Revista Brasileira de Ciência do Solo

Division - Soil Processes and Properties | Commission – Soil Chemistry

Characterization of Organic Matter under Different Pedoenvironments in the Viruá National Park, in Northern Amazon

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ABSTRACT: Soil organic matter (SOM) fractions result from a variety of environmental processes, which affect incorporation and production rates, decomposition, alteration, and/or mineralization of organic matter. The aim of this study was to characterize SOM under the environments of rain forest, wooded *campinarana* (grasslands), arboreal-shrubby *campinarana*, grassy-woody *campinarana*, and pioneer plants of the Viruá National Park, in the north of the Brazilian Amazon. After chemical and physical characterization and soil classification, total organic carbon (TOC), total N, microbial activity, organic C from fulvic acid fractions (FA), humic acid (HA), and humin (Hu) were determined at two depths (0.00-0.15 and 0.15-0.30 m). The TOC was lower in the grassy-woody *campinarana*, arboreal-shrubby *campinarana*, and pioneer formation areas than in the rain forest. Higher values of microbial activity were related to forest ecosystems in soils without physical or water restrictions and with better fertility compared to the other areas. The Hu predominated in all vegetation types studied, especially in the surface layer, because of the more soluble nature of HA and FA; and the higher values of HA/FA ratios in wooded campinaranas indicate that these environments contribute to higher losses of humic substances through fulvic acid forms, due to better drainage conditions.

Keywords: soil organic carbon, humic substances, *campinarana*, Quartzipsamment, Spodosol.

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Received: August 1, 2014

Approved: October 15, 2015

How to cite: Vale Júnior JF, Nicodem S, Melo VF, Uchôa SCP, Cruz DLS. Characterization of Organic Matter under Different Pedoenvironments in the Viruá National Park, in Northern Amazon. Rev Bras Cienc Solo. 2016;v40:e0140480.

INTRODUCTION

The Viruá National Park is situated in the far north of Brazil, in the state of Roraima, with several vegetation physiognomies and complex ecosystems that are specific to the Amazon region, especially the *campinarana*, characterized by open and scleromorphic shrubby vegetation (3-4 m), low species diversity, and high endemism (Barbosa and Ferreira, 2004). The phytophysiognomical gradations of wooded *campinaranas* are associated with different levels of soil hydromorphism. With increasing soil hydromorphism, the wooded *campinarana* is replaced by arboreal and shrubby *campinaranas*, then grassy-woody *campinarana*, and, finally, completely herbaceous vegetation.

Hydromorphic soils predominate in the Viruá National Park, largely composed of Spodosol and Quartzipsamment. The Spodosol are predominant in all types of *campinaranas* (from wooded to grassy-woody). In Quartzipsamment, the predominant vegetation is open and of small size. There are also inselbergs and forest and mountain landscapes. In contrast to the *campinarana* soils, some of the Oxisol, Inceptisol, and Plinthic Acrudox soils under forest areas are more clayey and were formed from acidic rocks and gneiss (Mendonça et al., 2013).

The Viruá National Park soils are generally characterized as acidic and dystrophic, with kaolinite in the clay fraction (Mendonça et al., 2013). Soil organic matter (SOM) is the nutrient reserve responsible for maintaining vegetation because it increases nutrient availability, ion retention, and soil aggregation (Luizão and Luizão, 1997). The decomposition of plant litter and the formation and mineralization of SOM are affected by climate, soil properties (pH, moisture, exchangeable bases), root activity, microorganisms, soil biota, and agricultural management (Canellas and Façanha, 2004; Gama-Rodrigues and Gama-Rodrigues, 2008).

Soil microbial activity is directly linked to the microbial biomass, which, in turn, depends on SOM availability, aeration, moisture, temperature, structure, texture, nutrient compounds, pH, and the presence of parasitic or antagonistic microorganisms (Mendes et al., 2015). The low nutrient availability and high Al saturation of soils in the Amazon environment are responsible for the low values of CO_2-C from microbial activity; the results of this activity are positively correlated with organic C levels (Vale Júnior et al., 2011).

The different fractions of humified organic C of the soil indicate the quality of SOM in this environment. Conditions of intense SOM oxidation favor generation of fulvic acid in place of humic acids (Moreira and Siqueira, 2002). Among these environmental conditions, soil aeration and temperature stand out. The SOM characterization in this environment is important for increasing knowledge regarding pedological relationships with phytophysiognomies, defining conservation practices and guiding the conservation management plan of the park.

Studies of several geoenvironments in the Viruá National Park indicated that in the sandy complexes of campinaranas and associated areas, like Spodosol areas, the C stock was 9,450.9 Gg C, considered one of the highest C stocks in Amazon soils (Mendonça et al., 2013). In this environment, microbial activity is restricted because of the lack of dissolved oxygen in soils (caused by periodic saturation), nutrient deficiency, slow SOM decomposition, and the presence of recalcitrant plant matter. Due to these characteristics, vast areas of the lower Branco River and the middle Negro River have been called the “Northern Pantanal” (Santos et al., 1993; Vale et al. 2014). Thus, knowledge of the physical and chemical characteristics of these environments can provide a benchmark for comparisons with future scenarios. In this context, the aim of this study was to characterize the SOM in different phytophysiognomies of the Viruá National Park, analyzing TOC, total N, microbial activity, and the organic C of humic fractions.

