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CARBON STOCKS IN ORGANIC MATTER FRACTIONS AS AFFECTED BY LAND USE AND SOIL MANAGEMENT, WITH EMPHASIS ON NO-TILLAGE EFFECT

ESTOQUES DE CARBONO EM FRAÇÕES DA MATÉRIA ORGÂNICA AFETADOS PELO USO E MANEJO DO SOLO, COM ÊNFASE AO PLANTIO DIRETO

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SUMMARY

Land use and soil management may affect both labile and humified soil organic matter (SOM) fractions, but the magnitude of these changes is poorly known in subtropical environments. This study investigated effects of four land use and soil management systems (forest, native pasture, and conventional tillage and no-tillage in a wheat/soybean succession) on (i) total soil organic carbon (SOC) stocks (0 to 250mm depth) and on (ii) carbon (C) stocks in labile (coarse, light) and humified (mineral-associated, humic substances) SOM fractions (0 to 25mm depth), in a Hapludox soil from southern Brazil. In comparison to the adjacent forest site, conventionally tilled soil presented 36% (46.2Mg ha^{-1}) less SOC in the 0 to 250mm depth and a widespread decrease in C stocks in all SOM fractions in the 0 to 25mm depth. The coarse (>53 µm) and light (<1kg dm^{-3}) SOM fractions were the most affected under no-tillage, showing 393% (1.22Mg C ha^{-1}) and 289% (0.55Mg C ha^{-1}) increases, respectively, in relation to conventional tillage. Similar results were observed for mineral-associated SOM and humic substance C pools (34% and 38% increases, respectively) under no-tillage. Compared with labile SOM fraction results, the percentual increments on C stocks in humified fractions were smaller; but in absolute terms this C pool yielded the highest increases (3.06 and 2.95Mg C ha^{-1}, respectively). These results showed that both labile and humified organic matter are better protected under the no-tillage system, and consequently less vulnerable to mineralization. Humified SOM stabilization process involving interactions with variable charge minerals is probably important in maintaining and restoring soil and environmental quality in tropical and subtropical regions.

Key words: *soil organic matter, physical fractionation, light fraction, coarse fraction, no-tillage.*

RESUMO

O uso e manejo do solo podem afetar as frações lábeis e humificadas da matéria orgânica (MO), mas a magnitude destas alterações é pouco conhecida em ambientes subtropicais. Este estudo avaliou os efeitos de quatro sistemas de uso e manejo do solo (mata, campo nativo, preparo convencional e plantio direto na sucessão trigo/soja) sobre (i) o estoque de carbono orgânico total (COT) (0-250mm), e nos (ii) estoques de carbono (C) em frações lábeis (grosseira, leve) e humificadas (associada aos minerais, substâncias húmicas) da MO na camada superficial (0-25mm) de um Latossolo bruno, no Sul do Brasil. Comparado à mata, o solo sob preparo convencional apresentou 36% (46,2Mg ha^{-1}) menos COT na camada de 0-250mm, bem como um decréscimo generalizado no estoque de C em todas frações da MO na camada de 0-25mm. As frações grosseira (>53 µm) e leve (<1kg dm^{-3}) da MO foram as mais afetadas pelo sistema plantio direto, com incrementos no estoque de C de 393% (1,22Mg ha^{-1}) e 289% (0,55Mg ha^{-1}), respectivamente, em relação ao preparo convencional. Os estoques de C na MO associada aos minerais e nas substâncias húmicas aumentaram de forma semelhante (incrementos de 34% e 38%, respectivamente) no sistema plantio direto. Apesar dos aumentos percentualmente menores no estoque

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de C nas frações humificadas do que nas lábeis, em termos absolutos, os maiores incrementos ocorreram na matéria orgânica associada aos minerais e nas substâncias húmicas (3,06 e 2.95Mg C ha^{-1}, respectivamente). O sistema plantio direto resultou num ambiente biologicamente menos oxidativo, favorável à preservação das frações lábeis e humificadas da MO. O processo de estabilização da MO pela sua interação com minerais de carga variável é provavelmente um fator fundamental na manutenção e recuperação da qualidade do solo e do ambiente em regiões tropicais e subtropicais.

