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# SOIL CARBON STOCKS AND COMPARTMENTS OF ORGANIC MATTER UNDER CONVENTIONAL SYSTEMS IN BRAZILIAN SEMI-ARID REGION[1]

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**ABSTRACT** - The objective of this study was to evaluate the effect of the conversion of secondary native vegetation (NV) to conventional systems (agriculture and pasture) in soil organic carbon (SOC) and carbon of fractions particulate organic matter (POM) and mineral-associated organic matter (MAOM) in the Brazilian semi-arid region. The study was carried out in the municipalities of Delmiro Gouveia, Inhapi and Pariconha, in Alagoas, Brazil. Soils were collected in the layers of 0-0.1, 0.1-0.2 and 0.2-0.3 m. The treatments analyzed were: agricultural crops with 4, 15 and 30 years and pasture with 10 years. As a reference, the secondary Caatinga was used. The results show that in soils with sandy texture (*Neossolos Quartzarênico and Regolítico* – Arenosols and Regosols, respectively), there were reductions in SOC levels and carbon in the compartment associated with minerals. The inverse can be observed in the clay-textured *Argissolo* (Acrisols), with 30 years of cultivation, in which there was an increase in SOC and C in the quantitative fractions of soil organic matter. In addition, despite the sandy texture of the *Neossolo Regolítico*, POM levels were increased in the pasture system in comparison to native vegetation, but it was not enough to recover the original SOC content of this system.

**Keywords**: Caatinga. Agriculture. Pasture. Particulate organic matter.

# ESTOQUES DE CARBONO DO SOLO E COMPARTIMENTOS DA MATÉRIA ORGÂNICA SOB SISTEMAS CONVENCIONAIS NO SEMIÁRIDO BRASILEIRO

**RESUMO** – O objetivo deste estudo foi avaliar o efeito da conversão da vegetação nativa secundária (VN) em sistemas convencionais (agricultura e pastagem) no carbono orgânico total (COS) e carbono das frações da matéria orgânica particulada (MOP) e, matéria orgânica associada aos minerais (MOAM) no semiárido brasileiro. O estudo foi realizado nos municípios de Delmiro Gouveia, Inhapi e Pariconha, em Alagoas. Os solos foram coletados nas camadas de 0-0.1, 0.1-0.2 e 0.2-0.3 m. Os tratamentos analisados foram: cultivos agrícolas com 4, 15 e 30 anos e, pastagem com 10 anos. Como referência utilizou-se a Caatinga secundária. Os resultados mostram que em solos com textura mais arenosa (Neossolos Quartzarênico e Regolítico – *Arenosols* e *Regosols*, respectivamente) há reduções nos níveis de COS e carbono no compartimento associada aos minerais. O inverso pode ser observado no Argissolo (*Acrisols*), de textura argilosa com 30 anos de cultivo, o qual ocorreu um aumento no COS e C nas frações quantitativas da matéria orgânica do solo. Além disso, apesar da textura arenosa do Neossolo Regolítico, os níveis de MOP foram aumentados no sistema de pasto em relação à vegetação nativa, todavia não o suficiente para recuperar o conteúdo original de COS desse sistema.

**Palavras-chave**: Caatinga. Agricultura. Pastagem. Matéria orgânica particulada.

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# INTRODUCTION

In the Brazilian semi-arid region, land-use change occurs through deforestation and burning of native vegetation (NV) known as "Caatinga", followed by conventional soil tillage for implementing rainfed agriculture, usually by smallholders who cultivate short-cycle crops, in parallel with extensive livestock farming (MEDEIROS et al., 2020). In addition, this region has short and irregular periods of rainfall and high evapotranspiration and temperature, which limits the production of plant biomass and hampers soil organic matter (SOM) accumulation in these systems (MEDEIROS et al., 2021).

Land-use systems with the burning of NV, intense and continuous conventional soil tillage, monocultures with low input of organic material, and inadequate fallow periods are responsible for the degradation of the physical, chemical and biological properties of soils, which reduces the levels of SOM, and soil organic carbon (SOC) (SANTANA et al., 2019; MEDEIROS et al., 2020). These systems emit large amounts of greenhouse gas (GHG), contributing to global warming.

In this perspective, due to the relationship between increased GHG emissions and climate change, C storage in SOM has been considered an effective strategy to drain atmospheric $CO_2$ (COTRUFO et al., 2019). According to Cambardella and Elliott (1992), in SOM, C can be accumulated both in the labile fraction, defined as particulate organic matter (POM) and in the stable fraction, defined as mineral-associated organic matter (MAOM). POM consists of partially decomposed residues of plants and animals, with many structural compounds of C, which remain in the soil, among other factors, due to the physical protection inside the aggregates and reduction of microbial action (COTRUFO et al., 2019; SOUCÉMARIANADIN et al., 2019). On the other hand, MAOM is formed by microbial compounds that remain in the soil due to the chemical bonding of functional groups of SOM with soil colloids (silt and clay minerals), as well as the physical protection in microaggregates (DUVAL et al., 2018).

However, there divergent results regarding the impact of conventional systems on the levels of POM, MAOM and SOC. For example, Figueiredo, Resck and Carneiro (2010) observed that well-managed pasture promoted increases in SOC, POM and MAOM compared to agricultural systems and NV. On the other hand, Kunde et al. (2016) found reductions in SOC, POM and MAOM in sugarcane areas after 1, 3 and 5 years of use in comparison to NV. However, these results were obtained in the Cerrado and Pampa regions, under soil and climate conditions totally different from those of the Brazilian semi-arid region. For the Brazilian semi-arid region, these data are underrepresented in current research. Maia et al. (2007) observed C losses from the labile fractions (oxidizable C fractions) and stable fractions (humic substances) of SOM in the conventional agricultural system compared to NV and agroforestry systems in the semi-arid region of Ceará. Similarly, Marinho et al. (2016) found significant reductions in SOC, labile and stable fractions of SOM in conventional agriculture compared to NV in the semi-arid region of Rio Grande do Norte. Conversely, Monroe et al. (2021) found increases in SOC and POM/MAOM fractions in irrigated mango areas compared to NV in the semi-arid region of Bahia. Although some studies show that conventional systems affect the SOM dynamics (ASSMANN et al., 2014; DUVAL et al., 2018), in the Brazilian semi-arid region, studies evaluating the impacts caused by these systems on the labile (POM) or stable (MAOM) fractions of SOM are still incipient, so further studies are needed. Therefore, the hypothesis of this study is that the replacement of NV with agricultural crops reduces the input of organic material, negatively affecting the total soil C and granulometric fractions of SOM. Thus, the objective of this study was to evaluate the effect of the conversion of NV to conventional systems (agriculture and pasture) on SOC stocks and on the granulometric fractions (POM and MAOM) of SOM of different soils in the Brazilian semi-arid region.

# MATERIAL AND METHODS

The study was carried out in the municipalities of Delmiro Gouveia, Inhapi and Pariconha, in the state of Alagoas, Brazil (Figure 1).

