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Oxidizable carbon fractions in Red Latosol under different management systems¹

Frações oxidáveis do carbono em Latossolo Vermelho sob diferentes sistemas de manejo

Roni Fernandes Guareschi^{1,2*}, Marcos Gervasio Pereira² e Adriano Perin³

ABSTRACT - The aim of this study was to evaluate the oxidizable fractions of organic C in a Red Latosol in an area of cerrado under a no-tillage system (NT) with different years of implantation, and to compare them to areas of native cerrado and pasture. The experimental design used was completely randomized with five replications. Treatments consisted of five areas: native cerrado (NC) “*stricto sensu*”; pasture (PA) planted with *Brachiaria decumbens*; NT with 3 (NT3); NT with 15 (NT15) and NT with 20 (NT20) years of implantation. There was an increase in the ground-surface mass of vegetable residue as a function of the time of implantation of the NT. An increase in C content and the carbon-management index (CMI) can be seen as a function of the time of implantation of the NT. In the area of NT20 the greatest values of C were quantified, compared to the area of cerrado. In general, there are increased labile and stable MOS fractions as a function of the implantation time of the NT, while the areas SPD15 and SPD20 present a C content among fractions, respectively similar and/or superior to the area of NC. Regardless of the area evaluated, a predominance of the more stable MOS fractions (F3+F4) can be seen. The area of PA, due to inadequate management, shows a more advanced stage of degradation when compared to the other areas, as there is a large reduction in the levels of total C, of C in the more labile and stable MOS fractions, as well as lower CMI values.

Key words:No-tillage. Grassland. Soil organic matter. Labile carbon.

RESUMO - Objetivou-se com este trabalho avaliar as frações oxidáveis de C orgânico em um Latossolo Vermelho em área de cerrado sob sistema de plantio direto (SPD) com diferentes anos de implantação, e compará-las a áreas de cerrado nativo e pastagem. O delineamento utilizado foi inteiramente casualizado, com cinco repetições. Os tratamentos consistiram de cinco áreas: cerrado nativo (CE) “*stricto sensu*”; pastagem plantada (PA) com *Brachiaria decumbens*; SPD com 3 (SPD3); SPD com 15 (SPD15) e SPD com 20 (SPD20) anos de implantação. Foi observado aumento na massa dos resíduos vegetais da superfície do solo em função do tempo de implantação do SPD. Verifica-se aumento nos teores de C e no índice de manejo de carbono (IMC) em função do tempo de implantação do SPD. Na área de SPD20 quantificaram-se maiores valores de C em relação à área de cerrado. De maneira geral, verifica-se aumento das frações lábeis e estáveis da MOS em função do tempo de implantação do SPD, sendo que as áreas SPD15 e SPD20 apresentam teores de C dentre as frações semelhantes e/ou superiores respectivamente a área de CE. Independentemente da área avaliada, observa-se que há predomínio das frações mais estáveis da MOS (F3+F4). A área de PA devido a um manejo inadequado apresenta-se em estágio de degradação mais avançado quando comparado às demais áreas, pois se observa uma grande redução dos teores de C total, C das frações mais lábeis e estáveis da MOS, bem como menores valores de IMC.

Palavras-chave: Plantio direto. Pastagem. Matéria orgânica do solo. Carbono lábil.

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INTRODUCTION

The no-tillage system of farming (NTS) first appeared in the *cerrado* in 1981 as an alternative to minimize the impacts caused to the soil by the different forms of usage. According to Carvalho *et al.* (2010) keeping plant residue (PR) on the surface, and not ploughing the soil, besides reducing the emission of CO₂ into the atmosphere, also helps to increase the stock of C and N in the soil, bringing other benefits such as an increase in microbial diversity, and an improvement in the fertility and physical properties of the soil (FOLEY *et al.*, 2005).

As well as the changes in the levels of organic matter in cultivated soils, there are also changes seen in the quality, and notably in the degree of oxidation and lability (SHANG; TIESSEN, 1997). Studies have shown that deforestation and cultivation of the soil, not only promote significant losses of carbon, but also contribute to the reduction of organic fractions of greater lability, generating an increase in the already high degree of aromaticity (SILVA; ANDERSON; VALE, 1999).

