

CARBON AND BIOMASS STOCKS IN A FRAGMENT OF CERRADÃO IN MINAS GERAIS STATE, BRAZIL

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ABSTRACT: This study aimed at quantifying carbon (C) and biomass stocks in shoot portion, leaf litter, roots and soil within a fragment of dense savanna 'cerradão', 158.5 ha in area, located in Minas Gerais state. Measures were quantified using dendrometric parameters obtained during the forest inventory and collection of leaf litter, root and soil samples. Furrows were dug in the soil each 100 cm long, 50 cm wide and 100 cm deep in order to collect root samples at depths of 0-30 cm, 30-50 cm and 50-100 cm, and soil samples from the layers 0-10 cm, 10-20 cm, 20-40 cm, 40-60 cm and 60-100 cm, as well as any leaf litter from the surrounding surface. Analyses were performed in the Organic Matter Study Laboratory (DCS/UFLA) to determine C contents in the above matrices, using an Elementar analyzer model Vario TOC Cube. Higher C contents and stocks and lower density were noted in topmost soil layers. In cerradão, shoot portion was found to be the matrix contributing the most to biomass production, followed by roots and leaf litter. Carbon stock in the fragment was 139.7 Mg ha⁻¹. Soil was the matrix contributing the most to stocked C (64.8%), followed by the shoot portion (26.3%), roots (5.2%) and leaf litter (3.7%).

Key words: Forest inventory, carbon sequestration, cerrado, biomass, leaf litter.

ESTOQUES DE CARBONO E BIOMASSA DE UM FRAGMENTO DE CERRADÃO EM MINAS GERAIS, BRASIL

RESUMO: Este trabalho foi desenvolvido para quantificar o estoque de carbono (C) e biomassa presente na parte aérea lenhosa, serrapilheira, raízes e solos, num fragmento de cerradão com 158,5 ha, em Minas Gerais. As quantificações foram realizadas por meio de medidas dendrométricas tomadas durante o inventário florestal e de coleta de amostras de serrapilheira, raízes e solo. No solo, foram perfuradas trincheiras de 100 cm de comprimento, 50 cm de largura e 100 cm de profundidade, onde foram coletadas as raízes, nas profundidades de 0 a 30, 30 a 50 e 50 a 100 cm, amostras de solo, nas camadas de 0 a 10, 10 a 20, 20 a 40, 40 a 60, e 60 a 100 cm, bem como toda serrapilheira da superfície da trincheira. As análises dos teores de C, nas matrizes mencionadas, foram realizadas no Laboratório de Estudo da Matéria Orgânica, DCS/UFLA, utilizando-se um analisador Elementar modelo Vario TOC Cube. Os maiores teores e estoques de C e a menor densidade são notados nas camadas superficiais de solo. No cerradão, a parte aérea arbórea é a matriz que mais contribui para a produção de biomassa, seguida pelas raízes e serrapilheira. O estoque de carbono no fragmento de cerradão foi de 139,7 Mg ha⁻¹; o solo é matriz que mais contribui para esse C armazenado (64,8%), seguido pela parte arbórea lenhosa (26,3%), raízes (5,2%) e serrapilheira (3,7%).

Palavras-chave: Inventário florestal, sequestro de carbono, cerrado, biomassa, serrapilheira.

1 INTRODUCTION

The cerrado biome occupies around 2 million Km² in area and is the second largest vegetation unit in Brazil (LIMA et al., 2009), accounting for an expressive fraction of the Earth's ecosystems (ADUAN et al., 2003). This highly representative vegetation of Brazil is found in 15 states, including the Federal District (MARIMON JUNIOR; HARIDASAN, 2005). In Minas Gerais alone,

the cerrado covers 12,290,460.0 ha, with variations that include *campo*, *campo rupestre*, *campo cerrado*, *cerrado*, *cerradão*, and *vereda* (CARVALHO, L. M. et al., 2008). Rufini et al. (2010) argue that in recent years, due to anthropic activities such as urban and agricultural expansion, infrastructure and mineral production, the rate of deforestation and destruction of the cerrado has been on the rise, to a point where about 80% of the biome has already been destroyed (REZENDE et al., 2006), with

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hardly any knowledge about carbon stocks in the soil-plant system or about most suitable methodologies to quantify the carbon stocked in this important Brazilian ecosystem.

