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SOIL-WATER CHEMISTRY CHANGES AFTER SLASHING AND BURNING OF A "TERRA FIRME" FOREST PARCEL IN ALTA FLORESTA, MATO GROSSO, BRAZIL IN SOUTHERN AMAZON

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ABSTRACT

Disturbance effects of slashing and burning a forest plot on the chemical composition (major cations and anions) of soil-water that percolates the topsoil (20 cm) are studied. The work was conducted at the Fazenda Caiabi (9°57'42.2" S; 56°20'52.05" W) in Alta Floresta (MT) during three rainy periods (1999-2003) after a burning experiment (August 1999). In general, in the burned site, for all chemicals except Cl^-*, there was a pulse in solute concentrations following the burning with a subsequent decay in the following periods. Two years after this pulse, the solute content decays to values lower than ones observed in the primary forest soil-water. It is most likely that intense leaching through the topsoil occurs just after the burning, followed by absorption due to vegetation regeneration.*

RESUMO

Neste estudo avaliou-se a composição química da água do solo (cátions e ânions maiores em solução) em sua porção superior (20 cm). O estudo foi realizado na Fazenda Caiabi (9°57'42,2" S; 56°20'52,05" W) no município de Alta Floresta (MT) durante os três períodos chuvosos (1999-2003) após um experimento de queimada (agosto 1999). Observou-se que, na parcela queimada, todas as espécies químicas estudadas, exceto o Cl^-, apresentaram um pulso nas concentrações após a queimada, seguido por um decaimento nos períodos seguintes e que dois anos após a queimada, o conteúdo de solutos na água do solo decaiu para valores inferiores aos observados na floresta primária. É provável que ocorra uma lixiviação intensa na parte superior do solo logo após a queimada seguida por uma absorção devido a rebrota da vegetação secundária.

INTRODUCTION

Environmental impacts of the conversion of primary forest to pasture or other agricultural purposes in the Amazon Region are well documented. Creation and maintenance of these pastures involve forest felling, the extraction of economically important wood, the burning of biomass, and the sowing of fodder. This is a low cost process because, due to biomass burning, soil nutrients become mobilized and, therefore, more readily available to plants. This process can, for instance, increase the amounts of exchangeable cations such as Mg and K that allow pasture to be productive during the five or so years after conversion. However, with the passage of time, the pasture undergoes degradation, which is described by Macedo & Zimmer (1993) as a process of vigor and productivity loss, of decrease in the capacity to resist pests, diseases and invasion of alien species, and the decrease or total loss of the capacity to maintain enough biomass production for livestock. The practice of slash and burn significantly impacts the soil system, which can modify the hydrological and nutrient cycling processes that involve evapotranspiration, the water paths in the soil system and the input of nutrients by rainfall, throughfall and litterfall, and their cycling through the soil system (root absorption, weathering, leaching, etc.). Williams *et al.* (1997) studying a small catchment in central Amazon observed that the slash-and-burn agricultural practices leads to an increase in overland flow, erosion, and result in large losses of solutes from the root zone with an extensive leaching; however, solute transfers were diminished along the pathways stages from throughflow to groundwater. Studies concerning forest-pasture conversion show that this type of land-use-change practice causes appreciable increase in soil pH and exchangeable cation content at least up to nine years after pasture creation (Moraes *et al.,* 1996), and that these modifications occur mainly in the top soil layer.

Studies regarding soil solution are common in the Northern Hemisphere and include diverse experiments focusing on the evaluation of different methods utilized to monitor forests, pastures, or cropland soils (Giesler *et al.*, 1996; Ludwig *et al.*, 1999; Titus *et al.*, 2000).

Although scarce in tropical regions, especially in the Amazon region, studies have shown that several years after the slashing and burning, a significant reduction of nutrients occurs in soils (Parker, 1983). This impoverishment can be due to: (i) the removal of the forest and, therefore, the disruption of the internal recycling that is common in poor soils and (ii) the leaching of nutrients that are mobilized during the forest burning but that are not completely fixed by the vegetation that regenerates the place.

Holscher *et al.* (1997a) and Piccolo *et al.* (1994) showed that there is a significant decrease of the solute content in the soil solution after two subsequent months of the forest burning. Studies regarding nutrient loss (Markewitz *et al.*, 2004) and nutrient balance (Sommer *et al.*, 2004) in shifting cultivation, with and without slashing and burning, pointed out that these losses can be minimized if fire-free practices are implemented.

