Land-Use Effect on Soil Carbon and Nitrogen Stock in a Seasonally Dry Tropical Forest

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Abstract: Total organic carbon (TOC) and total nitrogen (TN) concentration in the soil are an indicator of soil degradation. To understand how land-use may impact these concentrations in seasonally dry tropical forests (SDTF), we analyzed the effect of four land-uses on TOC stocks (STK.TOC) and TN stocks (STK.TN) in a semi-arid region of Brazil. Soil samples were collected in 12 trenches (three sites × four land-uses—dense caatinga (DC), open caatinga (OC), pasture (PA) and agriculture (AG)), in the 0–10; 10–20 and 20–30 cm layers or as far as the bedrock. The data were compared by the Kruskal–Wallis test ($p \leq 0.05$) and similarity investigated by cluster analysis. STK.TOC and STK.TN the surface layer (0–10 cm) showed no significant difference ($p \leq 0.05$) between the DC, OC and PA land-uses. The similarity in STK.TOC and STK.TN values between DC, OC and PA, indicate that it is possible to explore SDTF to produce biomass and protein by adopting open caatinga and pasture land uses on Neosols with very low TOC stocks. The greatest reduction in STK.TOC and STK.TN in the agriculture land-use may lead to soil degradation and contribute to the addition of CO$_2$ to the atmosphere.

Keywords: land use; soil organic carbon; caatinga; semi-arid; carbon stock

1. Introduction

Nowadays, humanity faces the great challenge of supplying the demand for food and fibre production and reduce added greenhouse gases (CO$_2$, CH$_4$, and N$_2$O) to the atmosphere [1,2]. Forest systems are efficient in carbon sequestration, storage and resulting reduction of carbon dioxide emissions from soils [3]. In recent decades, research on the importance of land-use as a carbon sink [4,5] or source [6] has gained importance in studies on reducing greenhouse gases to the atmosphere [7]. For food and fiber production, we must adopt management practices that promote total organic carbon stock (STK.TOC) and total nitrogen stock (STK.TN) in the soil.

The increase in STK.TOC comprises the removal of CO$_2$ from the atmosphere and its storage in areas of long-term reserves [8], with the soil being the largest surface carbon sink (2500 Pg), equivalent to three times the amount stored in the terrestrial biomass [9]. Carbon can remain longer in the soil than in plant biomass and can remain stored for decades, making soil an excellent carbon sink [10]. The stability of this element in the soil depends mainly on the land-use management adopted in the...
area [7]. Traditional land-use management practices in seasonally dry tropical forests (SDTF), like biomass burning, residue removal, conventional tillage, and clean cultivation, monoculture and intensive grazing lead to soil degradation [11].

The conventional management of farming systems coupled with low biomass production [4,12], contributes to the reduction of the organic matter content, STK.TOC and STK.TN in SDTF [13]. The unplanned use of plowing and harrowing on cultivated land stimulates the oxidation of organic matter and degradation of the soil structure [7,14]. In SDTF, this process is more intense due to the ready availability of solar energy and uncertainty of rainfall—the predominant hot semi-arid climate is characterized by a poor temporal and spatial distribution of rainfall [15], with a frequent occurrence of both dry years and consecutive dry days during the rainy season.

The SDTF is found in all five continents [16], of which, the two largest areas are in South America, one including northern Paraguay, a small part of Argentina and the southwest of Bolivia, the second corresponding to the Brazilian Northeast [16]. Together, these two areas represent 54% of the total global SDTF (10,510^4 km^2). In general, SDTF is used for grazing purposes (cattle, sheep, and goats) [17]. Livestock farming is considered an activity with the greatest environmental impact, due to the reduction of the forests and the use of native vegetation as a food source. In fact, areas of native vegetation have a greater stock of plant biomass than areas of pasture or of short-cycle agricultural crops [18].

Faced with the need to produce fiber and protein to meet the demand for food, the question becomes which land-use has the greatest potential to retain carbon and nitrogen stored in the soil in an SDTF? In order to answer this question, a study was developed to analyze the effect of land-use (dense vegetation, open vegetation, agriculture and pasture) on the stocks of organic carbon and total nitrogen in an SDTF in the Brazilian semi-arid region.

