Geochim. Brasil., 8(1): 51-63, 1994

HYDROCHEMISTRY OF SOIL SOLUTION COLLECTED WITH TENSION-FREE LYSIMETERS IN NATIVE AND CUT-AND-BURNED TROPICAL RAIN FOREST IN CENTRAL AMAZÔNIA

M.C. Piccolo[1], F. Andreux[2], C.C. Cerri[1]

1. Centro de Energia Nuclear na Agricultura, Universidade de São Paulo, Piracicaba, SP, Brasil

2. Centre de Pedologie Biologique, Nancy, França

Recebido em: 12/93. Aprovado para publicação em: 03/94

ABSTRACT

The mineral composition of the soil solution was studied during 16 months (one dry season and two humid periods), using zero-tension cylinder and plate lysimeters in native and burned forest on a yellow clayey latosol in Central Amazônia. In both sites and both types of lysimeters, Al^{3+}, Si^{4+}, NO_3^- and SO_4^{2}- were the predominant ions. Cylinder lysimeters measured greater concentrations of most ions than plate lysimeters, suggesting higher fluxes of ions as a result of the disturbance associated with installation of cylinder lysimeters. In the soil surface (0 to 0.20 m) and cylinder lysimeters the total fluxes of the most abundant ions (Si^{4+}, NH_4^+, NO_3^-, MG^{2+}, SO_4^{2-}; K^+, Ca^+, Mn^{2+}) were higher in the burned forest, during the humid period immediately following forest cutting and burning in the natural forest. Fluxes of Na^+, Cl^- and Zn^+ were larger in the native forest than in the burned forest, and fluxes of Al^{3+} and Fe^{2+} were similar in both forests. During the first dry season and second rainy season that followed the forest cutting and burning, the fluxes of all elements in surface soils were larger in the native forest than in the burned forest. A greater percentage of total rainfall passed through the cylinder lysimeters in the burned forest during the first humid period following cutting and burning, but a greater percentage of total rainfall was collected from lysimeters in native forest during the following dry season and second humid period. The total amount of water percolating the cylinder lysimeters decreased in both sites with time, suggesting a deterioration of the soil structure. Continued litter input to the forest soil may be the main cause of the observed high ionic fluxes through the soil, but not in cut and burned forest, it may contribute to higher fluxes of water of the deforested area approximately six months after the forest cutting and burning.

RESUMO

A composição mineral da solução do solo foi estudada durante 16 meses (uma estação seca e dois períodos úmidos), utilizando lisímetros de gaveta e cilíndrico (tensão zero), em dois locais: um em floresta natural e outro após o desmatamento e queimada da vegetação da floresta. As áreas estudadas estão localizadas na Amazônia Central e os solos aí encontrados são do tipo latossolo amarelo argiloso. Em ambos os locais e nos dois sistemas lisimétricos, os íons Al^{3+}, Si^{4+}, NO_3^- e SO_4^{2-} foram predominantes na solução do solo, sendo que as concentrações maiores foram observadas na solução do solo amostrada com lisímetro cilíndrico. Esse resultado sugere que os fluxos iônicos mais elevados observados nos lisímetros cilíndricos decorre da alteração do solo devido a instalação desses lisímetros. Os fluxos totais dos íons mais abundantes (Si^{4+}, NH_4^+, NO_3^-, Mg^{2+}, SO_4^{2-}; K^+, Ca^+ e Mn^{2+}), determinados nos lisímetros cilíndricos durante o primeiro período úmido na superfície do solo (0 a 0,20 m), foram maiores sob floresta queimada do que sob floresta natural. Os fluxos de Na^+, Cl^- e Zn^{2+} foram maiores sob floresta natural e os fluxos de Al^{3+} e Fe^{2+} foram similares para os dois locais. Os fluxos dos íons durante a estação seca e durante o segundo período úmido, após o corte e a queima da floresta, foram maiores para todos os elementos na superfície do solo sob floresta natural. A maior porcentagem da precipitação percolada, coletada com os lisímetros cilíndricos, foi observada sob floresta queimada durante o primeiro período úmido, após o corte e a queima da vegetação, e sob floresta natural durante a estação seca e o segundo período úmido. A recuperação total da água percolada através dos lisímetros cilíndricos decresceram com o tempo nos dois locais, sugerindo a deterioração da estrutura do solo. A entrada contínua de serapilheira para o solo da floresta natural pode ter contribuído para os altos fluxos iônicos observados aproximadamente seis meses após o corte e a queima da floresta.

