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Soil carbon stock in silvopastoral system, pasture and sugarcaneculture

Reserva de carbono en el suelo de sistemas silvopastoriles, pastizales y de plantación de caña de azúcar

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ABSTRACT

The conversion of natural system in tillage agriculture areas is largely responsible for the reduction of Organic Carbon stock (*OC-stock*) in the soil and increases C-CO_2 atmospheric release in tropical countries. The objective of this study was to evaluate the impacts of different situations of soil uses (silvopastoral, pasture and sugarcane) in *OC-stocks* of Utilsols in the regions of *Vale do Rio Doce* in the state of *Minas Gerais*. It was determined contents of total soil organic carbon (*SOC*) and soil bulk density (*Bd*) in different situations studied. The use of anthropic soil is promoting the increase of the soil *Bd* due to the deployment of cultures being preformed mechanically, therefore the systems provided higher content of *SOC* and consequently increased the *OC-stock*. The highest content of *SOC* was found in the area with sugarcane. The studied situations provided increase in the *OC-stock* in depth 0-10 cm, of 5,397 Mg ha^{-1}, 3,494 Mg ha^{-1} and 1,964 Mg ha^{-1} for sugarcane, silvopastoral system and pasture. The management of fertilization and harvesting of sugarcane in the region of the city *Governador Valadares* is efficient in increasing the *OC-stock*, including being greater than the secondaryforest, and the silvopastoral site shows a greater potential in carbon stocking in the surface layers (0-10 cm and 10-20 cm) compared to continuous grazing areas.

Key words: conversion system, organic residue inputs, soilcarbon.

RESUMEN

La conversión de sistemas naturales en tierras agrícolas es uno de los principales factores responsables por la reducción de la reserva de C en el suelo y el aumento de la liberación de C-CO_2 atmosférico en los países de clima tropical. El objetivo del presente estudio fue evaluar el impacto de los diferentes usos del suelo (silvopastoril, pastizales y plantación de caña de azúcar) en las reservas de C de un suelo arcilloso rojo-amarillo ubicado en la región del Valle del Río Doce, Minas Gerais. Para este fin fueron determinados los contenidos de carbono orgánico total (SOC) y la densidad del suelo (Bd) en los distintos sistemas estudiados. El uso antrópico del suelo está favoreciendo el aumento de la Bd en función de la mecanización del suelo. Sin embargo, los sistemas proporcionaron niveles de SOC elevados al suelo y consecuentemente se incrementaron las reservas de C. En el área con caña de azúcar se encontraron los niveles más elevados de SOC. En las áreas estudiadas se observó un incremento de los estoques de C entre la profundidad de 0-10 cm, de 5397 Mg ha^{-1}, 3494 Mg ha^{-1} y 1964 Mg ha^{-1} para las áreas con caña de azúcar, sistema silvopastoril y pastizal, respectivamente. El manejo de la fertilización y de la cosecha de caña de azúcar en la región de Gobernador Valadares es eficiente en el incremento de las reservas de C en el suelo, siendo incluso superior que las reservas encontradas en el fragmento florestal, y el área silvopastoril presenta mayor potencial para el almacenamiento de C en los estratos superficiales (0-10 cm y 10-20 cm) comparado con las áreas de pastoreo continuo.

Palabras clave: *conversión de sistemas, aporte de residuos orgánicos, carbono orgánico total.*

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Introduction

The conversion of natural system in tillage agriculture areas is largely responsible for the reduction of organic carbon stock (*OC-stock*) in the soil and increases C-CO_2 atmospheric release in tropical countries (Neves *et al.*, 2004). The function of the soil as a source or greenhouse gases sink depends on the management system in which they are submitted (IPCC, 2001).

Management systems that favor the larger input of organic residue to the soil are important alternative to increase the sink capacity of C-CO_2 atmospheric and global warming mitigation (Macedo *et al.*, 2008). These systems can contribute mainly to the areas that suffer conversion in an exploratory form and currently are degraded. A great part of these areas can be related to areas used for animal feed as pasture and/or sugarcane field.

In Brazil it is estimated that 80% of the agriculture regions economically important in the Amazon and Cerrado are found in some degradation stage or degraded (Dias-Filho, 2010). In the region *Vale do Rio Doce* in *Minas Gerais* the scenario repeats itself especially in *Governador Valadares* which if one of the most degraded region of the state.