In a study carried out in the Venezuelan Amazon, Uhl & Jordan (1984) showed that, after three years of the forest burning, soil nutrients leached from the burned site returned to the previous levels found in the primary forest soil. They attributed this decline in solute concentration to a combination of high production rates with the high storage capacity of the secondary vegetation, and a decline of the substratum that is easily degradable and leads to the reduction of the leaching.

Slashing and subsequent burning of the forest can also produce pulses of chemical species in solution in the soil-water and in the soil derived from the washing of ash by the first rainfall after the forest fire, and contributing to abnormal input of nutrients and other products generated by the biomass burning into the soil system. This solution interacts with the solid phase of the soil, modifying the chemical composition of the soil solution and, therefore, modifying the solution that percolates through the soil.

This paper reports on the results of a comparative study done on the solute content of soil-water that moves by gravity within the topsoil in its way to the root active zone, in both an undisturbed primary forest, referred as primary forest henceforth, and an experimentally slashed and burned forest. The objective of this study is to evaluate modifications of slash and burning process on the soil-water chemistry by comparing them with the equivalent solutes in the soil solution of a primary forest area, and assessing the decay time of these solute concentrations through their time evolution.

To achieve this objective, the concentrations of major ions (Na^+, K^+, Mg^{2+}, Ca^{2+}, NH_4^+, Cl^-, NO_3^- and SO_4^{2-}) were determined in soil-water sampled using zero tension lysimeters at 20 cm depth, during three rainy periods between 1999 and 2003, following the experiment of slash and burning of the forest in 1999.

EXPERIMENTAL AREA AND METHODS

The slashing and burning experiments were carried out at the Caiabi Farm (9°57'42.2" S; 56°20'52.05" W), located near the city of Alta Floresta, in northern Mato Grosso State, Brazil (Figure 1). This work was done at the same site used for tests to estimate biomass consumption and carbon release rates to the atmosphere through the process of forest clearing and burning. The tests were performed in square plots of 1 ha and a detailed description of the tested areas and slash-and-burn experiments is found in Carvalho *et al.* (2001).

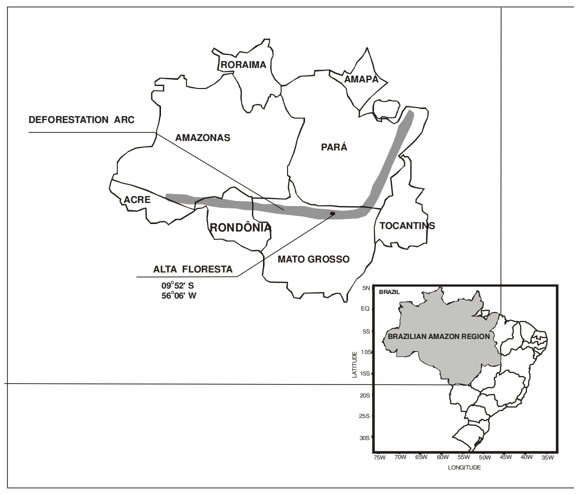

Figure 1: Localization of the sampling sites within the Brazilian Amazon Region.

Soils of the region are red-yellow latosols (Brazilian Soils Classification), highly weathered mineral soils and with deep profile. They have low natural fertility with the main active part being at the first 20 cm (Vieira & Santos, 1987). The general chemical characteristics of the profile are: i) [0-20] cm - Organic Matter (OM) minimum 25.4 $mg.kg^{-1}$ and maximum 41.4 $mg.kg^{-1}$ Base Saturation (BS) minimum 1.2 $mEq.kg^{-1}$ and maximum 1.9 $mEq.kg^{-1}$, Exchangeable Aluminum minimum 16.2 $mEq.kg^{-1}$ and maximum 22.8 $mEq.kg^{-1}$ and Phosphorus minimum 5.4 $mg.kg^{-1}$ and maximum 7.0 $mg.kg^{-1}$ and ii) [20-100] cm - Organic Matter (OM) minimum 13.4 $mg.kg^{-1}$ and maximum 19.6 $mg.kg^{-1}$ Base Saturation (BS) minimum 0.8 $mEq.kg^{-1}$ and maximum 1.0 $mEq.kg^{-1}$, Exchangeable Aluminum minimum 9.0 $mEq.kg^{-1}$ and maximum 14.6 $mEq.kg^{-1}$ and Phosphorus minimum 1.0 mg.kg^{-1} and maximum 2.4 mg.kg^{-1}. The mean maximum percentage in clay content in the profile (0-100) cm is 81 % and the minimum is 61 %.

