

EFFECT OF MANAGEMENT SYSTEMS AND COVER CROPS ON ORGANIC MATTER DYNAMICS OF SOIL UNDER VEGETABLES⁽¹⁾

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SUMMARY

Vegetable production in conservation tillage has increased in Brazil, with positive effects on the soil quality. Since management systems alter the quantity and quality of organic matter, this study evaluated the influence of different management systems and cover crops on the organic matter dynamics of a dystrophic Red Latosol under vegetables. The treatments consisted of the combination of three soil tillage systems: no-tillage (NT), reduced tillage (RT) and conventional tillage (CT) and of two cover crops: maize monoculture and maize-mucuna intercrop. Vegetables were grown in the winter and the cover crops in the summer for straw production. The experiment was arranged in a randomized block design with four replications. Soil samples were collected between the crop rows in three layers (0.0-0.05, 0.05-0.10, and 0.10-0.30 m) twice: in October, before planting cover crops for straw, and in July, during vegetable cultivation. The total organic carbon (TOC), microbial biomass carbon (MBC), oxidizable fractions, and the carbon fractions fulvic acid (C_{FA}), humic acid (C_{HA}) and humin (C_{HUM}) were determined. The main changes in these properties occurred in the upper layers (0.0-0.05 and 0.05-0.10 m) where, in general, TOC levels were highest in NT with maize straw. The MBC levels were lowest in CT systems, indicating sensitivity to soil disturbance. Under mucuna, the levels of C_{HA} were lower in RT than NT systems, while the C_{FA} levels were lower in RT than CT. For vegetable production, the C_{HUM} values were lowest in the 0.05-0.10 m layer under CT. With regard to the oxidizable fractions, the tillage systems differed only in the most labile C fractions, with higher levels in NT than CT in the 0.0-0.05 m layer in both summer and winter, with

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no differences between these systems in the other layers. The cabbage yield was not influenced by the soil management system, but benefited from the mulch production of the preceding maize-mucuna intercrop as cover plant.

Index terms: organic carbon, oxidizable fractions, microbial biomass, humic fractions.

RESUMO: *INFLUÊNCIA DE SISTEMAS DE MANEJO E COBERTURA VEGETAL NA DINÂMICA DA MATÉRIA ORGÂNICA DE SOLO CULTIVADO COM HORTALIÇAS*

A produção de hortaliças em sistemas conservacionistas tem crescido no Brasil com reflexos positivos na qualidade do solo. Considerando que os sistemas de manejo alteram a quantidade e a qualidade da matéria orgânica, este trabalho teve por objetivo avaliar a influência de diferentes sistemas de manejo e cobertura vegetal na dinâmica da matéria orgânica de um Latossolo Vermelho distrófico, cultivado com hortaliças. Os tratamentos avaliados consistiram na combinação de três sistemas de manejo de solo: plantio direto (PD); plantio com preparo reduzido (PPR); e preparo convencional (PC), e duas coberturas vegetais: milho e consórcio milho e mucuna. No inverno, foram cultivadas hortaliças; e no verão, cobertura vegetal para palhada. O delineamento experimental utilizado foi de blocos ao acaso com quatro repetições. As amostras de solo foram coletadas na entrelinha de cultivo da hortaliça em três profundidades (0,0-0,05; 0,05-0,10 e 0,10-0,30 m), em duas épocas de amostragem: em outubro, antes do plantio das culturas para formação de palhada; e em julho, durante o cultivo da hortaliça. Foram determinados o carbono orgânico total (COT), o carbono da biomassa microbiana (CBM), das frações oxidáveis, e o carbono das frações ácido fúlvico (C_{AF}), ácido húmico (C_{AH}) e humina (C_{HUM}). As principais alterações nos atributos avaliados ocorreram nas profundidades mais superficiais (0,0-0,05 e 0,05-0,10 m), onde, de maneira geral, o PD com palhada de milho se destacou com os maiores teores de COT. Os valores do CBM foram menores nos sistemas de PC, evidenciando-se sensível ao revolvimento do solo. Os sistemas com preparo reduzido foram inferiores ao plantio direto com mucuna nos teores de C_{AH} e ao preparo convencional nos teores de C_{AF} . O uso do preparo convencional do solo para produção de hortaliças apresentou os menores valores de C_{HUM} na profundidade de 0,05-0,10 m. Entre as frações oxidáveis, os sistemas de preparo se diferenciaram somente nas frações mais lábeis do C, sendo o PD superior ao PC na profundidade 0,0-0,05 m, tanto no verão quanto no inverno, não havendo diferenças entre esses sistemas nas demais profundidades. A produtividade de repolho não foi influenciada pelo sistema de manejo do solo, mas foi beneficiada pelo uso do consórcio milho + mucuna como planta de cobertura formadora de palhada.

Termos de indexação: carbono orgânico, frações oxidáveis, biomassa microbiana, frações húmicas.

