soil systems

Article

Organic C Fractions in Topsoil under Different Management Systems in Northeastern Brazil

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Abstract: The conversion from native forest to other land-use systems can decline the soil organic carbon (SOC) in tropical soils. However, conservationist management could mitigate SOC losses, promoting the functioning and stability of agricultural soils. This study aimed to address the influence of conversion from native forest to different land-use systems on SOC fractions in Northeastern Brazil. Topsoil soil samples were collected in areas under pasture (PAS), no-tillage (NT1 and NT2), eucalyptus (EUC), and native forests of Cerrado in Northeastern, Brazil. Total organic C, microbial biomass (MBC), particulate (POC), and mineral-occluded organic C (MOC), as well as fulvic acids (C-FA), humic acids (C-HA), and humin (C-HUM) fractions were accessed. The results showed that land conversion maintained similar levels of humic fractions and total organic carbon (TOC) stocks in the PAS, NT1, NT2, and EUC as compared to native Cerrado. Soils with the input of permanent and diverse fresh organic material, such as NT2, PAS, and EUC, presented high levels of MBC and POC, and the lowest C-FA:TOC and C-HA:TOC ratios. The land conversion to agricultural systems that include cropping rotations associated with pasture species such as Mombasa grass and eucalyptus prevents topsoil losses of active C compartments in the Cerrado of the Brazilian Northeast. It suggests that sustainable and conservationist management should be emphasized to maintain and improve the status of soil organic C.

Keywords: Cerrado; no-tillage; soil quality; oxisols

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1. Introduction

The conversion of native forests to agricultural land-use and management systems has promoted changes in soil properties and functions [1,2] mainly leading to a decline in soil organic C (SOC) [3]. This is particularly important to tropical soils since they present naturally low SOC content and significant C losses after the adoption of intensive land use [4]. Indeed, previous studies have shown that the conversion of tropical forests to intensive land use decreased by about 25% to 32% of the SOC content [5–7]. On the other hand, conservationist land uses can decrease the C losses and bring positive effects on SOC content [8,9].

SOC is an essential component for the suitable functioning and stability of soils, influencing their chemical, physical, and biological properties [10,11]. This component presents different fractions, being characterized as humic and non-humic, which have different recycling times and forms of protection [12]. The humic fractions (HF) represent the greatest fraction of SOC, which is highly persistent and stable [13], and contains three main compartments known as fulvic acids (C-FA), humic acids (C-HA), and humins (C-HUM) [14]. On the other hand, non-humic fractions (NHF) consist of a wide range of soluble substances and present more sensitivity to changes due to their rapid turnover [15]. Thus, the distinct characteristics presented by these SOC fractions may confer higher or lower stability, mainly against the effects of the conversion of native forests to different land-use and management systems.

Interestingly, it is well-known that land-use change affects the SOC content, especially in the topsoil layers. For example, a meta-analysis performed by Angers et al., and Luo et al. [16,17], demonstrated that the conservationist no-tillage (NT) system increased SOC concentration in the upper topsoil layers and the effects of NT on SOC stocks were particularly significant at a depth of 0.10 m. Similarly, Haddaway et al. [18] found that significant differences in SOC stocks across different soil management systems were noticeable in the upper soil layer and the effects disappeared when considering the full profile up to 150 cm depth. Increased SOC content in the topsoil is a relevant aspect of soil quality, considering that the soil surface is a vital interface associated with mechanisms that affect soil productivity and its environmental quality [19,20]. However, little information is available about the effects of the conversion from native forest to different land-use systems on SOC fractions in the uppermost layer of tropical soils. This is important since each fraction distinctly influences the soil functioning [21]. In addition, the assessment of SOC fractions will provide knowledge about how different land-use or management systems affect the potential losses, accumulation, mineralization, and humification processes of SOC [22,23].

In Northeastern Brazil, different land-use systems are adopted, such as no-tillage, silviculture, and pastures, which can distinctly influence the SOC status. For instance, previous studies in Brazil found that no-tillage practices increased the SOC content as compared to conventional farming [24], while the pasture system increased the SOC content as compared to a native forest [25]. In silvicultural systems, Araujo et al. [26] observed that the cultivation of eucalyptus did not reduce the SOC content as compared to native forests.

Although studies have reported positive or no significant changes in no-tillage, silviculture, and pastures on SOC content [27], little is known about the effects of these systems on SOC fractions and stocks in the topsoil of a Cerrado from the Northeast of Brazil. Here, we hypothesize that SOC and C fractions in the topsoil of areas converted from native Cerrado vegetation in the Brazilian Northeast are differently influenced by distinct agricultural systems. We also hypothesize that topsoil C status in well-managed agricultural systems can be maintained at similar values to those found in native vegetation. Our objective was to study the influence of no-tillage, eucalyptus, and pasture on SOC fractions and stock in soils from Northeastern Brazil.

