Universidade Federal Rural do Semi-Árido
Pró-Reitoria de Pesquisa e Pós-Graduação
https://periodicos.ufersa.edu.br/index.php/caatinga
ISSN 1983-2125 (online)

http://dx.doi.org/10.1590/1983-21252025v3812508rc

Scientific Article

Soil aggregation and organic carbon under different management systems in the cerrado of Mato Grosso

Agregação do solo e carbono orgânico sob diferentes sistemas de manejos no cerrado mato-grossense

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ABSTRACT - Soil organic matter is one of the most important indicators of the quality and sustainability of native and cultivated ecosystems, as it influences the chemical and physical properties of the soil, such as cation exchange capacity, aggregation, water retention, and supply of nutrients to plants. This study evaluated the physical properties and distribution of organic carbon in soil aggregates under different management practices. Disturbed and undisturbed soil samples were collected in the 0.0-0.1 m, 0.1-0.2 m, and 0.2-0.3 m layers under conservationist (rainfed and irrigated) and conventional (rainfed) management. The chemical properties and particle size, soil density, and organic carbon content in macro and microaggregates were assessed for the three management types. For conservationist management, in addition to these analyses, the weighted mean diameter, geometric mean diameter, aggregate stability index, and total soil porosity were determined. The data were analyzed using the Kruskal-Wallis test and the t-test, as there was no experimental design, and some of the data did not meet the normality test (Shapiro-Wilk). Soil density and total porosity did not differ for conservationist management (rainfed and irrigated). The irrigated conservationist management exhibited aggregates with larger weighted and geometric mean diameters and a higher aggregate stability index. Conservationist management (rainfed and irrigated) showed higher organic carbon contents in macro and microaggregates.

Keywords: Organic matter. Crop rotation. Cover Plants.

RESUMO - A Matéria Orgânica do Solo, é um dos mais importantes indicadores da qualidade e sustentabilidade dos ecossistemas nativos e cultivados, pois influencia os atributos químicos e físicos do solo, como a capacidade de troca catiônica, a agregação, a retenção de água e o fornecimento de nutrientes para as plantas. Este estudo teve por objetivo, avaliar os atributos físicos e a distribuição do carbono orgânico nos agregados de solos sob diferentes manejos. Foram coletadas amostras de solo deformadas e indeformadas nas camadas de 0-0,1 m; 0,1-0,2 m e 0,2-0,3 m, em manejos de produção conservacionistas (sequeiro e irrigado) e manejo de produção não conservacionista (sequeiro). Avaliou-se os atributos químicos, granulométricos, a densidade do solo e os teores de carbono orgânico nos macro e microagregados para os três manejos. Para os manejos de produção conservacionistas, além dessas análises, realizou-se a determinação do diâmetro médio ponderado, do diâmetro médio geométrico, do índice de estabilidade de agregados e da porosidade total do solo. Os dados foram analisados por meio dos testes Kruskal -Wallis e teste t, devido à ausência de delineamento experimental, e por parte dos dados, não atenderem o teste de Normalidade (Shapiro-Wilk). A densidade e a porosidade total do solo não diferiram nos manejos conservacionistas (sequeiro e irrigado). O manejo conservacionista irrigado teve agregados com maiores diâmetros médios ponderado e geométrico, e maior índice de estabilidade de agregados. Os manejos conservacionistas (sequeiro e irrigado) tiveram maiores teores de carbono orgânico nos macros e microagregados.

Palavras-chaves: Matéria orgânica. Rotação de culturas. Plantas de cobertura.

Conflict of interest: The authors declare no conflict of interest related to the publication of this manuscript.

Received for publication in: February 18, 2024.
Accepted in: June 18, 2024.

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INTRODUCTION

In recent decades, the conversion of native areas to agriculture has intensified in the Central region of Brazil, especially in the state of Mato Grosso, and has brought with it a worrying 24% to 52% reduction in soil organic carbon, according to estimates by Santos et al. (2019a). Faced with this challenge, the agricultural sector has been seeking more sustainable production models, such as conservationist agriculture, which is a production model that prioritizes techniques to improve soil health in all aspects (chemical, physical, and biological).