According with the results of Magid & Christensen (1993) and Ranger *et al.* (2001) soil-water studies for nutrient studies and cycling processes require the use of tension lysimeters; however, when leaching processes are the focus, the most suitable instruments for sampling the soil-water are zero tension lysimeters. Because the purpose of this study was to evaluate the chemical changes and time evolution of the soil-water that moves under gravity forces through the top soil, we choose the zero tension lysimeters to obtain the soil-water samples.

To install the lysimeters, two trenches 1.5 m wide, 2.5 m long and 1.0 m deep were dug, one in the forest area and the other in the slash and burn experiment area. The observational period lasted from September 1999 until February 2003 and was divided in three intervals named PERI (from September 1999 until January 2000), PERII (from October 2001 until April 2002) and PERIII (from September 2002 until February 2003), which were the rainiest intervals during the period considered. Regarding the rainfall total deviations from normal it was observed that PERI was normal, PERII was below the normal with negative deviation up to -200 mm for March and April and PERIII was above the normal with positive deviation up to + 200 mm for December, 2002 and January, 2003 (Climanalise Bulletin, September 1999 – February 2003: www.cptec.inpe.br/products/climanalise).

Each lysimeter is composed of a 628 cm^2 polyethylene tray inserted into the soil through the sidewalls of the trenches in the undisturbed primary forest and in the slashed and burned ones. The tray was connected with a hose to a 1 – liter container to collect the soil-water samples (Figure 2). Samples were collected fortnightly and, at each collection time, the container was replaced with a clean one irrespectively of the presence of solution or not (during dry spells no water percolated through the soil). Due to logistic problems which could lead to sample contamination, it was not possible to measure the collected volume.

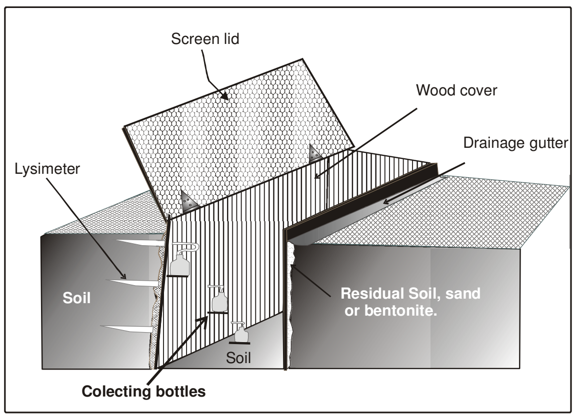

Figure 2: Schematic figure of the Lysimeters deployment.

Each sample of collected soil-water was vacuum filtered to remove suspended solids and microorganisms using pre-washed Millipore membrane filters with a 0.22 mm pore diameter. After filtering, samples were separated into two 30 ml aliquots: (i) for the major anions, stored in a high-density polyethylene bottle without preservative and (ii) for the major cations, stored in a polyethylene bottle acidified with 0.1 % high-purity chloridric acid. All aliquots were stored at 4 °C until analysis, following the procedure described by Apello & Postma (1994).

The ionic species were determined with a Dionex DX-500 liquid-ion-chromatograph in the NUPEGEL-ESALQ/USP Laboratory (Nucleus for Research in Geochemistry and Geophysical of the Lithosphere - Luiz de Queiroz Agricultural Superior School/ University of São Paulo in Piracicaba, São Paulo). To determine the basic cations and ammonium, a CS12 analytical column with sulfuric acid as the eluent was used. For the anions, an AS4A analytical column with sodium carbonate/ bicarbonate as the eluent was used. The precision of these analyses depends on the system configuration, on the sample concentrations range and on the analyzed species. Artificial Rainwater 409 certificated sample from Environmental Canada and primary standards from the UK Natural Environmental Research Council (Forti *et al.*, 2000a) were used to determine the percentage of the precision and accuracy of the analytical procedures (Miller & Miller, 2000) which are presented in Table 1.

Table 1: Analytical precision (PR) and accuracy (AC) in % for each ion.