There is increasing interest in indentifying the managements systems of cultures and pastures that promote the improvement of *OC-stock* in the soil. Having sugarcane management as a reference, this was previously done with burning to facilitate the culture management and harvest. Due to environmental concerns, in the last two decades the sugarcane production system uses cane vinasse to fertilize the plantation and mechanized harvest. Another important aspect is the adoption of integrated livestock farm forest system, agroforestry system and silvopastoral system. Silvopastoral system is appointed to be an important potential to recover the *OC-stock* lost in the soil (Neves *et al.*, 2004).

The decrease of C-CO_2 emission and the increase of soil organic carbon stock results in improving the soil quality, increasing productivity, contributing to the sustainability of agroecosystem and the mitigation of global warming (Silva & Mendonça, 2007). Thus, the objective of this study was to evaluate the impacts of different situations studied (silvopastoral, pasture and sugarcane) in *OC-stock* of Utilsol in the regions of *Vale do Rio Doce* in the state of *Minas Gerais*.

Materials and Methods

The study was held in the University Vale do Rio Doce (UNIVALE)'s experimental field on Campus II, located in *Governador Valadares* in the state of *Minas Gerais*. The experimental field is bounded by geographical coordinates, 18º51' S latitude and 41º56' W longitude, and altitude: 148 m (Figure 1). The climate in the region is tropical sub-hot and sub-dry, according to Koppen's classification. The average annual temperature is 25 ºC (June) to 27 ºC (February), the average rainfall is 1,114 mm per year from November to March. The description of the physical and chemical characteristics of soil are found in Tables 1 and 2 and all collecting sites are located on a plain relief, being that the soil of these sites are classified as Utisol.

The management systems evaluate was: sugarcane (SC), silvopastoral (SP), pasture (PT) and secondaryforest (SF) used as a reference site. All sites were deforest over 70 years and were submitted to sugarcane plantations for 30 years with no history of manure or liming before the establishment of the experiment.

The managed site with sugarcane (SC) crop was established 5 years ago having as a prior use a sugarcane cultivation. The current sugarcane plantation was held in a furrow after plowing and harrowing of the total area, the spacing used was 2.0 x 0.80 m with liming, mineral fertilizer (N-P-K) and organic fertilizer at planting. In the following years the implantation of the sugarcane fertilization (N-P-K) was carried out to a yield above 80 ton per ha^{-1} as described by Alvarez V. *et al.* (1999). This site is irrigated since its implantation and harvesting of sugarcane and performed manually leaving soil mulching.

The site occupied with silvopastoral system (SP) was implanted 11 years ago with intercropping of coconut and *Brachiaria brizantha* pasture and the previous use with conventional corn plantations. The coconut implantation was held in holes with a spacing of 6.0 x 6.0 m performing liming and fertilizer N-P-K at planting and cover according to the nutritional demand (Alvarez V. *et al.*, 1999). Before the pasture implantation was performed bean planting, the silvopastoral site (coconut/pasture) is irrigated and the animals intensively graze being divided into plots.

The managed site with pasture (PT) was implanted 6 years ago and the current pasture

