

Carbon stock of the herbaceous layer under diferente plant cover in fragments of Caatinga¹

Estoque de carbono do estrato herbáceo em coberturas vegetais em fragmentos de Caatinga

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ABSTRACT - Climate change and the extensive areas of dry tropical forests (DTF) used in the production of pasture determine the need to investigate alternative managements that would make it possible to increase carbon stock. As such, the aim of this research was to estimate the carbon stock in the herbaceous layer of two fragments of seasonally dry tropical forest: i) a fragment of dry tropical forest under 40 years of regeneration and ii) forest submitted to the thinning of trees with a diameter <10 cm. The research was carried out over nine years (2010-2018) in two micro basins inserted in a fragment of DTF in the district of Iguatu, Ceará. Herbaceous material was collected continuously every month in each micro basin, with 10 replications, giving a total of 2,160 samples (2 micro basins x 10 replications x 12 months x 9 years). The material was dried in an oven at 60 °C; the biomass content was then determined and later converted to carbon content. The carbon stock varied according to the rainfall in the region. The area under thinning recorded greater carbon stock for 80% of the months over the study period compared to the area under regeneration. It was found that the thinning management afforded the greatest amounts of carbon stock during both the rainy and the dry seasons, differing statistically from the area under regeneration ($\alpha=0.05$), and is one alternative for increasing the carbon stock of the herbaceous layer.

Keywords: Forest. Biomass. Thinning. Semi-arid region.

RESUMO - As mudanças climáticas e as extensas áreas com florestas tropicais secas (FTS) empregadas na produção de pastagem determinam a necessidade da investigação de manejos alternativos que possibilitem o aumento do estoque de carbono. Nesse sentido, objetivou-se com essa pesquisa estimar o estoque de carbono do estrato herbáceo em dois fragmentos de floresta tropical sazonalmente seca: i) fragmento de floresta tropical seca, com 40 anos de regeneração e o ii) floresta submetida ao raleamento das árvores com diâmetros < 10 cm. A pesquisa foi conduzida em duas microbacias inseridas em fragmento de FTS, no município de Iguatu Ceará durante nove anos (2010-2018). As coletas de material herbáceo foram realizadas mensalmente e ininterruptamente com 10 repetições em cada microbacias, totalizando 2160 amostras (2 microbacias x 10 repetições x 12 meses x 9 anos). O material foi secado em estufa a 60 °C e em seguida determinou-se o teor de biomassa, posteriormente converteu-se em teor de carbono. O estoque de carbono variou de acordo com a ocorrência de chuvas na região. A área submetida ao raleamento registrou maior estoque de carbono em 80% dos meses durante o período estudado, quando comparado com à área em regeneração. Observou-se que o manejo com raleamento proporcionou as maiores quantidades de estoque de carbono tanto na estação chuvosa, quanto na seca diferindo estatisticamente da área em regeneração ($\alpha =0,05$), sendo uma alternativa para aumentar o estoque de carbono oriundo do estrato vegetativo herbáceo.

Palavras-chave: Floresta. Biomassa. Raleamento. Semiárido.

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INTRODUCTION

Dry Tropical Forests (DTF) play an important role in the global carbon (C) cycle and represent more than 42% of tropical forests worldwide (ALLEN *et al.*, 2017). The focus of research into carbon stock has concentrated on moist tropical forests (BENNETT; PETERSON; GORDON, 2009; ERKTAN; MCCORMACK; ROUMET, 2018; THAKUR *et al.*, 2019) and on temperate forests (SOLLY *et al.*, 2018). However, the same cannot be said about dry tropical forests (ALLEN *et al.*, 2017), where there are few studies on C sequestration and stock (CAO *et al.*, 2019; CORONA-NUÑEZ; CAMPO; WILLIAMS, 2018). In dry forests, management for storing carbon and mitigating climate change has received significant international attention over the last decade (MATTSSON *et al.*, 2016; THAKUR *et al.*, 2019; ANDRADE *et al.*, 2020).