Cerradão is a rare type of forest vegetation that once occupied only 1% of the cerrado areas of Brazil, known for being recurrent in dystrophic and mesotrophic soils and for having variable floristic composition according to local soil fertility (MARIMON JUNIOR; HARIDASAN, 2005). Tree and shrub species predominate in that floristic group, forming a dense, continuous canopy layer (CAMPOS et al., 2006; SOUZA et al., 2010), which implies greater biomass production and higher C storage than other cerrado ecotypes.

In forest ecosystems, it is in the soil that greater carbon stocks are found. Fernandes and Fernandes (2009), adapted from Jantalia et al. (2006), found 81.9 Mgha⁻¹ of C in cerrado soil in the 0-40 cm layer, and 24.18 Mgha⁻¹ of C in cerradão soil of the Pantanal, in the same layer (FERNANDES et al., 1999). Melo and Durigan (2006) obtained estimates of 50 Mgha⁻¹ for carbon stocked in the soil of native Brazilian cerrado. Scolforo et al. (2008a) studied five cerradão fragments in Minas Gerais and estimated values that range from 27.5 Mgha⁻¹ to 45.1 Mgha⁻¹ of C for the shoot portion of cerradão. Roots are main entry points of carbon in the soil. Paiva and Faria (2007) found 46.63 Mg ha⁻¹ of root biomass in the 0-2 m soil layer, and 22.38 Mg ha⁻¹ of C in the same layer, for a cerrado *sensu stricto* fragment located in the Federal District. As regards leaf litter, which is the compartment contributing the least to carbon stock, Aduan et al. (2003) studied different floristic communities of the cerrado and found carbon stocks, as adapted from Ottmar et al. (2001), of 0.10, 0.37, 0.97 and 0.97 Mgha⁻¹ of C for *campo limpo*, *campo sujo*, *cerrado sensu stricto* and *cerrado denso* respectively, noting that these areas had been subjected to forest burnings more than a year prior to data collection.

According to Aduan et al. (2003), knowledge of carbon cycles in the cerrado ecosystem is yet rudimentary, particularly its stock and flow patterns, on account of the shortage of timely, accurate estimates. These authors also point out that literature available on Brazilian cerrado is scarce and fragmented.

With the above in mind, this study aimed to quantify biomass and carbon stocks in shoot portion, leaf litter, roots and soil of a cerradão fragment located in Limeira do Oeste, Minas Gerais state.

2 MATERIAL AND METHODS

The study was performed in a cerradão fragment, 158.5 ha in size, located at central coordinate 19°31'65"S and 50°39'65"W (Figure 1), in the municipality of Limeira do Oeste, Minas Gerais. According to local climate zoning and based on Thornthwaite moisture index (TMI), the fragment falls into the B₂-humid class group, with a moisture index of 40% to 60%, an average temperature between 19°C and 20°C, and total accumulated precipitation in the range of 1,500 mm to 1,600 mm. Potential evapotranspiration is relatively low, with an annual water deficit in the agricultural soil of around 87 mm (CARVALHO, L. G. et al., 2008).

The predominant local soil is Latosol, characterized as being a deep, highly weathered soil, naturally with low fertility and typically with good physical properties (CURI et al., 2008).

A forest inventory was compiled for the fragment in February 2010, comprising 30 plots, each 1000 m² in area, to a total of 3 ha. Dendrometric variables being measured included total height and DBH (diameter 1.30m aboveground) of every plant having a DBH ≥ 5 cm. Inventory data were processed by software SISNAT (SCOLFORO et al., 2003), using the volume equation proposed by Scolforo et al. (2008b), for this floristic community, which derived an adjusted R² of 98.78%, a Syx of 0.13848 m³ and a Syx (%) of 26.07. The equation is given as follows:

$$Vol = \exp(-9.7003574958 + 2.3603328234 * \ln(DBH) + 0.5063592154 * \ln(Ht))$$

Where: DBH = diameter at breast height (1.30m aboveground) (cm), Ht = total height (m), Vol = volume outside bark (m³), exp = exponential, Ln = natural logarithm.

