THE INFLUENCE OF A SILVOPASTORAL SYSTEM ON CARBON STOCKS IN THE BRAZILIAN SAVANNA

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Climate changes have caused wide ranges of adversities. The deforestation process, resulting in degradated pastures, is one of the main sources of greenhouse gases. Trees in pastures, constituting silvopastoral systems, have the potential to reduce greenhouse gases levels in the atmosphere. Aimed at evaluating trees' contribution to carbon sink, the present experiment was conducted in Lagoa Santa, Minas Gerais State, Brazil. The system has been under development since 1984, through the natural regeneration of pioneer trees of the species *Zeyheria tuberculosa* Vell. Bur, a native species of the Brazilian savanna. Tree density was 160 ha^{-1} and the grass forage chosen was *Brachiaria brizantha* cv. Marandu. The total carbon stocked in the silvopastoral systems was 69,536.42 kg ha^{-1}: 13,995.04 kg, in the trees, 2,430.78 kg in the annual trees litterfall, and 53,110.60 kg in a depth of 0 to 40 cm of soil. Soil carbon stock in the monoculture was 61,081.25 kg ha^{-1} of carbon. The apparent increase in the silvopastoral systems carbon stocks demonstrates the possibility of conciliation between animal production and greenhouse gases reduction.

Keywords: deforestation; degradation; pastures; productivity; sustainability; trees

1. Introduction

The largest proportion of Carbon (C) emissions results from the burning of fossil fuels and tropical deforestation (Albrecht & Kandji, 2003). The actual concentration of greenhouse gases (GHG) in the atmosphere is approximately 430 parts per million (ppm) CO_2, considerably higher than the 280 ppm from the period before the Industrial Revolution. The current level of GHG has already caused a global warming of more than 0.5ºC. If the current flow of emissions were to stabilize, it is expected that the planet's temperature would increase from 2 to 3 ºC. However, it is predicted that, in 2050, the CO_2 levels in the atmosphere will reach 550 ppm and subsequently continue to increase (STERN..., 2006).

The climatic change will have severe impacts as heavier floods, more intensive droughts, and, consequently, crop yields decline. However, much of these risks can be reduced through the implementation of a strong mitigation policy. The annual costs of stabilizing the concentration of GHG in the atmosphere at 500-550 ppm CO_2 are estimated to be around 1% of the annual global Gross Domestic Product (GDP). On the other hand, the damages caused by the impacts represents 5% of the annual global GDP. As the planet heats up, its capacity to absorb C decreases, thus making the reduction of emissions an urgent and imperative issue (STERN…, 2006).

The C sink in terrestrial biomes has been proposed to compensate GHG emissions (Dixon, 1995). Tropical forests are important in the global cycle of C because they contain more than half of the forests' biomass and 20% of the soil's C (Schwendenmann & Pendall, 2006). It is estimated that tropical deforestation contributes to 20% of global warming (Sanchez, 1995). In Brazil, from 1988 to 1994, the liquid emissions of CO_2 (gross emissions minus the removals promoted by the regeneration of the biomes) caused by land use changes were estimated at 722 Tg (Tg =10^{12} g or million of tons). The Amazon and Brazilian savanna biomes represented 59% and 26% of this total, respectively (Fidalgo *et al.*, 2006).

The area of the Brazilian Savanna is around 200 million ha. It was estimated that, in 1999, almost 10% of its area has been burned. The burning of the biomass releases 90% of the C from the soil's surface in the form of GHG, increases the soil's temperature and, consequently, CO_2 emissions (Krug *et al.*, 2006). In this biome, the biomass the below the soil surface can in fact overwhelm the aerial biomass, which is used as an adaptation strategy to overcome droughts and burning. Due to the high C sink capacity and the vast area, the Brazilian savanna becomes very important in the climate change context. It is the Brazilian ecosystem most affected by agriculture expansion, annually losing 3.4 million ha. The native vegetation has been replaced by monocultures, like soybean, that do not have the same C sink capacity (Delitti *et al.*, 2003).