Ion	Na^+	K^+	Mg^{2+}	Ca^{2+}	NH_4^+	Cl^-	NO_3^-	SO_4^{2-}
				%				
PR	3	3	8	8	10	3	3.5	8
AC	7	9	11	9	11	8	10	8

RESULTS AND DISCUSSION

The seasonal variation of the sample ionic content (Na^+, K^+, Mg^{2+}, Ca^{2+}, NH_4^+, Cl^-, NO_3^- and SO_4^{2-}), for the three sampling periods and for the different sites, are presented in Figures 3a to 3h. Mean concentration values in $\mu Eq.L^{-1}$ of the solutes in the forest soilwater for the location of the present study and other locations in the Amazon are shown in Table 2 for comparison of the concentration values magnitude. The solute concentration values found in the primary forest site are comparable with other ones determined in different locations in the Amazon Region, such as the ones in Central Amazon near Manaus (Forti & Neal, 1992) and in Northeastern Amazon, in the Amapá State (Forti *et al.*, 2000b; Melfi & Forti, 1997).

Table 2: Mean concentration values of the solutes ($\mu Eq.L^{-1}$) in the forest soil water for the location of the present study and other locations in the Amazon: Caiabi - this study; Duke - Duke Reserve, Central Amazonia (Forti & Neal 1992) and SNV - Serra do Navio, Northeastern Amazonia (Melfi & Forti, 1997).

Ion	Na^+	K^+	Mg^{2+}	Ca^{2+}	NH_4^+	Cl^-	NO_3^-	SO_4^{2-}
				$\mu Eq.L^{-1}$				
Caiabi	12.2	152	52.8	58.3	246	74.2	289	22.9
Duque	103	43.2	46.3	54.0	9.44	60.6	-	89.6
SNV	78.5	29.7	27.2	18.2	24.8	55.0	146	23.9

A pulse of Mg^{2+}, K^+, Ca^{2+}, NH_4^+ and NO_3^- concentrations was observed for the first period, which occurred approximately 2 months after the slash and burn experiment; these high concentrations remained high until the end of this period. One year after the slash and burn experiment, during the second and third observational period, concentration values decayed to values equivalent to those found in the primary forest area such as Na^+ and Mg^{2+} or lower, such as

K^+ and NO_3^-. Piccolo *et al.* (1994) also observed that ionic losses from surface soils to soil solution following forest slash and burn were lower than the ones in the primary forest. Thus, ionic decrease can be attributed to the depletion of available pools and rapid uptake of the remaining pools by vigorous regrowing vegetation (Buschbacher *at al.*, 1988; Uhl & Jordan, 1984) and leaching.

