DOI: 10.5433/1679-0359.2014v35n6p3053

Carbon stock, chemical and physical properties of soils under management systems with different deployment times in western region of Paraná, Brazil[1]

Estoque de carbono, propriedades químicas e físicas do solo em sistemas de manejo com diferentes tempos de implantação na Região Oeste do Paraná, Brasil

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Abstract

The objective of this study was evaluate the organic carbon stock and chemical and physical properties of soils in management systems with different deployment times under clayey Red Latosol in western region of Paraná, Brazil. Five managed areas and a reference area (native forest) without anthropic action were analyzed in completely randomized design with five repetitions. Management systems include three areas with different time of first adoption of no-till: 6 years – NT_6 (transition phase), 14 years – NT_{14} (consolidation phase) and 22 years – NT_{22} (maintenance phase); 16 years of no-till, and in the last four years with integration of maize and ruzigrass (*Brachiaria ruziziensis*) – (NT+B) and an area of permanent and continuous extensive cattle pasture of coast-cross (*Cynodon dactylon*) – (Pa). Physical and chemical properties, total soil organic carbon (TOC) stock and carbon stratification index (SI) of soils were evaluated in depths of 0-0.05; 0.05-0.10; 0.10-0.20 and 0.20-0.40 m. The macroporosity (MA) was higher in the area of native forest, ranging from 0.23 to 0.30 $m^3 m^{-3}$ and the microporosity (MI) was higher in cultivated areas. The areas of NT+B and P presented lower ratio macroporosity/total pore volume (MA/TPV). For soil bulk density (BD) and soil penetration resistance (SPR), the managed areas show higher values, suggesting the occurrence of compacted subsurface layers. Native forest area showed the highest TOC levels in the depths of 0-0.05 and 0.05-0.10 m, reaching 30.5 g kg^{-1} in the 0-0.05 m soil layer. There was negative change on TOC stocks in the managed areas in relation to forest area, being more evident in the more superficial soil layers. The SI was greater than one, however there is a reduction in function of adoption time of no-till. There was higher soil compaction in the managed areas, and the NT in soybean/maize succession system does not contribute effectively to the increase of TOC stocks.

Key words: No-till, carbon accumulation, crop succession

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Recebido para publicação 12/09/13 Aprovado em 21/01/14

Resumo

O objetivo do presente estudo foi avaliar os estoques de carbono, atributos químicos e físicos do solo em sistemas de manejo com diferentes tempos de implantação na região oeste do Paraná, Brasil. Foi utilizado o delineamento inteiramente casualizado com cinco repetições, e as áreas com diferentes tempos de adoção do sistema plantio direto (SPD) foram: 6 anos (fase de transição), 14 anos (fase de consolidação) e 22 anos (fase de manutenção); 16 anos de SPD, sendo nos últimos quatro anos com integração milho safrinha e *Brachiaria*; uma área de pastagem permanente coast-cross (*Cynodon dactylon*) e uma área de mata nativa. Os atributos químicos e físicos, o estoque de carbono e o índice de estratificação (IE) foram avaliados nas camadas de 0-0,05, 0,05-0,1, 0,1-0,2 e 0,2-0,4 m. A macroporosidade (MA) foi superior na área de mata, variando de 0,23 a 0,30 m^3 m^{-3} e a microporosidade (MI) foi superior nas áreas cultivadas. As áreas de SPD+B e pastagem apresentaram menor relação macroporos/volume total de poros (MA/VTP). Tanto para a densidade do solo (DS), quanto para a resistência à penetração (RP), as áreas manejadas apresentam valores superiores, o que sugere a ocorrência de camadas subsuperficiais compactadas. A área de mata apresentou teores de carbono orgânico total superiores nas camadas de 0-0,05 e 0,05-0,1 m, alcançando 30,5 g kg^{-1} na camada de 0-0,05 m. Observa-se variação negativa nos estoque de carbono orgânico total nas áreas manejadas em relação à área de mata, sendo mais evidente nas camadas mais superficiais. O IE foi superior a um, porém verifica-se redução em função do tempo de adoção do SPD. Verifica-se maior compactação do solo nas áreas manejadas, e o SPD no sistema de sucessão soja/milho não contribui de forma efetiva para o aumento dos estoques de carbono orgânico do solo.

Palavras-chave: Sistema plantio direto, acúmulo de carbono, sucessão de culturas

Introduction

In tropical soils, soil organic matter (SOM) is one of the main properties responsible for the maintenance of its quality, and monitoring of the soil carbon levels can identify changes in the management systems adopted in relation to the quality and quantity of this organic fraction in cultivated soils (CARTER, 2002).

In agroecosystems, the amount of total soil organic carbon (TOC) stored results from the balance between inputs of carbon (C), mainly from crop residues, and C outputs from the SOM decomposition (ÁLVARO-FUENTES; EASTER; PAUSTIAN, 2012). Annual C accumulation may present high variability between regions, especially due to the diversity climate (tropical, subtropical and temperate climate), soil types, crop rotations and management practices adopted in relation to areas under natural vegetation (MARRIOTT; WANDER, 2006). Thus, the C level can remain stable, increase or decrease in relation to the natural system (FRAZÃO et al., 2010).

Adequate levels of SOM, besides maintaining the soil fertility, can minimize the impacts of agricultural practices on the environment due to C sequestration (BERNOUX et al., 1999). The adoption of soil management practices that minimize their disturbance may increase C inputs and reduce decomposition rates and carbon dioxide (CO_2) emissions into the atmosphere, consequently, increase TOC stocks (KRAGT et al., 2012) and, thus, are considered important soil management options to mitigate global warming (CERRI et al., 2011). Therefore, studies in different management systems are fundamental to the understanding of soil C dynamics (BERNOUX et al., 1999).

In addition to C stocks, the soil cultivation can change some physical properties such as soil bulk density (BD), total soil porosity (TSP) and pore distribution by size (BERTOL et al., 2004) compared to unimproved land. Some of these properties are associated with soil structural stability, as the BD (STONE; SILVEIRA, 2001), soil resistance to root penetration (RP) (BEUTLER; CENTURION, 2004) and TSP (OLIVEIRA et al., 2004), and these properties are used to assess the impacts of soil use and management on soil physical quality. In management systems of long-term without soil disturbance such as no-till (NT) and permanent pasture (P), when not properly managed, the reduction of the macroporosity and increasing of BD has been detected (BERTOL et al., 2001).

The adoption of conservation cropping systems such as NT has increased considerably in the last decades (DIMASSI et al., 2013). Comparing areas of NT with 4, 8 and 12 years of implementation and an area in conventional tillage (12 years), Marcolan and Anghinoni (2006) found that after four years under NT, the soil had regained its original condition for physical properties: BD, macro- and microporosity and TSP. With respect to the soil chemical properties, the properly managed systems may promote increased TOC levels and stocks (PLAZA-BONILLA; CANTERO-MARTINEZ; ÁLVARO-FUENTES, 2010) and improve the phosphorus and exchangeable bases levels, especially in the superficial layers, over the course of time system deployment (DALCHIAVON et al., 2012). Furthermore, it has been reported significant relationships between adoption time of the NT and TOC stocks (UMAKANT; USSIRI; LAL, 2010).

