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Organic matter in a dystroferric Red Latossol under no-tillage

Matéria orgânica em um Latossolo Vermelho distroférrico sob sistema plantio direto consolidado

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Abstract

Soils of the Cerrado have chemical, physical, and biological limitations for agriculture, which, associated with climate factors, contribute to their impoverishment. The maintenance and accumulation of soil organic matter are considered the best option of addressing this problem and to ensure a sustainable production. The purpose of this study was to evaluate different fractions of organic matter, and carbon and nitrogen contained in these compartments of a very clayey dystroferric Red Latossol under different crop rotations and at different depths under long-term no-tillage in Dourados, state of Mato Grosso do Sul. The experiment was arranged in a randomized block design with three replications, and the treatments in a 5x4 factorial design, with five crop rotation systems (1 – vetch + oat + oilseed radish/ soybean/ radish/ maize/ vetch + oats + radish/ soybean; 2 – sunflower/ soybean/ vetch + oat + radish/ maize/ sunflower/ soybean; 3 – oat/ soybean/ sunflower/ maize/ oat/ soybean; 4 – vetch + oat/ soybean/ brachiaria/ maize/ brachiaria/ soybean; 5 – vetch/soybean/vetch/maize/vetch/soybean), in four soil layers (0-5, 5-10, 10-15, 15-20 cm). Particle size was analyzed to determine the particulate fraction of organic matter (POM), and carbon (C-POM) and nitrogen (N-POM) in it. It was concluded that the levels and stock of C-POM, and nitrogen contents in the soil are not influenced by the different crop rotation systems. Crop rotation 4 increased the levels and stock of total organic carbon (TOC), carbon associated with soil minerals (C-MOM) and the total C/N ratio and total C/N ratio associated with soil minerals. The highest levels of TOC, C-POM, C-MOM, total nitrogen, N-POM and nitrogen associated with soil minerals (N-MOM) were found in the 0-5cm layer.
Key words: Crop rotation, size fractions, organic carbon, soil nitrogen

Resumo

Solos cultivados do Cerrado possuem limitações químicas, físicas e biológicas, que associadas a fatores climáticos contribuem para seu empobrecimento. A manutenção e acúmulo da matéria orgânica do solo têm sido considerados a melhor alternativa para que isto se reverta e resulte em produções sustentáveis. O objetivo deste trabalho foi avaliar diferentes frações da matéria orgânica do solo, e o carbono e nitrogênio contido nestes compartimentos, num Latossolo Vermelho distroférrico, muito argiloso, em diferentes rotações de culturas e em diferentes profundidades do solo sob plantio direto consolidado, no município de Dourados, MS. O delineamento experimental foi em blocos casualizados

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com três repetições, e os tratamentos organizados num esquema fatorial 5x4, sendo cinco sistemas de rotação de culturas: 1- ervilhaca+aveia+nabo/ soja/ nabo/ milho/ ervilhaca+aveia+nabo/ soja, 2 – girassol/ soja/ ervilhaca+aveia+nabo/ milho/ girassol/ soja, 3 – aveia/ soja/ girassol/ milho/ aveia/ soja, 4 – ervilhaca+aveia/ soja/ braquiária/ milho/ braquiária/ soja, 5- ervilhaca/ soja/ ervilhaca/ milho/ ervilhaca/ soja; e quatro profundidades do solo: 0-5, 5-10, 10-15, 15-20 cm. Foi utilizado o fracionamento granulométrico para determinação da fração particulada da matéria orgânica (MOP), e o carbono (C-MOP) e nitrogênio (N-MOP) nela contidos. Concluiu-se que os teores de C-MOP, seu estoque no solo e os teores de nitrogênio no solo não são influenciados pelos diferentes sistemas de rotação de culturas. A rotação de cultura 4 proporciona maiores teores e estoques de carbono orgânico total (COT), carbono associado aos minerais do solo (C-MOM) e maior relação C/N total e associada aos minerais do solo. A maior concentração de COT, C- MOP, C-MOM, nitrogênio total, N-MOP e nitrogênio associado aos minerais do solo (N-MOM) é verificada na profundidade de 0 a 5 cm.

Palavras-chave: Rotação de culturas, frações granulométricas, carbono orgânico, nitrogênio do solo

Introduction

Latosol is the predominant soil class in approximately 46% of the area originally covered with cerrado vegetation (REATTO; CORREIA; SPERA, 1998), 95% of which are dystrophic soils (SPERA; CORREIA; REATTO, 2006). Soils of this class are widely suitable for agriculture, but since the chemical, physical and biological properties are limited, aggravated by climatic factors, the management of these soils should minimize these restrictions. To ensure yields with economic and agricultural sustainability, it is recommended that in addition to liming and fertilization, the levels of soil organic matter be maintained and, if possible, raised (SPERA; CORREIA; REATTO, 2006).

