CARBON SEQUESTRATION AND NUTRIENT RESERVES UNDER DIFFERENT LAND USE SYSTEMS[1]

Maria Ivanilda Aguiar[2], Jamili Silva Fialho[3], Mônica Matoso Campanha[4] e Teógenes Senna Oliveira[5]

ABSTRACT – This study evaluated the contribution of agroforestry (AFS) and traditional systems to carbon sequestration and nutrient reserves in plants, litter and soil. The study was carried out in the semiarid region of Brazil in a long-term experiment on an experimental farm of the goat and sheep section of the Brazilian Agricultural Research Corporation (Embrapa). Two agroforestry systems were investigated: agrosilvopastoral (ASP) and forest-pasture areas (SP) as well as traditional agriculture management (TM), two areas left fallow after TM (six fallow years - F6 and nine fallow years - F9) and one area of preserved Caatinga vegetation (CAT). Soil, litter and plants were sampled from all areas and the contents of C, N, P, K, Ca and Mg per compartment determined. The AFS (ASP and SP) had higher nutrient stocks than the traditional and intermediate stocks compared to the preserved Caatinga. In the ASP, a relevant part of the nutrients extracted by crops is returned to the system by constant inputs of litter, weeding of herbaceous vegetation and cutting of the legume crops. After fallow periods of six and nine years, carbon and nutrient stocks in the compartments soil, litter and herbaceous plants were similar to those of the preserved Caatinga (CAT), but still lower than under natural conditions in the woody vegetation.

Keywords: Agroecology; Family farming; Agroforestry.

SEQUESTRO DE CARBONO E RESERVA DE NUTRIENTES EM DIFERENTES SISTEMAS DE USO DA TERRA

RESUMO – Objetivou-se conhecer a contribuição de sistemas agroflorestais (SAFs) e tradicionais para o sequestro de carbono e a reserva de nutrientes presentes nas plantas, serrapilheira e solo. O estudo foi realizado na região semiárida brasileira, em experimento de longa duração realizado na Fazenda Experimental da Embrapa Caprinos e Ovinos. Estudaram-se dois sistemas agroflorestais: agrossilvipastoril (ASP) e silvipastoril (SP) e um tradicional (AG), sendo também utilizadas duas áreas sob pousio após o manejo tradicional (seis anos - F6 e nove anos   F9) e uma área de Caatinga conservada (CAT). Nessas áreas, foram realizadas coletas de solo, serrapilheira e plantas, sendo os teores de C, N, P, K, Ca e Mg quantificados em cada um desses compartimentos. Os SAFs (ASP e SP) apresentaram estoques de nutrientes superiores ao tradicional e intermediários em relação à Caatinga conservada. No ASP, grande parte dos nutrientes extraídos pelas colheitas volta ao sistema por meio das entradas via serrapilheira, capinas das herbáceas e poda das leguminosas. Os estoques no solo, na serrapilheira e nas plantas herbáceas após os períodos de pousio de seis e nove anos foram semelhantes à Caatinga conservada, porém os estoques do estrato arbóreo foram inferiores à condição natural.

Palavras-chave: Agroecologia; Agricultura familiar; Sistemas agroflorestais.

[1] Recebido em 21.09.2012 aceito para publicação em 23.10.2013.
[2] Instituto Federal de Educação, Ciência e Tecnologia do Piauí, Campus Corrente. E-mail: <ivanildaaguiar@yahoo.com.br>.
[3] Universidade Estadual do Ceará, Centro de Ciências da Saúde. E- mail: <jamilifialho@yahoo.com.br>.
[4] Empresa Brasileira de Pesquisa Agropecuária, Embrapa Milho e Sorgo. E-mail: <monicamc@cnpms.embraba.br>.
[5] Departamento de Solos da Universidade Federal de Viçosa. E-mail:<teo@ufv.br>.

1. INTRODUCTION

The stability of ecosystems over time is based on energy flow, nutrient cycling and the regulation of their plant and animal populations. Within these systems, nutrients move in cycles from biotic to abiotic components (ODUM, 1969). In conventional agricultural ecosystems, this cycling is minimal because of the large amount of nutrients immobilized in plant and/ or animal products that are exported (GLIESSMAN et al., 2007). Thus, the production of these systems depends on the constant nutrient input through fertilizers. Therefore, the intercropping of trees with crops and/ or pasture has gained attention in recent decades due to the biomass production and nutrient storage and cycling of these agroecosystems, restoring the imbalance caused by the export of agricultural products and animals (GLIESSMAN, 2005).

Some studies confirmed the contribution of trees to nutrient cycling by indirect assessments of the nutrient levels and/or stocks in agroforestry systems (AFS) (IWATA et al., 2012; LIMA et al., 2010; MAIA et al., 2006; 2007; 2008). From the nutrient pools contained in the different components of plant biomass (live and dead) the cycling of the chemical elements can be quantified to evaluate the sustainability of these systems (DELITTI, 1995). Another important aspect of AFSs is the determination of C, since assessing C stocks means evaluating the techniques applied in the AFS to mitigate the effects of climate change caused by practices that cause increased CO_2 emissions to the atmosphere (SOTO-PINTO et al., 2010). In addition, the maintenance of C stocks in agricultural areas is an alternative source of income for farmers, which can participate in the international carbon market (ANTLE et al., 2007; PEREZ et al., 2007). For Montagnini and Nair (2004), AFSs contribute to carbon sequestration because of their potential of C storage in the different tree species that are maintained, aside from the storage of this element in the better preserved soils. However, for these authors, this potential has not yet been adequately recognized and exploited.

In the semiarid region of Brazil, AFSs have been studied as an alternative to the traditional agricultural management, widely adopted by farmers in the region (ARAÚJO FILHO; CARVALHO, 2001; DRUMOND et al., 2004; MARIN et al., 2006). Studies by Aguiar et al. (2010), Iwata et al. (2012), Maia et al.(2006; 2008), Nogueira et al. (2008), and Silva et al. (2011) demonstrated the beneficial effects of agroforestry systems on the soil chemical, physical and biological properties, as well as on the preservation of the plant diversity (ALMEIDA et al., 2009; CAMPANHA et al., 2011). Some of the above studies were developed in experimental areas of the National Goat and Sheep Research Center (CNPCO), in the northern part of the Ceará State, Brazil, where agroforestry systems are being studied as an alternative to the traditional management of family farming.

The conventional management in family agriculture in this region is based on the so-called slash-and-burn system, beginning with deforestation, with extraction of useful wood, and burning of the stubbles (woody and leafy), followed by cultivation for two or three consecutive years. After the third year, the area is left fallow for approximately ten years, usually with animal grazing. Over the years, the use of this management has led to serious degradation problems (ARAÚJO FILHO, 2002). In response, agroforestry as proposed by CNPCO is designed to integrate the traditional activities to maintain a biomass and nutrients flow between the areas designated for each activity on the same property and promote the conservation of the Caatinga (thorny deciduous savannah). Within the studied model, areas with an agrosilvopastoral management (20%) were identified, in which trees are grown alongside with agricultural crops and protein banks (legume pasture) for sheep and goats; silvopastoral areas with native pasture for goats and sheep and maintenance of 38% of the tree cover, and an area under preserved Caatinga without human intervention. Alongside, areas are cultivated for different periods in the traditional slash-and-burn system. Although a number of studies have been carried out in these areas, none of them analyzed the potential for C sequestration or the nutrient reserves maintained in these agroecosystems. Therefore, the purpose of this study was to evaluate the contribution of agroforestry and traditional management practices for carbon sequestration and nutrient reserves in plants, leaf litter and soil.