An approach that aims to quantify the biomass and carbon in tropical forests, including sustainable alternatives for land use, is of considerable importance (AQUINO *et al.*, 2017; PEREIRA JÚNIOR *et al.*, 2016), given the pressures placed on natural resources in the production of fibre and food. To use the vegetation as a carbon deposit, it is necessary to understand the climatic, structural and biological conditions that promote increases and/or decreases in the stored amounts of carbon (BENNETT; PETERSON; GORDON, 2009; SUN *et al.*, 2011).

Since the 17th century, occupation for use as pasture, and the practice of so-called nomadic or migratory agriculture, have brought an itinerant agriculture of deforestation and burning and the extraction of firewood to the caatinga, to meet the demand of the growing human population for food (PIMENTEL, 2016). Livestock in the region has followed a model of mixed exploitation, with the simultaneous predominance of cattle, goats and sheep. Even today, breeding regimes are mostly intensive, based on a practice of overgrazing, with caatinga vegetation being the main and, in many cases, the only source of food for the herds (ARAÚJO FILHO, 2013).

Knowing that the Caatinga stands out for having a high level of forage plant species in its herbaceous, shrub and tree layers (ARAÚJO FILHO, 2013), several alternatives for sustainable management of the Caatinga have been proposed, among them, thinning. This management is suggested by researchers as an alternative for conserving the natural resources of semi-arid ecosystems (AQUINO *et al.*, 2017; ARAÚJO FILHO, 2013). The technique consists in the selective control of woody species, by which some tree and shrub species are removed from the vegetation, leaving space for the development of undergrowth, such as small herbaceous plants (PIMENTEL, 2016; SAVADOGO *et al.*, 2008).

In areas covered by herbaceous species, the desiccating effect on the seeds and seedlings of woody species is mitigated, since the herbaceous plants act to maintain the temperature and humidity of the soil (RIBEIRO FILHO *et al.*, 2016). Based on the gradual deposition of herbaceous biomass on the ground (AMORIM *et al.*, 2014; ASAYE; ZEWDIE, 2013), the question is whether an increase in the herbaceous layer can contribute to mitigate climate change in dry tropical forests. As such, the aim of this work was to estimate the potential carbon stock of the herbaceous layer in a fragment of caatinga submitted to two types of management: CT₅ (Caatinga submitted to thinning for 5 years) and CR₄₀ (Caatinga under regeneration for 40 years).

MATERIAL AND METHODS

The study area comprises two experimental micro basins, located in the sub-basin of the Upper Jaguaribe, an experimental area of the campus of the Federal Institute of Education, Science and Technology of Ceará (IFCE), in Iguatu, Ceará, Brazil (Figure 1).

The two micro basins are adjacent, but under different vegetation management (Figure 2): CT₅ (Caatinga submitted to thinning for 5 years) and CR₄₀ (Caatinga under regeneration for 40 years), with an area of 1.15 and 2.06 ha respectively.

According to the Köppen classification, the climate of the region is type BSh' (hot semi-arid), with the mean monthly temperature during the coldest month always greater than 18 °C (INSTITUTO NACIONAL DE METEOROLOGIA, 2018). To better understand the rainfall regime in the study area, the historical series of the district of Iguatu from 1974 to 2017 was analysed. The mean annual rainfall is 997 ± 306 mm yr⁻¹ with a potential evapotranspiration of 2,113 mm yr⁻¹, based on the Penman-Monteith/FAO 56 method (FUNDAÇÃO CEARENSE DE METEOROLOGIA E RECURSOS HÍDRICOS, 2018). The Aridity Index developed by Thornthwaite is 0.47 and is classified as semi-arid. The rainfall in the district of Iguatu has a unimodal distribution, with a high concentration during March and April (Figure 3).

Based on the annual historical series of total rainfall, the Humidity Index (I_H) proposed by Navarro Hevia (2002) for the period under study (2010-2018) was applied, comprising five classes (Table 1).

