CHARACTERIZATION OF HEADWATERS PEATS OF THE RIO ARAÇUAÍ, MINAS GERAIS STATE, BRAZIL

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ABSTRACT

Peatlands are soil environments that accumulate water and organic carbon and function as records of paleo-environmental changes. The variability in the composition of organic matter is reflected in their morphological, physical, and chemical properties. The aim of this study was to characterize these properties in peatlands from the headwaters of the Rio Araçuaí (Araçuaí River) in different stages of preservation. Two cores from peatlands with different vegetation types (moist grassland and semideciduous seasonal forest) from the Rio Preto [Preto River] headwaters (conservation area) and the Córrego Cachoeira dos Borges [Cachoeira dos Borges stream] (disturbed area) were sampled. Both are tributaries of the Rio Araçuaí. Samples were taken from layers of 15 cm, and morphological, physical, and chemical analyses were performed. The ^{14}C age and $\delta^{13}C$ values were determined in three samples from each core and the vertical growth and organic carbon accumulation rates were estimated. Dendrograms were constructed for each peatland by hierarchical clustering of similar layers with data from 34 parameters. The headwater peatlands of the Rio Araçuaí have a predominance of organic material in an advanced stage of decomposition and their soils are classified as Typic Haplosaprists. The organic matter in the Histosols of the peatlands of the headwaters of the Rio Araçuaí shows marked differences with respect to its morphological, physical, and chemical composition, as it is influenced by the type of vegetation that colonizes

Received for publication on June 10, 2014 and approved on December 22, 2014.
DOI: 10.1590/01000683rbcs20140337

it. The peat from the headwaters of the Córrego Cachoeira dos Borges is in a more advanced stage of degradation than the peat from the Rio Preto, which highlights the urgent need for protection of these ecosystems/soil environments.

Keywords: Histosol, soil organic matter, carbon isotopes.

RESUMO: *CARACTERIZAÇÃO DE TURFEIRAS DAS CABECEIRAS DO RIO ARAÇUAÍ, MINAS GERAIS*

Turfeiras são pedoambientes acumuladores de água e carbono orgânico e funcionam como registros de mudanças paleoambientais. A variabilidade da constituição do material orgânico está refletida em seus atributos morfológicos, físicos e químicos. Este trabalho objetivou caracterizar morfológica, física e quimicamente turfeiras das cabeceiras do rio Araçuaí em diferentes estádios de conservação. Dois testemunhos de turfeiras de fitofisionomia diferentes (Campo Limpo Úmido e Floresta Estacional Semidecidual) da cabeceira do rio Preto (conservada) e do córrego Cachoeira dos Borges (antropizada), ambos afluentes do rio Araçuaí, foram amostrados em camadas de 15 cm, onde foram realizadas análises morfológicas, físicas e químicas. Em três amostras de cada testemunho, foram datados por ^{14}C, determinados os valores de $\delta^{13}C$ e estimadas as taxas de crescimento vertical e de acúmulo de carbono orgânico. Foram construídos dendrogramas para cada turfeira por meio de agrupamento hierárquico das camadas semelhantes para 34 parâmetros. As turfeiras das cabeceiras do rio Araçuaí apresentaram predominância de material orgânico em estágio avançado de decomposição e seus solos são classificados como Organossolos Háplicos sápricos típicos. A matéria orgânica dos Organossolos das turfeiras das cabeceiras do rio Araçuaí evidenciou marcante diferença em relação à sua composição morfológica, física e química, sendo influenciada pela fitofisionomia que a coloniza. A turfeira da cabeceira do córrego Cachoeira dos Borges demonstrou estádio de degradação mais avançado em relação à turfeira do rio Preto, o que evidencia a premente necessidade de proteção desses pedoambientes.

Palavras-chave: Organossolo, matéria orgânica do solo, isótopos de carbono.

INTRODUCTION

Peatlands are ecosystems consisting of Histosols whose genesis is the result of favorable environmental conditions for the accumulation of organic material (Silva et al., 2013a). Dead plants are deposited in superimposed layers, forming peatlands, with variations in their morphological, physical, and chemical properties according to the plant composition, degree of decomposition, and amount of organic matter (Garcia, 1996; Ebeling et al., 2011).

It is estimated that there are about 420 million hectares of peatlands in the world, or 3 % of the land surface (Gorham, 1991; Campos et al., 2012). In Brazil, peatlands occupy about 611,883 ha, or 0.07 % of the country (Valladares, 2003; Pereira et al., 2005; Valladares et al., 2008). About 1.6 trillion t of C are stored in the Earth's soils (Martinelli et al., 2009) of which approximately 455 billion t of C are contained in the peatlands, corresponding to 28 % of all C stored in soils (Gorham, 1991; Campos et al., 2010), which shows its importance in the global cycle of this element.

Despite small geographic representation in Brazil, peatlands have great environmental importance; in addition to being large C accumulators, they are typically found in headwaters, functioning as regulators of water dynamics (Silva, 2005a). These soil-environments store large volumes of water during the rainy season, freeing them gradually during dry periods (Ingram, 1983; Moore, 1997; Price and Schlotzhauer, 1999; Campos et al., 2012). Therefore, maintenance of peatlands is a key strategy for the continuity of some river basins.

In general, the composition of peatland organic matter is not well known and shows high variability, especially in stages of decomposition. Peatlands may have wide heterogeneity in their composition throughout their depth, which depends on the geological environment and climatic conditions during their formation (Shimada and Carvalho, 1980). Their chemical and elemental composition is linked to the stage of decomposition of organic matter (Embrapa, 2013). Therefore, from the physico-chemical and morphological characterization of this material, it is possible to understand changes in degradation of the organic material (Conceição et al., 1999). Furthermore, knowledge of the composition of this material may guide the most adequate management for these environments so as to minimize emissions of gases that cause the greenhouse effect, ensuring the preservation of watercourses and conservation of ecosystems.

In the Serra do Espinhaço Meridional – SdEM (Espinhaço Meridional Range), the formation of the geological basis that contained the mires occurred during the Mesozoic and Cenozoic Eras (Silva, 2005b; Horák et al., 2011). Silva et al. (2013b), mapped 14,288 ha of peatlands, distributed along the SdEM, with a stock of 6,120,167 t of organic matter (428 t ha^{-1}) and storage of 142,138,262 m^3 of water (approximately 10,000 m^3 ha^{-1}). These peatlands are colonized by vegetation known as moist grassland and semideciduous seasonal forest (Silva et al., 2013a) and are at various stages of preservation since they are located under full protection in conservation areas, as well as outside them, being used as pastures (Bispo, 2013). In addition to their influence on the carbon cycle, these peatlands are responsible for the continual flow of the Rio Araçuaí, the main tributary of the Jequitinhonha river, and these two watercourses are the only perennial rivers in the semiarid northeast part of the state of Minas Gerais, Brazil (Bispo, 2013).

Despite the environmental importance of peatlands, few studies on these environments have been conducted in tropical countries, particularly in Brazil. Hypothetically, their properties can be influenced both by the type of colonizing plants and by the stage of conservation. The aim of this study was to characterize the morphological, physical, and chemical headwater peatlands of the Rio Araçuaí colonized by two types of vegetation under different uses.

MATERIAL AND METHODS

Characterization of the study area

The Drainage Basin of the Rio Araçuaí (DBRA) is located between 16º 40' S and 18º 20' S latitude and 41º 50' W and 43º 25' W longitude in the northeast region of the State of Minas Gerais, Brazil, and drains an area of 16,273 km^2, covering 25 municipalities (IGAM, 2013). Ten of these municipalities use the Araçuaí river waters for human consumption. The headwaters of the tributaries of the upper course of this river, the Córrego Cachoeira dos Borges and the Rio Preto, are located in the municipalities of Felício dos Santos and São Gonçalo do Rio Preto, respectively, both inside the peatlands (Figure 1).

The Rio Preto is about 70 km long and comprises about 2.5 % of the area of the DBRA (Lanna, 2010). To preserve its springs/water sources, the Parque Estadual do Rio Preto (PERP) [Rio Preto State Park] was created, which includes this and other headwaters at altitudes from 1,400 to 1,600 m (Silva, 2004). The Córrego Cachoeira dos Borges, with an approximate length of 75 km, is outside the limits of the PERP. Its peatlands are used for grazing cattle and horses, and, furthermore, are subject to other anthropogenic interferences, such as periodic burning.