MATERIALS AND METHODS

Access and localization

The Viruá National Park is located in the municipality of Caracaraí, state of Roraima, Brazil, and has an area of 227,011 ha (Figure 1), between the parallels 00° 58′ 29″ and 01° 42′ 25″ N and the meridians 61° 00′ 14″ and 61° 15′ 20″ W.

Characterization of the area under study

According to the Köppen climate classification system, the southern region of the park is of Amw climate type (monsoon rain), while the northeast region is of Aw climate type (wet summer and dry winter). The 30-year rainfall records reveal variation from 1,300 to 2,350 mm per year, with an annual average of 1,794 mm (ANA, 2009).

The average altitude is 46 m, and the relief is generally flat to slightly rolling, with predominance of sandy hydromorphic soils developed from reworked Pre-Cambrian materials with Plio-Pleitocene sediment known as the Içá formation and Holocenic Aeolian covers (Brasil, 1975). This geological unit largely comprises a deep sandy mantle, formed by in situ pedogenesis of Cenozoic sediments or igneous and metamorphic rocks, as shown in studies of soils from the state of Amazonas (Bravard and Righi, 1990; Mendonça et al., 2013). The high rainfall contributes to soil podzolization and arenization processes (Schaefer et al., 2008).

The main groups of vegetation types that occur in this area of study are rain forest, *campinaranas*, and pioneer formations (Figure 2). The rain forest is subdivided into dense submontane rain forests, which occur on relatively shallow soils with rocky outcrops that cover higher sections of the hills known as "Serra do Preto" and "Serra da Perdida"; dense rain forests of lowlands in areas not subject to flooding, below 100 m altitude; and alluvial dense rainforests, found in alluvial terraces and river banks.

The *campinarana*s are a typical vegetation formation of the Guyanese Shield, which is affected by the Negro, Orinoco, and Branco River basins, generally occupying tabular

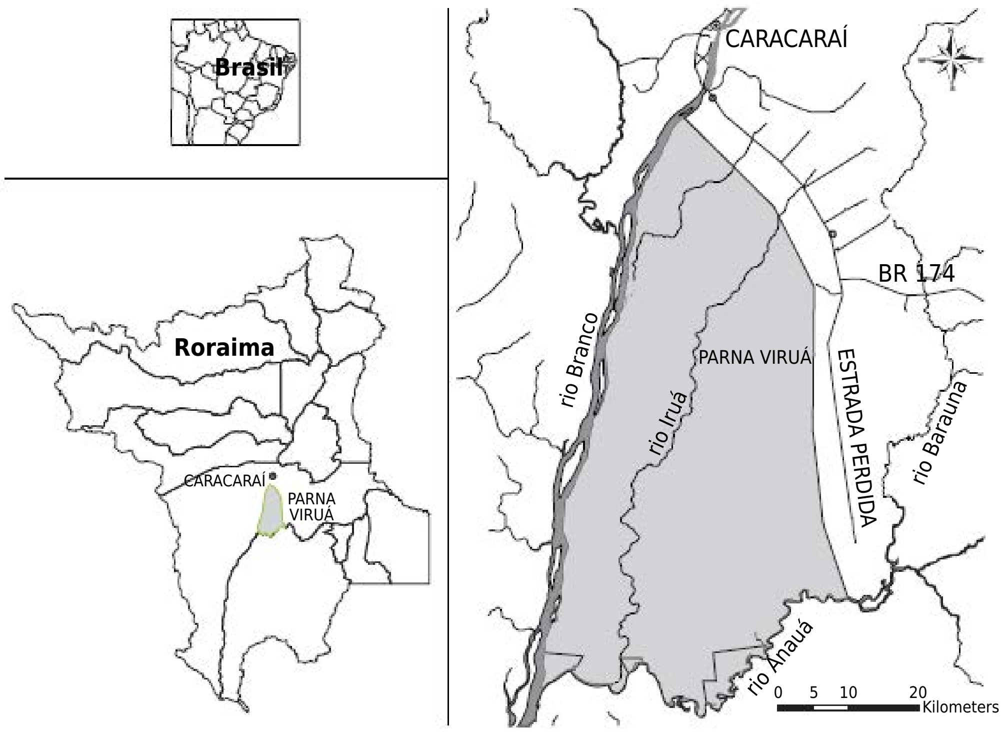

Figure 1. Localization of Viruá National Park in the state of Roraima, Brazil.

sandy areas that are highly leached. Besides the tabular areas, there are *campinaranas* lying in broad closed depressions on Aquod Spodosol soil. The *campinaranas* are classified in three formation groups, namely wooded *campinarana*, arboreal-shrubby *campinarana*, and grassy-woody *campinarana*.

