CARBON POOLS AND SOIL FERTILITY IN AN OXISOL FROM CERRADO UNDER DIFFERENT COFFEE PRODUCTION SYSTEMS

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ABSTRACT: Humus fractionation and soil fertility from agroforestry, organic and conventional coffee production systems from Brazilian Cerrado were studied. The objectives included the investigation of the impact of different managements on the humus composition as well assessing how the management affects the soil fertility.

KEYWORDS: Soil organic matter; Agroforestry system; Organic system; Sustainability.

INTRODUCTION: Cultivation of coffee in conventional systems affect soil organic matter (SOM), decreasing the content of the most labile carbon fractions. As a result, the impoverishment of already weathered soils is usually observed at the Brazilian Cerrado. To reduce this effect, many practices have been proposed. Agroforestry systems are structurally diverse compared to monocrops and improve the use of natural resources by accessing different sources of light, water and nutrients. Organic farming avoids the use of synthetic fertilizers and emphasizes organic inputs for nutrient supply. Humic substances (HS) are the major components of stabilized SOM and its content and chemical characteristics have been used as indicators of soil quality. Humic acids (HA) are the part of the HS formed by an association of hydrophobic compounds stabilized at neutral pH by hydrophobic forces, and fulvic acids (FA) are formed by the association of small hydrophilic molecules with enough acid functional groups to keep fulvic clusters dispersed in solution at any pH (Piccolo, 2002). It has been proposed that the greater participation of hydrophobic fractions (i.e. HA) in agricultural lands represent better chemical and fertility conditions to growing plants. Canellas et al. (2003) associated the highest carbon content in HA and FA fractions (C_{HA}/C_{FA} ratio) to greater availability of nutrients in a soil under long-term (55 years) of non-burning management of sugar cane. We studied the influence of agroforestry and organic coffee systems, in comparison to conventional plantation, on the humic fractions distribution in an Oxisol from Brazilian Cerrado hypothesizing that the adoption of these systems rapidly increase the C_{HA}/C_{FA} ratio, with direct impacts on soil fertility.

MATERIAL AND METHODS: The experiment was established in 2007 at Embrapa Hortaliças (Brasilia – DF). Agroforestry system consisted of *Gliricidia sepium* and coffee plants (*Coffea arabica*). The organic system cultivation used only fertilizers permitted on organic productions. Both received, during the planting, composts produced from castor meal (300 g plant^{-1}), lime (2 ton ha^{-1}) and magnesium thermophosphate (500 g plant^{-1}). Every 6 months, an organic fertilizer based on cattle and chicken manure and castor meal (300 g plant^{-1}) was applied. The conventional cultivation received mineral fertilization (NPK) according to soil analysis, mechanical and chemical weed control. Fifteen soil sub-samples (Dystrophic Red-Yellow) were collected to obtain a composite soil sample in each treatment, at 0-0.05, 0.05-0.10 and 0.10-0.20 m depths. Organic matter fractionation was performed according to Guerra and Santos (1999). The soils were submitted to 2 mol L^{-1} H_3PO_4 solution which separated the light organic matter (LOM) through density and also solubilized the free fulvic acids (FFA) fractions. Thereafter, a 0.1 mol L^{-1} NaOH solution (1:20) was used to solubilize the FA and HA. The insoluble residue obtained was called humins (HUM). The HA was separated from the FA through precipitation in acid medium obtained with the addition of concentrated H_2SO_4 down to pH 1–1.5. Carbon content in each fraction was determined using dichromatometry. Analysis of the soil pH (measured in water; 1:2.5 ratio), P and K^+ contents (extracted by Mehlich–1 solution), Ca^{2+}, Mg^{2+} and Al^{3+} (KCl 1 mol L^{-1}) and total organic carbon (TOC – modified Walkley-Black procedures). All analysis were performed using three replicates as described by EMBRAPA (1997).