In the Brazilian savanna, there are approximately 49.6 million ha of cultivated pastures, mainly of *Brachiaria* (Martha Júnior & Vilela, 2002). Around 80% of these pastures are degraded (Peron & Evangelista, 2004). It is believed that the introduction of trees into the agricultural systems produces an enormous potential to store C, which could occur through agroforestry systems (AS). If these systems were introduced in the degraded areas and pastures without trees, from 1.1 to 2.2 Pg (Pg=10^{15} g or one billion ton) could be stored annually – an amount that corresponds to 10-15% of the total annual emissions. Globally, the AS could potentially be implemented in 585-1275 x 10^6 ha (Dixon, 1995). However, the goal of AS is to generate sustainable food production and C storage is just one positive consequence of an increase in photosynthetic rates due to the introduction of trees and less pressure for deforestation (Schroeder, 1994).

Buurman *et al.* (2004) considers that the term “sequestration” describes a process rather than a specific situation. Thus, it is more appropriate to use the term “stock”. In this light, this work aimed to assess the influence of the *Zeyheria tuberculosa* Vell. Bur (ZT) tree on the storage of C in a silvopastoral system (SPS), a modality of an AS that combines trees, pastures, and animals, in the Brazilian savanna biome.

2. Material and methods

2.1. Study area

The present experiment was conducted in an SPS, corresponding to the Brazilian savanna biome, at the private Grota Funda farm, in Lagoa Santa, Minas Gerais, Brazil, 19° 35 ' 36 " S, 43° 51 ' 56 " W, at an altitude of 747 m above sea level. The system has been under development since 1984 through the natural regeneration of a native tree species named *Zeyheria tuberculosa* Vell. Bur. - family: Bignoniaceae (ZT). During natural regeneration management, the undesirable species were cut down and minimal distances of 4 m between ZT trees were maintained. The trees were 15-23 m tall with a chest diameter of 40-60 cm. This species was chosen due to its wood quality, fast growth, straight trunk, intermediate canopy density, and resistance to cattle grazing during establishment of the SPS. The density adopted was 160 trees/ha. No fire was used during the establishment. Limestone and natural phosphate, according to prior soil analysis, were applied. The forage chosen was the *Brachiaria brizantha* cv. Marundu (BBM), which replaced a pasture of *Hyparrhenia rufa*. The seeds were distributed manually among the trees (Viana *et al.*, 2002). An adjacent pasture, control area, was also established using the same methodology, but without trees. The stocking rate (bovine) in both pastures was adjusted to the forage production and ranged from 0.8 to 1.5 animal units ha^{-1}. The soil is a Red-Yellow latosol by the Brazilian soil classification (Typic Acrustox - USDA classification) with 651 $g.kg^{-1}$ clay, 211 $g.kg^{-1}$ silt, and 138 $g.kg^{-1}$ sand.

2.2. Data sets

In an attempt to evaluate the nutrient cycling in the SPS, the annual litterfall of tree leaves, fruits, and branches was estimated. For this purpose, four traps (net panels, with a mesh of 4 x 6 mm), randomly distributed in the area under the trees’ influence ,were used. Each trap had an area of 27 m² and was 1.5 m from the ground. During 2005, 12 collections at 30-day intervals were realized. For statistical analysis, the senesced material was grouped according to season: summer (from December to February), autumn (from March to May), winter (from June to August), and spring (from September to November).

Soil was sampled in February of 2006 with nine sampling points taken in each system (Figure 1). Soil samples were collected in the following depths: 0 - 10, 10 - 20, and 20 - 40 cm. The samples for chemical analysis were collected using a Dutch auger. In four of nine points, three of which were located on the central diagonal line, samplings for physical analyses, in addition to the samples for chemical analysis, were collected at the previously cited depths, totalizing 24 samples. At the five remaining points, only samples for chemical analysis were collected. For all samples, the medium third was collected. Following the recommendation of Hamburg (2000), the soil bulk density and C concentrations was measured in the same sample.

Meteorological data was supplied by the meteorological department, at the Tancredo Neves International Airport, located in the neighboring city of Confins, at the following geographic coordinates: 19º54' 32'' S and 43º58' 18'' W.

Aimed at measuring the amount of C stored in the trees, six average-sized trees were cut down at 10cm above the soil; divided into leaves, branches, and trunk; and weighed. The average chest diameter (CD) of 100 trees of the system was 57.7 cm. It was determined that the roots biomass corresponded to 15% of the aboveground components (Andrade & Ibrahim, 2003).

2.3. Lab analysis

After collection, the litterfall was classified in leaves, branches, fruits, and others (material which was impossible to distinguish); weighed; pre-dried at 60ºC for 72 hours; and milled at 1 mm. The samples were analyzed for dry matter (DM) and ash (COMPÊNDIO…, 1998). Phosphorus (P), calcium (Ca^{+2}), and potassium (K) were determined trough calorimetric, permanganometric, and flame photometric techniques, respectively.