Soil organic carbon, the main component of Soil Organic Matter (SOM), plays a vital role in the sustainability of the agricultural ecosystem due to its capacity to support soil ecosystem services worldwide (LAVALLEE; SOONG; COTRUFO, 2020). Maintaining and increasing SOM is a slow process and requires appropriate management, particularly in tropical regions where the decomposition rate is accelerated by climatic conditions (SANTINI et al., 2019).

The relationship among soil biological activity, decomposition, and stabilization of SOM, and soil aggregation has been widely recognized since the last century (BRONIK; LAL, 2005). Factors such as texture, clay mineralogy, cation content, aluminum, iron oxides, and organic matter influence the stability of aggregates (AMÉZKETA, 1999).

Soil aggregation is an important indicator of soil physical quality and positively correlates with SOM levels (KING et al., 2020). Aggregates interfere with the dynamics of water, gases, and root penetration, influencing the long-term sustainability of the soil (RABOT et al., 2018). Conservationist systems, such as regeneration, favor aggregate stability and carbon retention in the soil (ROSSI et al., 2016).

In addition, practices such as irrigation can increase biomass production and soil microbial activity, promoting greater aggregate stability and increased organic carbon content (SEBEN JUNIOR; CORÁ; LAL, 2016). Applying organic waste can also influence the formation of biogenic aggregates, contributing to soil health (PEREIRA et al., 2021).

Research into soil aggregation and organic carbon is vital to understanding how different management practices affect soil structure and carbon retention. This is particularly relevant in the Cerrado of Mato Grosso, a key agricultural region in Brazil, where land conversion and inadequate management practices can lead to significant losses of soil organic carbon, compromising soil fertility and long-term sustainability.

This study aimed to evaluate how different agricultural management systems influence soil physical attributes, aggregation, and the distribution of organic carbon in soil aggregates under irrigation (using fertigation for 20 years) and rainfed cultivation.

MATERIAL AND METHODS

Study sites

This study was conducted at the Capuaba Farm, located at 13º17'15.072" S, 56º05'11.436" W (Figure 1), and an altitude of 425 meters, in Lucas do Rio Verde, state of Mato Grosso. According to the Brazilian Soil Classification System, the farm is located in the Cerrado biome and has soil identified as Latossolo Vermelho Amarelo distrófico with a very clayey texture (SANTOS et al., 2018). According to Alvares et al. (2013), the climate of this region is characterized as tropical savannah (Aw-type in the Köppen-Geiger climate classification), with an average annual temperature of 25.4°C and an average annual rainfall of 1,451 mm, whose particle size and chemical characteristics are shown in Table 2.

The second area, in the Girassol Farm, is located at 16º52'30.626" S, 54º1'4.843" W (Figure 1), and an altitude of 720 meters, in Pedra Preta, state of Mato Grosso. According to the Brazilian Soil Classification System, the farm is located in the Cerrado biome and has soil identified as Latossolo Vermelho distrófico with a clayey texture (SANTOS et al., 2018). According to Alvares et al. (2013), the climate of this region is characterized as tropical savannah (Aw-type in the Köppen Geiger climate classification), with an average annual temperature of 22.0°C and an average annual rainfall of 1,950 mm, the particle size and chemical characteristics are shown in Table 2.

