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Artigos

Total organic carbon and nutrient contents in the soil and litter layer in Tijuca National Park, Rio de Janeiro, Brazil

Carbono orgânico total e conteúdo de nutrientes no solo e na serapilheira no Parque Nacional da Tijuca, RJ

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ABSTRACT

The forests of Brazilian Atlantic coast are poorly studied in terms of nutrient pools and dynamics. The purpose of this study was to determine the amounts and contents of organic carbon and Ca, Mg, K, Na, P, and N in the soil and the litter layer on slopes and in valley bottoms in Tijuca National Park, Rio de Janeiro, Brazil. The nutrient cycling process on slopes (more oligotrophic environments) and valley bottoms (less oligotrophic environments) was also compared. Samples were collected from 15 plots (100 m² each), 10 on slopes (Conde, Cobras and Tijuca) and five in valley bottoms (Valley bottom 1 and 2). The soil compartment (exchangeable/available and total nutrient contents to a depth of 0.30 m) and litter compartment (O1 and O2 horizons) were evaluated. The total organic carbon content in the soil and litter biomass on slopes were higher than in the valley bottoms. On slopes, there was a clear separation of horizons O1 and O2 in the litter layer, unlike the valley bottoms, probably due to a higher nutrient content in these positions. The difference in nutrient availability was most evident for K. These results characterize the study area as oligotrophic, although it has considerable potential for replacement of nutrients lost by leaching.

Keywords: Tropical forests; Low tropical mountain ecosystems; Nutrient cycling

RESUMO

As florestas da costa atlântica brasileira são pouco estudadas quanto às quantidades e à dinâmica de nutrientes. Os objetivos deste trabalho foram estimar os teores e conteúdos de carbono orgânico, Ca, Mg, K, Na, P e N no solo e na serapilheira dos ambientes de encosta e fundos de vale do Parque Nacional da Tijuca, Rio de Janeiro, RJ. Os processos de ciclagem de nutrientes nas encostas (ambientes mais oligotróficos) e dos fundos de vale (ambientes menos oligotróficos) também foram comparados. Foram estabelecidas 15 parcelas de amostragem, cada uma com 100 m², 10 em encostas (vertentes do Conde, das Cobras e da Tijuca), e cinco em fundos de vale (fundos de vale 1 e 2). O compartimento solo (nutrientes trocáveis/disponíveis e totais até a profundidade de 0,30 m) e o compartimento serapilheira (separada em horizontes O1 e O2) foram avaliados. O teor de carbono orgânico total no solo das encostas foi maior que o nos fundos de vale. Nas encostas, a serapilheira também apresentou maior biomassa, com separação nítida dos horizontes O1 e O2, o que não ocorreu nos fundos de vale. Aparentemente, a disponibilidade de nutrientes nos dois ambientes foi o que gerou tais diferenças, com a tendência de aumento nos teores no solo nos fundos de vale. Diferenças entre fundos de vale e encostas foram mais evidentes para o K. Os resultados deste estudo caracterizaram a área estudada como oligotrófica, embora com considerável potencial de reposição dos elementos perdidos por lixiviação.

Palavras-chave: Florestas tropicais; Ecossistema baixo-montano; Ciclagem de nutrientes

1 INTRODUCTION

The quantity and nutrient dynamics of the Brazilian Atlantic forests have not been adequately studied. The studies generally do not cover all the compartments and flows of the forest system (NUNES *et al.*, 1991; SAMPAIO *et al.*, 1993; KINDEL; GARAY, 2001). In the Tijuca Forest, in the municipality of Rio de Janeiro, a number of studies have been conducted, focusing the upper basin of the Cachoeira River, and mostly concentrated in forest hydrology (ROSAS, 1991; MIRANDA, 1992) and nutrient cycling (OVALLE, 1985; LOPES, 1994). According to these authors, the litter layer plays an important role in maintaining the high infiltration capacity of the surface soil and in transferring of elements from vegetation to soil.