The OM content was estimated as the difference between the DM and the ash content. The C content was estimated as 58% of OM (Nelson & Sommers, 1982). The total nitrogen content was determined through Kjeldahl (Cunniff, 1995) and lignin contents by digesting samples in a 72% H_2SO_4 solution for three hours, according to Robertson & Van Soest (1981). These analyses took place at the Animal Nutrition Laboratory of the School of Veterinary Sciences at the Federal University of Minas Gerais (UFMG). The soil chemical analyses were done in the Soil Analysis Laboratory of the Federal University of Uberlândia /MG, according to EMBRAPA (1999), and the physical analyses at the Soil and Water Laboratory of Federal University of Viçosa/MG, according to EMBRAPA (1997).

2.4. Statistics

The Lilliefors and Bartlett tests were used to check normality and homoscedasticity, respectively (Cochran & Cox, 1968).

The litterfall data was described through the estimates of average, minimum, and maximum values, standard deviation, coefficient of variation (CV), and graph of profile.

A split plot design was also used in a two-way ANOVA. To compare treatment means, the Student Newman Keuls (SNK)'s Least Significance difference test was used at a 5% probability level. Considering the seasonal effect, a factorial arrangement was formed, placing the vegetation (leaves, branches, fruits, and others) in the plot and the season in the subplot.

The amount of C stocked in the trees was calculated through the multiplication of the trees average amount of C by the trees density in the area, 160 ha^{-1}.

In relation to soil C content, another Split plot design was used. To compare treatment means, the Student Newman Keuls (SNK)'s Least Significance difference test was used at a 5% probability level. Considering the depth effect, a factorial arrangement was formed, placing the system in the plot and the depth in the subplot. The Pearson correlations were used to assess the relationships between the soil C content and the other soil chemical attributes. Regression models, using the backwards procedure, were also performed to examine these relationships.

The amount of soil C stocked in each depth was calculated through the multiplication of the values of soil C content, buck density, and the number of 10 cm layers per depth evaluated (Buurman *et al.*, 2004).

3. Results

In table 1, soil chemical attributes are represented. The values of Ca^{+2} and base saturation (BS) were slightly higher in the SPS than in the monoculture. On the other hand, the opposite occurred to the pH, P, K, and Al^{+3} (Aluminum) attributes.

Table 1 - Chemical attributes of soils under silvopastoral system (SPS) and monoculture (Lagoa Santa-2006)

Variable	Depth (cm)					
	Monoculture			SPS		
	0-10	10-20	20-40	0-10	10-20	20-40
pH (H_2O –1:2.5)	4.86±0.22	4.75±0.23	4.75±0.11	4.64±0.28	4.61±0.19	4.64±0.11
Phosphorous (mg dm^{-3})	2.57±0.86	1.79±0.75	1.09±0.35	1.89±0.58	1.71±0.33	1.06±0.21
Potassium (mg dm^{-3})	135.87±35.69	70.13±14.72	42.5±17.46	95.63±36.90	82.5±30.26	49.37±35.84
Calcium (cmolc dm^{-3})	0.67±0.31	0.39±0.19	0.23±0.07	0.76±0.27	0.6±0.17	0.27±0.14
Magnesium (cmolc dm^{-3})	0.59±0.36	0.27±0.24	0.13±0.07	0.56±0.21	0.41±0.13	0.12±0.05
Aluminum (cmolc dm^{-3})	1.74±0.55	2.31±0.33	2.5±0.17	1.71±0.50	1.96±0.28	2.35±0.21

Variable	Depth (cm)					
	Monoculture			SPS		
	0-10	10-20	20-40	0-10	10-20	20-40
H + Al (cmolc dm-³)	9.5±1.56	10.11±1.41	10.05±0.46	8.9±1.58	8.99±1.11	9.31±0.73
Sum of bases (cmolc dm-³)	1.6±0.68	0.84±0.46	0.45±0.14	1.57±0.45	1.22±0.30	0.54±0.17
CEC (cmolc dm-³)	3.34±0.27	3.13±0.18	2.96±0.09	3.29±0.11	3.17±0.17	2.86±0.15
CEC7 (cmolc dm-³)	11.1±0.96	10.95±1.00	10.51±0.44	10.49±0.49	10.21±0.85	9.85±9.85
Bases saturation (%)	15±7	8±6	4±1	15±6	12±4	6±2

Hydrogen + Aluminum (H + Al), effective cation exchange capacity (CEC) and cation exchange capacity at pH 7.0 (CEC7)

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Table 2 presents the contribution of the tree to soil fertility through litterfall. It was estimated that 160 trees ha^{-1}, over a one year period, added approximately 4,360.20 kg ha^{-1} of organic matter (OM) and 2,430.68 kg ha^{-1} of C to the pasture.