INTRODUCTION

The Amazon Basin contains about two thirds of the total area of world tropical forests, with about 7 millions of km², and one of the largest diversity of animal and plant species (Malingreau & Tucker, 1988).

Deforestation of the Amazon Basin has been increasing and is estimated to have reached a rate of 21,000 km² per year (Fearnside et al., 1990). The most traditional land use consists of felling the main trees, removing economically important wood, and burning the remaining vegetation (Fearnside, 1984). In the cleared areas, annual and perennial crops as well as pastures have been introduced (Dematte, 1988). In other places, extensive grazing pastures have been installed and maintained for more than ten years, resulting in strong modifications in litterfall, faunal and microbial populations, and related biogeochemical cycles.

Little is known about the composition of the soil solution, its role in the nutrient cycling in tropical forests and changes that follow land-use alterations. Lysimeters systems allow collection of the whole percolating soil solution with a periodicity that can vary from daily to weekly, according to local and microclimatic conditions. Several different methods have been reported to characterize the soil water in central Amazônia, including cylinder tension-free lysimeters (Santos & Ribeiro, 1975), porous cup samples (Northcliff & Thornes, 1978), cylindrical tension-free lysimeters and plate collectors (Chauvel et al., 1989), conical traps to collected water percolating through litter material (Luizão, 1989), and cylindrical tension-zero lysimeters (Uhl & Jordan, 1984). The present work describes an experiment with tension-free lysimeters that was carried out during 16 months (one dry season and two humid periods) in the Central Amazonian forest. The concentrations and fluxes of the major soluble ions in native and cut and burned forest vegetation are compared.

MATERIALS AND METHODS

Location and climate

The field studies were carried out in the farm of the "Fundação Centro de Apoio ao Distrito Agropecuário" (FUCADA), located in the State of Amazonas, Brazil, near the Boa-Vista Highway (2°36'N and 60°02'E), 40 km north of Manaus. The farm was established in 1985 in an area of tropical rain forest, part of which has been clear-cut and replaced by annual crops and pastures. The native vegetation is a high and primary forest, which was classified by the "Instituto de Pesquisas Agropecuárias da Amazônia Ocidental" (IPEAAOc, 1971) as "Floresta Equatorial Úmida de Terra Firme". Litterfall and roots represent major nutrient inputs to the soil under forests growing on poor soils (Singh, 1968; Gosz et al., 1976; Herrera et al., 1978).

The regional climate is Am in the Koppen classification and corresponds to a "rainy tropical climate" with a relatively dry season between July and September (Marques Filho et al., 1981). The mean annual temperature is 26.7°C, with minimum values of 23.5°C and maximum values of 31.2°C. The mean annual precipitation is 2.10 m. The rainy period is concentrated between November and May, with 82% of the total annual rainfall, and a maximum in March. The soil water balance, carried out using the Thornthwaite method (IPEAAOc, 1971), shows a highly significant period of water deficit between July and October, and another period with a large water excess from Jannuary to May. The humid tropical climate favors mineral weathering, with a permanent removal of the solutes through percolation processes (Van Raij, 1991).

Soils

The soils, located in flat or gently rolling terrain, are "latossolos amarelos muito argilosos" (oxisols) in the Brazilian taxonomy (Camargo et al., 1987) or "xanthic feralsols" in the FAO classification (FAO-UNESCO, 1988). They are developed on uplands of a tertiary sediments belonging to the Barreiras complex (Lucas et al., 1984). They have a high content (70-80%) of iron-poor kaolinite clay minerals in the whole profile, and a soil organic matter (SOM) content of less than 4% in the 0 to 0.1 m layer; these soils are generally deep, well drained and with low erosion rates. Their most characteristic vegetation is the dense rain forest (Dias et al., 1980; Guillaumet & Kahn, 1982).

The forest was covered with a leaf litter, containing between 5 and 6 kg m^{-2} of carbon (Klinge et al., 1975). A thin (0 to 0.01 m) O horizon, formed by decomposing plant remains, was followed by a Al (0.01 to 0.07m) and a A3 (0.07 to 0.20 m) with decreasing light brown to grayish color (from 10YR 6/3 to 10YR 7/4). Soils had clay texture and a moderate, fine to medium, subangular blocky structure. Many fine and very fine pores and channels and many fine to coarse roots were visible. In the entire profile, the consistency was firm when moist, plastic and sticky when wet, and the transition between horizons were flat and diffuse. In the A_3 horizon, sparce fragments of charcoal were observed. The underlaying B_{21} (0.20 to 0.43 m), B_{22} (0.43 to 0.80 m), B_{23} (0.80 to 1.20 m), and B_{24} (1.20 to 1.70 m) horizons were yellow (from 10 YR 7/6 to 7/8), and similar in texture, structure and porosity to the surface horizons. Increasing friability and decreasing root density with increasing depth were the only noticeable changes.