Climate in the region is classified as tropical mountainous, according to the Köppen classification, with a well-defined rainy season (average rainfall of

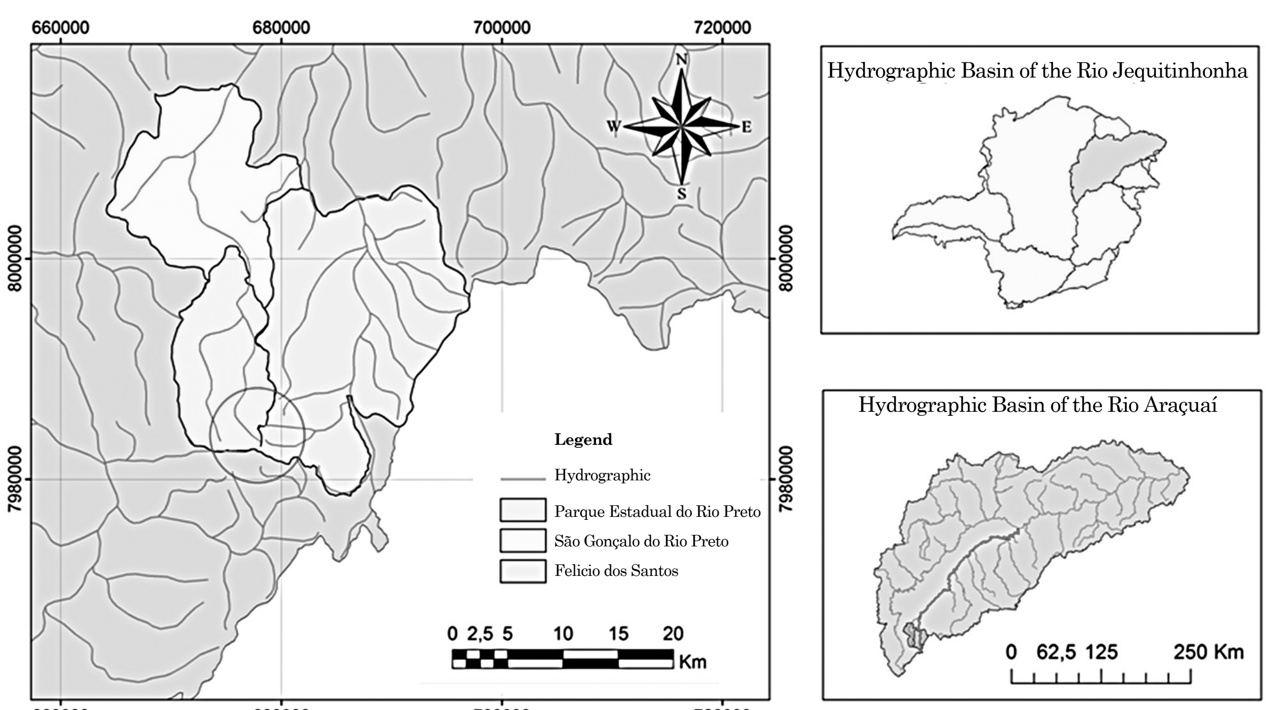

Figure 1. Collection area of the core samples in the tributaries of the headwaters of the Rio Araçuaí.

223 mm) and dry season (average quarterly rainfall of 8 mm), and an average annual temperature of 19 °C (Silva, 2004).

The regional lithology that serves as the basis for deposition of organic materials is predominantly quartzite, with some phyllite outcroppings. The Histosols that make up the peatlands are usually found in flooded depressions, and are colonized by wet grassland (WGL) and semi-deciduous forest (SDF) vegetation types, both from the Cerrado biome (Campos et al., 2010; Silva et al., 2013a).

Soil sampling and characterization

For this study, the headwater peatlands from the Rio Preto (conservation area) and Córrego Cachoeira dos Borges (anthropized area) (Figure 1) were sampled with the aid of a vibracore (Martin et al., 1995) and an aluminum tube (6 m length, 3" diameter, and 1/8" thickness). The aluminum tube was placed vertically and a vibrator hose was coupled to it, connected to a generator. The vibration causes the tube to lower into the peat until reaching the basal mineral substrate, without causing soil compaction. The tube was then sealed to create a vacuum and was removed from the peat with a pulley attached to a tripod. Two cores were collected per peatland in the two vegetation types (WGL and SDF), for a total of 4 cores, which were taken to the laboratory where they were opened lengthwise and sampled at about every 15 cm. Data collection, sampling, and transport of the material were carried out according to Horák (2010).

The cores were morphologically described according to Santos et al. (2005) and the Manual Técnico de Pedologia [Pedological Technical Manual] (IBGE, 2005). Characterization analyses of the organic material, performed according to Embrapa (2013), were the following: degree of peat decomposition according to the von Post scale (Stanek and Silc, 1977); unrubbed (URF) and rubbed fibers (RF); sodium pyrophosphate ($Na_2P_2O_7$) solubility; pH in $CaCl_2$; organic matter content (OM) and mineral material content (MM); gravimetric moisture (GM); minimum residue (MR); and bulk density of the organic matter (BDO).

The bulk density (BD) and the particle density (PD) were determined by methods described by Embrapa (1997). Total porosity (TP) was estimated from the values of BD and PD by the following expression: TP = (1 - BD / PD) × 100.

Chemical analyses performed according to Embrapa (1999) were: pH in water; Ca^{2+}, Mg^{2+}, and Al^{3+}, extracted with KCl (1 mol L^{-1}) and analyzed by atomic absorption spectrophotometry; K, P, Zn, Cu, Fe, and Mn extracted with Mehlich-1 (K content was analyzed by a flame photometer, P was analyzed by a colorimeter, and Zn, Cu, Fe, and Mn contents were analyzed by an atomic absorption spectrophotometer); and potential acidity (H+Al), extracted with calcium acetate (0.5 mol L^{-1} at pH 7) and determined by titration with 0.005 mol L^{-1} NaOH. From the above data, we calculated the sum of bases (SB), cation exchange capacity at pH 7 (CEC), effective cation exchange capacity (t), base saturation (V value), and aluminum saturation (m value).

Elemental concentrations were determined by dry combustion in an elemental analyzer LECO CHNS/O, TruSpec Micro model, where the gases emitted were quantified in an infrared detector. To quantify the C, H, and N contents, the samples were burned at 1,075 °C in a quartz tube. To quantify O content, an independent module was used at a temperature of 1,300 °C in a pyrolysis furnace (inert atmosphere). The amino acid cysteine (C = 29.99 %; H = 5.03 %; N = 11.66 %, and O = 26.63 %) was used as a reference to calibrate the equipment. From the results obtained, the following atomic ratios were calculated: H/C = [(%H/1) / (%C/12)]; C/N = [(%C/12) / (%N/14)]; and O/C = [(%O/16) / (%C/12)].

The ^{14}C was determined by liquid scintillation spectrometry of low background radiation. The results were corrected to natural isotopic fractionation (-25 ‰) and presented in ^{14}C standard age in years before the present (BP) em 1σ (68.3 % probability - Pessenda and Camargo, 1991). The ^{13}C was determined by mass spectrometry, according to the method recommended by Groning and Groot (2004). Soil samples from three layers of each core were used after being air dried, ground in a porcelain mortar, and sieved through a 0.053 mm mesh sieve.

The vertical growth rate (RVG) and carbon accumulation rate (RCA) from the peats were determined by the following equations:

$$RVG = (LS - US) / (II - IS) \quad \text{Eq. 1}$$

in which RVG is vertical growth rate (mm yr^{-1}), LS is lower sample depth (mm), US is upper sample depth (mm), II: radiocarbon age from lower sample (BP), IS: radiocarbon age from upper sample (BP).

$$RCA = (LS - US) \times BD \times TC \times 10 / (II - IS) \quad \text{Eq. 2}$$

in which RCA is carbon accumulation rate (g m^{-2} yr^{-1}), and TC is total carbon (dag kg^{-1}).