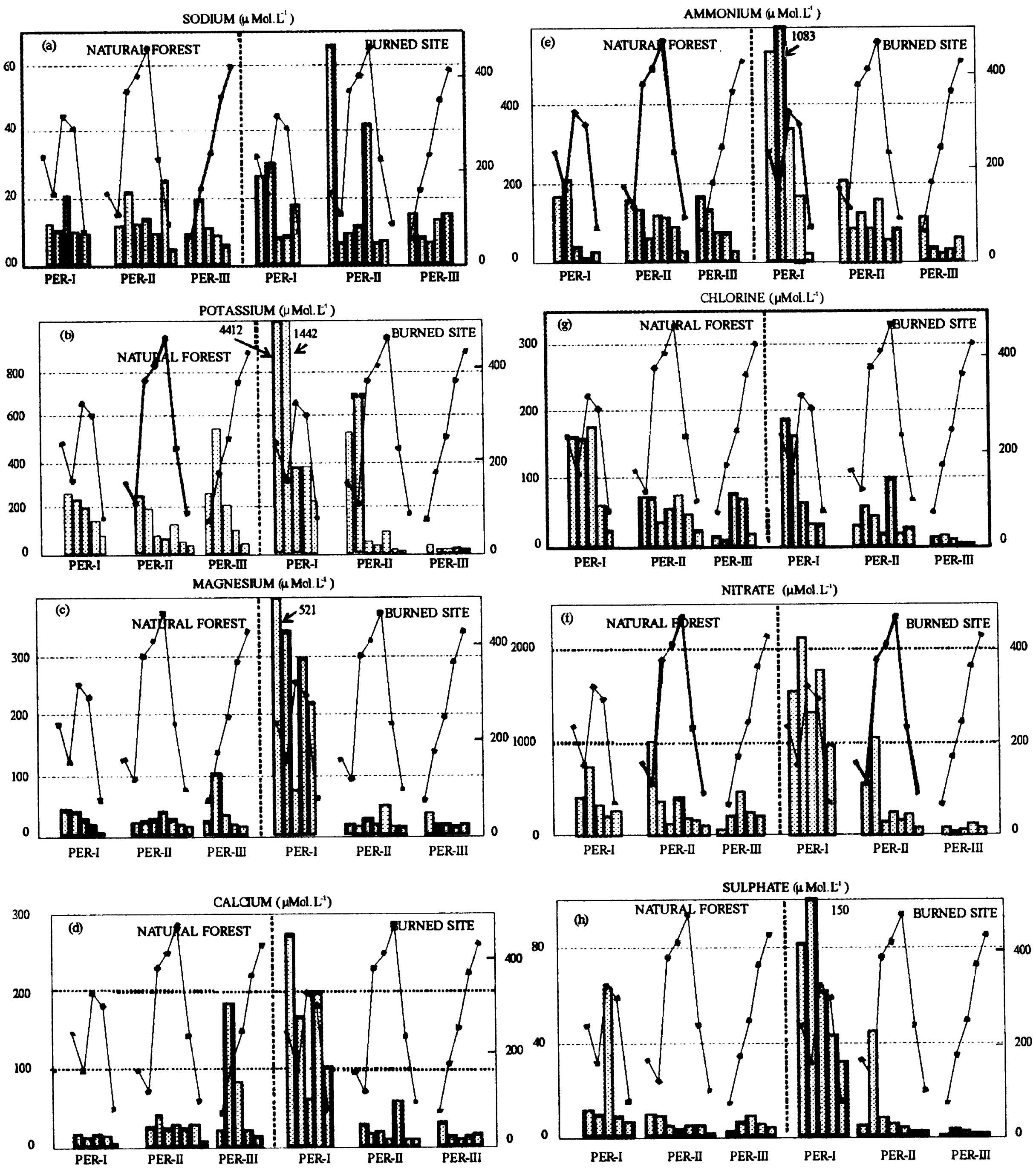

Figure 3: Monthly variation of Na^+, K^+, Mg^{2+}, Ca^{2+} NH_4^+, NO_3^-, Cl^- and SO_4^{2-} in solution (µMol.L^{-1}) in soilwater (20 cm depth) for the primary forest and burned sites during the three observational periods (PER-I: Sep1999-Jan2000, PER-II: Aug2001-Apr2002 and PER-III: Sep2002-Feb2003): columns. The rainfall heights (mm) for the same three periods are plotted in the secondary axis as a line.

The Na^+ concentration peaks observed during the second period in the burned area can be attributed to a concentration effect due to the low rainfall. The Cl^- concentration peaks observed from the second observational period onward, both in the primary forest, and in the burned area, can be attributed to an evapotranspiration effect due to the growth of regeneration vegetation in the burned area (Neil *et al.* 2006).

Lower concentrations observed in the burned area when compared with the primary forest during the third observational period are attributed to a dilution effect by the rainfall and due to a lower evapotranspiration in the burned area (Forti *et al.,* 2000b). Therefore, the observed variations of the soil-water solute concentrations in the primary forest area are comparable with the variability of the water amount circulating within the soil system and with nutrient cycling processes.

To identify a possible interrelationship among the concentrations and summarize the data set through the underlying dimensions or factors which describe them with a smaller number of concepts than the whole set of ionic concentrations, a factor analysis was used with varimax rotation (Morrison, 1978). The factor analysis results are presented in tables 3 and 4 for the forest and slash and burn site, respectively. These tables show equations which estimate the common factors after rotation has been performed, which was done to simplify the explanation of the factors. Also shown is the estimated communality, which can be interpreted as estimating the proportion of the variability in each variable attributable to the extracted factor.

Table 3: Factor Matrix with varimax rotation calculated for the solutes in the soil-water of the primary forest and communality values between variables (significant values in boldface).

Ion	Factor			Communality
	1	2	3	
Na^+	0.32458	-0.12858	**0.77617**	0.72433
K^+	**0.81398**	0.43747	0.09453	0.86288
Mg^{2+}	**0.93393**	0.10716	0.04215	0.88548
Ca^{2+}	**0.94849**	-0.20217	0.03584	0.94178
NH_4^+	0.40776	**0.74351**	-0.20950	0.76297
Cl^-	-0.16765	**0.82450**	0.46585	0.92492
NO_3^-	0.02446	**0.90532**	0.01448	0.82042
SO_4^{2-}	-0.12554	0.19376	**0.91556**	0.89156

Table 4: Factor Matrix with varimax rotation calculated for the solutes in soil-water for the burned site and communality values among the variables (significant values in boldface).