Comparison of the organization (structure and functioning) of different tropical forests is often hampered by differences in environmental conditions (rainfall, latitude, altitude, geological bedrock, floristic composition, etc.) that may affect the cycling mechanisms and affect comparisons (AYERS, 1997; KINDEL; GARAY, 2002). An appropriate model to study element cycling at locations with different nutrient availability and pools is the one based on slopes and valley bottoms. Due to the water movement, slopes are nutrients donor areas, while valley bottoms are receiving areas. Thus, within relatively short distances, there are contrasting environments, representing an ideal model for studies on nutrient pools and availability and the relation with forest structure and functioning.

Clevelario Jr. (1988) quantified the biomass and the contents of Ca, Mg, K, Na, and P in the litter of the Tijuca Forest and found differences in the speed of litter decomposition on slopes and in valley bottoms. On slopes, the decomposition is slower, which was attributed to the action of vegetation on the microbiota, which responds to the greater nutrient scarcity in this environment. The proximity between the two environments minimizes the differences on major environmental factors, yet does not preventing the existence of differences in nutrient availability.

The aim of this study was to estimate the amounts and contents of total organic carbon, Ca, Mg, K, Na, P, and total N in the soil and in the litter layer on slopes and in valley bottoms of the upper Cachoeira River Basin, Tijuca National Park, Rio de Janeiro, Brazil, and compare the nutrient pools of these positions.

2 MATERIALS AND METHODS

This study was conducted in the upper basin of the Cachoeira River, Tijuca National Park, Rio de Janeiro, Brazil. The park is located between coordinates 22°55’ and 23°00’ S and 43°11’ and 43°19’ W, in the highest parts of the Tijuca Massif, surrounded by the urban area of the city of Rio de Janeiro. The Cachoeira River Basin is located on the Atlantic side of the Tijuca Massif, with an area of 345 ha (3.45 km^2) (NETTO *et al.*, 1980).

The bedrock of the Cachoeira Basin consists of gneisses and granites. The mountainous relief has steep slopes and altitudes ranging from 462 m (basin outflow) up to 1,022 m, due to the lithological heterogeneity of the basin. The average slope declivity is 18°, and 50% of the slopes have an inclination between 12° and 22° (NETTO *et al.*, 1980). Inclination is lowest in the valley bottoms (almost flat areas). Oxisols are predominant in the valley bottoms, and Litosols and Entisols in the highest and steepest parts of the basin, all with low natural fertility (EMBRAPA, 1980). The soil texture is sandy and sandy-clay.

The climate, according to Köppen climate classification, is humid tropical (Af) in the lower part (up to 500 m) and humid subtropical (Cfa) at the highest points (MATTOS *et al.*, 1976). Average annual temperature is 22°C and average annual precipitation is 2,300 mm, concentrated from September to April. The Tijuca Park is covered with humid tropical submontane forest.

Ten sampling plots of 100 m² (10 m × 10 m) each were distributed on slopes (87% of the basin), six on the left side of the Conde River Sub-basin. On this slope, the six plots were placed along a transect, from the base to nearly the top of the toposequence, forming a continuous area of 600 m². Two more contiguous plots were placed on slope in the Cobras Sub-basin and two others (also contiguous) on the slope of Tijuca peak. Five plots were outlined in the valley bottoms, three contiguous plots between Caveira Rivers I and II (Valley Bottom 1), and the other two, also contiguous, on the left bank of Caveira River II (Valley Bottom 2).

A composite soil sample was collected (0-0.30 m depth) from each plot. Two undisturbed soil samples per plot were collected by the Kopeck's volumetric ring method (EMBRAPA, 1997).

For evaluation of nutrient concentration in the litter layer, samples were collected from a randomly located square of 0.25 m² (0.5 m × 0.5 m) per plot. In slope plots, litter was separated into O1 horizons (early phase of litter decomposition) and O2 horizons (advanced phase of litter decomposition). In the valley bottoms there was no such partition. The difference in procedures and the area used for sampling followed Clevelario Jr. (1988), who found differences in litter structure between slopes and valley bottoms. In the valleys bottoms there was no formation of the O2 layer. The litter was weighed, oven-dried (80ºC), weighed again, and then ground and samples digested by sulfuric acid or a mixture of nitric-perchloric acids. The N content was determined by Kjeldahl method, in the sulfuric extract. The contents of Ca and Mg (atomic absorption spectrometry), K and Na (flame photometry) and P (colorimetry) were determined in the nitric-perchloric extract.