2. Materials and Methods

2.1. Study Site

This study was carried out at Farm New Zealand, Uruçuí, PI, Brazil (07°33′08″ S and 44°36′45″ W; 378 m above sea level). The climate is Aw (Köppen) and the average temperature and rainfall are 27 °C and 817 mm, respectively [28]. The rainy season extends from November to May and the dry season, from June to October. The soil is classified as Oxisol (Yellow Latosol) [26]. In this study, four management systems were evaluated as follows: pasture (PAS); no-tillage with soybean, under maize straw, in a soybean/maize succession (NT1); no-tillage with maize, under grass straw, in a soybean/maize/Mombasa rotation

(NT2); and eucalyptus (EUC) (Figure 1; Table S1). As a reference, we evaluated a native Cerrado forest (NF).

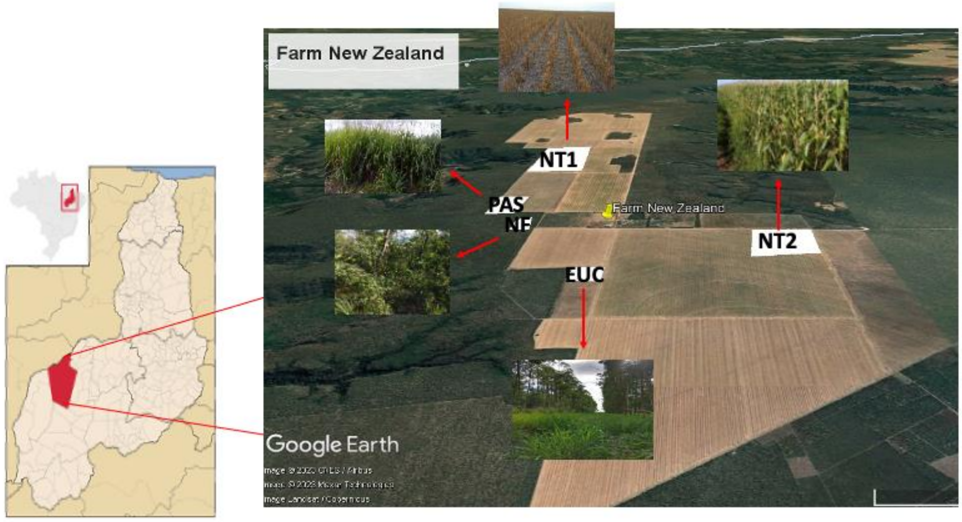

Figure 1. Map of Farm New Zealand showing the evaluated areas. PAS: Pasture species (Mombasa); NT1 and NT2: No-tillage system; EUC: Eucalyptus; NF: Native Cerrado forest.

The management systems PAS, NT1, and NT2 started in the 2004/2005 cropping season after the conversion of a native Cerrado to agricultural land use. After native forest removal, all areas received the application of lime (6 Mg ha^{-1}), which was incorporated at a depth of 0.22 m, using a 28 in disc plow. The area under EUC was implanted in the 2005/2006 cropping season using clones of *Eucalyptus urograndis* planted in the spacing of 3 m × 1.5 m (totalizing ~2200 plants per h), with each row spaced 14 m between them. Between the rows, rice followed by cowpea was sown and fertilized with 300 kg ha^{-1} of NPK 10-30-10. In the 2006/2007 cropping season, soybeans were sown using fertilization of 350 kg ha^{-1} of NPK 5-20-20. After soybean harvesting, Mombasa grass was sown for grazing. Fertilization during the implantation of the pasture was done using 150 kg ha^{-1} of NPK 06-21-06, containing 12% Ca, 3% S, and 0.3% Zn (w/w). Topdressing fertilization in the Mombasa grass between EUC rows was performed in March/2006, January/2007, and January/2008, with 200 kg ha^{-1} of NPK 20-00-20. The Mombasa grass was used for grazing at a stocking rate of 2.4 cow units ha^{-1} until 2009 and remained fallow from 2010 to 2017.

