felt exploited. The situation led them to start planting fruit species among the trees that existed on the site, with the aim of marketing the fruit mainly. Today, the family lives solely on what they produce on the property.

The second agroforestry system (AFS2) was implemented in 2012 when a family was awarded an underground dam through the "One Land and Two Waters (P1+2)" program. In the project, one of the family members learned about agroforestry, and decided to implement it in the area of the underground dam.

Both AFS were implemented without technical monitoring and did not follow a predetermined spacing between species. The absence of spacing does not mischaracterize the system as agroforestry, but it is important to implement management strategies and consequently improves productivity of the system. Currently, both AFS followed the advice from the Technical Assistance and Rural Extension Company (EMATER) and civil society institutions, such as the Diocesan Social Action of Patos (ASDP).

Regarding the sources of water for maintenance, in AFS1, the water comes from the river that cuts through the property. This water source is used only for irrigating the species existing in the system since the water is not considered drinkable for human consumption. AFS2 was implemented in an area with an underground dam; however, a drip irrigation system, whose water comes from a well powered by wind energy, existing in the area (windmill) to maintain sufficient soil moisture for existing species in the system. Table 2 presents the advantages and difficulties faced by the farmers in AFS.

The perception that the quality of life improved confirmed the results obtained by ARAÚJO FILHO et al. (2010), who verified the optimization of the nutrient renewal cycle in soil and increase in net family income, and by COSTA et al., (2002), who highlighted the use of the family system as the predominant labor, favoring self-management of activities and ecological associations close to natural ecosystems.

Structure, floristic composition, and uses of species in agroforestry systems

Figure 1 shows the topographic survey of the Trincheiras farm, where the AFS1 is inserted.

Table 2 - Farmers' responses on the advantages, difficulties, maintenance costs, and implantation of agroforestry systems.

Questions	--Farmers' Replies--	
	AFS1	AFS2
What are the advantages of working with AFS?	Less aggression to the environment, more quality of life.	Soil conservation, quality food.
What are the biggest difficulties of working with AFS?	Lack of water during periods of drought.	Manpower
Cost of maintenance	R$: 200.00/month	R$: 500.00/month

The property has 19 ha, and the area that comprises the agroforestry systems within the property is approximately 0.50 ha. AFS1 is located next to a plantation of *Pennisetum purpureum* Schum. (capim elefante) with an area of 1.1 ha. The plantation is connected to the system by functioning as a windbreak, and it is used as a source of fodder for the animals on the property.

AFS2 is inserted in a property of 4.0 ha, a considerably smaller area in relation to AFS1 (Figure 2). However, the area that comprises the agroforestry systemsis relatively larger than that of AFS1 (0.75ha). Structurally, it differs from AFS1 in that it is located with in an underground dam of 1.95 ha.

Regarding species composition, 400 individuals of 22 different species were found in