In tropical and subtropical regions, where climatic conditions accelerate microbial decomposition, the amount of plant residue needed to maintain the stock of soil organic matter (SOM) is greater than in temperate regions (MIELNICZUK et al., 2003). However, in a study on the effect of no-tillage (NT) on the relationship between soil mineralogy and organic matter, Silva Neto et al. (2008) stated that NT did not affect the mean levels of total organic carbon in the 0 – 20 cm layer in a dystroferric Red Latosol in a subtropical region (Santo Angelo, RS) as well as in another in the Cerrado (Dourados, MS).

The management system is another factor that rapidly alters SOM accumulation (MIELNICZUK et al., 2003). Bayer, Bissani and Zanatta (2006) expressed concern about the degradation of organic matter in the Brazilian Cerrado, which is reduced to 50% of its original level after only 2-5 years of conventional soil management, as a result of bioclimatic activities and reduced capacity of crop residue assimilation of the soil in the dry season. The organic matter in these acidic soils is predominantly degraded into variable charge minerals, e,g., kaolinite and iron and aluminum oxi-hydroxides, with serious consequences of reducing the N availability and cation retention capacity and increasing Al toxicity as well as the soil retention capacity of P in unavailable forms, aside from the effects on soil biology and physics.

The adoption of a no-tillage (NT) management, with the high residue input of the system, can induce the recovery of SOM levels within a short period (BAYER; MIELNICZUK, 1997; AMADO et al., 1999). Although the quantities are smaller than of other components in most soils, SOM is mainly responsible for the maintenance and sustainability of an ecosystem (MARTIN NETO; ANDRIULO; TRAGHETTA, 1996; PEREIRA; BURLE; RESCK, 1992), which is why the SOM content is considered a key indicator of the sustainability and environmental quality of agroecosystems (SÁ et al., 2001; SHUKLA; LAL; EBINGER, 2006; SALTON et al., 2008; SPERA et al., 2009).

In view of the importance of SOM, it is essential to quantify the composing fractions to understand the pedogenic processes that define or influence the soil properties (PEIXOTO, 1997). The separation of SOM in particle-size fractions can underlie the evaluation of changes resulting from a greater vulnerability of these fractions caused by the management (BAYER et al., 2004; NICOLOSO et al., 2008).

The particle-size analysis of a soil by the separation of primary organo-mineral complexes is based on the hypothesis that, due to the difference in the mineralogical composition, the particles of each soil texture class are related differently with SOM, showing that the organic minerals of each of these classes differ in composition, function and dynamics (CHRISTENSEN, 1986). In this analysis, SOM was therefore subdivided into particulate organic matter (POM), corresponding to the size fraction of sand particles (>53 μm), and the organic material associated with the minerals (MOM), corresponding to the size fraction of silt and clay particles (<53 μm) (SALTON et al., 2005).

Particulate organic matter is the labile part of SOM, which responds sensitively to the soil management system (SALTON et al., 2005), for consisting mainly of non-complexed organic matter (NCOM) (ROSCOE; MACHADO, 2002), i.e., predominantly of organic waste in initial decomposition stages, when it is still possible to identify fragments of plant material, fungal hyphae and fauna exoskeletons (CHRISTENSEN, 2000). The MOM is the more stable part, with no immediate response to changes in soil management practices, representing the medium and long-term carbon stock in the soil (SALTON et al., 2005). According to Campos et al. (2011), the particulate fraction of C is an accurate quality indicator of management systems, while the organic C associated to minerals is an important sink of atmospheric C-CO_2 in clayey Latosol. The authors reported that C retention in this stable SOM fraction contributed to values ob over 80% of the total C sequestered in NT soil in the evaluated crop rotation systems.

Since the conservation management system increases the content of organic carbon and nitrogen in soil, and because of the need to know the effects of labile fractions of soil organic matter (POM), especially in tropical environment (PINHEIRO et al., 2004), the purpose of this study was to evaluate different fractions of soil organic matter, and carbon and nitrogen contained in these compartments, in a dystroferric Red Latossol under different long-term no-till crop rotations.