INTRODUCTION

A number of management and crop systems are being used in the Cerrado (savanna-like vegetation) region of Brazil, with impacts on soil components, above all on the compartments of soil organic matter (SOM). In conventional systems, the soil acts as a source of carbon (C) to the atmosphere (Bayer et al., 2004), whereas no-tillage (NT) is an alternative to minimize impacts on the soil by different forms of land use. The basic principles of NT lead to a reduction in CO₂ emissions to the atmosphere and increase the C and N stocks in the soil (Carvalho et al., 2010).

The importance of SOM to improve the soil chemical, physical and biological properties is widely recognized. Aside from the evaluation of the contents,

several analytical procedures were developed in recent years to understand the functions of the SOM fractions. Among these, the soil microbial biomass is responsible for biochemical and biological processes in the soil and substantially affected by the environmental conditions (Balota et al., 2008). When the organic residue input to the soil is increased and the amount of roots is large, the microbial biomass is stimulated, increasing the microbial population (Souza et al., 2010).

Aside from microbial C, the humified fractions of SOM represent an important compartment that performs several beneficial functions in the soil. Chemical fractionation is one of the oldest analytical procedures for SOM analysis. The humic fractions have been used as soil quality indicators, due to the strong interaction of humic substances with mineral materials and their relationship with soil

management (Fontana et al., 2006). Several studies have reported the influence of agricultural management systems on the humic fractions (Barreto et al., 2008; Portugal et al., 2008; Santana et al., 2011). The use of no-tillage, for example, preserves organic C in all humic fractions (Rosa et al., 2008). On the other hand, in systems with soil tillage, the fulvic acids and humin contents tend to increase and humic acids tend to decrease (Cunha et al., 2001).

To deepen the understanding about the stability level of C, the organic matter can be fractionated according to the susceptibility degree to oxidation in acidic media. In this sense, a procedure that divides SOM carbon in four fractions (F1, F2, F3, and F4) was proposed by Chan et al. (2001). The most easily oxidized fractions F1 and F2 are associated with nutrient availability and macroaggregate formation (Blair et al., 1995; Chan et al., 2001). The fractions F3 and F4 however are related to compounds with higher chemical stability and molar mass, originating from decomposition and humification (Stevenson, 1994).

Characteristics related to lability, the ease of oxidation and the amount of microbial biomass activity, along with yield data of agriculturally relevant crops, can serve as tools to assess crop sustainability from the point of view of soil preservation.

There is a growing demand for vegetable production on a scale parallel to the population growth. To meet this need, vegetable production on a larger scale must be accompanied by management systems that enable production increase combined with production sustainability, preserving the soil quality. In grain production, for example, conservation tillage has been widely used. But for the production of vegetable crops, few studies have addressed this type of management and its influence on vegetable production.

Accordingly, this study aimed to evaluate the influence of different management systems and cover crops on the dynamics of organic matter in a dystrophic Red Latosol under vegetables.

MATERIAL AND METHODS

The experiment was conducted on an experimental field of Embrapa Hortaliças, Brasília, at 997.6 m asl. The climate is Cwa, according to Köppen's classification, e.g., humid temperate with dry winters and hot summers. The experimental area was classified as clayey Oxisol (Santos et al., 2006).

The experimental area was originally covered by dry grassland vegetation (Cerrado) and used for vegetable cultivation under conventional tillage (CT) since the 1980s. The experiment was installed in December 2007 in a completely randomized block design with four replications. The plots (12 × 9 m)

were evaluated in four replications, in a 3 × 2 factorial design. The treatments consisted of three soil management systems (no-tillage - NT; reduced tillage - RT; and conventional tillage - CT) and two plant cover types for straw supply (maize monoculture - M and maize-*Mucuna aterrima* intercrop -MM), grown in the summer (December to April) and vegetables planted in the winter. The crops, plant stand and fertilizers used from 2007 to 2011 are listed in table 1 and the chemical properties of the studied soil, sampled prior to the experiment, in table 2.

Times and depths of soil sampling

The composite samples were collected at depths of 0.0-0.05, 0.05-0.10 and 0.10-0.30 m, in two samplings. The first sampling was performed in October 2011, at the beginning of the rainy season considered "summer", at the beginning of the fifth experimental year, and the second in July 2012 at the end of the fifth year, in the stage of full development (cabbage-head formation), considered "winter".

For each composite sample, two subsamples were randomly collected between the crop rows. The samples were homogenized, placed in labeled plastic bags and stored in a cold chamber at 4 °C for microbiological analyses. Part of this material was air-dried, ground and all soil was sieved (<0.5 mm) for the other analyses.

