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Can Soil Organic Carbon Pools Indicate the Degradation Levels of Pastures in the Atlantic Forest Biome?

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Abstract

In Brazil, a large part of the Atlantic Forest was deforested in pastures, which were developed on the basis of natural fertility and organic matter content of the new deforested soil. However, as time went by the organic matter content in these areas have been decreasing causing soil degradation. The objective of this study was to evaluate the organic matter as a quality indicator of Ultisols in different levels of pasture degradation in the region of *Governador Valadares-MG.* Four sites of pastures were chosen at different levels of degradation, observed visually, two capoeiras in different stages of natural recovery and forest site (reference). Soil samples were collected at three depths (0.00-0.05, 0.05-0.10 and 10-0.20 m) in two seasons of the year (rainy and dry seasons) in the middle third of the landform with three replicates. The following attributes were determined: soil organic C, free light fraction, particulate organic matter, particulate organic C, mineral-associated organic C and dissolved organic matter. The experimental results showed that the soil organic matter appeared efficient in discriminating soil quality between degraded forest/pasture, as well as between degraded capoeira/pasture. But, it was not sensitive to discriminate within levels of degraded pastures. Among the organic matter pools studied, the most sensitive soil quality indicators were: particulate organic matter and dissolved organic matter, in the following degraded order verified from these indicators: forest < capoeira 1 = capoeira 2 < pastures (1, 2, 3 and 4).

Keywords: soil quality, organic matter pool, particulate organic matter, degradation, ultisols

1. Introduction

The soil organic matter, almost entirely originates from vegetable residue which composition varied depending on the pre-exisiting species. The major contribution to the increase of C stock in the soil is related to the contribution of residues from roots and plant exudates (Chabbi & Rumpel, 2009; Rasse et al., 2005).

Furthermore, the deforestation of the native forest in areas of agriculture or pasture has led to reduction of C stock in soil (Milne et al., 2007), especially in areas that are poorly managed which leads to soil degradation. In the tropical region this situation is worsened when compared to the temperate region. Lal (2004) documented a reduction of about 60% in the levels of C in temperate environment and 75% or more in soils cultivated in the tropics after different periods of deforestation of natural forest to agricultural systems.

The largest reduction of C in the tropics has been related to the oxidation of organic matter caused by increased microbial activity in the soil of this region due to weather conditions such as high temperatures and soil moisture (Davidson et al., 2000; Scala-Jr et al., 2000; Wood et al., 2012).

In Brazil most of the natural ecosystem was turned into pastures, estimated about 172 millions of hectares (IBGE, 2006), and developed according to natural fertility and organic matter content of newly deforested soil. Forests were converted to fodder crops with high yield potential, and consequently with high requirements for soil fertility such as Colonião grass. With the depletion of this fertility, farmers began to introduce forage species less exigent in fertility, with consequently lower productivity to the point that even less exigent such as *Brachiaria* cannot develop (Oliveira & Corsi, 2005). This situation of deforestation is accompanied by soil degradation and today it is one of the most responsible for large emissions of CO_2 of Brazilian soil, as pointed out in studies developed in Amazonia (Fearnside & Barbosa, 1998; Fernandes et al., 2002), providing the deforestation of large tracts of land.

Vale do Rio Doce in the city of Governador Valadares, a region of the Atlantic Forest, is one of the biodiversity hotspots of Brazil. This aspect was pointed out by Baruqui et al. (1985) who showed that the succession of the forest for establishing pastures caused decreased levels of nutrients and C of the soil, reflecting the changes of more productive grasses to less productive grasses.

In the study developed by Lima et al. (2008), was found that various cites of the region of *Vale do Rio Doce* has decreased C stock in sites of degraded pastures in comparison to the forest with Ultisols. This study indicated that the organic matter pools of soil can be used as a soil quality indicator in the degraded pasture in the region. Overall, there is a lack of studies indicating the effectiveness of C pools to indicate the degrees of degradation of pasture in the tropics.

In tropical soils, that are highly weathered, soil organic matter is fundamental to manage chemical, physical and biological properties of the soil (Six et al., 2002; Wisawapipat et al., 2010). Therefore, decreasing the levels of organic matter leads to less soil productivity and consequently lower yield of forage, increasing the exposure of soil and favoring the process of accelerated erosion.

The objective of this study was to evaluate the soil carbon pools as a quality indicator of Ultisols in different levels of degradation in pastures, sites of capoeira in natural regeneration and in a secondary forest (reference).

2. Material and Methods

2.1 Site Description

The study sites were located in the city of Governador Valadares in the region *Vale do Rio Doce*, Minas Gerais (18^0 47′ 30″ S and 41^0 59′ 80″ W) with average altitude 245 m (Figure 1).