The different fractions of oxidation of C in the soil, proposed by Chan, Bowman and Oates (2001) are based on the separation of four fractions with decreasing degrees of oxidation, i.e. through the use of increasing concentrations of sulphuric acid the fractions, F1, F2, F3 and F4 are separated out. These correspond respectively to concentrations of 3; 6; 9 and 12 mol L⁻¹ of sulphuric acid.

The fractions F1 and F2 are associated with the availability of nutrients and the formation of macro-aggregates (CHAN; BOWMAN; OATES, 2001), F1 is the fraction of greater lability in the soil, and highly correlated to the free light fraction of soil organic matter (SOM) (MAIA *et al.*, 2007). The fractions F3 and F4 however, are related to compounds of greater chemical stability and higher molecular weight which originate from the decomposition and humification of the SOM. The fraction F4 is the most resistant in the soil, being called the "passive component" in simulation models of SOM (CHAN; BOWMAN; OATES, 2001).

Due to the scarcity of results regarding the effects of the adoption of NTS on the degree of oxidation of SOM, studies are necessary to assess the distribution of these fractions under this system, with the aim of demonstrating the impact of this type of interference on the activity of the ecosystem, and/or to determine the quality of soil in these areas in the medium and long term.

Starting from the above, the aim of this study was to evaluate the oxidisable fractions of soil organic C in grassland areas under a no-tillage system, and compare them to areas of native vegetation and pasture.

MATERIAL AND METHODS

The study was carried out at the Montividiu Tiuba Farm, in the municipality of Montividiu, in Goiás (17°27'52.2" S, 51°10'33.1" W, altitude 890 m). The average annual rainfall in the region is 1,740 mm, with a warm tropical climate, classified as Aw by the Köppen system, and mainly flat terrain. The soils in the study areas have been classified as Red Distroferic Oxisols (EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA, 2006).

Four areas were analysed, namely: pasture with *Brachiaria decumbens* (PA); three years of NTS, with soybean cultivation in the summer and lying fallow for the rest of the year (NTS3); 15 years of NTS, rotating soybeans in the summer with maize or sorghum for the later harvest (NTS15); and 20 years of NTS, rotating soybeans in the summer with maize (NTS20). The experimental design was completely randomized with five replications. The plots consisted of four soil-management systems and one of strictly native *cerrado* (NC) used as reference.

With each management system, a representative area of 150 x 150 m, each in a similar position on the landscape were randomly chosen and marked out. In each area five trenches were dug with a surface area of approximately 1.0 x 1.0 m and a depth of 1.0 m, where undisturbed soil samples were collected employing a Kopeck ring (EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA, 1997) at depths of 0.0-0.05 m and 0.05-0.10 m. Samples of disturbed soil were also collected, which were then air dried, broken up and passed through a sieve of 2mm mesh, resulting in a fine, air-dried earth, which was used to characterize the chemical attributes of the soil and for particle-size analysis, following the Empresa Brasileira de Pesquisa Agropecuária (1997). The results of the characterization are given in Table 1.

The area of pasture with *Brachiaria decumbens* (17°25'58.5" S, 51° 09'39.4" W, altitude 804 m), has been cultivated with approximately 1.5 animal unit per hectare. The area of NTS3 (17°27'20.9" S, 51°10'16.3" W, altitude 858 m) was established in 1987 with the removal of the *cerrado*. It was used for pasture for 20 years, after that rice was grown for 1 year, and 3 years ago NTS was adopted with soybean being cultivated. The area of NTS15 (17°28'16.8"S, 51°11'20.4"W, altitude 899 m), has a history of 27 years of conventional tillage with soybean crops in the summer and maize in the winter, NTS being adopted in 1995. The area of NTS20 (17°28'31.7" S, 51°10'43.6" W, altitude 898 m) has had the same usage as the area of NTS15, however NTS was adopted in 1990. Currently, the areas of NTS15 and NTS20 are being planted with soybeans in the summer and maize or sorghum in the off-season. The *cerrado* being analysed is located

Table 1 - Chemical attributes and particle size analysis in the areas of *cerrado* (CE), pasture (PA) and no-tillage system with 3 (NTS3), 15 (NTS15) and 20 (NTS20) years of usage