Crop management

Maize was sown on all plots on December 08, 2011, in rows spaced 0.80 m apart and five seeds per meter. Phosphate fertilizer was applied (100 kg ha⁻¹ P₂O₅). The commercial hybrid Ag1045 of the company Agrocere® was used with a population of 55,000 plants ha⁻¹. In the maize-mucuna intercrop treatments, the species were sown in a row spacing of 1.60 m and two seeds per meter, 30 days after maize sowing. In mid-March 2012, the MM intercrop was harvested with a straw crushing-shredding device (Triton®), leaving the straw on the ground. The CT plots were tilled (plowing and disking) and the RT plots tilled once with a leveling disc harrow, only for surface incorporation of the crop residues to a maximum depth of 0.05 m.

On May 16, 2012, cabbage seedlings of cv. Astrus Plus (Seminis®) were planted on all plots, in the treatments mentioned above. A spacing of 0.70 × 0.60 m was used with 23,089 plants ha⁻¹ on a total plot area of 108 m² (12 × 9 m). At planting, fertilization consisted of 100 kg ha⁻¹ P₂O₅. Sidedressing was performed with ammonium sulfate 20 and 40 days after transplanting at two fertilization rates (6 and 10 g/plant, respectively). Other cultural practices were performed according to the official crop-specific recommendations (Filgueira, 2000).

Ninety days after transplanting, 20 cabbage plants per plot were harvested. The harvested plants per treatment were weighed and the cabbage heads

Table 1. History of crops, plant density and fertilization

Growing season	Crop		Stand	Fertilization	
	Summer	Winter	Plant ha ⁻¹	At planting	Sidedressing
2007/2008	maize	Onion	400,000	600 kg ha ⁻¹	400 kg ha ⁻¹
	maize + mucuna			N-P-K fertilizer 04-30-16	Ammonium sulphate
2008/2009	maize	Cabbage	23,089	1250 kg ha ⁻¹ Single	500 kg ha ⁻¹
	maize + mucuna			superphosphate + 250 kg ha ⁻¹	Ammonium sulphate
2009/2010	maize	Broccoli	23,089	1000 kg ha ⁻¹ Single	500 kg ha ⁻¹
	maize + mucuna			superphosphate + 250 kg ha ⁻¹	Ammonium sulphate
2010/2011	maize	Pumpkin	3,333	300 kg ha ⁻¹ Single	150 kg ha ⁻¹
	maize + mucuna			superphosphate	Ammonium sulphate
2011/2012	maize	Cabbage	23,089	556 kg ha ⁻¹ Single	370 kg ha ⁻¹
	maize + mucuna			superphosphate	Ammonium sulphate

Table 2. Chemical properties of the studied soil

Property ⁽¹⁾	Layer		
	0.0-0.05 m	0.05-0.10 m	0.10-0.30 m
pH(H ₂ O)	5.4±0.3 ⁽²⁾	5.5±0.3	5.5±0.3
P (mg kg ⁻¹)	77.8±36.1	75.3±23.6	54.1±27.2
K (mg kg ⁻¹)	125.9±18.4	103.7±15.2	93.3±16.0
Na (mg kg ⁻¹)	7.9±0.8	8.1±0.6	8.2±0.7
Ca ²⁺ (cmol _c kg ⁻¹)	9.1±1.2	5.6±1.2	5.1±1.2
Mg ²⁺ (cmol _c kg ⁻¹)	2.6±0.9	1.84±0.4	1.7±0.34
Al ³⁺ (cmol _c kg ⁻¹)	0.05±0.05	0.05±0.06	0.07±0.05
H + Al (cmol _c kg ⁻¹)	7.7±1.2	7.41±1.1	7.0±1.34

⁽¹⁾ Properties evaluated as proposed by Embrapa (1997). ⁽²⁾ Values corresponding to the mean and standard deviation of the samples in each layer (n = 24) in the study treatments.

evaluated for marketable quality, to finally estimate the yield (kg ha⁻¹).

Laboratory analysis

The microbial biomass carbon (MBC) was determined by the method of microwave irradiation-extraction, described by Ferreira et al. (1999), by which the soil samples were irradiated in a microwave oven for 137 s. The MBC was extracted with a 0.5 mol L⁻¹ K₂SO₄ solution. The amount of MBC was determined by the difference between C extracted from irradiated and non-irradiated soil samples, using a correction factor (k_C) of 0.33 (Mendonça & Matos, 2005).