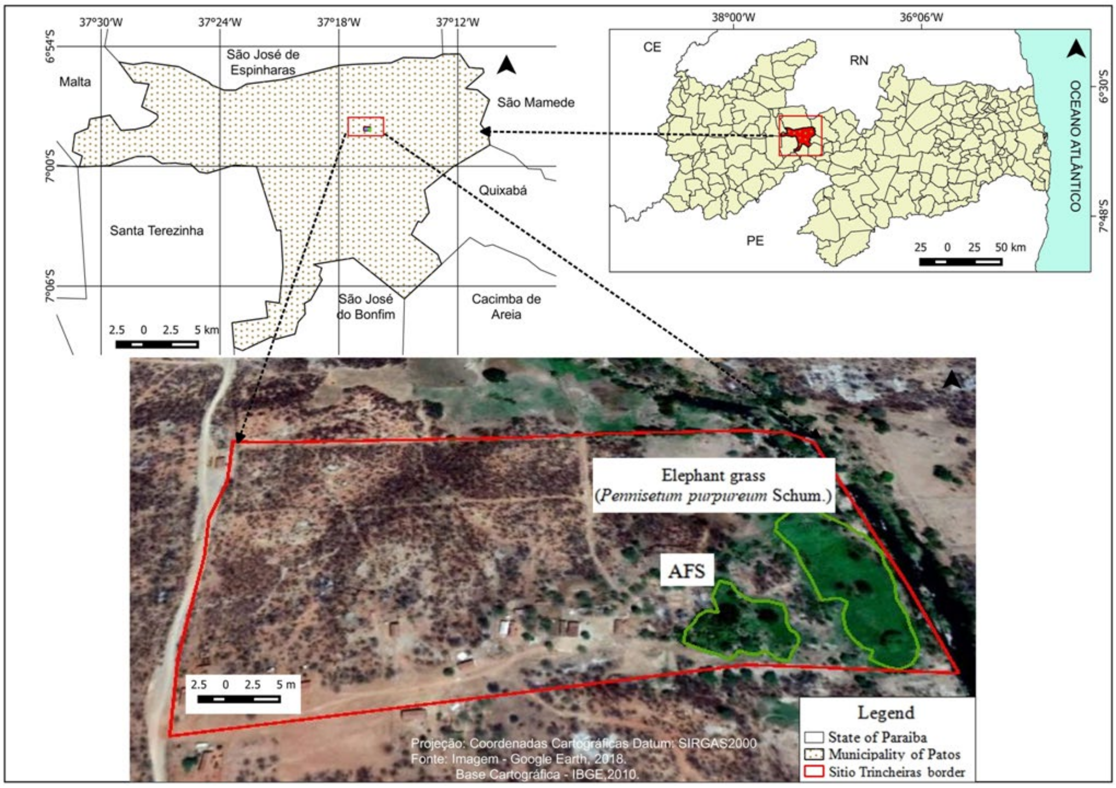

Figure 1 - Topographic survey of the area of Trincheiras farm, municipality of Patos-PB, with the location of AFS1 within the property.

AFS1. Of the 400 individuals found, 18.25% were native shrub/arboreal species, and 81.25% were fruit species. However, of the 22 species existing in AFS1, the diversity of shrub/arboreal species (54.5%) was greater than the diversity of fruit species (45.5%). Among the shrub/arboreal species, *Mimosa tenuiflora* (Jurema Preta) was dominant in AFS1, with 23 individuals (5.75%). Regarding fruit trees, individuals of the species *Malpighia emarginata* (acerola) predominated, with 135 individuals (33.75%) (Table 3).

Considering that AFS1 was implemented in an area where native species already existed, the predominance of *Mimosa tenuiflora* indicates that the area had been previously exploited since the species is considered a pioneer species and often establishes it self in areas where vegetation has been removed. The fruit species *Malpighia emarginata* has a good marketability and is well adapted to the soil and climate conditions of the region, which facilitates management.

Table 4 shows the results of the characterization of the species reported in AFS2. There were 330 individuals of 19 different species, 38.79% of which were shrub/trees and 61.21% were fruit species.

Regarding the number of species, AFS2 also showed a greater diversity of shrubs/trees compared to the diversity of fruit trees, being 52.63% and 47.37%, respectively. *Leucaena leucocephala* (leucena) was the dominant tree species with 64 individuals, corresponding to 19.39%. Of the fruit species, the acerola was dominant with 143 individuals and corresponded to approximately half of the individuals of all fruit trees (43.33%) (Table 4).

In both AFS, the primary use of shrub/arboreal species is for ground cover. In other words, these species provide environmental conditions, mainly shading, for the fruit trees to develop, and these are the ones that provide part of the livelihood of the family, because they sell them fresh or their pulp.

According to ROSA et al. (2007), besides the food issue, cultural tradition is another factor that influences the floristic composition of these areas, since traditional knowledge about the cultivation and use of plants is transmitted from generation to generation.