2. MATERIAL AND METHODS

2.1. Description of the study area and management systems

The study was conducted at Crioula Farm, within the National Caprine and Ovine Research Center (CNPCO) of EMBRAPA in Sobral, Ceara´ State, Brazil. The mean annual air temperature and rainfall in Sobral are 27 °C and 821 mm (IPECE, 2011a), respectively. The climate is equatorial tropical dry, very hot and semi-arid, classified as BSw'h' by Köppen (BRASIL, 1981). The rainy season lasts from January to May (IPECE, 2011a). In the experimental area (3°41'S, 40º20'W), the average annual rainfall over the past 10 years was 989 mm. The soil in the area consists of patches of typical Ortic Chromic Luvisol and typical Hypochromic Luvisol (AGUIAR et al., 2010). The vegetation is a thorny deciduous savannah, regionally known as Caatinga (COLE, 1960).

The following management systems were evaluated: (1) **agrosilvopast**ure (ASP), where maize (*Zea mays* L.) was grown since 1998 and sorghum (*Sorghum bicolor* L.) since 2005, in alleys formed by legumes (*Leucaena leucocephala* (Lam) R. de Wit. and *Gliricida sepium* (Jacq.) Steud). In this area, the native vegetation was cut back and thinned in 1997, preserving 20% of the tree cover (MAIA et al., 2006). The area was divided into two equal sub areas (3.5 ha), one for sheep and one for goat production. In the crop areas (maize and sorghum), weeding was performed by hand to control herbaceous species. During the dry period, the areas were used as a protein bank (consisting of the legumes *L. leucocephala* and *G. sepium*) for sheep and goat females, which grazed daily for one hour; (2) Silvopastoral (SP) area of 9.2 ha, subdivided into two sub-areas for grazing of sheep and goat females. According to Maia et al. (2006), this management was adopted in 1997 when the woody vegetation was thinned and cut back, preserving approximately 38% of the natural tree cover; (3) traditional agriculture management (TM): a 1.0 ha area, cleared and burned in 2009 (dry season) and used for maize (*Zea mays* L.) and sorghum (*Sorghum bicolor* L.) monoculture, tilled by hand, in the rainy season of 2010; (4) six fallow years after conventional farming (F6): a 1.0 ha area on which all vegetation was cleared and burned in 2001, tilled by hand for maize and cowpea (*Vigna unguiculata* L. Walp) cultivation in 2002 and 2003. For two years, a herd of 10 mother goats was left to graze plant residues in the area after harvest and from 2004 onwards, the area was left fallow to allow regeneration of native vegetation; (5) nine years fallow after conventional cultivation (F9): similar management as in F6, but with deforestation and burning in 1999 and planting in 2000 and 2001, and fallow since 2002; (6) area under preserved Caatinga (CAT): native vegetation, regionally known as Caatinga, consisting of a thorny deciduous savanna, used as reference for the managed areas. This area remained untouched by human intervention for over 50 years. The management areas are adjacent to each other, separated by corridors (width 2 m) and, in some cases, transition areas of 50 m.

2.2. Carbon and nutrient stocks in the soil

For the determination of total N, P, K, Ca, Mg, and total organic carbon (TOC), six disturbed soil samples per area were collected from the layers 0 - 0.05, 0.05 - 0.10 and 0.10 - 0.20 m. The soil nutrient content was analyzed according to methods proposed by Embrapa (1997) and Yeomans and Bremner (1988). The TOC and N pools were calculated by multiplying their contents (g kg^{-1}) by the mass contained in the evaluated layers. The mass was obtained considering bulk density, determined by the clod method (EMBRAPA, 1997) and the soil volume per layer per hectare. The stocks of P, K, Ca and Mg were determined by multiplying their respective contents (g dm^{-3}) by the soil volume per layer per hectare.

2.3. Carbon and nutrient stocks in litter

The litter produced by trees and shrubs was collected by installing 10 collectors of 0.5 m^3 (1.0 m × 0.5 m × 1.0 m) per area, at a height of approximately 1.1 m above the soil surface. The senescent material retained in the collectors was collected monthly for one year. After sampling, the material was placed in bags, labeled and taken to the laboratory, dried in a convection oven at 65 °C for 72 hours, weighed and ground. Data of litter production per area and year were obtained and the nutrient levels (C, N, P, K, Ca and Mg) determined according to Malavolta et al. (1989). The annual nutrient input through litter was calculated by multiplying the nutrient levels in the litter by total litter produced per area.

2.4. Carbon and nutrients stocks in plants

All shoots of spontaneous herbaceous species in the sampled plots were collected in the rainy season in two years. The collected material was placed in plastic bags and taken to the laboratory where it was dried, weighed, ground, and subsequently analyzed for the contents of N, P, K, Ca, Mg, and C (MALAVOLTA et al., 1989). The carbon and nutrient stocks contained in the herbaceous plants were obtained by multiplying the nutrient content by the total plant biomass.

The different parts of woody plants (trunk, branches and leaves) were collected to quantify the stored nutrients. The branches (diameter of approximately 3 cm) and leaves were collected with a billhook from the northern, southern, eastern and western part of the canopy (mid-height) towards the north, south, east and west of the canopy. Material from the tree trunk was collected at a height of 1.30 m with an increment borer, extracting material from the bark to the core. The collected material was wrapped in paper bags and taken to the laboratory, dried in a forced air oven at 65 °C for 72 hours and then weighed and ground. The dried material was analyzed for the contents of C, N, P, K, Ca, and Mg (MALAVOLTA et al., 1989). Nutrient stocks in trees were calculated by multiplying nutrient content by the plant biomass, for each part (trunk, branches and leaves). The plant biomass was determined by allometric equations based on measurements of diameter at breast height (1.3 m) (SILVA; SAMPAIO, 2008), considering that of the total aboveground plant biomass 70% is in the trunk, 25% in the branches and 5% in the leaves (SILVA; SAMPAIO, 2008).

Nutrient and C stocks in the agricultural species were determined in samples of leucaena, gliricidia, maize and sorghum in the agrosilvopastoral system (ASP) and of maize and sorghum under traditional management (TM). The collected material was placed in plastic bags and sent to the laboratory to be dried, weighed, ground, and subsequently analyzed for C, N, P, K, Ca, and Mg, as proposed by Malavolta et al. (1989).

To test the effects of the management systems, data stocks of carbon and nutrients obtained in the different compartments (soil, litter and plants) were subjected to analysis of variance (ANOVA) and means were compared by Tukey's test at 5% probability.