These types likely correspond to successive stages of vegetation cover strongly controlled by edaphic factors. The wooded *campinarana* occurs on sandy tabular pediplains, with the presence of small diameter trees, 15 m height and a smaller crown than trees in the rain forest, which have a relatively continuous canopy. The arboreal-shrubby *campinarana* predominates on hydromorphic soils, with small-sized and spaced vegetation. The grassy-woody *campinarana* is a type of vegetation that covers the waterlogged plains of lowlands affected by (upwelling) groundwater (Veloso, 1991; Gribel et al., 2008). Pioneer formations have a grassy phytophysiognomy with predominance of the Cyperaceae family and palms, such as buritis (*Mauritia flexuosa*).

Field work

Seven soil profiles, representative of different vegetation covers, were opened for soil classification. They were distributed in a mosaic form that covered all the soil-vegetation relationships, described as two wooded *campinaranas* (FC1 and FC2), arboreal-shrubby *campinaranas* (ASC), grassy-woody *campinaranas* (GWC), pioneer formation (PF), and two rain forests (RF1 and RF2) located in the residual relief (hill) of the park. The soil horizon description and sampling for soil classification were performed according to Santos et al. (2013b). All the soil profiles were classified according to the Brazilian Soil Classification System (Santos et al., 2013a) up to the fourth level, after which the Soil Taxonomy Classification was applied (Soil Survey Staff, 2014).

Chemical and physical characterization of soil profiles

Soil pH in water, P, K, Ca, Mg, Al, and H+Al were determined according to Donagema et al. (2011). The sum of bases (SB), total and effective cation exchange capacity (T and t, respectively), base saturation (V), and Al saturation (m) were calculated from the results. Particle size analysis was determined with the pipette method, with soil dispersion being promoted by shaking in an alkaline medium (Donagema et al., 2011).

Pedoenvironment sampling

Soil samples were collected from each profile in a 7 m radius, at three points and two depths (0.00-0.15 and 0.15-0.30 m), each point corresponding to one replication. Soil sampling was performed to evaluate TOC, total N, CO_2 evolution, and fractionation of organic matter.

Soil TOC was determined according to Yeomans and Bremner (1988) through wet oxidation of organic matter with 0.167 mol L^{-1} $K_2Cr_2O_7$ in sulfuric medium and external heating.

For evaluation of CO_2 evolution in the laboratory, 15 g of 4 mm aggregates were weighed and placed in hermetically sealed glass jars of 0.5 dm^3, and soil moisture was adjusted to 65 % of field capacity (Mendonça and Matos, 2005). Each jar received a vial of 30 mL of 0.5 mol L^{-1} NaOH solution to capture CO_2, and a vial of 30 mL of H_2O to maintain constant moisture. The duplicated samples were kept at constant temperature (25 °C) by refrigeration. The CO_2 assessment was performed at the following intervals: 2, 4, 7, 11, 16, 22, 29, and 36 days. After the containers were opened, the vials containing NaOH were removed and replaced by another vial until the end of the period, care being taken to leave each container open for 15 min for air exchange. After each interval, other vial containing 30 mL of 0.5 mol L^{-1} NaOH was inserted for a new incubation period. The resulting CO_2 was measured in 10 mL NaOH solution (previously incubated with the soil), with the addition of 10 mL of 0.05 mol L^{-1} $BaCl_2$ solution plus phenolphthalein indicator (1 %), titrated with 0.25 mol L^{-1} HCl solution (duplicated).