Statistical analysis

The layers sampled were classified into similar groups by hierarchical cluster analysis. Thus, data from 34 parameters (value and chroma – Munsell color system, von Post scale, URF, RF, GM, TP, BD, BDO, PD, OM, MM, MR, P, K, Ca, Mg, Al, H+Al, SB, t, CEC, m value, V value, Fe, Zn, Cu, Mn, C, N, H, and O) evaluated in each core were self-scaled (subtracted from the mean and divided by standard deviation) to minimize the interference of scale. The data were standardized in standard scores (z scale) and dendrograms were constructed using the Euclidean distance, with the unweighted pair group method with arithmetic mean (UPGMA) being used for grouping samples. Choice of the method was based on the assumption that the cophenetic matrix generated by that method had a higher Pearson correlation with the original distance compared to others. The higher the correlation, the better the representativeness of the analysis (Landeiro, 2011; Provete et al., 2011).

RESULTS AND DISCUSSION

Characterization of organic matter and soil physical properties

There is predominance of organic layers in all the core samples, but buildup of roots and mineral material (sand) was observed in surface and sub-surface layers (Table 1). In the Rio Preto peat core sample (CRP) under WGL, a "water layer" was observed from the 120 to 170 cm depth. Horák et al. (2011) also found a water layer in a peat core sample in the SdEM in the layer from 60 to 137 cm. Boatman and Tomlinson (1973), Barber (1981), and Foster and Fritz (1987) describe the formation of a water layer in peatlands as related to changes from drier to wetter climatic conditions.

Analysis of the core samples show predominance of organic materials in advanced stages of decomposition, classified according to the von Post scale as sapric - H10 to H8 (Table 1), and all samples were classified as Organossolos Háplicos sápricos típicos (Embrapa, 2013), corresponding to Typic Haplosaprists (Soil Survey Staff, 2010).

These materials have high rates of OM (até 90 dag kg^{-1}), dark coloring, and low fiber content (RF and URF), which lead to bulk density (BD), gravimetric moisture (GM), bulk density of the organic matter (BDO), and the minimum residue (MR) showing typical values of the Histosols class (Kämpf and Schneider, 1989; Conceição et al., 1999; Valladares, 2003; Valladares et al., 2008; Silva et al., 2009; Campos et al., 2010; Horák et al., 2011; Silva et al., 2013a,b).

In the first 75 cm of depth, the OM contents were higher in CRP when compared to the core sample of the Córrego Cachoeira dos Borges (CCCB) (Table 1). Root biomass production from colonizing species of the WGL may have influenced OM accumulation in the upper layers, while high contents of OM in SDF probably occurred due to shoot biomass deposition from deciduous woody species (losing their leaves in the dry season). In addition, the higher content of lignin in woody species compared to herbaceous species leads to greater resistance to decomposition of the OM (Moreira et al., 2006; Potes et al., 2010), hence, its greater accumulation. Silva et al. (2013a) quantified lignin and cellulose in the species found in greatest abundance in the peatlands from the SdEM and they obtained the highest contents in woody species.

In general, the URF, RF, OM, TP, and GM contents decreased in depth in the core samples from the Rio Preto peats, whereas BD, BDO, Dp, MR, and MM increased (Table 1). Similar behavior was detected by Pontevedra-Pombal and Martinez-Cortizas (2004), Valladares et al. (2008), Silva et al. (2009), Campos et al. (2010), and Horák et al. (2011), which may be attributed to the stage of decomposition of OM being more advanced with depth (Table 1).

The BD values ranged from 0.07 kg dm^{-3} in the layers more enriched with organic matter to 1.59 kg dm^{-3} in the sandy layers (Table 1), and these results corroborate the data from Kämpf and Schneider (1989), Conceição et al. (1999), Valladares (2003), Valladares et al. (2008), Campos et al. (2010), Horák et al. (2011), and Silva (2011) in characterization studies of Histosols from different regions of Brazil. Overall, the BD values were higher in the CCCB in relation to the CRP, probably related to trampling from cattle and horses and the more advanced age of this peat.

The GM is directly related to the TP (Table 1). Horák et al. (2011) observed that the decrease of GM at depth is related to the greater contribution of the mineral fraction, which acts to reduce soil water retention. In addition, since the deeper samples are older than samples from the upper horizons, the deeper samples have more polymerized OM. However, fibric materials typically exhibit a predominance of macropores, thus favoring the flow of water. In the process of decomposition and mineralization of the OM, the macropores collapse, decreasing the size of the pores and the total porosity (Andriesse, 1988; Soares, 2011).

Chemical properties

The CEC of the Histosols is high and is directly related to organic matter. In contrast, the SB and V values are very low, a reflection of the chemical poverty of the rocky foundation, and high leaching (Tables 1 and 2). The values of all chemical characteristics are in agreement with data from Pereira et al. (2005), who assessed 254 histic horizons in Brazil.

Waterlogged Histosols of higher altitude, like those in this study, typically have low base saturation and low pH (Pereira et al., 2005). Such conditions, combined with cold weather, are favorable to accumulation of OM because they restrict its decomposition (mineralization) (Santos et al., 2005). Furthermore, the occurrence of high Al^{3+} values shows the álico character (low nutritional

Table 1. Physical and morphological properties of peat soils under two vegetation types from the headwaters of tributaries of the Rio Araçuaí (average of two observations)

