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Estimation of carbon stock in the soil plant system of the main phytophysiognomies of the cerrado of west Bahia, Brazil

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Abstract
The work was carried out in the western region of Bahia in five phytophysiognomies of cerrado. The regional climate is of the Aw type with rainy summers and dry winters. The main soils are Red-Yellow Latosol, Quartzarenic Neosol and Dystrophic Haplic Gleysol with texture varying from sandy to sandy loam. Soil samples were taken up to 0.40 m to determine the soil carbon and for plant biomass models already established by other authors were chosen. The total soil carbon content followed the decreasing order: VRD>CRD>CSS>CCS>CCL. This may reflect the difference in density of plants in these phytophysiognomic compartments, although there is no significant difference between the soils under the phytophysiognomies of CCS and CCL. The soils under the five phytophysiognomies, on average, presented a carbon stock of 50.63 Mg ha-1. The studied phytophysiognomies in aboveground vegetation presented carbon stocks ranging from 0.05 to 23.36 Mg ha-1.This variation is explained by the plant diversity of each phytophysiognomy. Therefore, the accumulation of carbon depends on the richness and size of species of the area. In general, the upper soil layers stored greater amounts of carbon. Aboveground biomass and in roots stand out for higher carbon production in biomass, the phytophysiognomies of CRD and CSS.
Keywords: native forest; vegetal suppression; “cerradão”, soil.

Estimativa do estoque de carbono no sistema solo planta das principais fitofisionomias do cerrado do oeste da Bahia, Brasil

Resumo
O trabalho foi desenvolvido na região Oeste da Bahia em cinco fitofisionomias de cerrado. O clima regional é do tipo Aw, com verão chuvoso e invernos seco. Os principais solos são Latossolo Vermelho-Amarelo e Neossolo Quartzarênicos, com textura variando de arenosa a franco arenosa. As amostras de solo foram retiradas até 0,40 m, para determinar o carbono do solo, para a biomassa vegetal, foram escolhidos modelos já consagrados por outros autores. O teor carbono total do solo obedeceu a seguinte ordem decrescente: VRD>CRD>CSS>CCS>CCL, fato que pode refletir a diferença de adensamento de plantas nesses compartimentos fitofisionômicos, apesar da não haver diferença significativa entre os solos sob as fitofisionomias de CCS e CCL. Em média, os solos sob as cinco fitofisionomias apresentaram média de estoque de carbono de 50,63 Mg ha^{-1}. As fitofisionomias estudas, na vegetação acima do solo, apresentaram estoque de carbono variando 0,05 a 23,36 Mg ha^{-1}. Essa variação é explicada pela diversidade vegetal de cada fitofisionomia. Portanto, o acumulo de carbono depende da riqueza e porte das espécies da área. De modo geral, as camadas superficiais do solo armazenaram maiores quantidades de carbono. A biomassa acima do solo e nas raízes, destacam-se por maiores produção de carbono na biomassa, as fitofisionomias de CRD e CSS.
Palavras-chave: mata nativa; supressão vegetal; cerradão; solo.

Introduction

Natural forests are of great importance in preserving biodiversity and protecting soil and water. This protection may not occur due to factors such as the excessive use of natural resources, the expansion of the agricultural frontier and forestry, urban and industrial growth (PEIXOTO *et al.,* 2016).

The extreme west of Bahia, mainly in the geomorphological compartment of the Chapadões do Rio Grande, with sandy soils and predominantly savannah vegetation (cerrado), has become of great economic importance for Bahia in recent decades. This ecosystem occupies an area of approximately 9.1 million hectares of which 5.5 million are arable (FALEIRO, 2015). The Cerrado biome is strategic for Bahia because in addition to influencing climate and water variables due to its ecosystem services, this area becomes relevant for the conservation of biodiversity and the economic development of the State. Its phytophysiognomic variation presents characteristics from dense vegetation to fields with a predominance of herbaceous vegetation. Each of these phytophysiognomies has a very important role in the physical properties and in the soil carbon stock, acting according to Renner (2004) as a "sinkholes" of CO2.