Palavras-chave: *matéria orgânica do solo, fracionamento físico, fração leve, fração grosseira, plantio direto.*

INTRODUCTION

Soil organic matter (SOM) is an important factor in evaluating management system quality (DORAN & PARKIN, 1994). In warm and wet tropical and subtropical climatic regions, rapid SOM (~58%C) decline occurs under conventional management systems involving intensive soil disturbance (TIESSEN ***et al***., 1992; PARFITT ***et al***., 1997). In southern Brazil, a 50% loss of original SOM was observed whitin 10 to 15 years of wheat/soybean succession under conventional tillage (PÖTTKER, 1977). The SOM degradation has negative effects mainly on cation exchange capacity, nutrient availability, aggregate stability and microbial activity (BAYER & MIELNICZUK, 1999).

In order to improve soil conservation and to maintain or restore crop productivity in tropical and subtropical Brazilian regions, large changes in land use and soil management were initiated in the 80's (MIELNICZUK ***et al.***, 1983). Elimination of crop residue burning, adoption of conservation tillage, and introduction of crop residues management, including legume cover-crops for N supply, are examples of soil conservation strategies adopted (MIELNICZUK ***et al***., 1983). Consequently, SOM increased due to both reduced losses through biological decomposition and erosion, and increased plant residue additions on soil surface (BURLE ***et al***., 1997; BAYER ***et al***., 2000). The highest SOM increase was reported mainly on surface layers but SOM storage in total soil profile was also positively affected (BURLE ***et al***., 1997).

Both labile and humified SOM fractions may show different susceptibility to land use and management effects. In cold and/or semiarid region, the C stocks in labile particulate SOM fraction constitutes approximately 50% of total soil organic carbon (SOC) (CHAN, 1997; FRANZLUEBBERS & ARSHAD, 1997), and is the most affected by agricultural practices (CHAN, 1997). Hot and humid environment favours microbial activity that leads to intensive decomposition and humification of labile SOM fractions (BAYER & BERTOL, 1999). As a result, the reduced C pool of these fractions represents a smaller proportion of the total SOC, compared with more humified SOM fractions (CAMBARDELLA & ELLIOT, 1992; BAYER & BERTOL, 1999).

In tropical and subtropical regions, interaction between SOM and variable charge minerals can result in increased SOM protection from microbial attack compared with that found in less-weathered temperate soils (MARTIN ***et al***., 1982; PARFITT ***et al***., 1997). Great stability of mineral-associated SOM in highly weathered soils, which may be important in maintaining and restoring soil quality, determines the soil potential for acting as an atmospheric CO_2 sink in tropical and subtropical regions (PARFITT ***et al***., 1997). Our hypothesis is that the C stock in more humified fractions represents a greater proportion of the total SOM and show a higher increase (in absolute terms) under no-tillage, compared with that in labile SOM fractions. To test this hypothesis, the present study evaluated the effect of different land use and soil management systems (forest, native pasture, and conventional tillage and no-tillage in a wheat/soybean succession) on: (i) total soil organic carbon (SOC) (0 to 250mm depth) and; (ii) C stocks in labile (light, coarse) and humified (mineral-associated, humic substances) SOM fractions (0 to 25mm depth) in a Hapludox soil under subtropical climatic conditions from southern Brazil.

MATERIAL AND METHODS

Site descriptions

The soil studied was a Hapludox (Humic Ferrasol and Brown Latosol by FAO and Brazilian taxonomies, respectively), located in western Santa Catarina State, Southern Brazil. Soil samples were collected from four adjacent sites under different land use and soil management: forest, native pasture, and wheat-soybean succession under conventional tillage and no-tillage. These sites have a slope ~13% and were located in identical relief position, with less than 300m between sites. Some chemical and physical soil characteristics are shown in Table 1. Regional climate is subtropical, hot and humid, with mean annual temperature of 16ºC and rainfall of 2061mm. The forest consisted of native vegetation, and was replaced by cultivated systems approximately 50 years ago. Native pasture was consisted of spontaneous grass and legume species

Table 1 - Some chemical and physical characteristics of the Hapludox soil (0 to 250mm depth).