The NT1 area was cultivated with soybeans for two years following the conversion from native Cerrado. In 2007, maize was sown, followed by soybean (2008), millet (2009), maize, for two years (2009 and 2010), and cotton (2011). From this point, a maize/soybean succession was established until 2017, when soybeans were cultivated. In NT2, after native Cerrado conversion and in the same area, soybeans were sown followed by Mombasa grass used for grazing at a density of 2.4 animal unit ha^{-1}. This was repeated from 2006 to 2009. After 2010, a sequence of soybean/millet, cotton, maize, and soybean was used, and in 2016 Mombasa grass was sown followed by maize. The PAS area followed the same crop sequence as in NT1 until 2015. Mombasa grass was implanted in 2016 in the area for grazing at a density of 2.4 animal units ha^{-1}. In 2017, forage grass was desiccated with glyphosate and maize was cultivated.

The areas NT1, NT2, and PAS were fertilized according to the requirements of each plant species cultivated [29]. In 2011, dolomitic limestone was applied at 2.5 t ha^{-1}. In 2015, gypsum was applied at 1 t ha^{-1}, along with mono-ammonium phosphate at 160 kg ha^{-1}, potassium chloride at 120 kg ha^{-1}, ammonium sulfate at 250 kg ha^{-1}, and urea at 230 kg ha^{-1}.

2.2. Soil Sampling and Chemical Analysis

Soil sampling was performed in May 2017, at the end of the rainy season. The area within each management system was divided into five transects 20 m spaced from each other. In EUC, as a strategy to cover the complete system in a more representative way, each transect included samplings from the eucalyptus rows, the eucalyptus canopy projection outside the rows, and between the eucalyptus rows (Figure S1). Within each transect, five soil subsamples were taken (0–0.10 m depth) at points 20 m spaced apart. The five subsamples collected in each transect were pooled together to form a composite soil sample. In total, five replications (each one representing the composite sample from transects) were considered in each treatment (consisting of a total of 25 soil samples) covering an area of approximately 1 ha. Soil samples were sieved (2 mm) and homogenized for soil analysis. Soil pH was evaluated in a 1:2.5 soil/water extract; Ca^{2+}, Mg^{2+}, and Al^{3+} were extracted with KCl 1 mol L^{-1} − Ca^{2+} and Mg^{2+} were determined by atomic absorption spectrometry and Al^{3+} by titration; potential acidity (H+Al) was determined via extraction with 0.5 mol L^{-1} of calcium acetate and quantified by titration; and K^+ and available P were extracted with Mehlich-1 (H_2SO_4 0.0125 mol L^{-1} and of HCl 0.050 mol L^{-1})—the determination of K concentration was made through flame photometry and P was determined by colorimetry [30]. The values of the chemical properties are shown in Table S2.

2.3. Analysis of SOC Fractions

The soil microbial biomass carbon and nitrogen (MBC) were analyzed by the irradiation–extraction method [31,32] and the soil basal respiration was determined by quantifying CO_2 released after 7 days of incubation, under aerobic conditions in soil samples, with moisture content adjusted to 60% of field capacity [30]. The metabolic quotient (qCO_2) was obtained by the relationship between the soil basal respiration and MBC, according to the methodology described by Alef [33].

Total organic carbon (TOC) contents were determined by the 990.03 combustion method [34], employing an auto-analyzer, Leco CN628 (Leco Corp., St. Joseph. MI, USA). Carbon stock (C-stock) was obtained by the method of soil mass correction, using the soil bulk density (Ds) measured in the areas of each treatment and the native Cerrado forest as a reference [35]. This approach eliminates the influence of different soil bulk densities in over- or under-estimating the total C-stock across soil management systems. C-stock was calculated using the expression: C-stock= (TOC × Ds × ts), where ts represents the thickness of the soil layer considered.

Humic substance fractioning was performed according to the differential solubility technic, using the concepts of humic fractions established by the International Humic Substances Society, developed by [36], by obtaining the values of fulvic acids (C-FA), humic acids (C-HA), and humins (C-HUM). Physical fractioning of soil organic matter was performed according to [37], by obtaining the values of particulate organic carbon (POC) and mineral organic carbon (MOC).

2.4. Statistical Analysis

The soil was very homogenous across the different treatments. The data referring to soil biological attributes, carbon stocks, and chemical and physical fractioning of soil organic matter were checked for normality and homogeneity of variances and submitted for a one-way ANOVA, according to a completely randomized design. When significant, data were compared using the Tukey test (5% of probability). Additionally, a multivariate analysis was performed to compare the structure of SOC fractions among treatments using the principal components analysis (PCA) on log-transformed data. To explore the relationship between soil C fractions and microbial attributes, Spearman's rank correlation coefficients were applied, and the correction was made using Benjamini–Hochberg false discovery rate (FDR) method. Heatmaps were generated to further check for correlations.