Marinho Junior *et al.* (2020) evaluating the capacity to store carbon in Cerrado soils verified that different vegetation covers have different carbon storage capacities. The changes caused by soil exploration alter its capacity to store CO2 adsorbed by plants (SANTANA *et al.*, 2019). Therefore, the knowledge of the variation in amount of carbon stored in the soil and vegetation by phytophysiognomies can strategically guide the agricultural use of the soil.

Anthropogenic actions that contribute to the emission of CO2 into the atmosphere are changes in vegetation cover, more specifically deforestation and fires in which changes caused by forest fragmentation and reduction of native areas result in the loss of ecological functions, including the production of oxygen, storage and CO2 capture (DANTAS *et al.*, 2017).

This work aimed to determine the carbon stocks in the soil/plant system of the Cerrado biome since the importance of carbon for the environmental balance both in the soil and in the plants of the different phytophysiognomies of Cerrado of Western Bahia is known.

Material and Methods

Area location

The study was carried out in areas of five different phytophysiognomies of the Cerrado of Western Bahia, whose location with geographic coordinates and altitude are shown in Table 1.

Table 1. Coordinates of sampling points in the five studied physiognomies.

Phytophysiognomies	Coordinates and altitude
Cerradão (CRD)	12º 04’ 46”of south latitude, 46º 08’ 1.9” of west longitude of Greenwich at an altitude of 797 m
Cerrado *stricto senso* (CSS)	12 º 27’ 43.4’’of south latitude and 45 º 27’ 49.2 of west longitude of Greenwich at an altitude of 680 m.
Dirty Field (CCS)	12° 23’ 8.61’’ south latitude and 45° 22’ 29.13’’of west longitude of Greenwich at an altitude of 722 m.
Clean Field (CCL)	12° 24’ 7.54’’of south latitude and 45° 21’ 21.1’’ of West longitude of Greenwich at an altitude of 718 m.
Vereda(Pathway) (VRD)	12° 28’ 22.2 of south latitude and 44° 55’ 3.8’’ of west longitude of Greenwich at an altitude of 654 m.

Climate and soil

The regional climate according to Köppen's classification is of the Aw type characterized as Tropical Seasonal Dry Winter. The average annual temperature is approximately 24ºC, with a minimum of 18ºC and a maximum of 34ºC and the average annual rainfall varies from 700 mm to 1,400 mm and the months of November, December, January and March are the ones with the highest rainfall.

The region presents a flattened platform topography with altitudes between 700 and 900 m, flat to smooth wavy relief and predominant geological formation of sandstones from the Urucuia Formation (EMBRAPA, 1976). The soils of the studied phytophysiognomies were classified according to the Brazilian System of Soil Classification (EMBRAPA, 2018) as Dystrophic Red-Yellow Latosol (LVAd) (CRD), Ortic Quartzarenic Neosol (RQo) (CSS, CCS, CCL) Dystrophic Haplic Gleysol (GXbd) (VRD) with grain size and texture in Table 2.

Table 2. Granulometric analysis at depths from 0 to 40 cm in the study areas.