The oxidizable organic matter fractions were determined according to the procedure proposed by Chan et al. (2001) and modified by Rangel et al. (2008), summarized as: samples of 0.5 g of fine air-dried soil were placed in 250 mL Erlenmeyer flasks, adding 10 mL of 0.167 mol L⁻¹ K₂Cr₂O₇ and 2.5; 5; 10; and 20 mL of H₂SO₄, corresponding, respectively, to final

H₂SO₄ concentrations of 3, 6, 9, and 12 mol L⁻¹. Oxidation without external heat source was carried out and the extracts were titrated with a solution of 0.4 mol L⁻¹ Fe(NH₄)₂(SO₄)₂.6H₂O, using phenanthroline as indicator. The SOM was separated in four fractions, with decreasing degrees of oxidation:

Fraction 1 (F1): C oxidized by K₂Cr₂O₇ with 3 mol L⁻¹ H₂SO₄;

Fraction 2 (F2): difference between C oxidized by K₂Cr₂O₇ with 6 and 3 mol L⁻¹ H₂SO₄;

Fraction 3 (F3): difference between C oxidized by K₂Cr₂O₇ with 9 and 6 mol L⁻¹ H₂SO₄;

Fraction 4 (F4): difference between C oxidized by K₂Cr₂O₇ with 12 and 9 mol L⁻¹ H₂SO₄.

The C of the humic fractions of organic matter (fulvic acid, humic acid and humin) was determined by the method of Mendonça & Matos (2005).

Statistical analyses

The data were subjected to analysis of variance and means compared by the Tukey test (p<0.05), using the SAS statistical software (SAS, 2002).

RESULTS AND DISCUSSION

The TOC concentrations ranged from 14.7 g kg⁻¹ in CT_{MM} in the 10-30 cm layer to 25.6 g kg⁻¹ in NT_{MM} in the surface layer 0.0-0.05 m, both in the winter, with a gradual decrease with increasing depth (Table 3). In both sampling periods (summer and winter) the TOC values were higher in NT_{MM} than in CT_M and CT_{MM} in the surface layer (Table 3). Also in this layer, considering only the winter, the TOC levels were higher in the two systems under no-tillage

(NT_{MM} and NT_M) than CT. These results suggest that the supply of materials in different quantities and qualities contributes to increase the soil C content, as laid out by Guareschi et al. (2012). It was also observed that the maize-mucuna intercrop promoted increases in surface TOC levels, which persisted in the different seasons. This is a positive characteristic for the production of vegetables in different seasons. As reported by Amado et al. (2001), the use of mucuna in no-tillage maize promotes an increase in organic C stocks. However, in this study, despite the use of this intercrop, annual soil tillage induced a reduction in organic matter compared to no-tillage in the same intercrop.

Under reduced tillage, the TOC levels were intermediate between NT and CT in both sampling periods in the 0.0-0.05 m layer. In the 0.05-0.10 m layer, only CT_M had higher TOC levels than RT_{MM} in summer (Table 3). This may have been due to the effect of plowing, incorporating organic residues in deeper layers. Similar results were found by Pereira et al. (2010), who reported the highest TOC levels at this depth in CT, under maize and soybean.

In the 0.10-0.30 m layer, no differences were observed in TOC concentrations between the management systems in both seasons (Table 3). These

results demonstrated that the changes caused by the management systems in the TOC levels were restricted to the surface layer (0.0-0.05 and 0.05-0.10 m) with little change in deeper layers, as observed by Pereira et al. (2010) for soybean and maize and by Menezes & Silva (2008) for potato after six years of organic management.

When only the soil tillage system was evaluated regardless of the cover crop in both sampling times (summer and winter), differences were restricted to the 0.0-0.05 m layer, in which the TOC levels were higher in NT than RT in summer and than CT in winter (Figure 1a,b).

The MBC levels ranged from 146.78 to 438.27 mg kg⁻¹ with a gradual decrease with increasing depth (Table 3). In general, in relation to the MBC content, the greatest differences between systems were found in the summer season at both depths. In winter, only RT_M was superior to RT_{MM} in the 0.0-0.05 m layer, with no differences between other systems and depths.

In winter sampling, differences between the systems were only observed in the 0.0-0.05 m layer, with highest C content in RT_{MM} and NT_{MM}, as also observed in the first sampling, due to the input of diversified organic material. No statistical differences were found in the other studied layers.

Table 3. Total organic carbon (TOC), microbial biomass carbon (MBC) and microbial quotient (qMic) in soil under different tillage systems and cover crops, in three layers and sampling times