The carbon stock present in the shoot portion up to 3 cm was quantified as Mg ha⁻¹ using the equation proposed by Scolforo et al. (2008c). Model fitting provided the following measures of accuracy: an adjusted R² of 93.33% and a Syx of 51.33%.

$$C = \exp(-10.9925732677 + 2.2705953017 * \ln(Dbh) + 0.5646506234 * \ln(Ht))$$

Where: DBH, Ht, exp, Ln = as defined previously, C = carbon stock (Mg).

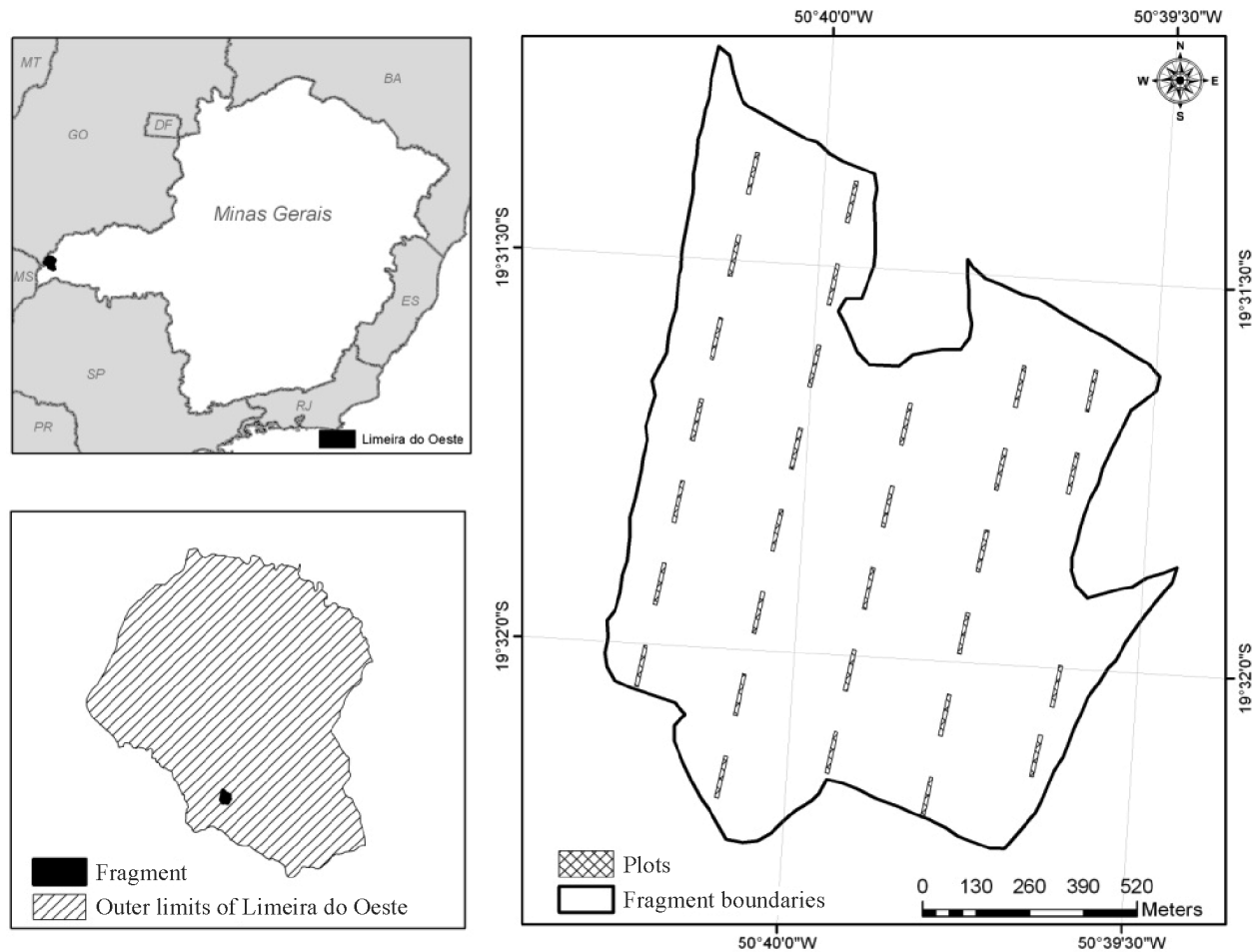


Figure 1 – Location map of the study site.