Ion	Factor		Communality
	1	2	
Na^+	0.00796	**0.95141**	0.90525
K^+	**0.76235**	0.17154	0.61060
Mg^{2+}	**0.92431**	0.04881	0.85673
Ca^{2+}	**0.88837**	0.07747	0.79520
NH_4^+	**0.76762**	0.45017	0.79143
Cl^-	**0.77944**	0.45005	0.93428
NO_3^-	**0.88424**	-0.01939	0.78226
SO_4^{2-}	**0.87053**	0.16114	0.78379

For the forest site, the data set produced three factors explaining 85 % of the variability of the data. Factor 1 explained 38 % of the variance, with high loading of K^+, Mg^{2+} and Ca^{2+}, which is associated with the exchanges processes in the soil solid phase; factor 2, with high loading of ammonium, chorine and nitrate, explains 28 % of the variance and it can be associated with the biological processes of nitrification and denitrification and dilution due to the high load of chlorine; factor 3 explains 19 % of the variance, with high loading of sodium and sulfate and moderate load on chlorine, which are minor ions not active in the biogeochemical cycles in the soil solution, thus allowing us to associate it with leaching in this soil layer.

The same analysis was carried out with the data set from the burned area. It produced a factor explaining 66 % of the variance, and another explaining 14 %. All the species but sodium have high loading in factor 1, and sodium has high load in factor 2, which could be related to the base exchange capacity of the local soil. For this data set, only one factor explains almost all of the variance; therefore, this high loading on such factor is an indication that the forest fire derived chemicals predominates over other factors that could influence the chemical composition of the soil-water.

The Pearson coefficients of the correlation matrix with linear association are presented on Tables 5 and 6 and confirm the factor analyses results for both sites. This matrix shows high correlation coefficients among the base cations K^+, Mg^{2+} and Ca^{2+} and NH_4^+ and NO_3^-, and a significant correlation between NH_4^+ and NO_3^- and between Cl^- and SO_4^{2-}. For the burned site the correlation matrix shows coefficients with high significance level for all ions but Na^+, which has a low but significant correlation with NH_4^+.

Table 5: Correlation matrix with Pearson coefficients with linear association for the solute concentrations in the primary forest. In parentheses is the significance (P) of the estimated correlation; P values below 0.05 indicate statistically significant non-zero correlation at the 95 % confidence level (significant values in boldface).

	Na^+	K^+	Mg^{2+}	Ca^{2+}	NH_4^+	Cl^-	NO_3^-	SO_4^{2-}
Na^+	1	0.2007	0.1907	0.2223	0.2088	0.0954	-0.0651	0.0124
	(0.0000)	(0.2477)	(0.2724)	(0.1993)	(0.2286)	(0.5856)	(0.7103)	(0.9437)
K^+		1	**0.7455**	**0.6720**	**0.5828**	**0.4596**	**0.4407**	0.1679
		(0.0000)	(0.0000)	(0.0000)	(0.0002)	(0.0055)	(0.0081)	(0.3351)
Mg^{2+}			1	**0.8996**	0.2846	0.0367	0.0428	0.0061
			(0.0000)	(0.0000)	(0.0975)	(0.8342)	(0.8072)	(0.9723)
Ca^{2+}				1	0.1751	-0.1220	-0.0447	-0.0253
				(0.0000)	(0.3143)	(0.4850)	(0.7986)	(0.8852)
NH_4^+					1	**0.4681**	**0.4934**	0.0775
					(0.0000)	(0.0046)	(0.0026)	(0.6579)
Cl^-						1	**0.6448**	**0.5170**
						(0.0000)	(0.0000)	(0.0015)
NO_3^-							1	(0.1858)
							(0.0000)	(0.2852)
SO_4^{2-}								1
								(0.0000)

For a better comparison among the solutions that are the object of this study, chemical species transfer from the ground to soil at 20 cm depth was estimated assuming that all the water that reaches the ground floor is transferred to this soil

Table 6: Correlation matrix with Pearson coefficients with linear association for the solute concentration in the burned site. In parentheses is the significance (P) of the estimated correlation; P values below 0.05 indicate statistically significant non-zero correlation at the 95 % confidence level (significant values in boldface).