3. RESULTS

3.1. Carbon and nutrient stocks in different compartments of the management systems

Of the two areas under agroforestry, the stocks of C and nutrients (N, P, K, Ca and Mg) in the soil (Fig. 1) and C and P in litter (Fig. 2b and 2c) were similar between SP and CAT. But in the herbaceous plants (Fig. 3) in SP there was an increase in C and nutrient stocks and a decrease in the tree component of the vegetation (Fig. 4). In ASP the stocks of C, N, K, Ca, and Mg in the soil were similar to those in CAT (Fig. 1), while the P stock was higher in ASP. In this area, the C and P litter stocks and C, Ca and Mg stocks in the herbaceous plants were similar to CAT. However, the C nutrient stocks in trees, as well as N, K, Ca and Mg in litter were lower than in CAT. Although ASP promoted the same C stocks in soil as CAT, the results for this variable were lower than those in SP.

In the soil under traditional management, no changes in C and nutrient stocks were observed (Fig. 1), compared to preserved Caatinga, but these stocks increased in the herbaceous stratum (Fig. 3) and were reduced in the litter (Fig. 2). It is noteworthy that there was no contribution to C and nutrient stocks in the tree component in this area (TM), since in this management the trees had been eradicated.

The stocks in the fallow areas (F6 and F9) were similar to CAT in the soil compartment (Fig. 1). In the area left fallow for nine years the stocks in litter (Fig. 2) and in herbaceous plants (Fig. 3) were also similar to those under native conditions. But in the area left fallow for six years the C, P and Mg stocks in the litter (Fig. 2) and C, N, P, K, and Ca in herbaceous plants were higher (Fig. 3) than those in CAT. However, with regard to the tree component, the two fallow periods were insufficient to build up stocks similar to those in CAT (Fig. 4).

3.2. Proportion of C and nutrient stocks in the soil, litter and plant compartments

In the areas affected by human intervention (TM, ASP, SP, F6 and F9), most C was stored in the soil. More than 79% of C contained in the SP and TM areas were found in the soil (Table 1). In the area under ASP, as well as F6 and F9, the proportion of soil C was about 57% lower. These last three areas did not differ from each other, in terms of percentage of carbon in the soil. In the area under CAT the pattern differed from the other areas, since most C is contained in plants (66.7%).

As C, the highest proportion of total N, Ca and Mg in agroecosystems is found in the soil (Table 1). Potassium is also more abundant in the soil of managed and fallow areas, but it is represented at higher proportions in the vegetation in CAT (Table 1). Phosphorus however was stocked in greater proportion in the soil in both agroforestry systems (SP and ASP), as well as under traditional management (TM) and after six fallow years (F6). The pattern in the area F9 was

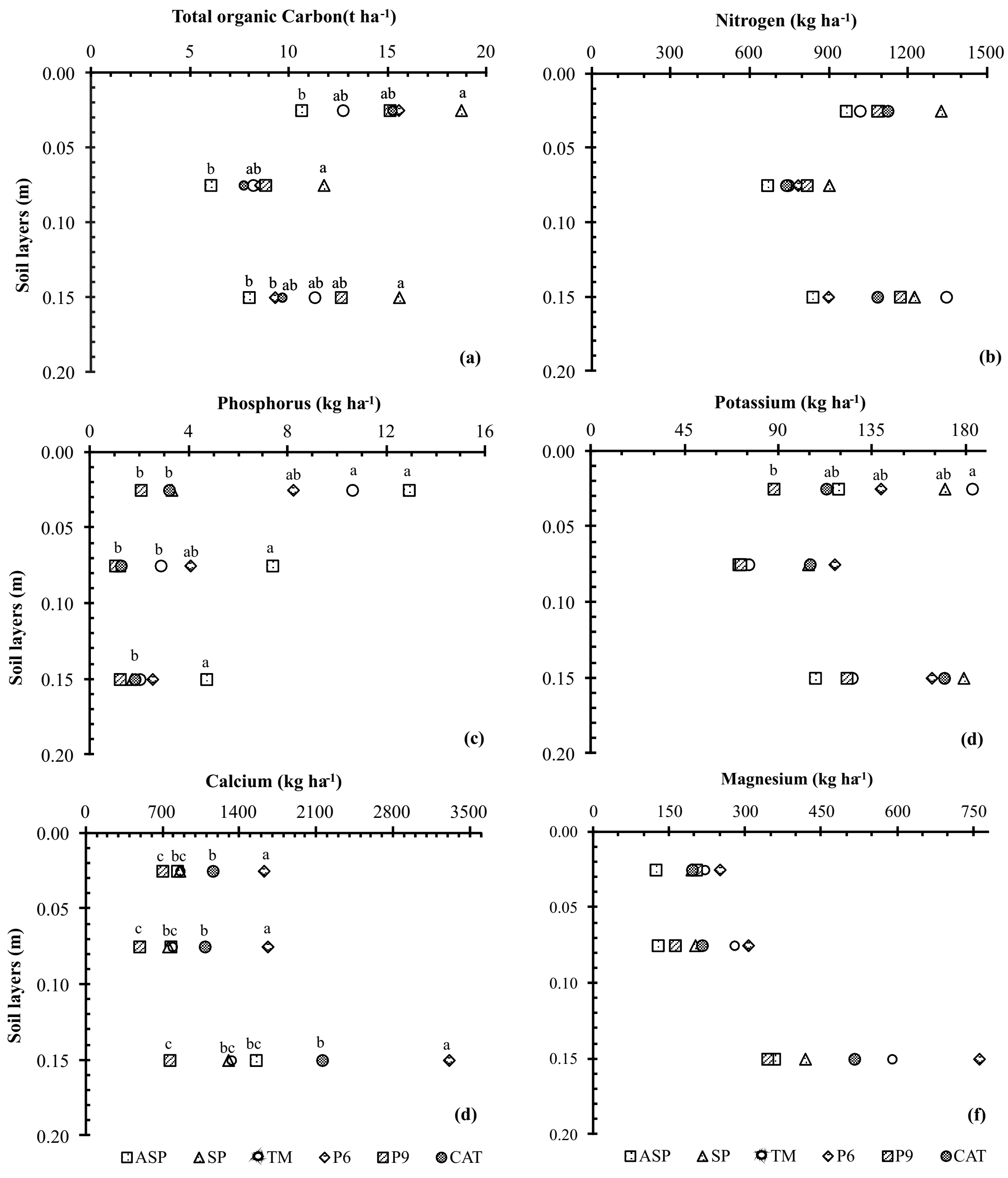

Figure 1 – Stocks of total organic carbon (TOC), N, P, K, Ca and Mg in the soil layers (0.00-0.05, 0.05-0.10, 0.10-0.20 m) under agrosilvopastoral (ASP), silvopastoral (SP), traditional management (TM), fallow period of six (F6) and nine (F9) years after traditional management, and under preserved Caatinga vegetation (CAT), in Sobral - CE. Points followed by the same letters, within each layer, do not differ statistically by Tukey's test at 5% probability.