The soil samples were air-dried and sieved (2 mm) and the following characteristics were determined: particle size, particle density, and pH in water and in KCl (EMBRAPA, 1997); exchangeable Al with KCl 1 mol L^{-1}, available Ca, Mg, P, and K (ion-exchange resin), total N by the Kjeldahl method, and total organic carbon by the Walkley-Black method; exchangeable Na with ammonium acetate, pH 7.0 (BRAGA, 1980); and Mg, K, Na, and total P by nitric-perchloric digestion of soil samples (BRASIL, 1988). The physical characterization, total N, exchangeable Al, pH in water and in KCl, and total organic C analyses were performed in duplicate, and the others analyses in triplicate. The total soil porosity was calculated according to Embrapa (1997). To calculate the total and available nutrient contents in soil, the layer of 0-0.30 m was considered as the exploitation limit of fine roots. The soil density and the amount of air-dried fine-earth in each plot were also determined.

To test differences between slopes and valley bottoms, the following non-parametric tests were used: U of Mann-Whitney, Kolmogorov-Smirnov, Kruskall-Wallis and the non-parametric Spearman correlation (SIEGEL, 1975). The non-parametric tests do not require knowledge of distribution of population data, and are more appropriate for small samples.

3 RESULTS AND DISCUSSION

In all plots, the sand fraction was predominant, with soils ranging from sandy-loam, sandy-clay-loam to sandy-clay (Table 1). The low silt/clay ratio indicates that the soils are relatively young, in spite of being classified as Oxisols. Although with wide variation, sand levels on the Cobras slope were higher than on the Conde and Tijuca slopes, which have a similar texture composition (Table 1). In the valley bottoms, plots of Valley Bottom 2 have higher sand contents than those of Valley Bottom 1, where silt content is higher than in the rest of the basin. Higher silt and clay contents in the valley bottoms compared to slopes, as proposed by Netto *et al.* (1980), was not observed, probably due to the small number of sampling points.

Particle density was similar in all sampling points, most likely due to the similarity of texture and mineralogical soil composition in the basin (predominance of sand fraction, mainly quartz). There were no significant differences (Mann-Whitney, $p<0.10$) between values of bulk density on slopes and in valley bottoms (Table 1).

Total porosity was high, greater than 50%. According to Nunes *et al.* (1991), the water infiltration rate in the first centimeters of soils the Cachoeira Basin is high. Rosas (1991), studying another part of the Cachoeira Basin, found values of soil texture, porosity and densities similar to those obtained in this study.

In all sampled situations soil is acidic, with pH in water ranging from 4.0 to 4.4 and pH in KCl from 3.5 to 3.7. The pH values in the valley bottoms and on the Tijuca slope were higher, although the differences were not statistically significant (Mann-Whitney, $p<0.10$) (Table 1). Similar results were obtained by Ovalle (1985) and Rosas (1991).

The highest Al^{3+} contents were found on the slopes, differing significantly (Mann-Whitney, $p<0.002$) from those found in the valley bottoms (Table 1).

The contents of total organic C were higher on the slopes than in the valley bottoms (Mann-Whitney, $p<0.02$) (Table 1). This result was probably due to the greater amount of litter, especially in the O2 horizon (half-decomposed material), found on the slopes. The higher contents of total organic C on the slopes, especially on the most oligotrophic ones (Conde and Cobras), increased nutrient retention and Al^{3+} complexation in these environments. This partially compensates the more adverse soil conditions on the slopes than in the valley bottoms. Similar results were found in tropical forests of Puerto Rico (LODGE; ASBURY, 1988) and New Guinea (EDWARDS;

GRUBB, 1977), and were attributed to a greater litter loss through surface runoff from the valley bottoms.