	Na^+	K^+	Mg^{2+}	Ca^{2+}	NH_4^+	Cl^-	NO_3^-	SO_4^{2-}
Na^+	1	0.1440	0.0643	0.1995	**0.3728**	0.1978	-0.214	0.0438
	(0.0000)	(0.3454)	(0.6749)	(0.1888)	(0.0117)	(0.1927)	(0.8888)	(0.7749)
	K^+	1	**0.7385**	**0.6050**	**0.5781**	**0.3620**	**0.4167**	**0.4901**
		(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0145)	(0.0044)	(0.0006)
		Mg^{2+}	1	**0.9435**	**0.5314**	**0.3489**	**0.4897**	**0.4280**
			(0.0000)	(0.0000)	(0.0002)	(0.0188)	(0.0006)	(0.0034)
			Ca^{2+}	1	**0.5221**	**0.4557**	**0.5801**	**0.4771**
				(0.0000)	(0.0002)	(0.0017)	(0.0000)	(0.0009)
				NH_4^+	1	**0.6147**	**0.4098**	**0.5513**
					(0.0000)	(0.0000)	(0.0048)	(0.0001)
					Cl^-	1	**0.6565**	**0.7435**
						(0.0000)	(0.0000)	(0.0000)
						NO_3^-	1	**0.8466**
							(0.0000)	(0.0000)
							SO_4^{2-}	1
								(0.0000)

depth through infiltration. The amount of water reaching this soil depth at the primary forest site was estimated as the difference between the rainfall (P) and the evapotranspiration (ET). ET value (67.7 %) used in this study were obtained from literature (Leopoldo *et al.*, 1995). The amount of water that reached the soil at 20 cm for the burned experimental area was assumed to be the difference between the rainfall (P) and an evapotranspiration value of 41.8 % obtained from Leopoldo *et al.* (1995) for a similar clayish soil, during the first period (PER-I) because the soil was bare during that period. Due to the fact that during the second (PER-II) and third (PER-III) periods there were vegetation sprouts on the site, the amount of water that infiltrated was assumed to be the difference between the rainfall (P) and the evapotranspiration (67.6 %) following Holscher *et al.* (1997b), The interception was neglected because in this time scale it is eventually evaporated and therefore incorporated within the ET values or it infiltrates into the soil as dripping waters from the canopy. The rainfall, evapotranspiration and infiltration values for the different areas are presented in Table 7.

Table 7: Rainfall (P) measured values in the experimental area, primary forest evapotranspiration (ET-F), bare soil (ET-B) and calculated infiltration values for the primary forest (INF-F) and burned area (INF-B). All values are in mm.

Periods	P	ET-F	ET-B	INF-F (20 cm)	INF-B (20 cm)
			mm		
Per-I	1015	686	424	328	591
Per-II	1297	877	878	419	419
Per-III	832.3	563	564	269	269

Chemical transfer calculations were done by pooling the data by monthly mean values for the two sites which, together with the maximum and minimum concentration values, are presented in Table 8 in this table bold figures indicate that the mean values obtained for natural forest and the corresponding one in the burned site are statistically different at 95 % confidence interval for each period. The average amount of solutes in kg.ha^{-1}, transferred to the 20 cm layer of the topsoil, during the different observational periods, is presented in Table 9.

Table 8: Mean concentration, maximum (MAX) and minimum (MIN) values in µEq.L^{-1} of solutes in the soil-water at 20 cm depth for the three periods in the primary forest and burned areas. Bold figures indicate that the mean values of the forest and the corresponding one in the burned site are statistically different at 95 % confidence interval for each period.