Significant ($p < 0.05$) positive and negative correlations are represented in blue and red, respectively. All statistical analyses were performed using the R software [38].

3. Results

The results showed no significant differences in humic fractions (C-HA, C-FA, and C-HUM) between the evaluated areas (Figure 2). In contrast, the microbial fraction (MBC) varied between sites. The topsoil in pasture and eucalyptus presented higher MBC values (124.7 and 117.3 mg kg^{-1}, respectively) than NT1 (54.6 mg kg^{-1}) and the native forest (69.9 mg kg^{-1}), while NT2 (97.7 mg kg^{-1}) had similar MBC values than the other sites.

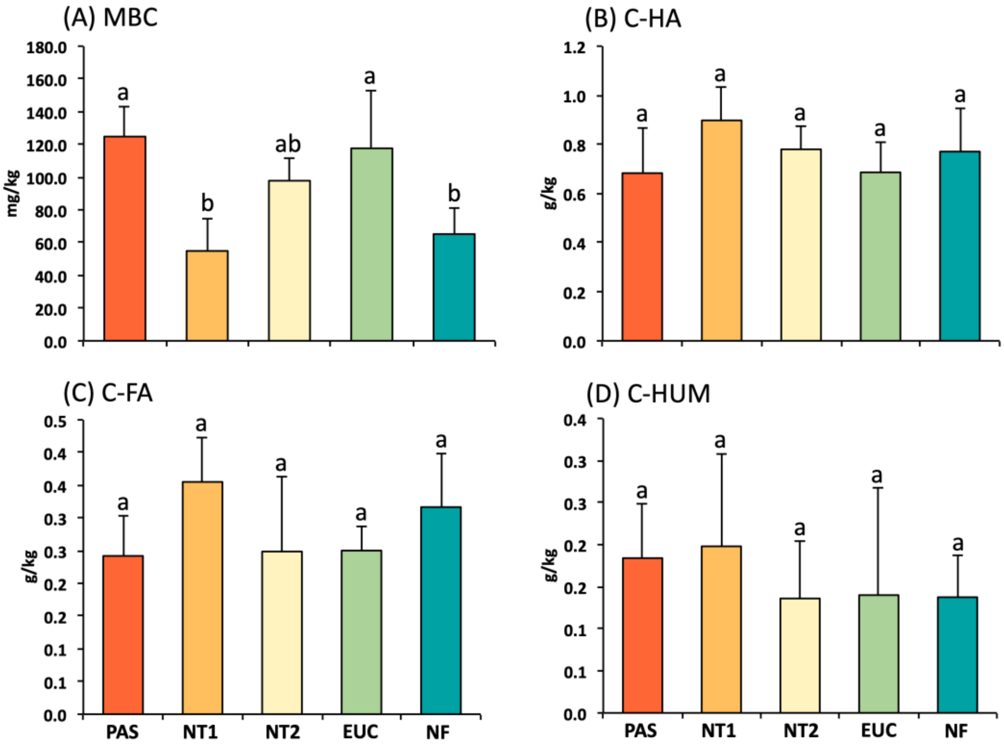

Figure 2. Microbial biomass carbon (MBC) (**A**), humic acid (C-HA) (**B**), fulvic acid (C-FA) (**C**), and humin (C-HUM) (**D**) fractions in the 0–0.10 m depth. Vertical lines on the bars indicate standard errors of means ($n = 5$). Treatments with different letters on the bars are significantly different ($p \leq 0.05$) by the Tukey test. PAS: Pasture species (Mombasa); NT1 and NT2: No-tillage system; EUC: Eucalyptus; and NF: Native Cerrado forest.

The values of MOC, TOC, and C-stock in topsoil did not vary between the areas under different management systems and the native forest. However, POC values in the topsoil were higher under native forest (0.047 g kg^{-1}) than under NT1 (0.022 g kg^{-1}) (Figure 3). The POC values under NT2 (0.026 g kg^{-1}), pasture (0.027 g kg^{-1}), and eucalyptus (0.031 g kg^{-1}) did not differ from each other, and native forest and NT1.

The ratios between C-fractions and TOC content showed variations between sites, except for the C-HUM:TOC ratio (Figure 4). The topsoil values of MBC:TOC were higher under pasture (1.15), NT2 (0.86), and eucalyptus (1.09) than under NT1 (0.41) and NF (0.48). In contrast, the highest topsoil values of C-HA:TOC and C-FA:TOC were observed under NT1 (8.32 and 3.31, respectively) as compared to pastures (6.13 and 2.16, respectively), and eucalyptus (4.85 and 1.77, respectively). Topsoil C-HA:TOC values in NT1 were also higher than those observed in the native forest (5.57), while C-FA:TOC in NT1 was higher than those observed in NT2 (2.10). The topsoil values regarding C-HUM:TOC did not vary among sites.