Figura 1 – Mapa de localização da área de estudo.

After distributing the plots and compiling the forest inventory, 30% of the plots were randomly selected in which were collected leaf litter, root and soil matrices for C determination. In each selected plot, positions were randomly selected with the relevant horizontal (width) and vertical (length) distance to leaf litter, root and soil sampling points. The sampling points were positioned somewhere within 0-10 m widthwise and 10-100 m lengthwise, obtaining two subplots per plot (Figure 2). Random selection of the lengthwise distance started from 10 m onward, as a regrowth study is taking place in the 0-10m interval.

The litter, root and soil samples were collected in March and April 2010. For litter sampling, a 0.5 m² (0.5 m x 1 m) template was used with which all existing material was collected. The same template was used for

root sampling, yet here a furrow 100 cm deep was dug. The root material was separated according to soil depth, namely the layers 0-30 cm, 30-50 cm and 50-100 cm, noting that root sorting also followed thickness classes, namely <5mm, 5.1-10 mm and >10 mm.

Both leaf litter and root samples were stored in paper bags, each labeled with fragment name and plot number. Bags with root samples were additionally labeled with soil depth and thickness class. The samples were washed and dried at 65-70°C in a forced-air oven to a constant weight, then weighed to determine dry biomass (g), crushed by a knife mill and then sieved (0.250 mm sieve). The analysis of root samples focused specifically on carbon stocks at different soil depths, rather than separating them by diameter class.

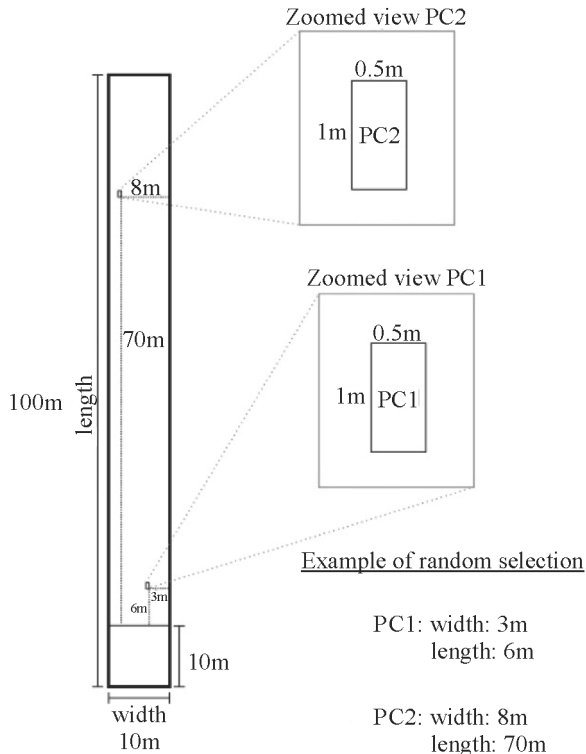


Figure 2 – Graphic illustration of the randomly selected sampling points.

Figura 2 – Esquema da parcela com os pontos amostrais sorteados.

The same procedure as above was adopted for soil sampling, only at different depths, namely the layers 0-10cm, 10-20cm, 20-40cm, 40-60cm, and 60-100cm. All material being sampled was stored in plastic bags labeled with plot number and sampling depth. The soil samples were macerated in a porcelain mortar using a pestle, then air-dried and sieved (0.250 mm sieve). The local soils are typically sandy (79.67% sand, 18.22% clay and 2.11% silt) and acidic, providing average values of pH in water of 4.89, 0.74 cmol/dm³ of Ca²⁺, 0.55 cmol/dm³ of Mg²⁺, 0.54 cmol/dm³ of Al³⁺, 61.03 mg/dm³ of Fe²⁺, 30.65 mg/dm³ of Mn²⁺, 0.37 mg/dm³ of Zn²⁺, 0.09 mg/dm³ of B, and base saturation of 26%.

During soil sampling for density determination, a volumetric metal ring 82.643741 cm³ in volume was used. Soil samples were collected from the same depths as established for analysis of carbon percentage, being dried at a 105°C and weighed. Density (cm³) was derived for each sampling depth based on sample weight and volume.

Because litter, root and soil were sampled from two sampling points, the option of choice was to form one composite sample per plot, yet observing depth and thickness in the case of root samples.