System ⁽¹⁾	0.0-0.05 m		0.05-0.10 m		0.10-0.30 m	
	Summer	Winter	Summer	Winter	Summer	Winter
	TOC (g kg ⁻¹)					
NT _M	21.3 AB	23.3 A	18.4 AB	17.7 A	15.7 A	15.4 A
NT _{MM}	23.3 A	25.6 A	17.8 AB	17.9 A	14.8 A	15.1 A
RT _M	22.5 AB	21.8 B	17.1 AB	18.1 A	15.2 A	16.4 A
RT _{MM}	21.9 AB	22.8 AB	16.4 B	17.5 A	14.8 A	14.9 A
CT _M	20.0 B	20.1 BC	19.4 A	18.0 A	16.0 A	15.1 A
CT _{MM}	19.8 B	19.0 C	18.5 AB	17.9 A	15.8 A	14.7 A
	MBC (mg kg ⁻¹ C)					
NT _M	363.2 B	197.7 AB	262.3 B	262.3 A	169.5 BC	223.1
NT _{MM}	400.5 AB	199.1 AB	322.6 A	274.5 A	219.1 A	235.9
RT _M	305.2 C	238.1 A	190.7 D	210.3 A	173.4 BC	271.2
RT _{MM}	438.3 A	146.8 B	254.5 BC	262.3 A	209.3 B	207.7
CT _M	320.4 C	204.7 AB	251.2 C	264.3 A	156.4 C	222.7
CT _{MM}	290.5 C	201.0 AB	281.6 AB	272.4 A	210.4 AB	256.3
	qMic (%)					
NT _M	1.71	0.85	1.43	1.48	1.08	1.45
NT _{MM}	1.72	0.78	1.81	1.53	1.48	1.56
RT _M	1.36	1.04	1.12	1.16	1.14	1.65
RT _{MM}	2.00	0.64	1.55	1.50	1.41	1.39
CT _M	1.49	1.02	1.29	1.47	0.98	1.48
CT _{MM}	1.47	1.06	1.52	1.52	1.33	1.74

⁽¹⁾ NT: no-tillage; RT: reduced tillage; CT: conventional tillage; M: maize monoculture; MM: maize-*Mucuna aterrima* intercrop. Means followed by the same letter in the column do not differ from each other by the Tukey test at 5 %.

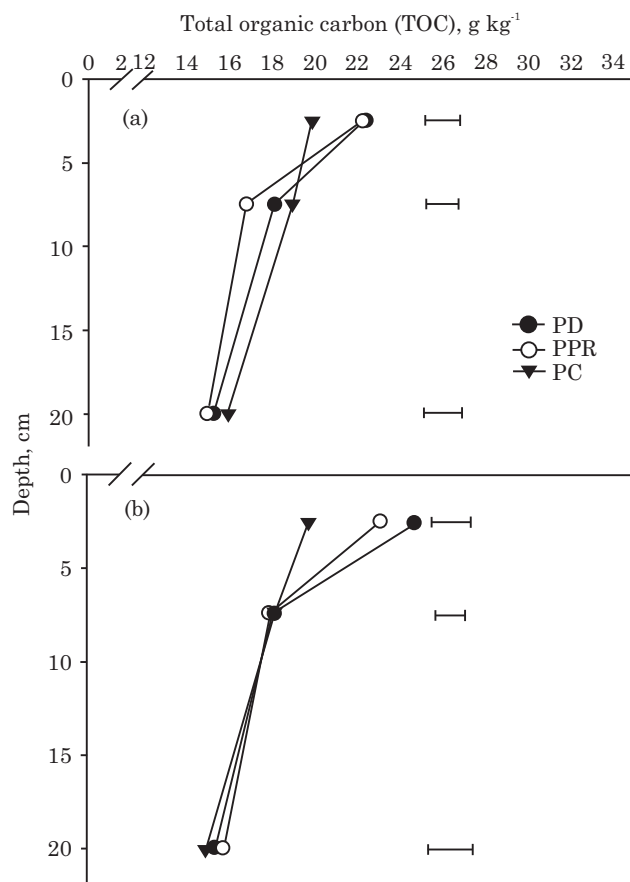


Figure 1. Total organic carbon (TOC) in Oxisol under different tillage systems, in summer (a) and winter sampling (b). NT, RT and CT are, respectively, no-tillage, reduced tillage and conventional tillage. The horizontal bars refer to the least significant difference (LSD) by the Tukey test ($p < 0.05$).

The highest TOC levels resulted in a stimulation of the microbial biomass. Thus, the MBC levels were higher in the conservation systems (NT and RT), which can be explained by the greater sensitivity of microbial C, which is affected positively by the higher accumulation of organic substrate and negatively by soil disturbance, as observed by several authors for Cerrado soils (Figueiredo et al., 2007, 2010; Silva et al., 2007; Carneiro et al., 2008, 2009; Cunha et al., 2011). In the summer, regardless of the cover crop, in the 0.0-0.05 m layer, the MBC levels in NT were on average 29 %, i.e., higher than under CT.

The maize-mucuna intercrop in the summer for straw formation for soil mulching increased the MBC contents in NT and RT at all depths and CT in the subsurface layers, compared to the systems using only the grass species as cover crop. According to Cardoso et al. (2009), this increase is related to the higher, continuous and varied input of organic substrates from the greater diversity of species and with different

degrees of susceptibility to decay. In situations with increased input of organic residues in the soil and with high root amounts, the microbial biomass is stimulated, resulting in population growth and activity increase (Souza et al., 2010).