The N contents reflect the organic C distribution. N levels were higher on slopes, especially at Conde, than in valley bottoms (Mann-Whitney, $p<0.002$) (Table 1). Nitrogen is generally not a limiting nutrient in humid tropical forests, since biological fixation is intense in these forests (CARPENTER, 1992). Additionally, the Tijuca Forest is near a large urban center, with industrial activities and fossil fuel combustion releasing large quantities of N oxides to the atmosphere, a significant portion of the pollute reaches the soil through rainfall. According to Lopes (1994), about 8 kg ha^{-1} yr^{-1} of NO_3^- was brought to this forest through rain.

Table 1 – Physical and chemical properties of soil samples (0-0.30 m) on the slopes and in the valley bottoms of the Tijuca Forest

Area	Sand				Density		TP[2]	pH		Al^{3+}	Total[3]	
	Coarse	Fine	Silt	Clay	Part.[1]	Soil		H_2O	KCl		OC	N
	——— g kg^{-1} ———				kg dm^{-3}		%			$cmol_c$ dm^{-3}	— g kg^{-1} —	
Slope												
Conde	458	93	123	326	2.5	1.2	53.7	4.1	3.5	2.8	49	2.7
Cobras	583	108	93	216	2.5	1.3	50.6	4.0	3.6	2.5	46	2.3
Tijuca	458	91	123	328	2.5	1.0	60.3	4.3	3.7	2.7	39	2.4
Mean	483	95	117	305	2.5	1.1	54.7	4.1	3.6	2.7	46	2.6
s	59	17	25	52	0.04	0.1	4.7			0.4		0.3
Valley Bottom												
Valley 1	440	162	169	230	2.5	1.2	52.2	4.4	3.6	1.9	34	2.0
Valley 2	636	95	89	181	2.6	1.2	53.0	4.2	3.7	1.5	30	1.4
Mean	518	135	137	210	2.5	1.2	52.5	4.3	3.7	1.7	32	1.8
s	113	43	44	48	0.03	0.05	2.4			0.3		0.4
Total mean	495	109	123	273	2.5	1.2	53.9	4.2	3.6	2.4	41	2.3
s	79	33	32	67	0.03	0.01	4.1			0.6		0.5

Source: Clevelario Jr. (1988)

In where: Conde: mean of six sample plots; Cobras, Tijuca and Valley Bottom 2: mean of two plots; Valley Bottom 1: mean of three plots; s: standard deviation. [1]Particle density; [2]Total porosity; [3]Total organic carbon (OC) and total nitrogen (N).

Despite wide variations between sampling areas for available nutrient contents, slopes had higher values than valley bottoms for Ca, lower for K and similar for P. For all nutrients, the Tijuca slope has much higher contents, possibly due to a geological substrate richer in nutrients (Table 2). For Na and Mg, available contents in the valley bottoms were intermediate. Total contents were higher in the valley bottoms than on the slopes for Mg and K, similar for P and lower for N and Na (Tables 1 and 2). Total contents were highest on the Tijuca slope. Higher total values for P and Na in less sandy soils (Spearman correlation, $p<0.10$) indicated that primary and secondary minerals rich in these elements are concentrated in the finer soil fractions (silt and clay).

Table 2 – Mean concentrations of available/exchangeable and total nutrients in soil samples (0-0.30 m), on slopes and in valley bottoms of the Tijuca Forest

Area	**Ca**	**Mg**		**K**		**Na**		**P**	
	Avail	**Avail**	**Total**	**Avail**	**Total**	**Exch**	**Total**	**Avail**	**Total**
	——— mg dm^{-3} ———								
				Slope					
Conde	68.4	22.5	310	40.6	636	16.2	166	7.1	326
Cobras	74.6	29.3	211	34.8	552	8.0	106	7.9	222
Tijuca	120.8	34.6	790	74.7	1572	26.1	184	9.9	375
Mean	80.1	26.3	387	46.3	807	16.5	158	7.8	315
s	30.5	11.8	221	17.2	411	10.3	30	1.8	61
				Valley Bottom					
Valley 1	42.3	24.9	495	48.1	1143	17.0	138	7.9	275
Valley 2	76.5	20.9	744	44.3	1349	9.9	155	7.3	245
Mean	56.0	23.3	595	46.5	1225	14.1	145	7.7	263
s	22.3	3.6	262	4.7	326	4.4	27	0.8	32
Total mean	72.1	25.3	456	46.4	946	15.7	153	7.8	298
s	29.6	9.8	247	14.0	425	8.6	29	1.5	57

Source: Clevelario Jr. (1988)

In where: Conde: mean of six sample plots; Cobras, Tijuca and Valley Bottom 2: mean of two plots; Valley Bottom 1: mean of three plots. Avail (Ca, Mg, K, P): available (resin-extracted); Exch (Na): exchangeable (extracted by ammonium acetate, pH 7.0); Total: total by nitric-perchloric digestion; s: standard deviation.