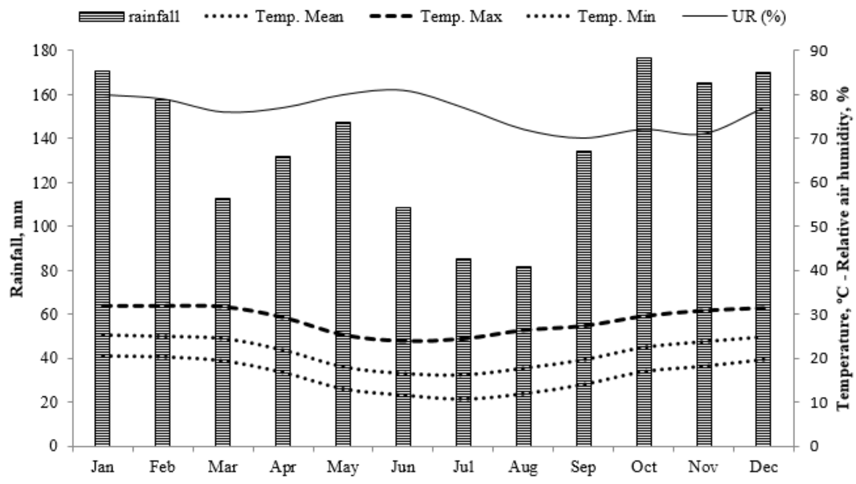
One of the strategies used to evaluate the soil changes due to the use type and management techniques is the assessment of the chemical, physical and biological properties, comparing soils managed with those without management under natural vegetation (BARROS; COMERFORD, 2002). Thus, the present study investigated the changes in the organic carbon stock and chemical and physical properties of soils in management systems with different deployment times under clayey Red Latosol in western region of Paraná, Brazil.

Material and Methods

Soil samples were taken from commercial areas managed under different agricultural uses located in the Guaíra municipality, western region of the Paraná State, Brazil. The climate, according to Köppen classification is Cfa, that is, a subtropical climate with relatively warm and wet summer (CAVIGLIONE et al., 2000). The mean rainfall is approximately 1500 mm, the highest monthly mean temperature is over 28 °C and the lowest is below 18 °C (Figure 1). Rainfall, relative humidity, and temperature data during the period of 1973 and 2011 in the study region are shown in Figure 1. According to the detailed soil survey of the Paraná State (EMBRAPA, 2007), soils of the study areas are classified as clayey Rhodic Hapludox (Eutroferric Red Latosol in the Brazilian classification (EMBRAPA, 2013).

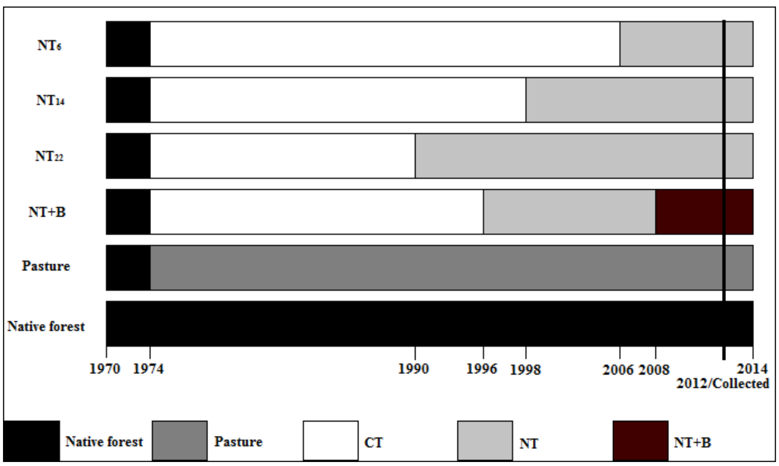
Five managed areas and a reference area (native forest) without anthropic action were evaluated, totaling six different management systems analyzed in completely randomized design with five repetitions (Figure 2). The five managed areas include three areas with different time of first adoption of no-till: 6 years – NT_6 (transition phase), 14 years – NT_{14} (consolidation phase) and 22 years – NT_{22} (maintenance phase) (ANGHINONI, 2007); 16 years of no-till, and in the last four years with integration of maize and ruzigrass (*Brachiaria ruziziensis*) (NT+B) and an area of permanent and continuous extensive cattle pasture of coast-cross (*Cynodon dactylon*) (Pa). The stocking density of animals on pasture area is 3.5 AU ha^{-1}. A detailed description of the study areas is shown in Table 1.

Figure 1. Total monthly rainfall (mm), relative air humidity (%), mean, maximum and minimum temperatures (°C) during the period of 1973 to 2011 in the study region.



Source: Meteorological Station of the Agronomic Institute of Paraná - IAPAR (24º18' S and 53º55' W, Palotina, Paraná, Brazil).

Figure 2. Historic and changes of soil use in the experimental areas, with their dates of implementation in each system: CT: conventional tillage; NT: no-till; NT+B: no-till with integration of tropical grasses of the genus *Brachiaria*.



Source: Elaboration of the authors.

Table 1. Historic and description of the experimental areas (management systems) studied under Rhodic Hapludox in the western region of Paraná State, 2012.

Treatment	Management system	Description
NT_6	No-till for 6 years	Area situated at 270 m of altitude, located at 24º09’092’’ S and 54º13’368’’ W. No-till (6 years – transition phase). Total area of 20 hectares.
NT_{14}	No-till for 14 years	Area situated at 298 m of altitude, located at 24º09’938’’ S and 54º14’190’’ W. No-till (14 years – consolidation phase). Total area of 17 hectares.
NT_{22}	No-till for 22 years	Area situated at 297 m of altitude, located at 24º15’454’’ S and 54º10’361’’ W. No-till (22 years – maintenance phase). Total area of 77 hectares.
NT+B	No-till + Brachiaria	Area situated at 281 m of altitude, located at 24º09’136’’ S and 54º13’676’’ W. No-till with integration of maize + ruzigrass (*Brachiaria ruziziensis*). Total area of 20 hectares.
Pa	Pasture	Area situated at 302 m of altitude, located at 24º11’025’’ S and 54º12’449’’ W. Total area of 2 hectares.
F	Native forest	Area under native vegetation (Atlantic Forest – Seasonal semideciduous forest) situated at 295 m of altitude, located at 24º11’029’’ S and 54º11’898’’ W used as a reference area. Total area of 2 hectares.

Source: Elaboration of the authors.

All areas after conversion of the conventional tillage system to no-till were cultivated with soybean (*Glycine max* L., Merrill) in the summer (October to February) followed by maize (*Zea mays* L.) or wheat (*Triticum aestivum* L.) in the fall-winter (March through July). Except for the integration area of maize and ruzigrass (*Brachiaria ruziziensis*), where ruzigrass was sown in the system with the purpose of increasing the production of straw for the cultivation of subsequent soybean. In all no-till areas with soybean and maize/wheat, the fertilization used in the last years of cultivation was carried out by applying 270 kg ha^{-1} 02-20-18 formulation at sowing and inoculation with *Bradyrhizobium japonicum* (150 mL of inoculum for every 50 kg of seeds) and 270 kg ha^{-1} of 10-15-15 formulation at sowing, respectively. Lime was applied every four years, at a rate of 1.7 Mg ha^{-1} with the exception of the no-till area for 14 years, that after the conversion of sowing system (conventional tillage to no-till in 1998), has not received practical correction of soil acidity. In the permanent pasture area were not performed correction or fertilization practices during the entire implementation period. In each study area was delimited five plots of 400 m^2 for the collection of soil samples. Each plot represented a repetition or experimental unit.