***Figura 1** – Estoques de carbono orgânico total (COT), N, P, K, Ca e Mg nas camadas de solo (0,00-0,05; 0,05-0,10; e 0,10-0,20 m) nos sistemas agrossilvipastoril (ASP), silvipastoril (SP), cultivo tradicional (TM), pousio de seis e nove anos após o cultivo tradicional (F6 e F9) e sob vegetação de Caatinga conservada (CAT), em Sobral, CE. Pontos seguidos de letras iguais dentro de cada camada não apresentam diferença estatisticamente significativa pelo teste de Tukey a 5% de probabilidade.*

similar to CAT, where P was stored mainly in plants (Table 1). Nutrient stocks in the herbaceous plants and litter were much lower than in the other compartments (Table 1).

4. DISCUSSION

The lowest TOC amount present in ASP in relation to SP may result from management practices adopted in ASP, such as weeding the herbaceous species, which turns the soil and promotes the decomposition of organic waste added constantly. The absence of soil tillage and permanent vegetation cover in SP ensures higher TOC contents and therefore culminate in higher C stocks. This result confirms findings of Maia et al. (2007), who had evaluated the organic carbon stock in these areas eight years earlier.

Another important aspect is to differentiate the live (trees and herbaceous vegetation) from the dead (litter) plant components. Generally, the production of biomass and C stocks depends on the age of the agroforestry systems and the management structure and form (ALBRECHT; KANDJI, 2003; TAKIMOTO et al., 2008). The structure of the herbaceous component (diversity and biomass) in SP was different from that observed in ASP. Although grazed, the herbaceous stratum in SP contains a larger number of plants and

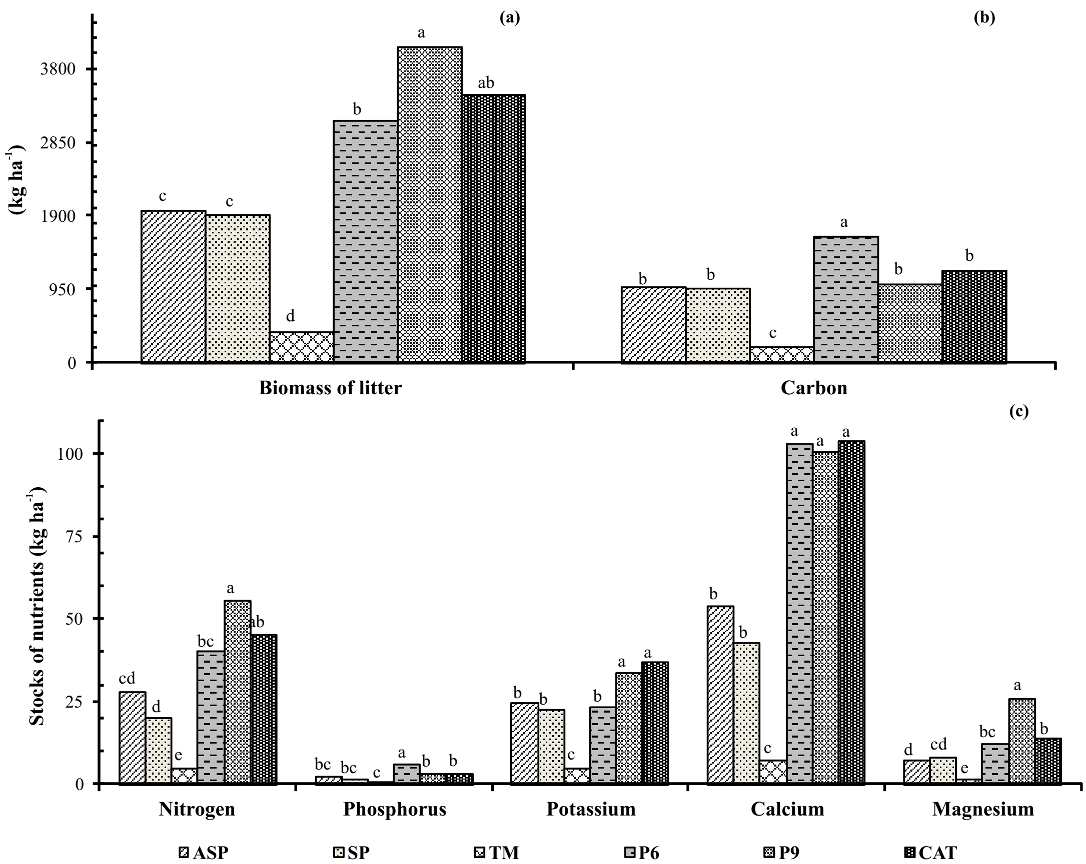

Figure 2 – Annual biomass production of litter and stocks of C, N, P, K, Ca, and Mg under agrosilvopastoral (ASP), silvopastoral (SP), traditional management (TM), fallow period of six (F6) and nine (F9) years after traditional management, and under preserved Caatinga vegetation (CAT), in Sobral - CE.

Figura 2 *– Produção anual de biomassa da serrapilheira e estoque de C, N, P, K, Ca e Mg nos sistemas agrossilvipastoril (ASP), silvipastoril (SP), cultivo tradicional (TM), pousio de seis e nove anos após o cultivo tradicional (F6 e F9) e sob vegetação de Caatinga conservada (CAT), em Sobral, CE. Colunas seguidas de letras iguais não apresentam diferença estatisticamente significativa pelo teste de Tukey a 5% de probabilidade.*

species (AGUIAR et al., in press) as well as a greater amount of biomass (AGUIAR et al., 2013), so the contribution of C in herbaceous plants was substantially higher in this area.

Silvopastoral systems can be significant carbon sinks, via soil, but in some intensively managed agroforestry systems with annual crops the TOC stocks are lower (MONTAGNINI; NAIR, 2004). The total C stocks observed in the studied agroforestry systems were high compared to other semi-arid regions, according to Montagnini and Nair (2004). In a period of 13 years, ASP and SP stored a total of 3.3 and 4.4 C t $ha^{-1}yr^{-1}$, respectively in the studied compartments. Considering only the stocks in tree biomass and assuming that one ton of carbon in tree biomass is equivalent to a reduction of 3.67 t of carbon dioxide in the atmosphere (TURNER et al., 1995), the potential reduction of CO_2 emissions to the atmosphere by SP and ASP would corresponds to 5.0 and 8.8 t $ha^{-1}yr^{-1}$, respectively. These values represent 26 and 47% of the carbon sequestration that occurs in woody vegetation in an area of preserved Caatinga.

In addition, the AFS may also have an indirect effect on C sequestration, by helping to reduce the pressure on native vegetation areas, which are the greatest terrestrial C sinks. Another important contribution of agroforestry systems to C sequestration, in particular in the semiarid region of northeastern Brazil, is the prevention of burning of vegetation, which is a common practice in traditional systems. Extrapolating the data collected in ASP to the 13 years of management use, it was estimated that ASP prevented the clearing of approximately 23 hectares. Assuming that under traditional management 16.2 tons of woody material are burned per hectare (MAIA et al., 2006), the emission of over 1,000 tons of CO_2 was avoided by using ASP instead of TM.