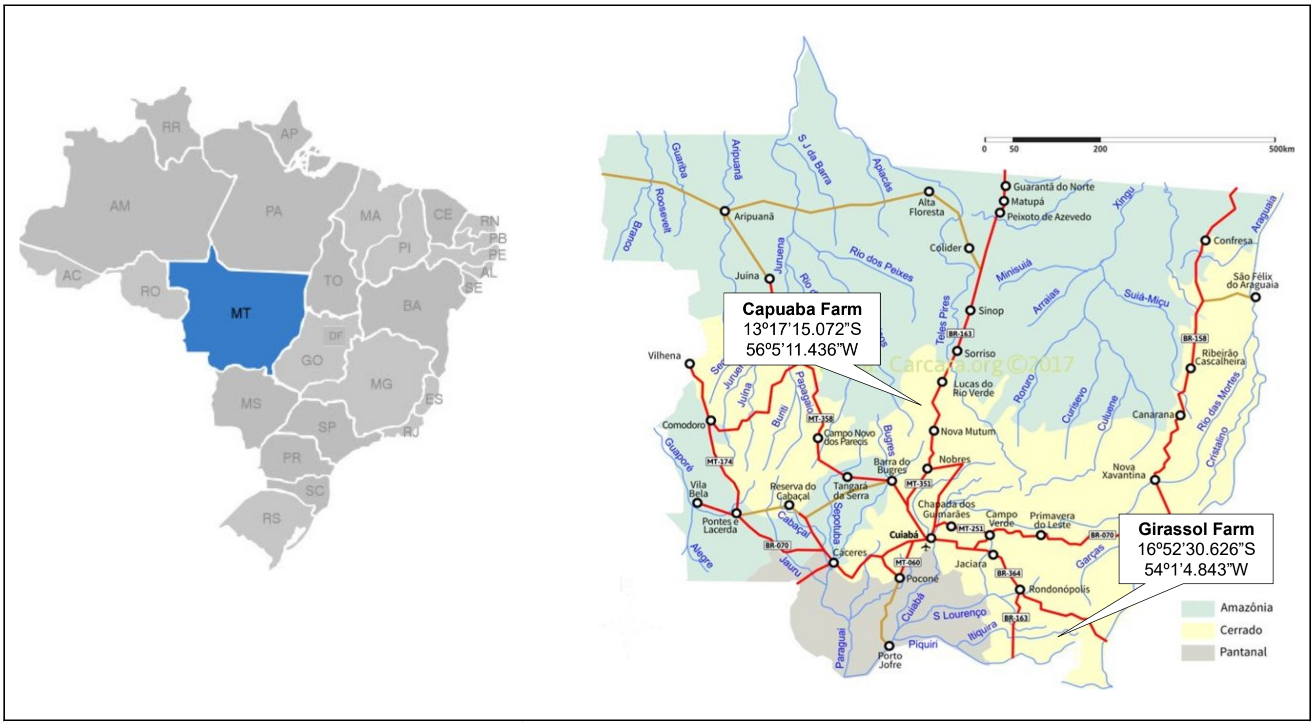

Figure 1. Location of study areas: Capuaba Farm (Lucas do Rio Verde) and Girassol Farm (Pedra Preta), MT, Brazil.

The management used at the Capuaba Farm has conservationist characteristics compared to that used at the Girassol Farm. These characteristics include: greater crop diversification, increased use of cover crops in the off-season, intercropping in the production system, mainly with grasses, and no disturbing soil with plows or harrows over the last thirty years.

The study areas were identified as follows: Capuaba Farm with irrigated conservationist management (ICM), Capuaba Farm with rainfed conservationist management (RCM), and Girassol Farm with rainfed non-conservationist management (RNCM). A detailed history of each area is provided in Table 1.

Table 1. Crop sequence in the study areas (2018-2022). Capuaba Farm, municipality of Lucas do Rio Verde, and Girassol Farm, municipality of Pedra Preta, MT, Brazil.

Crop season	CM (Capuaba farm)				NCM (Girassol farm)	
	Irrigated		Rainfed		Rainfed	
	1ª Crop	2ª Crop	1ª Crop	2ª Crop	1ª Crop	2ª Crop
2017/2018	Soybean	Corn + *U. plantaginea*	Rice	Cover crops intercropping	Soybean	Cotton
2018/2019	Soybean	Rice	Soybean	corn + *U. plantaginea*	Soybean	Cotton
2019/2020	Soybean	Corn + *U. plantaginea*	Soybean	corn + *U. plantaginea*	Soybean	Cotton
2020/2021	Soybean	Corn/chia	Soybean	Cover crops intercropping	Soybean	Corn
2021/2022	Soybean	Corn + *U. plantaginea*	Rice	Fodder radish	Soybean	Corn