Soil properties		Land use and soil management systems			
		Forest	Native pasture	Conventional tillage	No-tillage
Particle size distribution (g kg^{-1})[1]					
Clay		302	329	557	443
Silt		415	512	295	479
Sand		283	159	148	78
Color[2]	Dry	10yR 4/3	10yR 4/3	7.5yR 4/4	10yR 3/3
	Wet	10yR 3/3	10yR 3/2	7.5yR 3/3	10yR 3/3
Iron oxides (g Fe kg^{-1})[3]					
Fe-DCB		41.8	41.7	55.7	57.2
Fe-oxalate		3.98	3.96	2.68	3.97
pH (1:1 soil:water)[4]		5.2	4.9	6.9	6.2
Aℓ (c $mo\ell_{(+)}$ kg^{-1})[4]		1.4	4.0	0.0	0.0
Ca ($cmol_{(+)}$ kg^{-1})[4]		4.9	1.3	8.3	8.5
Mg ($cmol_{(+)}$ kg^{-1})[4]		3.3	0.9	6.8	5.0
P (m g kg^{-1})[4]		11	20	4	10
K (m g kg^{-1})[4]		266	136	100	247

[1] EMBRAPA (1997); [2] MUNSELL (1994); [3] MEHRA & JACKSON (1960); [4] TEDESCO ***et al***. (1995).

and had sustained light grazing pressure for the previous 20 years. No-tillage has been employed for the last 10 years, and a wheat (*Triticum aestivum* L.)/soybean (*Glicine max* (L.) Merr) succession has been used in both no-tillage and conventional tillage, the latter consisting of a single disk plow plus two disking twice a year, with an approximately 200 mm soil disturbance depth.

Soil sampling

Soil samples were collected in April 1996 from 0 to 25, 25 to 50, 50 to 75, 75 to 125 and 125 to 250mm depths, from three random field replicates (subsamples) for each site. Soil samples were taken from a random area of $0.045m^2$ (0.15m x 0.30m), air dried, grounded and sieved with a 2mm screen.

Physical and chemical SOM fractionation

Soil organic matter from 0 to 25mm depth was fractionated physically and chemically. Physical fractionation consisted of adding 50g soil to 300mℓ distilled water in a plastic recipient. After gently mixing the suspension by circular manual movements, the floating organic matter (density <1kg dm^{-3}), i. e. the light fraction, was removed of the supernatant by suction at liquid surface. To separate coarse (>53 µm) from mineral-associated SOM fraction (<53 µm), 20g soil and 70mℓ distilled water plus two glass beads were agitated for 15 hours in a horizontal shaker (BAYER & BERTOL, 1999). Soil suspension was then washed through a >53µm sieve and the coarse fraction was separated. Chemical fractionation of humic substances was carried out using NaOH 0.5moℓ ℓ^{-1} (SWIFT, 1996) on composited soil samples, obtained by combination of three field replicates (subsamples). Alkaline extraction (1:5 soil/extractant ratio) was performed three times in succession, and the soluble (humic and fulvic acids) and insoluble (humine) humic substances were separated. The mass of oven dried (60ºC) SOM fractions was quantified and the C content analyzed.

Chemical analysis

Whole soil and SOM fractions, except for mineral-associated SOM fraction, were analyzed for organic C by wet sulfocromic oxidation (NELSON & SOMMERS, 1982). The C contents of total humic substances represents the sum of the C contents of soluble and insoluble fractions. Bulk soil density was determined on indeformed soil samples collected from a single field replicate. The values of bulk soil density were used to calculate SOM pools based on an equivalent soil mass (ANGERS ***et al***., 1997; PETERSON ***et al***., 1998). The C pool in mineral-associated SOM was calculated as the difference between total soil organic C content and organic C content in coarse SOM.