The climate of the municipalities is hot and dry semi-arid, with an average annual temperature of 28 ºC and average annual rainfall of 550 mm, irregularly distributed between April and August (MAIA et al., 2019). The averages of rainfall and maximum and minimum temperatures of the municipalities where the soils were collected are presented in Figure 2.

All croplands were in production (non-experimental), under rainfed agricultural systems without best management practices such as irrigation, crop rotation, intercropping, fertilizing (organic or inorganic) and crops are chosen randomly, depending on some reasons, such as seed availability, market price, etc., (Table 1). Crop residues are generally available for animal grazing. In general, 2-3 years of fallow are adopted in the areas, followed by mowing, burning of plant biomass and soil tillage, usually performed with animal-drawn plow (conventional tillage), with crops of 4-5 consecutive years. The pasture area had been dominated by Pangola grass (*Digitaria umfolozi* D.W.Hall) for 10 years. However, previously, this area had been cultivated for 30 years with maize and common bean. In each locality, the area of secondary NV was adjacent to the area of cultivation or pasture, being at most 100 m away, in the same position on the relief, with similar soil type and texture.

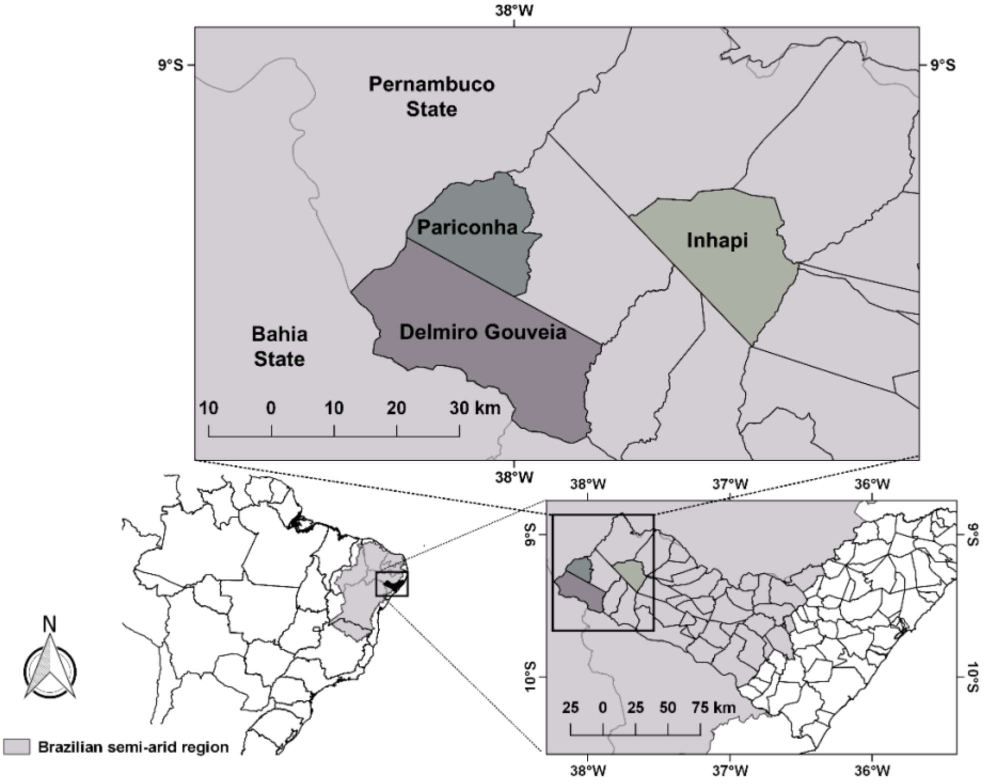

**Figure 1**. Location of the study areas in the semi-arid region of the state of Alagoas, Brazil.

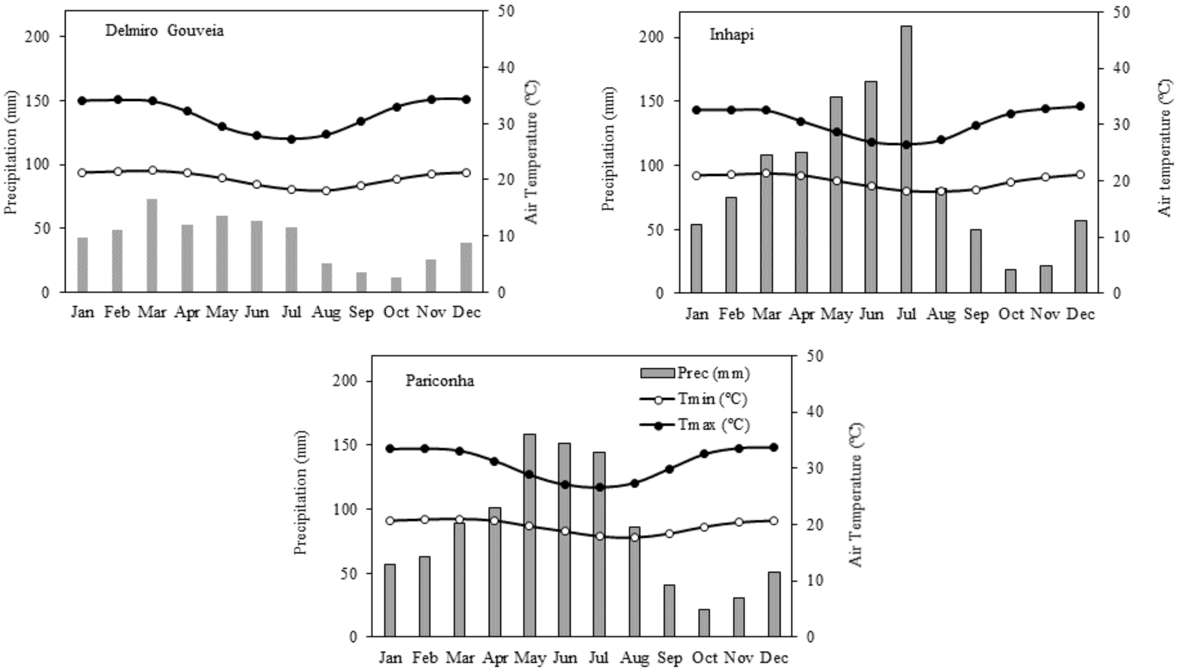

**Figure 2**. Averages of rainfall and temperature of the municipalities studied in the Brazilian semi-arid region.

**Table 1**. Description of soil types, land-use systems and geographic coordinates of the evaluated areas.

| Location | Type of soil | Land-use system | Geographic Coordinates |
|---|---|---|---|
| Delmiro Gouveia | *Neossolo Quartzarênico*[1] (RQ) – Arenosols[2] | Secondary native vegetation (Caatinga) – RQNV, with about 40 years of regeneration. | 09º29'004" S; 37º56'24.3" W, altitude of 255 m |
| | | Agricultural area with four years of cultivation alternated with maize, common bean and cassava - RQCr4. | |
| | | Agricultural area with 15 years of cultivation with maize, common bean and cassava - RQCr15. | |
| Inhapi | *Argissolo* (P) – Acrisols | Secondary native vegetation (Caatinga) – PNV, with about 40 years of regeneration. | 09º12'13.20" S; 37º44'11.44" W, altitude of 320 m |
| | | Agricultural area with 30 years of cultivation alternated with maize and common bean, with maize as the last crop - PCr30. | |
| Pariconha | *Neossolo Regolítico* (RR) – Regosols | Secondary native vegetation (Caatinga) - RRNV, with about 40 years of regeneration. | 09º17'04.7" S, 38º02'43.4" W, altitude of 421 m |
| | | Agricultural area with four years of cultivation alternated with maize and common bean - RRCr4. | |
| | | Pasture area with 10 years of planting - RRPa10. | |

[1] Santos et al. (2013).
[2] IUSS (2022).