Depth	Color	Post	Classification	URF	RF	GM	TP	BD	BDO	PD	OM	MM	RM
cm				%				kg dm^{-3}			dag kg^{-1}		m m^{-1}
Wet grassland - Rio Preto													
0-15	10YR 6/3	H5	hemic	40	21	776	92	0.12	0.09	1.40	77	23	0.02
15-30	10YR 5/3	H10	sapric	28	15	1.058	94	0.09	0.07	1.41	77	23	0.01
30-45	10YR 4/3	H10	sapric	25	14	1.347	95	0.07	0.05	1.39	78	22	0.01
45-60	10YR 3/2	H10	sapric	17	3	681	92	0.13	0.08	1.49	61	39	0.04
60-75	10YR 2/1	H8	sapric	35	19	328	88	0.28	0.12	1.60	46	54	0.11
75-90	10YR 2/1	H8	sapric	38	19	279	84	0.30	0.12	1.92	41	59	0.12
90-105	10YR 2/1	H8	sapric	37	14	277	83	0.30	0.12	2.10	42	58	0.12
105-120	10YR 2/1	H7	hemic	36	22	220	75	0.43	0.11	2.32	32	68	0.21
120-170						Water layer							
170-185	10YR 3/2	H10	sapric	22	5	62	65	1.01	0.08	2.66	8	92	0.62
185-200	10YR 2/1	H10	sapric	27	10	99	79	0.84	0.08	2.41	12	88	0.50
200-215	10YR 3/2	H10	sapric	21	6	79	72	0.92	0.08	2.45	9	91	0.56
215-230	10YR 2/2	H9	sapric	20	8	53	63	1.09	0.06	2.58	6	94	0.68
230-245	10YR 2/1	H10	sapric	20	1	60	63	0.94	0.07	2.52	7	93	0.58
Semi-deciduous forest - Rio Preto													
0-15	10 YR 5/4	H5	hemic	52	31	579	89	0.15	0.13	1.29	85	15	0.01
15-30	10 YR 4/3	H8	sapric	43	15	614	93	0.14	0.10	2.17	74	26	0.03
30-45	10 YR 3/3	H8	sapric	23	6	571	93	0.15	0.10	1.57	68	32	0.03
45-60	10 YR 3/4	H9	sapric	30	10	649	91	0.13	0.10	1.43	73	27	0.02
60-75	10 YR 3/3	H7	hemic	18	9	539	90	0.16	0.11	1.46	70	30	0.03
75-90	10 YR 3/3	H8	sapric	25	11	460	89	0.18	0.12	1.59	66	34	0.04
90-105	10 YR 4/4	H7	hemic	27	10	572	89	0.15	0.11	1.51	73	27	0.03
105-120	10 YR 3/3	H8	sapric	30	9	578	91	0.15	0.10	1.46	70	30	0.03
120-135	10 YR 3/4	H9	sapric	23	3	438	88	0.19	0.11	1.80	56	44	0.06
135-150	10 YR 3/3	H10	sapric	15	6	385	88	0.21	0.10	1.92	50	50	0.07
150-165	10 YR 3/3	H10	sapric	25	7	366	88	0.23	0.09	1.94	42	58	0.09
165-180	10 YR 3/3	H10	sapric	22	3	344	87	0.25	0.11	2.35	46	54	0.10
180-195	10 YR 3/3	H10	sapric	25	8	384	86	0.22	0.13	1.79	58	42	0.06
195-210	10 YR 2/2	H10	sapric	23	3	372	90	0.25	0.14	1.78	57	43	0.08
210-225	10 YR 2/2	H10	sapric	15	2	148	70	0.56	0.13	2.50	27	73	0.29
225-240	10 YR 2/2	Sand	-	12	5	52	47	1.17	0.09	2.92	10	90	0.72
240-255	10 YR 7/2	Sand	-	3	1	36	49	1.34	0.08	2.59	6	94	0.84
Wet grassland - Córrego Cachoeira dos Borges													
0-15	10 YR 6/3	H5	hemic	45	29	883	94	0.10	0.07	1.64	71	29	0.02
15-30	10 YR 4/3	H9	sapric	32	13	829	93	0.11	0.07	1.76	65	35	0.03
30-45	10 YR 4/4	H9	sapric	30	16	678	93	0.12	0.07	1.73	59	41	0.03
45-60	10 YR 3/4	H8	sapric	27	11	548	91	0.16	0.08	1.59	54	46	0.05
60-75	10 YR 4/3	H5	hemic	43	30	327	87	0.26	0.09	2.26	35	65	0.11
75-90	10 YR 4/3	H9	sapric	24	11	378	89	0.26	0.10	1.58	48	52	0.10
90-105	10 YR 6/3	H5	hemic	48	24	514	91	0.18	0.10	1.43	60	40	0.06
105-120	10 YR 6/3	H6	hemic	42	19	712	91	0.13	0.12	1.43	90	10	0.01
120-135	10 YR 5/3	H9	sapric	47	23	366	88	0.19	0.16	1.55	84	16	0.02
135-150	10 YR 2/1	H10	sapric	15	0	148	77	0.49	0.27	2.12	55	45	0.14
150-165	10 YR 2/1	H2	fibric	60	43	54	60	1.03	0.25	2.58	24	76	0.52
Semi-deciduous forest - Córrego Cachoeira dos Borges													
0-15	10 YR 3/4	H2	fibric	42	25	148	77	0.49	0.20	1.93	41	59	0.19
15-30	10 YR 2/1	H9	sapric	37	11	198	79	0.38	0.23	1.79	61	39	0.10
30-45	10 YR 2/1	H10	sapric	23	5	205	80	0.36	0.21	1.78	59	41	0.10
45-60	10 YR 2/1	H10	sapric	23	4	206	80	0.35	0.19	1.77	56	44	0.10
60-75	10 YR 2/1	H9	sapric	16	2	192	80	0.40	0.19	2.03	47	53	0.14
75-90	10 YR 2/1	H10	sapric	14	3	160	78	0.46	0.15	2.20	32	68	0.21
90-105	10 YR 2/1	H10	sapric	27	1	157	81	0.44	0.15	2.28	33	67	0.20
105-120	10 YR 2/1	H10	sapric	30	2	131	77	0.53	0.15	2.30	28	72	0.26
120-135	10 YR 2/1	H10	sapric	25	3	124	75	0.59	0.14	2.38	25	75	0.30
135-150	10 YR 2/1	H10	sapric	27	3	88	65	0.75	0.13	2.31	19	81	0.41
150-165	10 YR 2/1	H10	sapric	28	4	128	77	0.55	0.15	2.34	28	72	0.26
165-180	10 YR 2/1	Sand	....	14	1	66	65	0.96	0.10	2.71	10	90	0.57
180-195	10 YR 7/4	Sand	....	5	2	24	44	1.50	0.03	2.69	2	98	0.98
195-210	10 YR 7/3	Sand	....	20	20	24	43	1.59	0.03	2.81	2	98	1.04
210-225	10 YR 7/4	Sand	....	10	10	27	46	1.50	0.02	2.76	2	98	0.98

Color: color by sodium pyrophosphate; Post: von Post scale; Classification: classification of soil organic matter in the stage of decomposition; URF: unrubbed fibers; RF: rubbed fibers; GM: gravimetric moisture; TP: total porosity; BD: bulk density; BDO: bulk density of the organic matter; PD: particle density; OM: organic matter content; MM: mineral material content; MR: minimum residue; (-): does not apply to the type of material.

Table 2. Chemical properties of peat soil under two vegetation types from the headwaters of tributaries of the Rio Araçuaí (average of two observations)