Área	pH H ₂ O	P* mg kg ⁻¹	Ca	Mg	K ⁺	Al	H+Al	T	V	Clay	Silt	Sand
			-----mmol _c dm ⁻³ -----						--%--	-----g kg ⁻¹ -----		
0-0.05 m												
CE	4.4	9.5	8.0	19.0	2.0	5.0	133.0	162.0	17.8	410	170	420
PA	5.7	2.1	39.0	47.0	2.0	0.0	73.0	163.0	54.6	600	190	210
NTS3	5.2	26.7	16.0	20.0	3.0	1.0	36.0	77.0	52.9	590	270	140
NTS15	5.0	33.6	26.0	29.0	3.0	1.0	46.0	106.0	56.4	630	170	200
NTS20	6.2	32.1	26.0	28.0	3.0	0.0	28.0	86.0	67.1	410	120	470
0.05-0.10 m												
CE	3.6	5.8	0.0	11.0	1.0	9.0	99.0	110.0	10.7	390	200	410
PA	5.6	1.5	30.0	30.0	1.0	0.0	50.0	112.0	54.8	570	240	190
NTS3	5.1	20.9	9.0	17.0	3.0	1.0	38.0	66.0	42.0	610	270	120
NTS15	4.9	29.1	19.0	19.0	3.0	2.0	40.0	82.0	52.6	670	160	170
NTS20	5.3	29.2	18.0	18.0	3.0	1.0	39.0	79.0	50.3	460	110	430

*P determined with a Mehlich extractor¹

inside the reserve area of the Montividiu Tiúba Farm (17°27'52.2" S, 51°10'3.3" W, altitude 890 m).

Basic fertilisation of the main crops of the agricultural systems were the following: 1) NTS3 and NTS15: a) soybean (summer), 458 kg ha⁻¹ of 02-20-20 formula, b) maize (winter), 312 kg ha⁻¹ of 12-15-15 formula at sowing and 120 kg ha⁻¹ urea, as coverage at 25 DAE; 2) NTS20: a) soybean (summer) - 200 kg ha⁻¹ of 02-20-20 formula plus 60 kg ha⁻¹ of K₂O and P₂O₅ as coverage, b) maize (winter), 30 kg ha⁻¹ N plus 60 kg ha⁻¹ P₂O₅ plus 70 kg ha⁻¹ K₂O in the furrow and 120 kg ha⁻¹ urea as coverage at 25 DAE. NTS3 was treated with lime in 2006 and 2010, NTS15 was treated in 2007, and NTS20 in 2008. The area of PA received an application of 2 mg ha⁻¹ of dolomitic limestone in 2009.

The amount of plant residue (PR) deposited on the soil surface in each study area was determined with the aid of a metal guage (0.25 m²) and subsequent collection of the PR. In each study area 20 samples were taken. The collected PR samples were dried in an oven under forced ventilation at a temperature of 65 °C for 72 hours, and then weighed. From this data, the amount of dry mass of the surface PR was determined per hectare.

The C content was quantified by dry combustion using a CHNS analyzer. Fractionation of C by degrees of oxidation was also performed (CHAN; BOWMAN; OATES, 2001), four fractions with decreasing degrees of oxidation being obtained: a) Fraction 1 (F1): C oxidized by K₂Cr₂O₇ in an acid medium of 3mol L⁻¹ H₂SO₄; b) Fraction 2 (F2): C difference oxidized by K₂Cr₂O₇ in an acid medium

of 6 and 3 mol L⁻¹ H₂SO₄; c) Fraction 3 (F3): C difference oxidized by K₂Cr₂O₇ in an acid medium of 9 and 6 mol L⁻¹ H₂SO₄; d) Fraction 4 (F4): C difference oxidized by K₂Cr₂O₇ in an acid medium of 12 and 9 mol L⁻¹ H₂SO₄.

The C content in the F1 fraction was considered to be labile carbon (C_L) of the soil (RANGEL *et al.*, 2008), whereas the non-labile carbon (C_{NL}) was determined by difference (C_{NL}=C-C_L). The percentage of total carbon (C) of the soil was determined by dry combustion using a CHNS analyzer and then used to calculate the ratio C_L/C, the Carbon Sharing Index (CSI). Based on changes in the C content of the soil in the reference area (of native vegetation) and of the soil under pasture and NTS, the following indices were calculated: (CSI) = C_{cultivated}/C_{reference}, Lability (L) = C_L/C_{NL}, Index of Lability (IL) = L_{cultivated}/L_{reference} and Carbon Management Index (CMI) = CCI x IL x 100, following Blair, Lefroy and Lisle (1995).