In calculating the above index, the data for total annual rainfall must be sorted before the Humidity Index (I_H) can be determined for each year, using Equation 1:

$$I_U = \frac{P}{\bar{P}} \quad \text{Equation (1)}$$

where: P - annual precipitation (mm) and \bar{P} - mean annual precipitation of the historical series (mm)

The history of land use and occupation shows that before 1980 the areas of both experimental micro basins were used for the cultivation of subsistence species, especially maize (*Zea mays* L.) and cotton (*Gossypium* L.),

and have been maintained in various stages of regeneration and succession since that time (AQUINO *et al.*, 2017). CT_5 was submitted to thinning in December 2008, 2010 and 2012. During thinning, plants with a circumference equal to or greater than 10 cm at breast height, and herbaceous-sized individuals, were preserved, and organic residue from the thinning was kept in place. However, it is important to note that throughout the experiment there was no grazing in any of the experimental plots.

Figure 1 - Location of the experimental area

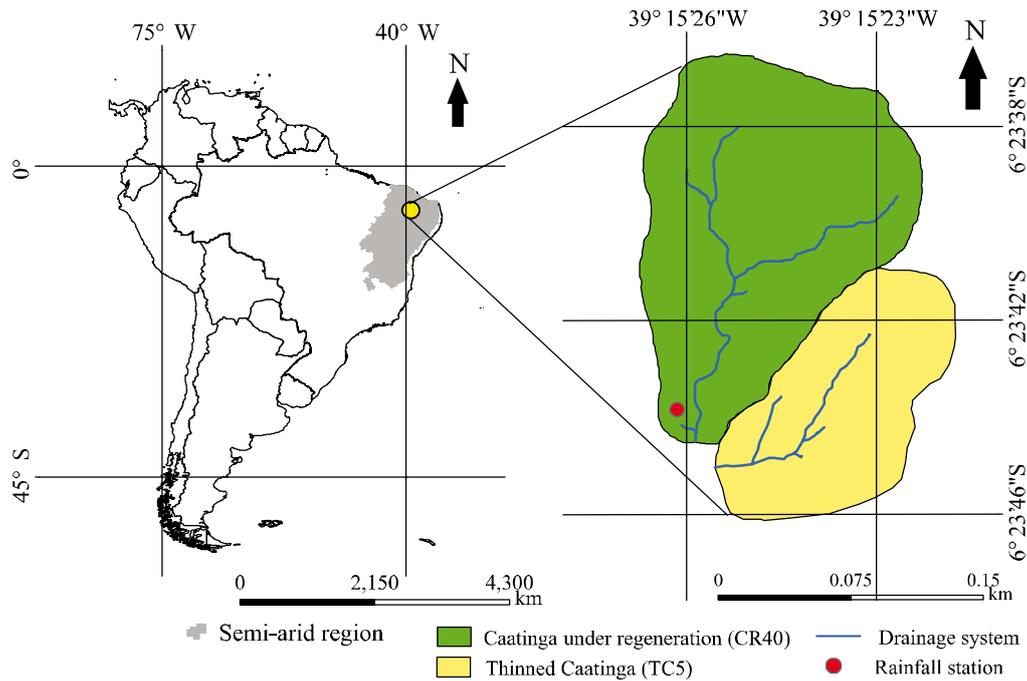
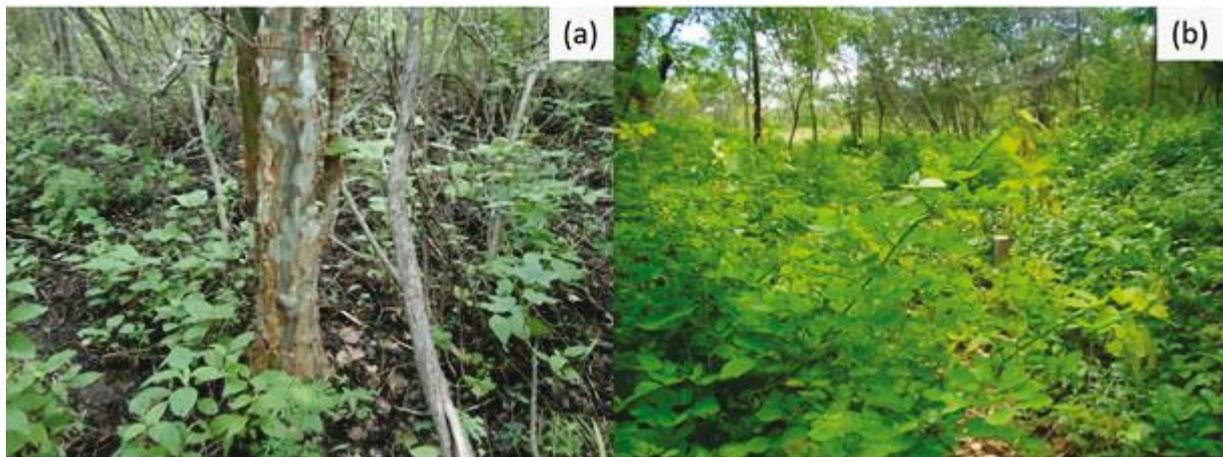