Material and Methods

This research is part of a long-term experiment initiated in 1997, involving grain yield based on crop rotation and succession planting, in SPD, deployed at the Experimental Farm of Agricultural Sciences, Federal University of Grande Dorados – UFGD (latitude 22 ° 14 ‘00 “S, longitude 54 ° 49’ 00” W and 450 m asl), in Dourados – MS. The soil was classified as a very clayey dystroferric Red Latossol (LVdf), originally under Cerrado vegetation, and according to Köppen´s classification, the climate is Cwa, humid mesothermal (MATO GROSSO DO SUL, 1990).

The experiment was arranged in a randomized block design with three replications, and the treatments in a 5x4 factorial design, with five crop rotation systems (Table 1) at four soil depths (0-5, 5-10, 10-15 , 15-20 cm), totaling 20 treatments and 60 plots (36 x 11 m or 396 m^2), on which autumn-winter and summer crops were sown. The experimental area was limed in 1999 with a broadcast application of 1,000 kg ha^{-1} of limestone (relative neutralizing power 86%) on the surface, which is the dose calculated to raise the base saturation to 60%. The winter crops were not fertilized, while the summer crops soybean and maize were fertilized with 300 kg ha^{-1} 00-20-20 NPK fertilizer and 300 kg ha^{-1} 08-20-20, respectively. Aside from the initial fertilization, a topdressing of 90 kg ha^{-1} N as urea was also applied to maize.

Table 1. Crop rotations systems with summer and winter crops, from 2006 to 2008.

Crop rotation systems	Year					
	................2006.............		................2007.............		..................2008........	
	winter	summer	winter	summer	winter	summer
1	hv+bo+or	soybean	or	maize	hv+bo+or	soybean
2	sunflower	soybean	hv+bo+or	maize	sunflower	soybean
3	black oat	soybean	sunflower	maize	black oat	soybean
4	bo+hv	soybean	brachiaria	maize	brachiaria	soybean
5	hv	soybean	hv	maize	hv	soybean

Legend: hv= hairy vetch; bo=black oat; or= oilseed radish.
Source: Elaboration of the authors.

Soil samples were collected from all plots in July 2009, from six small trenches per treatment and replication, dug with a straight shovel. Simple profile samples were taken with a metal plate, and from these, one composite sample per layer. Undisturbed soil was collected with an Uhland sampler (stainless steel cylinder, diameter 5.57 cm, height 4.1 cm), at four depths. After sampling, the disturbed soil samples were air-dried, sieved (2 mm) and analyzed for fertility according to the methodology described by Embrapa (1997) (results in Table 2).

The organic matter was physically fractionated by the particle size analysis method described by Cambardella and Elliott (1992) with the modification of using sodium hydroxide (NaOH) 0.1 N at 5:1 (soil: solution) as dispersing agent (NUNES et al., 2008) to be able to discriminate the mineral-associated particulate fraction.

The carbon content in the particulate fraction of organic matter (C-POM) was determined by wet combustion (WALKLEY, BLACK, 1934), and later calculated, considering the mass of each fraction, represented by particles larger than 53 μm (g kg $^{-1}$).

The nitrogen content in the particulate fraction of organic matter (N-POM) was determined by the semi-micro-Kjeldahl method (MALAVOLTA; VITTI; OLIVEIRA, 1997), and subsequently calculated considering the mass of each fraction, represented by particles > 53 μm (g kg $^{-1}$).

Carbon (C-MOM) and nitrogen associated with soil minerals (N-MOM) were calculated by the difference total values obtained in the samples without chemical dispersion with values obtained from samples of particulate organic matter, respectively (CAMBARDELLA; ELLIOTT, 1992).

The bulk density was determined by the volumetric ring method (EMBRAPA, 1997). The average values of bulk density obtained was 1.24; 1.27; 1.24; 1.27; and 1.32 kg dm^{-3} in crop rotations 1, 2, 3, 4, and 5 respectively, and 1.09; 1.32; 1.34; and 1.31 kg dm^{-3} at depths 1, 2, 3, and 4 respectively.

The carbon and nitrogen stocks were calculated considering the sampled soil depth and bulk density, adapted from Rangel and Silva (2007):

$$q = \frac{ec \,.\, th.bd}{10}$$

where:

q = element pool / stock (t ha^{-1})

ec = element content (g kg^{-1})

th = layer thickness (cm)

bd = soil density (kg dm^{-3}).

Data were subjected to analysis of variance to verify the effects of crop rotation systems. Means wee compared by Tukey's test at 5% probability, using the statistical package SAEG (SAEG, 2007).

Table 2. Mean data of the chemical properties and bulk density of the soil analyses of each crop rotation system in four soil layers, in 2009.