Depth	pH		P	K	Ca^{2+}	Mg^{2+}	Al^{3+}	H+Al	SB	t	T	m	V	Fe	Zn	Cu	Mn
	$CaCl_2$	H_2O															
cm			mg dm^{-3}		cmol$_c$ dm^{-3}							%		mg dm^{-3}			
Wet grassland - Rio Preto (depth 3.44 cm)																	
0-15	3.90	4.76	3.34	116.18	0.60	0.30	2.66	22.10	1.20	3.86	23.30	69	5	215.55	1.54	1.06	4.94
15-30	3.95	4.83	6.07	34.54	0.40	0.10	3.00	30.90	0.59	3.59	31.49	84	2	131.11	0.77	1.06	2.82
30-45	4.22	4.71	5.35	28.26	0.20	0.10	3.90	30.90	0.37	4.27	31.27	91	1	57.77	0.77	1.06	2.11
45-60	4.30	4.93	6.34	3.14	0.20	0.10	3.26	24.70	0.31	3.57	35.01	91	1	44.44	1.02	1.06	1.41
60-75	4.29	4.80	5.20	3.14	0.10	0.10	3.20	22.10	0.21	3.41	22.31	94	1	31.11	0.25	1.06	1.41
75-90	4.37	4.80	5.08	3.14	0.20	0.10	2.92	17.70	0.31	3.23	18.01	90	2	24.44	0.25	1.06	0.70
90-105	4.37	4.71	5.43	3.14	0.20	0.10	2.28	19.80	0.31	2.59	20.11	88	2	22.22	0.25	1.06	0.70
105-120	4.42	4.91	6.94	3.14	0.10	0.10	2.04	22.10	0.21	2.25	22.31	91	1	22.22	1.02	2.13	0.70
120-170	Water layer																
170-185	4.39	4.81	10.55	3.14	0.30	0.10	1.22	11.40	0.41	1.63	11.81	75	3	35.55	1.28	3.20	0.70
185-200	4.40	4.82	13.66	3.14	0.20	0.10	1.44	17.70	0.31	1.75	18.01	82	2	37.77	0.77	3.20	0.70
200-215	4.30	4.79	14.46	3.14	0.10	0.10	1.70	17.70	0.21	1.91	17.91	89	1	24.44	1.02	2.13	0.70
215-230	4.40	4.89	15.56	3.14	0.20	0.10	1.36	12.70	0.31	1.67	13.01	82	2	35.55	1.54	2.13	0.70
230-245	3.60	4.96	16.32	3.14	0.10	0.10	1.10	8.10	0.21	1.31	8.31	84	3	22.22	1.02	2.13	0.70
Semi-deciduous forest - Rio Preto (depth 2.52 cm)																	
0-15	3.51	4.52	11.46	263.76	0.40	0.20	3.12	43.10	1.28	4.40	44.38	71	3	266.66	1.79	1.06	9.18
15-30	3.43	4.28	6.34	91.10	0.50	0.20	5.32	43.10	0.93	6.25	44.03	85	2	266.66	1.02	1.06	4.94
30-45	3.39	4.39	6.53	21.98	0.20	0.10	5.80	43.10	0.36	6.16	43.46	94	1	31.11	0.51	1.06	2.82
45-60	4.02	4.42	8.88	6.28	0.20	0.10	4.04	24.70	0.32	4.36	25.02	93	1	11.11	0.25	1.06	0.70
60-75	3.71	4.42	7.36	3.14	0.10	0.10	4.30	30.90	0.21	4.51	31.11	95	1	8.88	0.25	1.06	0.70
75-90	4.08	4.19	7.36	3.14	0.10	0.10	3.76	24.70	0.21	3.97	24.91	95	1	6.66	0.25	1.06	0.70
90-105	3.53	4.29	8.58	3.14	0.10	0.10	3.16	22.10	0.21	3.37	22.31	94	1	2.22	0.25	1.06	0.70
105-120	4.27	4.42	11.60	3.20	0.10	0.10	2.96	17.70	0.21	3.17	17.91	93	1	22.22	0.77	1.06	0.70
120-135	4.20	4.40	13.52	3.20	0.10	0.10	2.96	17.70	0.21	3.17	17.91	93	1	2.22	0.51	1.06	0.70
135-150	4.44	4.49	13.37	3.20	0.10	0.10	3.34	19.80	0.21	3.55	20.01	94	1	2.22	0.51	1.06	0.70
150-165	4.19	4.59	14.91	3.20	0.20	0.10	2.98	19.80	0.31	3.29	20.11	91	2	2.22	0.51	1.06	0.70
165-180	4.24	4.39	16.49	3.20	0.20	0.10	3.10	22.10	0.31	3.41	22.41	91	1	2.22	0.51	1.06	0.70
180-195	4.08	4.53	13.29	3.20	0.10	0.10	3.72	24.70	0.21	3.93	24.91	95	1	2.22	0.25	1.06	0.70
195-210	4.29	4.79	8.36	3.20	0.10	0.10	4.28	27.70	0.21	4.49	27.91	95	1	2.22	0.25	1.06	0.70
210-225	4.02	4.90	4.39	6.40	0.10	0.10	4.90	24.70	0.22	5.12	24.92	96	1	6.66	0.25	1.06	0.70
225-240	4.17	5.08	2.58	9.60	0.10	0.10	2.66	9.10	0.22	2.88	9.32	92	2	4.44	0.51	1.06	0.70
240-255	3.74	5.22	0.46	3.20	0.10	0.10	0.24	1.40	0.21	0.45	1.61	54	13	4.44	0.51	1.06	0.70
Wet grassland - Córrego Cachoeira dos Borges (depth 3.20 cm)																	
0-15	3.59	4.69	5.16	57.38	0.50	0.10	1.50	14.20	0.75	2.25	14.95	67	5	66.66	0.77	1.06	1.41
15-30	3.84	4.46	4.81	51.34	0.30	0.10	5.42	43.10	0.53	5.95	43.63	91	1	113.33	0.77	1.06	0.70
30-45	3.92	4.60	3.57	15.10	0.20	0.10	4.92	38.60	0.34	5.26	28.94	94	1	33.33	0.51	1.06	0.70
45-60	4.00	4.46	1.43	6.04	0.10	0.10	3.54	34.50	0.22	3.76	34.72	94	1	19.99	1.02	1.06	0.70
60-75	3.96	4.50	2.21	15.10	0.10	0.10	3.32	27.70	0.24	3.56	27.94	93	1	53.33	0.51	1.06	0.70
75-90	3.91	4.37	2.40	3.02	0.10	0.10	3.78	30.90	0.21	3.99	31.11	95	1	8.88	0.51	1.06	0.70
90-105	3.95	4.27	2.07	3.02	0.10	0.10	4.20	34.50	0.21	4.41	34.71	95	1	6.66	0.25	1.06	0.70
105-120	3.95	4.20	1.62	3.02	0.20	0.20	3.94	43.10	0.41	4.35	43.51	91	1	6.66	0.51	1.06	0.70
120-135	4.04	4.22	2.44	3.02	0.10	0.10	4.20	30.90	0.21	4.41	31.11	95	1	2.22	0.25	1.06	0.70
135-150	4.02	4.43	1.98	3.02	0.10	0.10	5.66	34.50	0.21	5.87	34.71	96	1	22.22	1.28	2.13	0.70
150-165	3.95	4.75	1.40	6.04	0.10	0.10	3.38	19.80	0.22	3.60	20.02	94	1	66.66	0.77	6.40	0.70
Semi-deciduous forest - Córrego Cachoeira dos Borges (depth 2.31 cm)																	
0-15	3.99	4.44	4.04	131.20	0.20	0.10	4.26	24.70	0.64	4.90	25.34	87	3	95.55	1.79	1.06	2.47
15-30	4.18	4.39	5.93	64.00	0.30	0.10	4.18	27.70	0.56	4.74	28.26	88	2	11.11	0.51	1.06	1.41
30-45	4.20	4.58	2.62	12.80	0.20	0.10	3.94	24.70	0.33	4.27	25.03	92	1	4.44	0.25	1.06	0.70
45-60	4.24	4.88	2.93	6.40	0.20	0.10	3.18	22.10	0.32	3.50	22.42	91	1	6.66	0.25	1.06	0.70
60-75	4.44	5.07	2.73	6.40	0.20	0.10	2.60	19.80	0.32	2.92	10.12	89	2	6.66	0.25	1.06	0.70
75-90	4.50	5.30	2.62	3.20	0.10	0.10	1.98	17.70	0.21	2.19	17.91	90	1	6.66	0.25	1.06	0.70
90-105	4.42	5.24	2.04	6.40	0.20	0.10	2.06	15.90	0.32	2.38	16.22	87	2	6.66	0.25	1.06	0.70
105-120	4.42	5.23	2.23	3.20	0.10	0.10	2.20	15.90	0.21	2.41	16.11	91	1	13.33	0.25	1.06	0.70
120-135	4.33	5.19	2.20	3.20	0.10	0.10	1.94	15.90	0.21	2.15	16.11	90	1	19.99	0.25	1.06	0.70
135-150	4.45	5.22	2.43	3.20	0.10	0.10	1.74	17.70	0.21	1.95	17.91	89	1	17.77	0.25	1.06	0.70
150-165	4.51	5.18	1.54	3.20	0.10	0.10	2.00	15.90	0.21	2.21	16.11	91	1	17.77	0.25	1.06	0.70
165-180	4.31	5.16	1.73	3.20	0.10	0.10	0.70	8.10	0.21	0.91	8.31	77	3	37.77	0.25	1.06	0.70
180-195	5.29	6.14	1.05	3.02	0.10	0.10	0.14	1.50	0.21	0.35	1.71	40	12	128.88	0.25	1.06	0.70
195-210	5.06	5.90	1.09	3.02	0.10	0.10	0.14	1.70	0.21	0.35	1.91	40	11	131.11	1.02	1.06	0.70
210-225	4.74	5.76	1.51	3.02	0.10	0.10	0.18	1.70	0.21	0.39	1.91	46	11	91.11	0.25	1.06	0.70

SB: sum of bases; t: effective cation exchange capacity; T: cation exchange capacity at pH 7.0; m: aluminum saturation; V: base saturation.

potential in the subsoil) (value m > 50 %) in all the core samples (Table 2). However, the reliability of the routine method for determination of Al^{3+} is compromised for soils with high OM, since the Al^{3+} content may be overestimated by high H^+ content generated by ionization of organic acids (Ebeling et al., 2008; Coelho et al., 2010; Campos et al., 2014).

The low pH value in Histosols is more related to the organic acid contents than to the aluminum contents in solution (Andriesse, 1984; Lepsch et al., 1990; Mendonça, 1999; Silva et al., 2008). Silva et al. (2008) also detected high acidity and buffering capacity, conditioned by the high organic carbon content present in Histosols.

The K^+ contents are higher in the upper layers, reaching 264 mg dm^{-3} at a depth of 0-15 cm of CRP colonized by SDF (Table 2). This corroborates the results found by Conceição (1989), Couto (1984), Horák et al. (2007), and Campos et al. (2010). This probably occurred due to the addition of K^+ at the surface through biomass deposition. Natural paleo-fires should also not be ruled out as a source of ashes.

The P averages of the CRP were higher than those of the CCCB, and in the CRP, the averages of the SDF were higher than the averages of WGL (Table 2). This may be related to the wealth of OM originating from woody vegetation. In the CCCB, there was a significant decline in P at depth in both vegetation types (Table 2), which may be due to the addition of this element at the surface, given that this peat is anthropized.

The values of Al^{3+} and aluminum saturation (m value) were very high and highest in the core samples collected under the SDF in the CRP (Table 2). This may be related to the proximity of the edge with an outcropping of a quartzite bolder (Campos et al., 2010; Horák et al., 2011), a possible source of Al^{3+}.

The most abundant micronutrients in the core samples were Fe >>> Cu > Zn >Mn. The Fe, Mn, and Zn contents decreased at depth in core samples under the two vegetation types from the CRP (Table 2).

Potential acidity was higher in soils under WGL from CCCB and under SDF from CRP (Table 2). Silva et al. (2008), in a comparative study of methods for estimating H+Al, found that soil organic carbon was the property that most influenced the parameter in question.

The low SB was mainly due to the low nutrient content of waters that pass through the rocky base and the source material (Alvarez V et al., 1999) (Table 2). The greatest values of SB were found in the upper layers, with a decrease up to the 60-75 cm layer for both peats (Table 2).