Figure 2 - Plant cover of the micro basins: (a) caatinga under regeneration; (b) thinned caatinga



Source: Collection of the Group for Research on Water and Soil Management in the Semi-arid Region (MASSA)

Figure 3 - Mean monthly rainfall and potential evapotranspiration from 1974 to 2017

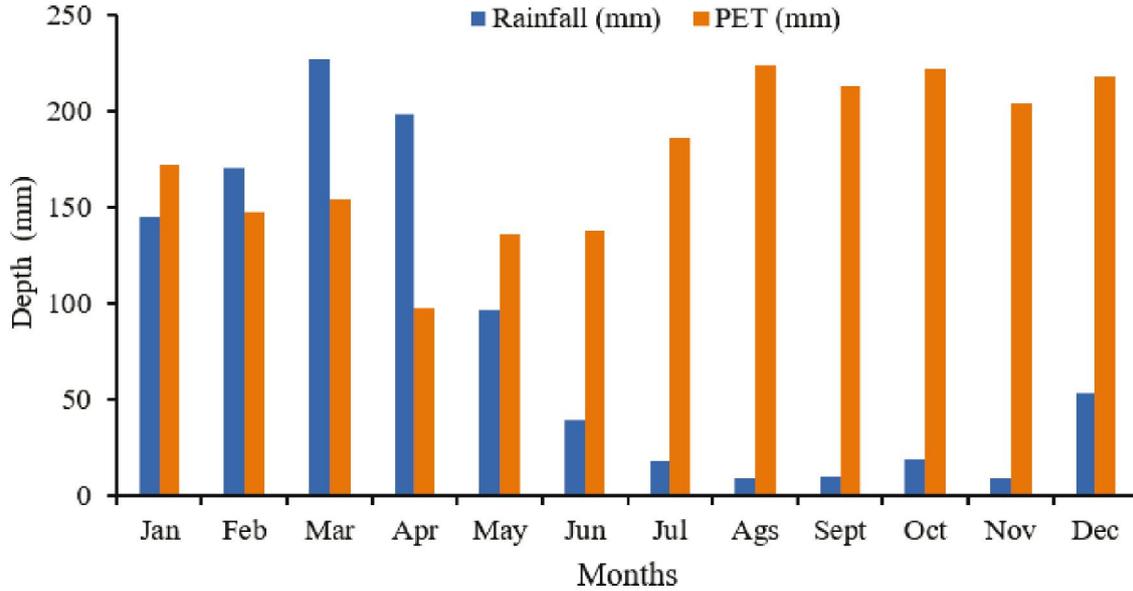


Table 1 - Classes of the Humidity Index (I_H) proposed by Navarro Hevia (2002)

Year classification	IH	Years under study by class
Very wet	$I_H > 1.3$	2011
Wet	$1.1 < I_H \leq 1.3$	
Normal	$0.9 < I_H < 1.1$	2010 and 2012
Dry	$0.7 \leq I_H < 0.9$	2013, 2014 and 2018
Very dry	$I_H < 0.7$	2015, 2016 and 2017

To quantify the production of herbaceous biomass in the micro basins, 20 samples (10 in each micro-basin) were collected monthly from January 2010 to December 2018, giving a total of 2,160 samples (2 areas x 10 replications x 12 months x 9 years). For this, a metallic template with a surface area of 1 m² was thrown at random and all the herbaceous material inside was collected. The material collected in each plot was weighed while still fresh; this was chopped to make the material more uniform and a sub-sample of approximately 500 g was then removed, as per the methodology proposed by Silva and Queiroz (2002). From these sub-samples, the moisture and dry matter were determined using equations 2 and 3. The material was identified, weighed and later placed in a forced air circulation oven at temperatures of around 60 °C (± 5 °C) to constant weight, and the dry weight quantified.