The lowest MBC values were found under CT in the 0.0-0.05 m layer, justified by the fact that soil disturbance induces higher decomposition rates of organic materials, reducing the substrate for microbial development, as already observed in an Oxisol in the Cerrado (Nunes et al., 2011). Similar results of the effect of soil management were reported by Kandeler et al. (1999), who found higher values of soil microbial biomass in areas under minimum and reduced tillage and a 50 % increase in the 0.0-0.10 m layer, three years after the introduction of minimum tillage in areas under conventional cultivation. This reduction in TOC levels and consequently in microbial biomass decreases the soil quality under vegetable cultivation (Valarini et al., 2011).

In general, a stratification of MBC levels was found with decreasing values in deeper layers. Under no-tillage the MBC levels always decreased in depth. In the other systems, this reduction was crop-dependent (maize or maize-mucuna). This MBC stratification demonstrates the effect of organic matter accumulation in the surface and root action, favoring microbial proliferation.

The MBC fraction accounted for between 0.64 and 2.00 % TOC, in agreement with results of Matias et al. (2009) and Pragana et al. (2012) in Yellow Latosol under soybean in the Cerrado region of Piauí; Nunes et al. (2011) in a field experiment with maize-soybean rotation, in the Cerrado of the Federal District; and Matoso et al. (2012) in Red-Yellow Latosol, under different land uses in Amazonia.

The highest MBC contents were observed in conservation tillage systems, indicating greater C availability to the soil microbiota, since the MBC:TOC ratio is an indicator of the availability of organic matter to microorganisms, and a high microbial ratio indicates that the organic matter is very active and prone to changes (Sampaio et al., 2008).

With regard to the oxidizable fractions, as there was no influence of the interaction soil tillage \times cover crop on any of the fractions, the effect of cover crop was disregarded and only the effect of tillage systems on the oxidizable fractions of soil organic C was addressed (Table 4). In this study, the fractions were grouped according to their lability (F1 + F2) and recalcitrance (F3 + F4). For Majumder et al. (2008), the fractions F1 and F2 can be considered good indicators of sustainability of the system, while the F4 fraction is the most resistant in the soil. It is called "passive compartment" in SOM simulation models with a recycling time of up to 2,000 years (Chan et al., 2001).

Table 4. Fractions of oxidizable carbon in soil of different tillage systems, soil layers and sampling times

System ⁽¹⁾	Fraction of oxidizable carbon			
	F1 + F2		F3 + F4	
	Summer	Winter	Summer	Winter
g kg ⁻¹				
0.0-0.05 m				
NT	13.4 A	11.6 A	8.9 A	11.7 A
RT	13.6 A	10.4 AB	8.7 A	12.4 A
CT	11.6 B	8.8 B	8.3 A	11.0 A
0.05-0.10 m				
NT	10.6 AB	8.1 A	7.6 A	9.7 A
RT	9.7 B	7.5 A	7.2 A	10.4 A
CT	11.2 A	8.2 A	7.8 A	9.8 A
0.10-0.30 m				
NT	8.7 A	7.2 A	6.6 A	9.0 A
RT	9.4 A	6.1 A	5.6 A	9.4 A
CT	9.8 A	6.5 A	6.2 A	8.7 A

⁽¹⁾ NT: no-tillage; RT: reduced tillage; CT: conventional tillage; M: maize monoculture; MM: maize-*Mucuna aterrima* intercrop. Means followed by the same letter in the column do not differ from each other by the Tukey test at 5 %.

In the soil sampled in the summer, the C contents in the most labile fractions were between 8.7 g kg⁻¹ in NT in the 0.10-0.30 m layer to 13.6 g kg⁻¹ in RT in the 0.0-0.05 m layer. These amounts represented, on average, 50 % of TOC, demonstrating that the labile and recalcitrant fractions of organic matter were similar in soil under vegetables in the different management systems. A similar behavior was observed by Rangel et al. (2008), who reported that the F1 fraction represented 30-50 % of the TOC in the 0.0-0.10 m layer. This shows the presence of organic matter with higher bioavailability in the surface soil layer, which explains the higher MBC levels, in response to the increased amount of substrate with greater TOC availability in conservation tillage systems.

In the 0.0-0.05 m layer, the C content in the CT system was lowest (11.6 g kg⁻¹) in the fractions F1 + F2, reflecting the influence of soil tillage on the degradation of easily oxidizable organic C. In the intermediate layer (0.05-0.10 m), the C content in CT did not differ from that in NT but was higher than in RT, showing an inversion of layers due to soil tillage. This demonstrates that the influence of soil management systems is more significant in the upper soil layers.

The C content of the most stable fractions (F3 and F4) varied from 8.7 to 12.4 g kg⁻¹, with no significant differences between soil depths, showing that the tillage system had little influence on the most

recalcitrant fractions, due to their greater physical and chemical soil protection (Loss et al., 2010a).