In general, most C in the agroecosystems is stored in the soil. The proportion of soil C becomes larger in relation to the vegetation components in areas with little or no tree cover (MANLAY et al., 2002; TAKIMOTO et al., 2008), as observed in TM, where 89.5% of C was stored in the soil. Although high C stocks in the soil were observed in TM, the total C stocks were reduced by 16% compared to ASP and by 65% compared to CAT. Other studies in TM areas confirmed this decreasing trend, particularly for the soil compartment (MAIA et al., 2007; VEUM et al., 2011; NOVARA et al., 2012).

In the F6 and F9 areas, C stocks were recovered from the soil, litter and herbaceous compartments, being more evident when comparing these areas with CAT. Nevertheless, the stocks in the woody vegetation of

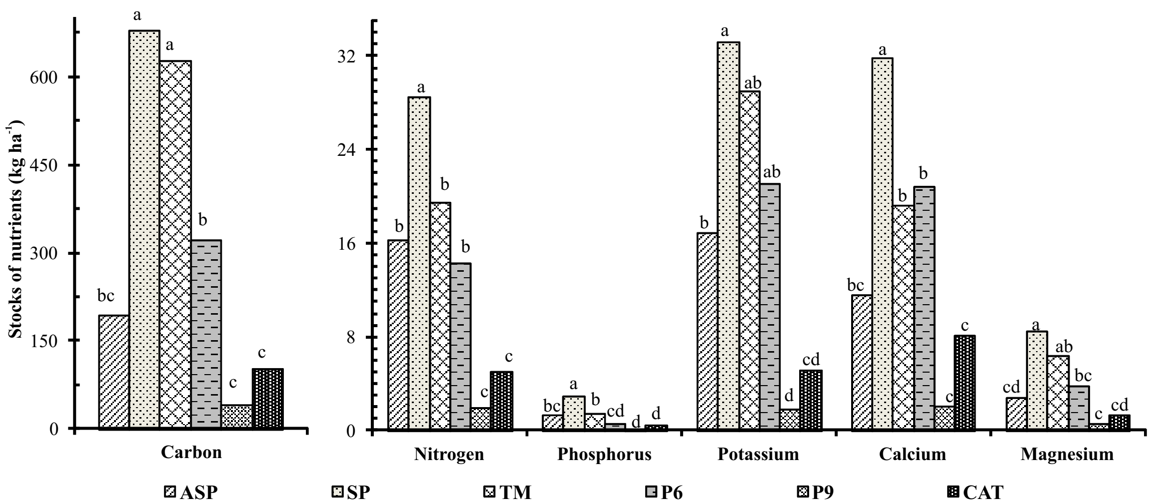

Figure 3 – Stocks of C, N, P, K, Ca, and Mg in the biomass of herbaceous plants under agrosilvopastoral (ASP), silvopastoral (SP), traditional management (TM), fallow period of six (F6) and nine (F9) years after traditional management, and under preserved Caatinga vegetation (CAT), in Sobral - CE.

Figura 3 – *Estoque de C, N, P, K, Ca e Mg na biomassa das plantas herbaceas nos sistemas agrossilvipastoril (ASP), silvipastoril (SP), cultivo tradicional (TM), pousio de seis e nove anos após o cultivo tradicional (F6 e F9) e sob vegetação de Caatinga conservada (CAT), em Sobral, CE. Colunas seguidas de letras iguais não apresentam diferença estatisticamente significativa pelo teste de Tukey a 5% de probabilidade.*

the fallow areas were lower, indicating the still incomplete recovery from the slash-and-burn impact initiating agricultural production. Other studies showed that in the fallow areas (F6 and F9), despite a greater number of plant and tree species (AGUIAR et al., in press), the biomass was still not recovered in comparison with the native conditions (AGUIAR et al., 2013). Thus, these areas produced on average, respectively, 3.9 and 2.9 C t ha^{-1}yr^{-1}, i.e., 11 and 14 more years would be necessary to reach levels similar to those in CAT areas. Thus, it would take an estimated period of 17 to 23 years to achieve fully recovered C stocks in the tree layer in F6 and F9. Another noteworthy aspect is that these areas do not respond to the recovery process in a similar way and that the estimated restoration time is not the same. These results show that the traditionally