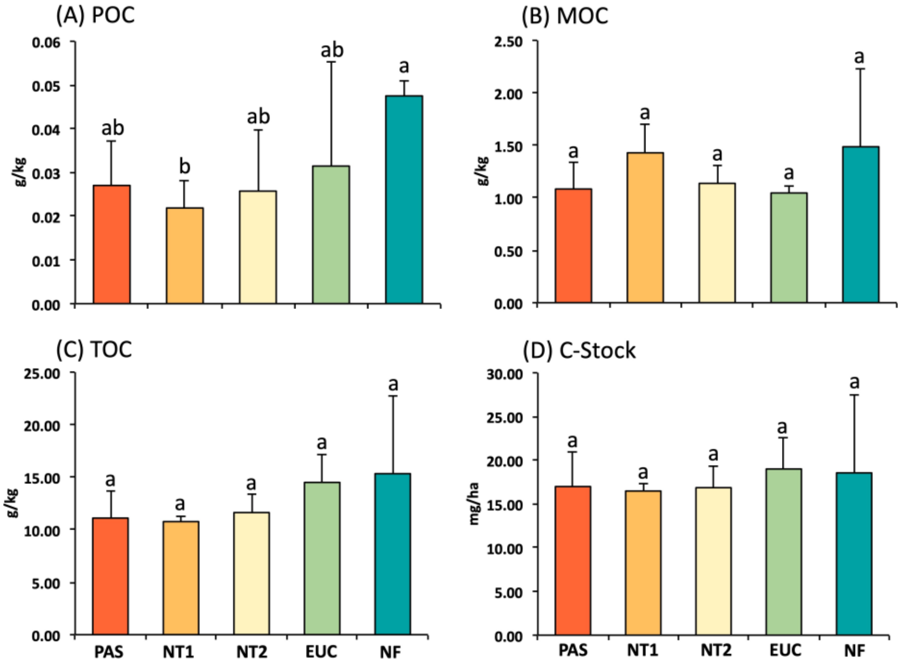

Figure 3. Particulate organic carbon (POC) (**A**), mineral organic carbon (MOC) (**B**), total organic carbon (TOC) (**C**), and carbon stock (C-Stock) (**D**) in the 0-0.10 m depth. Vertical lines on the bars indicate standard errors of means (n = 5). Treatments with different letters on the bars are significantly different ($p \leq 0.05$) by the Tukey test. PAS: Pasture species (Mombasa); NT1 and NT2: No-tillage system; EUC: Eucalyptus; and NF: Native Cerrado forest.