The CEC varied between the vegetation types from CCCB and the highest t values were obtained in SDF of the CRP in the layers from 15-45 cm (Table 2). High CEC in Histosols is mainly due to the presence of organic colloids, which have a large specific surface area (Brady, 1989; Brady and Weil, 1999). According to Silva and Mendonça (2007), almost all of the CEC values in Histosols may be related to high organic carbon content.

Elemental composition and C/N, H/C, and O/C ratios

The contents of C, H, N, and O varied between the peats and among vegetation types, with ranges of 31.8 and 34.3 %, 4.8 and 4.9 %, 2.0 and 2.2 %, and 17.7 and 15.5 % for the WGL and SDF from the CRP; and 38.0 and 26.0 %,3.3 and 3.3 %, 1.4 and 1.5 %, and 12.8 and 16.6 % for the WGL and the SDF from the CCCB, respectively (Figures 2 and 3). González-Perez et al. (2008) and Fontana (2009), studying Histosols in Brazil, found C of 48.9 to 57.4 %, H of 3.8 to 5.5 %, N of 2.3 to 3.8 %, and O of 33.2 to 41.2 %. All these values are inside the ranges of variation found in the peats surveyed.

The CRP (conservation area) had average C, H, N, and O contents higher than those of the CCCB (disturbed area). In the CRP, the average concentrations of C and N from the core sample under SDF were higher than those of the core sample under WGL. The contents of C, N, and O decreased with depth under the two vegetation types from CRP (Figure 2), which indicates the natural process of decomposition with loss of carbon dioxide (CO_2), and the ability of the vegetation in maintaining constant addition of OM on the soil surface. The losses of organic matter in Histosols under management practices are mainly influenced by the depth of drains and soil tillage (Bayer and Mielniczuk, 1999), which stresses the need for conservation of the natural conditions in which these soil environments are found.

In the CCCB the contents of C and O were higher in the SDF compared to the WGL, and N content decreased with depth (Figure 3).The high values of C, H, O, and N in the 105-135 cm layer of the core samples from WGL in the CCCB (Figure 3) showed the biggest accumulation of OM, due to a larger concentration of roots in this layer (Table 1); after death, these roots increased the OM content of these layers.

Regarding the differential accumulation of organic material, Horák et al. (2011) point out that the evolution of the sources of this material in the soil is linked to the dynamics of climate and vegetation in past time periods; this can be shown by palynology, stable isotopes of C, and radiocarbon dating, among other techniques. In peatlands near those studied here, through palynology and C isotope techniques, Horák et al. (2011) found evidence of a climate wetter than the current one 8090 years BP

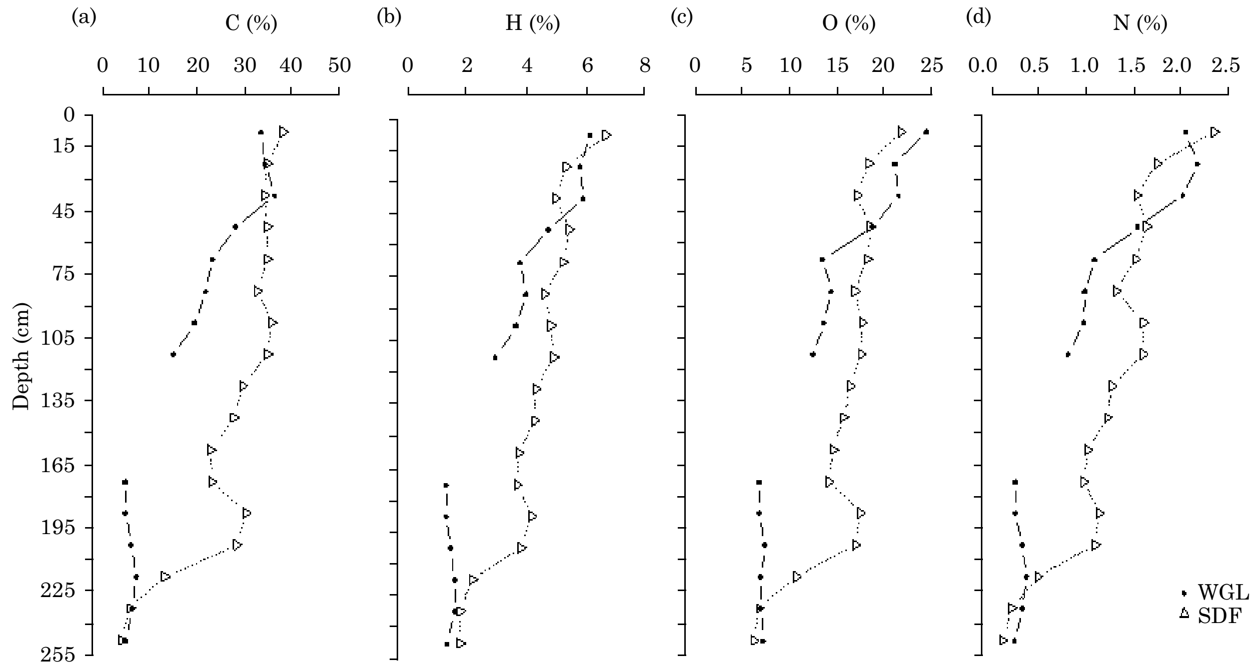

Figure 2. Average contents of (a) carbon (%C), (b) hydrogen (%H), (c) oxygen (%O), and (d) nitrogen (%N) in depth in core samples under wet grassland (WGL) and semi-deciduous forest (SDF) from the peat in the headwaters of the Rio Preto.

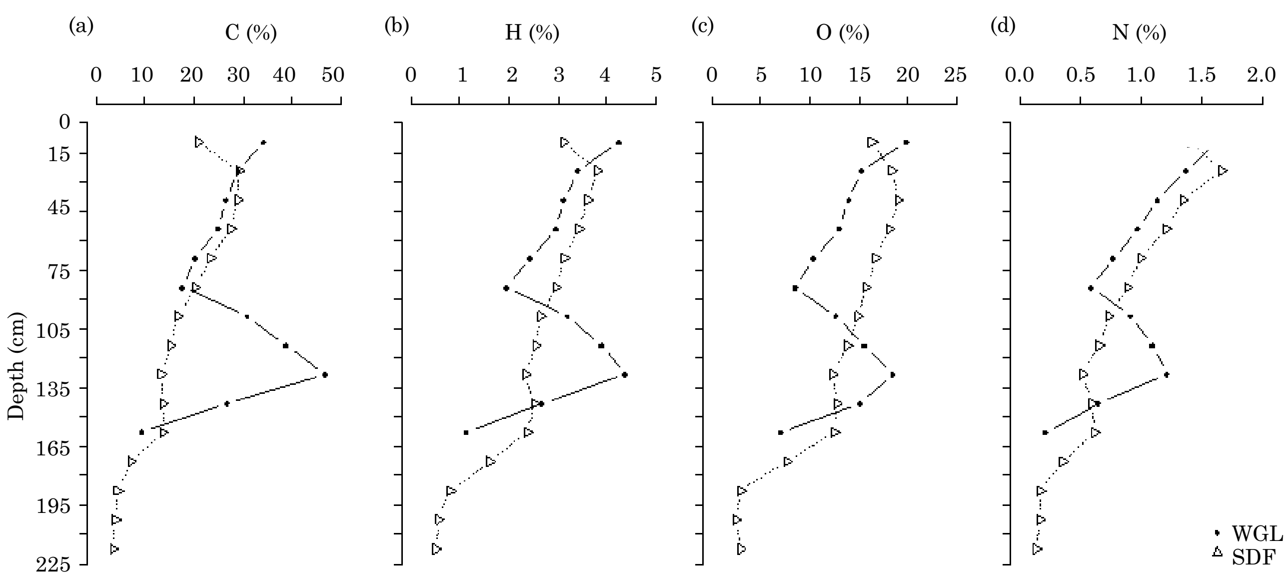

Figure 3. Average contents of (a) carbon (%C), (b) hydrogen (%H), (c) oxygen (%O), and (d) nitrogen (%N) in depth in core samples under wet grassland (WGL) and semi-deciduous forest (SDF) from the peat in the headwaters of the Córrego Cachoeira dos Borges.