Statistical analysis

Analysis of the statistical significance of the effects of land use and soil management on total SOC and C stocks in labile and humified SOM fractions was perfomed using the mean standard deviation, calculated from data of the three field subsamples (n=3). The relation between the C stocks in different SOM fractions was evaluated by significance of determination coefficient (r^2) at $P<0.05$. Mean standard deviation was not calculated for C stocks in total humic substances because composited soil samples with no field replicates were used.

RESULTS AND DISCUSSION

Soil Organic Carbon (SOC) and C stocks in labile SOM fractions

Compared to forest site, soil cultivation led to a decrease of total SOC (Table 2). In the 0 to 250mm soil layer, SOC decreased 36% (46.2$Mgha^{-1}$) under conventional tillage, compared with the

Table 2 - Soil organic carbon (SOC) distribution within the profile (0 to 250mm depth) of a Hapludox soil under different land use and soil management systems.

Land use and management system	Depth (mm)					
	0-25	25-50	50-75	75-125	125-250	0-250
	Kg m^{-3}					Mg ha^{-1}
Forest	92.1 (±2.6)	65.8 (±0.8)	57.6 (±0.2)	48.5 (±2.8)	40.1 (±2.4)	128.3
Native pasture	71.8 (±4.7)	67.2 (±1.4)	58.1 (±4.8)	49.9 (±2.8)	38.2 (±1.1)	122.0
CT	36.7 (±0.7)	33.5 (±0.5)	33.7 (±0.8)	32.9 (±0.3)	31.7 (±0.8)	82.1
NT	53.8 (±1.8)	45.4 (±1.4)	39.4 (±1.0)	33.9 (±1.0)	37.3 (±0.8)	98.2

A wheat/soybean succession has been used in both conventional tillage (CT) and no-tillage (NT) systems.
Values in parenthesis represent the mean standard deviation (*n*=3).

adjacent forest site. Native pasture and no-tillage had higher SOC than conventional tillage. No-tillage increased SOC in approximately 20% (16.1Mg ha^{-1}), compared with conventional tillage. The C distribution in soil profile under native pasture and no-tillage showed a similar pattern to that observed in the forest site, with the highest organic C concentrations in surface layers. In conventionally tilled soil, organic carbon concentrations were relatively similar along the profile, and that was attributed to soil disturbance at 200mm soil layer.

Variation of C stocks in light SOM fraction (<1kg dm^{-3}) in the management systems had a linear correlation with that in coarse SOM fraction (>53µm) (C-light SOM=0.13+0.56 C-coarse SOM, r=0.94, P<0.05) and, C stocks in light and coarse SOM fractions represented 14 and 23% of total SOC in forest site, respectively (Table 3). Compared to the forest site, organic C pool in light and coarse SOM fractions decreased 48% (1.42Mg ha^{-1}) and 66% (3.41Mg ha^{-1}), respectively under native pasture and 94% (2.78Mg ha^{-1}) and 94% (4.89Mg ha^{-1}), respectively under conventional tillage (Table 3). Under conventional tillage, the ratios C-light SOM/total SOC and C-coarse SOM/total SOC decreased to 0.02 and 0.03, respectively (Table 3). Stocks of these labile-C pools were much lower than those determined by CHAN (1997) and FRANZLUEBBERS & ARSHAD (1997), which showed that C stocks in particulate organic matter (equivalent to coarse fraction in this study) represented almost half of total SOC. Those studies were performed with soils from cold and semiarid regions, which present a lower biological activity. In a warmer and wetter subtropical climate, such that of southern Brazil, environment favours SOM decomposition and humification, resulting in a lower labile SOM C pool when compared with those of other regions. Additionally, management systems with intensive soil disturbance, e.g., conventional tillage in the present study, result in crop residue fractionation, more favorable temperature regimes and intense soil-organic matter-microorganisms contact, accelerating decomposition and humification, mainly of labile SOM fractions (BAYER & BERTOL, 1999).