		Na^+	K^+	Mg^{2+}	Ca^{2+}	NH_4^+	Cl^-	NO_3^-	SO_4^{2-}
					µEq.L^{-1}				
					PRIMARY FOREST				
PER-I	MEAN	12.4	**182**	**47.7**	**20.8**	**90,5**	118	**417**	**34.0**
	MAX	23.2	280	76.2	28.4	209	180	755	104
	MIN	9.07	74.6	8.06	5.18	8.30	21.8	230	11.7
PER-II	MEAN	15.2	**135**	47.7	51.7	111	67.1	384	**12.4**
	MAX	24.2	346	70.6	78.9	179	140	1186	25.2
	MIN	8.32	46.0	33.6	33.3	70.2	40.4	94.5	5.25
PER-III	MEAN	10.8	**221**	67.0	119	94.3	**34.1**	**204**	**9.65**
	MAX	18.5	494	182	332	168	68.9	420	16.6
	MIN	5.94	41.7	21.5	21.4	24.1	7.21	10.3	3.59
					BURNED SITE B				
PER-I	MEAN	18.6	**1622**	**665**	**350**	**425**	86.7	**1582**	**150**
	MAX	30.1	5688	1235	574	1083	163	2122	315
	MIN	7.91	224	165	130	19.0	33.4	944	62.6
PER-II	MEAN	23.9	**255**	46.2	55.3	113	45.2	492	**36.6**
	MAX	64.5	779	87.9	151	207	92.7	1178	102
	MIN	6.42	3.52	22.2	17.4	52.5	16.3	105	1.74
PER-III	MEAN	10.9	**20.2**	39.1	32.3	50.1	**8.35**	**59.1**	**3.65**
	MAX	16.8	38.1	74.5	68.1	111	15.0	94.4	6.49
	MIN	6.82	8.88	24.3	19.5	24.6	0.24	28.1	1.11

The variation of the transfers among the different observational periods for the primary forest site can be attributed mainly to the hydrological condition of each period because the concentration variation has an important component derived from the amount of water circulating within the soil system.

Table 9: Solutes transfer average values (total for each observational period), in kg.ha^{-1}, for 20 cm soil depth for the primary forest and burned areas.

TOT DEPOSITION	Na^+	K^+	Mg^{2+}	Ca^{2+}	NH_4^+	Cl^-	NO_3^-	SO_4^{2-}
				kg.ha^{-1}				
PRIMARY FOREST								
PER-I	0.933	23.3	1.90	1.37	5.34	13.7	84.2	5.36
PER-II	1.43	22.1	2.43	4.35	8.36	9.98	99.8	2.50
PER-III	0.665	23.2	2.19	6.39	4.56	3.25	34.1	1.25
BURNED SITE B								
PER-I	2.53	375	47.7	41.4	45.2	18.2	579	42.5
PER-II	2.30	41.8	2.35	4.64	8.51	6.73	128	7.38
PER-III	0.670	2.12	1.28	1.74	2.43	0.80	9.90	0.472

After the slash and burn of the forest, a pulse of load for all ions was observed for the first month; afterwards, it decreases along time, showing decay. The decay time can be evaluated through the ratios between the burned and the primary forest loads, whose values are shown in Table 10. These ratios indicate that, in two years, the chemical composition of the soil-water solution at 20 cm depth decays, for all ions to values lower than the ones found in the soil-water of the undisturbed primary forest except for Na^+. A decay time equivalent to the observed in this work was found by Uhl & Jordan (1984) in San Carlos de Rio Negro, in the Venezuelan Amazon.

Table 10: Ratios between the deposition values for burned (B) and primary forest (F) sites for the three observational periods for each ion.

	Na^+	K^+	Mg^{2+}	Ca^{2+}	NH_4^+	Cl^-	NO_3^-	SO_4^{2-}
				B/F				
PER-I	2.7	16	25	30	8.5	1.3	6.9	7.9
PER-II	1.6	1.9	0.97	1.1	1.0	0.67	1.3	3.0
PER-III	1.0	0.09	0.58	0.27	0.53	0.25	0.29	0.38

In general, an intense leaching into the first 20 cm soil depth of the specific solutes measured is observed during the first rainy season after the slash and burn. In the following seasons, these chemicals are absorbed by the growth of vegetation; thus, their transfer to the soil profile decays.

CONCLUSIONS

This study showed that the solute contents in the soil-water reach peak concentrations immediately after the slash and burn of the forest, with values up to 30 times larger than those observed in the primary forest. Two years after this pulse, the solute content decays to values lower than ones observed in the primary forest soil-water. This happens because the burned area, which is surrounded by forest, is quickly recolonized by regrowth of secondary vegetation that most likely has high productivity and nutrient storage rate. The observed annual variations in the leaching of solutes through soil-water at 20 cm depth for the primary forest are due to hydrological variations within the soil. In the burned area, even considering uncertainties in the estimated values, solute content variations can be attributed initially to a lack of biological activities and plant uptake and subsequently to the vigorous vegetation regrowth. The conclusion from these results is that, within the first months after the slash and burn of the forest, an intense leaching of nutrients through the soil profile occurs, eventually contributing to an abnormal increase of nutrients in the topsoil. However, this process is attenuated in time, and in two years, the soil-water chemical content reaches values equivalent to the ones observed in the primary forest soil-water.

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