(before the present) and a drier climate than the current one 2,500 years BP and 430 years BP.

Using a multi-proxy approach (stratigraphy, physical properties, ^{14}C dating and LOE, pollen, and geochemical analysis data) in five peatlands near the areas of this study, Horák-Terra (2014) found evidence of wet and warm weather from 7.4 to 4.2 thousand years BP, dry and hot weather from 4.2 to 2.2 thousand years BP, sub-wet weather from 1.2 thousand years to 400 years BP, and sub-wet weather <400 years BP. In this last period, human activities were responsible for significant changes recorded in peatlands, which were more severe in the CCCB.

The water layer found under the WGL from the CRP (Table 1 and Figure 2), described by Barber (1981) and Foster and Fritz (1987) as a record of changes from drier to wetter conditions, is located in the layer from 120 to 170 cm with a ^{14}C age from 4226 to 7664 years BP (Table 3). This coincides with evidence of wetter and warmer weather in peatlands near the CRP (Horák-Terra, 2014). The $\delta^{13}C$ value of the layer with an age of 7,764 years BP is -18.20 ‰ and this is associated with a greater contribution of grasses compared to the layer of 4426 years BP (-22.10 ‰), associated with a greater mix of plants, and with the contribution of woody plants (Table 3). These data corroborate those found by Horák-Terra (2014) and allow us to infer a drier climate before 7,764 years BP.

In regard to the annual growth (RVG) and the average annual increase of C (RCA) of peatlands, values ranging from 0.10 to 0.61 mm yr^{-1} and from 2.93 to 36.62 g m^{-2} yr^{-1}, respectively, were obtained, and were greater under SDF as compared to WGL (Table 3). These results are within the range of values found for tropical peatlands (Campos et al., 2010; Horák et al., 2011; Silva et al., 2013b) and temperate peatlands (Tolonen, 1979; Armentano and Menges, 1986; Gorham, 1991; Pontevedra-Pombal, 2002). However, the CRP, perhaps because it is younger, has higher RVG and RCA in the two vegetation types in relation to the CCCB (Table 3). Greater losses of OM in the latter, which is not protected, should also not be ruled out. The radiocarbon age of the layer from 15-30 cm from WGL in the CCCB (1,221 years BP) is far higher than the radiocarbon age of the same layer in the other core samples, showing degradation of OM, possibly by fires, which favor the regrowth of vegetation for grazing.

The atomic ratios show variation among the peats (Figures 4 and 5). The C/N ratio of the organic residues is one of the factors controlling the decomposition rate (Heinrichs et al., 2001). In tropical Histosols, as in the soils of this study, C/N ratios higher than 16 affected N availability (Andriesse, 1988). In this sense, the Histosols assessed proved to be in a slow process of mineralization (Figures 4 and 5), corroborating the sapric feature of most layers (Table 1).

The reduction of the O content with depth (Figures 2 and 3) suggests the lowest amount of oxygen functional groups in the OM of these layers. But, the values of the O/C ratio were higher than 0.5 in the core samples under the SDF (Figures 4 and 5), which, according to Steelink (1985), suggests the presence of a greater amount of oxygen functional groups in these materials, such as carboxyl groups (COOH).

In the humification process, there is an increase in N content and decline in C, H, and O contents (Ebeling, 2010). However, the high H contents (Figures 2 and 3) may be considered common for Histosols, where the release of H+ is due to the decomposition process of plant residues (Soares,

Table 3. Radiocarbon ages, $\delta^{13}C$ content, vertical growth rate (RVG), and carbon accumulation rate (RCA) in peats from tributaries of the Rio Araçuaí

Peat/Vegetation type	Average depth	^{14}C age	$\delta^{13}C$	RVG	RCA
	cm	yr BP	‰	mm yr^{-1}	g m^{-2} yr^{-1}
Rio Preto					
Wet grassland	22.5	143	-22.12	0.22	7.88
	112.5	4,226	-22.10	0.32	18.86
	217.5	7,664	-18.20		
Semi-deciduous forest	22.5	57	-24.25	0.42	22.73
	112.5	2,194	-24.58	0.61	36.62
	202.5	3,666	-22.99		
Córrego Cachoeira dos Borges					
Wet grassland	22.5	1,221	-17.88	0.10	2.93
	82.5	7,149	-22.36	0.15	14.12
	142.5	11,129	-23.81		
Semi-deciduous forest	22.5	59	-22.06	0.19	20.37
	97.5	4,030	-25.07	0.13	10.33
	157.5	8,555	-23.23		

Average depth: average depth of the layer in the soil profile; BP: before the present.

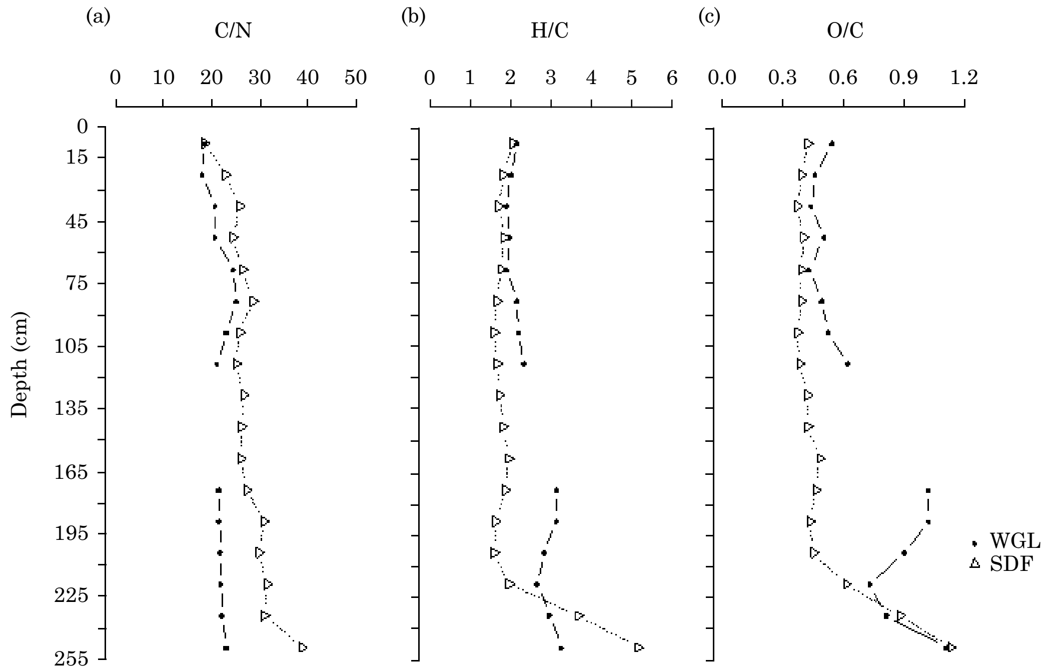

Figure 4. Ratios: (a) carbon/nitrogen (C/N), (b) hydrogen/carbon (H/C), (c) oxygen/hydrogen (O/H), and (d) oxygen/carbon (O/C) in depth in core samples under wet grassland (WGL) and semi-deciduous forest (SDF) from the peat in the headwaters of the Rio Preto.