Compared to conventional tillage, no-tillage led to a C pool increase of 289% (0.55 Mg ha^{-1}) and 393% (1.22Mg ha^{-1}) in light and coarse SOM fractions respectively. The C-light SOM/total SOC and C-coarse SOM/total SOC ratios increased to 0.06 and 0.11 respectively under no-tillage (Table 3). In Santa Catarina State, Brazil, a recent study has shown an increase of 275% and 17% of C stock, respectively in coarse and total SOM fractions of no-tilled soil (9 years), when compared to conventional tillage results (BAYER & BERTOL, 1999). Higher relative changes of labile SOM fractions indicates that these fractions are quite sensitive to changes in agricultural practices, particularly in the early stages of adoption (JANZEN ***et al***., 1992; BREMNER ***et al***., 1995).

Table 3 - Changes on C stocks in both coarse and light SOM fractions in the 0 to 25mm depth of a Hapludox soil under different land use and management systems.

Management systems	C stock	Δ		C-fraction/ SOC
	Mg ha^{-1}	Mg C ha^{-1}	%	
		Coarse SOM		
Forest	5.20 (±1.82)	-	-	0.23
Native pasture	1.79 (±0.19)	-3.41	-66	0.10
CT	0.31 (±0.03)	-4.89	-94	0.03
NT	1.53 (±0.18)	+1.22	+393	0.11
		Light SOM		
Forest	2.97 (±0.41)	-	-	0.14
Native pasture	1.55 (±0.22)	-1.42	-48	0.09
CT	0.19 (±0.01)	-2.78	-94	0.02
NT	0.74 (±0.15)	+0.55	+289	0.06

Δ Values for native pasture and conventional tillage (CT) were calculated in relation to the forest site; and Δ values for no-tillage (NT) were calculated in relation to the CT. A wheat/soybean succession has been used in NT and CT systems. Values in parenthesis represent the mean standard deviation (*n*=3).

Carbon stocks in humified SOM fractions

Mineral-associated SOM C pool (<53μm) showed a linear correlation with that of total humic substances (C-humic substances=-2.22+1.10 C-mineral-associated SOM, r=0.98, P<0.05). The C stocks in mineral-associated SOM and in humic substances in forest soil were 17.82 and 18.06 Mg ha^{-1}, representing 77% and 78% of total SOC, respectively (Table 4). The values obtained for these two stable SOM pools were relatively similar, indicating that mainly organic compounds in advanced humification degree probably composed mineral-associated SOM.

Compared to the forest soil, C stock in mineral-associated SOM under native pasture and conventional tillage decreased respectively 9% (1.66 Mg ha^{-1}) and 50% (8.96Mg ha^{-1}), whereas in humic substances it diminished 18% (3.3Mg ha^{-1}) in native pasture and 57% (10.29Mg ha^{-1}) in CT soil (Table 4). Under no-tillage, organic C pools in mineral-associated SOM and humic substances were 34% (3.06Mg ha^{-1}) and 38% (2.95Mg ha^{-1}) greater than under conventional tillage, respectively. Although the increase of C stock in the humified fractions under no-tillage were proportionally lower in comparison with increments in the more labile fractions (light and coarse SOM), the increase of absolute C pool was ~2.5 to ~5 times higher than that observed for labile fractions, representing from 68% to 71% SOC increase under no-tillage.

Higher C stocks in humified SOM fractions than in labile fractions are probably due to climatic conditions favorable to organic matter decomposition (mainly labile fractions), as well as to physical and chemical stability of mineral-associated SOM and humic substances. In tropical and subtropical soils, variable charge mineral and SOM interactions probably promote a great SOM protection against biological decomposition (PARFITT ***et al***., 1997). Under conventional tillage, the intensive soil disturbance results in decreased aggregate stability negatively affecting structural SOM stability (CARTER ***et al***., 1994; FELLER & BEARE, 1997). Under no-tillage, an opposite effect occurs: an intensified soil aggregation, which apparently represents an important process in soil organic matter accumulation (FELLER & BEARE, 1997; SOLLINS ***et al***., 1996). Probably this mechanism plays a major role under warm and wet conditions when compared to colder and dryer regions.