Depht	Density	Granulometry			Textural Class
		Sand	Silt	Clay	
(m)	Mg/m³	.....................g kg..................			
		CRD			
0,00 – 0,10	1,58	75,06	5,50	19,44	Sandy loam
0,10 – 0,20	1,48	73,55	7,74	18,71	Sandy loam
0,20 – 0,30	1,36	73,54	8,50	17,96	Sandy loam
0,30 – 0,40	1,46	75,18	9,77	15,05	Sandy loam
		CSS			
0,00 – 0,10	1,23	89,07	2,93	7,99	Sandy
0,10 – 0,20	1,24	82,91	9,60	8,48	Loam sand
0,20 – 0,30	1,28	86,64	7,88	6,31	Loam sand
0,30 – 0,40	1,32	86,64	4,12	9,25	Loam sand
		CCS			
0,00 – 0,10	1,49	83,11	3,86	13,04	Loam sand
0,10 – 0,20	1,51	84,00	3,06	12,94	Loam sand
0,20 – 0,30	1,57	83,41	2,99	13,59	Loam sand
0,30 – 0,40	1,56	82,32	2,46	15,22	Sandy loam
		CCL			
0,00 – 0,10	1,58	85,30	2,35	12,35	Loam sand
0,10 – 0,20	1,52	85,88	1,84	12,27	Loam sand
0,20 – 0,30	1,54	85,48	1,39	13,14	Loam sand
0,30 – 0,40	1,54	81,60	0,87	15,72	Sandy loam
		VRD			
0,00 – 0,10	0,87	58,56	22,16	38,52	Clay loam
0,10 – 0,20	1,09	56,70	1,85	34,00	Sandy clay loam
0,20 – 0,30	1,25	87,83	1,83	6,57	Sandy
0,30 – 0,40	1,31	91,03	0,87	6,34	Sandy

Soil sampling

Trenches were randomly opened at 4 points at depths of 0.00-0.10, 0.10-0.20, 0.20-0.30 and 0.30-0.40 m to determine the carbon stocks in the three compartments (soil, shoots and roots) in each area. The collections were carried out between the months of July 2016 to December 2017 and were carried out in duplicates in each layer, collecting those with an intact and deformed structure. Samples with undisturbed structure were collected with the aid of a volumetric ring with a Samples with undisturbed structure were collected with the aid of a volumetric ring with a diameter and height of 0.05 m and samples with a deformed structure were collected with the aid of a hoe. These were stored in properly identified plastic bags and taken to the Soil Physics and Chemistry Laboratory, both at the State University of Bahia-Campus IX for analysis.

Determination of the physical and chemical attributes of the soil

Physical attributes (soil granulometry and density (BD)) and total soil organic carbon (TOC) were investigated in all soils under different phytophysiognomies. The particle size was determined by the total dispersion pipette method using sodium hydroxide (NaOH) as a dispersing agent according to the methodology of (EMBRAPA, 2017). Soil density was determined by the volumetric ring method according to equation 1 (Embrapa, 2017).

$$BD = \frac{Ms}{V} \quad (1)$$

Where: (Ms) = dry soil mass at 105 ^{o}C and (V) = ring volume.

TOC determination was made by hot oxidation with potassium dichromate according to the methodology described by (EMBRAPA, 2017) and the carbon stock in each of the sampled layers was estimated from expression 2:

$$Stock\ C = \frac{TOCxBDxe}{10} \quad (2)$$

Where: (Stock C) is the carbon stock in Mg ha-1; (TOC) is the total organic carbon content in g kg-1; (BD) is the soil density of the studied horizon in kg dm-3 and (e) is the layer thickness in centimeters (CARDOSO *et al.*, 2010)

Estimation of plant biomass and above ground carbon

The understory and litter collection was carried out with the aid of a metallic frame of dimension 1 m² (1m x 1m) arranged in random places within the study area. After the demarcation of the grids, the material was fully collected, stored in plastic bags and sent to the laboratory.

The woody vegetation in each of the areas was sampled in plots of 10 x 10 m (100 m2) by the non-destructive method, where all woody individuals with a diameter greater than 10 cm were measured at circumference at breast height (CAP), approximately 1.30 m) and tree height (H) estimated with a graduated ruler in meters. The estimated vegetable mass was determined by the allometric equation proposed by Rezende *et al.* (2006), equation 3.

$$B= -0{,}49129 + 0{,}02912xDb^{2}\ xHt \quad (3)$$

Where: (B)=biomass (kg.ind-1), (Db)=base diameter (cm) and (Ht)=height (m).