Table 2 - Average and standard deviation values of annual contribution of *Zeyheria tuberculosa* Vell. Bur. to soil in a silvopastoril system in the Brazilian savanna biome (Lagoa Santa/MG - 2005)

Variable	Avarage composition of litter (%)	kg ha^{-1} year^{-1}
Total dry matter	100	4,360.2
Ash	3.88 ± 0.94	169.23
Organic matter	96.12 ± 0.94	4,191.0
Carbon	55.74 ± 0.43	2,430.78
Calcium	0.61 ± 0.29	26.5
Phosphorus	0.07 ± 0.04	3.2
Nitrogen	1.79 ± 0.55	78.0
Potassium	0.90 ± 0.59	39.4
Lignin	45.04 ± 8.00	-
Carbon/Nitrogen	31.10 ± 11.03	-
Lignin/Nitrogen	25.16 ± 9.46	-

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The C contents in the litter components presented few variations during the year (Table 3). The C content was lower in all components during the winter, except for branches, which seems to be the component with the highest C content, except in spring.

Table 3 - Seasonal average and standard deviation values of carbon in the tissues of *Zeyheria tuberculosa* Vell. Bur. (Lagoa Santa/MG - 2005)

Tissue	Season			
	Summer	Autumn	Winter	Spring
Leaves	55.73 ±0.22 Ab	55.46 ± 0.03 Ab	54.94 ± 0.97 Ba	55.38 ± 0.19 Ab
Fruits	56.08 ± 0.09 Aab	55.61 ± 0.31 Ab	54.60 ± 0.11 Bb	55.72 ± 0.49 Aab
Branches	56.46 ± 0.37 Aa	56.28 ± 0.39 ABa	55.93 ± 0.97 ABa	55.78 ± 0.31 Bab
Others	56.23 ± 0.17 Aab	55.85 ± 0.05 Aab	54.92 ± 0.57 Bb	56.02 ± 0.26 Aa

Averages followed by distinct letters, capital letter referring to tissue and small letter referring to season, differ at the 5% significance level (SNK test)

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Table 4 describes the density values, C contents, and amount of C stored per area. In the monoculture, in the 0 - 10 cm layer, the bulk density tended to be higher, while the C content was significantly greater ($P<0.05$) than in the SPS. On the other hand, in the 20 - 40 cm layer, despite the higher C content in the monoculture, the density tended to be greater in the SPS, resulting in similar C amounts ($P>0.05$) between the systems. Apparently, the total C amount stored in the soil was greater in the monoculture.

Table 4 - Average and standard deviation values of bulk density, carbon (C) percentage and total C ha^{-1}, in soils under silvopastoral system (SPS) and monoculture (Lagoa Santa-2006)

System	Deep*	Thickness (10cm)	Bulk density	C (%)	Total C (kg ha^{-1})
Monoculture	0-10	1	1.15 ± 0.15 Aa	2.18 ± 0.56 Aa	26130.45 Aa
	10-20	1	0.94 ± 0.09 Aa	1.51 ± 0.23 Ab	14772.60 Ac
	20-40	2	0.95 ± 0.03 Aa	1.05 ± 0.07Ac	20178.20 Ab
SPS	0-10	1	1.11 ± 0.11 Aa	1.62 ± 0.14 Ba	19089.25 Ba
	10-20	1	1.11 ± 0.18 Aa	1.37 ± 0.14 Ab	16261.75 Aa
	20-40	2	1.09 ± 0.13Aa	0.81 ± 0.10 Bc	17759.60 Aa
	CV (%)	-	11.77	17.5	16.89

Averages followed by distinct letters, capital letter referring to system and small letter referring to depth, Differ r at the 5% significance level (SNK test)

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Table 5 shows the total weight, DM content, and C amount in each tree component. The trunk produced the highest contribution to C stocks.