2. Materials and Methods

2.1. Location of the Study Area

The study area is inserted in a seasonally dry tropical forest, known as the Caatinga Phytogeographical Domain. We investigated three sites: Pentecost, Piquet Carneiro, and Quixadá, in the State of Ceará, Brazil (Figure 1). The three sites share the same climate: (BSh) hot semi-arid with average monthly temperatures above 18 °C. The mean annual rainfall is 760 mm (Pentecost), 725 mm (Piquet Carneiro, Brazil) and 765 mm (Quixadá, Brazil). At each site, we investigated four types of land-use: dense caatinga (DC), open caatinga (OC), agriculture (AG) and pasture (PA).

According to the Brazilian System of Soil Classification [19], the soil at the three sites is classified as a eutrophic Lithic Neosol. The class of Neosols includes shallow soils composed of mineral or organic material less than 20 cm thick, presenting no diagnostic B horizon. This class of soil is intrinsic to regions with a semi-arid climate [20], since in this environment climate conditions are marked by low rainfall and high rates of evapotranspiration, which favors the occurrence of soils with a low degree of weathering.

The typical composition of the natural vegetation at the three sites is seasonally dry tropical forest, varying in character from herbaceous to arboREAL-shrub species, typically deciduous and xerophilous with a great variety of thorny species [12]. The land use found at the three sites is composed of the following phyto–ecological units [21]. Crystalline caatinga with arboreal fragments, and dense and open shrub. The characteristics of the land-uses under study at the three sites are shown in Table 1.
Table 1. Land-use description at the three sites under study.

| Site             | Land Use       | Species                                      | Usage History                                      | Photos of the Sites |
|------------------|----------------|----------------------------------------------|---------------------------------------------------|---------------------|
| Pentecoste       | Dense Caatinga (DC) | *Caesalpinia pyramidalis* (Tul); *Thlaoa glauccapra* (Mart.); *Auxemma oncocalyx* (Fr. All.) Baill; *Manihot pseudoglaziovii* (Müll.Arg) | under regeneration for 40 years protected from cattle by wire mesh fences | ![Image](image1.png) |
|                  | Open Caatinga (OC) | *Mimosa tenuiflora* (Willd); *Cydonia oblonga* (Mill); *Mimosa caesalpiniaefolia* (Benth) | under regeneration for 31 years protected from cattle by wire mesh fences. | ![Image](image2.png) |
|                  | Agriculture (AG)  | *Phaseolus vulgaris* (L.)                   | used for agriculture for 15 years most common crop: rainfed common bean (*Phaseolus vulgaris*). | ![Image](image3.png) |
|                  | Pasture (PA)     | *Elionurus candidus* (Trin.)                | used as pasture for 20 years under preserved caatinga prior to pasture. | ![Image](image4.png) |
| Piquet Carneiro  | Dense Caatinga  | *Caesalpinia pyramidalis* (Tul), *Manihot pseudoglaziovii* (Müll.Arg); *Mimosa tenuiflora* (Willd); *Mimosa caesalpiniaefolia* (Benth); *Cydonia oblonga* (Mill) | under regeneration for 35 years stones on the surface | ![Image](image5.png) |
| Location     | Vegetation Type | Vegetation | Regeneration Details                                           |
|--------------|-----------------|------------|---------------------------------------------------------------|
| Open Caatinga | Mimosa caesalpiniaefolia (Benth); Cydonia oblonga (Mill); Mimosa tenuiflora (Willd) | under regeneration since 1998 | rainfed crops (Zea mays L.) prior to regeneration |
| Agriculture  | -               | -          | agriculture for 12 years                                      | most common crop: rainfed bean (Phaseolus vulgaris) |
| Pasture      | Elionurus candidus (Trin.) | used only for animal feed since 2000 | native grass: such as Elionurus candidus |
| Dense Caatinga | Caesalpinia pyramidalis (Tul), Mimosa tenuiflora (Willd), Mimosa caesalpiniaefolia (Benth), Cydonia oblonga (Mill) | Caatinga with free access for animal grazing for 5 years. | |
| Quixadá      | Open Caatinga   | Mimosa caesalpiniaefolia (Benth), Cydonia oblonga (Mill), Mimosa tenuiflora (Willd), Caesalpinia pyramidalis (Tul), Bauhinia forficata (Link) | under regeneration for 30 years | almost completely thinned caatinga |
| Agriculture  | Zea mays (L.)   | under conventional management since 2005 | most common crop: rainfed maize (Zea mays, L.) |
| Pasture                  | -                | used as pasture for small animals since 2003 native leguminous species |
2.2. Soil Samples