In the humic acid fraction the C contents (C_{HA}) ranged from 3.72 to 6.20 g kg⁻¹. Effects of tillage system and cover crop on the HA levels were only observed in the summer sampling and in the surface layers (0.0-0.05 and 0.05-0.10 m) (Table 5). At that time, reduced tillage systems (RT_M and RT_{MM}) had lower HA levels than NT_{MM} in the 0.0-0.05 m layer. This same pattern of superiority of NT_{MM} was also observed in the 0.05-0.10 m layer. The C_{HA} levels in this layer were also higher for maize-mucuna intercrop under reduced tillage than for maize monoculture, demonstrating the positive effect of intercropping on the SOM quality, reflecting positively on vegetable production. However, in the 0.10-0.30 m layer, no differences in humic fractions between the systems were observed. The C content in the fulvic acid fraction (C_{FA}) ranged from 2.88 in RT_M in the 0.05-0.10 m layer in the winter to 4.31 g kg⁻¹ in NT_M in the same layer in the summer, as similarly reported by Fontana et al. (2006). No differences were detected between the systems in any of the soil layers.

In the humin fraction, the C levels (C_{HUM}) varied from 6.19 in NT_{MM} in the winter to 12.25 g kg⁻¹ in the NT_M in the summer, both in the 0.05-0.10 m layer. The C_{HUM} accounted for the greatest portion of TOC, as also observed by Barreto et al. (2008) and Loss et al. (2010b). This predominance of C_{HUM} is related to its insolubility and resistance to biodegradation, favored by the formation of stable clay-humic complexes (Fontana et al., 2006).

In the winter sampling, the C_{FA} levels differed between management systems in the 0.05-0.10 m layer only, with higher content in CT_M (3.68 g kg⁻¹) than in RT_M (2.88 g kg⁻¹).

In soil collected from the tillage systems in summer, independently of the cover crop, the C_{HUM} levels in the treatments NT and RT were higher than in CT in the two upper layers. In all three soil management systems, higher C_{HUM} levels were observed in the 0.05-0.10 m layer. In the deepest layer, no differences were observed between tillage systems (Figure 2a). In the winter sampling of the systems, the C_{HUM} levels did not differ between layers (Figure 2b).

Despite the absence of statistical differences between the sampling times, the C contents of the humic substances, especially in the humin fraction, were on average higher in summer than in winter. This pattern may be due to the greater input of plant residues from maize or maize and mucuna straw, with higher temperatures and water availability in this season. These conditions favor the decomposition of these residues for the subsequent formation of humic substances, as similarly observed by Silva et al. (2006) and Loss et al. (2010b).

Table 5. Carbon of humic fractions in soil of different management systems, cover species, layers and sampling times

System ⁽¹⁾	Humic acid		Fulvic acid		Humins	
	Summer	Winter	Summer	Winter	Summer	Winter
g kg ⁻¹						
0.0-0.05 m						
NT _M	4.73 AB	4.55 A	3.39 A	3.39 A	10.82 A	8.52 A
NT _{MM}	5.52 A	5.02 A	3.99 A	3.55 A	11.02 A	8.55 A
RT _M	4.07 B	4.99 A	3.45 A	3.47 A	11.46 A	9.43 A
RT _{MM}	4.03 B	4.57 A	3.42 A	3.83 A	11.32 A	9.48 A
CT _M	4.27 AB	5.16 A	3.37 A	3.69 A	8.92 A	8.59 A
CT _{MM}	4.57 AB	4.68 A	3.85 A	3.53 A	9.00 A	9.00 A
0.05-0.10 m						
NT _M	5.32 ABC	4.54 A	4.31	3.49 AB	12.25 A	6.90 A
NT _{MM}	6.20 A	3.72 A	4.13	3.03 AB	12.13 A	6.19 A
RT _M	4.60 C	3.81 A	3.52	2.88 B	11.83 A	7.52 A
RT _{MM}	5.64 B	4.55 A	4.29	3.03 AB	12.00 A	6.22 A
CT _M	5.76 AB	4.44 A	3.75	3.68 A	9.49 B	7.01 A
CT _{MM}	5.48 ABC	4.22 A	3.75	3.19 AB	9.02 B	7.09 A
0.10-0.30 m						
NT _M	4.52 A	4.60 A	3.25 A	3.52 A	8.83 A	7.69 A
NT _{MM}	4.56 A	4.42 A	3.06 A	3.36 A	8.25 A	6.64 A
RT _M	3.72 A	4.04 A	2.97 A	3.30 A	8.89 A	7.23 A
RT _{MM}	4.36 A	4.05 A	3.22 A	3.84 A	7.65 A	8.68 A
CT _M	4.53 A	4.22 A	3.11 A	3.60 A	8.72 A	6.90 A
CT _{MM}	4.73 A	4.57 A	3.40 A	3.99 A	7.59 A	6.90 A

⁽¹⁾ NT: no-tillage; RT: reduced tillage; CT: conventional tillage; M: maize monoculture; MM: maize-*Mucuna aterrima* intercrop. Means followed by the same letter in the column do not differ from each other by the Tukey test at 5 %.