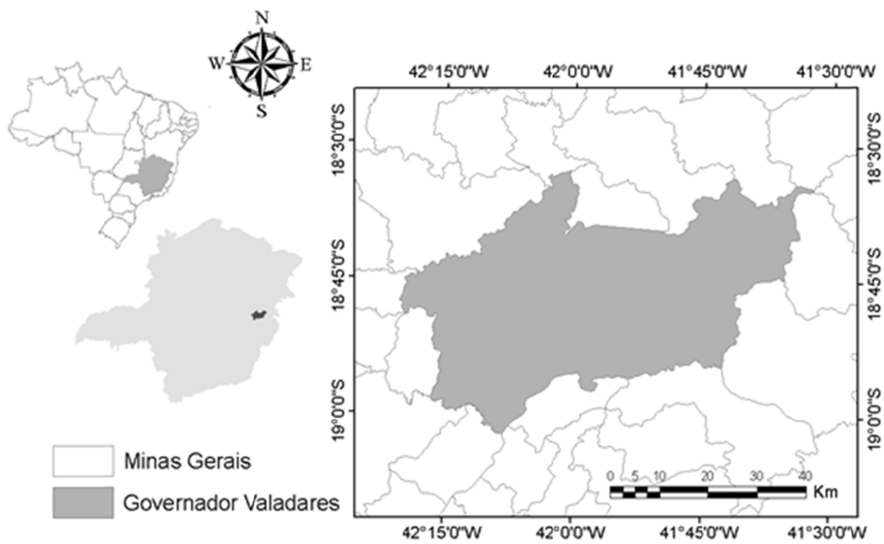

Figure 1. Location of Governador Valadares - MG

Soil samples were collected at a rural property called "Guzerra Duas Meninas". The rural property is engaged in beef cattle and milk and the soil is covered mainly by *Brachiaria brizantha* cv. Marandu. The farm area is 499.2 ha and there are currently 180 animals.

The climate of the region is type Aw (tropical with a dry season in the winter when the average temperature in the coldest month is higher than 18ºC and the precipitation of the driest month is lower than 60 mm) according to the Koppen classification. The mean annual precipitation is 1133 mm, with the occurrence of the greatest volume of precipitation between November and January. According to the weather station of the University of Vale do Rio Doce, the mean annual temperature is 25.6 ºC, with a maximum and minimum mean ranging between 28.7ºC and 18.3ºC, respectively. The soil of the farm was classified as Ultisol with a clay texture; the common rate of soil recovery and grazing systems in the study sites are listed in Table 1.

The study sites were: four degraded pastures, with increasing levels of degradation according to the visual character: degraded pasture 1, degraded pasture 2, degraded pasture 3 and degraded pasture 4; two capoeiras with different stages of natural recovery, capoeira 1 and capoeira 2 and the secondary forest used as a reference (Table 1).

The increasing degree of degraded pastures (1, 2, 3 and 4) was evaluated using a methodology proposed by Rocha-Junior (2012) using a method of tape to assess the degree of exposure of soil and weed infestation. This method consists of 500 readings done from the upper part of the experimental plot using a metric tape of 50 m stretched horizontally. In each meter a reading was done identifying the types of vegetation and soil exposed. After the determination of 50 readings on the horizontal part, continued the reading 1 meter down vertically repeating this procedure 10 times until the formation of a mesh with 500 readings. This method was used to select the pastures in different levels of degradation (Table 1).

The sites of study consisted in seven sites of collection (10 x 50 m with a greater extent in opposite direction to the slope of the land), presenting a slope of 0.40 m m^{-1} with a variation of ± 0.04 m m^{-1}, placed in the middle third of a convex landform.

Table 1. Summary description of sites and treatments at each site

Sites	Soil/Texture	Brief history	Date of sampling	Grazing system	Rate of soil recovery
Forest	Ultisol/ clayey	Secondary vegetation established for over 60 years	Rainy season, November, and dry season, July		100% recovery
Capoeira 1	Ultisol/ clayey	Process of natural regeneration for 9 years, shrubby	Rainy season, November, and dry season, July		100% recovery
Capoeira 2	Ultisol/ clayey	Process of natural regeneration for 7 years, undergrowth	Rainy season, November, and dry season, July		100% recovery
Pasture d. 1[a]	Ultisol/ clayey	*B. brizantha* planted in 2006, without liming and soil fertilization, previously managed with fire	Rainy season, November, and dry season, July	Continuous	9% soil exposed 80% pasture 11% weeds
Pasture d. 2	Ultisol/ clayey			Continuous	15% soil exposed 78% pasture 7% weeds
Pasture d. 3	Ultisol/ clayey			Continuous	22% soil exposed 5% pasture 73% weeds
Pasture d. 4	Ultisol/ clayey			Continuous	34% soil exposed 47% pasture 19% weeds

[a]Pasture degraded.

2.2 Soil Sampling and Analysis

The sampling of soil was conducted in two periods, rainy (November) and dry (July) season, at three depths, 0.00-0.05, 0.05-0.10 and 0.10-0.20 m, with 15 replicates per plot. The samples were air dried and sieved at 2 mm to obtain fine air dried soil.