Table 5 - Average and standard deviation values of dry matter (DM) weight, DM percentage and carbon (C) weight in the tissues of *Zeyheria tuberculosa* Vell. Bur. (Lagoa Santa/MG - 2005)

Tissue	DM weight (kg)	DM (%)	C weight (kg)
Trunk	99.47 ± 11.29	64.57 ± 2.32	49.73 ± 5.65
Branches	41.88 ± 13.05	64.57 ± 2.32	20.94 ± 6.52
Leaves	10.78 ± 2.98	51.19 ± 4.19	5.39 ± 1.49

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In table 6, the total amounts of C per component, in both systems, are presented. The amount of C stored in the trees was estimated at 13,995.04 kg ha^{-1}. If the amount of C stored underground in the SPS was also considered, the total amount stored in this system would be 69,536.42 kg ha^{-1} of C. In the monoculture, the total stock would be 61,081.25 kg ha^{-1} of C.

Table 6 – Avarage carbon amounts in some components of monoculture an silvopastoral system (SPS) in the Brazilian savanna biome (Lagoa Santa/MG – 2006)

Compartment	Monoculture (kg ha^{-1})	SPS (kg ha^{-1})
Trunk	-	7,956.80
Branches	-	3,350.40
Leaves	-	862.40
Total overground	-	12,169.60
Roots (15% total overground)	-	1,825.44
Trees (overground + roots)	-	13,995.04
Litterfall from trees	-	2,430.78
Soil	61,081.25	53,110.60
System (trees + soil)	61,081.25	69,536.42

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Most soil variables in this study showed significant correlation with soil C content (Table 7). The correlations with P, ferrum (Fe), and manganese (Mn) were higher than 0.80 (P<0.01).

Table 7 - Pearson correlations between soil carbon (C) and the others chemical soil attributes (Lagoa Santa/MG – 2006)

Soil variable	soil C	Soil variable	soil C
pH	-	CaK	-0.3047 **
Phosphorus	0.8662 ***	MgK	-
Potassium	0.7371 ***	Ca Mg K	-
Sulfur	-0.2401 *	Ca / CEC7	0.5838 ***
Calcium	0.6790 ***	Mg / CEC7	0.6955 ***
Magnesium	0.7497 ***	K / CEC7	0.6761 ***
Aluminum	-0.6264 ***	H + Al / CEC7	-0.6980 ***
H + Al	-	Ca + Mg / CEC7	0.6466 ***
Sum of bases	0.7819 ***	Ca + Mg + K / CEC7	0.7185 ***
CEC	0.7515 ***	Borum	0.7029 ***
CEC 7	0.3887 **	Cuprum	0.7185 ***
Bases saturation	0.7038 ***	Ferrum	0.8680 ***
Aluminum saturation	-0.7544 ***	Manganese	0.8378 ***
Ca / Mg	- 0.5127 ***	Zinc	0.7038 ***

Hydrogen plus aluminum (H+Al). effective cation exchange capacity (CEC) and cation exchange capacity at pH 7.0 (CEC7). Ca / Mg. Mg / CEC7 . K / CEC7 . H+Al / CEC7 . (Ca+Mg) / CEC7. (Ca+Mg+K)/ CEC7 ratios

-. ***. **. * (t test: P>0.05; P<0.001; 0.01; 0.05. respectively)

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The regression models for C contents as compared to the other soil variables, for each system, are represented in Table 8.

Table 8 – Regression parameters of the regression of C amounts in function of the other soil attributes in soils under monoculture (Mono) and silvopastoral system (Lagoa Santa/MG – 2006)

System	Model	R² adjusted
Monoculture	0.6714 + 0.0390 BS + 0.0027 Fe + 0.0429 Mn	0.9402
SPS	1.1870 + 0.4738 P – 0.0103 m	0.8529

Bases saturation (BS). aluminum saturation (m)

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The soil variables that most influenced the C contents in the monoculture were base saturation (BS), Fe, and Mn, while in the SPS, these variables were P and aluminum saturation (m).