Table 4 - Changes on C stocks in mineral-associated SOM and humic substances in the 0 to 25mm depth of a Hapludox soil under different land use and management systems.

Management systems	C stock	Δ		C-fraction/ SOC
	Mg ha^{-1}	Mg C ha^{-1}	%	
	Mineral-associated SOM			
Forest	17.82 (±1.82)	-	-	0.77
Native pasture	16.16 (±0.18)	-1.66	-9	0.90
CT	8.86 (±0.03)	-8.96	-50	0.97
NT	11.92 (±0.19)	+3.06	+34	0.89
	Total humic substances			
Forest	18.06	-	-	0.78
Native pasture	14.76	-3.30	-18	0.82
CT	7.77	-10.29	-57	0.85
NT	10.72	+2.95	+38	0.80

Δ Values for native pasture and conventional tillage (CT) were calculated in relation to the forest site; and Δ values for no-tillage system (NT) were calculated in relation to the CT. A wheat/soybean succession has been used in NT and CT systems. Values in parenthesis represent the mean standard deviation (*n*=3). Humic substances were extracted from composited samples, obtained by combination of three subsamples and, thus, was not possible to calculate the mean standard deviation values.

CONCLUSIONS

Soil cultivation led to a decrease in SOC stocks. In a wheat/soybean succession, no-tillage promoted increases on C stocks in labile and humified SOM fractions, compared to conventional tillage. Light and coarse SOM were the fractions most sensitive to changes in the management system. Compared with labile fractions, a higher absolute C stocks increase occurred in humified SOM fractions under no-tillage. Humified SOM fraction stability is essential in maintaining and restoring soil and environmental quality in tropical and subtropical regions.

REFERENCES

ANGERS, D.A., BOLINDER, M.A., CARTER, M.R., ***et al.*** Impact of tillage practices on organic carbon and nitrogen storage in cool, humid soils of eastern Canada. **S oil Till Res**, v.41, p.191-201, 1997.

BAYER, C., MIELNICZUK, J. Dinâmica e função da matéria orgânica. In: SANTOS, G.A., CAMARGO, F.A.O. (Eds.), **Fundamentos da matéria orgânica do solo: ecossistemas tropicais e subtropicais**. Porto Alegre : Genesis, 1999. p.9-26.

BAYER, C., MARTIN-NETO, L., MIELNICZUK, J., ***et al.***

Effect of no-till cropping systems on soil organic matter in a sandy clay loam Acrisol from Southern Brazil monitored by electron spin resonance and nuclear magnetic resonance. **Soil Till Res**, v.53, p.95-104, 2000.

BAYER, C., BERTOL, I. Características químicas de um cambissolo húmico afetadas por sistemas de preparo, com ênfase à matéria orgânica. **Rev Bras Ci Solo**, v.23, p.687-694, 1999.

BREMNER, E., ELLERT, B.H., JANZEN, H.H. Total and light-fraction carbon dynamics during four decades after cropping changes. **Soil Sci Soc Am J**, v.59, p.1398-1403, 1995.

BURLE, M. L., MIELNICZUK, J., FOCCHI, S. Effect of cropping systems on soil chemical characteristics, with emphasis on soil acidification. **Plant Soil**, v.190, p.309-316, 1997.

CAMBARDELLA, C.A., ELLIOT, E.T. Particulate soil organic-matter changes across a grassland cultivation sequence. **Soil Sci Soc Am J**, v.56, p.777-783, 1992.

CARTER, M.R., ANGERS, D.A., KUNELIUS, H.T. Soil structure and organic matter fractions under pernennial grasses. **Soil Sci Soc Am J**, v.58, p.1194-1199, 1994.