After being processed, the material was sent to the Organic Matter Study Laboratory of the Federal University of Lavras, for determination of the carbon percentage in each sample. Analyzes were performed using an Elemental analyzer, model Vario TOC Cube. In the carbon meter, 10-20 mg of soil sample was used, as well as 1.5-6 mg of leaf litter and root samples. The samples were placed in tin capsules and injected in a dry combustion chamber at 950°C. The evolved CO₂ gas from each sample was quantified in a NDIR infrared sensor, correlating the evolved carbon with the weight unit of the sample.

The organic carbon stock in the soil was quantified as mega gram per hectare (Mg ha⁻¹), for each layer sampled. In this calculation, the expression proposed by Veldkamp (1994) was used:

$$St C = (CO \times Sd \times t)$$

where: St C = organic carbon stock at a given depth (Mg ha⁻¹), CO = total organic carbon content at the depth sampled (%), Sd = soil density at the depth sampled (g/cm³), t = thickness of soil layer (cm).

The carbon stock present in leaf litter and in roots was quantified as Mg ha⁻¹ of C, as a function of dry biomass and C content of each sample. The biomass value was extrapolated to 1 ha and, subsequently, depending on the carbon content present, the C stock was derived. Descriptive statistics was adopted for data analysis, evaluating the following parameters: mean, standard deviation, coefficient of variation, maximum and minimum values.

3 RESULTS AND DISCUSSION

Data in Table 1 reveal that results are consistent with values found by Scolforo et al. (2008a) in a study comprising five cerradão fragments in Minas Gerais in assorted regrowth and density stages, which provided mean values of 1649.01 plants/ha, 17.58 m²/ha of basal area, 117.49 m³/ha of volume and 56.32 t/ha of dry matter.

The similar variability in carbon, volume and dry weight is due to the direct correlation of these variables in calculation of carbon.

Table 1 – Dendrometric data, including density, basal area, volume and dry weight for a forest fragment in Minas Gerais.

Tabela 1 – Informações dendrométricas de densidade, área basal, volume e peso de matéria seca de um fragmento florestal em Minas Gerais.

Statistics	Trees/ha	Basal area (m ² /ha)	Volume (m ³)	Dry weight (Mg/ha)
Mean	1006.33	15.42	127.22	70.49
Maximum	1620.00	23.70	256.50	144.50
Minimum	620.00	7.30	41.30	23.00
SD	229.43	3.78	51.82	29.07
CV (%)	22.80	24.51	40.73	41.24

SD = standard deviation; CV = coefficient of variation.

3.1 Carbon stock – Shoot portion

Carbon stocks were quantified separately in each of the four compartments, namely shoot portion, leaf litter, roots and soil. The shoot portion stocks 36.78 Mg ha⁻¹ of C on average, with a minimum C value of 16.42 Mg ha⁻¹, a maximum C value of 68.20 Mg ha⁻¹, standard deviation of 17.48 Mg ha⁻¹ and coefficient of variation of 47.52%. Scolforo et al. (2008a) studied five cerrado fragments in Minas Gerais and found estimated values ranging from 27.5 Mg ha⁻¹ to 45.1 Mg ha⁻¹ of C, with mean values of 35.08 Mg ha⁻¹ of C, very close to the findings in this study.

The coefficients of simple linear correlation between volume, dry weight and carbon stock were 0.9994, 0.99989 and 0.92173 respectively. This correlation is an evidence of the strong participation of these variables in estimation of carbon stock.

3.2 Carbon stock – Leaf litter

As for leaf litter, the mean dry biomass output was found to be 11.67 Mg ha⁻¹, with a mean carbon content of 45.94%. The product of C content and biomass is carbon stock, which in this matrix provided a mean stock of 5.36 Mg ha⁻¹ (Table 2).

Table 2 reveals a high coefficient of variation (91.79%) for carbon stock. However, variability in carbon content was low (2.93%). Variation in carbon stock is significantly affected by volume and dry weight. According to Scolforo et al. (2008c), carbon content in the shoot portion is in the range of 48%, close to values found in this study.

Table 2 – Descriptive statistics of biomass, carbon stock and carbon content in leaf litter of a forest fragment.