System*	Lay.	MO	pH	pH	P	K	Al	Ca	Mg	H+Al	CTC	V	Ds
	cm	g kg^{-1}	$CaCl_2$	SMP	mg dm^{-3}	........................mmol$_c$ dm $^{-3}$.......................						%	
	0-5	35.1	4.9	6.1	34.7	12.3	0.6	41.6	28.2	51.7	133.8	61.4	1.0
1	5-10	27.0	4.7	5.7	26.5	6.2	1.6	32.8	20.0	72.7	131.7	44.8	1.3
	10-15	20.3	4.5	5.7	19.1	3.9	1.4	29.0	15.3	70.0	128.1	40.0	1.3
	15-20	18.9	4.7	5.8	7.1	2.5	2.0	27.9	15.6	80.7	116.8	37.0	1.3
	0-5	35.9	4.4	6.0	45.9	10.6	0.8	38.6	25.0	65.0	139.2	53.3	1.1
2	5-10	27.7	4.5	5.7	28.8	5.9	1.6	30.5	16.3	64.0	126.7	41.6	1.3
	10-15	25.2	4.5	5.8	15.8	4.3	1.3	31.0	15.2	61.7	120.0	44.3	1.3
	15-20	22.2	4.5	5.9	5.6	2.9	1.8	28.0	14.3	73.3	110.8	38.9	1.3
	0-5	42.0	4.9	6.0	40.3	13.0	0.7	38.9	26.3	58.0	136.3	57.4	1.0
3	5-10	27.8	4.5	5.7	32.3	6.6	1.8	29.7	16.9	76.0	129.1	41.1	1.3
	10-15	25.5	4.6	5.7	26.5	4.9	1.4	30.2	14.7	66.7	123.6	42.2	1.3
	15-20	24.2	4.6	5.8	7.5	3.8	2.2	28.0	14.1	76.7	115.4	38.0	1.3
	0-5	47.1	4.8	6.0	39.1	9.9	0.6	40.7	27.9	55.7	134.1	58.5	1.1
4	5-10	33.8	4.7	5.9	24.0	5.8	1.2	35.7	22.7	64.0	128.2	50.1	1.3
	10-15	35.7	4.7	5.8	14.4	4.0	1.4	29.1	17.1	61.3	121.2	42.6	1.4
	15-20	23.2	4.6	5.9	4.8	2.8	1.4	27.4	15.4	71.0	106.9	41.4	1.3
	0-5	39.7	4.8	6.1	47.2	8.7	0.5	38.3	26.8	50.3	124.1	59.4	1.2
5	5-10	29.8	4.4	5.7	28.2	6.1	1.4	27.3	17.4	72.7	123.5	41.2	1.4
	10-15	26.9	4.6	5.7	11.7	4.6	1.2	29.6	14.9	63.0	110.9	43.2	1.4
	15-20	23.2	4.7	5.9	5.1	3.4	1.8	26.3	15.1	76.0	122.0	37.7	1.3

*1 – vetch + oat + oilseed radish/ soybean/ radish/ maize/ vetch + oats + radish/ soybean; 2 – sunflower/ soybean/ vetch + oat + radish/ maize/ sunflower/ soybean; 3 – oat/ soybean/ sunflower/ maize/ oat/ soybean; 4 – vetch + oat/ soybean/ brachiaria/ maize/ brachiaria/ soybean; 5 – vetch/soybean/vetch/maize/vetch/soybean.
Source: Elaboration of the authors.

Results and Discussion

No statistical differences were observed for any of the studied variables in the interaction of the five systems of crop rotation with the four depths (Tables 3, 4 and 5). This can be explained by the tendency of the no-tillage system of stabilizing the soil properties by the addition of crop residues without soil disturbance. Six, Elliot and Paustian (1999) and Balesdent, Chenu and Balabane (2000) reported that this management form induces a series of strongly interrelated physical, chemical and biological processes, often synergistic with each other, as in the case of processes that increase the aggregate stability and organic matter pools in the soil.

Table 3. Mean squares of the contents de total organic carbon (TOC), carbon in the particulate organic matter (C-POM) and mineral-associated carbon (C-MOM), and the respective stocks in the surface of a dystroferric Red Latossol under different crop rotation systems and in different soil layers.