The following determinations related to organic matter were done: soil organic carbon (SOC) by dry oxidation after soil combustion with an elemental analyzer CHNS/O (*Perkin Elmer CHNS/O 2400*); particulate organic matter (POM) determined using $Na_2OH_6P_2O_5$ (5 g L^{-1}) solution as a dispersant in a proportion of 1:3 (soil: dispersing soil). The material was suspended after 16 hours of resting, then sieved in a sieve of 0.53 mm to separate the POM. Afterwards, C content in POM (POC) was quantified with the same elemental analyzer, and the organic C content of the mineral-associated organic matter (MAOC) was calculated by the difference SOC-POC. This process was done according to the methodology proposed by Cambardella and Elliot (1992) with adjustments described by Figueiredo et al. (2010).

Moreover, the free light organic fraction (FLF) was determined by floating in water using a NaOH 0.2 *N* solution as a dispersant in a proportion of 1:2 (soil: dispersing solution); the material was agitated and separated by flotation in a sieve of 0.25 mm (Anderson & Igram, 1989); dissolved organic matter (DOM) was extracted in distilled water in a proportion of 1:2 (soil: water) and determined by colorimetry in reading absorbance (495 nm) performed in a spectrophotometer (Bartlett & Ross, 1988).

2.3 Statistical Analysis

In the ANOVA the degrees of freedom for the treatment (study sites) was decomposed in six orthogonal contrasts between them (Table 2), studying each season and depth separately. The significance contrast was tested by the *F* test ($p < 0.05$ and 0.01).

To compare the means among the depths within the same site, an honestly significant difference (h.s.d) was used by the Tukey test at 5% probability. To evaluate the correlations between the study variables, the Pearson correlation ($p < 0.05$ and 0.01) was applied. An analysis of variance was performed in the SISVAR software (Ferreira, 2000).

Table 2. Orthogonal contrasts to compare the study sites

Orthogonal contrasts[a]	Study sites [b]						
	F	C1	C2	P1	P2	P3	P4
C_1	6	-1	-1	-1	-1	-1	-1
C_2	0	2	2	-1	-1	-1	-1
C_3	0	1	-1	0	0	0	0
C_4	0	0	0	3	-1	-1	-1
C_5	0	0	0	0	2	-1	-1
C_6	0	0	0	0	0	1	-1

[a]C_1: Forest vs Capoeira (1 and 2) + Pasture (1- 4); C_2: Capoeira 1 + Capoeira 2 vs Pasture (1-4); C_3: Capoeira 1 vs Capoeira 2; C_4: Pasture 1 vs Pasture (2-4); C_5: Pasture 2 vs Pasture (3 and 4); C_6: Pasture 3 vs Pasture 4. [b]F: Forest; C1: Capoeira 1; C2: Capoeira 2; P1: Pasture degraded 1; P2: Pasture degraded 2; P3: Pasture degraded 3; P4: Pasture degraded 4.

3. Results and Discussion

The study sites presented remarkable changes in different soil organic matter pools especially in the surface layer. Statistical differences were also observed within the same site, among the soil layers (Table 3). The content of SOC in the surface layers (0.00-0.05 and 0.05-0.10 m), after the dry season presented values between 9.64 and 15.91 g C/kg soil. The soil under forest did not show significant SOC differences when compared to soils from other sites at dry season (Table 4, C_1).

In the subsurface (0.10-0.20 m) the SOC contents after the dry season were between 9.18 and 11.03 g C/kg soil. Negative contrasts were verified between forest and other sites (Table 4, C_1) indicating that the pastures sites, mainly pasture 1 (less degraded) influenced the negative results of the contrast. The pastures showed higher concentration of the roots in the surface layer, therefore this can increase the input of organic matter to the soil compared to the forest site and elevate the contents of SOC (Moraes et al., 1996).

Table 3. Mean values of organic matter pools in degraded pastures, capoeiras and forest sites, at two seasons rainy and dry, in Ultisols of Governador Valadares