RESULTS AND DISCUSSION: TOC was higher in the agroforestry system at 0-0.05 m layer (Table 1). Conservation practices as leguminous cover crop improve the plant biomass and contribute to greater amounts of residues added to the soil. The presence of trees promoted frequent input of organic residues on soil, mimicking natural systems by increasing residues returns and minimizing C removal (Guimarães et al., 2013). In Brazilian Cerrado, meanwhile, carbon mineralization is fast due to the high temperature, rainfall and microbial activity (Kaschuk et al., 2012) and only managements with usual input of residues enable increase in the TOC. In this way, the volume of compounds applied to the organic system was not enough to promote an increase when compared to the conventional system. Conventional system presented the highest TOC at 0.10-0.20 m. Humus fractionation by chemical procedures showed, however, that 88% of the TOC present in that management (0.10-0.20 m layer) was correlated to HUM fraction (Fig. 1), the most recalcitrant carbon form. Using the average of the three depths, the participation of HUM was: conventional (79% of the TOC) > organic (75%) > agroforestry (67%). Furthermore, agroforestry showed the highest LOM content and the average of the three depths showed that 13% of the TOC in the agroforestry was associated with LOM, while to organic and conventional sites this fraction represented 5 and 2%. LOM fraction decrease sharply with deep and no LOM was detected after 0.1 m deep to conventional system (Table 1; Fig. 1). In general, FA content increased from the topsoil to the samples obtained at 0.05-0.10 m and decreased at the 0.10-0.20 m layer, showing a strong dynamic due the solubility of this carbon pool in both alkaline and acid environment. To HA, at the 0-0.05 m layer, only a slight difference was observed between conventional and agroforestry systems. On other hand, organic system was 38 and 15% richer in HA when compared to conventional and agroforestry system, respectively. At 0.10-0.20 m layer, agroforestry and organic systems were, respectively, 150% and 50% richer than the conventional system, demonstrating a clear trend of enrichment in that humic fraction with depth. Relationship between the carbon in the HA and FA fractions (C_{HA}/C_{FA} ratio) has been associated to the better chemical and fertility environment achieved in soil managements that preserve the SOM. In our study, meanwhile, C_{HA}/C_{FA} ratio followed the sequence: conventional > agroforestry > organic system (Table 1) but the results pointed to a poor and acid environment in the conventional system (Table 2). Agroforestry and organic systems decreased the soil acidity (pH, H+Al and Al^{3+}) at the 0-0.05 m layer. On conventional system, the exchange complex was saturated with Al^{3+} (mean of 15%) and the pH was low, presumably due to the high doses of nitrogenous fertilizers in NH_4^+ form. Conversion of NH_4^+ to nitrate forms is followed by the release of H^+ ions. In fact, conventional system showed the lowest values for pH, sum of bases, base saturation and ($Ca^{2+}+Mg^{2+}$), whereas agroforestry and organic showed the exchange complex occupied by cations with alkaline character and low acidity, mainly in the top soil. Available P increased in agroforestry systems at the top soil (Table 2). The turnover of P forms accumulated in the vegetal biomass produced in higher amounts by arborous legume species contributed for this increment. Degraded soils re-vegeted with *Acacia mangium* increased the available P in a relatively short time period (3 years) due a combined effect of nutrient cycling and reducing P fixation that occurred because of the higher SOM content (Schiavo et al., 2009). Agroforestry showed a marked decrease of available P in the sample obtained at 0.10-0.20 m probably due to the conversion of part of the inorganic into organic P forms. The converted organic P forms are not reached by the extractor used in the P available analysis (Nelson et al., 1953). Levels of organic P increases considerably in agricultural soils when managements based on the preservation of SOM are adopted (Busato et al., 2005).

CONCLUSIONS: In our view, C_{HA}/C_{FA} ratio need to be carefully considered when used to access the quality of soils and managements in Brazilian Cerrado since, in general, the classical indicators of soil fertility (acidity, base saturation, TOC and nutrients levels) were favorable in the soils under agroforestry and organic management but its C_{HA}/C_{FA} ratio showed the lowest values. Many works have associated higher C_{HA}/C_{FA} ratios to greater availability of nutrients and a better chemical environmental to growing plants, but most part of the works used long-term managements, resulting in cumulative larger organic matter inputs. We suggest that the relatively short-term of agroforestry (5 years) or the amounts of organic matter applied to organic systems was sufficient to increase the soil fertility, but not enough to increase the C_{HA}/C_{FA} ratio. Also, to agroforestry in special, the great LOM participation did not represent an increase in the C_{HA}/C_{FA} ratio, pointing to a difficulty in increasing the levels of more stabilized fractions of the SOM. The chemical nature of the residues from *Gliricidia* plants need to be deeply explored to clarify the influence of this residue on the humification process.

Table 1. Carbon pools in different coffee production systems in the Brazilian Cerrado.

Crop system	Depth	Total C	LOM	C_{FFA}	C_{HA}	C_{FA}	C_{HUM}	C_{HA}/C_{FA}
	m	....			g kg^{-1}		....	
Conventional	0-0.05	23.0 b	0.8 b	0.6 b	1.3 b	0.7 b	11.7 b	1.9
Organic		22.7 b	1.5 b	1.1 a	1.8 a	1.7 a	13.8 a	1.1
Agroforestry		26.1 a	3.8 a	0.9 ab	1.5 ab	0.9 b	11.5 b	1.7
Conventional	0.05-0.10	22.9 a	0.4 b	1.1 b	1.4 a	1.7 ab	12.0 b	0.8
Organic		20.2 b	1.0 b	1.3 a	2.0 a	2.2 a	20.0 a	0.9
Agroforestry		21.9 ab	1.9 a	1.0 b	1.0 b	1.4 b	10.0 b	0.7
Conventional	0.10-0.20	21.8 a	0.0 c	0.9 b	0.6 b	0.3 b	12.1 b	2.0
Organic		19.4 b	0.5 b	0.9 ab	0.9 a	0.8 a	13.9 a	1.1
Agroforestry		19.4 b	0.9 a	1.2 a	1.5 a	1.2 a	11.5 b	1.3

For each layer, averages followed by same letter in column are not different (Tukey test, $p < 0.05$).