Source of variation	........................Content			................Stock		
	TOC	C-POM	C-MOM	TOC	C-POM	C-MOM
Block	10.379	0.087	8.935	3.251	0.027	2.777
Crop rotation (CR)	50.776*	0.146 ns	53.929*	23.536*	0.070 ns	24.165*
Depth (Lay.)	283.859*	79.316*	75.768*	44.726*	21.491*	15.212*
CR*Lay.	5.613 ns	0.066 ns	5.168 ns	2.215 ns	0.025 ns	2.085 ns
Error	7.113	0.257	7.179	3.458	0.055	3.517
CV(%)	15.557	25.040	17.723	17.372	19.894	19.686

*: significant by the F test at 5% probability;
ns: non-significant by the F test at 5% probability;
CV: Coefficient of variation.
Source: Elaboration of the authors.

Table 4. Mean squares of the contents of total nitrogen (NT), nitrogen in particulate organic matter (N-POM) and nitrogen associated to minerals (N-MOM), and the respective stocks in a dystroferric Red Latossol under different crop rotation systems and in different soil layers.

Source of variation	.......................Content			...............Stock		
	NT	N-POM	N-MOM	NT	N-POM	N-MOM
Block	0.089	0.005	0.054	0.038	0.001	0.025
Crop rotation (CR)	0.048 ns	0.003 ns	0.042 ns	0.050 ns	0.001 ns	0.039 ns
Depth (Lay.)	2.804*	0.362*	1.171*	0.462*	0.099*	0.149*
CR*Lay.	0.056 ns	0.001 ns	0.068 ns	0.021 ns	0.001 ns	0.025 ns
Error	0.055	0.003	0.055	0.026	0.001	0.026
CV(%)	16.816	38.231	18.635	18.633	33.886	20.288

*: significant by the F test at 5% probability;
ns: non-significant by the F test at 5% probability;
CV: Coefficient of variation.
Source: Elaboration of the authors.

Table 5. Mean squares of the total C/N ratio, C/N ratio in the particulate organic matter (C/N- POM) and C/N ratio in the mineral-associated organic matter (C/N-MOM) of a dystroferric Red Latossol under different crop rotation systems and in different soil layers.

Source of variation	...........................C/N ratio.......................		
	total	POM	MOM
Block	5.219	33.484	6.237
Crop rotation (CR)	27.067*	35.607 ns	32.308*
Depth (Lay.)	8.624 ns	18.896 ns	14.578 ns
CR*Lay.	5.270 ns	19.223 ns	5.869 ns
Error	5.485	25.566	6.140
CV(%)	18.620	30.264	20.154

*: significant by the F test at 5% probability;
ns: non-significant by the F test at 5% probability;
CV: Coefficient of variation.
Source: Elaboration of the authors.

Vezzani and Mielniczuk (2009) emphasized the importance of the no-tillage system in agriculture, with a direct influence on the soil quality, creating a sustainable agricultural system. In a study that analyzed the differences between bare soils and soil covered with crops, Neves et al. (2005) indicated this management as a form of recovery of degraded areas.

The levels of total carbon (TOC) and C-MOM as well as their respective pools, were significant for crop rotations (Table 3). The levels of TOC and C-MOM were highest in the rotation system 4 (brachiaria/maize/brachiaria/soybean), and lowest in system 1 (rapeseed/maize/oats + vetch + rapeseed/soybean) (Table 6). This difference was possibly due to the benefits left by brachiaria, which is regionally very well-adapted, thus producing a large biomass yield, which is transformed into SOM (FONSECA et al., 2007).

Table 6. Mean values of the contents of total organic carbon (TOC), carbon in the particulate organic matter (C-POM) and mineral-associated carbon (C-MOM), with the respective stocks in a dystroferric Red Latossol under different crop rotation systems and in different soil layers (mean of 12 replications).

Crop	.........................Content ($g\ kg^{-1}$)..................			..................Stock ($t\ ha^{-1}$).............		
rotation*	TOC	C-POM	C-MOM	TOC	C-POM	C-MOM
1	14.70 b	2.18 a	12.52 b	35.64 c	4.92 a	30.72 c
2	16.10 b	1.91 a	14.19 b	40.52 bc	4.48 a	36.04 bc
3	17.31 ab	2.02 a	15.30 ab	41.92 bc	4.52 a	37.40 abc
4	20.27 a	1.94 a	18.33 a	50.68 a	4.48 a	46.20 a
5	17.34 ab	2.09 a	15.25 ab	45.32 ab	5.16 a	40.20 ab
LSD	3.12	-	3.13	8.68	-	8.76
GM	17.14	2.03	15.12	42.80	4.72	38.12

Means followed by the same letter in the column did not differ from each other by Tukey's test at 5 % probability.
LSD: least significant difference;
GM: general mean;
**1 – vetch + oat + oilseed radish/ soybean/ radish/ maize/ vetch + oats + radish/ soybean; 2 – sunflower/ soybean/ vetch + oat + radish/ maize/ sunflower/ soybean; 3 – oat/ soybean/ sunflower/ maize/ oat/ soybean; 4 – vetch + oat/ soybean/ brachiaria/ maize/ brachiaria/ soybean; 5 – vetch/soybean/vetch/maize/vetch/soybean.
Source: Elaboration of the authors.