For the determination of the soil physical properties, in each of the agricultural uses described above, 10 completely random disturbed soil samples per plot were collected from the 0-0.05; 0.05-0.10; 0.10-0.20 and 0.20-0.40 m layer, to determine soil texture, water-dispersible clay (WDC), soil flocculation degree (FD), soil particle density (PD), as previously described by Embrapa (1997). Twenty completely random samples of undisturbed soil were also collected from the 0-0.05; 0.05-0.10; 0.10-0.20 and 0.20-0.40 m soil layer from each location, using a 46.2 cm^3 cylindrical sampler, to determine soil bulk density (BD), macroporosity (MA) and microporosity (MI) by the tension table method (EMBRAPA, 1997), and total soil porosity (TSP) by summing the values for macro- and microporosity. From the data of the total porosity, the ratio macroporosity/total pore volume (MA/TPV) was calculated (TAYLOR; ASCHCROFT, 1972). Soil penetration resistance (SPR) and gravimetric soil water content (SWC) were quantified in saturated samples and after reaching equilibrium in tension table (field capacity), using a static penetrometer (model MA-933).

For the chemical analysis, soil also was sampled at depths of 0-0.05; 0.05-0.10; 0.10-0.20 and 0.20-0.40 m using a hole auger in ten different points per plot. Soil samples were air dried and ground to pass through a 2 mm mesh screen and analyzed. Soil pH in 0.01 mol L^{-1} $CaCl_2$ solution was determined potentiometrically in a 1:2.5 (soil:solution) suspension using a combined calomel reference glass electrode and pH meter. Aluminum (Al), calcium (Ca) and magnesium (Mg) were extracted by 1 mol L^{-1} KCl solution in a 1:10 (w:v) soil-to-extractant solution ratio and Al was determined by titration with 0.015 mol L^{-1} NaOH; Ca and Mg determined by atomic absorption spectrophotometry. Available phosphorus (P) and exchangeable potassium (K) were extracted by Mehlich-1 solution in a 1:10 (w:v) soil-to-extractant solution ratio and P was determined by colorimetry at 725 nm wave length and K was determined by flame photometry. Potential acidity (H+Al) was extracted by 0.5 mol L^{-1} calcium acetate solution buffered to pH 7.0, and determined by titration with 0.1 mol L^{-1} NaOH. All chemical analyzes were performed by adopting standard procedures (EMBRAPA, 2009).

Organic carbon was quantified by oxidation with 0.167 mol L^{-1} potassium dichromate in the presence of sulfuric acid, followed by titration with 1.0 mol L^{-1} ammonium Fe(II)sulfate (EMBRAPA, 2009). From the results obtained, the total soil organic carbon (TOC) stocks were calculated by the equivalent mass method (ELLERT; BETTANY, 1995; SISTI et al., 2004). To verify the tendency of TOC accumulation or loss compared to the reference system (native forest), the change of TOC stock compared to the forest (ΔTOC, Mg ha^{-1} cm^{-1}) was calculated by the difference between the mean values of TOC stock this system (reference) and in each other systems evaluated. The value obtained was then divided by the depth (cm) of each layer.

With the TOC data, was also calculated the carbon stratification index (SI), which is based on the relation between the TOC levels in the surface layer compared to the lower layers. Values higher than one indicate C accumulation on the surface, and the most distant of the unit indicates that the better the soil quality. The existence of values less than one indicates that the system are losing quality (FRANZLUEBBERS, 2002).

In the winter season of 2012, after the maize harvest, the amount of accumulated crop residues on the soil surface was determined by taking samples from ten random points per plot, using a 0.25 m^2 wooden frame. In the forested area leaves, small and thick branches were collected on the soil surface and in pasture area the grasses residues were collected. The collected plant material was oven-dried at 60 °C for five days and then weighed.

Data were submitted to analysis of variance (ANOVA), and the results of different management systems were compared by Tukey test ($p < 0.05$). As complementary analysis, multivariate technique was used by canonical analysis, involving all the variables studied (physical, chemical and carbon stock), from which was reduced data group in linear combinations, generating scores of the first two canonical variables that explain over 80% of the total variation (CROSS; REGAZZI, 1994), the score was projected in two-dimensional graphics. The grouping method of Tocher modified, with the purpose of discriminate the treatments with highest similarity, and for grouping the different management systems from the matrix of generalized Mahalanobis distance was also used. The graph based on canonical analysis and the groups formed by the grouping method of Tocher modified was generated using the Genes software for Windows (CRUZ, 2006).

Results and Discussion

Soil physical properties

All study areas have clay content above 600 g kg^{-1}, being classified as very clayey texture (Table 2). Data of water-dispersible clay (WDC) and soil flocculation degree (FD) infer the degree of soil aggregation (EMBRAPA, 1997), and the highest values of FD in the 0-0.05 m soil layer were observed in the pastures and native forest areas, 85 and 86%, respectively, differing of NT_6 and NT+B areas (Table 2). The NT_{14} and NT_{22} areas had presented similar WDC values to native forest, except in the 0-0.05 m layer to the area under NT_{14}. In all management systems and layers, the values of soil particle density (PD) ranged from 2.72 to 2.84 g cm^{-3}, similar to those values reported by Lourente et al. (2011) in a Distroferric Red Latosol. The lower values for PD, especially in the first two layers, in the forested area was due to higher levels of soil organic matter (SOM). One factor that contributes to the reduction of the PD is the SOM content (BRADY; BUCKMAN, 1983).

For macroporosity (MA) were observed in all layers, higher values in the forested area, ranging from 0.23 to 0.30 m^3 m^{-3}, except for the NT_6 area in the 0-0.05 m soil layer, that showed similar values to the forest area (Table 3). There was tendency of reduction in the MA in depth, especially in areas managed under NT, with values of 0.08 m^3 m^{-3} in the 0.10-0.20 m soil layer in the NT_6 system. Similar results were reported by Torres, Fabian and Pereira (2011) in areas of NT and permanent pasture, compared with the natural vegetation.

Table 2. Particle size analysis, water-dispersible clay (WDC), soil flocculation degree (FD) and particle density (PD) of soils under management systems with different deployment times in the western region of Paraná, Brazil, in 2012.