The aboveground carbon stock was estimated by multiplying the values found in the biomass by the percentage determined by Vieira *et al.* (2009) in which they found the value of 0.4171 of carbon in plant biomass, therefore, the carbon stock (C stock) was determined by equation 4.

$$C\ Stock\ = B\ x\ 0{,}4171 \quad (4)$$

Estimation of biomass and carbon from roots

In a study in cerrado stricto sensu, Azevedo (2014) found that 62.62% of the dry plant mass are in the roots. Therefore, the root biomass (BR) was determined by the following expression 5.

$$BR = B\ x\ 0{,}6262 \quad (5)$$

Where: B is aboveground biomass

The carbon stock in belowground biomass (CR Stock) will be determined according to the results of Azevedo (2014), which is 40.45% of the dry plant mass, according to expression 6:

$$CR\ Stock = BR\ x\ 0{,}4045 \quad (6)$$

Statistic

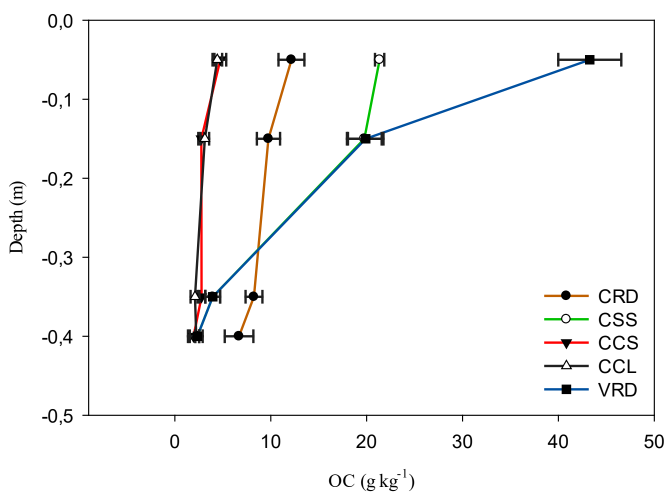
Soil carbon data were subjected to analysis of variance by the ASSISTAT 7.7 program and the means were compared by the Tukey test (p<0.05)

Results and discussion

Total organic carbon and soilless carbon stock

The total organic carbon content of the soils (TOC) under the different physiognomies of the cerrado (Figure1) showed a decrease in relation to depth. The higher concentration in the first layer (0-0.10 m) followed this order: VRD>CRD>CSS>CCS>CCL This fact may reflect the difference in density of plants in these phytophysiognomic compartments, although there is no significant difference between the soils under the CCS and CCL phytophysiognomies. These two phytophysiognomies have low carbon contents, as found by Fagundes *et al.* (2019), mainly CCS.

Figure 1. Soil carbon in the five phytophysiognomies studied in the Cerrado of Western Bahia.



The distribution of carbon in the soil that decreases with depth and the greater concentration in the most superficial layer also indicates the influence of the amount of litter deposited on the soil. This promotes a greater concentration of organic matter, together with the low mobility and solubility of the C deposited in the soil, making the surface part of the soils in all phytophysiognomies to have the highest TOC contents. Reinforcing this statement, Assis *et al.* (2015) say that the physical and chemical structure of the soil will be more complex the greater the quantity and diversity (quantity, quality and frequency of contribution) of the phytomass made available to the system.

Evaluating the surface layer between 0.00-0.10

When evaluating the surface layer between 0.00-0.10 m shown in Table 3, it is verified in this layer the largest contribution of carbon stock in all soils under the different phytophysiognomies. However, they showed significant differences between the soils. It is observed that the soil under VRD obtained the highest carbon stock value and was different from the others. The second largest carbon stock was CRD, which was also statistically superior to soils under CSS, CCS and CCL.