$$H(\%) = \left(\frac{W_{hs} - W_{ds}}{W_{hs}} \right) * 100 \tag{2}$$

$$DM = W_{hs} - \left[\frac{(W_{hs} * H(\%)_{total})}{100} \right] \tag{3}$$

where: W_{hs} - wet weight of the sample (g); W_{ds} - dry weight of the sample in the oven (g); $H\%$ - percentage humidity of each sample; DM - amount of dry matter of the samples (g).

The monthly stock of herbaceous biomass was estimated by multiplying the mean amount of herbaceous biomass found in 1 m² by the total area (10,000 m²). To estimate the carbon in the herbaceous layer, a factor of 0.38 was used, as determined by Pereira Junior *et al.* (2016), for structures in the shrub and tree layer of the area under study. As such, the carbon was calculated by multiplying the total herbaceous biomass by a factor of 0.38.

To assess the normality of the carbon-stock data, the Shapiro-Wilk test was used at a significance of 5%. The multivariate statistical technique of Hierarchical Cluster Analysis (HCA) was used to identify similar groups of the mean annual carbon stock. The algorithm employed was *cyti-block*, and Ward 's method was used for linkage. To define the separation of the groups formed in the dendrogram, the distances between the linkage plots

for the years under analysis that correspond to a rescaled distance of 3.39 were noted. Since the data showed no normality, the mean values were compared by means of the Kruskal-Wallis non-parametric test, for α equal to 5%, using the SPSS 16.0 software.

RESULT AND DISCUSSION

The levels of carbon stored in CT₅ were higher for 80% of the months under study, with a mean value for the analysed period of 0.55 Mg ha⁻¹, while in CR₄₀ the stock was 0.38 Mg ha⁻¹ (Figure 4), differing statistically by the Kruskal-Wallis test with α equal to 5%.

This result expresses the effect of a change in shading on dry matter production in the herbaceous layer, and consequently on the carbon stock. It is known that thinning provides more available light, thereby promoting a denser herbaceous layer (OLIVEIRA *et al.*, 2018). Riginos *et al.* (2009), studying the Kenyan savannah, registered greater development of herbaceous species where the tree vegetation was less dense, and negative results for herbaceous plants in an area with more shading.

It should also be noted that as of October 2012 (Figure 4), two years after the second thinning was carried out, the carbon-stock thresholds for the areas of CT₅ and CR₄₀ started to converge, demonstrating the regeneration of tree vegetation in the thinned area. This was also seen by Cademus *et al.* (2014), who found that carbon stock decreased as the age and the area shaded by the recovery of the shrub and tree vegetation increased. Researchers such as Sterck *et al.* (2011), and Allen *et al.* (2017), found that in tropical forests during years of low rainfall (<800 mm

year), native species reduce their rate of growth during the dry period, adapting to the drought.

Analysing the mean annual C stock for the CT₅ and CR₄₀ micro basins (Figure 5), it can be seen that there was a statistical difference by the Kruskal-Wallis test, for α equal to 5%, between the managements in 2010, 2011 and 2012, years identified by the humidity index (Table 1) as normal (2010 and 2012) and very wet (2011).

Biological and ecological processes above and below ground in dry forests are influenced by the availability of water (ALLEN *et al.*, 2017), where the effects of any increase in the variability, season or duration of the rainfall can alter these processes in different ways, reducing the carbon stock in the herbaceous layer.

The seasonal analysis confirms what is seen in the annual analysis, i.e. for both the rainy and dry seasons there is a statistical difference at a level of 5% significance by t-test, for 2010, 2011 and 2012 only (Figure 5). It can also be seen that the carbon-stock thresholds for the dry season (July to December), are closer, which is attributed to the variable population dynamics, a result of the climate and a short life cycle (PEREIRA JÚNIOR *et al.*, 2016).