Since carbon (TOC) is the predominant element in the composition of organic matter, it is an indicator of soil qualityand must therefore be routinely evaluated. According to the interpretation table of chemical properties of Cerrado soils proposed by Sousa and Lobato (2002), in the 0-20 cm layer of very clayey soils with annual crops, values below 16 $g\ kg^{-1}$ carbon are considered low, 16 – 20 $g\ kg^{-1}$ medium and 21 – 30 $g\ kg^{-1}$ are considered appropriate. Comparing these levels with those observed in this study, TOC was only low in rotation system 1 (rapeseed/maize/oats + vetch + rapeseed/soybean). In all other systems the levels were medium (Table 6).

In addition to the TOC and C-MOM levels, the values of C-POM in the comparison of soil layers were also significant (Table 3). For these variables, the highest values were generally found at a depth of 5 cm, with significant decreases with increasing depth (Table 7). Lopes et al. (2004) stated that in no-tillage areas in southern Brazil, the carbon concentration tends to increase gradually over the years in the 0 – 10 cm layer, decreasing significantly in the deeper layers. Loss et al. (2009) also reported that the TOC levels tended to be higher in the 0-5cm than the 5-10cm layer, and suggested that this behavior demonstrates a greater influence on the content of the SOM of the residues of the different cover crops left on the surface.

Table 7. Mean contents of total organic carbon (TOC), carbon in the particulate organic matter (C-POM) and mineral-associated carbon (C-MOM) and respective stocks in a dystroferric Red Latossol under different crop rotation systems and in different soil layers (mean of 15 replications).

Depth	..........................Content (g kg^{-1})..................			..................Stock (t ha^{-1}).............		
(cm)	TOC	C-POM	C-MOM	TOC	C-POM	C-MOM
0-5	23.18 a	5.45 a	17.72 a	12.64 a	2.95 a	9.68 ab
5-10	16.95 b	1.26 b	15.69 ab	11.23 ab	0.83 b	10.40 a
10-15	15.51 bc	0.76 bc	14.74 bc	10.45 b	0.51 c	9.94 a
15-20	12.94 c	0.36 c	12.31 c	8.50 c	0.41 c	8.08 b
LSD	2.62	0.40	2.63	1.82	0.23	1.84
GM	17.14	2.03	15.12	10.70	1.18	9.53

Means followed by the same letter in the column did not differ from each other by Tukey's test at 5 % probability.
LSD: least significant difference; GM: general mean.
Source: Elaboration of the authors.

Nascimento et al. (2003) evaluated the effect of legume cultivation on the chemical properties and organic matter of degraded soil after three years and observed that the organic matter in the 0 – 10 cm layer was significantly higher than in the 10 – 20 and the 20 – 30 cm layers, due to the greater accumulation of plant residues on the soil surface.

Neves et al. (2005) also observed greater amplitudes in the soil C content between different management systems in the 0-10 cm than the 20-30 cm layer.

In the organic matter of dystroferric Red Latossol under different management forms, sampled in Dourados, Maracajú and Campo Grande (MS), Salton et al. (2005) found that the use of different management systems promoted changes in soil carbon stocks, which were most intense in the surface layer. They found that these changes were influenced by the particulate fraction of SOM (POM), whose dynamics is mainly driven by the availability of crop residues in the soil surface. Similarly, Loss et al. (2009) reported that POM can efficiently indicate differences between areas, especially in the 0-5cm layer, when the different management and rotation/intercropping systems produce different input amounts of plant residues.

The C-MOM stock was greater in the 5 – 15 cm than the 15-20 cm layer (Table 7). Since MOM is more stable, the increased pool observed was possibly a result of the long period of no-tillage management, influencing deeper layers.

The levels of C-POM and the respective stocks were much lower than of C-MOM, both in relation to the different crop rotations and to the layers (Table 7). This can be explained by the reduced specific surface area and surface charge density of the sand (particles> 53 mM) where POM is found (CHRISTENSEN; BERTELSEN; GISSEL-NIELSEN, 1989), which is the fraction which has little or no strongly linked organic material and is poor in organo-mineral complexes (BALDOCK et al., 1992; CHRISTENSEN, 1986). The particulate is the most labile soil fraction, responding readily to changes in the management system, whereas the mineral fraction is the most stable part, showing no sensitivity to changes in soil tillage (SALTON et al., 2005).