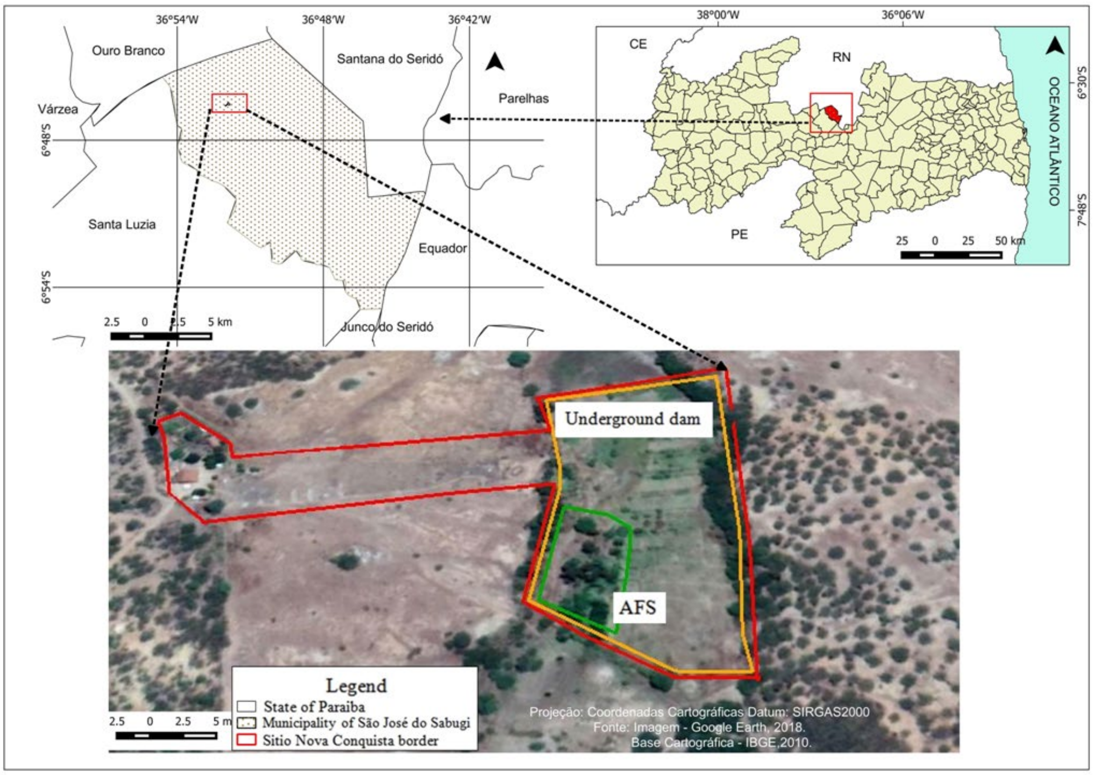

Figure 2 - Topographic survey of the Nova Conquista farm, municipality of São José do Sabugi-PB, with the location of AFS2 within the property.

Table 3 - Characterization of shrub/arboreal and fruit species found in AFS1, located in Trincheiras farm, Patos-PB.