Sites	Depth (m)	Rainy season					Dry season				
		SOC[a]	POC[b]	MAOC[c]	FLF[d]	DOM[e]	SOC	POC	MAOC	FLF	DOM
		g C/kg soil			g O.M./ kg soil	mg C/kg soil	g C/kg soil			g O.M./ kg soil	mg C/kg soil
Forest	0.00-0.05	27.87±9.62	16.78±5.47	11.87±4.16	22.48±9.20	189.13±2.71	15.15±5.30	6.07±3.90	9.09±1.40	11.66±8.53	193.12±0.29
	0.05-0.10	14.47±0.91	6.93±1.62	7.53±0.71	5.78±2.59	190.15±0.34	11.93±2.33	4.22±1.21	7.73±1.12	5.53±2.70	192.99±0.20
	0.10-0.20	14.33±3.78	7.17±2.04	7.17±3.29	4.86±2.42	189.94±0.14	9.81±2.23	1.65±0.64	8.16±1.59	2.48±0.66	191.44±0.99
	(h.s.d.)[f]	18.97	11.36	9.36	17.69	4.75	10.77	7.19	4.31	14.87	5.39
Capoeira 1	0.00-0.05	15.34±1.01	3.97±0.73	11.37±0.51	1.41±0.03	190.38±0.63	15.91±1.08	5.95±3.90	10.02±2.12	8.76±2.44	192.79±0.07
	0.05-0.10	12.82±0.71	2.38±0.54	10.44±0.34	0.99±0.34	189.64±0.14	12.07±0.50	3.12±0.33	8.95±0.71	4.57±0.94	193.33±0.05
	0.10-0.20	10.36±0.91	2.43±0.99	7.93±0.53	0.42±0.11	188.82±0.27	10.19±0.97	1.59±0.30	8.62±0.72	5.82±3.82	192.35±0.59
	(h.s.d.)	2.45	2.32	1.5	1.85	1.44	3.17	2.42	4.26	8.96	4.36
Capoeira 2	0.00-0.05	16.07±1.43	5.53±0.83	10.54±1.28	4.99±2.00	193.84±0.11	15.87±0.41	5.67±1.42	10.2±1.01	11.37±2.80	194.45±0.27
	0.05-0.10	11.83±0.37	3.28±0.41	8.55±0.15	2.23±1.63	190.45±2.78	12.06±1.97	4.18±2.62	7.88±1.21	4.47±1.56	186.96±1.94
	0.10-0.20	9.54±0.34	2.45±0.39	7.09±0.72	0.52±0.15	190.42±0.52	9.69±0.80	2.07±0.27	7.62±0.53	4.64±2.06	182.19±3.84
	(h.s.d.)	2.75	1.86	2.54	4.71	5.06	4.13	5.13	2.87	6.92	8.78
Pasture d. 1	0.00-0.05	14.49±0.90	5.93±1.62	8.57±0.72	3.14±0.06	171.05±3.72	14.01±0.30	6.75±1.06	7.26±1.36	6.45±1.20	190.55±1.08
	0.05-0.10	12.36±0.56	3.73±1.04	8.63±1.19	1.87±0.27	184.02±3.14	12.09±0.51	3.45±0.36	8.64±0.46	5.03±1.67	190.52±0.93
	0.10-0.20	11.59±0.51	2.67±0.34	8.92±0.22	0.67±0.19	187.71±0.95	10.33±0.32	3.12±0.50	7.21±0.33	2.38±0.56	189.67±0.99
	(h.s.d.)	2.33	3.85	2.86	1.06	8.73	2.46	2.37	3.33	3.77	3.24
Pasture d. 2	0.00-0.05	14.37±3.18	5.83±1.95	8.55±2.99	5.02±0.37	184.80±7.74	15.87±2.34	4.63±1.56	11.23±1.89	4.96±0.78	186.93±3.27
	0.05-0.10	12.78±1.15	5.85±3.51	6.93±4.45	3.56±0.45	189.64±0.74	9.64±0.76	2.06±0.16	7.58±0.81	2.95±1.10	188.32±2.23
	0.10-0.20	9.65±0.75	2.39±0.86	7.26±0.12	1.02±0.11	188.55±0.56	9.18±0.41	3.32±0.79	5.78±0.52	1.66±0.20	188.38±1.81
	(h.s.d.)	6.34	7.18	9.32	1.30	13.42	4.34	3.83	4.42	2.57	7.09
Pasture d. 3	0.00-0.05	13.94±0.24	4.92±1.18	9.01±1.40	2.82±0.25	189.20±0.79	13.77±1.33	5.96±0.77	7.81±1.10	2.49±0.41	188.25±0.63
	0.05-0.10	12.12±0.49	4.58±0.40	7.54±0.87	1.12±0.09	188.99±1.33	11.53±0.58	2.61±0.11	8.89±0.66	1.34±0.43	185.44±0.43
	0.10-0.20	9.51±0.47	4.95±3.57	7.08±1.28	1.06±0.25	188.66±0.70	9.26±0.31	3.21±0.45	6.13±0.74	0.69±0.17	183.58±2.87
	(h.s.d.)	1.30	6.62	3.63	0.75	3.19	3.04	3.48	3.13	1.06	8.63
Pasture d. 4	0.00-0.05	14.42±0.92	5.42±1.51	9.56±1.24	5.39±0.82	190.11±0.16	13.97±0.46	3.84±0.36	10.13±0.51	7.07±1.98	192.01±1.58
	0.05-0.10	13.69±0.42	3.01±0.86	10.68±0.55	3.68±1.02	190.15±0.54	11.99±0.73	2.85±1.32	9.14±1.04	4.96±3.55	188.42±2.10
	0.10-0.20	12.22±0.80	3.23±1.16	8.98±0.56	1.35±0.50	189.52±0.25	11.03±0.30	2.49±0.91	8.54±0.62	6.27±5.98	187.88±0.72
	(h.s.d.)	2.43	3.84	2.62	2.92	1.59	1.81	3.16	2.52	13.27	5.27

[a]SOC: Soil organic C; [b]POC: Particulate organic C; [c]MAOC: Mineral-associated organic C; [d]FLF: Free light fraction; [e]DOM: Dissolved organic matter; [f](h.s.d.): honestly significant difference, at the level of 5% after the Tukey`s test.