Collection and preparation of samples for analysis of the soil physical and chemical attributes

The soil samples were collected in 2022 between July and August. Disturbed soil samples were collected using a straight shovel in the 0.0-0.1 m, 0.1-0.2 m, and 0.2-0.3 m layers in each area at georeferenced points. At the Capuaba farm, 30 points were collected (15 in the irrigated area and 15 in the rainfed area) and 20 at the Girassol farm. The samples were used for particle size and chemical characterization and for determining aggregate stability and soil aggregate carbon. The results of the particle size and chemical characteristics of the soils are shown in Table 2.

Table 2. Particle size, pH, Organic Matter (OM), Al, H, H+Al, P, K, Ca, Mg, the sum of bases (SB), cation exchange capacity (T), and base saturation (V) of the soils studied in the 0.0-0.3 m layer in 2022.

Area	Layer	Sand	Silt	Clay	pH	Al	H	H+Al
	m	---------------- g kg^{-1} ----------------			$CaCl_2$	---------- $cmol_c\ dm^{-3}$ ----------		
ICM	0.0 – 0.1	173	83	744	5.11	0.00	3.59	3.59
	0.1 – 0.2	151	76	773	4.37	0.37	4.79	5.16
	0.2 – 0.3	130	85	785	4.43	0.29	3.98	4.27
RCM	0.0 – 0.1	215	78	707	5.42	0.00	2.74	2.74
	0.1 – 0.2	193	78	729	4.53	0.15	3.96	4.11
	0.2 – 0.3	177	77	746	4.63	0.11	3.31	3.42
RNCM	0.0 – 0.1	362	71	566	5.11	0.00	3.50	3.50
	0.1 – 0.2	355	71	574	4.72	0.07	4.18	4.25
	0.2 – 0.3	343	70	587	4.73	0.07	3.69	3.76

Area	Layer	OM	P_{resin}	K	Ca	Mg	SB	T	V
	m	g kg^{-1}	mg dm^{-3}	---------------------- $cmol_c\ dm^{-3}$ ----------------------					%
ICM	0.0 – 0.1	30.01	67.00	0.12	4.09	0.97	5.18	8.77	59.0
	0.1 – 0.2	20.16	17.20	0.07	1.08	0.25	1.40	6.56	21.3
	0.2 – 0.3	10.77	04.59	0.06	0.64	0.18	0.88	5.15	17.3
RCM	0.0 – 0.1	20.89	43.09	0.21	4.14	1.04	5.39	8.13	65.5
	0.1 – 0.2	20.02	10.72	0.10	1.27	0.25	1.62	5.73	28.4
	0.2 – 0.3	10.71	02.64	0.09	0.70	0.15	0.94	4.36	21.7
RNCM	0.0 – 0.1	20.96	27.98	0.17	4.05	1.35	5.56	9.06	61.2
	0.1 – 0.2	20.31	22.32	0.10	2.77	0.77	3.63	7.88	46.1
	0.2 – 0.3	10.88	09.99	0.08	1.97	0.54	2.59	6.35	40.7

ICM = Capuaba Farm with irrigated conservationist management; RCM = Capuaba Farm with rainfed conservationist management; RNCM = Girassol Farm with rainfed non-conservationist management (RNCM).

To determine soil density, undisturbed samples were collected using Kopeck-type rings with $50cm^3$ from the 0-0.1 m, 0.1-0.2 m, and 0.2-0.3 m layers from 30 points at the Capuaba farm (15 points on the ICM and 15 points on the RCM) and 20 points on the RNCM at the Girassol Farm.

After collection, the samples were packed in plastic bags (disturbed samples) and aluminum cans (undisturbed samples), duly identified, and sent to the Soil Fertility Laboratory of the Federal University of Mato Grosso in Cuiabá, MT.

In the laboratory, the disturbed samples were air dried and crumbled manually, respecting the points of weakness of the aggregates, then crumbled and sieved using 4 mm and 2 mm sieves, obtaining the aggregate classes.