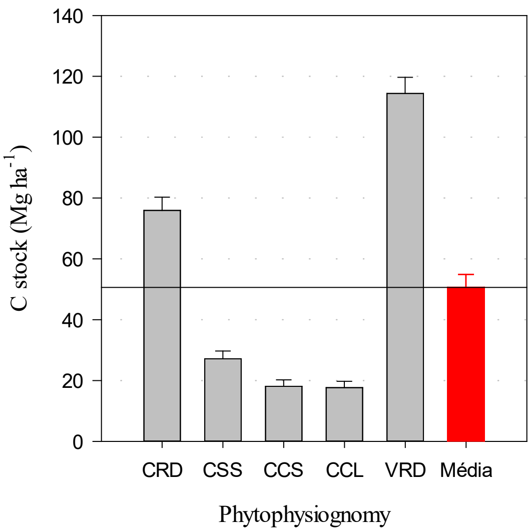
Table 3. Soil carbon stock values in the areas under cerradão, cerrado stricto sensu, dirty field and clean field by soil layer.

Physiognomie	Depht (m)			
	0,00 - 0,10	0,10 - 0,20	0,20 - 0,30	0,30 - 0,40
CRD	27,03 bA	20,39 bB	15,18 aC	13,33 aC
CSS	11,85 cA	5,74 cB	5,13 bB	4,40 bB
CCS	7,49 dA	4,08 cAB	3,69 bB	2,83 bB
CCL	6,99 dA	4,62 cAB	2,79 bB	3,25 bB
VRD	76,23 aA	29,46 aB	5,25 bC	3,42 bC

CV= 14.81% Lowercase letters indicate the means in the column and the uppercase letters in the lines. The means followed by the same letter do not differ statistically from each other by the Tukey test at 5% probability.

When analyzing the soil carbon stock under CRD, CSS, CCS and CCL, a gradual reduction of carbon stock in depth is observed, despite the significant differences in the first and second layer in soils under CRD and CSS. While the soil under VRD showed a decrease in carbon stock between the first and second layer by more than 60%, even with small clay variation. Between the second and third layers, the decrease in C stock was 82% and between the layers of 0.10-020 m and 0.30-0.40 m there was a decrease of 88% (Table 3. Figure 2 shows the results of the carbon stock up to a depth of 0.40 m. In this Figure, it is observed that the soils under the CRD and VRD Phytophysiognomies had the highest values and both were above the average, while the CSS, CCS and CCL reached the lowest carbon stocks in the soil and were below the average of the soils under the five phytophysiognomies. With an average of 50.63 Mg ha-1 in soils under the five phytophysiognomies, the cerrado of Western Bahia presented values above those reported by Giongo *et al.* (2011) and below the results of Costa *et al.* (2018).

Figure 2. Soil carbon stock in areas of cerradão, cerrado stricto sensu, dirty fiels, clean field and footpath in the 0.00 – 0.40 m layer.