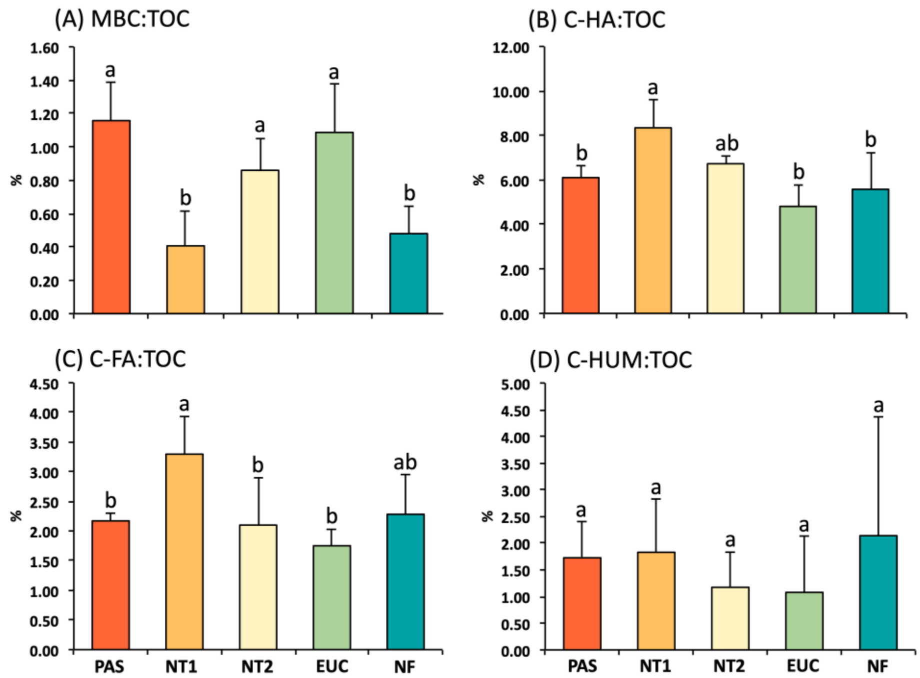

Figure 4. Microbial biomass carbon to total organic carbon (MBC:TOC) (**A**), humic acid to total organic carbon, (C-FA:TOC) (**B**), fulvic acid to total organic carbon (C-HA:TOC) (**C**), and humin to total organic carbon (C-HUM:TOC) (**D**) ratios in the 0–0.10 m depth. Vertical lines on the bars indicate standard errors of means (n = 5). Treatments with different letters on the bars are significantly different ($p \leq 0.05$) by the Tukey test. PAS: Pasture species (Mombasa); NT1 and NT2: No-tillage system; EUC: Eucalyptus; and NF: Native Cerrado forest.

The PCA analysis explained 99.1% of the total variation in the first two axes of the graph and clustered the samples into two main groups (Figure 5A). Group 1 comprised pasture and eucalyptus that were correlated with MBC and MBC:TOC. Group 2 consisted of NT1 and native forests that were correlated with humic fractions, POC, and MOC. The heatmap showed the correlations among SOC fractions (Figure 5B). MBC correlated positively with MBC:TOC ratio and negatively with C-FA:TOC and C-HA:TOC ratios. The C-FA and C-HA fractions correlated negatively with the MBC:TOC ratio and both fractions correlated positively with MOC. The C-FA:TOC ratio exhibited a positive correlation with C-HA:TOC.

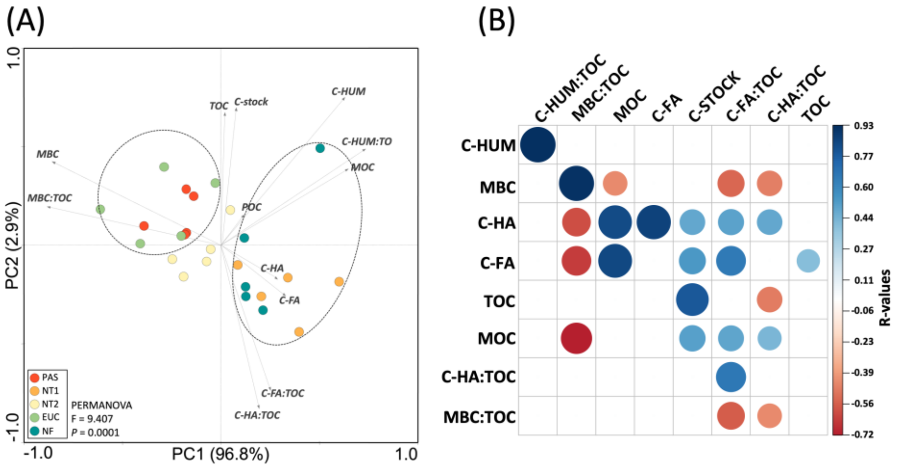

Figure 5. (**A**) Principal component analysis biplot comparing the structure of SOC fractions among treatments. The dashed lines in the graph indicate significant clusters (PERMANOVA, $p < 0.05$). (**B**) Heatmap showing the Spearman's rank correlation coefficients and statistical significance between SOC fractions. Blue and red colors indicate significant positive and negative correlations, respectively ($p < 0.05$).

4. Discussion

In general, land-use changes did not reduce TOC stocks under the conditions of this study, although previous studies have reported changes in TOC stock following land conversion from native forests to croplands in tropical soils [39–43]. Despite these previous studies, TOC stocks and their humic fractions remained at similar levels in PAS, NT1, NT2, and EUC as compared to the native Cerrado. The results showed a high standard deviation which probably occurred due to some variation along the transect [44], which contributed to the increase of the standard deviation. However, the statistical analysis was robust to show significant differences. Although no differences were observed in TOC stocks, MBC and POC fractions showed distinct responses according to the different agricultural systems ($p < 0.05$). These results are partly in line with the hypothesis that SOC and C fractions are differently influenced by distinct agricultural systems.