The results were evaluated using normality (Lilliefors) and homogeneity of error variances by the Cochran and Bartlett test. They were then subjected to variance analysis (F test), and the mean values were compared by the Tukey test at 5% probability using the statistical software ASSISTAT.

RESULTS AND DISCUSSION

Of all the variables analyzed, only the ratio of labile C to total C, lability, the carbon lability index (0-0.05 m)

and fraction F2 (0.05-0.10 m) were not significantly affected ($p < 0.05$) by the management systems (Table 2). The data showed a normal distribution and homogeneity of the variances. There was a statistical difference in the number of PRs deposited on the surface of the soil (Table 3).

The larger amount of PRS in the *cerrado* area is due to litter deposition, this area is also not subject to anthropic action. Similar results to this study were observed by Maman *et al.* (2007) when assessing the *Cerradão* Biome in southwestern Mato Grosso, where authors found yields of 9.5 Mg ha⁻¹ of dry litter matter.

As for the areas of NTS, it can be seen that where this system has been installed for more time (15 and 20 years) more residue is produced, similar to that in the areas of 15 and 20 years and greater than in the area of NTS3.

When comparing areas of NTS with the area of *cerrado*, it appears that even in areas where NTS has been installed the longest (15 and 20 years), the production of residue was not sufficient to achieve those values quantified in the area of *cerrado*. The lesser residue production is attributed to the greater difficulty in establishing cover vegetation, due to the long periods

Table 2 - Summary of variance analysis, test for normality and homogeneity of variances for plant residues on the soil surface (1), total soil carbon (2), fraction F1 (3), F2 (4), F3 (5), F4 (6), non-labile carbon (7), ratio of labile C/C total (8), carbon component index (9), lability (10), lability index (11) and carbon management index (12)

SV	DF	Variables											
		1	2	3	4	5	6	7	8	9	10	11	12
		Square mean											
		0 - 0,05 m											
Trt	4	4.0**	92.5**	14.0**	3.6**	21.1**	20.3**	134.5**	9.8 ^{ns}	0.3**	0.0 ^{ns}	0.0 ^{ns}	2957.3*
Res	20	0.1	0.1	0.2	0.1	0.6	1.3	0.5	4.9	0.0	0.0	0.0	89.7
CV (%)		4.2	3.1	8.6	16.8	11.4	12.0	3.8	9.2	3.7	12.1	15.3	12.6
Ks		0.6 ^s	0.2 ^s	0.2 ^s	0.2 ^s	0.1 ^s	0.2 ^s	0.3 ^s	0.1 ^s	0.3 ^s	0.1 ^s	0.1 ^s	0.1 ^s
Coch		0.5 ^H	0.4 ^H	0.4 ^H	0.4 ^H	0.4 ^H	0.4 ^H	0.3 ^H	0.4 ^H	0.5 ^H	0.5 ^H	0.4 ^H	0.3 ^H
0.05 - 0.10 m													
Trat	4		99.4**	10.1**	0.9 ^{ns}	8.5**	16.2**	165.9**	60.6**	0.1**	0.0**	0.3**	4357.7**
R	20		0.2	0.2	0.2	0.4	0.5	0.4	6.9	0.0	0.0	0.0	99.7
CV (%)	--		2.8	6.8	27.9	10.5	11.0	3.5	10.2	4.6	13.6	13.5	12.1
Ks			0.2 ^s	0.1 ^s	0.2 ^s	0.1 ^s	0.2 ^s	0.2 ^s	0.1 ^s	0.3 ^s	0.1 ^s	0.2 ^s	0.2 ^s
Coch			0.4 ^H	0.4 ^H	0.4 ^H	0.4 ^H	0.4 ^H	0.4 ^H	0.6 ^H	0.5 ^H	0.7 ^H	0.6 ^H	0.4 ^H

SV - Source of variation; DF - degrees of freedom; Trt - treatments; Res - residue; Ks - Kolmogorov-Smirnov normality test; Coch - Cochran Test; **, * e ^{ns} - Significant to 1%, 5% e non-significant respectively by the F test., CV (%) - Coefficient of variation as a percentage; ^s - normal data distribution; ⁿ - non-normal data distribution; ^H: Variâncias are homogeneous; ^{NH}: Variâncias are not homogeneous