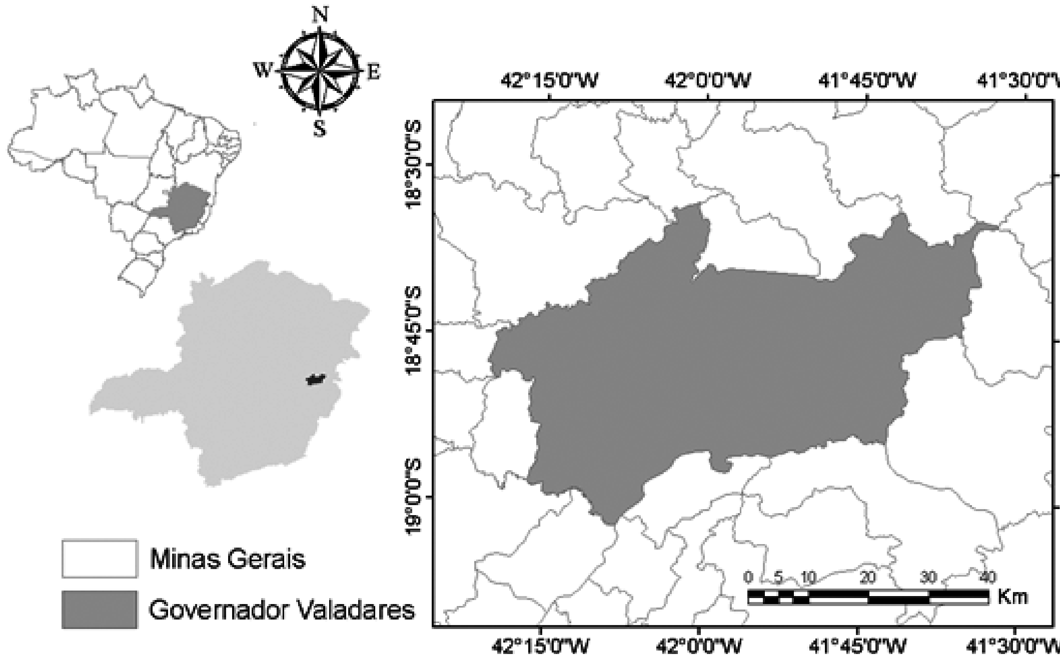

Figure 1. Geographic coordinates of the studied situations 18º51’ S and 41º56’ W.

Table 1. Soil physical characteristics of the studied situations in the depth 0-30 cm.

Studied situations	Physical characteristics[(1)]			
	Coarse sand	Fine sand	Silt	Clay
	[%]			
Silvopastoral	44.66	19.68	20.88	14.79
Sugarcane	40.21	11.03	25.2	23.56
Pasture	43.68	4.67	16.65	35.00
Secondary forest	22.83	17.80	31.87	28.00

[(1)] Embrapa (1997).

Table 2. Soil chemical characteristics of the studied situations in the depth 0-30 cm.

Studied situations	Chemical characteristics [(1)]									
	P	K^+	Ca^{2+}	Mg^{2+}	Al^{3+}	H+Al	t	BS	AS	P-rem
	[mg dm^{-3}]		[cmol$_c$ dm^{-3}]					[%]		[mg L^{-1}]
Silvopastoral	5.2	97.2	2.2	0.9	0	4.0	3.34	45.58	0	16
Sugarcane	6.1	97.1	1.2	1.2	0	5.6	2.64	32.12	0	13
Pasture	15.9	155.6	4.8	0.4	0	3.6	6.19	60.87	0	13
Secondary forest	9	117.05	4.8	0.8	0	4.5	5.89	56.73	0	11

[(1)]P, K^+, Ca^{2+}, Mg^{2+}, Al^{3+}, H+Al, CEC effective (t), Bases saturation (BS); Aluminum saturation (As) (Embrapa, 1997); P remaining (P-rem) (Alvarez V. *et al.*, 2000).

of *Pennisetum purpureum*. The previous use accomplished with *Brachiaria brizantha* pasture in extensive, the implantation of pasture was done with plowing, harrowing, liming and planting fertilizer. The pasture is irrigated and intensively used in plots systems. The secondary forest (SF) comprises secondary vegetation established for approximately 30 years with previous use of sugarcane planting in a conventional systems done by burning the crop.

Soil samples were collected in June 2010 at a depth of 0-10, 10-20 and 20-30cm with five replicates. The attributes evaluated were: soil organic carbon (*SOC*) according to Yeomans & Bremner (1988); bulk density (*Bd*) done by the volumetric ring method; pH in the water and in KCl; after, delta pH was calculated (Embrapa, 1997). The *OC-stock* accumulated in each soil layer was calculated from the expression:

$$OC\text{-}stock = Bd * SOC * PD/10$$

In:
OC-stock: Carbon stock in the layer studied (Mg ha^{-1})
SOC: Soil organic carbon (g Kg^{-1})
Bd: Bulk density (Kg dm^{-3})
PD: Profile depth (cm)

The normal distribution of data was studied thru the Shapiro-Wilk test and homogeneity of variance thru the Bartlett test. Analysis of variance (ANOVA) ($P \leq 0.05$) followed the randomized design being studied each depth separately: when significant, the means were compared thru the Turkey test ($P \leq 0.05$) using the SoftwareSISVAR (Ferreira, 2000). The means and standard error were calculated from an average of five replicated in three depths (0-10 cm, 10-20 cm and 20-30 cm). The bulk density was compared from the confidence interval of 95%.