The clay-size fraction increases, with depth, up to 94% below 1 m (Table 1). The low fertility was illustrated by the low values of pH, exchangeable bases, cation exchange capacity and base saturation. Carbon (C) and nitrogen (N) contents decrease sharply in the first 0.20 m, as did exchangeable bases. The C/N ratio was relatively low and decrease with depth from 11 to 6.

Experimental Design

The study sites, consisting of a native forest and cut and burned forest site, were located on a flat plateau, at an elevation of about 500 m. The native and burned areas were about 1000 m apart. Felling was performed manually in July 1986; the felled material was piled up, allowed to dry on site, and burned in December 1986; in the burned area, litter and the woody debris were converted into a 0.01 to 0.04 m thick layer of ash, charcoal, and imperfectly burned residues, which amounted to about 1.0 kg m^{-2} (Cerri et al., 1991). The soil surface remained bare for several weeks, and exposed to sunlight and rainfall, and the residues of burning were progressively decomposed and mixed together with soil microaggregates and particles.

At each site, in January 1987, a pit of 3 m long and 2 m wide, with one floor located at 2 m and another at 3 m depth, was dug, without altering the forest floor. Two types of lysimeters were installed (Fig. 1).

Cylinder lysimeters – These devices were cut from PVC tubes 0.13 m in diameter, and 0.20 or 1.20 m in long. A round plate of PVC, perforated with 1 mm holes, was placed at the bottom end of each tube. Before adjusting the plate, a nylon net with a 200 μm mesh was placed on its internal face. The tubes were then placed vertically against one wall of the pit. Soil profiles in the cylinders were reconstructed from soil collected from the pit at 20 cm intervals. The 0.20 m long lysimeter contained mixed soil from 0-0.20 m. The 1.20 m long lysimeter contained soil collected from 1.20 to 1.00 m, 1.00 to 0.80, 0.80 to 0.60, 0.60 to 0,40 and 0.40 to 0.20. The amount of soil added inside the cylinder for each layer was calculated based on soil bulk density. At the bottom of each lysimeter, a funnel and a teflon pipe were connected to transfer the percolates to a plastic tank. Duplicate 0.20 m lysimeters were installed at each site, and a single 1.20 m lysimeter was used.

Plate lysimeters – These devices were firm plastic trays 0.50 m long and 0.40 m wide, with one end removed. In one end of the tray, opposite to the removed side, a 10 mm hole was drilled, to which small plastic outlet was attached, used to connect a teflon pipe similar to that used for the cylinders. The trays were then placed in horizontal slots carved into one wall of each pit. Duplicate plates were installed in the 0.20 m in the native forest and in the burned site. One plate was installed in each site at 0.60 m and 1.50 m depths.

After installation of all devices, the pit walls were covered with planks, and the pits were covered with a mobile plastic.

Organization of Sampling

Sampling was conducted from February 1987 to May 1988. Sampling was carried out daily, or as frequently as the minimal volume required for the analyses (50 to 100 ml) was obtained. We considered data from 3 periods: 1) the first humid period (February to May 1987), 2) the dry season (June to October 1987) and 3) the second humid period (February to May 1988). The period between November 1987 and January 1988 was not considered to allow a direct comparison between the same months of the humid period of both years. Daily rainfall data were obtained from the FUCADA station records.

The ions NH_4^+-N, NO_3^--N, SO_4^{2-}; Cl^-, Al^{3+}, Ca^{2+}, Fe^{2+}, K^+, Mg^{2+}, Mn^{2+}, Na^+, Si^{+4} and Zn^{2+} were followed during 16 months of the experiment in leachate from both plate and cylinder lysimeters. The soil input-output water balance was calculated for the cylinder lysimeters. Fluxes (ion concentration multiplied by water volume collected) of each element from the cylinder lysimeters were calculated for

Table 1 – Main physical and chemical characteristics of the study soil (IPEAAOc, 1971).