CHAN, K. Y. Consequences of changes in particulate organic matter in Vertisols under pasture and cropping. **Soil Sci Soc Am J**, v.61, p.1376-1382, 1997.

DORAN, J.W., PARKIN, T.B. Defining and assessing soil quality. In: DORAN, J.W., COLEMAN, D.C., BEZDICEK, D.F., ***et al.*** (Eds). **Defining soil quality for a sustainable environment**. Madison : Soil Science Society of America, 1994. p.3-21.

EMBRAPA. Centro Nacional de Pesquisa de Solos. **Manual de métodos de análise de solo**. 2.ed. rev. atual. Rio de Janeiro, 1997. 212p.

FELLER, C., BEARE, M.H. Physical control of soil organic matter dynamics in the tropics. **Geoderma**, v.79, p.69-116, 1997.

FRANZLUEBBERS, A.J., ARSHAD, M.A. Particulate organic carbon content and potential mineralization as affected by tillage and texture. **Soil Sci Soc Am J**, v.61, p.1382-1386, 1997.

JANZEN, H.H., CAMPBELL, C.A., BRANDT, S.A., ***et al.*** Light-fraction organic matter in soils from long-term crop rotations. **Soil Sci Soc Am J**, v.56, p.1799-1806, 1992.

MARTIN, J.P., ZUNINO, H., PEIRANO, P., ***et al.*** Decomposition of 14C-labelled lignins, model humic acids polymers, and fungal melanins in allophanic soils. **Soil Biol Biochem**, v.14, p.289-293, 1982.

MEHRA, O.P.; JACKSON, M.L. Iron oxide removal from soils and clays by a dithionite-citrate system buffered with sodium bicarbonate. **Clays Clay Miner**, v.7, p.317-327.

MIELNICZUK, J., WÜNSCHE, W.A., FERREIRA, T. Conservação do solo. **Rev Trigo e Soja**, n.66, p.17-21, 1983.

MUNSELL soil color charts. Rev. ed. New Windson : Kollmorgen Instruments-Macbeth Division, 1994. N.p.

NELSON, P.W., SOMMERS, C.E. Total carbon, organic carbon and organic matter. In: PAGE, A.L. (Ed). **Methods of soil analysis**. Madison : Soil Science Society of Agronomy, 1982. p.539-579.

PARFITT, R.L., THENG, B.K.G., WHITTON, J.S., ***et al.*** . Effects of clay minerals and land use on organic matter pools. **Geoderma**, v.75, p.1-12, 1997.

PETERSON, G.A., HALVORSON, A.D., HAVLIN, J.L., ***et al.*** Reduced tillage and increasing cropping intensity in the Great Plains conserves soil C. **Soil Till Res**, v.47, p.207-218, 1998.

PÖTTKER, D. **Efeito do tipo de solo, tempo de cultivo e da calagem sobre a mineralização da matéria orgânica em solos do Rio Grande do Sul.** Porto Alegre, 1977. 128p., Dissertação (Mestrado em Ciência do Solo) – Programa de Pós-graduação em Agronomia, UFRGS, 1977.

SOLLINS, P., HOMANN, P., CALDWELL, B.A. Stabilization and destabilization of soil organic matter: mechanisms and controls. **Geoderma**, v.74, p.65-105, 1996.

SWIFT, R.S. Organic matter characterization. In: SPARKS, D.L. ***et al.*** (Eds). **Methods of soil analysis. Part 3. Chemical methods**. Madison : Soil Science Society of America, 1996. p.1011-1065.

TEDESCO, M. J., GIANELLO, C., BISSANI, C.A., ***et al.***. **Análise de solo, plantas e outros materiais**. 2.ed.. Porto Alegre : Universidade Federal do Rio Grande do Sul, 1995. 174p.

TIESSEN, H., SALCEDO, I. H., SAMPAIO, E.V.S.B. Nutrient and soil organic matter dynamics under shifting cultivation in semiarid northeastern Brazil. **Agric Ecosyst Environ**, v.38, p.139-151, 1992.