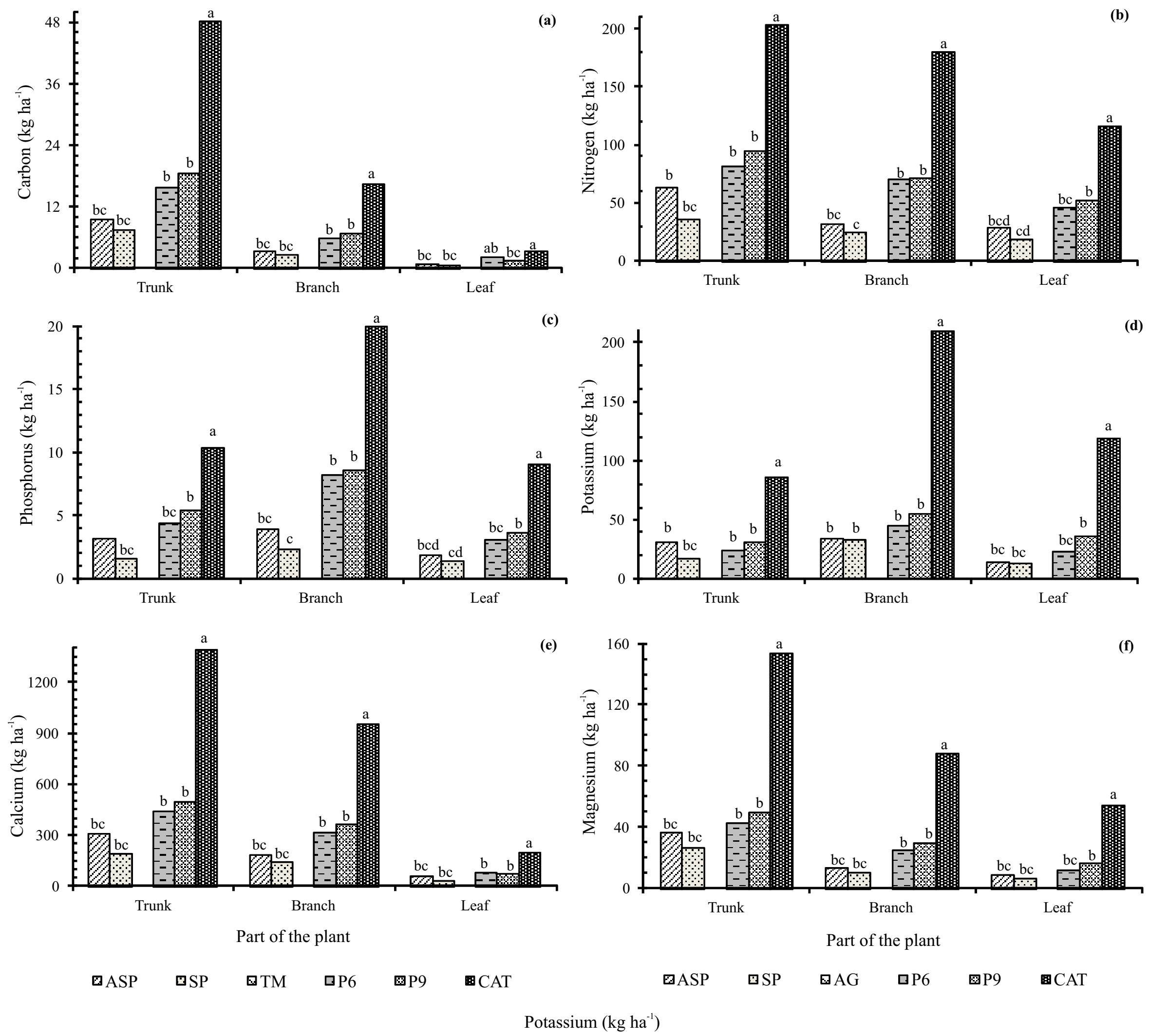

Figure 4 – Stocks of C, N, P, K, Ca, and Mg in the biomass of trees (trunk, branches and leaves) under agrosilvopastoral (ASP), silvopastoral (SP), traditional management (TM), fallow period of six (F6) and nine (F9) years after traditional management, and under preserved Caatinga vegetation (CAT), in Sobral - CE.

Figura 4 *– Estoque de C, N, P, K, Ca e Mg na biomassa das plantas arbóreas (caule, galhos e folhas) nos sistemas agrossilvipastoril (ASP), silvipastoril (SP), cultivo tradicional (TM), cultivo tradicional em pousio por seis (F6) e nove (F9) anos e sob vegetação de Caatinga conservada (CAT), em Sobral, CE. Colunas seguidas de letras iguais, em cada parte da planta, não apresentam diferença estatisticamente significativa pelo teste de Tukey a 5% de probabilidade.*

Table 1 – Percentage of C, N, P, K, Ca, and Mg stocks in the litter, soil and vegetation compartments under agrosilvopastoral (ASP), silvopastoral (SP), traditional management (TM), fallow period of six (F6) and nine (F9) years after traditional management, and under preserved Caatinga vegetation (CAT), in Sobral - CE.

Tabela 1 – *Porcentagem dos estoques de C, N, P, K, Ca e Mg nos compartimentos, solo e vegetação nos sistemas agrossilvipastoril (ASP), silvipastoril (SP), cultivo tradicional (TM), pousio de seis (F6) e nove (F9) anos após o cultivo tradicional e sob vegetação de Caatinga conservada (CAT), em Sobral-CE.*

Compartment		Areas					
		ASP	SP	TM	F6	F9	CAT
				Carbon (%)			
Litter		2.3ab	1.6bc	0.5d	2.8ab	1.6a	1.2ab
Soil (0-0.20 m)		57.7b	79.6a	89.5a	57.1b	57.2b	32.1c
	Trees	31.3b	17.6c	-	39.6b	41.2c	66.6a
Plants	Herbaceous	0.5cd	1.2b	1.75a	0.6b	0.1c	0.1b
	Crops	8.3a	-	8.2a	-	-	-
Total	t ha^{-1}	42.6	57.8	35.9	58.4	63.8	101.2
				Nitrogen (%)			
Litter		1.0bc	0.6cd	0.1d	1.3ab	1.7a	1.3ab
Soil (0-20 cm)		90.2b	96.4a	96.4a	91.7b	91.8b	84.3c
	Trees	4.5bc	2.2c	-	6.5b	6.5b	14.3a
Plants	Herbaceous	0.6ab	0.8a	0.6ab	0.5b	0.1c	0.2c
	Crops	3.7a	-	2.9b	-	-	-
Total	t ha^{-1}	2.7	3.6	3.2	3.0	3.3	3.5
				Phosphorus (%)			
Litter		3.7d	9.1dc	1.3d	15.5a	12.0ab	6.0cd
Soil (0-20 cm)		46.4a	39.3a	47.4a	40.4a	17.1b	12.6b
	Trees	16.5c	32.7b	-	42.6b	70.4a	80.4a
Plants	Herbaceous	2.6b	18.9a	4.5b	1.6b	0.5b	1.0b
	Crops	30.8b	-	46.8a	-	-	-
Total	kg ha^{-1}	53.8	15.7	32.6	36.6	24.9	49.4
				Potassium (%)			
Litter		4.9b	3.9b	1.0c	4.2b	7.7a	4.35b
Soil (0-20 cm)		59.5b	79.3a	79.0a	75.5a	64.2b	45.93c
	Trees	15.9b	11.0b	-	16.6b	27.7b	49.11a
Plants	Herbaceous	3.4b	5.8ab	6.0a	3.8ab	0.4c	0.6c
	Crops	16.3a	-	14.1a	-	-	-
Total	kg ha^{-1}	498.5	570.8	485.5	555.5	438.8	843.3
				Calcium (%)			
Litter		1.4b	1.3b	0.2c	1.4b	3.4a	1.5b
Soil (0-20 cm)		83.4b	87.0b	98.7a	87.2b	65.3c	62.3c
	Trees	14.4b	10.8b	-	11.1b	31.2a	36.1a
Plants	Herbaceous	0.3b	1.0a	0.6a	0.3b	0.1b	0.1b
	Crops	0.5a	-	0.5a	-	-	-
Total	t ha^{-1}	3.8	3.3	3.0	7.5	3.0	7.0
				Magnesium (%)			
Litter		1.0b	0.9b	0.1 c	0.9b	3.1a	1.1b
Soil (0-20 cm)		88.6bc	93.2ab	98.4a	93.3ab	85.4c	74.9d
	Trees	8.4bc	4.9c	-	5.6c	11.5c	23.9c
Plants	Herbaceous	0.4bc	1.0a	0.6 ab	0.3bc	0.1c	0.1c
	Crops	1.6a	-	0.9b	-	-	-
Total	t ha^{-1}	0.7	0.9	1.1	1.4	0.8	1.2

Columns followed by the same letter do not differ statistically by Tukey's test at 5% probability.

adopted fallow period of 10 years (ARAÚJO FILHO; CARVALHO, 2001) is insufficient for a full recovery of the areas and that the dynamics of recovery are not the same in the different areas.

In the litter the nutrient fraction was lower than in the soil and plant compartments. However, this fraction represents an important pathway for the transfer of nutrients to the soil through vegetation (HAIRIAH et al., 2006). Luizão et al. (2006) stated that agroforestry systems produce a lower total litter stock than native vegetation. Nevertheless, this litter material is easily decomposed and rapidly incorporated into the soil in the form of nutrients. These authors found higher P, Ca and Mg levels in litter of an agroforestry system than of a fallow area.

Higher P stocks in the litter of agroforestry areas may have been favored by increased absorption of this element since soil contents are higher (NOGUEIRA et al., 2008) and, consequently, higher levels in the litter, resulting in higher stocks. The lower stocks of N, P, Ca, and Mg were due to the lower amount of biomass produced in the litter of AFSs (Fig. 2a). On the other hand, in AFSs nutrients are more efficiently incorporated in the soil than in traditional systems. The results showed that the nutrient input was greater in SP and ASP than in TM. A great potential for savings by nutrient input through litter was observed in AFSs, favoring the cycling processes and sustainability of agroecosystems (LIMA et al., 2010).