In spite of what would be expected by the model proposed, nutrient contents were not clearly higher in the valley bottoms than on the slopes with similar substrates

(Conde and Cobras). Nevertheless, this does not mean that the model of a higher nutrient availability in the valley bottom than on the slopes was not valid. The cation exchange capacity (CEC) of clays in the basin was low (ROSAS, 1991). Therefore, more than the nutrient pool retained in soil, the movement of subsurface water flows enriched with nutrients from slopes made valley bottoms less oligotrophic than the slopes.

The ratio between the total and available contents in the soil (total/available) for P, K, Mg, and Na (Table 3) is an indication of the medium- and long-term nutrient limiting potential for the forest. It indicates the ability of soil minerals to replace the available/exchangeable fraction of each nutrient. Magnesium and K appear to be the most critical elements in the medium and long terms, with mean total/available indices lower than those of P. The possibility of Mg and K depletion in the soil is much higher than that P (Table 3). However, this may be the result of more intense P plant uptake, reducing the soil available content, and thus raising the total/available indices. Moreover, the possibility of P depletion seems to be greater than the total/available indices indicate, since part of the total P is immobilized by Fe and Al oxides in forms unlikely to return to the soil available fraction (CAMPELLO *et al*., 1994).

Low total/available Na indices were probably due to low plant uptake and intense Na addition by the rain (LOPES, 1994).

Total/available indices for P, K and Mg were high on the Tijuca slope. This, the Tijuca toposequence has the highest content and amount of available nutrients, as well as the greatest capacity for nutrient recovery. Valley bottoms were also favorable to potential for nutrient recovery from the soil, since the total/available indices were highest for K and Mg and intermediate for P. Contrasting conditions can be seen on the Conde and especially on the Cobras slopes with lower total/available indices for P, K and Mg than on the Tijuca slopes and valley bottoms (Table 3). These results confirm that the Cobras and Conde slopes are more oligotrophic than the Tijuca slope and valley bottoms. A situation similar to the Tijuca Forest (low available content and high total content) was found by Werner (1984) in tropical rainforests on basalt, in Costa Rica, and by Johnson *et al*. (2001) in Brazilian Amazon.

Table 3 – Available/exchangeable and total mean amount of nutrients in soil samples (0-0.30 m), on slopes and in valley bottoms of the Tijuca Forest, and the ratio between the total and available/exchangeable contents (T/A or T/Ex)

Area	**Ca**	**Mg**			**K**			**Na**			**P**			**N**
	Avail	**Avail**	**Total**	**T/A**	**Avail**	**Total**	**T/A**	**Exch**	**Total**	**T/Ex**	**Avail**	**Total**	**T/A**	**total**
	——— kg ha^{-1} ———													
	Slope													
Conde	199	66	898	13.6	117	1843	15.7	47	480	10.3	21	942	45.5	7795
Cobras	197	74	573	7.7	94	1525	16.2	22	301	13.3	22	633	29.4	6212
Tijuca	344	99	2232	22.5	215	4465	20.8	71	523	7.4	28	1064	37.6	6893
Mean	228	74	1100	14.9	132	2304	17.4	47	453	9.7	22	905	40.4	7298
s	85	31	616	6.8	52	1175	4.1	28	97	4.1	6	193	12.9	927
	Valley Bottom													
Valley 1	145	85	1689	19.9	164	3885	23.3	58	472	8.0	27	940	34.7	6846
Valley 2	261	71	2557	35.9	152	4618	30.5	34	530	16.3	25	838	33.9	4811
Mean	191	79	2036	25.6	159	4178	26.3	48	495	10.2	26	899	34.3	6032
s	75	11	921	11.4	15	1103	6.2	15	93	4.8	2.4	106	4.3	1280
Total mean	226.9	75.7	1412	18.6	141	2929	20.4	47	467	9.9	23.7	903	38.1	6876
s	59.9	25.4	834	9.5	44.3	1439	6.4	23.5	94	4.2	5.1	165	11.2	1184