Tabela 2 – Estatísticas descritivas de biomassa, estoque e teor de carbono na serrapilheira de um fragmento florestal.

Statistics	Biomass (Mg/ha)	C content (%)	Carbon stock (Mg/ha)
Mean	11.67	45.94	5.36
Maximum	19.31	47.80	8.88
Minimum	4.86	43.80	2.28
Standard Deviation	4.00	1.35	4.92
CV (%)	34.27	2.93	91.79

CV= coefficient of variation.

3.3 Carbon stock – Roots

The analysis of biomass production in the soil layer 0-100cm revealed that roots had a mean dry biomass of 16.38 Mg ha⁻¹, with a mean carbon content of 44.76% and a stock of 7.30 Mg ha⁻¹, standard deviation of 2.25 MgC ha⁻¹, maximum value of 10.80 MgC ha⁻¹, minimum value of 4.44 MgC ha⁻¹ and coefficient of variation of 30.85%. The high coefficient of variation is due to each sample being formed by miscellaneous roots from various species. Paiva and Faria (2007) found a root biomass value of 46.63 Mg ha⁻¹ and a carbon stock of 22.38 Mg ha⁻¹, considering a soil depth up to 200 cm, in cerrado *stricto sensu* of the Federal District, yet their estimates were based on collections up to 30 cm deep and using a depth conversion factor, which potentially results in inaccuracies when calculating total stock.

In roots, a higher carbon stock was found in the topmost soil layer, 0-30 cm, followed by layers 30-50cm and 50-100cm, with C stock percentages of 59.73%, 23.01% and 17.27% respectively for the 0-100cm depth interval. According to Aduan et al. (2003), in cerrado, 80% of the root biomass occurs along the topmost 30 cm soil layer, which explains the greater amount of carbon being stocked in the surface layer than in subsequent layers. In studying soil of the Brazilian cerrado, Abdala et al. (1998) collected root samples up to 6.2 m deep and found a biomass stock of 33.4 Mg ha⁻¹, with 80% of residue being found in the 0-100 cm layer.

3.4 Carbon stock – Soil

Soil holds higher carbon stocks than other compartments of a floristic community (ADUAN et al., 2003; CUNHA et al., 2009; PAIVA; FARIA, 2007). In the fragment being studied, the mean carbon content found in

the soil in the 0-100cm depth interval was 4.21%, while the carbon stock was 90.46 Mg ha⁻¹. Paiva and Faria (2007) found estimated carbon stock values of 271.23 Mg ha⁻¹ in the 0-200 cm layer, for a fragment of cerrado *sensu stricto* in the Federal District, noting that these estimates were based on samples collected from up to 20 cm down. The same authors, as adapted from Castro (1996), found values close to 95 Mg ha⁻¹ of C in the 0-200 cm depth layer, for cerrado soils. These values are close to results found in this study.

When soil samples were analyzed as per layer separately, it was in the 0-10 cm layer that the highest carbon content was found (2.59%). The mean carbon stock in it was 21.92 Mgha⁻¹, accounting for around 24% of all carbon stocked in soil up to a depth of 100 cm down (Table 3). Paiva and Faria (2007) found higher carbon contents in the 20-40cm layer, for soils of cerrado *sensu stricto* in the Federal District. Comparatively, according to Lima (2004), carbon contents under native forest, pastureland and eucalyptus environments were higher in the topmost soil layer than in other layers. Higher carbon content in the topmost layer is partly due to higher concentration of

organic matter on the ground, to larger amounts of leaf litter being deposited on the ground, and to low solubility and mobility of residue and organic compounds deposited by the shoot portion into deeper layers of the cerrado soil. The fact that processes involving humus formation and organic matter adsorption are intenser in topmost layers than in deeper layers should also be taken into account (STEVENSON, 1994). However, some authors argue that depths holding greater carbon concentrations will vary according to each floristic community (LAL, 2007; MARCHIORI JÚNIOR; MELO, 1999; MELO; DURIGAN, 2006; NOVAES FILHO et al., 2007; ZHENG et al., 2007). According to them, this can be explained by variations in each floristic community as to root system distribution and by exudation of organic compounds along the profile of different soil layers.