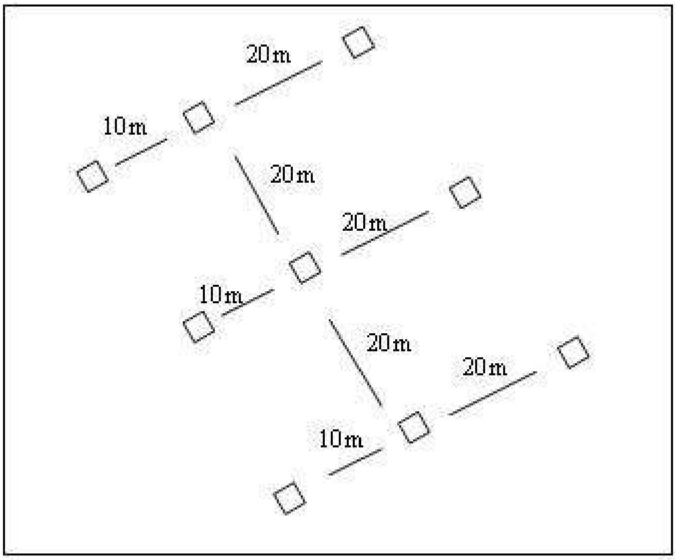

Figure 1.

Soil sampling diagram: three parallel lines were traced, 40m in length each, cutting the center of each system in a diagonal form. The first and third diagonal lines were 10m and 20m from the central line, respectively. In each line, three samples were collected 20m from each other, totaling nine sampling points in the SPS and nine points in an area out of its influence, which was set as the control treatment.

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4. Discussion

The total litter production (table 2) was in accordance with the production of the Brazilian savanna's native vegetation reported by Haridasan (2000), from 3.0 to 7.8 Mg ha^{-1}year^{-1}, depending on tree size. There was considerable contribution of nitrogen (N), K and Ca^{+2}, while P contribution remained low. The carbon/nitrogen (C/N) and lignin/N ratios proved to be high, at 31.10 and 25.16, respectively.

The higher values of C content and bulk density in the 0 - 10 cm layer (Table 4) may have contributed to the higher amounts of C stored at this depth in the monoculture. This is in accordance with the warning reported by Buurman *et al.* (2004) that density significantly affects the calculation of the stocks.

The root biomass shows positive correlation with forage production (Oliveira *et al.* 2003). The BBM production was evaluated by Sousa *et al.* (2007) within the same SPS of the present study. Using the same control treatment as a reference, this researcher concluded that the microclimate conditions under ZP trees contributed significantly to reducing ($P<0.05$) the DM production of the studied forage (average of five monthly samples during the rainy season). Therefore, it seems that the lower forage production in the shaded area implies a lower OM content in the 0 - 10 and 20 - 40 cm layers, in which there were higher OM contents in the monoculture. In these layers, there was most likely no litter influence and the grass roots were more aggressive during soil exploration and turned over more quickly. In this light, a study on tree density is called for, but reducing it slightly in an attempt to increase grass productivity and, consequently, soil C stocks.

Nevertheless, Delitti *et al.* (2003) reported that the soil surface layer presents greater seasonal variation in the biomass content due to higher exposure to climate variables. The work of Schwendenmann & Pendall (2006) in Panama clarifies that the amounts of C stored in the grass and forests are similar, especially if the area contains forage species with a high root biomass. They also concluded that the conversion of forests into grasslands did not in fact result in losses of N and C. On the other hand, Sanchez (1995) alerted that deforestation increases topsoil C emissions due to higher soil temperature, which speeds up organic matter decomposition. Moreover, as Milne & Haynes (2004) report, the conventional tillage following deforestation increases aeration and breaks up soil aggregates, in turn exposing organic matter which was previously physically protected against microbial attack by an aggregate structure.

According to Cerri *et al.* (2004), this decline in soil C stocks due to deforestation is almost universal. However, the balance of C after the conversion of forests into pastures depends on the forage productivity, which are many times affected by factors such as climate, native soil fertility, and grazing intensity. Thus, the grasslands soils can be either a net source of C, in the case of overgrazing, or a net sink if the pastures were well managed. Concerning the Amazon, after substituting forests with fertilized pastures of *Brachiaria brizantha*, the estimate, regarding forest soil C stocks increases to over 20 Mg ha^{-1} of C in the top 1 m of soil, whereas there is a loss of 0.5 Mg ha^{-1} of C in the 1-8 m layer, during the first 5 years following pasture rehabilitation. In the present study, the monoculture and the SPS were well managed, which may have contributed to an increase in the soil C content.