In each land-use system (treatments), soil samples were collected at five points, considered as repetitions, which were randomly selected, but always located in the same position of the relief and aiming to obtain the best spatial distribution within each chosen area (native vegetation, agriculture or pasture).

Soil sampling was performed in 2014 and, in agricultural areas, one week prior to soil tillage. Thus, the last soil tillage process occurred one year before sampling. The pasture area was fallow for approximately 4 months, without receiving any type of grazing. Soil samples were collected in layers of 0-0.1, 0.1-0.2 and 0.2-0.3 m. These samples were air-dried and sifted through a 2-mm mesh to remove stones and fragments of branches and roots before analysis. The main physical and chemical characteristics of each type of soil and land-use system are presented in Table 2.

**Table 2**. Physical and chemical characterization of the studied soils in the 0-0.3 m layer.

| Atributes | Soil type/Land-use system | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | *Neossolo Quartzarênico* (Arenosols) | | | *Argissolo* (Acrisols) | | *Neossolo Regolítico* (Regosols) | | |
| | RQNV | RQCr4 | RQCr15 | PNV | PCr30 | RRNV | RRCr4 | RRPa10 |
| Clay (%) | 8.43 | 8.48 | 6.95 | 20.96 | 25.27 | 4.77 | 7.58 | 3.57 |
| Sand (%) | 88.38 | 83.87 | 85.67 | 62.85 | 56.46 | 88.15 | 76.16 | 84.18 |
| Silt (%) | 3.18 | 7.65 | 7.38 | 16.19 | 18.27 | 7.08 | 16.25 | 12.26 |
| Bulk density (g $cm^{-3}$) | 1.42 | 1.49 | 1.42 | 1.45 | 1.44 | 1.52 | 1.51 | 1.60 |
| $Ca^{+2}$ ($cmol_c$ $dm^{-3}$) | 0.59 | 1.23 | 1.55 | 2.13 | 2.57 | 1.26 | 1.15 | 1.56 |
| $Mg^{+2}$ ($cmol_c$ $dm^{-3}$) | 0.13 | 0.21 | 0.47 | 0.63 | 0.72 | 0.44 | 0.35 | 0.29 |
| $K^+$ (mg $kg^{-1}$) | 61.00 | 84.00 | 109.33 | 87.33 | 96.67 | 66.67 | 56.00 | 103.60 |
| $Na^+$ (mg $kg^{-1}$) | 18.67 | 18.67 | 18.67 | 22.67 | 20.67 | 20.00 | 21.33 | 19.33 |
| CEC ($cmol_c$ $dm^{-3}$) | 5.64 | 6.15 | 5.71 | 5.62 | 5.78 | 4.96 | 3.57 | 3.81 |
| pH | 4.41 | 4.61 | 4.95 | 5.47 | 5.85 | 5.23 | 5.39 | 5.92 |

Soil organic carbon (SOC) was quantified by dry combustion in a Flash 2000 elemental analyzer (CHNS) (Thermo Scientific). In each soil layer sampled, bulk density (BD) was determined by the volumetric ring method (EMBRAPA, 2017).

The physical fractionation of SOM was performed by the granulometric method, proposed by Cambardella and Elliott (1992) to determine the C contents in the SOM fractions, particulate organic matter – POM (>53 μm) and mineral-associated organic matter – MAOM (<53 μm). POM contents were determined by wet oxidation of organic matter with 0.167 mol $L^{-1}$ $K_2Cr_2O_7$ in acidic medium (YEOMANS; BREMNER, 1988). MAOM contents were obtained by the difference between SOC and POM values (ASSMANN et al., 2014). The stocks of SOC, POM and MAOM were calculated by multiplying the concentration of C (g $g^{-1}$) of each compartment by BD (g $cm^{-3}$) and layer thickness (m). For the calculation of total carbon stock, the equivalent soil mass (ESM) approach was adopted according to Sisti et al. (2004). Soil under secondary native vegetation was used as a reference for the approach.

Data from the NV areas of each soil type were used in this study to calculate the carbon management index (CMI) of the land-use systems. CMI and its components were calculated according to Assmann et al. (2014). CMI considers POM as the labile fraction and MAOM as the non-labile fraction. CMI and carbon stock index (CSI) and carbon lability index (CLI) were calculated for the 0-0.3 m layer, considering the soil of secondary NV as a reference (CMI = 100 %). Besides that, variations in SOC, POM and MAOM stocks were also calculated in the areas of agriculture and pasture in relation to their reference NV areas.

The study areas were selected considering the homogeneity in the characteristics of soil, relief and proximity between them. The results were subjected to Bartlett's test for homogeneity and the Kolmogorov-Smirnov test for normality. Data were standardized ($\acute{X} = 0.0$ and $s^2 = 1.0$) and subjected to principal component analysis (PCA), calculating linear combinations of original variables obtained through eigenvalue higher than the unit ($\lambda > 1.0$) in correlation matrix, which could explain a percentage higher than 10 % of total variance (GOVAERTS et al., 2007).

Only the variables with a correlation quotient higher than 0.70 were kept in the composition of each principal component (PC) (HAIR et al., 2009). Variables that were not associated with PCs ($r < 0.70$) were removed from standardized database and a new analysis was applied. Afterwards, each principal component was subjected to multivariate analysis of variance (MANOVA) by Hotelling's $T^2$ test. All statistical analyses were performed using the Statistica software (STATSOFT, 2004).

## RESULTS AND DISCUSSION

In *Neossolo Quartzarênico*, the original variables evaluated in the experiment were reduced to two dimensions represented by the first two principal components ($PC_1$ and $PC_2$), with eigenvalues greater than one ($\lambda > 1.00$). $PC_1$ explains 65.55 % of the total variance and $PC_2$ represents 34.45 % of the remaining variance. The results of the analysis of variance for the correlation between the original variables and the principal components (PC) showed that in this soil class, all the variables studied had correlation coefficients greater than 0.90 (Table 3). For the *Argissolo*, $PC_1$ retained 87.30 % of the variance and $PC_2$ contributed with 12.70 % of the remaining variance. In this soil, the factor loadings (r) were greater than 0.80. As for the *Neossolo Regolítico*, $PC_1$ accounts for 69.84 % of this variance and $PC_2$ explains 30.16 %. We found a high correlation ($r > 0.90$) between the original variables and the PCs.