The undisturbed samples were removed from the volumetric ring and dried in an oven at 105ºC until a constant weight was achieved to calculate the soil density. Determining soil density, particle density, and total porosity followed the methods in Embrapa (1997).

For the aggregate stability analysis, wet sieving was conducted using samples with an average diameter of 3 mm (4 mm > Ø < 2 mm). Of this class of aggregates, 50 g were weighed for wet sieving and 20 g for calculating the moisture content of each sample. Two repetitions were conducted per sample.

The 50 g samples were pre-moistened on a sheet of filter paper and then placed on a set of sieves (2.0, 1.0, 0.5, 0.25, and 0.125 mm) in a Yoder immersion shaker. This set was subjected to vertical wet sieving at 42 cycles per minute for four minutes. After this period, the material retained on each sieve was removed, placed in previously weighed containers, identified, and taken to the oven at 105ºC until a constant dry mass was obtained (EMBRAPA, 1997). The mass of aggregates with particles smaller than 0.125 mm was obtained from the difference between the total dry mass and the dry mass retained on the sieves.

From the mass of aggregates retained on each sieve, the weighted mean diameter (WAD), geometric mean diameter (GMD), and aggregate stability index (ASI) were calculated. To calculate the aggregate stability index (ASI), the data generated under wet conditions were considered according to Castro Filho, Muzilli, and Podanoschi (1998) methodology.

The percentage of macroaggregates (Ø ≥ 0.25 mm) and microaggregates (Ø < 0.25 mm) was obtained by weighing 50 g of the sample that had passed the 2 mm sieve, after which this mass was sieved using the 0.25 mm sieve and the macro and microaggregates were obtained and weighed on an analytical balance. The percentage of macroaggregates and microaggregates in the samples was calculated using a simple rule of three.

The organic carbon content in macro and micro aggregates was quantified by wet oxidation with potassium dichromate ($K_2Cr_2O_7$) in an acidic medium, according to the method of Yeomans and Bremner (1988).

The Kruskal-Wallis test (analysis of three variables) and the t-test (analysis of two variables) were used in the statistical analysis of the data. These tests were chosen due to the absence of an experimental design and because some of the data did not meet the Normality test (Shapiro Wilk). To separate the data, multiple factor comparisons were conducted ($p<0.05$). All the analyses were conducted using Jamovi software (2022).

RESULTS AND DISCUSSION

Soil physical attributes under different management

The physical attributes of the soil were analyzed under different managements, specifically comparing irrigated conservationist management (ICM) and rainfed conservationist management (RCM). The results showed no significant differences in soil density (SD) and total porosity (TP) between the two types of management in the layers studied (Table 3). Both managements showed SD values considered not very restrictive for water and air permeability and root penetration.

Table 3. Mean and standard deviation of soil density (g cm^{-3}) and total porosity (m^3 m^{-3}) in three soil layers in the conservationist management.

Management	Soil Density (g cm^{-3})	Total Porosity (m^3 m^{-3})
	0.00 – 0.10 m	
ICM	1.131 ± 0.076 a	0.569 ± 0.045 a
RCM	1.082 ± 0.080 a	0.582 ± 0.032 a
	0.10 – 0.20 m	
ICM	1.145 ± 0.057 a	0.518 ± 0.157 a
RCM	1.165 ± 0.054 a	0.528 ± 0.028 a
	0.20 – 0.30 m	
ICM	1.205 ± 0.065 a	0.541 ± 0.046 a
RCM	1.196 ± 0.058 a	0.493 ± 0.052 a

Different letters in the columns indicate differences using the t-test for paired samples ($p<0.05$).

According to Reichert, Reinert, and Braida (2003), the critical range of soil density varies according to textural class: 1.25 to 1.30 kg dm^{-3} for very clayey soils; 1.30 to 1.40 kg dm^{-3} for clayey soils; 1.40 to 1.50 kg dm^{-3} for loamy soils; and 1.70 to 1.80 kg dm^{-3} for sandy loam soils. Both areas studied (ICM and RCM) are classified as very clayey soils (Table 2).