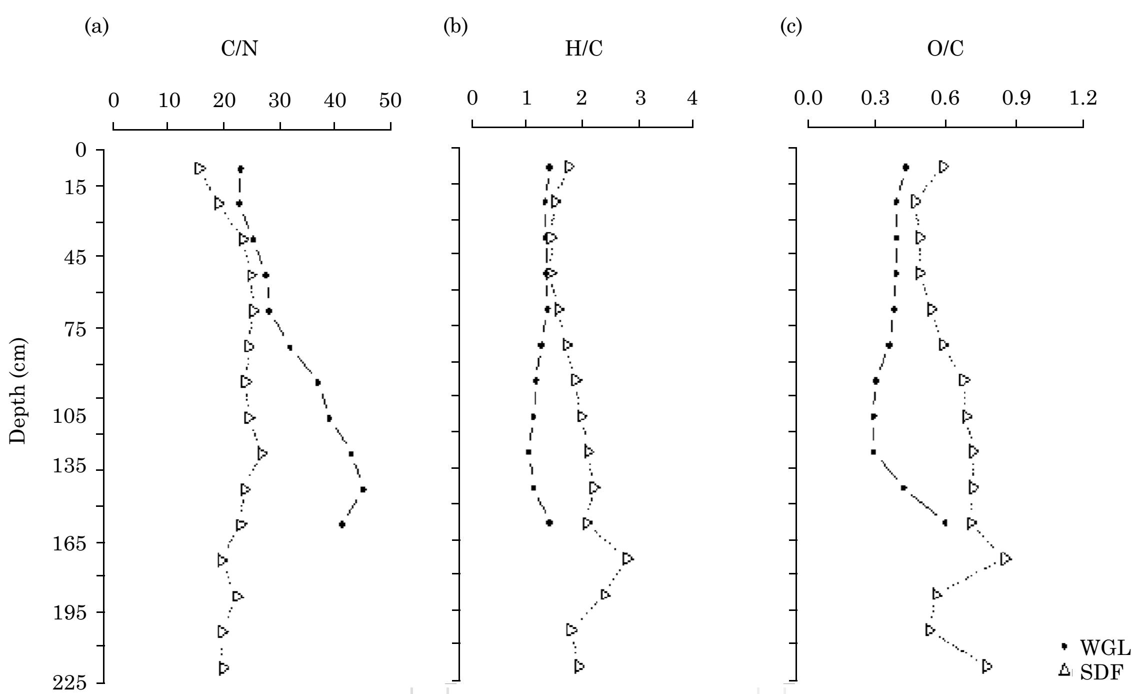

Figure 5. Ratios (a) carbon/nitrogen (C/N), (b) hydrogen/carbon (H/C), (c) oxygen/hydrogen (O/H), and (d) oxygen/carbon (O/C) in depth in core samples under wet grassland (WGL) and semi-deciduous forest (SDF) from the peat in the headwaters of the Córrego Cachoeira dos Borges.

2011). The high values of the H/C ratio (≥1.0) in all core samples (Figures 4 and 5) suggest a greater proportion of aliphatic components (Steelink, 1985; Canellas et al., 2005).

Similarity between the layers of the core samples

By analyzing dendrograms, it can be inferred that the core samples under SDF from the two headwaters, the uppermost layers (up to 30 cm), tended to be included in more well-defined clusters (Figures 6b and 6d). This behavior may indicate a marked influence of the diversity of arboreous species that colonized the area on the quality of organic matter and, consequently, on the maintenance of the characteristics of these layers. Under this vegetation type, the formation of two groups was found: one with larger dimensions, made up of layers of intermediate depths; and another, made up of deeper layers that are in more advanced stages of decomposition.

In the core samples under WGL of the two peatlands, the formation of groups composed by the layer of up to 15 cm indicates the important contribution of the high proportion of biomass of the roots produced by the herbaceous species that dominate the area; they have shallower root systems that form a tangle of roots in this layer (Figures 6a and 6c).The intermediate layers of the core samples

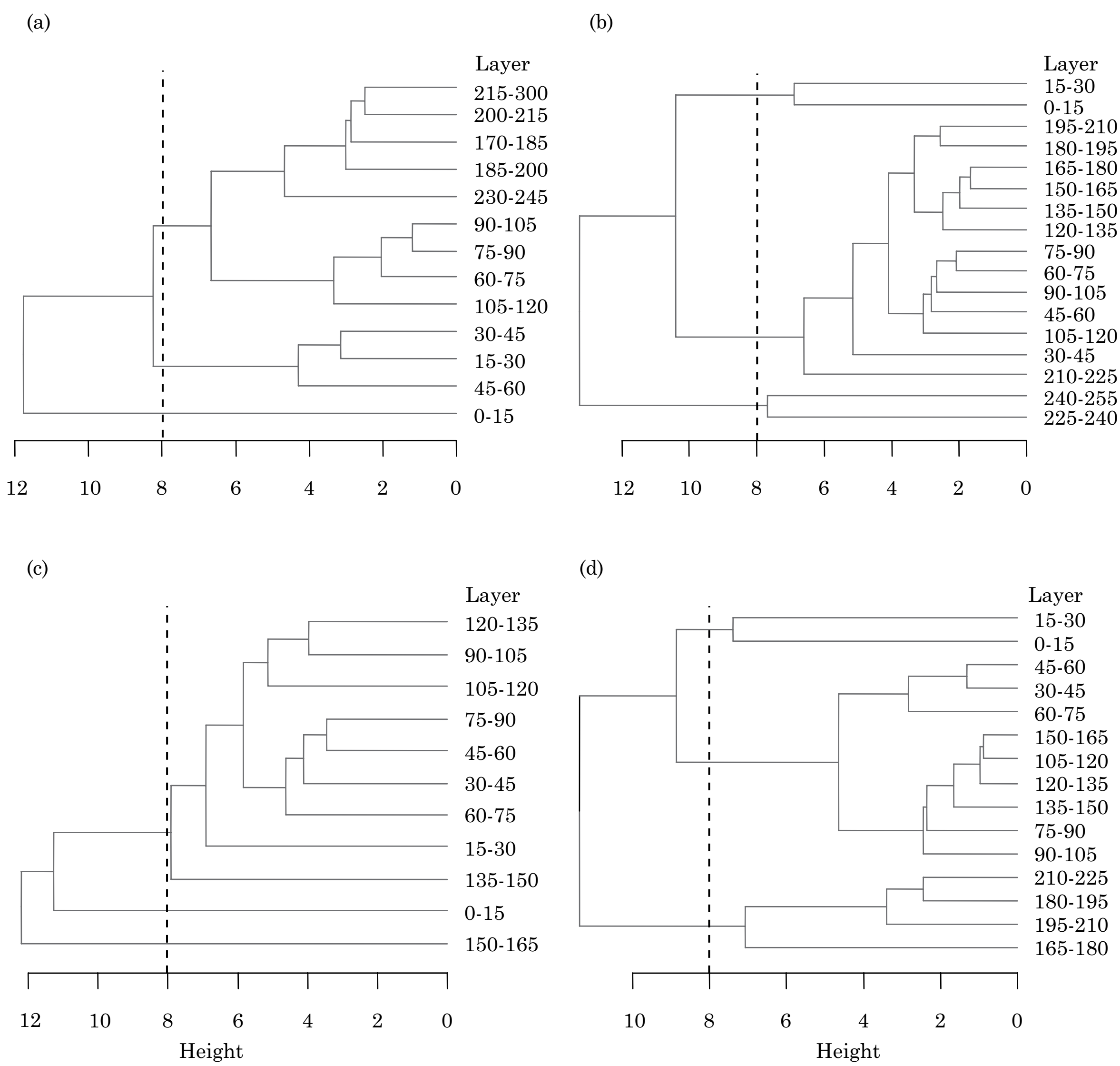

Figure 6. Dendrograms of Hierarchical Cluster Analysis of layers of peat soil core samples of the Rio Preto under (a) Wet grassland (WGL) and (b) Semi-deciduous forest (SDF); and of the Córrego Cachoeira dos Borges under (c) Wet grassland (WGL) and (d) Semi-deciduous forest (SDF), according to Euclidean distance (unweighted pair group method with arithmetic mean - UPGMA) using 34 physical, chemical, and elementary properties that were self-scaled by the mean and the standard deviation.

under WGL showed greater similarities, which resulted in the formation of larger groups (Figures 6a and 6c).The depths of 135-150 and 150-165 cm of the core samples under WGL from CCCB showed no similarity with the other layers, forming an isolated group (Figure 6c).This fact may be related to the proximity of these layers to the bedrock of the peatlands. Since it is rich in mineral material, it may have a considerable influence on the composition of these layers (Tables 1 and 2).

Cluster analysis showed that the degree of similarity between the layers of each core sample seems to be structured in accordance with the types of colonizing vegetation and environmental conditions (present and past) shown by the formation of well-defined groups and characteristics of the layers with different stages of decomposition.

ACKNOWLEDGEMENTS

The authors thank the FAPEMIG and CNPq for funding this study and CAPES for providing scholarships.

CONCLUSIONS

The headwater peatlands of the Rio Araçuaí show predominance of organic material in advanced stages of decomposition (sapric character) and their soils are classified as Typic Haplosaprists.

The organic matter of the Histosols studied shows notable differences regarding morphological, physical, and chemical composition, and it is influenced by the vegetation type that colonizes it.

The headwater peatlands of the Córrego Cachoeira dos Borges are older which, together with inferences of physical and chemical properties indicate a more pronounced stage of degradation in relation to the peat from the Rio Preto headwater.

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