Management system	Sand	Silt	Clay	WDC	FD	PD
	--------------------g kg^{-1}--------------------				%	g cm^{-3}
			0-0,05 m			
NT_6	170	216	614	152a	75b	2.77
NT_{14}	145	186	669	152a	77ab	2.75
NT_{22}	101	276	623	102abc	84ab	2.77
NT+B	173	209	618	146ab	76b	2.80
Pasture	86	292	623	90bc	85a	2.79
Native forest	118	265	617	86c	86a	2.72
CV(%)				23.6	5.7	
			0,05-0,1 m			
NT_6	167	220	613	152a	75a	2.79
NT_{14}	145	157	698	164a	76a	2.78
NT_{22}	101	271	628	120a	81a	2.79
NT+B	170	210	619	151a	76a	2.82
Pasture	87	293	620	142a	77a	2.80
Native forest	125	256	620	112a	82a	2.74
CV(%)				23.2	6.8	
			0,1-0,2 m			
NT_6	142	202	657	191a	71b	2.81
NT_{14}	126	150	724	169abc	77ab	2.82
NT_{22}	92	267	641	131bc	80a	2.80
NT+B	157	218	626	185ab	71b	2.84
Pasture	86	300	614	153abc	75ab	2.83
Native forest	104	282	614	123c	80a	2.76
CV(%)				18.7	5.4	

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			0,2-0,4 m			
NT_6	124	209	667	163b	76a	2.82
NT_{14}	104	141	755	183ab	76a	2.84
NT_{22}	81	256	663	145b	78a	2.82
NT+B	129	227	645	186ab	71ab	2.84
Pasture	74	227	700	228a	68b	2.84
Native forest	97	196	707	161b	77a	2.80
CV(%)				16.1	4.9	

Values represented by the different letters in the column, for each soil depth show significant differences (Tukey test, $P \leq 0.05$).
Source: Elaboration of the authors.

Although no differences in the 0-0.05 m soil layer has been found in areas under NT_{14} and NT_{22}, there was a tendency of reduction in the MA as a function of implantation time of NT. The same was observed for MI values, particularly in the 0-0.05 and 0.05-0.10 m soil layer, as well as are higher than the values of the native forest area. According to Viana et al. (2011), the drastic reduction of the MA in cultivated soils is due to the greater amount of compression by the intensive traffic of agricultural machinery. This tendency was also observed for total soil porosity (TSP), where there were no differences in the 0-0.05 m layer in the evaluated areas. For the other layers, the highest values were observed in the forested area, not differing of the pasture areas in the first three layers, and NT+B in the last layer evaluated.

Table 3. Porosity, bulk density (BD), ratio macroporosity/total pore volume (MA/TPV) penetration resistance (SPR) e water content (SWC) of soils under management systems with different deployment times in the western region of Paraná, Brazil, in 2012.

Management system	Soil porosity (m^3 m^{-3})			Ratio MA/TPV	Bulk density (Mg m^{-3})	Penetration resistance (MPa)		Water content θ (cm^3 cm^{-3})	
	Macro	Micro	Total			Rp_S	Rp_{24}	UM_S	UM_{24}
					0-0.05 m				
NT_6	0.23ab	0.36b	0.59a	0.39	1.22a	0.34c	0.79b	0.57a	0.36b
NT_{14}	0.20bc	0.39ab	0.59a	0.34	1.21a	0.41bc	0.69b	0.57a	0.39ab
NT_{22}	0.19bc	0.40ab	0.59a	0.32	1.15a	0.60b	0.82b	0.58a	0.40ab
NT+B	0.14bc	0.37ab	0.51a	0.27	1.30a	1.25a	1.63a	0.49a	0.37ab
Pasture	0.14c	0.42a	0.56a	0.25	1.15a	1.34a	1.53a	0.54a	0.43a
Native forest	0.30a	0.27c	0.57a	0.52	0.80b	0.08d	0.29c	0.56a	0.27c
CV (%)	23.6	8.3	7.6		8.3	14.6	8.5	7.9	8.4
					0.05-0.1 m				
NT_6	0.12b	0.39a	0.51bc	0.23	1.46a	0.88b	1.51cd	0.50b	0.39a
NT_{14}	0.13b	0.39ab	0.52bc	0.25	1.42a	1.10b	1.30d	0.50b	0.38ab
NT_{22}	0.09b	0.41a	0.50c	0.18	1.37ab	1.78a	2.09a	0.49b	0.41a
NT+B	0.1b	0.41a	0.51bc	0.20	1.46a	1.51a	1.79b	0.50b	0.41a
Pasture	0.15b	0.41a	0.56ab	0.27	1.20b	0.84b	1.58bc	0.54ab	0.41a
Native forest	0.26a	0.33b	0.59a	0.44	0.99c	0.25c	0.64e	0.57a	0.33b
CV (%)	29.6	7.6	5.2		8.1	15.8	9.2	5.6	7.7

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					0.1-0.2 m				
NT_6	0.08c	0.41a	0.49c	0.16	1.53a	1.39b	1.53b	0.48c	0.41a
NT_{14}	0.12bc	0.40a	0.52bc	0.23	1.38b	1.09c	1.31b	0.51bc	0.40a
NT_{22}	0.09bc	0.40a	0.49c	0.18	1.37b	1.61a	1.82a	0.48c	0.40a
NT+B	0.09bc	0.41a	0.50c	0.18	1.47ab	1.62a	1.91a	0.49c	0.41a
Pasture	0.15b	0.39a	0.54ab	0.28	1.23c	0.97c	1.50b	0.53ab	0.40a
Native forest	0.25a	0.33b	0.58a	0.43	1.11c	0.30d	0.89c	0.56a	0.33b
CV (%)	22.7	5.7	3.7		4.8	10.1	9.8	3.8	5.5
					0.2-0.4 m				
NT_6	0.09b	0.44a	0.53b	0.17	1.44a	0.96b	1.13b	0.52a	0.45a
NT_{14}	0.12b	0.41ab	0.53b	0.23	1.37ab	0.89bc	1.24b	0.52a	0.41ab
NT_{22}	0.11b	0.41ab	0.52b	0.21	1.28bc	0.77cd	1.08b	0.51a	0.42ab
NT+B	0.11b	0.43ab	0.54ab	0.20	1.49a	1.46a	1.63a	0.53a	0.43ab
Pasture	0.13b	0.40b	0.53b	0.24	1.23bc	0.69d	1.21b	0.51a	0.40b
Native forest	0.23a	0.33c	0.56a	0.41	1.12c	0.26e	0.75c	0.53a	0.33c
CV (%)	16.3	5.8	3.0		6.3	9.9	7.4	5.5	5.9

Values represented by the different letters in the column, for each soil depth show significant differences (Tukey test, $P \leq 0.05$).
SPRs e SPR_{24}: Soil penetration resistance in saturated samples and after reaching equilibrium (24 hs) in tension table, respectively.
SWCs and SWC_{24}: Soil water content in saturated samples and after reaching equilibrium (24 hs) in tension table, respectively.
Source: Elaboration of the authors.

In all layers, the areas under NT+B and pasture presented values of the ratio macroporosity/total pore volume (MA/TPV) less than 0.33 m^3 m^{-3}, minimum value, considered ideal for crop development (TORRES; FABIAN; PEREIRA, 2011). For the different adoption times of no-till the lowest values were observed in the subsurface soil layers, reaching 0.18 m^3 m^{-3} for the NT_{22} in the 0.05-0.10 and 0.10-0.20 m layers, and 0.16 and 0.17 m^3 m^{-3} for the NT_6 in the 0.10-0.20 m and 0.20-0.40 m soil layers, respectively. This standard differs from the reported forest area, where the values of this ratio ranged from 0.41 to 0.52 m^3 m^{-3}. In turn, in the 0-0.05 m layer, with the macropores reduction and micropores elevation due to the greater adoption time of NT there was decrease the ratio MA/TPV.