SD and TP were expected to show differences between the production models due to the greater availability of water and greater microbial activity in the ICM. Gong et al. (2015)

point out that irrigation interferes with the dynamics of SOM and that irrigated areas tend to have higher microbial activity because soil moisture remains close to field capacity over the year. However, the SD and TP results showed equality between ICM and RCM. This can be attributed to the conservationist management adopted in both areas several years ago, which includes no soil tilling, direct sowing, crop diversity, cover crops in the off-season, and intercropping with grasses (Table 1).

These managements aim to increase the contribution of SOM, both in depth with the development of roots and on the surface with the deposition of crop residues. Zheng et al. (2018) state that crop residues favor the formation of macroaggregates and are a carbon source for microbial activity. In addition, the frequent use of *Urochloa* grass as a ground cover plant or in intercropping with corn in the second crop may have contributed to the lack of differentiation in the systems regarding carbon. Santos et al. (2019b) observed lower soil density values in areas with *Urochloa* due to the intense action of the roots, which produce a large amount of biomass and form channels that increase the soil permeability.

The weighted mean diameter (WAD), geometric mean diameter (GMD), and aggregate stability index (ASI) showed differences between ICM and RCM in the 0.0-0.1 m layer. Still, they were similar in the 0.1-0.2 m layer (Table 4).

Table 4. Mean and standard deviation of weighted mean diameter (WAD), geometric mean diameter (GMD), and aggregate stability index (ASI) in two soil layers under irrigated (ICM) and rainfed (RCM) cropping systems.

Management	WMD (mm)	GMD (mm)	ASI (%)
		0.00 – 0.10 m	
ICM	1.52 ± 0.26 a	1.19 ± 0.65 a	92.27 ± 2.78 a
RCM	1.29 ± 0.36 b	0.65 ± 0.36 b	88.76 ± 4.41 b
		0.10 – 0.20 m	
ICM	1.30 ± 0.19 a	0.78 ± 0.25 a	92.94 ± 4.96 a
RCM	1.26 ± 0.26 a	0.72 ± 0.49 a	88.34 ± 11.00 a

Different letters in the columns indicate differences by the t-test between the management systems ($p<0.05$).

In the 0-0.1 m layer, the irrigated conservationist management (ICM) had a 16.3% higher weighted mean diameter (WAD), a 76.9% higher geometric mean diameter (GMD), and a 3.7% higher aggregate stability index (ASI) compared to the rainfed conservationist management (RCM) (Table 4). This difference can be attributed to water availability in the ICM, which favors the formation of more stable aggregates. Torres, Rodrigues Junior, and Vieira (2013) also concluded that irrigation positively impacts the increase in aggregate diameter compared to non-irrigated pasture areas. According to the authors, the root development of *Urochloa* in irrigated areas promotes soil aggregation by approximating mineral particles during root growth and the release of organic exudates.

Pires and Bacchi (2010) showed that wetting and drying cycles promote greater soil particle cohesion, increasing aggregate stability in irrigated areas. In the ICM, *Urochloa* is systematically used as a cover plant, unlike in the CSM (Table 1), which corroborates the findings of Loss et al. (2011), who observed higher values of WMD and GMD of aggregates in areas under integrated crop livestock system (ICLS), showing that integrated systems have the potential to improve the structural quality of the soil. This suggests that in the irrigated conservationist management system (ICM), the intense use of manure for 20 years may have favored the formation of biogenic aggregates due to the greater contribution of humic substances, which improve the degree of soil structuring and favor an increase in aggregate size (TAVARES et al., 2019). According to Pereira et al. (2021), biogenic aggregation brings benefits in increased organic matter content at different decomposition levels. This enrichment of the soil in organic matter occurs not only because of its concentration in these aggregates but also because it promotes greater stability in the water of the aggregates, which favors the protection and accumulation of organic matter.

These results underline the importance of management practices that promote the formation of biogenic aggregates to improve soil structure and increase carbon retention and overall soil fertility, contributing to more sustainable agriculture.