Source: Clevelario Jr. (1988)

In where: Conde: mean of six sample plots; Cobras, Tijuca and Valley Bottom 2: mean of two plots; Valley Bottom 1: mean of three plots. Avail (Ca, Mg, K, P): available by resin extraction (A); Exch (Na): exchangeable (extracted by ammonium acetate, pH 7.0) (Ex); Total (T): total by nitric-perchloric digestion (Mg, K, Na, P); Total N: Kjeldahl method; s: standard deviation.

The litter mass on the slopes was almost three times as high as in the valley bottoms (Mann-Whitney, $p<0.001$), especially when only the Conde and Cobras slopes, the most oligotrophic slopes, were considered (Table 4). However, the litter stocks in the valley bottoms were similar to the O1 horizon of the slopes, indicating that litter stocks mainly differ due to the absence of the O2 horizon in the valley bottoms. Oliveira and Lacerda (1993) reported 8.9 t ha^{-1} of litterfall for this forest, with no significant differences between the amounts deposited in areas with different slopes. Therefore, the formation of O2 layer on slopes is due to lower decomposition rates in this environment, possibly related to the exacerbated oligotrophy.

Table 4 – Mean litter mass in the O1 and O2 horizons, ratio between them and turnover time of litter on slopes and in valley bottoms of the Tijuca Forest

Area	Horizon		Total Litter	O2/O1	Litter turnover time
	O1	O2	O1+O2	Ratio	
	——————— t ha^{-1} ———————				year
			Slope		
Conde	7.0	20.1	27.1	2.85	3.0
Cobras	5.9	28.6	34.5	4.87	3.9
Tijuca	5.7	11.4	17.1	2.00	1.9
Mean	6.5	19.3	25.9	2.96	2.9
s	1.9	8.4	7.8	2.11	
			Valley Bottom		
Valley 1			10.6		1.2
Valley 2			7.9		0.9
Mean			9.5		1.1
s			3.5		
Total Mean			20.5		2.3
s			10.5		
			Ratios of litter mass: Slope / Valley bottom		
Mean ratio Slope/Valley bottom				2.7	
Mean ratio (Conde - Cobras) Slope/Valley bottom				2.9	

Source: Clevelario Jr (1988)

In where: Conde :mean of six sample plots; Cobras, Tijuca and Valley Bottom 2: mean of two plots; Valley Bottom 1: mean of three plots; s: standard deviation. Litter turnover time: ratio between the litter layer over the soil (total mass: O1+O2) and the annual litterfall [8.9 t ha^{-1} yr^{-1}, as found by Oliveira and Lacerda (1993)].

The relationship between litter mass and oligotrophy of the environment can be observed when different slopes are compared. A greater litter biomass was found on the Cobras slope, which was the poorest in nutrients (Table 5). On the Tijuca slope, the least oligotrophic one, less litter was accumulated, about 50% of the amount found on the Cobras slope. The differences between litter stocks on the slopes were due to the O2 horizon, which was more developed on Cobras than on the other slopes (Table 4).

The litter mass in this study was high when compared to the literature 4.6 t ha^{-1} (SCOTT *et al.*, 1992), 7.8 t ha^{-1} (BORÉM; RAMOS, 2002), 7.9 t ha^{-1} (PEREIRA *et al.*, 2008), 5.7 t ha^{-1} (CALVI *et al.*, 2009), due to longer turnover time (Table 4), common in oligotrophic forests. In these type of forests, litter accumulation is related to slower decomposition, rather than to more intense litterfall.

The Ca contents in the O1 horizon were similar in all plots, with the highest values in Valley Bottom 2 and the lowest on the Cobras slope (Table 5). Except for the Tijuca slope, Ca concentrations in the O2 horizon were much lower than in the O1, reflecting the nutrient depletion in the litter as decomposition proceeds. The higher Ca concentration in the O2 horizon of Tijuca was probably due to the greater Ca availability in the soil of this slope (Table 2).