Soil samples were collected at the 0–10; 10–20; 20–30 cm layers using a Dutch auger from 12 trenches (3 sites × 4 land-uses × 1 class of soil—Neosol). Due to the hard consistency of the soil under the agriculture land-use, samples from the 20–30 cm layer could not be collected. Undisturbed and disturbed soil samples (triplicates) were collected from 70 × 70 cm trenches to analyze density and chemical attributes, respectively. The undisturbed soil samples were collected using an auger with a diameter of 5.7 cm and a height of 5.3 cm, and were oven-dried at 105 °C for 72 h. The disturbed soil samples were sifted through a 4 mm mesh to eliminate any coarse material; then air-dried, crushed and sifted through a 2 mm sieve. All sample collection locations were marked and georeferenced and the altitude, slope, drainage, and vegetation of the areas were registered.

2.3. Bulk Density

Bulk density was evaluated using the volumetric ring method [22]. Sodium hydroxide (NaOH) 1N was used for the chemical dispersion of the particles. The clay fraction was quantified by the sieve-pipette method, the sand fraction by sifting, and the silt fraction evaluated using the difference between the total of the fine-earth sample from the oven and the sum of sand and clay [22].

2.4. Chemical Analysis of the Soil

The soil pH, exchangeable acidity (Al³⁺), potential acidity (H⁺ + Al³⁺) and components of the sorption complex (Na⁺, K⁺, Ca²⁺, Mg²⁺) were determined as proposed by [22] to calculate the cation exchange capacity (CEC) at pH 7 and percentage base saturation (V%). Total soil nitrogen (TN) was determined by sulfur digestion, followed by Kjeldahl distillation and titration with 0.02 mol L⁻¹ HCl [22]. Total organic carbon content (TOC) was determined by wet oxidation with 0.167 mol L⁻¹ potassium dichromate (K₂Cr₂O₇) in acid medium (H₂SO₄) with an external heat source using a block digester at 170 °C for 30 min. The excess dichromate after oxidation was titrated with a 0.2 mol L⁻¹ solution of ferrous ammonium sulfate (Fe(NH₄)₂(SO₄)⁺H₂O [23].
Since the core densities are very uniform (coefficient of variation is 9%) we used the simplest way to calculate TOC and TN stocks [24]. This methodology is based on the product of the TOC or TN concentration and the soil density of the core at a fixed depth as follows:

\[
\text{TOC}_{FD} = \sum_{i=1}^{n} BD_{es} \times C_{es} \times T_{es} \times 0.1
\]

\[
\text{TN}_{FD} = \sum_{i=1}^{n} BD_{es} \times N_{es} \times T_{es} \times 0.1
\]

where \(\text{TOC}_{FD}\) is the TOC stock to a fixed depth, \((\text{Mg ha}^{-1})\); \(\text{TN}_{FD}\) is the TN stock to a fixed depth, \((\text{Mg ha}^{-1})\); \(BD_{es}\) is the bulk density of core segment, \((\text{g cm}^{-3})\); \(C_{es}\) is organic C concentration of core segment, \((\text{g kg}^{-1})\); \(N_{es}\) is TN concentration of core segment, \((\text{g kg}^{-1})\); \(T_{es}\) is the thickness of soil segment \((\text{cm})\).

2.5. Statistical Analysis

The data sets were checked for normality by the Shapiro–Wilk test. Because they did not show a normal distribution, the non-parametric Kruskal–Wallis mean-comparison test was used at 5% significance, using the dense caatinga as reference.

To check the similarity between treatments for stocks of TOC and TN, the technique of multivariate analysis/hierarchical cluster analysis (HCA) was used. For the cluster analysis, the data were transformed and standardized to eliminate the effect of the units or scales of measurement. All the statistical analysis was carried out using SPSS v 16.0 software, and the figures produced using the Sigma Plot software.

3. Results and Discussion

Land-use and land management practices have a significant impact on soil quality. The present study was conducted to estimate the stocks of total organic carbon and total nitrogen in an SDTF in the Brazilian semi-arid region. We evaluated the total organic carbon and total nitrogen content in the soil in three layers (0–10 cm, 10–20 cm and 20–30 cm) in the following land-uses: dense caatinga (DC), open caatinga (OC), pasture (PA) and agriculture (AG).