Changes in land use, vegetation cover, and soil management practices can increase or decrease TOC status in the soil, which depends on several factors. Plant biomass is the primary C source of the soil and, therefore, its quality and abundance strongly drive the dynamic of soil organic matter (SOM) [45]. Thus, an increase in SOM is observed when the rates of organic C inputs and incorporation are greater than the decomposition [46]. The SOM turnover occurs through the action of microbial-enzyme accessibility to the substrate, and the physical protection of soil C in aggregates plays an important role in controlling this process [40,47,48]. In this study, areas under land-use change presented diversification and abundance of plant biomass. The soil under NT1, NT2, and PAS were cultivated under crop rotation including legume (soybean) and grasses (maize and millet in NT1, while maize, millet, and pasture in NT2). Moreover, Mombasa grass was cultivated in PAS in 2016 and 2017. The management practices used in these areas ensured that a sufficient volume of organic residues in the soil environment was protected against fast decomposition due to the lack of soil disturbance. Particularly, the root system from grasses may have played an important role in TOC accumulation, as root biomass is considered the main source of C in the soil [48,49]. In EUC, the absence of a significant effect on TOC compared to NF could also be explained by the presence of Mombasa between rows and the low decomposition rate of eucalyptus leaves, as reported by Pinheiro et al. [39]. The management systems adopted following land conversion from the native forest in our study were based on sustainable practices such as crop rotation involving legumes and grasses or the adoption of perennial crops such as eucalyptus and Mombasa. The results obtained bring evidence that these management practices ensured the maintenance of soil C status after the land-use conversion, which is an essential condition for agricultural sustainability and terrestrial environmental stability [50], especially in highly weathered tropical soils [51]. Moreover, the land-use types studied, especially PAS, NT2, and EUC are some of the agricultural components of the crop-livestock-forest integrated systems, which is a technology increasingly used in intensive grain production systems in the Brazilian Cerrado. Our results therefore reinforce the agronomic and environmental feasibility of these systems in a climate change scenario.

Higher topsoil values of MBC in PAS and NT2 compared to NT1 and NF were probably a result of the inclusion of Mombasa grass in these systems, which ensured a high input of organic sources to microbes due to the exudation from the roots [52]. Moreover, grass leaves contain a greater portion of labile C fractions, while forest residues contain more recalcitrant fractions [53]. Soil microbes preferentially utilize grass-derived C as food since it is easily decomposed, allowing a further increase in SOC cycling and converting more external C into SOC [54]. The input of highly degradable substrates (plant litter with high proportions of labile fractions) on the soil surface possibly boosted microbial growth, leading to high MBC values (50). The soil under EUC also showed high values of MBC (119 mg/kg), which is possibly related to the high input of plant litter and the favorable environment provided by the trees, specifically reducing soil temperature, and maintaining high soil moisture [55]. Besides, eucalyptus rows were surrounded by Mombasa grass that was kept under fallow for eight years, which contributed with input of fresh organic material into the soil.

Land-use conversion to agricultural systems that involved crop rotation and pasture species such as Mombasa grass (NT2, PAS, and EUC), maintained POC values similar to those found in native forests. Similar trends were observed by de Moraes Sá et al. [41] in areas converted to pasture, where POC stocks did not change over time. Particulate organic carbon is a labile SOM fraction originating from newly decomposed litter biomass, greater root systems, and root exudates [56]. Although representing a small proportion of the TOC, this labile C fraction is an important component of active C pools [57]. Besides, it is considered the most sensitive indicator for land-use change because POC consists of fresh organic materials or materials with early stages of decomposition [55,58,59].

Pasture, NT2, and EUC were more efficient in incorporating organic C in the soil as microbial biomass than NT1 and NF, as indicated by the highest MBC:TOC ratios on these land-use systems. Conversely, amongst land areas converted from native forest, NT1 showed the highest proportions of humic substances in relation to TOC, notably for H-FA and H-HA. The lowest MBC:TOC in NT1 is consistent with the limited availability of permanent labile organic C for microbial activity, as also demonstrated by the lowest POC values in this management system and reinforced by the negative correlation of MBC:TOC with H-FA and H-HA. Soil MBC is a very important component in tropical soils because it represents an active pool of available nutrients for plant uptake [60], and was strongly correlated with MBC:TOC. Thus, changes in MBC:TOC are indicative of the organic matter input to the soil, microbial incorporation efficiency, soil carbon loss, and stabilization of SOC by mineral fractions [61]. Our data suggest that the high and continuous inputs of fresh material, especially by the root system of Mombasa grass (in NT2, PAS, and EUC) and eucalyptus plant residues (in EUC) were responsible for the more pronounced dynamic of C incorporation into microbial biomass. The importance of plant root systems in ensuring high MBC:TOC values is corroborated by [62], who stated that the MBC:TOC ratio is highly dependent on C inputs from the rhizosphere.