The mean carbon stock for the rainy season in the CT₅ micro basin was 0.59 Mg ha⁻¹, while in CR₄₀ it was 0.39 Mg ha⁻¹ (34% lower). The mean value for carbon stock in CR₄₀ during the rainy season was lower than that recorded in CT₅ during the dry season, where the mean carbon stock was 0.51 Mg ha⁻¹. During the dry season, CR₄₀ presented a mean of 0.34 Mg ha⁻¹. The thinning management affords a greater increase in soil moisture (ANDRADE *et al.*, 2020), causing the herbaceous stratum to produce more biomass, consequently stocking more carbon during the different seasons (RIBEIRO

Figure 4 - Carbon stock in the herbaceous layer for the CT₅ and CR₄₀ managements in the caatinga biome with rainfall recorded from 2010 to 2018

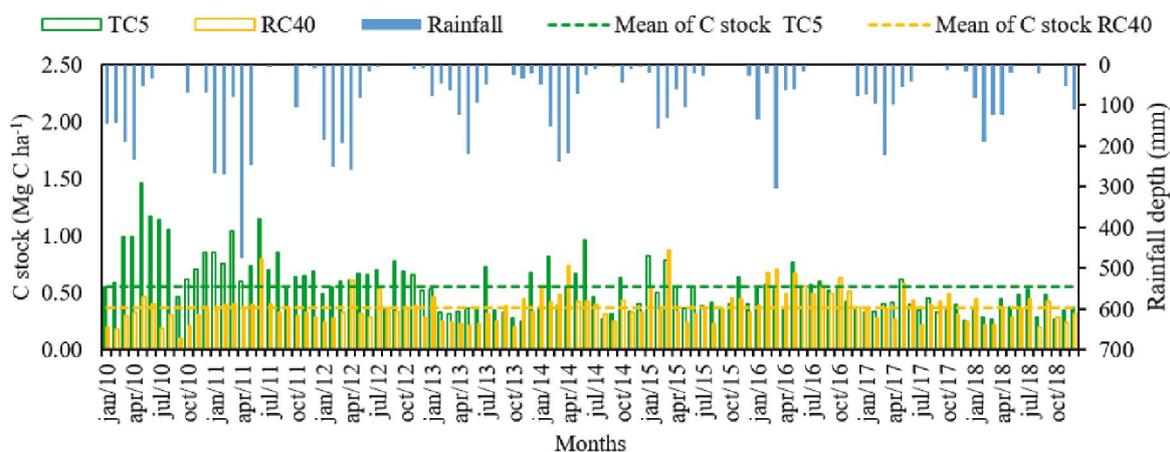
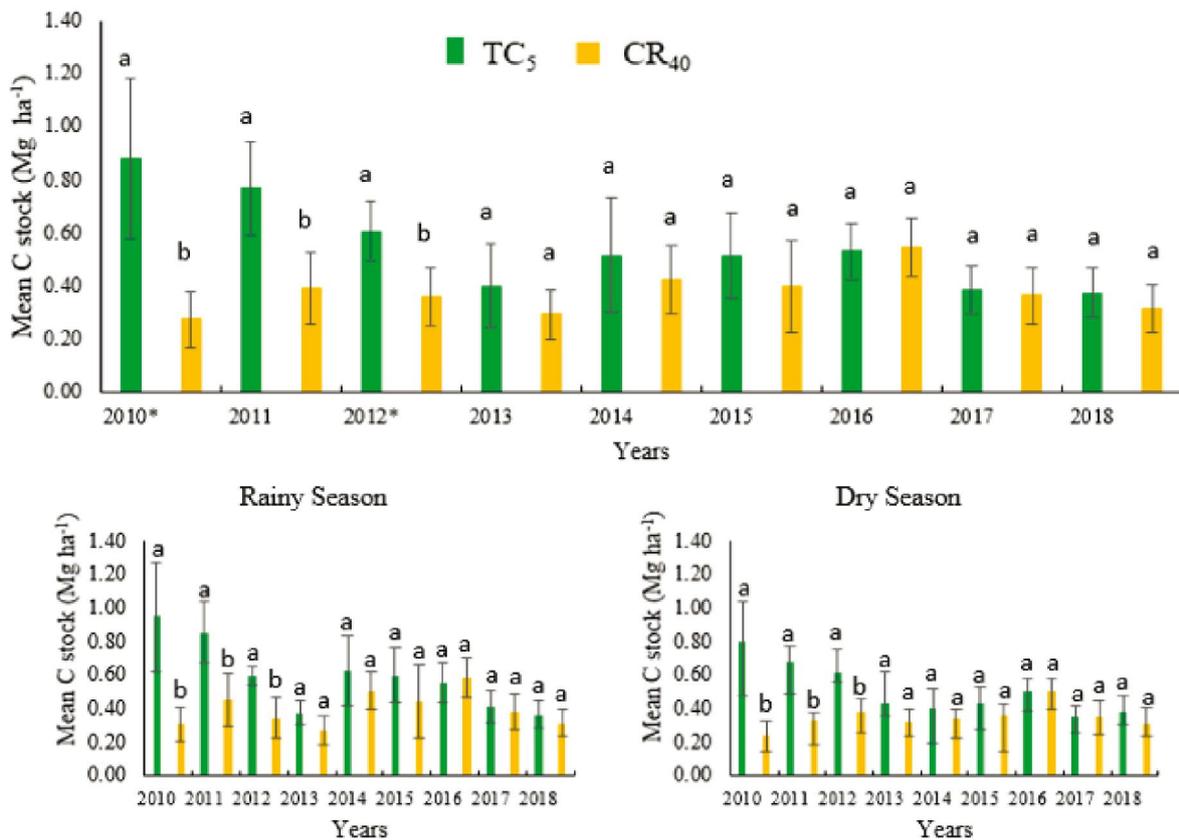