Organic carbon in macro and microaggregates under different production models

The analysis results of the different soil management systems showed significant variations in the proportions of macroaggregates and microaggregates at the different layers studied. In the 0.00-0.10 m layer, the rainfed non-conservationist management system (RNCM) showed a significantly higher percentage of macroaggregates (75.0%) compared to the irrigation conservationist management (ICM) and rainfed conservationist management (RCM), which showed 66.0% and 63.0%, respectively. Consequently, the proportion of microaggregates was lower in RNCM (25.0%) compared to ICM (34.0%) and RCM (37.0%).

This pattern was maintained in the 0.10-0.20 m soil layer, where RNCM also had the highest proportion of macroaggregates (78.0%), followed by ICM and RCM (66.0%). The proportion of microaggregates was lower in RNCM (22.0%) than in ICM and RCM (34.0%). At the 0.20-0.30 m layer, the RNCM had the highest proportion of macroaggregates (78.0%), while the ICM and RCM had similar proportions of macroaggregates (71.0% and 72.0%, respectively). The proportion of microaggregates followed the trend, being lower in RNCM (23.0%) and higher in ICM (29.0%) and RCM (28.0%).

These results indicate that the rainfed conservationist management (RNCM) has heavier aggregates. On the other hand, there were no significant differences between the irrigated (ICM) and rainfed (RCM) conservationist management systems, suggesting that irrigation did not have a significant impact on the proportion of macro and microaggregates in these systems (Table 5).

The results in Table 5 show that rainfed non-conservationist management (RNCM) had the highest percentages of macroaggregates in all soil layers and that there were no significant differences between ICM and RCM regarding macroaggregates and microaggregates.

Table 5. Mean and standard deviation of the percentage of macroaggregates and microaggregates in the 0-0.1 m, 0.1-0.2 m, and 0.2-0.3 m soil layers in three areas: irrigated conservationist management (ICM), rainfed conservationist management (ICM), and RNCM rainfed non-conservationist management (RNCM).

Management	Macroaggregates	Microaggregates
	------------------------------------ (%) ------------------------------------	
	0.00 – 0.10 m	
ICM	65.60 ± 5.12 a	34.40 ± 5.12 a
RCM	63.00 ± 4.17 a	37.00 ± 4.17 a
RNCM	75.45 ± 5.67 b	24.55 ± 5.67 b
	0.10 – 0.20 m	
ICM	65.50 ± 4.05 a	34.50 ± 4.05 a
RCM	66.30 ± 4.06 a	33.70 ± 4.06 a
RNCM	77.45 ± 4.40 b	22.55 ± 4.40 b
	0.20 – 0.30 m	
ICM	71.00 ± 5.49 a	29.00 ± 5.49 a
RCM	71.80 ± 7.58 a	28.20 ± 7.58 a
RNCM	77.51 ± 4.68 b	22.49 ± 4.68 b

Different letters in the columns indicate differences using the Kruskal-Wallis multiple comparisons test ($p<0.05$).

The results were unexpected, as it was expected that conservationist management (ICM and RCM) would show higher percentages of macroaggregates compared to rainfed non-conservationist management (RNCM), as suggested by the results of Fernandes et al. (2023), which demonstrated the importance of organic carbon in the formation of macroaggregates (>4 mm). However, this study analyzed macroaggregates smaller than 2.0 mm and greater than or equal to 0.25 mm and did not consider larger classes of macroaggregates. It is assumed that, when considering larger classes of macroaggregates (>2 mm), the percentages would be higher in conservationist management (ICM and RCM) compared to RNCM.

In conservationist management (RCM and ICM), there were no significant differences in the percentage of macroaggregates and microaggregates between the irrigated area (ICM) and the rainfed area (RCM). These areas are managed using very similar concepts involving crop diversification, the use of cover crops in the off season, and intercropping with grasses (Table 1).

Concerning the organic carbon content in macroaggregates (OCMA) and microaggregates (OCMI), the results in Table 6 show that in all the layers studied, the ICM and RCM management systems had significantly higher OCMA and OCMI contents compared to the RNCM management. There are no significant differences in OCMA content between ICM and RCM management, but there is a significant difference in OCMI content in the 0.00 0.10 m layer, where ICM has a higher content than RCM. For the other layers, the OCMI contents are similar between ICM and RCM.