**Table 3**. Eigenvalues, percentage of total explained variance and correlation quotient between the original variables and the principal components.

| | *Neossolo Quartzarênico* (Arenosols) | | *Argissolo* (Acrisols) | | *Neossolo Regolítico* (Regosols) | |
|---|---|---|---|---|---|---|
| | $PC_1$ | $PC_2$ | $PC_1$ | $PC_2$ | $PC_1$ | $PC_2$ |
| λ | 1.97 | 1.03 | 2.62 | 0.38 | 2.10 | 0.90 |
| $s^2$% | 65.55 | 34.45 | 87.30 | 12.70 | 69.84 | 30.16 |
| | Correlation | | Correlation | | Correlation | |
| SOC | 1.00 | 0.04 | -0.99 | 0.12 | -0.99 | 0.13 |
| POM | 0.31 | 0.95 | -0.86 | -0.50 | -0.43 | -0.90 |
| MAOM | 0.94 | -0.35 | -0.94 | 0.34 | -0.96 | 0.27 |

λ: eigenvalues; $s^2$%: percentage of total explained variance.

Figure 3 illustrates the two-dimensional projections of the two principal components ($PC_1$ and $PC_2$). For *Neossolo Quartzarênico*, in $PC_1$ the area of native vegetation (RQNV) in the 0-0.1 and 0.1-0.2 m layers differs from the other systems and soil layers, being formed by increases in POM and SOC. In $PC_2$, the RQNV and RQCr15 systems differ from RQCr4, with an increase in MAOM (Figures 3A and 3B).

In *Neossolo Regolítico*, it is observed that there was a difference only between the soil depths. In $PC_1$, although there was no significant difference between the systems, the RRNV showed a tendency to be superior to the others, with SOC and MAOM prevailing in this principal component. In $PC_2$, the pasture system (RRPa10) differs from the other systems in the 0.1-0.2 and 0.2-0.3 m layers, formed mainly by POM increases (Figures 3C and 3D).

In *Argissolo*, the results of the two-dimensional projections of the $PC_1$ and $PC_2$ components show that there was no significant difference between the land-use systems, but with a tendency to increase in the agricultural area (PCr30). $PC_1$ is characterized by increases in SOC and MAOM, while in $PC_2$ there were increases in POM (Figures 3E and 3F).

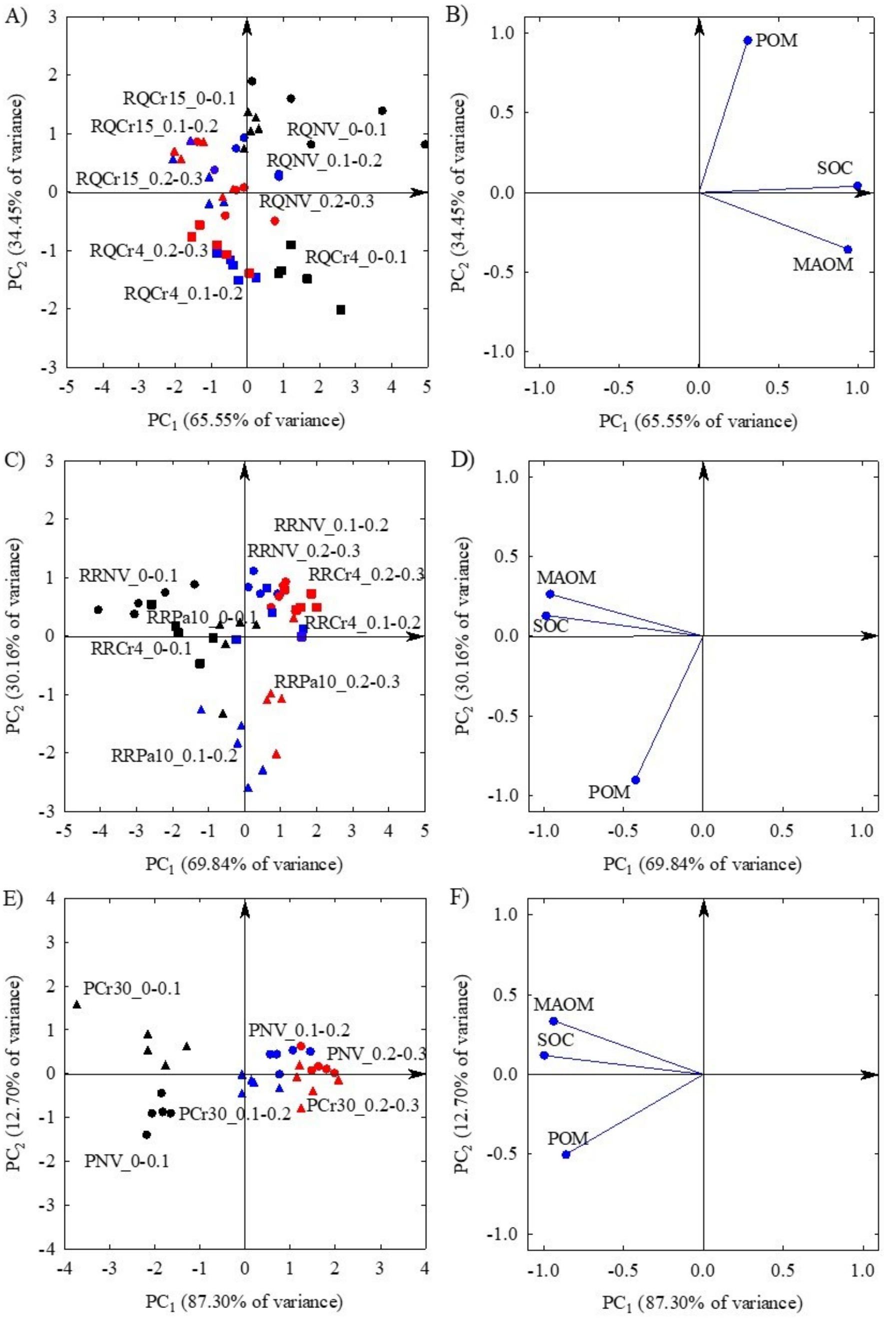

**Figure 3**. Two-dimensional projection of combinations of cropping systems and depths (A, C and E) and of the correlation coefficients between the original variables and the principal components (B, D and F).

The highest values of SOC, POM and MAOM stocks were found in the 0-0.1 m layer, with reductions between layers, in different types of soil and land-use systems (Table 4). In the *Neossolo Quartzarênico*, SOC stocks were higher in the secondary native vegetation area (RQNV), being 34.6 %, 27.9 % and 22 % greater than the agricultural system with 15 years of use (RQCr15) in the 0-0.1, 0.1-0.2 and 0.2-0.3 m layers. When considering the total layer (0-0.3 m), the areas RQCr4 and RQCr15 showed reductions in SOC of 4.1 and 9.7 Mg ha$^{-1}$, respectively, compared to RQNV. For the *Neossolo Regolítico*, the secondary native vegetation area (RRNV) had the highest SOC stocks in all layers, being 16.9 % and 43.4 % higher from systems with 4 years of use (RRCr4) and pasture with 10 years (RRPa10) in the 0-0.1 m layer. Considering the 0-0.3 m layer, the reductions of SOC in the areas RRCr4 and RRPa10 in comparison to RRNV were 7.5 and 11.5 Mg ha$^{-1}$, respectively. In the *Argissolo*, the stocks were higher in the agricultural system (PCr30) compared to NV (PNV), 11.5 %, 11.7 % and 5.5 % higher in the 0-0.1, 0.1-0.2 and 0.2-0.3 m layers, respectively. In the total layer, there was a 4.1 Mg ha$^{-1}$ increase of SOC in PCr30 (Table 4).