Data in Tables 3 and 4 reveal that when the soil is subdivided into equally thick layers, 10 cm in this case, carbon content in the topmost soil layer is around 5 times higher than in the deepest soil layer. If compared to the second layer (10-20cm), carbon content in the topmost layer is more than twofold higher than in the next layer.

Table 3 – Carbon contents in the soil, for each plot and soil layer, and descriptive statistics of data.

Tabela 3 – Teores de carbono em solo para cada parcela e camada de solo, e estatística descritiva dos dados levantados.

Plots	Sampling depth					0 - 100 cm
	0 - 10 cm	10 - 20 cm	20 - 40 cm	40 - 60 cm	60 - 100 cm	
1	1.91	0.88	0.66	0.47	0.37	4.28
5	2.24	1.17	0.69	0.72	0.51	5.33
11	1.53	0.66	0.51	0.69	0.39	3.79
12	1.56	0.86	0.53	0.51	0.42	3.88
14	1.37	0.78	0.60	0.50	0.45	3.70
16	2.07	0.76	0.61	0.48	0.40	4.32
22	1.42	0.79	0.76	0.67	0.41	4.04
26	0.97	0.74	0.65	0.45	0.37	3.18
30	2.59	1.07	0.68	0.60	0.46	5.40
Mean	1.74	0.86	0.63	0.57	0.42	4.21
Maximum	2.59	1.17	0.76	0.72	0.51	5.40
Minimum	0.97	0.66	0.51	0.45	0.37	3.18
SD	0.50	0.17	0.08	0.10	0.05	0.74
CV (%)	3.45	5.18	8.06	5.39	9.29	5.72

SD: standard deviation; CV(%): coefficient of variation.

Table 4 – Soil density for each plot, and descriptive statistics of data.**Tabela 4** – Densidade do solo para cada parcela e estatística descritiva dos dados.

Plots	Sampling depth				
	0 - 10 cm	10 - 20 cm	20 - 40 cm	40 - 60 cm	60 - 100 cm
1	1.18	1.31	1.32	1.32	1.39
5	1.1	1.42	1.43	1.34	1.38
11	1.37	1.31	1.34	1.37	1.42
12	1.27	1.33	1.51	1.39	1.43
14	1.3	1.37	1.4	1.38	1.45
16	1.4	1.44	1.54	1.43	1.53
22	1.28	1.24	1.37	1.39	1.47
26	1.26	1.28	1.41	1.47	1.49
30	1.19	1.15	1.31	1.41	1.39
Mean	1.26	1.32	1.41	1.39	1.44
Maximum	1.4	1.44	1.54	1.47	1.53
Minimum	1.1	1.15	1.31	1.32	1.38
SD	0.09	0.09	0.08	0.05	0.05
CV (%)	13.68	14.7	17.27	30.7	27.71

SD: standard deviation; CV(%): coefficient of variation.

Since carbon stock is a function of density (Table 4), carbon content and layer thickness, the parameter soil density directly influences calculation of carbon stocks. One can thus infer that carbon stock up to a depth of 40 cm accounts for 56% of the total found in the 0-100cm depth interval. By increasing the layer by 20 cm, that is, up to a depth of 60 cm, the carbon stocked there will then account for around 73% of all carbon stocked in the 0-100cm depth interval.

In this study, soil was the compartment found to hold the highest carbon stock. In comparing total carbon stocks between soil, leaf litter and roots, soil accounted for 87.91% of all carbon stocked in the fragment. If considering soil and roots, soil accounted for 92.53% of all carbon present in these two matrices. Similarly to this result, Abdala et al. (1998) reported that soil is responsible for storing more than 90% of the carbon existing under leaf litter in cerrados.

The mean total carbon stock in the fragment is 139.69 Mg ha⁻¹, with soil being the main carbon sink, stocking 64.8% (90.26 MgC/ha), followed by shoot portion, with 26.3% (36.78 MgC/ha), then roots, with 5.2% (7.30 MgC/ha) and leaf litter, which stocks 3.7% (5.23 MgC/ha) of C in the cerradão fragment.

4 CONCLUSIONS

In this study, the shoot portion contributed the highest biomass stock, followed by roots and leaf litter.

The topmost soil layers had the highest C contents and the lowest density, which increased the deeper the soil profile.

The soil matrix held the highest C stock in the cerradão fragment, followed by shoot portion, roots and leaf litter.

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