Results and Discussion

The means of *Bd* between the different studied situations ranged from 0.8 to 1.4 Kg dm^{-3} (Figure 2). The sites under silvopastoral system (SP), sugarcane (SC) and pasture (PT) didn`t present difference between each other when evaluated in surface and subsurface to *Bd*.The site with secondaryforest (SF) presented the lowest values of *Bd* in which they ranged from 0.8 to 0.9 Kg dm^{-3}. The results corroborate with research that studied the impact of pasture and sugarcane on bulk density (Centurion *et al.*, 2007; Muller *et al.*, 2004). The sites with greater intensity of use, in general, present highest

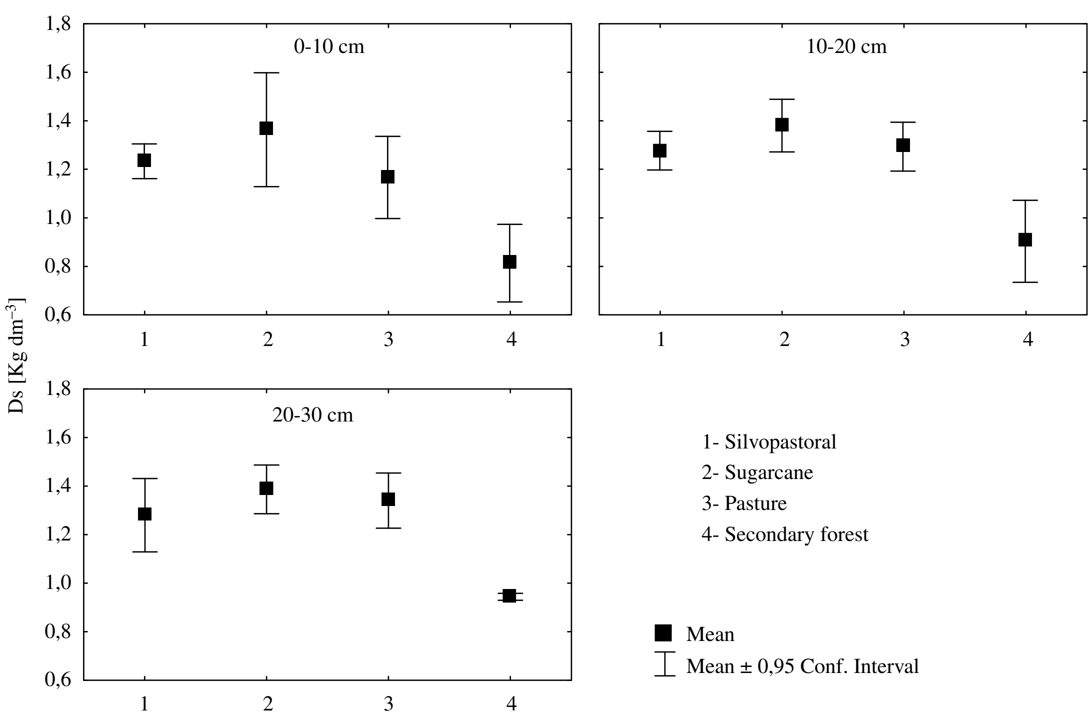

Figure 2. Bulk density (Bd) Kg dm^{-3} of the studied situations. For the same depth means followed by the same bar indicate no significant difference between the studied situations, at the level of 95% for confidence interval.

values of *Bd* (Aratani *et al.*, 2009). The results of implantations of these intensely plowed areas, or excess animals in the areasof grassland.

Soil management with the preparations of agricultural machinery and animal tramplingon soil, brings the microaggregates and the particles dispersed unit closer by expulsing air and water, which keeps them apart, increasing the bulk density by reducing the total soil volume at a expense of reduced porosity. This result was reported by Fidalsk *et al.* (2009) in a study conducted in a Oxisol indicating the main cause of the *Bd* increase in the conventional systems, soil preparation with plowing.

Another aspect that can be mentioned is the increase of bulk density values are the highest sand content in the sites of PT, SP and SC when compared to SF site.