As observed in Table 4, in the *Neossolo Quartzarênico*, the highest POM stocks were found in the RQNV area (except in the 0.2-0.3 m layer). In the 0-0.3 m layer the RQCr4 system showed a reduction of 5.8 Mg ha$^{-1}$ in POM, while in RQCr15 it was equal to 1.4 Mg ha$^{-1}$, both in comparison to RQNV. In the *Neossolo Regolítico*, the highest POM stocks were found in the RRPa10 system, in the layers 0.1-0.2 and 0.2-0.3 m. For the total layer, there were increases in POM of 0.5 and 2.9 Mg ha$^{-1}$ in the areas RRCr4 and RRPa10, respectively, compared to RRNV. In the *Argissolo*, POM stocks were higher in the PCr30 system compared to PNV, in the 0.1-0.2 and 0.2-0.3 m layers. For the 0-0.3 m layer, there was an increase of 0.3 Mg ha$^{-1}$ in the agricultural area.

These results denote that the pasture system has higher C stocks in the more labile fraction of SOM (POM) compared to the other systems. Besides, it is noted that in the PCr30 system there was an increase of 3 % compared to PNV, and in the RQCr15 system, despite the loss of POM (18.6 %) compared to RQNV, there was a recovery of 56.9 % compared to the losses that occurred in the RQCr4 system. These data show a POM recovery over time in different soil types; however, as this fraction is more exposed to microbial action in soils with sandy texture, it does not result in increased SOC (except in the PCr30). POM loss may also have been affected by soil moisture, which increased in the agricultural areas (Figure 2), likely stimulating increased POM decomposition.

The pasture area had a higher POM contribution and, in the RQCr15 area, there was a tendency of recovery of this compartment; however, it did not result in the increase of the total C. This response is related to the low clay content of *Neossolos Quartzarênico* and *Regolítico* (Table 2), since clay minerals act in the physicochemical protection of SOM (SIX et al., 2002; BLÉCOURT et al., 2019). Therefore, due to the low clay contents of these soils, consequently the cation contents (such as Ca) are low, which are very important for aggregation and occlusion of this SOM (DUVAL et al., 2018; JENSEN et al., 2019).

The MAOM stocks in the *Neossolo Quartzarênico*, the highest values were found in the RQCr4 system (except in the 0.2-0.3 m layer). In the 0-0.3 m layer, there were increments of 1.7 Mg ha$^{-1}$ in the RQCr4 system and reductions of 8.3 Mg ha$^{-1}$ in the RQCr15 system, in comparison to RQNV. In the *Neossolo Regolítico*, the RRNV system had the highest stocks of MAOM in all layers. The results in the 0-0.3 m layer show reductions in MAOM of 7.9 and 14.4 Mg ha$^{-1}$ in RRCr4 and RRPa10 systems, respectively, when compared to RRNV. In the *Argissolo*, the PCr30 system had the highest MAOM stocks (except in the 0.2-0.3 m layer). In the 0-0.3 m layer, there were increments in MAOM of 3.8 Mg ha$^{-1}$ in the agricultural area compared to NV.

Thus, given the results of the physical fractionation of SOM in the Brazilian semi-arid region, there is greater physicochemical stability in the soil with a more clayey texture in comparison to sandy ones, responsible for the protection of C (OLIVEIRA et al., 2016; JENSEN et al., 2019). These results somehow were already expected, as clay can reduce the rates of SOM mineralization, due to SOM stabilization, through chemical or physical-chemical bonding between OM and soil minerals, such as clay (SIX et al., 2002). In addition, clay contents are often positively associated with SOC level (BLÉCOURT et al., 2019). Therefore, the lower clay contents in *Quartzarênico* and *Regolítico* explain, in part, the higher SOC losses in sandy soils. Site-specific effects such as precipitation and moisture (BLÉCOURT et al., 2019) may also have influenced C losses in these soils (Figure 2).

**Table 4**. Stocks of soil organic carbon (SOC), particulate organic matter (POM) and mineral-associated organic matter (MAOM) in different layers, soil types and land-use systems in the Brazilian semi-arid region.

| Layer (m) | Soil type/Land-use system | | | | |
|---|---|---|---|---|---|
| | *Neossolo Quartzarênico* (Arenosols) | | | *Argissolo* (Acrisols) | |
| | RQNV | RQCr4 | RQCr15 | PNV | PCr30 |
| | SOC (Mg ha$^{-1}$) | | | | |
| 0-0.1 | 14.24 ±3.62* | 12.10 ±1.10 | 9.32 ±0.19 | 18.66 ±0.47 | 20.81 ±2.32 |
| 0.1-0.2 | 9.89 ±1.46 | 9.12 ±0.87 | 7.13 ±1.08 | 11.97 ±0.92 | 13.37 ±1.25 |
| 0.2-0.3 | 9.05 ±1.44 | 7.90 ±1.1 | 7.06 ±1.54 | 9.83 ±0.95 | 10.37 ±1.00 |
| 0-0.3 | 33.18 | 29.12 | 23.51 | 40.46 | 44.55 |
| | *Neossolo Regolítico* (Regosols) | | | | |
| | RRNV | RRCr4 | RRPa10 | | |
| 0-0.1 | 23.47 ±3.55 | 19.49 ±2.29 | 13.28 ±1.40 | | |
| 0.1-0.2 | 11.52 ±1.50 | 10.01 ±3.01 | 11.48 ±2.08 | | |
| 0.2-0.3 | 9.45 ±0.94 | 7.49 ±1.62 | 8.19 ±0.42 | | |
| 0-0.3 | 44.44 | 36.99 | 32.95 | | |
| | POM (Mg ha$^{-1}$) | | | | |
| | *Neossolo Quartzarênico* (Arenosols) | | | *Argissolo* (Acrisols) | |
| | RQNV | RQCr4 | RQCr15 | PNV | PCr30 |
| 0-0.1 | 3.59 ±0.37 | 0.72 ±0.25 | 2.68 ±0.16 | 5.12 ±0.46 | 3.53 ±0.38 |
| 0.1-0.2 | 2.32 ±0.26 | 0.47 ±0.12 | 1.73 ±0.40 | 1.75 ±0.40 | 2.90 ±0.29 |
| 0.2-0.3 | 1.73 ±0.40 | 0.68 ±0.16 | 1.81 ±0.26 | 1.44 ±0.17 | 2.13 ±0.48 |
| 0-0.3 | 7.64 | 1.87 | 6.22 | 8.31 | 8.56 |
| | *Neossolo Regolítico* (Regosols) | | | | |
| | RRNV | RRCr4 | RRPa10 | | |
| 0-0.1 | 1.95 ±0.35 | 2.15 ±0.21 | 1.87 ±0.51 | | |
| 0.1-0.2 | 1.07 ±0.10 | 1.41 ±0.30 | 3.02 ±0.37 | | |
| 0.2-0.3 | 1.05 ±0.17 | 1.00 ±0.15 | 2.12 ±0.61 | | |
| 0-0.3 | 4.07 | 4.56 | 7.01 | | |
| | MAOM (Mg ha$^{-1}$) | | | | |
| | *Neossolo Quartzarênico* (Arenosols) (Arenosols) | | | *Argissolo* (Acrisols) | |
| | RQNV | RQCr4 | RQCr15 | PNV | PCr30 |
| 0-0.1 | 10.65 ±3.51 | 11.38 ±1.32 | 6.64 ±0.31 | 13.53 ±0.53 | 17.27 ±2.23 |
| 0.1-0.2 | 7.57 ±1.43 | 8.65 ±0.95 | 5.40 ±1.24 | 10.21 ±0.70 | 10.46 ±1.05 |
| 0.2-0.3 | 7.32 ±1.70 | 7.22 ±1.30 | 5.24 ±1.61 | 8.39 ±1.00 | 8.23 ±1.00 |
| 0-0.3 | 25.54 | 27.25 | 17.28 | 32.13 | 35.96 |
| | *Neossolo Regolítico* (Regosols) | | | | |
| | RRNV | RRCr4 | RRPa10 | | |
| 0-0.1 | 21.52 ±3.21 | 17.33 ±2.43 | 11.41 ±1.31 | | |
| 0.1-0.2 | 10.45 ±1.50 | 8.59 ±2.88 | 8.46 ±2.34 | | |
| 0.2-0.3 | 8.39 ±0.94 | 6.48 ±1.54 | 6.07 ±0.67 | | |
| 0-0.3 | 40.36 | 32.40 | 25.94 | | |