While high C inputs to the soil by root systems of pasture species favored an increased MBC:TOC ratio, the high C-FA:TOC and C-HA:TOC values observed in NT1 were conditioned by an opposite pattern, i.e., a lower efficiency in providing continuous input of fresh organic matter, especially from the root systems [63]. Such a pattern resulted in an exhaustion of the labile C fractions (e.g., POC and MBC) in NT1, leading to a more pronounced remaining proportion of humified C fractions compared to TOC. Humic substances represent a significant portion of total SOC and play an important agronomic role significantly influencing the quality and productivity of agricultural soils [21]. Despite that, the data from NT1 suggest that the higher proportion of humic substances in relation to TOC in this area compared to other land-use systems is a result of a lesser capacity to produce fresh material or the production of lower quality plant residues in NT1.

An important remark regarding NT1 is that with a few exceptions, a soybean-maize crop succession prevailed in this system. This sequence of crops is mentioned in the literature as a combination that ensures improved environmental conditions and increased profitability [64]. Nonetheless, our data suggest that for the conditions of extensive production systems in the Cerrado of Brazilian Northeast, the exclusive monocultures of soybean and maize in succession are not effective in ensuring a topsoil pool of active C fractions. This statement is reinforced by the data from Luo et al. [17], who found that increasing cropping frequency is a more efficient strategy to increase C input agroecosystems.

The changes in soil C status found in our study may partly be a consequence of the thin topsoil layer considered. We showed that intensive agricultural systems combining crop rotation and the use of pasture grasses and eucalyptus increases the contents of active C pools (MBC and POC) in the topsoil. A broad set of studies converge with our findings, showing that major changes in SOC status in no-tillage systems occur close to the soil surface, in the 0.5–0.10 m [16,17,65] or the 0.15 m soil layer [18]. The continuous input of fresh organic material in the uppermost soil layers promotes high biological activity [18] leading to more immediate changes in the C status. On the other hand, in deeper soil layers, there is a lower fresh material input and higher recalcitrance of soil C forms compared to topsoil, making C forms unavailable to microbial communities [66]. These limitations at deeper soil layers make changes in C status slower.

On one hand, our results showed that management-dependent changes in topsoil C status might be useful to allow the comprehension of the dynamics of soil C sequestration in the short span. This is because changes in labile C fractions can also promote changes in TOC contents and the uppermost soil layers can contain approximately 47–50% of the total SOC stock found in the 0–100 cm soil layer [67,68]. On the other hand, changes promoted by the management system can also point towards long-term trends in a soil profile deeper than the 0.10–0.15 m soil layer both in tropical [69,70] and temperate regions [65]. Therefore, given the restricted thickness of the soil layer considered in our study, the results cannot be extrapolated to the whole soil profile and cannot be used as a model to estimate C sequestration under the land-use systems evaluated.

Taken together, our findings show the importance of soil quality, the crop rotation with more complex crop arrangements that include forage grasses, and the combination of these forage grasses with eucalyptus trees. Our results also call for the incorporation of these practices in intensive systems in converted areas in the Brazilian Northeast, to ensure more intense topsoil C dynamics, with implications for productive sustainability [19,71]. Despite that, future research efforts should be directed towards a detailed survey of C sequestration and fractions in a soil profile of 1 m or more [70]. This is necessary for a better comprehension of the mid- or long-term effects of intensive land-use systems in the soil C status under the conditions of the Brazilian Northeast and for a complete inventory of C stocks in areas converted from native Cerrado to agricultural use.

5. Conclusions

This study showed that native Cerrado forest to agricultural land uses does not significantly influence the topsoil C-stocks and the fractions of soil humic substances but reduces the topsoil POC fraction, partially confirming our hypotheses. The adoption of agricultural systems that involve complex cropping rotations including pasture species, such as Mombasa grass and eucalyptus, is decisive to ensure a permanent input of diverse plant residues, preventing the loss of topsoil active C compartments in the Cerrado of the Brazilian Northeast. Although this study did not show significant shifts in soil organic C fractions, it suggests that sustainable and conservationist management should be emphasized to maintain and improve the status of soil organic C. In addition, further studies should be done to monitor the pattern of soil organic C fractions in the long term.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/soilsystems7010011/s1, Figure S1. Sampling design. In NT1, NT2, PAS and NF, five 100-m transects distant approximately 20 m between them were sampled (A); In EUC, five 20-m spaced transects considered the transition from eucalyptus rows and spaces between rows (B). Five samples were taken per transect (red circles) and pooled to form a composite sample. Table S1. Historic of the crop systems applied in each area. Table S2. chemical properties (0-0.10 m depth) of the soils.

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