The Mg contents of the O1 horizon were higher on the Cobras and Tijuca slopes than on the Conde slope and valley bottoms. These results coincide with higher contents of exchangeable Mg in the soil of these areas (Tables 2 and 5). The K concentrations in the litter (O1 and O2 horizons) from valley bottoms and the Tijuca slope were higher than in Conde and Cobras, parallel to the levels of exchangeable K in the soil (Tables 2 and 5). The Na contents in the O1 horizon were higher than in the O2 and did not follow exchangeable Na contents in the soil, as was the case in the O2 horizon (Tables 2 and 5).

Cations contents in the O1 and O2 horizons showed progressive depletion as decomposition proceeded, indicating uptake by vegetation and/or leaching. This uptake and/or leaching is apparently most intense in more oligotrophic environments, such as the Cobras slope, where differences between the contents of O1 and O2 were greatest. These differences were minor on the Tijuca slope richer in nutrients. These results show that litter accumulation in more oligotrophic environments represents the storage of semi-decomposed organic matter rather than of cationic nutrients on the soil.

Phosphorus in the O1 and O2 horizons, followed the trend of cations, with the highest values on the Tijuca slope and valley bottoms, and the lowest on the Cobras slope (Table 5). However, there is no relation to available or total soil contents (Table 2).

Table 5 – Mean nutrient contents and amounts in litter on the slopes (divided in O1 and O2 horizons) and in the valley bottoms of the Tijuca Forest

Area	**Ca**		**Mg**		**K**		**Na**		**P**		**N**	
	O1	**O2**	**O1**	**O2**	**O1**	**O2**	**O1**	**O1**	**O2**	**O2**	**O1**	**O2**
	Content											
	——————————————— g kg^{-1} ———————————————											
Slope												
Conde	8.5	4.3	1.7	0.9	1.0	0.7	1.3	1.0	0.38	0.44	14.4	13.8
Cobras	7.9	5.0	2.3	1.2	0.9	0.5	1.3	0.9	0.35	0.41	15.3	12.1
Tijuca	8.6	9.0	2.3	1.9	1.2	1.0	1.1	1.1	0.61	0.60	12.3	12.6
Mean	8.4	5.3	1.9	1.2	1.0	0.7	1.3	1.0	0.42	0.46	14.2	13.2
s	1.3	2.7	0.4	0.5	0.2	0.2	0.1	0.1	0.14	0.09	2.3	2.2
Valley Bottom												
Valley 1	7.2		1.6		1.1		1.0		0.46		12.9	
Valley 2	10.9		1.7		1.3		1.2		0.57		15.0	
Mean	8.7		1.6		1.2		1.1		0.51		13.7	
s	2.3		0.1		0.2		0.1		0.07		1.6	
Total Mean	8.5		1.8		1.1		1.2		0.45		14.0	
s	1.7		0.4		0.2		0.2		0.12		2.1	
	Amount											
	——————————————— kg ha^{-1} ———————————————											
Slope												
Conde	60	73	11	17	7	12	9	19	2.6	8.4	99	262
Cobras	47	139	14	34	5	16	8	26	2.1	11.9	90	350
Tijuca	50	103	13	21	7	11	6	13	3.4	6.8	67	144
Mean	55	93	12	21	6	13	8	19	2.7	8.8	91	256
s	19	45	3	9	2	3	3	7	0.9	3.5	24	107
Valley Bottom												
Valley 1	81		17		11		10		4.8		135	
Valley 2	87		13		11		9		4.5		121	
Mean	84		15		11		10		4.7		129	
s	38		5		3		3		1.2		41	
Total Mean	65		13		8		9		3.3		104	
s	29		4		3		3		1.4		35	

Source: Clevelario Jr. (1988)

In where: Conde: mean of six sample plots; Cobras, Tijuca and Valley Bottom 2: mean of two plots; Valley Bottom 1: mean of three plots; s: standard deviation. The litter layer in the valley bottoms is equivalent to the O1 horizon of the slopes.