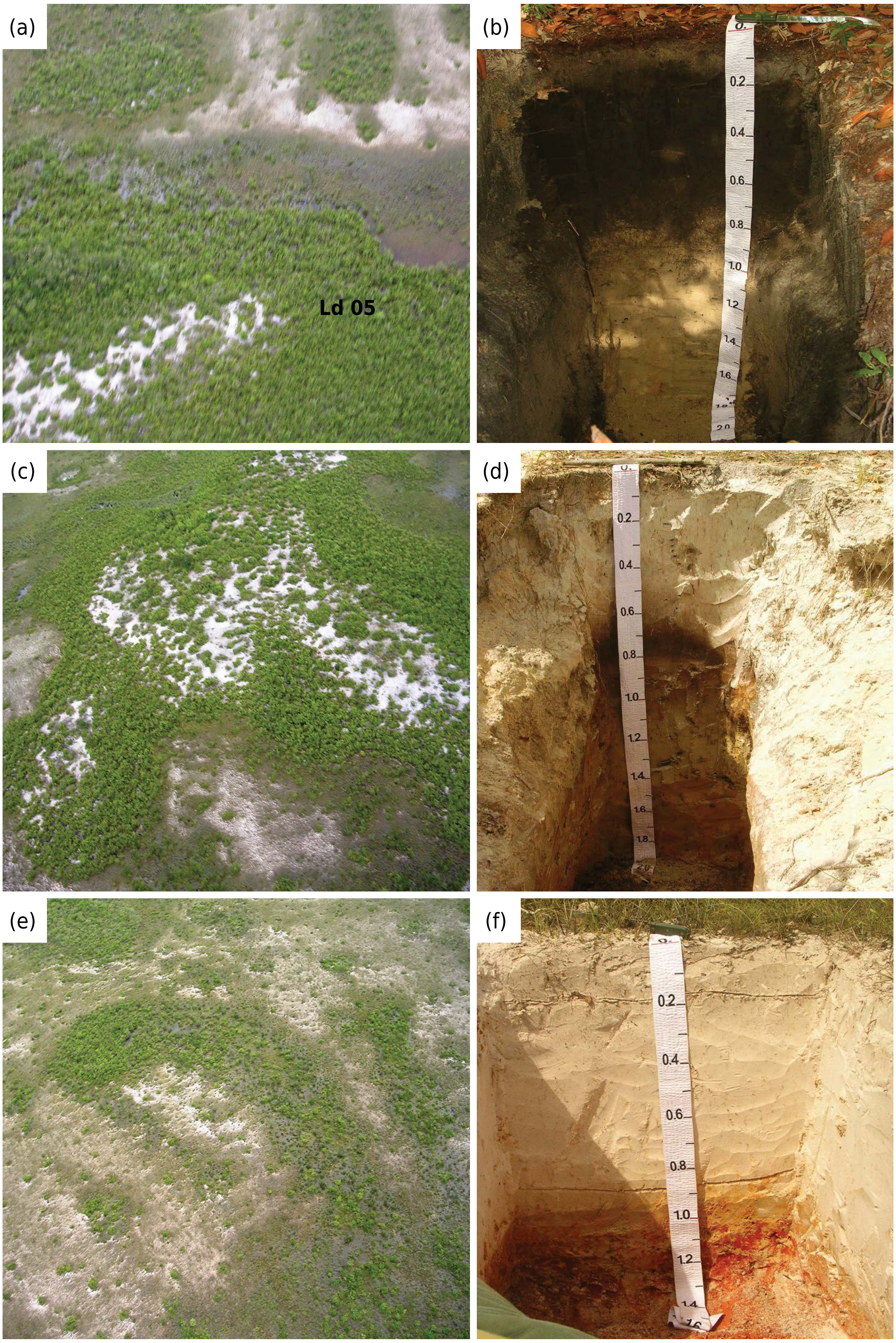

Figure 2. Pedoenvironments studied in the Viruá National Park. Dense rain forest (a); soil profile under dense rain forest – RF1 (b); wooded *campinarana* – FC1 e FC2 (c); soil profile under wooded *campinarana*– ASC (d); grassy-woody *campinarana* – GWC (e); and soil profile under grassy-woody *campinarana* (f). Photos: José Frutuoso do Vale Júnior.

The fractionation of humic substances was performed in triplicate through the differential solubility technique, using the concepts of humic fractions established by the International Society of Humic Substances and developed by Swift (1996). For HA and FA extraction, a 0.1 mol L^{-1} NaOH solution was used at the proportion of 1:10 p/v of soil/extractor with 1.0 g of soil and 24 h contact. Separation between the alkaline extract and residue was made by centrifugation at 3,858 *g* for 30 min. The residue was washed three times with the same extraction stock solution. The residue was collected and reserved for Hu determination. The pH of the alkaline extract was adjusted to 1.0±0.1 with an aqueous solution of 20 % H_2SO_4 and decanted for 18 h. The HA precipitate was separated from the soluble fraction of FA by centrifugation, and both volumes were measured in 50 mL of distilled water.

Quantitative determination of organic C of the FA and HA fractions was carried out with 5.0 mL of the extract, 1.0 mL of 0.042 mol L^{-1} $K_2Cr_2O_7$, and 5.0 mL of concentrated H_2SO_4 in a digester block at 150 °C (30 min) and titration with 0.25 mol L^{-1} $(NH_4)_2Fe(SO_4)_2$. Organic C was determined in the residue of the Hu fraction, after complete drying of the material at 65 °C and addition of 5.0 mL of 0.1667 mol L^{-1} $K_2Cr_2O_7$ and 10.0 mL of concentrated H_2SO_4 in a digester block at 150 °C and titration with 0.25 mol L^{-1} $(NH_4)_2Fe(SO_4)_2$ (Yeomans and Bremner, 1988).

The relationships between TOC and total N (C/N), HA and FA (HA/FA), and the concentrations of C in the humic fractions and their percentage in relation to TOC were calculated.

RESULTS AND DISCUSSION

Soil characterization

Soil particle analysis revealed the sandy nature of the soil under non-forest areas (FC1, FC2, ASC, GWC, and PF), and silt was the second most abundant fraction (Table 1). Soil classification was based on the sand fraction values: *Neossolo Quartzarênico* and *Espodossolo Ferrihumilúvico* (Santos et al., 2013a), corresponding to Aquic Quartzipsamment and Typic Endoaquod (Soil Survey Staff, 2014), respectively. The soils under forest areas (RF1 and RF2) showed different values compared to the soil pattern found in the park, and were characterized as clayey loam and clayey. The RF1 soil was classified as *Latossolo Vermelho Distrófico*, corresponding to Rhodic Acrudox, and the RF2 soil was classified as *Argissolo Vermelho-Amarelo Distrófico*, corresponding to Typic Hapludult (Table 1).

Chemically, the soils studied revealed an oligotrophic nature; soil pH, SB, and V had very low values. The SB (0 to 0.3 $cmol_c$ dm^{-3}) and available P (0.3 and 4.6 mg dm^{-3}) directly affected biomass production and, consequently, SOM values, indicating the nutritional dependence of these phytophysiognomies on organic residue cycling. The GWC vegetation on Quartzipsamment possibly has more dependence on SOM cycling because of lower levels of SB, available P, and high Al saturation.