Nunes et al. (2008), studying a dystroferric Red Latossol for 10 years under NT in the Cerrado region, fractionated the organic matter of this soil, and found higher values than in this study (Table 7), by the same methodology; they found 6.07; 3.70 and 2.05 g kg^{-1} for C-POM and 29.13; 25.13 and 22.33 g kg^{-1} for C-MOM, at 0-5, 5-10 and 10-20 cm, respectively.

Evaluating different management forms of an Oxisol of Goiânia, on the plot under no-tillage, Freitas et al. (2000) found values close to those of this study for fractional C, and a C-MOM content of 16.3 and 14.8 g kg^{-1} at 0-10 and 10-20 cm respectively, and the C-POM values were 3.5 and 2.0 g kg^{-1} in the same layers.

The differences between total nitrogen (TN), N-N-MOM and POM, and their pools were not significant in the comparison of crop rotations, but in the comparison of layers (Table 4). D'Andrea et al. (2004) obtained a similar result for NT, with no difference between the rotations studied, but significant differences when comparing soil layers.

Nitrogen is one of the essential elements for plant growth and is not found in the parent material of the soil. The presence of this nutrient in the soil, when not provided by fertilization, can be related to the presence of organic matter and to Fabaceae species, which form symbiotic associations with atmospheric nitrogen-fixing bacteria. Thus, the N contents in the particulate fraction, as those of C, for being the most sensitive fraction to changes in the soil, are the first to indicate changes in the balance of these nutrients in the soil (CONCEIÇÃO et al., 2005).

The values of N-POM, similar to carbon, were also much lower – both in different crop rotations systems and layers – than in the mineral-associated fraction (Table 8), for being poor in organo-mineral complexes.

Table 8. Mean contents of total nitrogen (NT), nitrogen in particulate organic matter (N-POM) and nitrogen associated to minerals of the soil (N-MOM), with the respective stocks I the surface layer (0-20 cm) of a dystroferric Red Latossol under different crop rotation systems (mean of 12 replications).

System*	......................Content (g kg^{-1})......................			..................Stock (t ha^{-1})..............		
	NT	N-POM	N-MOM	NT	N-POM	N-MOM
1	1.34 a	0.14 a	1.20 a	3.28 a	0.32 a	2.96 a
2	1.45 a	0.12 a	1.33 a	3.60 a	0.28 a	3.32 a
3	1.34 a	0.12 a	1.21 a	3.24 a	0.28 a	2.96 a
4	1.37 a	0.13 a	1.24 a	3.40 a	0.32 a	3.12 a
5	1.48 a	0.16 a	1.32 a	3.84 a	0.40 a	3.48 a
LSD	-	-	-	-	-	-
GM	1.39	0.13	1.26	3.48	0.32	3.16

Means followed by the same letter in the column did not differ from each other by Tukey's test at 5 % probability.
*1 – vetch + oat + oilseed radish/ soybean/ radish/ maize/ vetch + oats + radish/ soybean; 2 – sunflower/ soybean/ vetch + oat + radish/ maize/ sunflower/ soybean; 3 – oat/ soybean/ sunflower/ maize/ oat/ soybean; 4 – vetch + oat/ soybean/ brachiaria/ maize/ brachiaria/ soybean; 5 – vetch/soybean/vetch/maize/vetch/soybean.
LSD: least significant difference;
GM: general mean.
Source: Elaboration of the authors.

The highest mean values of total and fractionated nitrogen and their respective pools were higher in the 0-5 cm than in the other layers (Table 9). Amado et al. (2001) also observed a greater concentration of TN in this layer than in 15 – 20 cm.

Table 9. Mean contents of total nitrogen (NT), nitrogen in particulate organic matter (N-POM) and nitrogen associated to minerals in the soil (N-MOM), with the respective stocks in a dystroferric Red Latossol under crop rotations in different soil layers (mean of 15 replications).

Depth	........................Content (g kg^{-1}).................			..................Stock (t ha^{-1})..............		
(cm)	NT	N-POM	N-MOM	NT	N-POM	N-MOM
0-5	2.02 a	0.36 a	1.66 a	1.11 a	0.20 a	0.91 a
5-10	1.33 b	0.08 b	1.25 b	0.88 b	0.05 b	0.83 ab
10-15	1.15 bc	0.05 b	1.10 b	0.77 bc	0.03 bc	0.74 b
15-20	1.08 c	0.04 b	1.04 b	0.71 c	0.03 c	0.68 b
LSD	0.23	0.05	0.23	0.16	0.03	0.16
GM	1.39	0.13	1.26	0.87	0.08	0.79

Means followed by the same letter in the column did not differ from each other by Tukey's test at 5 % probability.
LSD: least significant difference; GM: general mean.
Source: Elaboration of the authors.