Table 4. Contrast of mean average of soil organic matter pools at three depths of Ultisols in rainy and dry season

Orthogonal contrasts[a]	Rainy season						Dry season					
	SOC[b]	POC[c]	MAOC[d]	POM[e]	FLF[f]	DOM[g]	SOC	POC	MAOC	POM	FLF	DOM
Depth 0.00-0.05 m												
C_1	78.57**	64.40**	14.17**	28.54**	28.54*	15.40	1.52	3.66	-2.13	20.41**	29.35*	14.22
C_2	5.60	-3.09	8.69*	6.75**	6.75	33.28**	5.95	1.95	4.01	7.52*	19.80*	15.84*
C_3	-0.73	-1.56	0.83	-2.42**	-2.42	-3.45	0.04	0.23	-0.19	-2.02**	-2.61	-1.22
C_4	0.75	1.61	-0.86	-4.35	-4.35	-50.95**	-1.56	5.82	-7.38	2.68	3.55	4.47
C_5	0.39	1.31	-0.92	-1.07	-1.07	-9.72	4.00	-0.53	4.53	-0.69	0.24	-6.40
C_6	-0.48	-0.50	0.02	-0.47	-0.47	-0.91	-0.20	2.12	-2.32	-0.46	-4.57	-3.76
Depth 0.05-0.10 m												
C_1	11.20**	18.77*	-7.57	29.40**	20.80*	7.99**	2.22	6.93	-4.71	22.33**	9.69*	24.95**
C_2	-1.64	-5.85	4.21	8.02**	-3.72	7.38**	3.04	3.64	-0.60	9.08**	3.80	7.89*
C_3	0.99	-0.90	1.89	-1.65	-1.23	-0.81	0.01	-1.06	1.07	-1.31	0.10	6.36**
C_4	-1.52	-2.26	0.74	-1.81	-2.95**	-16.72**	3.15	2.82	0.32	-0.20	5.83	9.38*
C_5	-0.25	4.11	-4.36	0.92	2.32	0.14	-4.21	-1.34	-2.88	-1.40	-0.40	2.78
C_6	-1.56	1.58	-3.14	-0.42	-2.56**	-1.15**	-0.49	-0.24	-0.26	-0.88	-3.62	-2.98
Depth 0.10-0.20 m												
C_1	23.14**	24.89**	-4.27	34.73**	24.12*	5.99*	-0.64	-5.92	5.08	20.58	-6.59	24.34*
C_2	-3.14**	-3.47	-2.19	5.77**	-2.22	4.06*	0.17	-4.80	4.77*	9.10**	9.92	-0.44
C_3	0.82**	-0.02	0.84	-2.32**	-0.11	-1.59*	0.50*	-0.48	0.98	-1.46	1.18	10.16**
C_4	3.41**	-2.56	3.45	-1.54	-1.41	-3.59	1.71**	0.34	1.18	-0.88	-1.48	9.17
C_5	-2.42**	-3.40	-1.54	0.46	-0.36	-1.05	-1.97**	0.95	-3.11	-1.28	-3.64	5.32
C_6	-2.69**	1.72	-1.89	-0.30	-0.28	-0.85	-1.89**	0.72	-2.41*	-1.16	-5.58	-4.30

*$p < 0.05$; **$p < 0.01$ (*F*-values). [a]C_1: Forest vs Capoeira (1 and 2) + Pasture (1- 4); C_2: Capoeira 1 + Capoeira 2 vs Pasture (1-4); C_3: Capoeira 1 vs Capoeira 2; C_4: Pasture 1 vs Pasture (2-4); C_5: Pasture 2 vs Pasture (3 and 4); C_6: Pasture 3 vs Pasture 4. [b]SOC: Soil organic C; [c]POC: Particulate organic C; [d]MAOC: Mineral-associated organic C; [e]POM: Particulate organic matter; [f]FLF: Free light fraction; [g]DOM: Dissolved organic matter.

For the rainy season, the soil under the forest presented higher content of SOC in all of the layers, ranging between 14.33 and 27.87 g C/kg soil at the depths 0.05-0.10 m and 0.00-0.05 m, respectively (Table 4, C_1).

The results in Tables 3 and 4 show that the conversion of the forest sites for the establishment of pastures or agriculture can result in decreasing levels of SOC, as already reported in literature (Rasiah et al., 2004; Marchão et al., 2009; Benites et al., 2010). By contrast, some authors found that soils under pasture can show higher contents of SOC when compared to forest sites, which can be due to the management of pastures (Desjardins et al., 2004; Oliveira et al., 2004; Martins et al., 2009).

When comparing the soil under capoeira 1 and 2 with soils under pastures 1, 2, 3 and 4, it was verified that the depths 0.00-0.05 m and 0.05-0.10 m have higher mean values of SOC in the soil under capoeiras (Tables 3 and 4), however no significant differences are noted in the contrasts (Table 4, C_2). The results are in agreement with those obtained by Pillon et al. (2011) in a study developed under a planted forest in comparison with pasture in Ultisol, which showed high contents of SOC in the surface layer and not significant differences between land uses.

It was to be expected that the soils under capoeiras would not differ from the soils under pastures due the time of 9 to 7 years after natural regeneration, which is considered a short period to reestablish the soil C content.