Table 3 - Plant residue deposited on the surface of the soil (PRS) in the areas assessed

Systems assessed	PRS (Mg ha ⁻¹)
CE	10.07 a*
PA	7.33 c
NTS3	7.32 c
NTS15	7.85 b
NTS20	8.65 b

*Averages when followed by the same lower case letter in any one column do not differ significantly across the different systems of soil usage by the Tukey test at 5% level

of drought and the occurrence of dry spells (FIDELIS *et al.*, 2003). The low production of residue in the area of pasture (PA) compared to the *cerrado* (EC), NTS15 and NTS20, is due to a combination of factors, such as low productivity, the absence of management systems (primarily of maintenance fertilization) and intensive grazing. According to the historical data of the area of PA, this has not received annual maintenance fertilization. According Zanine, Santos and Ferreira (2005) the lack of fertilization results in low productivity of the pasture. Table 4 shows the values of total soil carbon (C) in the evaluated crop systems.

Table 4 - Total soil carbon (C) of the crop systems evaluated

Depth (m)	Systems evaluated				
	CE	PA	NTS3	NTS15	NTS20
	C (g kg ⁻¹)				
0-0.05	30.76 b*	15.45 c	15.97 c	29.66 b	33.96 a
0.05-0.10	36.06 a	14.08 c	15.43 c	27.12 b	26.72 b

*Averages when followed by the same lower case letter in any one column do not differ significantly across the different systems of soil usage by the Tukey test at 5% level

In the layer at 0-0.05 m, higher concentrations of C as a function time since NTS implantation can be seen, and in the area of NTS20, values of C and N greater than those observed in the field of CE are already being quantified. Also at this depth the area of NTS15 presents a C content similar to that found in the area of CE. These results show that the supply of materials of different quantities and qualities in the NTS contributes to an increase in the C and N content, which can be attributed to the higher rate of carbon addition to the soil, resulting from an increase in the primary productivity of the ecosystem promoted by less turning of the soil. Similar results were found by Matias *et al.* (2009) where the authors found that in areas of NTS in a Latosol in the region of Uruçuí in Piauí, there were increases in C levels relative to the areas of original *cerrado*.

In the layer at 0.05-0.10 m, the area of CE showed the highest C and N content in relation to the other crop systems. The C content in the areas of NTS15 and NTS20 is similar and higher than the area of NTS3. According to Siqueira Neto *et al.* (2009) the *cerradão* presents larger amounts of carbon and nitrogen in the soil due to the continuous contribution of plant residues and the lack of disturbance to the system. In relation to the areas of NTS, an increase in the content of C and N as a function of time since implementation can be seen, but this increase is less significant than that observed in the surface layer (0-0.05 m).

One possible explanation for the low values of C in the area of NTS3 compared to the other crop systems, can be attributed to the short period since the system was adopted, as, according to Carvalho *et al.* (2009), the increase in SOM in the areas of NTS compared to other management systems may be related primarily to the time since implementation, because the accumulation of carbon in this system occurs very slowly, taking 10-15 years to become significant. In contrast, the low levels of C in areas of PA may be related to their low productivity, the absence of management and intensive grazing, the small input of plant residue and also a reduction in root-system distribution. Silva *et al.* (2004) also found that pastures with low productivity in various regions of the *cerrado* favoured a reduction in the carbon content of the soil.

In the layers at 0-0.05 and 0.05-0.10 m the F1 fraction (labile carbon) increased as a function of the time since implementation of the NTS, and that in the areas of NTS15 and NTS20 values of this fraction similar to those of the *cerrado* vegetation, and greater than in the area of PA (Table 5) are seen. The fraction F2 in the 0-0.05 m layer showed values similar to those discussed above for F1 however in the layer at 0.05-0.10 m no statistical differences were found between the areas assessed. From Table 5, one can also see that the fraction F3 at both of the depths analyzed also increased with the time since implementation of NTS, the values found in the area of NTS20 being greater than in the area of CE. As to the fraction F4, at both of the depths studied, the areas of NTS15, NTS20 and CE presented similar results being superior to those of the areas of PA and NTS3.