--------------------AFS 1--------------------				
--------------------Shrub/Arboreal Species--------------------				
Common name	Scientific name	Quant.	%	Main use
Leucena	*Leucaena leucocephala* (Lam) de Wit	7	1.75	Fodder/wood
Mata Fome	*Pithecellobium dulce* (Roxb.) Benth	2	0.5	Ground Cover
Pinhão Manso	*Jatropha curcas* L.	3	0.75	Ground Cover
Pereiro	*Aspidosperma pyrifolium* Mart. & Zucc	2	0.5	Ground Cover
Craibeira	*Tabebuia aurea* Benth. & Hook	4	1	Ground Cover
Catingueira	*Cenostigma pyramidale* (Tul.) Gagnon & G. P. Lewis	4	1	Ground Cover/wood
Faveleira	*Cnidoscolus quercifolius* Pohl	7	1.75	Ground Cover
Jurema Preta	*Mimosa tenuiflora* (Willd.) Poor.	23	5.75	GroundCover/energy
Ipê Roxo	*Tabebuia impetiginosa* Mart.	1	0.25	Ground Cover
Mamona	*Ricinus communis* L.	17	4.25	Ground Cover
Nim	*Azadirachta indica* A. Juss	1	0.25	Ground Cover
Angico	*Anadenanthera colubrina* (Vell.) Brenan	2	0.5	Ground Cover
Total of individuals	-	73	18.25	-
Total of species	-	12	54.5	-
--------------------Fruit Species--------------------				
Common name	Scientific name	Quant.	%	Main use
Coqueiro	*Cocos nucifera* L.	35	8.75	Food
Mamão	*Carica papaya* L.	15	3.75	Food
Acerola	*Malpighia emarginata* DC.	135	33.75	Pulp/trading
Pinha	*Annona squamosa* L.	17	4.25	Food
Goiabeira	*Psidium guajava* L.	13	3.25	Pulp/trading
Bananeira	*Musa spp*	97	24.25	Food/trading
Limoeiro	*Citrus limon* L.	5	1.25	Food/trading
Mangueira	*Mangifera indica* L.	6	1.5	Food/trading
Cajarana	*Cabralea canjerana* (Vell.) Mart.	1	0.25	Pulp/trading
Graviola	*Annona muricata* L.	3	0.75	Pulp/trading
Total of individuals	-	327	81.25	-
Total of species	-	10	45.4	-
Grand total of individuals	-	400	100	-
Total number of species	-	22	100	-

It is important to note that, in both AFS, there is cultivation of forage species, such as *Pennisetum purpureum (*capim elefante) and *Sorghum bicolor* (sorgo), both intended for the production of silage to feed the animals on the properties during the dry season.

In AFS2 cultivation of temporary crop species (corn and beans) is carried out only for domestic consumption contributing to the family's food and nutritional security. After arvest, the stubble remains in the area to decompose and are incorporated into the soil.

Analysis of soil fertility in agroforestry systems

The soils of the two systems (AFS1 and AFS2) are chemically balanced (Table 5), probably due to the management practices applied in both areas, such as the non-burning of land for land preparation and subsequent planting, a common practice adopted by farmers in the semiarid region. In addition, the crops present in the AFS areas show some dynamics as there is greater diversification of crops in the cropping systems, unlike what occurs in monocultures. Moreover, there is maintenance of soil cover.

Regarding pH, both soils were practically neutral at 6.5 and 6.4, respectively, close to the optimum pH range for plants, which is between 6.0 and 6.5 (MALAVOLTA, 1979). Although, organic matter was incorporated into the soil through practices such as composting, its quantity in both areas is considered low, with AFS1 in Trincheiras

Table 4 - Characterization of shrub/arboreal and fruit species found in AFS2, located in Nova Conquista Farm, São José do Sabugi-PB.

-----AFS2-----				
-----Shrub/Arboreal Species-----				
Common name	Scientific name	Quant.	%	Main use
Gliricídia	*Gliricidiasepium* (Jacq.) Steud.)	24	7.27	Fodder
Jurema Preta	*Mimosa tenuiflora* (Willd.) Poir	6	1.82	GroundCover/energy
Pinhão Manso	*Jatrophacurcas* L.	2	0.61	Ground Cover
Moringa	*Moringa oleífera* (Lam)	12	3.64	Forage/ seedlingproduction
Nim	*Azadirachta indica* A. Juss	14	4.24	GroundCover/natural def.
Leucena	*Leucaena leucocephala* (Lam) de Wit	64	19.39	Fodder/wood
Angico	*Anadenanthera colubrina* (Vell.) Brenan	1	0.30	Ground Cover
Carnaúba	*Copernicia prunifera* (Mill.) H. E. Moore	2	0.61	Ground Cover
Craibeira	*Tabebuia áurea* Benth. & Hook	1	0.30	Ground Cover
Eucalipto	*Eucalyptus ssp.*	1	0.30	Ground Cover
Pau Ferro	*Libidibia ferrea* (Mart. ExTul) L. P. Queiroz	1	0.30	Ground Cover
Total of individuals	-	128	38.79	-
Total of species	-	10	52.63	-
-----Fruit Species-----				
Common name	Scientific name	Quant.	%	Main use
Cajarana	*Cabralea canjerana* (Vell.) Mart.	19	5.76	Pulp/trading
Cajueiro	*Anacardium occidentale* L.	11	3.33	Pulp/trading
Mangueira	*Mangifera indica* L.	4	1.21	Pulp/trading
Pinha	*Annona squamosa* L.	4	1.21	Food
Coqueiro	*Cocos nucifera* L.	1	0.30	Food
Acerola	*Malpighia emarginata* DC.	143	43.33	Pulp/trading
Limoeiro	*Citrus limon* L.	2	0.61	Food
Tamarineiro	*Tamarindus indica* L.	8	2.42	Pulp/trading
Umbuzeiro	*Spondias tuberosa* L.	10	3.03	Pulp/trading
Total of individuals	-	202	61.21	-
Total of species	-	9	47.37	-
Grand total of individuals	-	330	100	-
Total number of species	-	19	100	-