*Mean values followed by the respective standard deviations.

The results of SOC and MAOM stocks showed that the greatest impacts occur in the 0-0.1 m layer. In the surface soil layer, normally there is greater supply of C by roots and litter, but also greater microbial activity and higher SOM mineralization rates compared to deeper layers (BLÉCOURT et al., 2019) and are due to the major disturbances that occur in this layer (SANTANA et al., 2019). For example, in the pasture area, these impacts are related to the pressure exerted by the animals (OLIVEIRA et al., 2016), which compacts the soil, reducing water infiltration and soil aeration and limiting root development, consequently, the input of SOM (MEDEIROS et al., 2021), and in agricultural areas these impacts are related to conventional management techniques, mainly the soil tillage and decrease of organic matter input (MEDEIROS et al., 2020). This effect has also been observed by de Blécourt et al. (2019) in semi-arid southern Africa, as well as in other Brazilian regions by Kantola, Masters, Delucia (2017), and Santos et al. (2011), who indicated higher losses of C in the surface layer of the soil.

The higher stocks of SOC and MAOM in the NV areas of the *Neossolo Quartzarênico* and *Neossolo Regolítico* occurred due to the absence of anthropic action and the constant input of organic residues to the soil, which favor the maintenance of SOM (SANTOS et al., 2011). On the other hand, the reductions in agricultural areas are related to conventional soil tillage, responsible for the fragmentation of aggregates, which alters their structure and results in the exposure and oxidation of SOM. In addition, the lower input of organic material (SCHIAVO et al., 2011) and edaphoclimatic conditions of the semi-arid region also favor the increase in SOM decomposition rate (FERREIRA et al., 2018; SANTANA et al., 2019), leading to significant reductions of C in these areas.

The granulometry of these soils is also worth to be mentioned, mainly due to the high sand contents in the *Neossolo Quartzarênico* (85.9 %) and *Neossolo Regolítico* (82.8 %) and the low silt and clay contents (Table 2). Low silt and clay contents result in lower physical protection of SOM by soil aggregates (DUVAL et al., 2018) and lower chemical protection due to the lower association of functional groups of SOM with soil colloids (JENSEN et al., 2019). Therefore, in sandy soils, such as *Neossolos Quartzarênico* and *Regolítico*, SOM is more accessible to the action of microorganisms, which facilitates its decomposition (OLIVEIRA et al., 2016).

Conversely, in the *Argissolo*, there were gains in SOC, POM and MAOM in the PCr30 area in comparison to NV (Table 4). The management practices carried out in PCr30 are identical to those performed in the other systems, but with longer cultivation time (30 years), which may have been sufficient to establish a new steady-state and, consequently, the stabilization of C losses. Granulometry may also have contributed to these results, especially by the higher contents of silt (17.2 %) and clay (23.1 %). These characteristics promote in the *Argissolo* greater physicochemical protection of SOM (CONCEIÇÃO et al., 2014).

The POM fraction was also reduced in the agricultural areas of the *Neossolo Quartzarênico* in comparison to the reference (RQNV), while in the *Neossolo Regolítico* there were increments of C in this fraction, mainly in the pasture area. The accelerated reduction of POM compromises the activity of microorganisms and C flow within the system (SOUCÉMARIANADIN et al., 2019). The accumulation of C in this fraction may be related to the addition of plant residues and the physical protection performed by soil aggregates (CAMBARDELLA; ELLIOTT, 1992; ASSMANN et al., 2014; COTRUFO et al., 2019). However, the large increase in the POM fraction in the RRPa10 area occurred probably due to the absence of constant soil tillage, as happens in agricultural areas (SALTON et al., 2011), the release of root exudates from grasses (OLIVEIRA et al., 2016), greater production of plant residues and thin roots with easier decomposition (SANTANA et al., 2019). In addition, this increase in POM in the pasture area must be related to the amount of biomass in this system (MEDEIROS et al., 2021), since according to Sampaio and Costa (2011), native pasture in the Brazilian semi-arid region has an input of 6 Mg ha$^{-1}$ year$^{-1}$ of aboveground biomass, 2 Mg ha$^{-1}$ year$^{-1}$ of belowground biomass and fixation of 120 Tg year$^{-1}$ of C in the biomass, which is greater than the aboveground (4 Mg ha$^{-1}$ year$^{-1}$) and belowground biomass input (1 Mg ha$^{-1}$ year$^{-1}$) and C fixation in the biomass (38 Tg year$^{-1}$) in the area of annual crops. These data confirm the differences in POM results found in this study.

Quantitative evaluation of soil organic matter fractions showed that the MAOM fraction stood out from the POM fraction in all land-use systems, regardless of soil layer or type (Figure 3). For example, in the *Neossolo Quartzarênico*, considering the 0-0.3 m layer, the MAOM fraction represented 93.2 %, 76.7 % and 73.2 % of SOC in the RQCr4, RQNV and RQCr15 systems, respectively. These results are relative since in the RQCr4 system there was a reduction in SOC, but not in MAOM. Therefore, the loss of C (75.5 %) in this system was in the POM fraction (Table 4). This effect can be justified by the short cultivation period (4 years), but the tendency is that if there are no changes in the management to recover POM, the MAOM fraction will also be affected, as can be observed in the RQCr15 system.