These results confirm the hypothesis that areas with conservation management favor the maintenance and accumulation of organic carbon in the soil. The management practices adopted in conservation management (ICM and RCM) (Table 1), such as no-tillage, plant diversity in the production system, and intercropping, especially with grasses, favor carbon accumulation in the soil.

Studies by Nijmeijer et al. (2019) suggest that practices such as no-tillage help maintain or even increase soil carbon concentrations. On the other hand, production systems that use management techniques with soil disturbance tend to reduce the organic carbon content in the soil over the years, leading these environments to degradation. Freitas et al. (2018) concluded that conventional systems are more unstable as they reduce soil carbon stocks due to continuous tillage.

The clay content can influence carbon fixation in the soil and thus alter the levels of OCMA and OCMI. As observed in the chemical and physical characteristics (Table 2), the clay content in the areas varies. In conservation management (ICM and RCM), the clay content ranged from 707.0 to 785.4 g kg^{-1}, while in the RNCM system, the clay content ranged from 566.3 to 587.0 g kg^{-1}. On average, the conservationist management areas have 29% more clay. Thus, the higher clay content in the ICM and RCM is expected to contribute to the OCMA and OCMI levels.

Table 6. Mean and standard deviation of organic carbon in macroaggregates and microaggregates (g kg^{-1}) of three layers (0-0.1 m, 0.1-0.2 m, and 0.2-0.3 m) in three areas: irrigated conservationist management (ICM), rainfed conservationist management (ICM), and RNCM rainfed non-conservationist management (RNCM).

Management	OCMA (g kg^{-1})	OCMI (g kg^{-1})
	0.00–0.10 m	
ICM	16.20 ± 5.12 a	17.20 ± 4.82 a
RCM	13.90 ± 3.45 a	14.30 ± 3.92 b
RNCM	05.08 ± 0.48 b	05.13 ± 0.28 c
	0.10–0.20 m	
ICM	13.10 ± 6.10 a	14.70 ± 3.47 a
RCM	11.30 ± 4.44 a	11.60 ± 5.00 a
RNCM	04.63 ± 0.37 b	04.87 ± 0.36 b
	0.20–0.30 m	
ICM	16.20 ± 3.09 a	16.90 ± 1.36 a
RCM	13.10 ± 4.85 a	16.20 ± 2.26 a
RNCM	04.50 ± 0.32 b	04.63 ± 0.34 b

Different letters in the columns indicate differences using the Kruskal-Wallis multiple comparisons test ($p<0.05$).

Conceição et al. (2008) found that physical protection was responsible for accumulating 54.0% of the total C in an Argissolo and 23.0% in a Latossolo Vermelho, demonstrating the importance of this mechanism for the accumulation of organic matter in soils under no-tillage and pasture compared to conventional systems. These results corroborate the theory of Oades and Waters (1991), who showed that 65% of the C in the Latossolo is found in the fraction associated with minerals, possibly due to the strong chemical interaction of the oxides with the organic fraction; this mechanism being the main responsible for stabilizing the SOM in this soil.

The greater availability of water during the driest period of the year certainly contributes to the greater development of cultivated plants and cover crops in the irrigated area, generating greater dry mass deposition. According to Campos, Pires, and Costa (2020), there is a greater production of total crop biomass in irrigated areas, promoting a greater amount of organic material that will be converted into organic carbon in the soil.

CONCLUSION

Conservation management increases carbon accumulation in soil macro and microaggregates, regardless of whether or not irrigation is used.

Irrigation under conservation management promotes higher weighted mean diameter (WAD) and geometric mean diameter (GMD), and a higher aggregate stability index (ASI).

Irrigation does not alter soil density and porosity in conservationist management or affect carbon accumulation in soil macro and microaggregates.

ACKNOWLEDGEMENTS

To the FAPEMAT for the financial support.

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