3.1. Bulk Density

There is a gradual increase in bulk density with depth due to the pressure exerted by the upper layers on the underlying layers [25]; and a reduction in the soil organic carbon content with depth [17]. There was no statistical difference \((p < 0.05)\) in bulk density for the different land-uses (Figure 2) at all layers, except for the deepest 20–30 cm layer, despite the gradual increase in the mean values for bulk density \((\text{g cm}^{-3})\) for DC and PA throughout the soil profile.

The bulk density in OC was significantly lower \((p < 0.05)\) than in DC at the 20–30 cm layer. Although the bulk density in PA showed higher values than under the other land-uses for all three layers, these differences were not significant at the 5% significance level. The lowest bulk density in the surface layer of DC is due to the greater contribution of organic matter by the necromass (dead trees and litter) [26] in the surface layer. In general, organic residue has a lower specific weight compared to the mineral fraction [27].

Upon replacing native vegetation by grazing a greater bulk density at the surface layer compared to a native forest [6] is expected. However, the mean values for bulk density in the areas under pasture (PA) did not differ statistically \((p < 0.05)\) from those in DC in the three layers (Figure 2). We believe that this fact can be explained by the presence of the herbaceous stratum (grasses and legumes), which favors a reduction in bulk density due to the high density of fine roots in areas with a predominance of annual plants [4,5].
3.2. Total Organic Carbon (TOC)

As expected, there was a clear stratification of TOC content (g kg⁻¹) with respect to depth (Figure 3). The average TOC content in the first layer (12.2, 10.8, 9.1 and 7.2 g kg⁻¹ for OC, DC, PA and AG, respectively) is statistically \( p < 0.05 \) higher than from those in the other layers for all land-uses (Figure 3) except PA on the deepest layer (20–30 cm), emphasizing the influence of depth on TOC.

The greatest levels of TOC in the 0–10 cm layer for the four land-uses may be explained by the deposition of organic residue [14] on the soil surface originating from the senescence and decomposition of plant biomass [28,29]. The increase of TOC and TN content in the third layer under PA with respect to DC and OC, may be due to the herbaceous and grass-root systems of C₄ plants (tropical grasses), as observed by [4]. Although there was a decrease in TOC content in the second and third layers, the second layer followed the TOC content pattern of the first layer for the different land uses.

Since livestock rarely grazes in DC and CA, the greatest TOC content in the 0–10 and 10–20 cm layers is due to the constant deposition of organic residue (leaves, branches, flowers, seeds, fruits, fine roots, and other organic matter). The highest inputs of organic residue on the soil surface occur during senescence and pruning of the vegetation [8,14].
uses in the same layer according to the Kruskal–Wallis test \( (p < 0.05) \). Different uppercase letters represent a statistical difference between layers for the same land use according to the Kruskal–Wallis test \( (p < 0.05) \).

The reduction of TOC content in agricultural sites (Figure 3) can be attributed to soil disturbance caused by agricultural practices, which accelerate the loss of carbon by burning and deforestation. It is, therefore, evident that anthropogenic interference tends to reduce the input of carbon to the soil, and that the removal of native vegetation detracts from the function of the forest as a carbon sink \[3,6,18\]. Despite AG having a lower TOC content than DC in all layers, only the 0–10 cm layer differed between land uses \( (p < 0.05) \). Although not significant, the open caatinga showed a greater TOC content than DC in the first two layers.

Under pasture, an increase in the TOC content was observed in the 20–30 cm layer (Figure 3). We believe that this increase in TOC content is due to the grass root system \[30\], the decomposition of residue, and the presence of root exudates. Organic carbon entering the soil in areas of pasture is due mainly to the decomposition of litter on the surface (0–10 cm) and of the underground roots (20–30 cm) \[31\].

3.3. Total Nitrogen (TN)

The pattern of TN content (Figure 4) was like that of the TOC content for all land-uses (Figure 4), i.e., the content decreases with increasing depth. This similarity in the pattern is explained by nitrogen and carbon being components of the structure of organic matter. The low accumulation of organic matter in semi-arid soils is due to the limited production of plant biomass and rapid mineralisation during the rainy season, which results in low levels of nitrogen. The low TN content for the four land-uses under investigation is possibly due to the water deficit, low soil moisture, low air humidity and high temperatures. These environmental conditions affect the soil, interfering with microbial activity \[2\].