Figure 5 - Mean carbon stock of the herbaceous layer for an area of thinned caatinga and an area of caatinga under annual regeneration for the rainy and dry seasons from 2010 to 2018



*Years when thinning occurred; **Vertical lines represent the standard deviation of the mean. The same letters within each year do not differ statistically by the Kruskal-Wallis test for α equal to 5%

FILHO *et al.*, 2016). When the dry and rainy seasons are compared, a slower growth response can be seen in trees that remain after extremely dry years (CAMPO, 2016), giving similar mean values for the same management at different times of the year.

In order to evaluate the mean annual data for carbon stocks in the two micro-basins, the hierarchical clustering technique was used, in which it is possible to see the formation of 3 groups (Figure 6).

Group 1 is represented by the carbon stocked in the herbaceous layer of CT₅ relative to 2010 and 2011, the period during which the herbaceous layer responded to the thinning carried out in the previous years (2008 and 2010), in addition to the influence of the rainfall during 2011, the only year classified as very wet (Table 1) and with rainfall concentrated during the first four months of the year (Figure 4), which afforded an increase in vegetation with a short phenological cycle, and in species with a root system composed of fine roots (AQUINO *et al.*, 2017). Studies that included DTF thinning saw the formation of an understory that favoured the growth of an herbaceous

layer from seeds deposited in a seed bank, increasing the rise in carbon stock (RIBEIRO FILHO *et al.*, 2016).

Group 2 is formed by the years 2012, 2014 and 2015 for CT₅, and 2016 for both managements. Group 3 includes 2010, 2011, 2012, 2013, 2014, 2015, 2017 and 2018 for the CR₄₀ management, and 2013, 2017 and 2018 for the CT₅ management. When specifically analysing the thinning management for the separation between groups 2 and 3, it is found that such behaviour is related to the smaller carbon stocks (Figure 5). It should be noted that the carbon stock for the last two years of the study is part of group 3 under both managements, which is attributed to the low rainfall depths recorded during the period and to the regeneration of the vegetation, since the last year in which thinning was carried out was 2012.