Taking into consideration the SOC, it was noted that it is possible to statistically discriminate the Forest from the other studied areas (Capoeiras and Pastures) only in the rainy season, except for the layer 0.20-0.40 m, where positive/negative and significant/not significant contrasts were observed at the same time, thus no trend was observed. This result indicates that the SOC contents are not able to discriminate the levels of degradation of the studied environments, especially among the pastures.

Corroborating with these results, Muller et al. (2004) did not find any difference in the SOC in pasture at different levels of degradation in an Ultisol in the Amazon region. Therefore, no relations of SOC were established with managements practices, pasture age and/or degree of degradation.

The content of SOC decreases with the depth. The depth 0.00-0.05 m presented the highest levels in all the sites and in both seasons. Pereira et al. (2008) reported similar results in the forest sites, the same observed by Costa et al. (2009) in sites of pastures under different managements. The highest mean value recorded for this attribute is found in the forest (27.87 g C/kg soil), but these site did not present any honestly significant differences (h.s.d) among the depths.

The depths 0.00-0.05 m was sensitive to the differences among the study sites, since this soil layer is directly affected by erosion process; therefore in the higher levels of pasture degradation there are higher exposure of soil and soil loss due to erosion and consequently higher loss of organic matter. Moreover, sites with higher soil exposure are providing less litter and less root growth which may be influencing these results.

The highest levels of POM and FLF are found in the forest site (Figure 2 and Table 3). The contrast between the forest site and the other sites showed statistical differences for POM, which was observed in all of the depths and seasons (Table 4, C_1). A similar behavior occurred for FLF, but the contrasts were significant only in the rainy season (Table 4, C_1), with the exclusion of depth 0.10-0.20 m and the dry season. The large input of vegetable residue provided by forest can be contributing to the increased content of POM and FLF, especially in the surface soil layer (Roscoe et al., 2001). It is noteworthy that the forest sites (secondary and/or native) can deposit large amount of litter in the soil (with values higher than 10 Mg ha^{-1} year) (Toledo et al., 2002; Vital et al., 2004).

The compartment POM show sensitivity in distinguishing statistical differences between the forest and other sites, also observed when comparing capoeiras 1 and 2 with pastures 1, 2, 3 and 4 (Table 4, C_1 and C_2). Through that compartment it was not possible to identify the levels of degraded pastures visually observed. The increasing order of degradation verified using POM is: pastures (4, 3, 2 and 1) > capoeira 1 = capoeira 2 > forest.

Two hypotheses may have influenced these results: the first is that the pasture sites, even under severe degradation as observed in pasture 3 and 4, presented a biomass production through the weeds which, to a lesser extent, can favor the accumulation of soil organic matter (Dias-Filho, 2011). The second hypothesis is due to the renovation of pastures with fire, which favored the accumulation of partially carbonized residues, contributing to the light fraction of soil (Roscoe & Buurman, 2003).