An increase of non-labile carbon (C_{NL}) over the time since implantation of the NTS was found, with that of the area of NTS20 being greater than the other areas measured at a depth of 0 to 0.05 m. However, in the 0.05-0.10 m layer, the area of CE presented the highest value of C_{NL} , followed by NTS15 and NTS20 which were similar, and higher than in the areas of PA and NTS3 (Table 5). Note also from Table 5 that there was no statistical difference between the areas evaluated for the proportion of labile carbon to total C (C_L/C) at a depth of 0-0.05 m, however at a depth of 0.05 to 0.10 m the area of NTS20 showed a higher proportion of C_L/C when compared to the other areas.

In a way similar to that observed for the levels of total C, it is noted that in general the areas of PA and NTS3 presented the lowest concentration of C in relation to the other areas for the fractions F1, F2, F3 and F4 and C_{NL} . These results demonstrate that the area of PA is in a more advanced stage of degradation due to mishandling, which is a reflection of the type of management adopted, as when this is compared to the area of CE (reference vegetation), there is a large reduction in the C content of the more labile and stable fractions of the MOS. According to Rangel *et al.* (2008) this reduction in the content of total C in the soil, and the changes in the composition of the organic matter compromise the sustainability of the agro-ecosystem,

Table 5 - Oxidizable fractions of organic carbon, non-labile carbon (C_{NL}) and proportion of labile carbon / total C (C_L/C) in different land use systems in Montividiu, Goiás

Systems Evaluated	Oxidisable fraction os carbon (g kg ⁻¹)				C _{NL} (g kg ⁻¹)	C _L /C (%)
	F1 (C _L)	F2	F3	F4		
0-0,05 m						
CE	7.50 ab*	3.00 ab	6.66 b	11.50 a	23.26 b	24.37 a
PA	3.83 c	1.16 c	4.00 c	6.33 b	11.61 c	24.68 a
NTS3	3.83 c	1.00 c	4.16 c	6.66 b	12.14 c	24.05 a
NTS15	6.16 b	2.17 b	7.83 b	10.83 a	23.49 b	20.79 a
NTS20	8.66 a	3.50 a	10.33 a	11.33 a	25.29 a	25.52 a
0.05- 0.10 m						
CE	8.83 ab	2.16 a	6.66 b	9.16 a	28.56 a	20.78 b
PA	5.00 c	1.17 a	4.33 c	3.83 b	10.25 c	27.14 b
NTS3	5.16 c	1.17 a	4.66 c	4.33 b	11.59 c	24.86 b
BTS15	6.66 b	1.50 a	6.33 b	7.83 a	20.95 b	22.75 b
NTS20	8.66 a	2.33 a	8.50 a	7.50 a	18.05 b	32.42 a

*Averages when followed by the same lower case letter in any one column do not differ significantly across the different systems of soil usage by the Tukey test at 5% level

since the greater availability of organic compounds in the soil can increase the capacity of cationic exchange (PAVINATO; ROSOLEM, 2008), microbial activity (SCHERER; BALDISSERA; NESI, 2007), reduce the negative effects of toxic aluminum (CIOTTA *et al.*, 2002; LIMA *et al.*, 2007) and reduce the adsorption of phosphate groups onto colloids in the soil (SOUZA *et al.*, 2006). The 20 years of PA which preceded the implementation of NTS in the area of NTS3, may be the reason for the similarity in the results observed for this area and in the area of PA (Table 5), since with the passage of the time of NTS implementation (NTS15 and NTS20) an increase in the C content of the fractions F1, F2, F3, F4 and C_{NL} can be seen. In some cases, the quantified values are similar to or even greater than those observed in the area of CE.

The increase of fractions F1 and F2 as a function of the time of implantation of the NTS, and the similarities observed between the areas NTS15 and NTS20 and the area of CE, occur due to the constant input under NTS of plant residue of various quantities and qualities to the surface of the soil, which over time promotes changes in the content and quality of the SOM. In studies on the fractionation of soil organic carbon Blair, Lefroy and Lisle (1995), Chan, Bowman and Oates (2001), Rangel *et al.* (2008) show that the highest levels of carbon in the fractions F1 and F2 tend to be found in areas where there is input of organic matter through plant residue, this increase being mainly related to the free light fraction of the SOM (MAIA *et al.*, 2007).