In addition to the dominance of sandy soils in the environments studied, these soils exhibited hydromorphism, being waterlogged part of the year and with upwelling groundwater in the rainy season (April to September). The hydromorphic condition creates an anaerobic soil environment that can directly influence SOM and microbial dynamics. The shallow groundwater in those areas is associated with a more conserving environment and organic matter accumulation (Mendonça et al., 2013).

Total organic C

Soil TOC levels ranged from 0.14±0.058 to 3.44±1.164 dag kg^{-1} in the 0.00-0.15 m layer, especially in the GWC and FC2 areas (Table 2). In these sandy environments, the formation of a C concentration gradient in the soil was observed, with the lowest values in GWC and PF, while the highest values were observed in FC1 and FC2. In the 0.15-0.30 m layer, the TOC levels ranged from 0.13±0.053 to 2.53±0.939 dag kg^{-1}, values similar to the surface layers, exhibiting a higher TOC concentration gradient in open vegetation (GWC) compared to wooded vegetation (FC1).

The TOC values observed in the soils under FC1 and FC2 are above the average of the values observed in Amazon soils. Temperature and rainfall conditions favor high SOM decomposition rates in tropical regions (Canellas and Façanha, 2004). However, lower values for most sandy soils may be related to the lower biomass production of native plant cover, and the sandy soil accelerates SOM decomposition (Zech et al., 1997). The soils in our study exhibited similar results to studies performed in the Amazon region (Mendonça et al., 2013), while the RF1 and RF2 values were similar to those observed by Luizão et al. (2004).

Total N and C/N ratio

The total N content in the 0.00-0.15 m layer ranged from 0.07±0.015 to 0.43±0.024 g kg^{-1}, and the pedoenvironment was separated into three groups: GWC with lower total N content; PF and ASC with intermediate values; and FC1, FC2, RF1, and RF2 with higher values. In the 0.15-0.30 m layer, the total N ranged from 0.09±0.064 to 0.38±0.070 g kg^{-1},

Table 1. Physical and chemical properties of representative soil profiles under the pedoenvironments studied in the Viruá National Park, Roraima, Brazil