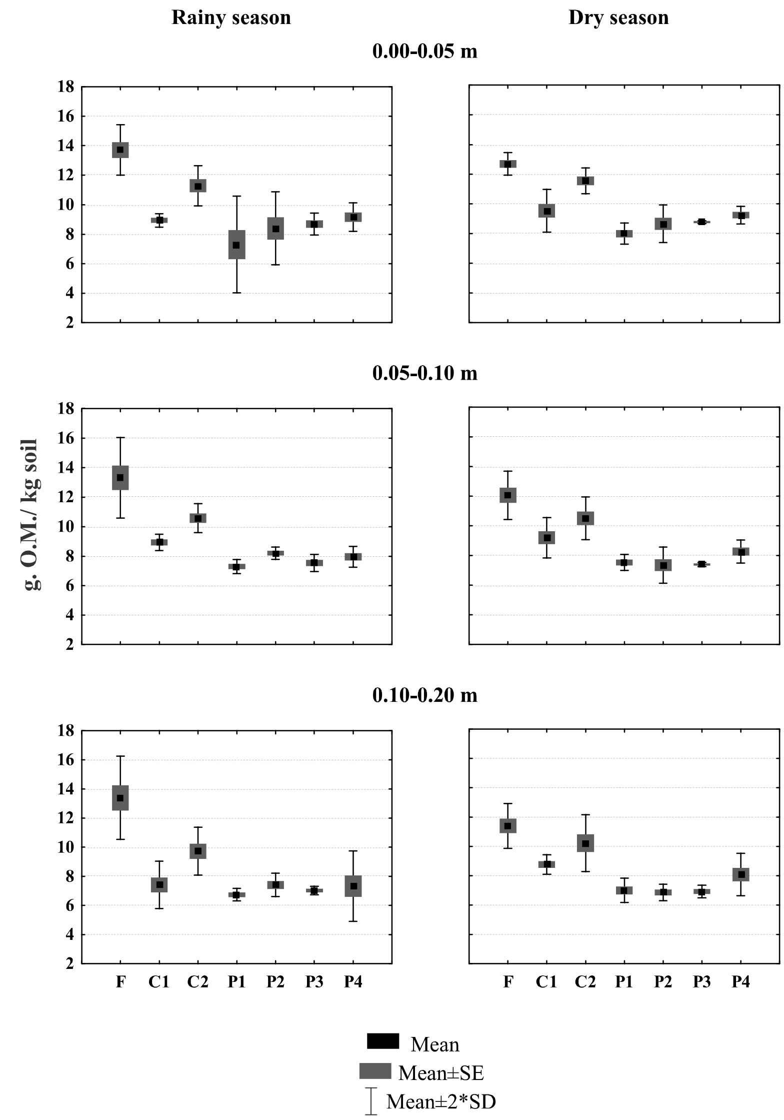

Figure 2. Particulate organic matter in three depths (0.00-0.05, 0.05-0.10 e 0.10-0.20 m) in Ultisol in two season, rainy and dry. F-forest; C1-capoeira 1; C2-capoeira 2; P1- pasture degraded 1; P2- pasture degraded 2; P3- pasture degraded 3 and P4- pasture degraded 4

The soil fractions POM and FLF presented a positive correlation coefficient (r), significant for the rainy season (r = 0.37**) and for the dry season (r=0.50**). This indicated that in an attempt to diffuse the light fraction as a degraded environment indicator, choosing to measure FLF instead of POM is a better option since this measure is cheaper and easily available for producers and technicians.

Among the study sites (forest, capoeira 1, capoeira 2, pasture 1, pasture 2, pasture 3, pasture 4), in most cases, no statistical differences were noted when evaluating the mineral-associated organic C (MAOC) (Table 4). The values of MAOC were between 5.78 and 11.87 C/kg soil, in both season and depths. This pool was not influenced by the levels of degraded pastures, thus indicating that the pasture degradation is restricted to light organic matter. Therefore, it is evident that MAOC is not sensitive to small changes noted visually in the pasture sites. Similar results were obtained by Souza et al. (2006), suggesting that MAOC should not be used as a degraded pasture indicator in a short term.

On the other hand, for the particulate organic carbon (POC), the forest site showed higher mean values for this pool during the rainy season (Table 3). The contrasts are significantly higher than the other sites, in all of the depths, condition not observed for the dry season. The capoeira sites 1 and 2 did not show differences in the contrast performed with pasture 1, 2, 3, and 4. The same is seen in the comparison between capoeira 1 and 2 (Table 4, C_3) and between pasture 1, 2, 3 and 4 (Table 4, C_4, C_5 and C_6).

These results reinforce the hypothesis of the influence of biomass production through weeds and charcoal from the renovation of pasture with burning. It is likely that both aspects are collaborating with the increase of C in light fraction, contributing to not have any differences between the pasture sites.

The light fraction has been recommended as a sensitive indicator for changes in management (Conceição et al., 2005; Xavier et al., 2006; Souza et al., 2006; Rangel & Silva, 2007). In this study, this indicator is only sensible to distinguish forest from other sites.

The mean contribution of MAOC to SOC is around 68.9% for rainy season and 71.0% for dry season (Figure 3). This indicates that most of the C consists of the most recalcitrant forms, as already reported in literature (Trumbore, 2000; Martins et al., 2009).

POC (more labile fraction) has a lower mean contribution in relation to SOC when compared to MAOC. The result of POC when compared to SOC is around 31.1% for rainy season and 28.9% for dry season (Figure 3). These results are similar to those obtained by Figueiredo et al. (2010), reporting that, on average 29.12% of SOC is composed by POC pools in areas with different managements in a Ultisol in the region of Planaltina-DF; but are higher than the results obtained by Costa et al. (2004), in a study developed in a Ultisol in Paraná in non-tillage areas in which 26.3% of SOC composed by POC.

Some factors may contribute to variation of MAOC pools and POC in different regions, such as soil type, texture and mineralogy, management and soil moisture; all these factors influence the accumulation and dynamics of soil organic matter (Gama- Rodrigues et al., 2005; Wiseman & Puttman, 2006; Jantalia et al., 2007).

When evaluating the POM, FLF, POC and MAOC pools among the soil depths within the same site, it appears that the soil depth that presents higher contents is the surface layer 0.00-0.05 m (Table 3). The higher content of organic matter on the surface is related to the direct effect of vegetable residue input through litterfall and the contribution of roots, especially in the pasture sites.

For dissolved organic matter (DOM), with the exclusion of depth 0.00-0.05 m, in the soil under forest the contrast value was significantly higher than the other sites in both seasons (Table 4, C_1), with mean values between 189.13 and 193.12 mg C/kg soil. Similar results were found in the contrast between the capoeiras 1 and 2 in comparison to pastures 1, 2, 3, and 4 (Table 4, C_2) with the exclusion of depth 0.10-0.20 m, where the soils under capoeira show higher mean values (Table 3). On the other hand, in the comparison among the pastures (1, 2, 3 and 4) contrasts are positive/negative and significant/not significant at the same time (Table 4, C_4, C_5 and C_6).

Even though the contrast did not show any clear difference among the levels of degraded pastures by the DOM evaluation, the highest mean value for these pools was found in the depth 0.00-0.05 m in the soil under pasture with the highest level of degradation (pasture 4) (Table 3). Anyhow, the DOM presents sensitivity in differentiating systems conversions, forest/pasture. Moreover, through these pools the natural recovery is restoring the content of DOM in the sites that were previously degraded pastures.