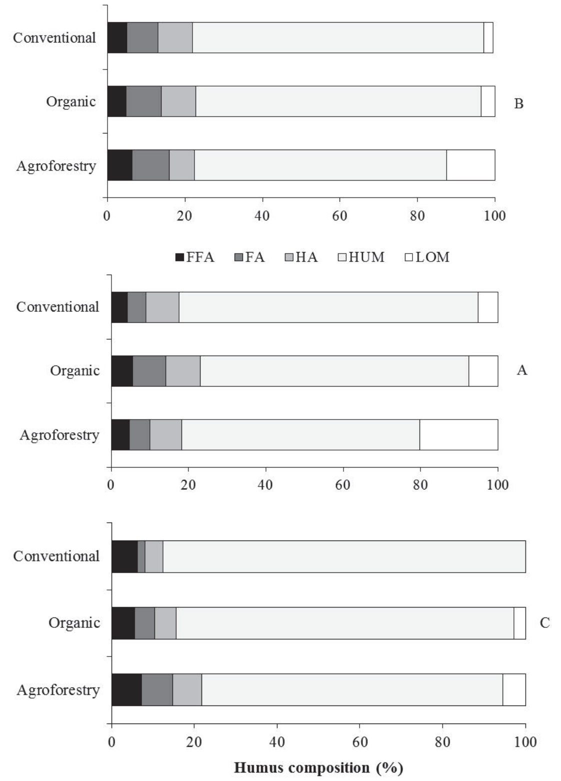

Figure 1. Distribution of humidified fractions: 0-0.05 m (A), 0.05-0.010 m (B) and 0.10-0.20 m (C). 100 % = FFA + FA + HA + HUM + LOM, representing, respectively, the carbon content present in the free fulvic acids, fulvic acids, humic acids, humins and low organic matter.

Table 2. Soil fertility attributes in different coffee production systems in the Brazilian Cerrado.

Crop system	Dep.	pH	Al^{3+}	(H+Al)	Ca^{2+} + Mg^{2+}	K^{+}	Effective CEC	CEC (pH 7.0)	SB	P	m
	m	H_2O	....			mmol$_c$ dm^{-3}			....	mg dm^{-3}	%
Conv.	0-0.05	5.3 c	4.5 a	80.5 a	18.5 c	5.9 b	28.9 c	104.8 b	24.4 c	18.0 b	15.6 a
Org.		6.4 a	0.0 c	47.9 c	42.0 b	6.6 a	48.6 a	96.4 c	48.6 b	15.0 c	0.0 c
Agrof.		6.0 b	0.5 b	59.0 b	50.5 a	3.5 c	54.5 b	113.0 a	54.0 a	22.9 a	0.9 b
Conv.	0.05-0.10	5.3 c	4.0 a	78.4 a	18.8 c	5.6 a	28.3 c	102.7 a	24.3 c	17.6 a	14.1 a
Org.		6.2 a	0.0 c	48.3 c	40.0 a	2.3 c	42.3 a	90.5 b	42.3 a	7.7 c	0.0 c
Agrof.		5.7 b	1.0 b	65.6 b	33.3 b	3.4 b	37.7 b	102.2 a	36.7 b	12.0 b	2.6 b
Conv.	0.10-0.20	5.4 b	4.0 a	76.3 a	17.3 b	4.4 a	25.7 a	98.0 a	21.7 b	9.4 a	15.6 b
Org.		6.0 a	0.5 b	49.1 c	25.0 a	1.9 b	27.4 a	76.0 c	26.9 a	5.7 b	1.8 c
Agrof.		5.5 b	4.3 a	68.1 b	13.5 c	1.6 c	19.8 b	83.1 b	15.1 c	2.6 c	23.0 a

Sum of bases (SB) = $Ca^{2+}+Mg^{2+}+K^{+}$; Effective cation exchange capacity = SB+Al^{3+}; Cation exchange capacity at pH 7.0 ($CEC_{pH7.0}$) = SB+(H+Al^{3+}); Aluminum saturation (m) = 100xAl^{3+}/t. For each layer, averages followed by same letter in column are not different (Tukey test, $p < 0.05$).

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