For the soil bulk density (BD), the forest area showed lower values, differing from five managed areas, especially in the first two layers, reaching 0.80 Mg m^{-3} in the 0-0.05 m layer. This result is due to the absence of any type of soil management or animal grazing in this area, and because the existing vegetation provides high presence of roots. In general, there was increase in the BD of managed areas, especially in the subsurface layers, reaching 1.53 Mg m^{-3} for the 0.10-0.20 m layer in the NT_6 system. Viana et al. (2011) in cultivated areas compared to native forest reported similar results. Dimassi et al. (2013) in long-term experiment (20 years) under NT, found values of 1.50 Mg m^{-3} in the 0.10-0.20 m soil layer. These values are close to the values considered critical (1.60 Mg m^{-3}) for crop development (SILVA; ROSOLEM, 2001).

There was increase of soil penetration resistance (SPR) with decreasing the soil water content (SWC). In the layers of 0.05-0.10 and 0.10-0.20 m, the highest SPR values, from 1.78 to 1.62 MPa for the saturated samples and from 2.09 and 1.91 MPa for the samples in field capacity were observed in the NT_{22} and NT+B, respectively. In all soil profile, the managed areas differed from the forest area in relation the SPR values. The high values found in managed areas may be related to traffic machines on condition of high soil moisture (MARCOLAN; ANGHINONI, 2006), being aggravated by the high clay content of the studied sites (Table 3). Soil penetration resistance values above 2.0 MPa are considered limiting to the root growth of the plants (TORMENA; ROLOFF; SÁ, 1998).

The values of density and resistance obtained indicate the presence of compacted layers in the subsurface, which may limit the root growth of plants cultivated in succession systems, and, consequently restrict crop yields, especially in times of drought stress, mainly by reducing the soil volume explored by the root system of plants. In such cases, the minimum soil disturbance with chisel plow in certain period of the NT (QUINCKE et al., 2007) has reduced soil compaction in the subsoil, between 0.15 to 0.25 m, as reported in the study of Ferreras et al. (2000). Dimassi et al. (2013) observed density values greater than 4% in areas that were not receive annual chiseling in relation the chiseled areas.

Soil chemical properties

The results of the soil chemical properties of the different areas studied are presented in Table 4. In general, the highest values of soil pH were observed in native forested and pasture areas, differing from the other areas in the 0.05-0.10 and 0.10-0.20 m layers. This standard differed from that observed for the NT_{14} area, which had lower values than the other areas. This fact is related to the absence of soil acidity correction after the implantation of no-till in 1998. Soil acidification is a continuous process that persists even after liming, since the decomposition of organic matter added H^+ ions to the soil, as well as the ion exchange that occurs between the plant roots and the soil colloids. In this process, the plants absorb for example K^+, Ca^{2+} and Mg^{2+} ions, releasing H^+ ions, increasing the soil acidity with the with successive crops (BARBOSA FILHO; FAGERIA; ZIMMERMANN, 2005). These low pH values in the soil under NT_{14}, justify the higher values of potential acidity (H + Al) in all evaluated layers, reaching the value of 5.4 $cmol_c\ dm^{-3}$ in the 0.05-0.10 m soil layer. Similar results were observed for the Al^{3+} levels, which was higher only in the area of NT_{14}, ranging from 0.10 to 0.50 $cmol_c\ dm^{-3}$.

Table 4. Soil pH ($CaCl_2$), phosphorus (P), potential acidity (H+Al), aluminum (Al), calcium (Ca), magnesium (Mg), potassium (K), total soil organic carbon (TOC), and TOC stock of soils under management systems with different deployment times in the western region of Paraná, Brazil, in 2012.

Management system	pH	P	H+Al	Al	Ca	Mg	K	TOC	TOC stock
		$mg\ dm^{-3}$	------------------		$cmol_c dm^{-3}$	-------------------		$g\ kg^{-1}$	$Mg\ ha^{-1}$
					0-0.05 m				
NT_6	5.8b	13.4b	2.9b	0.0b	5.5b	1.8a	0.5ab	12.1c	5.0c
NT_{14}	5.1c	14.9b	4.3a	0.1a	3.1c	1.0b	0.3bc	12.4c	5.1c
NT_{22}	6.0ab	21.8a	3.2b	0.0b	6.3b	1.3ab	0.6a	15.6bc	6.4bc
NT+B	6.0ab	26.6a	2.6b	0.0b	5.6b	1.1b	0.5ab	12.5c	5.2c
Pasture	6.2ab	10.7b	3.2b	0.0b	2.9c	1.0b	0.3c	19.0b	7.9b
Native forest	6.4a	9.7b	2.7b	0.0b	8.6a	1.0b	0.4bc	30.5a	12.5a
CV(%)	3.7	16.9	17.8	25.2	17.5	31.5	21.8	13.9	14.6
					0.05-0.1 m				
NT_6	5.5b	22.3bc	3.7bc	0.0b	4.2bc	1.2a	0.3abc	7.8c	4.4c
NT_{14}	4.8c	38.5a	5.4a	0.5a	2.2c	0.6b	0.2bc	8.5c	5.1bc
NT_{22}	5.5b	28.5ab	4.3ab	0.0b	5.3b	1.1ab	0.4a	10.7bc	6.4abc
NT+B	5.5b	20.2bc	3.1cd	0.0b	5.2b	0.7ab	0.3ab	9.3c	5.2bc
Pasture	6.4a	9.7cd	2.5d	0.0b	2.0c	0.6b	0.1c	13.7ab	7.4ab
Native forest	6.3a	6.2d	2.2d	0.0b	7.9a	0.9ab	0.3abc	16.7a	8.3a
CV(%)	4.3	31.3	16.9	26.4	26.0	31.3	32.5	17.0	21.5

continua

continuação

					0.1-0.2 m				
NT_6	5.3b	8.7ab	3.2b	0.0b	3.3bc	1.2a	0.2ab	5.2c	6.4d
NT_{14}	4.8c	13.3a	4.5a	0.5a	2.2cd	0.3cd	0.1b	6.6c	7.8cd
NT_{22}	5.5b	10.0ab	3.8ab	0.0b	4.5ab	0.8b	0.3a	9.3a	10.8ab
NT+B	5.3b	10.2ab	3.1bc	0.0b	3.9ab	0.6c	0.2ab	6.9bc	8.3bcd
Pasture	6.4a	8.4ab	2.2c	0.0b	1.6d	0.2d	0.1b	10.7a	12.4a
Native forest	6.1a	4.8b	2.2c	0.0b	5.3a	0.9b	0.2ab	9.1ab	10.2abc
CV(%)	3.7	30.3	15.6	24.1	22.6	19.9	40.9	14.6	14.8
					0.2-0.4 m				
NT_6	5.5bc	7.9a	2.8ab	0.0b	3.7a	1.0a	0.1b	4.5c	9.6c
NT_{14}	4.9d	6.0a	3.8a	0.3a	2.3bc	0.4bc	0.1b	5.1bc	10.9bc
NT_{22}	5.5bc	6.6a	2.7ab	0.0b	4.2a	0.8ab	0.2a	7.5a	16.2a
NT+B	5.4c	5.8a	2.7ab	0.0b	3.3ab	0.5bc	0.2a	4.8bc	10.6bc
Pasture	6.5a	6.3a	2.2b	0.0b	1.3c	0.2c	0.1b	7.3a	16.0a
Native forest	5.9b	4.7a	2.5ab	0.0b	4.2a	0.6abc	0.2a	6.8ab	13.9ab
CV(%)	4.1	29.6	24.7	22.5	18.4	37.7	40.7	17.5	14.3

Values represented by the different letters in the column, for each soil depth show significant differences (Tukey test, $P \leq 0.05$).
Source: Elaboration of the authors.