Milne & Haynes (2004) report considerable increases due to irrigation and fertilization in DM production, which result in larger returns of organic matter. Buurman *et al.* (2004) reported that a low quality of litterfall, a low pH, and high contents of Al^{+3}, although agronomically undesirable, actually favored C storage. In the present study, the Al^{+3} and C soil contents presented a correlation of -0.6264 ($P<0.001$), while the correlation between pH and C was not significant ($P>0.05$) (Table 7).

In relation to the studied tree, the trunk, which stocks C for a longer period of time, corresponded to 65.29% of the total C stocked in the aerial biomass (Table 5), followed by the branches, 27.48%, and the leaves, 7.23%. According to Shively *et al.* (2004) most of the C from branches, leaves, litterfall, and understory vegetation is released back into the atmosphere in less than 10 years. Schroeder (1994) reported that as the C added to the active pools decomposes in less than two years, the aim of C sequestration is to increase the size of the slow and passive soil carbon pools.

In the Brazilian savanna, the root contribution to the C sink is greater than in other biomes. As Haridasan (2000) reports, around 50% of the Brazilian savanna biomass corresponds to the roots. In contrast, in the tropical rainforests, this amount varies from 2.6 to 4.6% in the primary forests and from 11.0 to 19.5% in the secondary ones. Delitti *et al.* (2003) emphasize that in the Brazilian savanna the root biomass varies from 4 to 16 Mg ha^{-1} and can even surpass the aerial biomass. As Andrade & Ibrahim (2003) claim, the ratio in tropical forests varies from 3.0% to 49.0%; however, more cautious values, from 10% to 15%, must be used.

The greater C stock in the SPS is in accordance to Sharrow & Ismail (2004). These researchers reported that the SPS can store more C than planted forests or monoculture pastures because there is greater amount of biomass and nutrient cycling done by both the trees and the forage. Schroeder (1994) reports that the C amounts stocked due to AS introduction vary from region to region: nine t ha^{-1} of C in five years in semi-arid tropics, 21 t ha^{-1} of C in eight years in sub-humid tropics, and 50 t ha^{-1} of C in five years in the humid tropics.

In the Brazilian savanna, the substitution of natural vegetation, which is one of the highest primary productivities of the savanna (1000-2000 g m^{-2} of DM), with *Brachiria,* which five years after planting produces an average of 200-400 g m^{-2} of DM, reduces the soil C content (Brossard & Barcellos, 2005). The increase in productivity in agricultural systems may reduce the GHG emissions caused by deforestation and the degradation of pastures. Some measures, such as direct plantation and the introduction of AS, can store up to 1.3 Mg ha^{-1}year^{-1}of C (Steinfeld *et al.*, 2006). Worldwide, the AS has proven to be promising with respect to the increase in productivity in many regions by promoting system nutrient accumulation, reducing losses, improving soil structure, increasing OM and N contents (Issac *et al.*, 2005), reducing the evapotranspiration of plants, as well as storing C (Dixon, 1995). However, it appears that the ZT influenced soil fertility slightly (Table 1), despite the litterfall contributions of N, P, and Ca (Table 2).

The recovery of degraded areas is an effective way to increase soil C storage. This can take place through such practices as the combination of direct plantation with the use of vegetal residues and animal manure, thus resulting in high productivity and few losses from processes such as decomposition, leaching, and erosion. The trees in the AS improve the land cover as well as add C through vegetal tissues. Nevertheless, the soil C storage is a finite process, therefore it is also necessary to consider nitrous oxide (N_2O) and methane (CH_4) (Albrecht & Kandji, 2003).

In addition to the issue of climatic changes, the SPS also provide other environmental benefits, including soil conservation, the improvement of water quality and quantity, and the preservation of biodiversity and comfort for animals (Shrestha & Alavalapati, 2004). It is estimated that one ha of AS provides goods and services that compensate for 5-20 ha of deforestation (Dixon, 1995).

The variation between the data analyzed (Table 8) implies that the factors that influence soil C contents vary among systems, and according to Montagnini and Nair (2004), mixed stands of plants may be more efficient than monocultures.

5. Conclusions

There was apparently a greater amount of C stored in the SPS as compared to the BBM monoculture, despite the lower C content in the soil under trees. However, the storage of C could be increased through the optimizing of interactions among the SPS components. Due to the variation between the data analyzed and findings from the literature, it can be concluded that the factors that influence soil C contents vary among systems. Thus, it is important for future studies to assess the influence of other tree species and forages under distinct conditions, such as climate, density, and mixed stands.

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