Once the groups had been defined by HCA, the median was compared and a statistical difference was found between group 1 and the other groups for monthly carbon stock; however groups 2 and 3 did not differ statistically (Figure 7), demonstrating that the management of tree species favours the herbaceous layer during the early stages

Figure 6 - Variability in monthly carbon stock between the groups defined by HCA for the different managements from 2010 to 2018

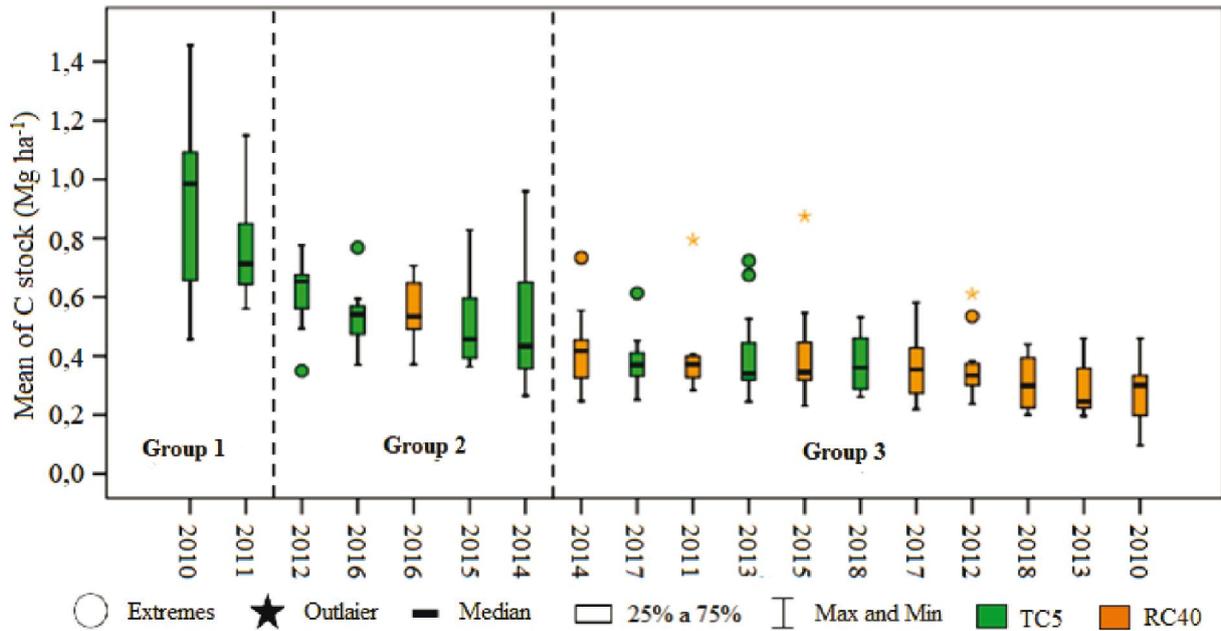
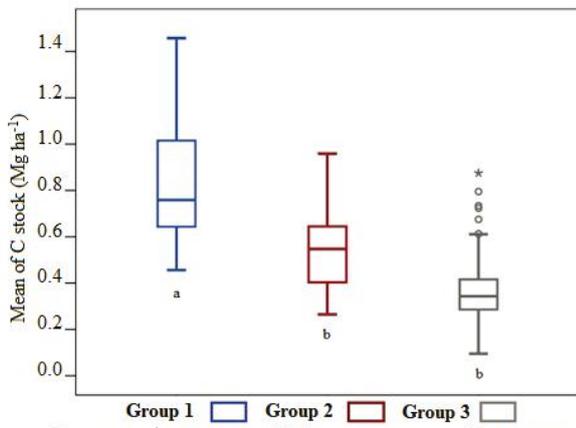


Figure 7 - Distribution of monthly carbon stocks in the groups formed by HCA



*boxplots followed by the same lowercase letter do not differ at 1% significance by the Kruskal-Wallis test

of succession, and is a determining factor in the floristic composition of the herbaceous plant community in dry forests (AMORIN *et al.*, 2014; MATTSSON *et al.*, 2016).

CONCLUSION

The technique of thinning (elimination of individuals with DBH<10 cm) applied to a dry tropical

forest - caatinga, can be an alternative for increasing the carbon stock in the herbaceous layer, since this management results in greater production of herbaceous biomass. Whether in the dry season or in the rainy season, the carbon stock was significantly greater in the thinned area. The significant effect of thinning on the carbon stock in the herbaceous layer occurred during the first three years (2010, 2011 and 2012) following application of the technique. After this period, the annual carbon stock began to stabilise. Two years without thinning proves to be the amount of time necessary for shading by the tree and shrub layer to compromise biomass production in the thinned area.

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