Average N contents on slopes were similar in the O1 and O2 horizons. In O1, the lowest N contents were detected on the Tijuca slope and Valley Bottom 1 (Table 5). The N values in O1 were similar to data obtained by Monteiro and Gama-Rodrigues (2004) in a montane forest of Desengano State Park in the north of the state of Rio de Janeiro. Nitrogen immobilization by microbiota may have caused the higher N contents in O2 on the Tijuca slope. Like the other elements, the difference in concentration between the O1 and O2 horizons was lowest in Tijuca and highest in Cobras, indicating a more rapid N depletion in O2 in most oligotrophic areas.

Average nutrient contents in O2 exceeded O1 on the three slopes studied. The discrepancy between contents of O2 and O1 was greatest for N and P, intermediate for K and Na, and lowest for Ca and Mg. The highest average contents in O2 horizon and total litter (O1 + O2) were always found in Cobras, due to its greater O2 quantity (Tables 4 and 5). However, mean contents in the O1 horizon in the valley bottoms were higher than on the slopes. On slopes, the highest mean P stock in O1 was found in Tijuca, while mean contents of Ca, K, Na and N were highest on Conde, and the highest Mg stock was detected on Cobras. For Na, the contents in the Cachoeira Basin were high when compared to the values found by Proctor *et al.* (1983) in forests of Indonesia (0.08 to 0.4 kg ha^{-1}).

The soil/litter ratios of nutrient contents (Table 6) show that Ca, with an index of 1.8, had the lowest relative participation of soil in the soil-litter system. This may be an indication that Ca scarcity a in the soil was greater than that of other elements. A possible “nutrient scarcity sequence” could be P (2.6), Mg (2.8) and K (8.6). However, other factors (chemical properties, relative abundance in biomass and soil, relative importance for plants, main compounds, etc) also affect the soil/litter ratio for each nutrient. For N, the extremely high soil/litter index (25) is due to the use of total content instead of the available/exchangeable content for soil. Thus, comparison of N with other nutrients is inadequate.

The mean values of nutrient soil/litter ratio were much higher in the valley bottoms and on the Tijuca slope than on the Conde and Cobras slopes. Therefore, on the valley bottoms and Tijuca, the soils are a far more important nutrient stock for the forest than on the Conde and Cobras slopes. On Cobras, the poorer soil and greater litter biomass increased the relative importance of litter for the storage, uptake and exchange (with roots) of nutrients outside the living biomass.

Table 6 – Ratio between mean nutrient contents in the available/exchangeable soil fraction (0-0.30 m) and litter (O1 + O2), on slopes and in valley bottoms of the Tijuca Forest

Area	Ca	Mg	K	Na	P	N
	——————————— soil/litter ratio ———————————					
			Slope			
Conde	1.5	2.3	6.1	1.7	1.9	22
Cobras	1.1	1.5	4.5	0.6	1.5	14
Tijuca	2.2	2.9	12.1	3.8	2.8	33
Mean	1.5	2.2	6.9	1.7	2.0	21
			Valley Bottom			
Valley 1	1.8	5.1	14.4	5.7	5.7	51
Valley 2	3.0	5.4	14.1	3.5	5.5	40
Mean	2.3	5.2	14.3	4.9	5.6	47
Total Mean	1.8	2.8	8.6	2.2	2.6	25

Source: Clevelario Jr. (1988)

In where: Conde: mean of six sample plots; Cobras, Tijuca and Valley Bottom 2: mean of two plots; Valley Bottom 1: mean of three plots.

4 CONCLUSIONS

The content of total organic carbon, total nitrogen, soil nutrients and litter biomass reveals the nutritional differences between slopes and valley bottoms of the Cachoeira River Basin, representing an interesting model for comparative studies of nutrient cycling.

The potential reserve of Mg, K, Na, N and P in soil, not available in the short term for vegetation, is large and can replace future losses from the system.

The Cachoeira River Basin can be classified as oligotrophic, particularly the slopes of Conde and Cobras, although with considerable potential for replacement of nutrients lost by leaching.

The greater litter mass on more oligotrophic slopes was due to the development of the O2 layer, composed by semi-decomposed material, poor in cationic nutrients.

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