Hor (Depth)	pH		P	K	Ca^{2+}	Mg^{2+}	Al^{3+}	H+Al	SB	t	T	V	m	TOC	San	Silt	Cla	Sil/Cla
	H_2O	KCl																
m			mg dm^{-3}		cmol$_c$ dm^{-3}							%		g kg^{-1}				
FC1 – Aquic Quartzipsamment under wooded *campinarana*																		
A (0.0-0.10)	4.6	3.2	3.7	21	-[1]	0.01	2.02	10.7	0.06	2.08	10.76	0.6	97.1	24.9	770	170	60	2.83
C1 (0.10-0.20)	5.0	3.7	2.5	9	-	-	2.31	12.1	0.02	2.33	12.12	0.2	99.1	23.4	720	210	70	3.00
C2 (0.20-0.85)	5.3	4.2	1.9	2	-	-	1.16	8.4	0.01	1.17	8.41	0.1	99.1	18.9	710	210	80	2.63
C3 (0.85-1.80)	5.4	4.6	0.8	1	-	-	0.00	1.4	0.00	0.00	1.40	0.0	0.0	2.3	700	220	80	2.75
ASC – Typic Endoaquod under arboreal-shrubby *campinarana*																		
A (0.0-0.10)	4.4	3.0	1.8	16	-	0.01	1.25	8.3	0.05	1.30	8.35	0.6	96.2	23.4	720	250	30	8.33
E (0.10-0.60)	5.2	4.0	0.8	1	-	-	0.00	0.5	0.00	0.00	0.50	0.0	0.0	2.3	840	120	40	3.00
Bh (0.60-0.80)	4.5	3.9	3.2	2	-	-	1.45	8.1	0.01	1.46	8.11	0.1	99.3	8.9	770	190	40	4.75
B (0.80-1.00)	4.9	4.2	0.9	1	-	-	0.77	8.4	0.00	0.77	8.40	0.0	100	12.9	710	180	110	1.64
C1 (1.00-1.40)	4.8	4.3	0.5	1	-	-	0.48	1.4	0.00	0.48	1.40	0.0	100	1.5	670	190	140	1.36
C2 (1.40-2.00)	5.0	4.3	0.3	1	-	-	0.39	1.3	0.00	0.39	1.30	0.0	100	0.8	680	160	160	1.00
FC2 – Aquic Quartzipsamment under wooded *campinarana*																		
A (0.0-0.15)	4.2	3.1	3.0	5	-	-	2.41	11.4	0.01	2.42	11.41	0.1	99.6	18.2	780	180	40	4.50
C1 (0.15-0.85)	4.9	4.3	1.4	3	-	-	0.67	6.0	0.01	0.68	6.01	0.2	98.5	10.6	760	180	60	3.00
C2 (0.85-1.50+)	5.0	4.5	1.9	0	-	-	0.19	1.6	0.00	0.19	1.60	0.0	100	3.6	670	240	90	2.67
GWC – Aquic Quartzipsamment under grassy-woody *campinarana*																		
A (0.0-0.18)	5.0	3.7	0.8	1	-	-	0.10	0.8	0.00	0.10	0.80	0.0	100	3.0	770	220	10	22.00
C1 (0.18-0.84)	5.3	4.5	0.6	1	-	-	-	0.5	0.00	0.00	0.50	0.0	0.0	0.8	920	50	30	1.67
C2 (0.84-1.10)	5.4	4.4	0.6	1	-	-	0.19	0.5	0.00	0.19	0.50	0.0	100	0.8	860	90	50	1.80
C3 (1.10-1.50+)	5.2	4.5	0.5	0	-	-	0.10	0.5	0.00	0.10	0.50	0.0	100	0.8	840	140	20	7.00
PF – Aquic Quartzipsamment under pioneer formation																		
A (0.0-0.17)	4.7	3.5	1.2	8	-	-	0.29	3.3	0.02	0.31	3.32	0.6	93.5	12.9	550	420	30	14.00
C1 (0.17-0.90)	5.6	4.6	0.9	2	-	-	-	0.5	0.01	0.01	0.51	2.0	-	0.8	710	280	10	28.00
C2 (0.90-1.20+)	5.7	4.6	4.6	-	-	-	-	0.3	0.00	0.00	0.30	-	-	0.8	750	240	10	24.00
RF1 – Rhodic Acrudox under dense rain forest																		
A (0.0-0.18)	4.2	3.8	2.0	38	0.05	0.15	1.16	7.2	0.30	1.46	7.50	4.0	79.5	26.5	400	170	430	0.40
AB (0.18-0.40)	4.7	4.1	1.1	9	-	-	0.87	4.5	0.02	0.89	4.52	0.4	97.8	12.8	310	150	540	0.28
Bw_1 (0.40-0.50)	5.5	4.3	0.7	2	-	-	0.19	3.2	0.01	0.20	3.21	0.3	95.0	9.9	250	140	610	0.23
Bw_2 (0.50-1.20)	6.5	4.8	0.6	0	-	-	-	1.7	0.00	0.00	1.70	0.0	0.0	3.8	250	120	630	0.19
RF2 – Typic Hapludult under dense rain forest																		
A (0.0-0.10)	4.1	3.8	2.9	18	-	-	1.64	8.9	0.05	1.69	8.95	0.6	97.0	23.4	430	280	290	0.97
AB (0.10-0.30)	4.6	4.0	1.7	8	-	-	0.96	4.5	0.02	0.98	4.52	0.4	98.0	10.6	390	290	320	0.91
BA (0.30-0.60)	4.6	4.1	0.7	2	-	-	0.87	2.7	0.01	0.88	2.71	0.4	98.9	5.3	300	280	420	0.67
Bw_1 (0.60-1.20)	4.7	4.1	0.7	1	-	-	0.58	2.1	0.00	0.58	2.10	0.0	100	3.8	360	230	410	0.56
Bw_2(1.20-2.00)	5.0	4.2	3.0	1	-	-	0.58	1.4	0.00	0.58	1.40	0.0	100	1.5	450	220	330	0.67

[1] not detected by the method. SB: sum of bases; V: base saturation; m: aluminum saturation; P: available P, extractor Mehlich-1; t: effective cation exchange capacity; T: cation exchange capacity at pH 7.0; San: sand; Sil: silt; Cla: clay; TOC: total organic carbon (Yeomans and Bremner method).

the lowest values being observed for GWC and ASC and the highest for RF2 and FC1. The higher total N can be explained by the high biomass production from arboreal vegetation and the diversity of species, including the Leguminosae family, which increase the incorporation of N-rich compounds in the soil. In soils under *campinarana*, Santos and Ribeiro (1975) observed that the N content was not a factor limiting development of natural vegetation; in this case, the leguminosae species appear to make up for any N deficiency through N-fixation.

The total N values are below those observed by Luizão et al. (2004) for soils under rain forest and those observed by Mafra et al. (2007) for wooded *campinaranas* in Spodosols. However, Moraes et al. (1995) found lower values of total N in Quartzipsamment than in Spodosols, while Oxisols had intermediate values. In this current study, the highest values were obtained in Oxisols under RF1 and RF2.

The C/N ratio ranges from 21.47±9.26 to 107.77±15.12 (by mass), indicating large N demand by soil microorganisms. The C/N ratio was lower for open vegetation (GWC) and higher for wooded environments. The Oxisols under FC1 and FC2 had a higher C/N ratio, contrary to other studies performed in the Amazon Region in which Spodosols had higher C/N ratios (Mafra et al., 2007). The higher C/N ratios observed in those environments were due to accumulation of material with generally high levels of lignin and phenolic compounds, anaerobic conditions for part of the year, Al toxicity, and the presence of secondary compounds derived from the plants used to prevent herbivory (Moreira and Siqueira, 2002). In the wooded environments, drainage is improved and the C/N ratio is lower.

Microbial respiration

Average accumulated microbial respiration at the surface layer was higher for FC1, RF1, and RF2 when compared to the other environments. Meanwhile, in the 0.15-0.30 m layer, a higher value was observed for FC2, followed by RF2 (Table 3). Those results may be associated with better soil drainage, which favors the occurrence of an oxidant atmosphere, while the arboreal vegetation in these environments contributes to higher levels of SOM (Table 2). The average values of respiration were higher in the 0.00-0.15 m layer, except for FC2, where they were higher in the 0.15-0.30 m layer.