farm showing a higher value (15.86 g.dm^{-3}) thanAFS2 in Nova Conquista farm (10.98 g.dm^{-3}). These results may be related to the low density of vegetation, irregular rainfall, and high temperatures, which probably prevented the incorporation of organic matter into the soil.

Regarding the essential nutrients (P, K, Ca and Mg), the two areas showed satisfactory levels. P, Ca, and Mg were at high levels, and Ca presented a medium level (Table 5).Table 5 shows that the quantity of sodium (Na) present in the soil of AFS1 (1.52 cmol$_c$ dm^{-3}) was a little higher than that in the soil ofAFS2 (0.22 cmol$_c$ dm^{-3}). As for the cation exchange capacity (CTC), the two areas presented moderate levels(AFS1 = 11.17 and AFS2 = 11.32), where as the percentage of base saturation

Table 5 - Results of chemical analysis of soils of agroforestry systemslocated in AFS1 and AFS2.

Local	pH	O.M.	P	Ca	Mg	K	Na	H + Al	CTC	V
	$CaCl_2$ 0.01M	g.dm^{-3}	mg.dm^{-3}	-----cmol$_c$ dm^{-3}-----						%
AFS1	6.5	15.86	52.9	5.0	3.3	0.25	1.52	1.1	11.17	90.16
AFS2	6.4	10.98	57.3	7.0	2.6	0.30	0.22	1.2	11.32	89.40

(V) was considered high (90.16 and 89.40) in AFS1 and AFS2, respectively. Soils with these values are considered eutrophic, that is, they have high fertility.

The values of CTC and V are of great importance to soil fertility. CTC indicates the capacity of the soil to adsorb cations in exchangeable form, which in general, serve as nutrients for plants.

Soils with such characteristics are of fundamental importance to any crop, whether agricultural or forestry. Thus, the development of AFS on the two properties contributes not only to production but also to the balance and dynamics of soil fertility in the studied areas.

CONCLUSION

Farmers consider agro forestry systems to provide lesser damage to the environment and better soil protection and quality food, which were considered as the main advantages of the system. According to the farmers that obtaining water during dry periods and the requirement of auxiliary labor are the two main difficulties of agro forestry systems (AFS) in the semiarid region.

In the two AFS studied, *Malpighia emarginata* (acerola) was the most predominant fruit species. The cultivation of agricultural species (corn and beans) in AFS2 was for the family's food and nutritional security. The two agro forestry systems contributed directly to the dynamics and productive sustainability of the farms where they were located, guaranteeing food security and increasing the monthly income of the family.

BIOETHICS AND BIOSSECURITY COMMITTEE APPROVAL

The project was evaluated and approved by the Research Ethics Committee (CEP)/Plataforma Brazil. Opinion n. 2.545. 992 on 15/3/2018.

DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflict of interest for this article. The founding sponsors had no role in the design of the study, in the collection, analyses, or interpretation of data, in the writing of the manuscript, and in the decision to publish the results.

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AUTHORS' CONTRIBUTIONS

All authors contributed equally for the conception and writing of the manuscript. All authors critically revised the manuscript and approved the final version.

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