From the results observed for fraction F1 (C_L), the ability of this fraction to demonstrate the changes promoted by the evaluated management systems can be seen, this attribute therefore is of great importance in the assessment of soil quality in no-tillage areas as a function of its time since implementation. Similar results were found by Rangel *et al.* (2008), where the author notes that the C_L showed greater potential to evaluate the impact of different planting densities and managements of coffee on the components of soil organic matter. Majumder *et al.* (2008) when assessing the fractions of oxidisable C in crop systems of rice and maize for 19 years in India, concluded that the F1 fractions can be considered a good indicator of the sustainability of the system, since they showed high correlation to the production of the corn and rice crops.

The F3 and F4 fractions increased from the area of NTS3 to that of NTS15, with values quantified in NTS15 being similar to those observed in the vegetation of the CE. From the above, it can be inferred that 15 years of NTS is the time required to return to the conditions found in the area of CE. This increase of the more recalcitrant fractions (F3 and F4) as a function of time since implementation of the NTS, may benefit from the maintenance of the mulch, less variation in moisture content and temperature, and the consequent creation of a favorable environment for the maintenance of SOM levels, with more stable fractions.

No significant differences were seen between the assessed areas for the percentage of C for the F1+F2+F3+F4 fractions with respect to the total C, thus it can be said that

regardless of the area and the depth evaluated, the fractions (F3+F4) represent on average 66.4% of the total C in the soil, while fractions (F1+F2) make up 33.6%. These results indicate that under such conditions of soil and climate, the areas assessed present the greater part of the total C as being distributed over the F3 and F4 fractions, which are related to compounds of greater chemical stability and molecular weight, originating from the decomposition and humification of the SOM. Zech, Haumaier and Hempfling (1990) state that in tropical soils, the bioavailability of organic matter is naturally less, the presence of organic compounds rich in aromatic and carboxylic groupings being increased.

The highest levels of C_{NL} from the area of NTS20 in relation to those from the CE show that there is a greater predominance of the more stable SOM fractions as a function of the NTS implementation time at a depth of 0-0.05 m. It can be considered that the increase in C_{NL} is of great importance to the stability of the NTS, since the C of the non-labile fraction has a slower cycle compared to the labile C, and acts both as a reserve of nutrients and in the chemical stabilization of micro-aggregates in the soil (ZECH *et al.* 1997).

At the depth of 0.05-0.10 m, the C_{NL} and total C data were related where the area of CE presented higher contents of C_{NL} and total C compared to other crop systems, and in the areas of NTS15 and NTS20 the C_{NL} and total C are similar and greater than in the areas of NTS3 and PA. It can be inferred that the lower levels of C in the areas of NTS15 and NTS20 compared to those of the EC, may have caused the lower concentration of C_{NL} in these areas at this depth. It can therefore be seen that at this depth, changes in the quantity and quality of the SOM, promoted by the NTS are not very significant, with no noteworthy differences being observed. It can be concluded that the C_{NL} at a depth of 0.05-0.10 m has a higher resistance to changes due to the increased protection offered by the depth, greater changes only being verified when there are appreciable changes in the levels of total C. Bremer, Ellert and Janzen (1995) reported that changes in the C of the labile fraction, promoted by changes in soil management are seen within a short period of time, while in the non-labile fraction, changes in the C can only be observed in the long term.

The lack of any significant difference in data of the proportion of labile carbon to total C at a depth of 0-0.05 m demonstrates that the results of C_L (oxidisable fraction F1) increase with the increase in total C content in each area evaluated, that is, each area has similar amounts of C_L relative to its total C content. It appears that the levels of C_L are more sensitive in showing modifications than the areas undergo. At a depth of 0.05-0.10 m the area of NTS20 presented a higher percentage for the ratio of labile carbon to total C in relation to all the other areas, that is, independent of the increase in total C content, the

C_L tends to increase. In general, the percentage values of C_L relative to total C were similar (25%) to those found by Shang and Tiessen (1997) when evaluating the lability of C in an Oxisol of the Chapada do Araripe in Pernambuco, and that Rangel *et al.* (2008) found in a Red forest Oxisol in the region of Machado in Minas Gerais.