Evaluating only the tillage systems, disregarding the straw used to cover the soil, the C_{HA}/C_{FA} index was between 1.16 and 1.50, similar to the values reported by Cunha et al. (2005) and Pessoa et al. (2012) and higher than those found by Lima (2001). This range indicates that the low-solubility fraction (C_{HA}), usually related to a higher condensation of humic compounds (Cunha et al., 2005), was predominant. A C_{HA}/C_{FA} ratio higher than 1 is an indicator of the predominance of organic matter of better quality (Cunha et al., 2005), which is essential for vegetable production.

The mean cabbage yield ranged from 78,908 to 90,440 kg ha⁻¹ (Table 6). Although the differences among tillage systems were not significant when evaluating only the factor cover crop, the mean yield on the maize-mucuna intercrop plots was higher (85,611 kg ha⁻¹) than on the summer crop plots with maize monoculture (79,334 kg ha⁻¹). The use of legume-grass intercrops is a management strategy that not only protects the soil and supplies N, but also provides dry matter production with intermediate C/N, reducing the decomposition rate of crop residues

and synchronizing N supply and demand of the crop (Aita & Giacomini, 2003; Giacomini et al., 2003; Carvalho et al., 2011, 2012).

Table 6. Cabbage yield under different tillage systems and cover crops

System ⁽¹⁾	Yield
	kg ha ⁻¹
NT _M	78,908 A
NT _{MM}	83,476 A
RT _M	79,651 A
RT _{MM}	90,440 A
CT _M	79,444 A
CT _{MM}	82,817 A
Cover plant ⁽²⁾	
maize	79,334 B
maize and mucuna	85,611 A

⁽¹⁾ NT: no-tillage; RT: reduced tillage; CT: conventional tillage; M: maize monoculture; MM: maize-*Mucuna aterrima* intercrop.

⁽²⁾ Mean yield, independent of soil tillage. Means followed by the same letter in the column do not differ from each other by the Tukey test at 5 %.

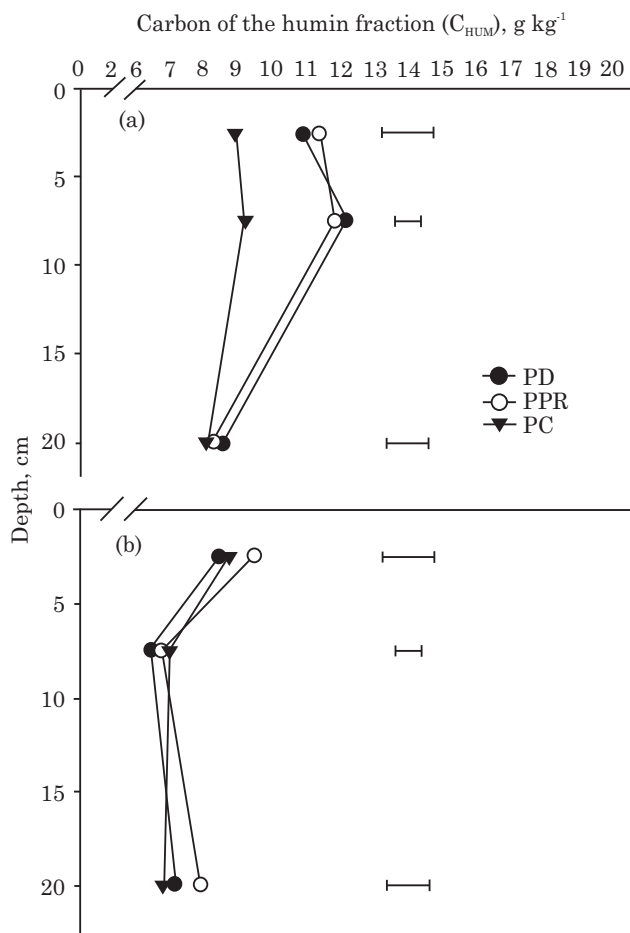


Figure 2. Carbon of the humin fraction (C_{HUM}) in Oxisol under different soil tillage systems, in summer (a) and winter sampling (b). NT, RT and CT are, respectively, no-tillage, reduced tillage and conventional tillage. The horizontal bars refer to the least significant difference (LSD) by the Tukey test ($p < 0.05$).

CONCLUSIONS

1. No-tillage vegetable production tended to increase the more labile and more easily oxidizable organic matter fractions, mainly in the upper layers.

2. Humic fractions were influenced by soil management in the surface layers only, and no-tillage with mucuna resulted in higher levels of humic acids and conventional tillage in higher levels of fulvic acids than the system with reduced tillage.

3. The C contents of the humin fraction in the 0.05-0.10 m layer were lowest in the conventional system of vegetable cultivation.

4. Regardless of the management system, the use of maize-mucuna intercrop as summer crop resulted in higher cabbage production.

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