In OC, the mean values for TN were 0.83 g kg\(^{-1}\) (0–10 cm) and 0.38 g kg\(^{-1}\) (10–20 cm), while in DC the mean values for TN were 0.75 g kg\(^{-1}\) (0–10 cm) and 0.28 g kg\(^{-1}\) (10–20 cm). The OC, therefore, showed increases of 9.64% and 26.32% when compared to DC in the first and second layers respectively. The greatest TN content found in DC, OC and PA showed a significant difference to AG only in the 0–10 cm layer. TN content in DC, OC and PA did not show a significant difference \( (p < 0.05) \) in any of the other three layers under study, except for the AG TN content in the 0–10 cm layer—significantly different \( (p < 0.05) \) from the other two layers. For the second and third layers, TN content did not present a significant difference within the layers and between layers (Figure 4). These results suggest that land-use impact on TN content is concentrated in the first 10 cm of the soil.

![Depth vs. Land Use](image-url)

*Individual standard deviations are used to calculate the intervals.*
Figure 4. Total nitrogen (TN) content by layer under different types of land-use in the semi-arid region of Brazil. Note: equal lowercase letters mean no statistical difference between land uses by the Kruskal–Wallis test ($p < 0.05$) in the same layers. Different uppercase letters mean statistical differences between layers for the same land-use layer by the Kruskal–Wallis test ($p < 0.05$).

The smallest TN content throughout the profile was recorded in AG, which is due to the lack of better management practices that might help maintain soil organic matter. Farmers use techniques that promote turning of the surface layer of the soil, employing cultivators and hoes for weeding and burning, in addition to not leaving areas of fallow. Another important fact is the nutrient export from the area by crops (bean and maize). Nitrogen is one of the most absorbed nutrients by the crops [32]. Such management results in the loss of organic matter [6] and promotes greater exposure of the soil surface, favoring mineralization of soil organic matter.

3.4. Stocks of TOC (STK.TOC) and TN (STK.TN)

The amount of TOC and TN stocked in all layers (0–30 cm), STK.TOC (Figure 5A) and STK.TN (Figure 5B), respectively, showed no significant difference ($p < 0.05$) for the four land-uses. However, among all land uses, AG showed the lowest STK.TOC (6.8 Mg ha$^{-1}$) and STK.TN (0.28 Mg ha$^{-1}$) means. These small values are related to (i) climate conditions (high temperatures, high solar radiation and a very long dry season) present in the semi-arid region of Brazil; (ii) the management practices (fire and conventional tillage) used in rainfed farms [11], confirming studies carried out around the world [33].

The replacement of native vegetation by an intensive agricultural system is responsible for the decrease in organic matter content, which leads to a reduction in soil carbon and nitrogen stock [34]. In tropical regions, the decrease in soil organic matter is approximately 50–70% over 10–20 years, and it is noteworthy that these losses are strongly related to the conventional cultivation and tillage systems [35]. This system alters the soil structure, fragmenting the macroaggregates and redistributing them as microaggregates, so that the organic matter that was protected from the action of microorganisms will be quickly mineralized [34,36], although [37] observed that land use with minimum disturbance in semi-arid regions is effective in maintaining carbon stock, microbial carbon and carbon in substances.

Figure 5. The stock of TOC (A) and TN (B) in the 0–30 cm layer for different land-uses in the semi-arid region of Brazil.

According to the HCA, STK.TOC and STK.TN was similar between land uses at the same depth, composing two groups. The cluster analysis validated the results of TOC and TN content (Figures 3 and 4) and confirm the decreasing trend with depth. The first layer (0–10 cm) of the land-uses DC, OC and PA (Figure 6) was separated from the rest of the layers, which showed maximum STK.TOC
and STK.TN values (Table 2). The 10–20 cm and 20–30 cm layers of all land-uses and first layer of AG land use formed the second group, which had the lowest STK.TOC and STK.TN.

Figure 6. Similarity of the attributes of TN and TOC stock for the four land-uses: dense caatinga (DC), open caatinga (OC), pasture (PA) and agriculture (AG).

The stocks of carbon and nitrogen are quantified mainly in the 0–10 cm layer, since the surface layer shows a significant accumulation of organic residue. AG is the only land-use with a surface layer that is part of group II. This similarity demonstrates that if there is intensive anthropogenic intervention, it promotes the loss of carbon and nitrogen [29], reducing the STK.TOC and STK.TN in the surface layer to the levels of the deeper layers. Reductions in TOC and TN stock compromises soil health [11] and reduces the resilience of the system to climate change.