The highest level of DOM in the soil under forest are probably the largest increase and the quality of organic substances in the environment, due to the areas under natural vegetation that provide diverse material from plants, as well as organic substances derived from decomposition of roots (Jiang & Xu, 2006; Favero et al., 2008).

It is evident that the sites with continuous input and material diversity (as already observed visually) are those that present the highest values for these pool. This aspect explains why the highest level of DOM was found in pastures with greater degradation than those with less degradation (Table 3). This result can be related to the diversity of plants found in the degraded pasture sites.

Since the litter and soil organic matter pools are potential sources of DOM (Kalbitz et al., 2000), the highest content of POM and FLF are contributing to the results found in the forest site, capoeira 1 and 2. These factors are associated with the absences of disturbances resulting in increased microbial activity, promoting the decomposition of organic matter, favoring the increases of DOM content (Jiang & Xu, 2006). These results are in agreement with those found by Favero et al. (2008) in studies of the same region, who found marked differences for DOM when comparing agroforestry system sites with pastures and degraded soils, being that the highest contents are found in the agroforestry system.

Furthermore, pastures sites that have homogeneity of input material to the soil, contribute to have a small difference among the values of DOM for the levels of pastures studied, except pasture 4. Moreover, the sites under native forest presented higher heterogeneity of deposited material and consequently higher content of DOM compared to the others sites (Rosa et al., 2003).

The increasing order of degradation verified using DOM is: pastures (3, 2 and 1) > pasture 4 > capoeira 1 = capoeira 2 > forest.

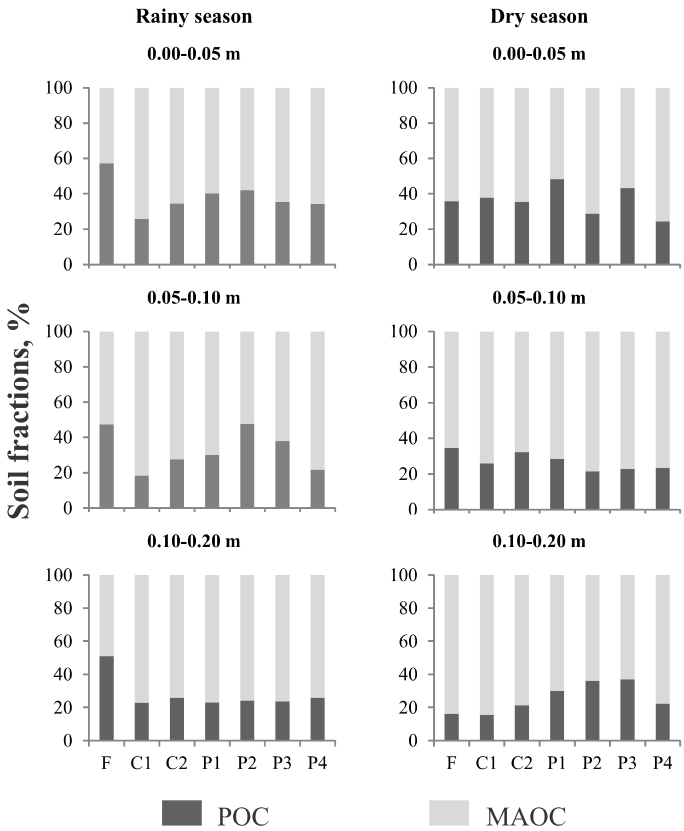

Figure 3. Percentage of organic carbon in particulate fraction and associated with minerals, at the three depths (0.00-0.05, 0.05-0.10 e 0.10-0.20) in Ultisoils, in two season rainy and dry. F- forest; C1- capoeira 1; C2- capoeira 2; P1- pasture degraded 1; P2- pasture degraded 2; P3- pasture degraded 3 e P4- pasture degraded 4. POC: particulate organic C; MAOC: Mineral-associated organic C

Although, the labile organic matter pools has been recommended as sensitive to soil management (Conceição et al., 2005; Souza et al., 2006; Pereira et al., 2010) and recommended as indicators for small variation of degradation, in the present study this compartment was not sensitive to the levels of pastures established. It is possible to note the differences between the conversions uses, but in pastures small differences were verified. This indicates that further studies are necessary, for example, for soil microbiota because it is a fraction that is more sensitive to small changes in soil management (Conceição et al., 2005; Lima et al., 2007). The improvement of methods for determining the tropical soil organic matter can lead to methods that are more sensitive to different soil uses.

4. Conclusions

The soil organic matter pools are indicators efficient to discriminate the soil quality in different study sites, allowing to differentiate the forest from other sites and capoeiras from the pastures.

It was possible to establish three groups: reference (forest), in recovery (capoeira 1 and capoeira 2), at some stage of degradation (pastures 1, 2, 3 and 4).

From the soil organic matter pools studied it was not possible to differentiate the levels of degraded pastures.

The soil organic matter pools that are more sensitive were: POM and DOM.

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