For the P concentration in the soil, only in the 0.20-0.40 m layer were not verified differences in the levels in different management systems. In the 0-0.05 m soil layer, areas of NT_{22} and NT+B showed upper values to the forest area. In the 0-0.05 and 0.05-0.10 m layers were observed upper P levels, reaching 35.5 mg dm^{-3} in the area of NT_{14} compared with the area of native forest. These results may be attributed to phosphate fertilization performed annually in soybean crops in summer and maize and/or wheat in the fall-winter and low natural fertility of the soil in relation to P of the forested area. Dalchiavon et al. (2012) in areas of NT also reported higher phosphorus concentration in surface layers. For exchangeable bases, especially Ca^{2+}, were observed higher levels in the area under forest vegetation, especially in the 0-0.05 and 0.05-0.10 m soil layers, reaching 8.6 $cmol_c$ dm^{-3} in the 0-0.05 m layer. Costa et al. (2007) obtained similar results on a Red Latosol of Mato Grosso do Sul, Brazil.

In general, higher Mg^{2+} levels were found in the area under NT_6, although differences were not observed between the layers for the area under NT_{22}, with values ranging from 1.0 to 1.8 $cmol_c$ dm^{-3} in the 0.20-0.40 m and 0-0.05 layers, respectively. For the K, the only area of NT_{22} differed from forest area in the 0-0.05 m layer with 0.6 $cmol_c$ dm^{-3} concentration. Higher K levels in the soil permit that below potassium fertilizers rates may be applied in fertilizer, without adversely affecting crop yields (DALCHIAVON et al., 2012).

Total soil organic carbon stock

For TOC, there was tendency of increased levels due to the adoption time of no-till, however without differences for the first two layers, with values ranging from 7.8 to 15.6 g kg^{-1} in the 0.05-0.10 and 0-0.05 soil layers for the NT_6 and NT_{22}, respectively (Table 4). The values presented here were lower than those reported by Souza and Alves (2003) in tropical soil of Mato Grosso do Sul, and by Guareschi; Pereira and Perin (2012a) in soil of Goiás, respectively with 8 and 3 years of first adoption of no-till, and Boddey et al. (2010) in soils of southern Brazil. Assessing the same crop rotation systems in southern Brazil, Sisti et al. (2004) did not find significant accumulations of TOC in the 0-0.30 m soil layer after 13 years under NT. In general, higher levels of TOC were verified for areas of forest, pasture and NT_{22}, however similar values to each other in the 0.10-0.20 and 0.20-0.40 m layers. For the 0-0.05 m layer, the area under forest had a level of 30.5 g kg^{-1} TOC, differing from the managed areas.

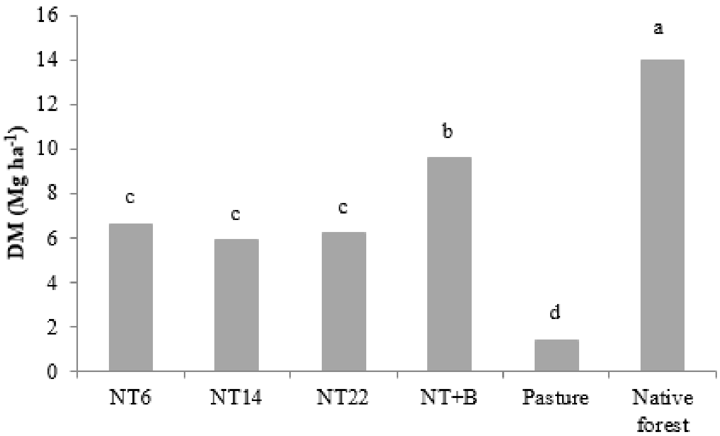
The lower TOC levels were verified in depth for the studied areas, confirming the results reported by Guareschi, Pereira and Perin (2012b) with the same soil type and crop rotation system (i.e., soybean in the summer and maize in winter) in areas under 3, 15 and 20 years of first adoption of no-till in the Goiás, Brazil. The decreased C levels in depth shows the contribution of the C inputs in the soil surface layer compared to the 0.05-0.10 m, 0.10-0.20 and 0.20-0.40 m layers. Expected results for systems without intensive soil tillage, as consolidated no-till.

The contribution of plant residues of crops for SOM was poor, because climate conditions favored the rapid decomposition of crop residues. This indicates the importance of the crop uses with higher C/N ratio to promote the formation of straw, which explains the results of the difference absence for the TOC levels in the upper layers of areas with different adoption times of the NT (Table 3). These results also reported by Paul et al. (2013) after four years of soybean-maize succession. Some recent studies have questioned whether the NT provides increased soil TOC stocks (BLANCO-CANQUI; LAL, 2008; CHRISTOPHER; LAL; MISHRA, 2009), because this increase also depends on the heterogeneity of crops installed in the area. The low values may be explained by the low C input coming from the management used in agricultural production (OGLE; SWAN; PAUSTIAN, 2012). For Brazilian tropical conditions in areas under NT for 20 years Oliveira et al. (2004) found higher accumulation of SOM in the soil surface layers in the soybean, maize and rice crops.

The highest values of total soil organic carbon (TOC) stocks were found in the forested area in the 0-0.05 m layer, differing from the managed areas, with value of 12.5 Mg ha^{-1} (Table 4). For the other layers, there are similar values in the areas under NT_{22}, pasture and forest. For the top two layers, the TOC stocks values increased with adoption time of the NT; however, there was no significant difference in the area under NT_{22} in the two layers, with a maximum value of 6.4 Mg ha^{-1}. These values were lower than those found by Guareschi, Pereira and Perin (2012a, 2012b), which used the same crop rotation systems, ranging of 3 to 20 years of cultivation under NT in the Brazilian tropical soils and Boddey et al. (2010) in southern Brazil with 17 years of succession under NT.

For the last two layers, there was tendency of increase of TOC stocks in the area under NT+B, however not differing areas of NT_6 and NT_{14}. This demonstrates that, for the condition studied, after four years of no-till with integration of maize + ruzigrass (*Brachiaria ruziziensis*), the C amount from of ruzigrass straw were not sufficient to raise the TOC stocks in relation to the areas of soybean and maize or wheat succession, although there are differences in the amount of dry matter (DM) after maize cultivation. The amount of DM of NT+N system was 9.58 Mg ha^{-1}, while areas in soybean and maize or wheat succession ranged from 5.87 to 6.63 Mg ha^{-1}, being different from each other (Figure 3). Proper management of integration systems can benefit the C inputs in the system and consequently increase the TOC stocks and soil fertility (BELL; MOORE, 2012), since the amount of crop residue that enters the system influences the addition rate of C to the soil (JOHNSTON; POULTON; COLEMAN, 2009). The magnitude of this process depends of the amount and quality of crop residues added to the soil surface (PAUL et al., 2013).

Figure 3. Amount of dry matter (DM) on the surface of the soil after winter season of 2012 under management systems with different deployment times and area of native forest in the western region of Paraná, Brazil.