It was expected that higher nutrient levels, especially of N, would be stocked in soil and litter of ASP, due to the input of periodically cut legumes (*L. leucocephala* and *G. sepium*). In agroecosystems using legumes in alley cropping, the legume cutting increases nutrient flows compared to those of natural forest (SZOTT, 1991). Moreover, the addition of nutrients in cut material can stimulate the increase in plant and litter production. A study of Daudin and Sierra (2008) on agroforestry showed that N from *G. sepium* is responsible for 57% of the nutrients absorbed by *Dichanthium aristatum* and of these, 31% were from biological fixation. However, this practice should be carefully tested, because the intensities and intervals between cuttings can influence the dynamics of the fixing nodules. In a study on *Erythrina poeppigiana*, Nygren and Ramirez (1995) showed that the nodules die after cutting and take 10 weeks to reappear.

The studied agroforestry systems showed great potential for nutrient cycling, with higher annual production of litter and nutrient input than TM and intermediary in comparison with CAT. In general, the total nutrient stocks in plants and soils were also lower than under CAT and higher than in TM. The low nutrient stocks in the soil were probably due to the constant removal at harvest (ASP) and by grazing (in SP). Kass et al. (1997) emphasized that in agroforestry systems, the high rates of nutrient removal retard the accumulation of N and soil organic matter. Thus, several years of AFSs would be needed to accumulate more pronounced levels. The productivity level in the ASP was above the regional averages found for traditional crops (IPECE, 2011b). In the agroforestry systems, the conditions of imbalance imposed by cultivation practices and the constant nutrient withdrawal by crops are offset favorably by the management practices adopted in this area, such as incorporation of adventitious plants in the soil (KASS et al., 1997). These imbalance conditions mean that there is, for example, higher content of nutrients added to the soil via herbaceous plants mowed regularly and left on the ground. Luizão et al. (2006) also emphasized the importance of adventitious plants as important components of the AFSs, due to the positive impact on the soil properties.

In the ASP area, the sum of nutrient inputs in litter, herbaceous vegetation and legume cutting returned to the soil about 50% of the nitrogen, 23% P, 60% K, 440% Ca, and 103% Mg removed by crops. In addition to these, nutrients can enter this type of management in animal dung. It is assumed that the manure input over time contributes to maintaining the system productivity. Unlike in AFSs, the largest contribution to nutrient return in the TM was that of herbaceous plants, which in the litter, returned 24% N, 12% P, 50% of K, 160% of Ca and 82% Mg removed at harvest, which is considerably less than the values returned in ASP.

5. CONCLUSIONS

The nutrient reserves and C stocks in agrosilvopastoral (ASP) and silvopastoral (SP) systems were intermediate between those of preserved Caatinga (CAT) and traditional systems (TM), inducing the conclusion that agroforestry systems have a great potential for carbon sequestration and nutrient cycling. The agrosilvopastoral system contributes to nutrient cycling by constant nutrient inputs through litter, weeding of herbaceous vegetation and cutting of the legumes, resulting in the return of a large part of the nutrients extracted by crops back to the system. In the areas left fallow for six and nine years, the carbon and nutrient stocks in the soil, litter and herbaceous compartments were similar to those in preserved Caatinga (CAT), whereas the stocks contained in woody vegetation were still lower.

6. ACKNOWLEDGEMENTS

The authors thank the National Council for Scientific and Technological Development (CNPq) for funding and scholarships of authors and the National Center for Goat and Sheep Research of the Brazilian Agricultural Research Corporation (CNPCO/EMBRAPA) for technical and logistical support. They are also indebted to Dr. Francisco Carlos Barbosa Nogueira for his valuable suggestions and revision of the manuscript.

7. REFERENCES

AGUIAR, M. I. et al. Sediment, nutrient and water losses by water erosion under agroforestry systems in the semi-arid region in northeastern Brazil. **Agroforestry Systems**, v.79, n.3, p.277-289, 2010.

AGUIAR, M. I. et al. Florística e estrutura de áreas de caatinga conservada e sob diferentes sistemas de manejo. **Ciência Florestal**, *in press*.

AGUIAR, M. I. et al. Does biomass production depend on plant community diversity?. **Agroforestry Systems**, v.87, n.3, p699-711, 2013.

ALMEIDA, M. V. R. et al. Biodiversidade em sistemas agroecológicos no município de Choró, CE, Brasil. **Ciência Rural**, v.39, n.4, p.1080-1087, 2009.

ALBRECHT, A.; KANDJI, S. T. Carbon sequestration in tropical agroforestry systems. **Agriculture, Ecosystems and Environment**, v.99, n.1, p.15-27, 2003.

ANTLE, J. M.; STOORVOGEL, J. J.; VALDIVIA, R. O. Assessing the economic impacts of agricultural carbon sequestration: Terraces and agroforestry in the Peruvian Andes. **Agriculture, Ecosystems and Environment**, v.122, p.435-445, 2007.

ARAÚJO FILHO, J. A. Histórico do uso dos solos da caatinga. In: ARAUJO, Q. R. (Org.) **500 anos de uso do solo no Brasil**. Ilhéus: Editus, 2002. p.329-337.

ARAÚJO FILHO, J. A.; CARVALHO, F. C. Sistemas de produção agrossilvipastoril para o semi-árido nordestino. In: CARVALHO, M. M.; ALVIM, M. J.; CARNEITO, J. C. (Org.). **Sistemas agroflorestais pecuários:** opções de sustentabilidade para áreas tropicais e sub tropicais. Brasília: FAO, 2001. p.101-110.

BRASIL. Ministério das Minas e Energia. **RADAMBRASIL. Folhas SB. 24/25** – Jaguaribe/Natal 1981. Geologia/Geomorfologia/ Pedologia/Vegetação/Uso Potencial da Terra. Rio de Janeiro: 1981. 740p. (Levantamento de Recursos Naturais).

CAMPANHA, M. M. et al. Estrutura da comunidade vegetal arbóreo-arbustiva de um sistema agrossilvipastoril, em Sobral, CE. **Revista Caatinga**, v.24, n.3, p.94-101, 2011.

COLE, M. M. Cerrado, Caatinga and Pantanal: the distribution and origin of the savanna vegetation of Brazil. **The Geographical Journal,** v.126, n.2, p.168-179, 1960.

DAUDIN, D.; SIERRA, J. Spatial and temporal variation of below-graund N transfer from a leguminous tree to an associated grass in an agroforestry system. **Agriculture, Ecosystems & Environment**, v.126, n.3-4, p.275-280, 2008.

DELITTI, W. B. C. Estudos de ciclagem de nutrientes: instrumentos para a análise funcional de ecossistemas terrestres. **Oecologia Brasiliensis**, v.1, p.469-486, 1995.