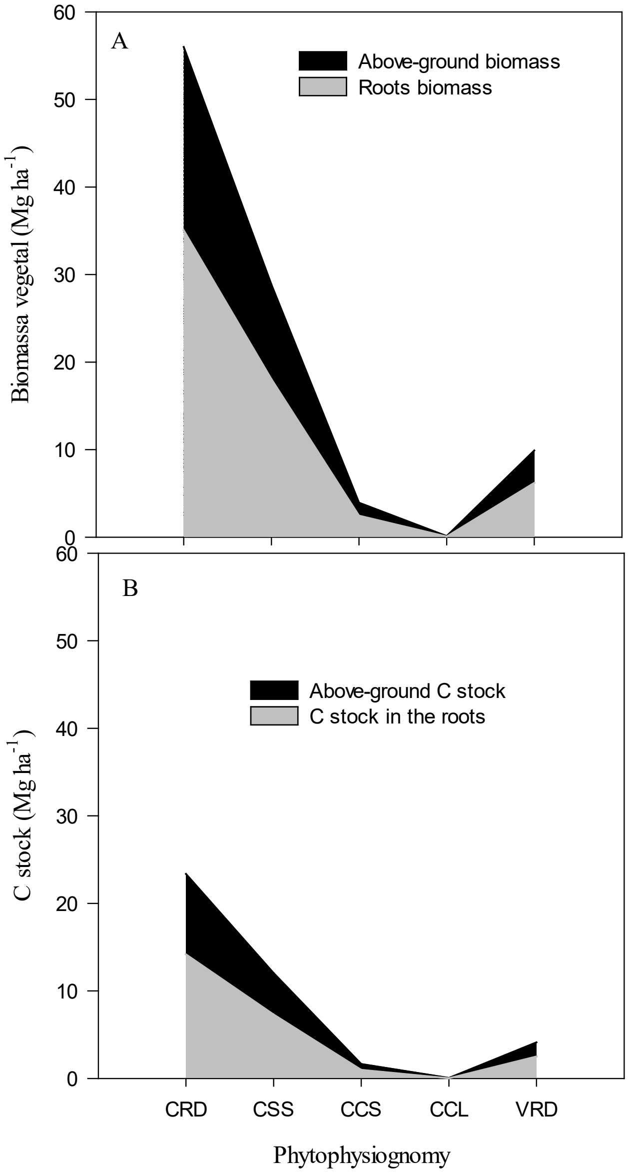


There are greater carbon stocks in soils under CRD and VRD because they have a more robust root system, greater amount of plant residues, greater plant biomass etc., especially for CRD. In addition, the soils that harbor these phytophysiognomies have higher clay content with a predominance of variable loads, which gives them lower rates of organic matter decomposition (BAYER *et al.*, 2011).

Carbon stock of the plant part (above and below the ground)

Figure 3 (A and B) shows the plant biomass and carbon stock above ground and in the roots of the CRD, CSS, CCS, CCL and VRD phytophysiognomies. Note that the highest aboveground plant biomass values were found in the CRD and CSS, with 56.00 and 28.84 Mg ha-1, respectively. While the other phytophysiognomies presented values below 10.00 Mg ha-1 (Figure 3A). Roquette (2018), in a review of Cerrado plant biomass found values between 23.67 and 61.21 Mg ha-1 for cerradão, for cerrado stricto sensu the variation was from 8.60 to 62.86 Mg ha-1. For cerrado dirty field, biomass production ranged from 8.45 to 11.40 Mg ha-1 and for cerrado clean field it found a biomass production of aboveground part of 5.5 Mg ha-1. Comparing the results of this work with the ranges found by the author above, it is verified that the CRD and CSS reached values within those ranges, while the CCS and CCL obtained plant mass production below the minimum range reported by him.

Figure 3. Plant biomass (A) and carbon stock (B), aboveground and in roots.