The higher values of CO_2 evolution in RF1, RF2, and ASC were due to accelerated, efficient cycling of organic matter in these environments, and possibly because of the greater diversity and size of the phytophysiognomies, associated with absence of hydromorphism. The higher release of CO_2 is due to biological activity, which is strongly evident in oxidant conditions (Follet and Schimel, 1989).

Table 2. Total organic carbon (TOC), total nitrogen, and C/N ratio in soils under different pedoenvironments at two soil depths, in the Viruá National Park, Roraima, Brazil

Pedoenvironment[1]	TOC	N	C/N	TOC	N	C/N
	0.00-0.15 m			0.15-0.30 m		
	g kg^{-1}			g kg^{-1}		
FC1	29.5± 11.8	39.0± 3.0	75.37±26.81	25.3±9.4	30±3.0	85.89±37.74
ASC	14.0± 4.5	17.0 ± 9.0	107.77±15.12	3.9±2.1	9.0±6.0	123.65±16.85
FC2	34.4± 11.6	39.0± 3.0	87.34±28.62	19.7±3.9	29±6.0	67.84±3.43
GWC	01.4± 0.6	7.0± 2.0	21.47±9.26	1.3±0.5	11.0±5.0	12.57±2.70
PF	4.8± 1.46	17.0± 1.5	26.48±9.55	6.6±1.6	23.0±4.0	30.16±11.54
RF1	14.7± 5.3	34± 1.0	42.86±15.12	17.0±1.8	38.0±7.0	46.01±11.23
RF2	18.9± 5.4	43±2.0	44.45±14.70	13.1±6.5	33.0±8.0	37.98±9.25

[1] FC1: Aquic Quartzipsamment under wooded *campinarana*; ASC: Typic Endoaquod under arboreal-shrubby campinarana; FC2: Aquic Quartzipsamment under wooded *campinarana*; GWC: Aquic Quartzipsamment under grassy-woody *campinarana*; PF: Aquic Quartzipsamment under pioneer formation; RF1: Rhodic Acrudox under dense rain forest; RF2: Typic Hapludult under dense rain forest.

Dynamic of humic substances

Humic acid was the dominant fraction in TOC in most of the soils studied (Table 4), especially in the Quartzipsamment under FC2 in the two soil layers. In the 0.15-0.30 m layer, there was reduction in HA and Hu in all pedoenvironments. In the soil from FC1, FC2, and GWC, the FA fraction showed accumulation in the 0.15-0.30 m layer. The GWC and PF had low values of FA and HA fractions. In ASC soil, the HA fraction was very low, corresponding to 3 % of the sum of the three fractions. The soils under RF1, RF2, FC1, and FC2 had higher values of Hu fractions (Table 4). The Hu proportion in the sum of fractions was higher in PF (85 %) and lower in FC1 (51 %), indicating the influence of Hu on the TOC values of those environments (Fontana et al., 2006). The association between Hu and soil mineral colloids promotes better resistance to the microbial mineralization process (Canellas et al., 2000).

Table 3. Accumulated values of microbial respiration of soils under different pedoenvironments and at two soil depths in the Viruá National Park, Roraima, Brazil

Pedoenvironment[1]	0.00-0.15 m	0.15-0.30 m
	mg kg^{-1} of CO_2-C on soil	
FC1	615.5 ± 30.1	399.8 ± 27.6
ASC	446.7 ± 10.2	372.6 ± 68.1
FC2	470.4 ± 20.9	648.6 ± 10.4
GWC	471.0 ±2.5	358.4 ± 15.5
PF	471.5 ± 50.9	301.9 ± 6.6
RF1	58.10 ± 15.6	399.4 ± 26.0
RF2	559.0 ± 62.3	487.5 ± 30.8

[1] FC1: Aquic Quartzipsamment under wooded *campinarana*; ASC: Typic Endoaquod under arboreal-shrubby campinarana; FC2: Aquic Quartzipsamment under wooded *campinarana*; GWC: Aquic Quartzipsamment under grassy-woody *campinarana*; PF: Aquic Quartzipsamment under pioneer formation; RF1: Rhodic Acrudox under dense rain forest; RF2: Typic Hapludult under dense rain forest.