In a dystroferric Red Latossol of Goiânia, Freitas et al. (2000) evaluated different soil managements, and found values close to those of this study in the no-tillage system for fractional N, with a concentration of N-MOM of 1.03 and 0.95 g kg^{-1} in 0-10 and 10-20 cm, respectively, and of N-POM 0.19 and 0.11 g kg^{-1} in the same layers.

Of the evaluated C/N ratios, the total C/N and associated with soil minerals (C/N-MOM) were significant when comparing the different crop rotations (Table 5) and for both, the highest value was found in the system of winter brachiaria (4) (Table 10). The reason was possibly because the residues of grasses have a high C/N ratio and, consequently, a slow decomposition. According to Muzilli (2006), species of the grass family induce aggregate formation more effectively, by the direct action of the roots as well as by the supply of more durable and stable organic residues.

Table 10. Mean values da total C/N ratio, C/N ratio in the particulate organic matter (C/N- POM) and C/N ratio in mineral-associated organic matter (C/N-MOM) in a dystroferric Red Latossol under different crop rotation systems and different soil layers (mean of 12 replications).

System*	....................................C/N ratio..		
	Total	POM	MOM
1	11.00 b	15.96 a	10.54 b
2	12.09 b	18.19 a	11.68 b
3	13.14 ab	18.90 a	12.80 ab
4	14.89 a	15.33 a	14.86 a
5	11.78 b	15.16 a	11.60 b
LSD	2.74	-	2.90
GM	12.58	16.71	12.29

Means followed by the same letter in the column did not from each other by Tukey's test at 5 % probability;
*1 – vetch + oat + oilseed radish/ soybean/ radish/ maize/ vetch + oats + radish/ soybean; 2 – sunflower/ soybean/ vetch + oat + radish/ maize/ sunflower/ soybean; 3 – oat/ soybean/ sunflower/ maize/ oat/ soybean; 4 – vetch + oat/ soybean/ brachiaria/ maize/ brachiaria/ soybean; 5 – vetch/soybean/vetch/maize/vetch/soybean.
LSD: least significant difference;
GM: general mean.
Source: Elaboration of the authors.

The balance of C/N ratio is very important for the organic matter and the role it plays in soil quality. The best option for this equilibrium is to alternate or intercrop grasses with other species, especially Fabaceae (MUZILLI, 2006).

The C/N ratio of all treatments was below 20 (Tables 10 and 11), which, according to Azevedo (2004), leads to an excess of N in the residues, which is mineralized and not used by microorganisms, remaining available for plants from the beginning of the crop cycle.

In a study of Silva (2007) in the same experimental area as of this study, with soil sampling in 2005 and 2006, the mean results for the same variables (TOC, C-POM, MOM-C, NT, N –POM, N-MOM, and their stocks and C/N total C/N-POM and C/N-MOM) were very close to the data of our study, in the different rotations as well as the soil layers.

Table 11. Mean values of total C/N ratio, C/N ratio in the particulate organic matter (C/N- POM) and C/N ratio in the mineral-associated organic matter (C/N-MOM) of a dystroferric Red Latossol under crop rotations in different soil layers (mean of 15 replications).

Depth	.....................................C/N ratio..		
(cm)	total	POM	MOM
0-5	11.76 a	15.38 a	11.07 a
5-10	12.85 a	16.49 a	12.65 a
10-15	13.49 a	16.85 a	13.41 a
15-20	12.21 a	18.11 a	12.05 a
LSD	-	-	-
GM	12.58	16.71	12.29

Means followed by the same letter in the column did not differ from each other by Tukey's test at 5 % probability.
LSD: least significant difference; GM: general mean.
Source: Elaboration of the authors.

Conclusions

The levels and stocks of C-POM and nitrogen in the soil were not influenced by the different crop rotation systems studied, under the experimental conditions;

Crop rotation 4 (vetch + oat/soybean/brachiaria/maize/Brachiaria/soybean) resulted in the highest TOC, C-MOM and their pools in the soil, and the highest total C/N ratio and MOM;

The concentrations of TOC, C-POM, C-MOM, TN, N-POM, and N-MOM were highest in the 0-5cm layer.

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