In the *Neossolo Regolítico*, MAOM represented 90.3 % of SOC in the RRNV, followed by RRCr4 (86.7 %) and RRPa10 (77.6 %). In the use systems of this soil, SOC stocks were reduced and

POM stocks increased. Thus, the reduction occurred in the MAOM, which is the most stable fraction of SOM. Despite the increments in POM, they were not sufficient to promote the increase in SOC, probably due to the lability of C in this fraction and the effect of the management adopted in these systems. The MAOM fraction was similar among the systems in the *Argissolo*, and the contribution of this fraction to SOC was 81.0 % in PNV and 80.2 % in PCr30, evidencing the greater stability of this soil for agricultural cultivation compared to the others.

The MAOM fraction was the main compartment in terms of quantity of C in all soils, with an average contribution ranging from 76.5 % to 93.2 %, depending on soil and land use (Figure 4). This fraction is composed of organic residues closely linked to the mineral fraction with a high degree of humification (CAMBARDELLA; ELLIOTT, 1992; COTRUFO et al., 2019). Thus, this chemical bond forms organomineral complexes and their location within soil microaggregates makes this SOM fraction highly stable (SANTOS et al., 2011). According to Figueiredo, Resck and Carneiro (2010), the biological oxidation of SOM reduces POM, and part of this C is converted to MAOM, which further accentuates the discrepancy between the C contents of these two fractions in this study. Although POM has contributed less than MAOM to SOC, this fraction is essential because both it serves as a bond for the more stabilized fraction of SOM (FIGUEIREDO; RESCK; CARNEIRO, 2010), provides energy for microorganisms associated with the humification process (CAMBARDELLA; ELLIOTT, 1992) and it is a very sensitive indicator of the effect of management on SOC (SOUCÉMARIANADIN et al., 2019). The POM also serves as an indicator of the amount of waste with the potential to be converted into more recalcitrant materials, such as the MAOM (CONCEIÇÃO et al., 2014).

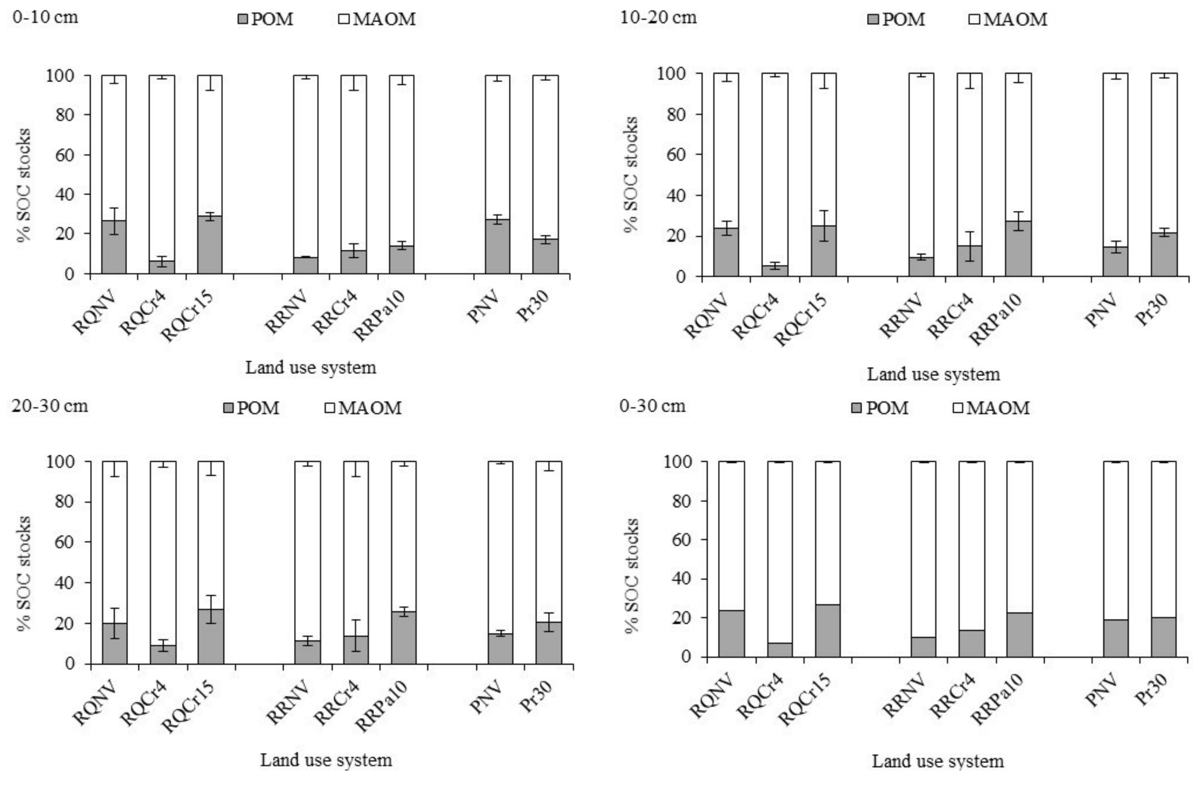

**Figure 4**. Proportion of particulate organic matter carbon (POM) and mineral-associated carbon (MAOM) in soil organic carbon (SOC) in the different land-use systems in the Brazilian semi-arid region.

The results show that in the *Neossolo Quartzarênico*, the RQCr4 system had the lowest CMI (20.1 %), while the CMI of 85.3 % was found in the RQCr15 system. The highest CMI values were found in the *Neossolo Regolítico*, equal to 112.0 % and 172.2 % in RRCr4 and RRPa10, respectively. In the *Argissolo*, the PCr30 had CMI of 101.3 % (Figure 5).

The CMI has been used by some researchers (SCHIAVO et al., 2011; ASSMANN et al., 2014; CONCEIÇÃO et al., 2014) to evaluate the impacts of agricultural systems on the dynamics and quality of SOM, in addition to soil management, because the higher the CMI value, the higher the quality of management and of SOM, and the opposite is also true. Conceição et al. (2014) report that CMI makes it possible to evaluate, at the same time, the effect of agricultural systems on the quantity and quality (lability) of SOM.

The CMI in the RQCr4 system was very low, meaning that the quality of SOM in this type of soil is already affected in the first years of planting, and over time there is a trend of recovery, being evidenced by CMI in the area with 15 years of use. In the *Neossolo Regolítico*, the pasture system had very high CMI, and this effect is related to the higher POM values. As this fraction corresponds to organic residues >53μm, its predominance in the pasture area probably occurs also because of the lower rate of decomposition of SOM in this system (CONCEIÇÃO et al., 2014). Furthermore, the higher POM and CMI values in the pasture area are probably related to the higher input of grass root biomass, which is important for SOM stabilization. According to Rasse, Rumpel and Dignac (2005), the residence time of C in roots is 2.4 times longer than C in aboveground biomass. The authors also emphasize that the root system also acts in the physicochemical protection of SOM through the activities of mycorrhiza and root hairs, especially in deeper horizons and chemical interactions with metal ions. Convergent results were reported by Santana et al. (2019), who found the highest concentrations of C in pasture areas compared to agricultural areas in the Brazilian semi-arid region. The authors highlight the importance of the root system of pastures, especially fine roots, which are easily decomposed for the stabilization of SOM. Adequate levels of POM are important because they ensure the flow of C in the soil and biological activity, resulting in the availability of nutrients to plants (SALTON et al., 2011).