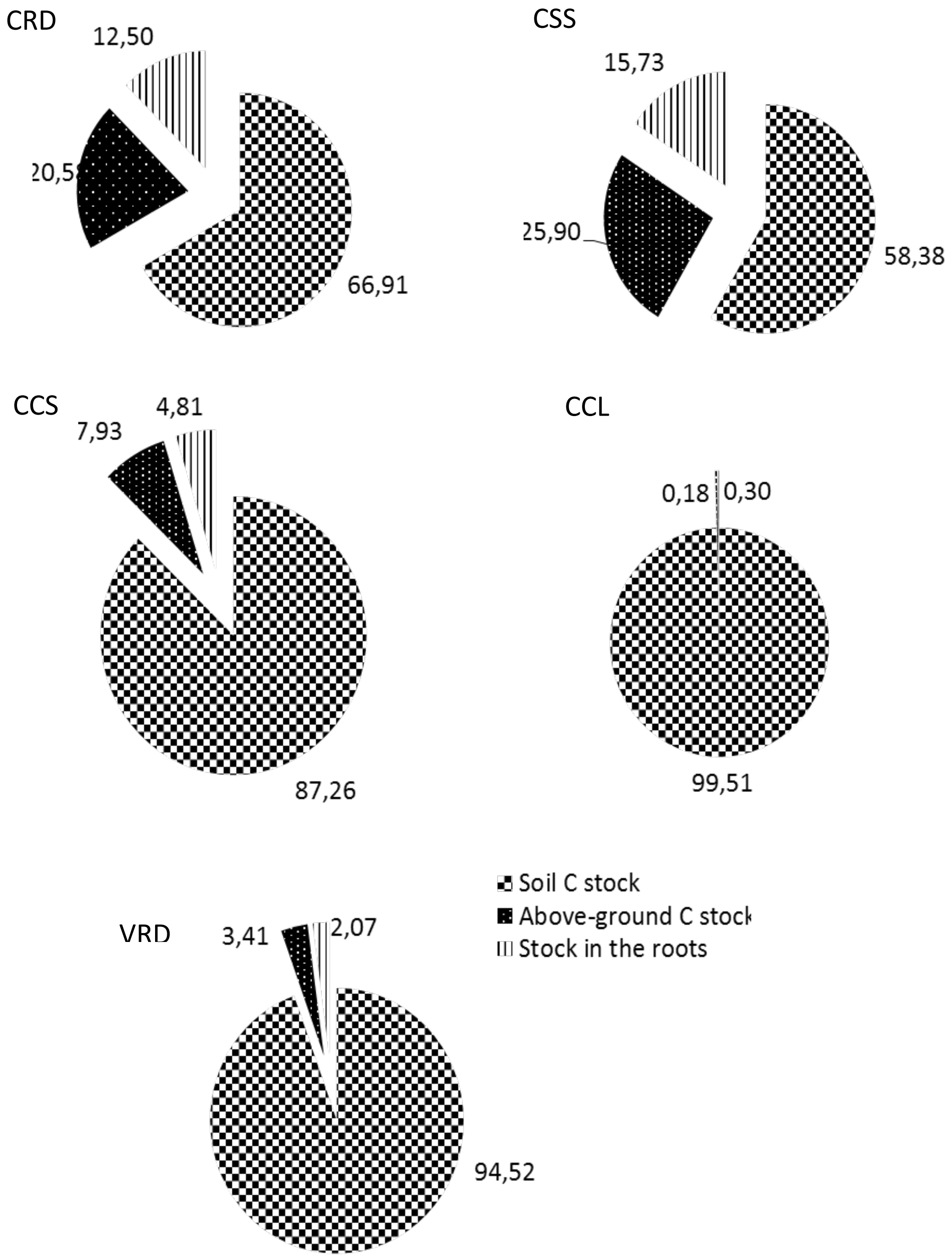
The Cerrado areas (CRD, CSS, CCS, CCL and VRD) showed carbon stock in the aboveground plant part, ranging from 0.05 to 23.36 Mg ha-1 in the phytophysiognomies from CCL to CRD, respectively. This variation is established by the plant diversity of each of the phytophysiognomies. The CCL has an area covered by grasses, while the cerradão is composed of trees, ranging from 8 to 15 m in height. Therefore, the carbon stock depends on the greater richness and size of species in the area (CAVANAUGH *et al.* 2014; SHIRIMA *et al.* 2015; SULLIVAN *et al.* 2017).

Cordeiro *et al.* (2018) found significant carbon gains in the cerrado of Minas Gerais over time, reaching approximately 33% from the first to the last measurement, which highlights the importance of this biome as a carbon sink, thus playing a key role in mitigating anthropogenic climate changes. This is corroborated by Pereira *et al.* (2020) who states that strategies that reduce human influence and stimulate the gain in biodiversity and tree growth, mainly protecting the survival of large individuals, are the best choices to maintain the regional carbon stock.