The loss of carbon and nitrogen identified in AG expresses an intensive and exhaustive use of the soil, with a high risk of system degradation. The reduction in TOC and TN in the soil results in a lower water-storage capacity, an increase in soil temperature and a reduction in aggregate formation, and compromises biological production, the quality of the environment and the health of both plants and humans [7,28].

The larger stock in the layers comprising group 1 can be explained by decomposition of the organic material input to the soil by the litter [30] and by the fine roots of the herbaceous stratum [5] that decompose rapidly [4] on the soil surface and tend to concentrate in the top 30 cm. Grasses, as well as forest species, can contribute significantly to the accumulation of carbon in the soil, especially when managed correctly [4].

The similarity in TOC and TN stock between DC, OC and PA in all layers (Figures 3 and 4), indicates that this land-use, when properly managed, does not promote a significant loss ($p < 0.05$) of TOC or TN, contributing to better soil quality. As such, it can be considered an alternative for fiber and food production in semi-arid regions. However, we understand that suitable stocking rates should be observed to avoid overgrazing, compaction, and soil degradation.

Another point to keep in mind is the soil class, Neosols, which has low clay content and no iron or aluminum oxides. According to [38], low clay soils have low chemical and physical protection capacity of its organic matter due to a lack of organic complex formations. Therefore, we believe that the median values <10 Mg ha$^{-1}$ in both, STK.TOC and STK.TN in each land use (Figure 6, Table 2) are due to the soil class—Neosols. Also, low values of TOC stock (2.70–6.55 Mg ha$^{-1}$) and TN stock (0.59–0.90 Mg ha$^{-1}$) were found by [39] for Quartzarenic Neosol in the Brazilian semi-arid tropics. Further, [40] observed low values in soil carbon stock (5.29–9.45 Mg ha$^{-1}$) in DC areas under Neosols.

In this study, the TOC and TN content for each land use appeared in the following order: OC > DC > PA > AG. The lowest concentration of TOC and TN in AG land use is due to (i) lower organic
matter input (deforestation, biomass production, crop harvest, tillage); (ii) The high consumption of nitrogen by crops and prolonged farming that increase soil mineralization and organic matter requirement [7]. Results suggest that OC and PA are the most suitable land uses on Neosols with very low total organic carbon stock because of: (a) higher litter input is a carbon and nitrogen source; (b) lower herbaceous plants improve soil moisture [41]; (c) a vertical distribution of root system is developed [5]. The distribution of the root system directly influences the TOC and TN vertical distribution. Abundant carbon resources are produced by aging, decay and root decomposition [9].

Table 2. Mean, minimum and maximum values, standard deviation and coefficient of variation for the STK.TOC and STK.TN attributes in the typic eutrophic Litholic Neosol class.

| Attribute | Descriptive Parameters | Group 1 | Group 2 |
|-----------|------------------------|---------|---------|
|           | Number of cases        | 3       | 8       |
| TOC (Mg ha⁻¹) | Mean ± SD                      | 9.49 ± 1.87 | 4.20 ± 1.52 |
|           | Maximum                 | 11.99   | 5.59    |
|           | Minimum                 | 7.48    | 2.06    |
|           | CV                      | 0.20    | 0.36    |
|           | Number of cases        | 3       | 8       |
| TN (Mg ha⁻¹)   | Mean ± SD                      | 0.58 ± 0.22 | 0.25 ± 0.13 |
|           | Maximum                 | 0.82    | 0.39    |
|           | Minimum                 | 0.29    | 0.00    |
|           | CV                      | 0.37    | 0.52    |

4. Conclusions

The present study reveals that the effects of land use on total organic carbon and total nitrogen content in the shallower soil layer (0–10 cm) was greater than on the deeper layers. Soil depth affects total organic carbon more than land-use, enabling exploitation of the SDTF-Caatinga to produce biomass and protein by adopting open caatinga and pasture use on Neosols with very low total organic carbon stock. Agricultural land-use shows a greater reduction in total organic carbon and total nitrogen stocks. Nonetheless, we understand that additional studies need to be developed to quantify the carrying capacity maintaining a thinned forest, offering better support to decision-makers for a sustainable management of the SDTF.

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