The PT site presented the highest value of pH in the surface and subsurface (Table 3), being the same for the sites of SF and SP in the depth of 0-10cm. The lowest value of these attribute were observed in the site with SC (Table 3). This result could have been influenced due to the increasing demand of nutrients from sugarcane mainly Ca^{2+}, Mg^{2+} and K^+ and inadequate fertilization and liming. The largest export of these bases causes increase in the H^+ ion activity reducing pH in the soil. Oliveira *et al.* (2010) in his study found an average export of 188 Kg ha^{-1} of K^+, 187 Kg ha^{-1} of Ca^{2+} and 66 Kg ha^{-1} of Mg^{2+} in cultivated areas with sugarcane irrigated under Ultisol. On the other hand, Braz *et al.* (2004) working with *Brachiaria brizantha* cv. Marandu and *Panicum maximun* cv. Mombaça in Ultisol found values of maximum export (evaluated the foliar limb up to 110 days) these grasses around 164 Kg ha^{-1} of K^+, 70 Kg ha^{-1} of $Ca^{2+}$and 40 Kg ha^{-1} of Mg^{2+}.

The delta pH values in general didn't differ between the studied situations (Table 3), except in the depth 0-10cm, where the site under SP system has lower values of this attribute, possibly the lowest clay content may have contributed this result (Table 1). The delta pH values indicate that the soil of the site in study presented negative charges, favoring the retention of cations and may favor the physical and chemical protection of soil organic matter.

Although the highest sand content in soil was observed in SC (Table 1), the highest average content of carbon (*SOC*) was verified in that site, this effect was observed in all the depths being significantly superior to other systems in used in the surface area 0-10 cm (Table 3). The same happened to the SP system presented the highest sand content compared to the sites of SF and PT and presented highest content *SOC* in comparison to these two systems. It was expected that soil with a clay-like texture to present the highest content of *SOC*. This positive relation was demonstrated for various Oxisol in

Table 3. pH, Delta pH, Soil organic carbon (SOC) and Organic carbon stock (OC-stock) of the studied situations.

Dephts	Studied situations				C.V. (%)
	Silvopastoral	Sugarcane	Pasture	Secondary forest	
			pH		
1	5.9 ± 0.003 a	5.0 ±0.186 b	6.1 ± 0.096 a	5.8 ± 0.065 a	3.07
2	5.9 ± 0.122 b	5.1 ± 0.020 c	6.3 ± 0.066 a	5.5 ± 0.118 b	
3	5.9 ± 0.069 b	5.5 ± 0.155 b	6.5 ± 0.033 a	5.9 ± 0.133 b	
			Delta pH		
1	–0.74 ± 0.055 a	–0.67 ± 0.056 ab	–0.55 ± 0.095 ab	–0.43 ± 0.015 ab	15.89
2	–0.68 ± 0.064 a	–0.67 ± 0.020 a	–0.72 ± 0.030 a	–0.49 ± 0.067 a	
3	–0.70 ± 0.077 a	–0.65 ± 0.044 a	–0.79 ± 0.076 a	–0.60 ± 0.049 a	
			Soil organic carbon [g Kg^{-1}]		
1	6.90 ± 0.031 ab	7.50 ± 0.019 a	6.00 ± 0.012 c	6.10 ± 0.010 bc	5.22
2	7.60 ± 0.012 a	7.60 ± 0.029 a	7.00 ± 0.030 a	6.90 ± 0.018 a	
3	7.70 ± 0.017 ab	8.00 ± 0.027 a	7.40 ± 0.011 ab	7.10 ± 0.011 c	
			Organic carbon stock [Mg ha^{-1}]		
1	8.54 ± 0.476 b	10.28 ± 0.149 a	7.01± 0.324 c	5.04 ± 0.298 d	6.06
2	9.80 ± 0.242 ab	10.44 ± 0.274 a	9.07 ± 0.028 b	6.22 ± 0.029 c	
3	9.89 ± 0.265 a	11.16 ± 0.501 a	9.98 ± 0.145 a	6.70 ± 0.124 b	

* For the same depth, different letters indicate a significant difference between the studied situations, at the level of 5%, after the Tukey's test. ± The standard deviation. Depth 1: 0-10 cm; 2: 10-20 cm; 3: 20-30 cm. C.V. (%): Coefficient of variation.

the Northwest region of the state of *Minas Gerais* (Zinn *et al.*, 2005) being observed similar results in different classes of soils in *São Paulo* (Luca *et al.*, 2009). This influence is linked to the capacity of soil organic matter to form different types of bonds with particles of high specific surface, such as clay and silt fractions favoring the colloidal protection (Silva & Mendonça, 2007).