Soil, above ground and root carbon stock

The soil/plant system of the native cerrado of Bahia has the largest carbon stock in the soil compartment, with values ranging from 58.38 (CSS) to 99.51% (VRD) of the total carbon stored in the system, as can already be seen. Second, aboveground carbon appears as a percentage between 0.30 (CCL) and 25.90% (CSS) of the stock. The smallest reservoir is the root system, which reached values between 0.18 (CCL) and 15.73% (CSS) of the total (Figure 4). In absolute terms, for CSS, the value obtained in this study for the aboveground carbon stock (12.03 Mg ha-1) was higher than that found in typical cerrado in the same region (8.67 Mg ha-1) by Oliveira *et al.* (2019), which may have occurred due to the use of different equations.

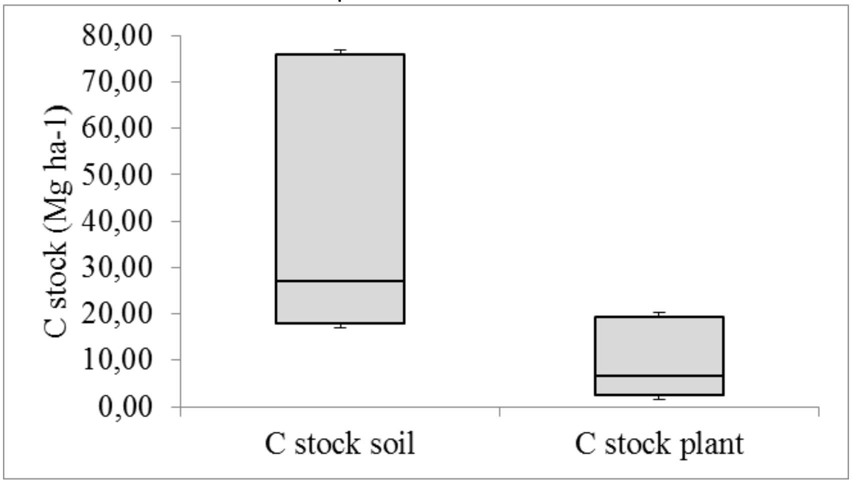
Figure 4. Carbon stock in the soil, above the ground and in plant roots (%) in areas with different Cerrado phytophysiognomies in Western Bahia.



Regarding the carbon stock in the roots, it is observed that CRD and CSS had the highest carbon volumes, with 14.18 and 7.31 Mg ha-1, respectively. In the other phytophysiognomies, the carbon stock ranged from 0.03 to 2.51 Mg ha-1. Values similar to these have already been found by Morais *et al.* (2017), which obtained a carbon stock in the roots of 0.11 Mg ha-1.

Soil and plant carbon stock content showed positive asymmetric distribution with 50% of the above values 27.12 Mg ha-1 for soil carbon stored and 6.64 Mg ha-1 for plant carbon stock (Figure 5). It is possible to observe that the soil carbon stock showed greater dispersion (interquartile range between 18.01 and 75.93 Mg ha-1), registered by the greater length of the box in relation to the plant carbon stock (interquartile range between 2.64 and 19.34 Mg ha-1).

Figure 5. Carbon stock distribution in soil and plant of Cerrado of Western Bahia.



The soil carbon stock was higher than that found in vegetation. The inputs of carbon into the soil through litter deposition and the loss in the form of CO2 from the respiration of living organisms promote a dynamic balance with greater carbon storage. On the other hand, the low density of trees in most cerrado phytophysiognomies also led to low carbon storage. Even so, this result was superior to that found by Rezende *et al.* (2006) and similar to the pattern of the study by Pereira *et al.* (2020).

Conclusion

1. The surface layer of the soil (0.00-0.10 m) stores more carbon than the subsurface layers and in the evaluated profile (0.00-0.40 m) the largest carbon stocks were with the soils under the phytophysiognomies of CRD and VRD;

. 2. In aboveground and root biomass, CRD and CSS phytophysiognomies store the greatest amount of carbon in relation to CCS, CCL and VRD.

3. The distribution of carbon stock in the soil showed 50% of the values above 27 Mg ha-1 and in the plant 6.64 Mg ha-1.

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