DRUMOND, M. A. et al. Contribuição da Embrapa Semi-árido para o desenvolvimento dos sistemas agroflorestais no Semi-árido brasileiro. **Agrossilvicultura**, v.1, n.2, p.145-153, 2004.

EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA – EMBRAPA. **Manual de métodos de análise de solo**. 2.ed. Rio de Janeiro: Ministério da Agricultura, 1997. 212p.

GLIESSMAN, S. R. et al. Agroecología: promoviendo una transición hacia la sostenibilidad. **Ecosistemas,** v.16, n.1, p.13-23, 2007.

GLIESSMAN, S. R. **Agroecologia**: processos ecológicos em agricultura sustentável. 2.ed. Porto Alegre: UFRGS, 2005. 653p.

HAIRIAH, K. et al. Litter layer residence time in forest and coffee agroforestry systems in Sumberjaya, West Lampung. **Forest Ecology and Management**, v.224, n.1, p.45-57, 2006.

INSTITUTO DE PESQUISA E ESTRATÉGIA ECONÔMICA DO CEARÁ - IPECE. **Perfil Básico Municipal, Sobral**. Fortaleza: SEPLAN–Secretaria do Planejamento e Coordenação, Governo do Estado do Ceará, 2011a.

INSTITUTO DE PESQUISA E ESTRATÉGIA ECONÔMICA DO CEARÁ - IPECE **Agronegócio Cearense:** um balanço de 2010 e desempenho no 1º trimestre de 2011. Fortaleza: SEPLAN–Secretaria do Planejamento e Coordenação, Governo do Estado do Ceará, 2011b.

IWATA, B. F. et al. Sistemas agroflorestais e seus efeitos sobre os atributos químicos em Argissolo Vermelho-Amarelo do Cerrado piauiense. **Revista Brasileira de Engenharia Agrícola e Ambiental,** v.16, n.7, p.730-738, 2012.

LIMA, S. S. et al. Serrapilheira e teores de nutrientes em argissolo sob diferentes manejos no norte do Piauí. **Revista Árvore**, v.34, n.1, p.75-84, 2010.

KASS, D. C. L.; SYLVESTER-BRADLEY, R.; NYGREN, P. The role of nitrogen fixation and nutrient supply in some agroforestry systems of the Americas. **Soil Biology Biochemistry**, v.29, n.5-6, p.775-785, 1997.

LUIZÃO, F. J**.** et al. Ciclos biogeoquímicos em agroflorestas na Amazônia. In: GAMA-RODRIGUES, A. C. et al. (Org.). **Sistemas agroflorestais:** bases científicas para o desenvolvimento sustentável. Campos dos Goytacazes: Universidade Estadual do Norte Fluminense Darcy Ribeiro, 2006. v.1. p.87-100.

MARIN, A. M. et al. Efeito da *Gliricidia sepium* sobre nutrients do solo, microclima e produtividade do milho em sistemas agroflorestais no agreste paraibano. **Revista Brasileira de Ciência do Solo**, v.30, p.555-564, 2006.

MANLAY, R. J. et al. Carbon, nitrogen and phosphorus allocation in agro-ecosystems of a West African savanna III. Plant and soil components under continuous cultivation. **Agriculture, Ecosystems and Environment**, v.88, n.3, p.249-269, 2002.

MAIA, S. M. F. et al. Impactos de sistemas agroflorestais e convencional sobre a qualidade do solo no semi-árido cearense. **Revista Árvore**, v.30, n.5, p.837-848, 2006.

MAIA, S. M. F. et al. Organic carbon pools in a Luvisol under agroforestry and conventional farming systems in the semi-arid region of Ceará, Brazil. **Agroforestry Systems**, v.71, n.2, p.127-138, 2007.

MAIA, S. M. F. et al. Frações de nitrogênio em Luvissolo sob sistemas agroflorestais e convencional no semi-árido cearense. **Revista Brasileira de Ciências do Solo**, v.32, n.1, p.381-392, 2008.

MALAVOLTA, E.; VITTI, G. C.; OLIVEIRA, A. S. **Avaliação do estado nutricional das plantas:** princípios e aplicações. Piracicaba: Associação Brasileira para Pesquisa da Potassa e do Fosfato, 1989. 201p.

MONTAGNINI, F.; NAIR, P. K. R. Carbon sequestration: na underexplointed enviromental benefit of agroforestry systems. **Agroforestry Systems,** v.61, n.1-3, p.281-295, 2004.

NOGUEIRA, R. S. et al. Redistribuição de carbono orgânico e fósforo pelo escoamento superficial em sistemas agrícolas convencionais e agroflorestais no semi-árido cearense. **Revista Ceres**, v.55, n.4, p327-337, 2008.

NOVARA, A. et al. Paired-site approach for studying soil organic carbon dynamics in a Mediterranean semiarid environment. **Catena**, v.89, n.1, p.1-7, 2012.

NYGREN, P.; RAMIREZ, C. Production and turnover of N_2 fixing nodules in relation to foliage development in periodically pruned Erythrina peoppigiana (Leguminosae) trees. **Forest Ecology and Management**, v.73, n.1-3, p.59-73, 1995.

ODUM, E. P. The strategy of ecosystem development. **Science**, v.164, p.262-270, 1969.

PEREZ, C. et al. Car carbon sequestration markets benefit low-income producers in semi-arid Africa? Potentials and challenges. **Agricultural Systems**, v.94, n.1, p.2-12, 2007.

SILVA, G. L.et al. Soil physical quality of Luvisols under agroforestry, natural vegetation and conventional crop management systems in the Brazilian semi-arid region. **Geoderma,** v.167-168, p.61-70, 2011.

SILVA, G. C.; SAMPAIO, E. V. S. B. Biomassas de partes aéreas em plantas da Caatinga. **Revista Árvore**, v.32, n.3, p.567-575, 2008.

SOTO-PINTO, L. et al. Carbon sequestration througнh agroforestry in indigenous communities of Chiapas, México. **Agroforestry Systems**, v.78, n.1, p.39-51, 2010.

SZOTT, L. T.; FERNANDES, E. C. M.; SANCHEZ, P. A. Soil-plant interactions in agroforestry systems. **Forest Ecology and Management**, v.45, n.1, p.127-152, 1991.

TAKIMOTO, A.; NAIR, P. K. R.; NAIR, V. D. Carbon stock and sequestration potential of traditional and improved agroforestry systems in the West African Sahel. **Agriculture, Ecosystems and Environment**, v.125, n.1, p.159-166, 2008.

TURNER, D. P. et al. Carbon sequestration by forests of the United States: current status and projections to the year 2040. **Tellus**, v.41, n.1-2, p.232-239, 1995.

VEUM, K. S. et al. Assessment of soil organic carbon an total nitrogen under conservation management practices in the Central Claypan Region, Missouri, USA. **Geoderma**, v.167-168, p.188-196, 2011.

YEOMANS, J. C.; BREMNER, J. M. A rapid and precise method for routine determimation of organic carbon in soil. **Communications in Soil Science and Plant Anallysis**, v.19, n.13, p.1467-1476, 1988.