Possibly, the increase of consumption of straw facilitated by improving the conditions of macroporosity, aeration of sandy soils favored the activity of decomposing microfauna decreasing the C/N ratio that is indicative of humification of organic soil matter, thus providing increased contents of *SOC* to the soil (Luca *et al.*, 2009).

Furthermore, the site of SC was observed high productivity (150 Mg ha^{-1}) provided an increased intake of plant residues. Given that the site with harvest sugarcane without fire promoted the return of soil of 24% of the total produced as straw (Trivelin *et al.*, 1996), the input of straw can be reached, 36 Mg ha^{-1} year, therefore contributing to the elevation of the content of *SOC*.

This aspect was verified in a study developed by Galdos *et al.* (2009) who observed in the harvested sugarcane area without fire the rising contents of soil carbon due to the higher amount of straw.

In the site of SP the input of organic matter provided by the *Brachiaria brizantha* pasture even under continuous pasture could have obtained similar results to those found by Franchini *et al.* (2011) in integrated livestock crop systems which was 9 Mg ha^{-1} year and 8 Mg ha^{-1} year, respectively inputted by roots system and shoots of intercropping.

The high productivity of pastures in region of *Governador Valadares* was pointed out in a study developed by Alencar *et al.* (2009). These authors found an average production of shoots in the areas of *Brachiaria brizantha* cv. Marandu up to 17 Mg ha^{-1} year in pastures well-established and managed. This indicates the potential of pastures in this region to input organic matter to the soil, being that this potential can increase when this system interplant with other cultures as noted in the SP systems.

Moreover, the secondary forest or native the amount of litter inputted by the soil can be higher than 10 Mg ha^{-1} year (Vital *et al.*, 2004), therefore the SF in the present study due to passing through a natural regeneration still has low litterfall (visually observed).

Contents of *SOC* at 10-20 cm depth in all studied situations showed similar behavior with contents ranging from 7.60 g Kg^{-1} to 6.90 g Kg^{-1}, no statistical difference was observed. In the depth of 20-30 cm the site of reference SF was the one with the lowest values of this attribute. Higher values of *SOC* found in the sites CN, SP and PT when compared to the reference site at a depth of 20-40 cm can be due to the plowing and harrowing in those sites were previously deploying of current culture in which incorporated organic matter found in the surface therefore increase the content of *C* in depth (Mendonça & Rowell, 1994).

Among the situations studied, the one that showed the greatest potential of *OC-stock* was the CN site in both surface and subsurface (Table 3). The lowest value of *OC-stock* was observed in the SF site, possibly due to the time of establishment of this area and management in which the soil was submitted previously to natural regeneration did not yet permit the increase of *OC-stock* in the soil.

The SP area showed results inferior to the CN site when evaluated the *OC-stock* (Table 3), therefore higher to the sites of PT and SF in the layer of 0-10 cm. In the layers 10-20 cm and 20-30 cm the SP and PT areas were statistically equal presenting values of *OC-stock* intermediate to the CN and SFsites.

The pastures sites may have presented a greater accumulation of *C* increase the *OC-stock* in the soil (Chan *et al.*, 2010). This factor is influenced by the type of management in which the pasture is submitted. When the under silvopastoral systems this stock can be similar to the forest areas (Neves *et al.*, 2004). In the present study the results shows the sites under PT and SP favored the stock higher than the SF.

Although the results of this present study have showed that the SP and PT sites favored the increase of *OC-stock* than the reference SF, studies found in the literature are often contradictory. Most of these studies show that the major input of organic matter provided by the roots, the soil with pasture areas present similar or higher contents to those found in the forest environments (Tarré *et al.*, 2001), while others showed values higher than the forest soils (Noordwijk *et al.*, 1997), provided by the largest global input of organic matter.