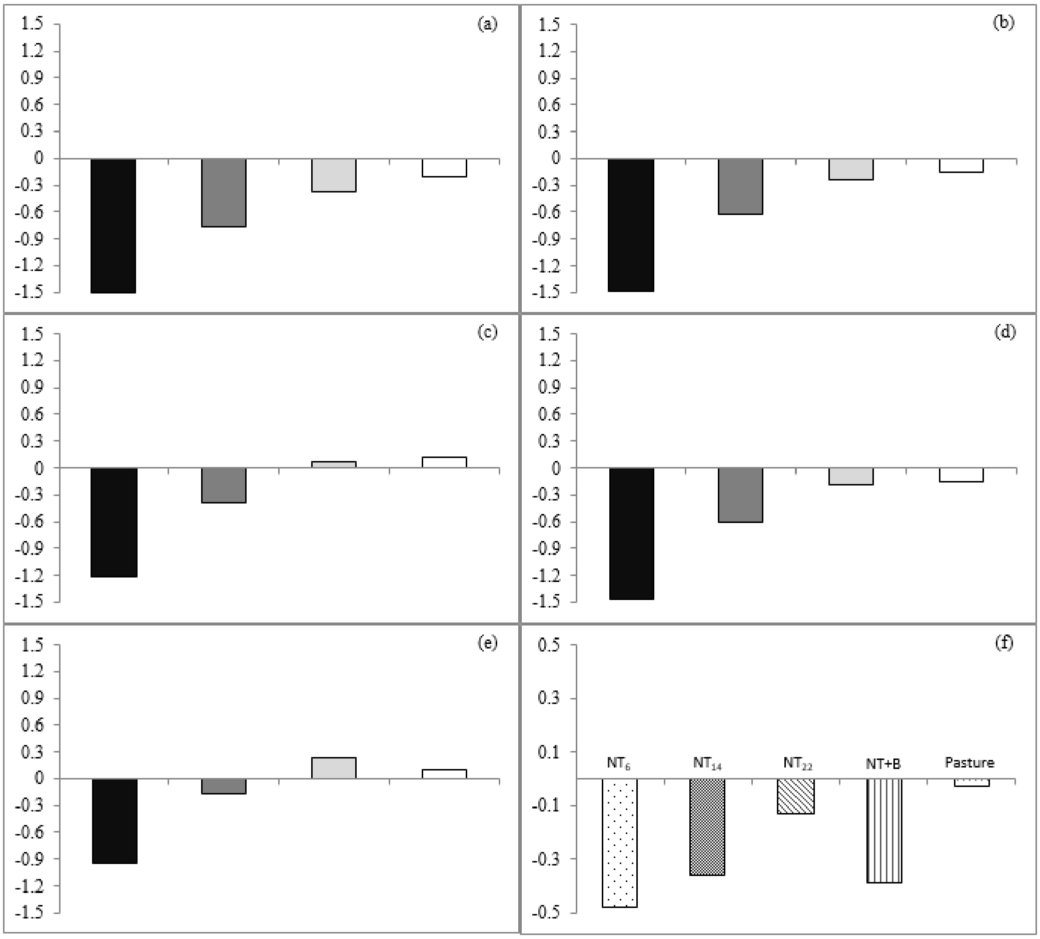


Source: Elaboration of the authors.

Changes in the vegetation and management practices may influence the TOC stock; they may change the input and loss rates of SOM (PLAZA-BONILLA; CANTERO-MARTÍNEZ; ÁLVARO-FUENTES, 2010). Changes in management systems have direct effect on the soil C balance. There was marked decrease in TOC stock in the surface soil layers, especially in the 0-0.05 m layer in relation to the forest area (Figure 4), indicating greater susceptibility of TOC oxidation in this soil layer under determined management systems. Even in management systems with high amount inputs of crop residue on the soil surface, in tropical regions it is difficult to increase the TOC levels and stocks, i.e. return to the levels of the areas under natural vegetation (BLAIR, 2000). This negative variation on TOC stock in the 0-0.05 m soil layer is most evident in areas under NT_6 (Figure 4a), NT_{14} (Figure 4b) and NT+B (Figure 4d), followed by areas under NT_{22} (Figure 4c) and pasture (Figure 4e). Virto et al. (2011) showed that the variation of TOC stocks could be positive or negative depending of C inputs in the agricultural production system. Paul et al. (2013) report that future studies should establish for different climatic regions and soil types, retention levels of minimum residues critical for the OC maintenance and soil conservation.

Negative variations of TOC stocks were observed in relation to the area of native forest for all layers evaluated in the areas of NT_6 (Figure 4a), NT_{14} (Figure 4b) and NT+B (Figure 4d). In turn, only in the 0.10-0.20 and 0.20-0.40 m layers, areas under NT_{22} (Figure 4c) and pasture (Figure 4e) showed positive change in TOC stock. In no-till, was not confirmed its potential for sequestering C as reported by Corazza et al. (1999). In this system, a more effective management of plant residues on the soil surface, and a crop rotation system more diverse can contribute to enhance the growth of deep roots and facilitate the C accumulation in the profile. This supports the hypothesis that the characteristics of crop rotation systems can determine the appropriate management systems, particularly for the C sequestration (D'ANDRÉA et al., 2004). These results were evident in the work of Sisti et al. (2004); Boddey et al. (2010) in southern Brazil, when using common vetch as a cover crop in the production system. The increasing complexity of rotation, depending on the region and soil type, can sequester around 200 kg C ha^{-1} yr^{-1} (WEST; POST, 2002).

Figure 4. Changes of TOC stock (ΔTOC stock) of managed areas at depths of 0-0.05 m (■), 0.05-0.10 m (■), 0.10-0.20 m (■) and 0.20-0.40 m (□) in relation to the area of native forest in the western region of Paraná, Brazil, in 2012. NT_6: no-till for 6 years (a), NT_{14}: no-till for 14 years (b), NT_{22}: no-till for 22 years (c), NT+B: no-till with integration of maize + ruzigrass (*Brachiaria ruziziensis*) (d), pasture (e) and soil profile of 0-0.40 m (f).



Source: Elaboration of the authors.

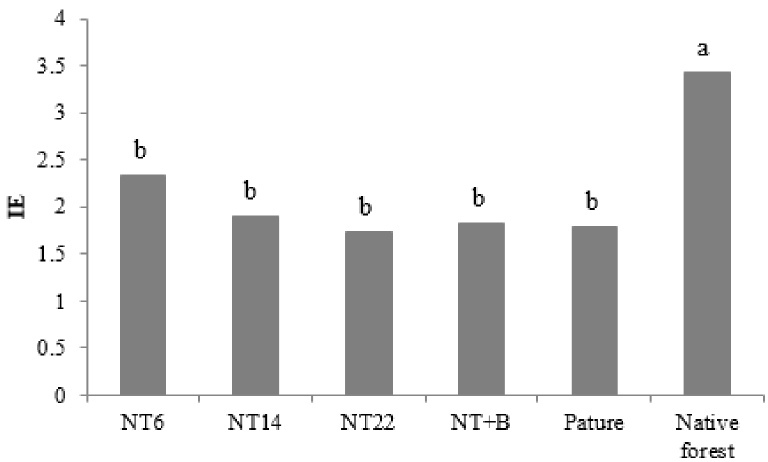
For pasture, negative change of TOC stock was observed in the first two layers (Figure 4e), however smaller than the other areas evaluated, mainly due to the contribution of pasture root system to accumulate C, as reported by Acharya, Rasmussen and Eriksen (2012), once the study area is occupied with permanent pasture for 39 years. For the Cerrado region, D'Andrea et al. (2004) observed positive change in the TOC stock in areas of permanent pasture with tropical grasses of the genus *Brachiaria*, mainly due to the continuous renewal of the root system, unlike what occurs in areas of degraded pastures. Increase of CO_2 emissions in degraded pastures have been reported compared with cultivated pastures (PLANT et al., 2011), being variable from region to region, as well as influenced by the C amount inputs in the production system, decomposition rate, soil texture (JOHNSTON, POULTON; COLEMAN, 2009), soil mineralogical composition and climate condition (WANG et al., 2010).