At both of the depths analysed, it can be seen that the carbon sharing index (CSI) and carbon management index (CMI) increased with the increasing implementation time of the NTS, and in the areas of NTS15 and NTS20 they were superior to those of NTS3 and PA (Table 6). Also using Table 6, it can be seen that there was no significant difference in lability or the lability index at a depth of 0-0.05 m.

The increase in CSI as a function of time since implementation of the NTS indicates that, in relation to the reference (CE), the NTS is contributing to the increase in levels of total C, with a C content similar to that of the area of CE being reached at a depth of 0-0.05 m in the area of NTS20. The higher values of CSI in the areas of NTS15 and NTS20 can be attributed to the constant and greater input of plant residue on the soil surface, which over time has contributed to increased levels of SOM. However, the area of PA, due to its low productivity, absence of management, intensive grazing and the low input of plant-residue, showed lower CSI values, indicating that the levels of total C had been reduced, that is, the values of the CSI were smaller than 1. Similar results were found by Rangel *et al.* (2008) when evaluating a typical Distroferic Red Latosol cultivated with coffee at different crop densities, in the south of Minas Gerais. The authors found that the highest and lowest CSI values were found in the areas where they saw respectively a higher and a lower accumulation of residue on the surface.

The results of L and IL have a correlation with the percentage of C_L to C and C_{NL} to C at both of the analysed depths. Because each area presents similar amounts of C_L and C_{NL} in relation to its content of total C, and of these variables being used in the calculations of L and IL, there is a statistical similarity between the areas at a depth of 0-0.05 m. However, at the depth of 0.05-0.10 m, the NTS20 area showed greater results of the ratio C_L to C, L and IL compared to the others. This pattern shows that this area provides a less oxidative environment, giving greater physical protection to the SOM, favouring a higher proportion of labile C compared to total C by increasing the rate of C lability in the soil. Similarly Blair, Lefroy and Lisle (1995) found in soils in Australia that lack of disturbance of the soil by the NTS promotes a greater proportion of labile C and consequently a greater C lability.

The increase in CMI values as a function of the time since implementation of the NTS, which was observed at both depths in the area of NTS20, demonstrates that

Table 6 - Carbon sharing index (CSI), lability (L), lability index (LI) and carbon management index (CMI), at depths of 0-0.05 and 0.05-0.10 m of a red latossol under different management systems in Montividiú, Goiás

Systems evaluated	Indices			
	CSI	L	IL	CMI
0-0.05 m				
CE	--	0.32 a	--	--
PA	0.50 c*	0.33 a	1.02 a	51.46 c
NTS3	0.52 c	0.32 a	0.99 a	51.46 c
NTS15	0.96 b	0.26 a	0.82 a	78.52 b
NTS20	1.10 a	0.34 a	1.06 a	117.86 a
0.05-0.10 m				
CE	----	0.26 b	----	----
PA	0.39 b	0.37 b	1.43 b	55.87 c
NTS3	0.43 b	0.33 b	1.27 b	54.42 c
NTS15	0.75 a	0.29 b	1.23 b	84.33 b
NTS20	0.74 a	0.48 a	1.83 a	135.95 a

*Averages when followed by the same letter in any one column do not differ significantly across the different systems of soil usage by the Tukey test at 5%

the management system employed in this area, together with no turning of the soil and the constant input of plant residue, has contributed to increase the capacity for preservation and restoration of the levels and/or the quality of the organic fractions. Rangel *et al.* (2008) when evaluating a Distroferric Red Latossol cultivated with coffee at different crop densities in southern Minas Gerais, also noted that higher CMI values were found in areas with greater amounts of coffee-crop residue (leaves and branches, among others) and a greater biomass of weeds.

The area of PA had the lowest CMI values, demonstrating once again that the type of management adopted is extremely detrimental to soil quality, leading to an advanced stage of soil degradation in this area.

CONCLUSIONS

1. An increase in the levels of the CMI and C can be seen as a function of the time since implementation of the NTS. In the area with 20 years NTS higher values of C relative to the area of *cerrado* were found;
2. In general, an increased in the labile and stable fractions of the SOM can be observed as a function of the time since implementation of the NTS, while the areas of NTS15 and NTS20 present a C content in the fractions, similar or superior respectively to those of the area of CE;
3. Regardless of the area evaluated, a predominance of the more stable SOM fractions (F3 + F4) can be seen.

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