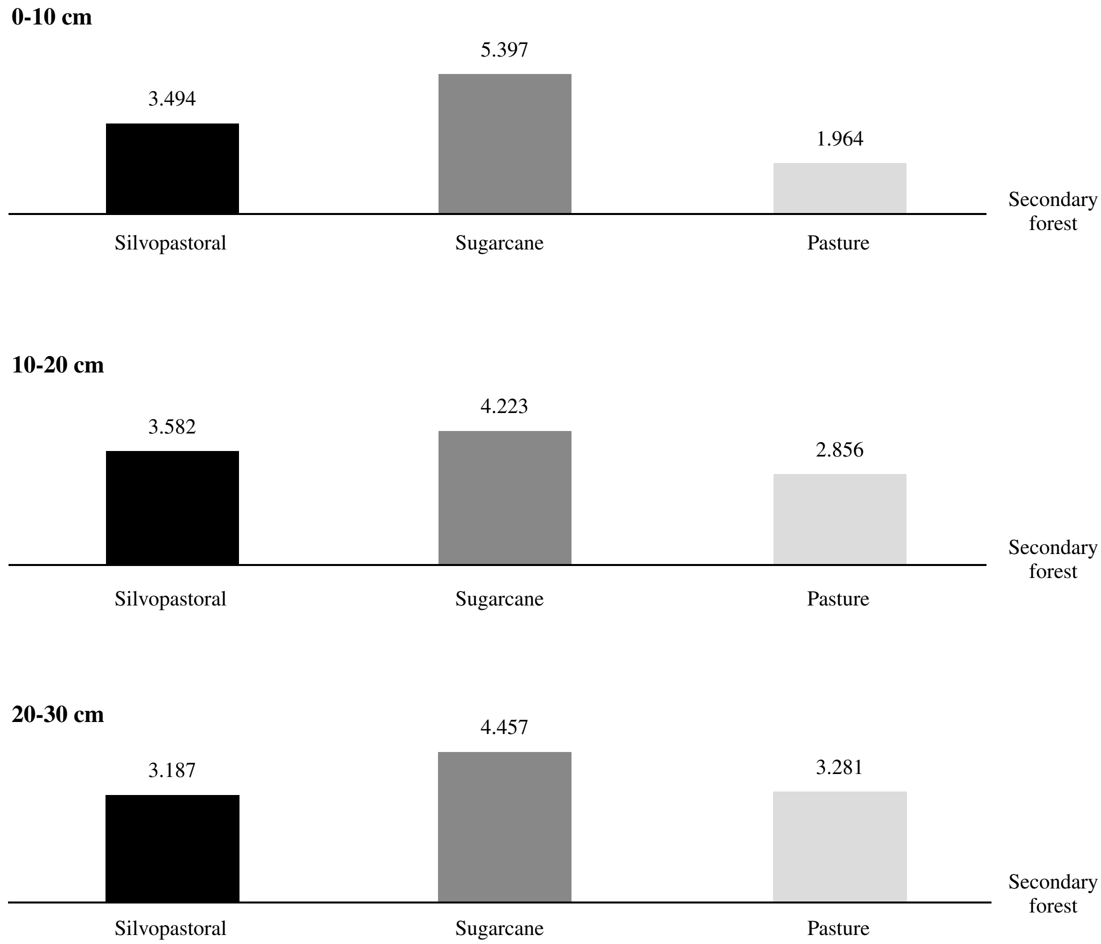

Figure 3. Soil organic carbon stock variation (OC-stock) Mg ha^{-1} of the studied situations compared with Secondary forest (SF).

When evaluated the variation of *OC-stock* in function to reference site of SF, all systems promote increments of *C* showing that the systems are efficient in increasing the *OC-stock* in soil and reducing the emissions of C-CO_2 (Figure 3). A special emphasis should be given to the CN sites in the depths of 0-10 cm, which promoted an increase of 5,397 Mg ha^{-1}, followed by SP (3,494 Mg ha^{-1}) and PT (1,964 Mg ha^{-1}).

These results allows to conclude that the management of fertilization and liming adopted and the no burning the sugarcane harvest has been effective in increasing the *OC-stock* of soil and that the SP systems in the surface layers (0-10 cm and 10-20 cm) are more efficient than continuous grazing system to raise the *OC-stock*.

Conclusions

1. The management of fertilization and harvesting of sugarcane (SC) in the region of *Governador Valadares*is efficient to increase the *OC-stock* of soil.
2. The silvopastoral(SP) systems in the surface layers (0-10 cm and 10-20 cm) are more efficient increasing the *OC-stock* of soil when compared to the continuous grazing system (PT).

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