Table 4. Carbon content of fulvic acid (FA), humic acid (HA), and humin (Hu), HA/FA ratio, and method efficiency in soils from the pedoenvironments studied at two soil depths in the Viruá National Park, Roraima, Brazil

Pedoenvironment[1]	FA[2]		HA[3]		Hu[4]		Sum[5]	HA/FA	ME[6]
	g kg^{-1}								
				0.00-0.15 m					
FC1	2.96±0.032	(10)[7]	11.78±0.047	(39)	15.55±0.135	(51)	30.29	3.98	1.03
ASC	2.47±0.021	(29)	0.12±0.011	(01)	5.81±0.082	(69)	8.39	0.05	0.60
FC2	2.35±0.024	(06)	0.17±0.102	(27)	25.66±0.001	(67)	3.818	4.32	1.11
GWC	0.58±0.036	(25)	0.07±0.001	(03)	1.66±0.017	(72)	2.31	0.11	1.66
PF	1.02±0.013	(13)	0.18±0.001	(02)	6.93±0.042	(85)	8.13	0.18	1.68
RF1	3.22±0.016	(18)	2.01±0.002	(11)	13.17±0.014	(72)	18.40	0.62	1.24
RF2	4.50±0.016	(20)	0.220±0.001	(10)	16.33±0.206	(71)	23.03	0.49	0.91
				0.15-0.30 m					
FC1	3.79±0.040	(18)	7.48±0.053	(35)	9.85±0.008	(47)	21.121	1.97	0.83
ASC	0.54±0.007	(59)	0.06±0.001	(07)	0.31±0.008	(34)	0.909	0.11	0.23
FC2	2.64±0.021	(12)	6.22±0.005	(28)	13.54±0.162	(60)	22.402	2.36	1.14
GWC	0.063±0.051	(36)	0.03±0.002	(02)	1.09±0.007	(62)	1.749	0.05	1.32
PF	0.78±0.006	(16)	0.08±0.001	(02)	3.99±0.008	(82)	4.853	0.11	0.74
RF1	2.25±0.016	(15)	1.41±0.015	(10)	10.97±0.101	(75)	14.620	0.63	0.75
RF2	2.20±0.048	(17)	1.06±0.012	(08)	10.00±0.091	(75)	13.260	0.48	0.78

[1] FC1: Aquic Quartzipsamment under wooded *campinarana*; ASC: Typic Endoaquod under arboreal-shrubby campinarana; FC2: Aquic Quartzipsamment under wooded *campinarana*; GWC: Aquic Quartzipsamment under grassy-woody *campinarana*; PF: Aquic Quartzipsamment under pioneer formation; RF1: Rhodic Acrudox under dense rain forest; RF2: Typic Hapludult under dense rain forest. [2] FA: fulvic acid; [3] HA: humic acid; [4] Hu: humin; [5] Sum: FA + HA + Hu; [6] Method efficiency: ME = (FA + HA + Hu) / TOC; [7] Values between parentheses correspond to the proportion of the fraction as percentage.

Recalcitrant material called humins are biological molecules derived from plants and soil microorganisms, and form a large part of the hydrophobic portions, with high resistance to degradation (Song et al., 2011). The absolute predominance of Hu in TOC has been reported in other studies on humic substances (Ebeling et al., 2011; Fontana et al., 2014). This high proportion of Hu in TOC fractions, especially in the 0.00-0.15 m layer, is related to the soluble nature of organic matter (FA and HA), which percolates the soil profile, while the Hu, because of its low solubility, is concentrated in surface layers (Benites et al., 2001).

The Hu fraction may have been overestimated by the method, which quantifies non-humic substances, including plant fragments that are insoluble in alkaline medium. It is also possible that association with clay (Simpson et al., 2007) can preserve some highly labile compounds, especially proteins and peptides. The significant presence of soil and plant termites in these environments causes predominance of Hu (Pinheiro et al., 2013).

The HA and FA ratio values (HA/FA), indicators of solubility and hydrophobicity, are greater than 1.0 in soils under wooded *campinaranas* (FC1 and FC2), confirming the presence of more stable organic matter (Fontana et al., 2006). The HA/FA ratio values above 1.0 can be explained by soil and climatic conditions in which polymerization and condensation processes are favorable, as in Histosols (Ebeling et al., 2011), for which Valladares et al. (2007) observed values of 14. In Oxisols and Ultisols, Ebeling et al. (2011) found values between 1.0 and 3.46, similar to the values found in this study.

In a toposequence, relief has an influence on water dynamics, which in turn determines the content of organic matter fractions, especially free fluvic acid, which are transported by lateral and vertical water flux in the soil (Canellas et al., 2000). In the case of the FC1 and FC2 formation, fluctuation of the water table explains humic acid losses, which, in combination with the sandy soils and intense rainfall, may account for the removal of soluble organic materials. In accordance with high fulvic acid losses, the value of humic acid in wooded environments is increased in relative terms. Humin predominates in all the soils studied, especially in the surface, whereas the soluble nature of organic acids, particularly fulvic acid, enable their loss through the soil profile, accumulating humic acid on depth and contributing to formation of spodic horizon from 2 to 3 m deep.

CONCLUSIONS

Soils under open phytophysiognomies with lower biomass, such as grassy-woody *campinaran*a, arboreal-shrubby *campinarana*, and pioneer vegetation, had lower TOC values than soils under dense rain forest.

Increased carbon mineralization was associated with soil with better chemical conditions and higher TOC content.

Humin predominates in all the soils studied, especially in the surface layer, as a result of the high solubility of fulvic acid and humic acid.

Higher HA/FA ratios in wooded *campinaranas* indicate that these environments contribute to higher losses of humic substances through fulvic acids forms, due to better drainage conditions.

ACKNOWLEDGMENTS

The authors would like to thank Program of Graduate Studies in Natural Resources – PRONAT – UFRR for their support and scholarship granted to the second author during his Master's degree.

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