As for the stability of SOM in the *Argissolo*, the CMI obtained in the PCr30 system was very close to that of the reference. This effect can be attributed to the greater physicochemical stability of this type of soil, corroborated by the values of SOC, MAOM and POM. Moreover, in PCr30, there was probably a new steady-state, for both SOC and SOM fractions (MAOM and POM), that is, the 30 years of cultivation allowed the C of fractions to rebalance, because the data of the other areas with shorter time of use and of other studies (OLIVEIRA et al., 2016; FERREIRA et al., 2018; SANTANA et al., 2019) using soils with a texture similar to that of PCr30 denote that, in general, there are losses in shorter cultivation periods.

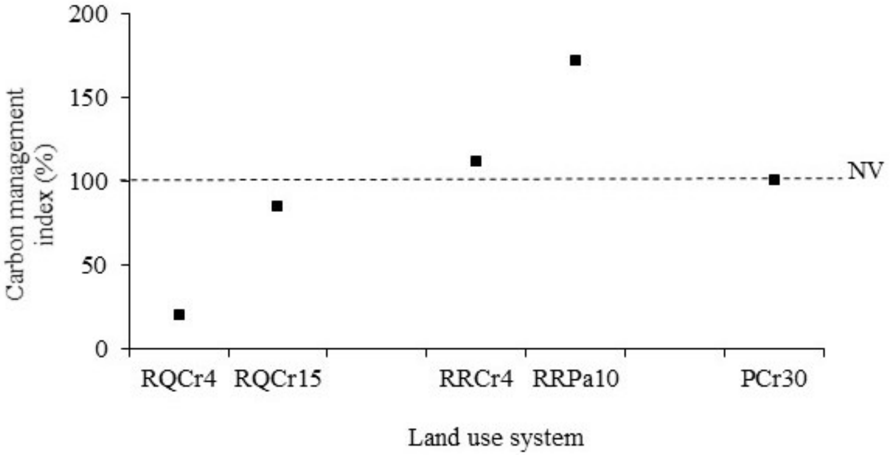

**Figure 5**. Carbon management index for the different types of soils and land-use systems in the Brazilian semi-arid region.

The values of SOC, POM and MAOM stocks of the secondary native vegetation areas were considered as initial C stocks and those of the agricultural areas as final C stocks. Considering the variations promoted by the types of land use and time of planting on SOC and the granulometric fractions of SOM (POM and MAOM), in the *Neossolo Quartzarênico*, all the converted areas had their stocks reduced, except for MAOM in the RQCr4. It is worth mentioning the trend of significant reduction in SOC and MAOM over time in agricultural areas. The variations of stocks in the *Neossolo Regolítico* showed reductions only in SOC and MAOM, with a tendency of increase in the losses over time. In addition, there was a significant increase in POM stocks in the RRPa10 system. For the *Argissolo*, the results of stock variations showed only gains of C, mainly in SOC and MAOM fraction (Figure 6).

The reductions in C stocks observed in the agricultural areas of the *Neossolo Quartzarênico* are related to the fragility of this soil in terms of physicochemical protection of SOM, due to the higher content of sand compared to those of silt and clay. Moreover, in the area in which this type of soil is located, an average annual rainfall of only 500 mm (Figure 2) was recorded, which leads to lower biomass input.

The results of stock variations in the *Neossolo Regolítico* show that in this soil there is an increase in the C levels of the most labile fraction of SOM (POM), which may be associated with the greater amount of rainfall in the region (900 mm). However, it does not contribute to the increase in SOC, probably because of the predominance of sand, resulting in lower formation of stable soil aggregates and, consequently, in low protection of SOM.

On the other hand, the *Argissolo* showed only gain of C, regardless of the evaluated compartment, confirming the greater stability of its organic matter in comparison to the others. It is also worth pointing out that the area where this soil is located had the highest average rainfall (1,100 mm), resulting in the increase in plant biomass production and greater input of organic residues, consequently leading to greater amount of C in the soil (SANTANA et al., 2019).

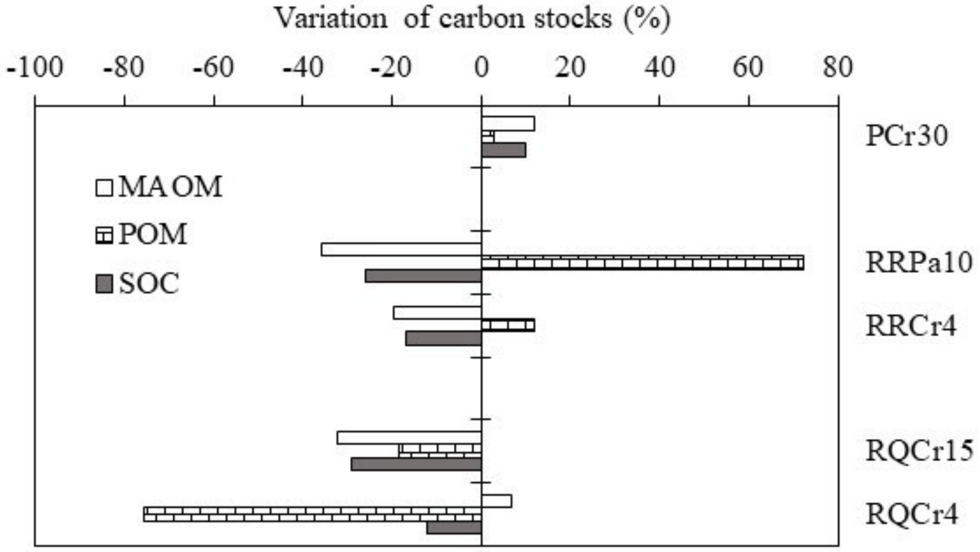

**Figure 6**. Variation of carbon stocks of SOM granulometric compartments (POM and MAOM) and SOC in comparison to native vegetation areas in the 0-0.3 m layer, in the Brazilian semi-arid region.

## CONCLUSION

In the soils with sandy texture (*Neossolos Quartzarênico* – Arenosols and *Regolítico* - Regosols), there were reductions in SOC levels and MAOM compartment, while in the clay-textured *Argissolo* (Acrisols) with 30 years of cultivation there was an increase in the total organic carbon and quantitative carbon fractions of organic matter in the soil. In addition, despite the sandy texture of the *Neossolo Regolítico*, POM levels were increased in the pasture system, but it was not enough to recover the original SOC content of this system.

There was a greater proportion of carbon bound to the fraction associated with minerals than in the particulate fraction. The CMI results indicate that in the *Neossolo Quartzarênico* the area of agriculture with 4 years of use reduces the quality of SOM, while the area with 15 years shows a trend of recovery of its quality, similar to what occurs in the agricultural area with 30 years in the *Argissolo*. In the *Neossolo Regolítico*, the results denote that, over time, the POM can be recovered in the agricultural system.

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