When analyzing the soil profile (Figure 4f) there was tendency decrease the negative values of TOC stocks in relation to forest area as a function of adoption time of the NT. Area under NT+B showed a negative change similar to the NT_{14} area. Different management practices, including the integration of grasses and legumes, improved of pasture, no-till and crop rotation can increase the TOC stock (HUTCHINSON; CAMPBELL; DESJARDINS, 2007).

The stratification index (SI) proposed by Franzluebbers (2002) was calculated in relation to TOC levels of 0-0.05 layer and the 0.10-0.20 m layer (arable layer). There was variation between 1.73 and 3.43 for the SI values in the NT_{22} and forest areas, respectively (Figure 5). Other studies have shown that the SI value can vary from 1.10 to 1.90 for conventional management systems and 2.10 to 4.10 for no-till system (FRANZLUEBBERS, 2002). Considering only managed areas, the SI values were increasing in the following order: 1.73 (NT_{22}), 1.78 (pasture), 1.82 (NT+B), 1.91 (NT_{14}) and 2.34 (NT_{6}). Tormena et al. (2004) studied areas with nine years of cultivation under rotation (maize/wheat/soybean/oat black/soybean/forage turnip) and crop succession (soybean/maize or wheat) in a Red Latosol of the Paraná; and found SI values of 1.73 and 1.28 to these areas, respectively, i.e., highest SI in the rotation system.

There is tendency of reduction in the SI values with the adoption time of the NT, and this is due to the C accumulation in the 0-0.05 m layer not be significant with the passage of the succession cultivations of soybean in the summer and maize or winter wheat, as can be seen in Table 4. There is no difference in TOC levels between areas under NT_{6}, NT_{14} and NT_{22} in the 0-0.05 and 0.05-0.10 m layers. In the area under forest, there was higher SI value (i.e., 3.43), indicating that occurred higher C accumulation in surface. Under cerrado vegetation, Salton (2005) observed SI value of 3.05 and the author pointed out that the use of this indicator has as an advantage the facility of obtaining its value depends only on TOC values for two soil layers, is not necessary the use of a reference area. Although there are no differences between areas managed, there was some degree of C stratification in depth, with values greater than one.

Figure 5. Stratification index (SI) of total organic carbon of soils under management systems with different deployment times and area of native forest in the western region of Paraná, Brazil, in 2012.



Source: Elaboration of the authors.

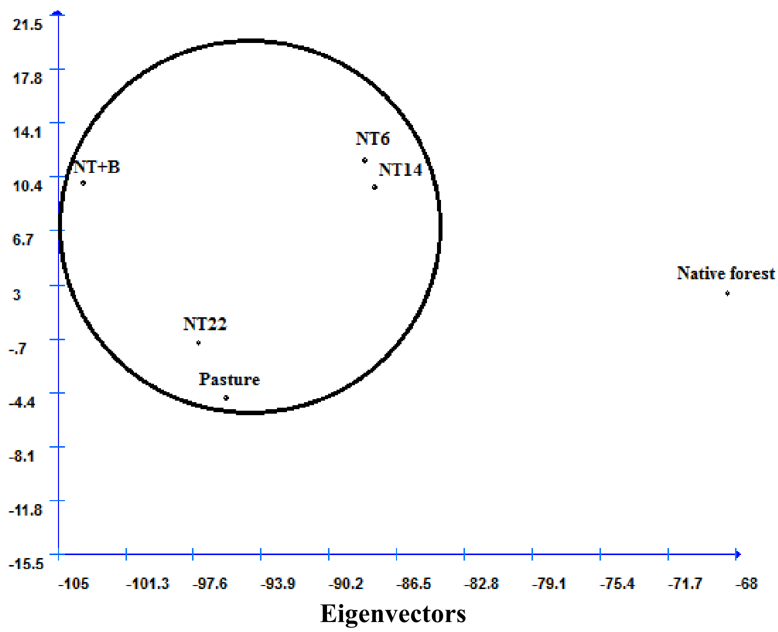
In the canonical analysis of physical and chemical properties and TOC stocks, the first and second canonical variable were 71.4 and 21.6% of the total variation, respectively, representing 93% of total variation, reaching the minimum requirements for evaluation by graphic dispersion

(CROSS; REGAZZI, 1994). Besides of the graphic dispersion, the grouping method of Tocher modified was used, showing the formation of two groups: the first formed by native forest area and the second group of the managed areas under NT_6, NT_{14}, NT_{22} NT+B and pasture (Figure 6). These results show that management systems with different deployment times showed a similar standard when considering the physical and chemical properties and soil C stocks.

The variables of less importance, for having greater weighting coefficient in the last canonical variables are the sand and silt contents and soil particle density (PD) for the physical properties and potential acidity and calcium level for chemical properties. Carneiro et al. (2009) showed in a test grouping for two soil types, which in both the physical properties were contributed the least to discriminate the evaluated management systems. With respect to the area of forest, the management systems caused reductions in several properties studied, which can lead to soil degradation over time, as reported also by Carneiro et al. (2009) in different management systems under Latosol and Neosol of the tropical region.

In general, there was equal conditions for all managed areas, which suggests that the management systems, especially areas with different adoption times of the NT in the crop succession system (soybean and maize or wheat), have little effect on the improvement of the soil properties compared with the area of native forest. The forest is a reference area for quality assessment of agricultural production systems. This may be due mainly by the absence of a system of crop rotation, involving a larger number of plant species, both in quantity and in quality, as well as different capacities to exploitation of their root system in depth.

Figure 6. Dispersion of different use and management systems of soils and grouping by the Tocher modified method from the first two canonical variables in an Eutroferric Red Latosol under management systems with different deployment times in the western region of Paraná, Brazil, in 2012.



Source: Elaboration of the authors.

Conclusions

In the managed areas, there was the presence of compacted subsurface layers, as reported by the highest values of soil bulk density and penetration resistance.

The soybean/maize or wheat succession systems under no-till does not contribute effectively to the increase of total soil organic carbon stocks, regardless of the deployment times of no-till.

There was negative change on total soil organic carbon stocks in the managed areas compared to native forest, mainly in the superficial soil layers.

Different management systems under long-term of no-till are not grouped with the native forest area, reference area, to consider all the physical and chemical properties, and organic carbon stocks.

Acknowledgments

To farmers by the availability of areas for the study.

To CAPES (Coordination for the Improvement of Higher Education Personnel), for providing scholarship to the authors.

To CNPq (National Council for Scientific and Technological Development), for financial support (Chamada Universal - MCTI/CNPQ N º 14/2012) and award for excellence in research to the authors.

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