		Granulometry %													
Depth	pH in water	Sand	Silt	Clay	Ca	Mg	Na	K	H	Al	CEC[1]	% Base	C	N	C/W
(m)	(1:1 w/v)	20-200 μm	2-20 μm	0-2 μm				c mole Kg^{-1}				Set	%	%	
0.00-0.07	3.4	13	10	77	0.42	0.10	0.05	0.08	14.6	4.2	19.4	3.1	4.16	0.36	11
0.07-0.20	3.9	12	8	80	0.12	0.06	0.03	0.05	6.5	2.1	8.9	3.4	1.66	0.16	10
0.20-0.43	4.5	6	9	85	0.06	0.02	0.03	0.03	4.2	1.0	5.3	1.9	0.85	0.10	9
0.43-0.80	5.1	7	2	91	0.04	0.02	0.02	0.02	2.4	0.8	3.3	3.0	0.45	0.05	8
0.80-1.20	5.3	6	1	93	0.06	0.02	0.03	0.02	2.2	0.8	3.1	3.2	0.34	0.05	7
1.20-1.70	5.4	5	1	94	0.04	0.02	0.02	0.02	2.1	0.4	2.6	3.8	0.24	0.04	6

1. CEC = cation exchange capacity (pH = 7.0)

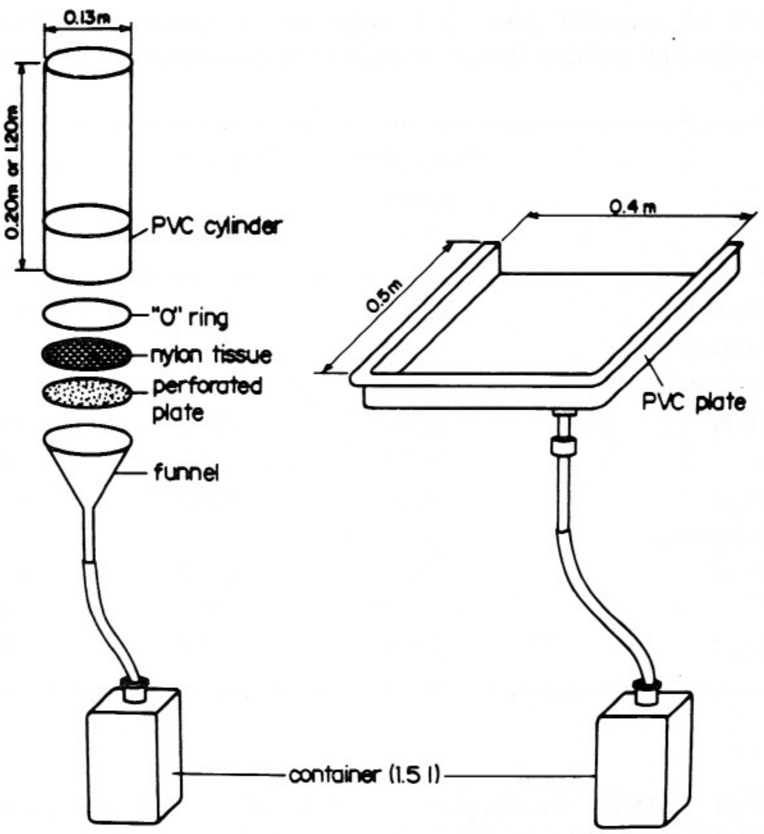

Figure 1 – Schematic representation of the cylinder and plate lysimeters.

each sample. Individual fluxes were summed to give the cumulative flux for each period.

Method of soil solution analysis

Analyses for total Si^{4+}, cations (NH_4^+, Na^+, K^+, Ca^{2+}, Mg^{2+}, Mn^{2+}, Fe^{3+}, Al^{3+}, Cu^+, Zn^{2+}), and mineral anions (SO_4^{2-}; NO_3^-, Cl^-) were carried out according to Standard Methods for the Examination of Water and Wastewater (1975). Solution pH was determined with a Metrohm 632 pH-meter. Water samples were then filtered through a 0.45 μm Millipore cellulose acetate filter; one part of the filtrate was preserved with 1ml L^{-1} of sulfuric acid, and another part with 1ml L^{-1} of nitric acid, to allow measurements of nitrogen forms and the other nutrients, respectively. In some cases, such a preservation treatment was not done, either immediately after water sampling, or at all. Ammonium (NH_4^+-N) and nitrate (NO_3^--N), Cl^- and SO_4^{2-} were analyzed in a Micronal B34211 spectrophotometer, using a continuous flow injection technique (Ruzicka & Hansen, 1981), by colorimetry for nitrogen and Cl^-, and turbidimetry for SO_4^{2-}: The main cations (Na^+, K^+, Mn^{2+} and Mg^{2+}) were analyzed in a Perkin Elmer Model 306 atomic absorption spectrophotometer. Other elements, such as Al^{3+}, Ca^{2+}, Fe^{3+}, Si^{4+} and Zn^{2+}, were measured by ICP spectrophotometer, using a Jarrel-Ash Model 975 spectrometer.

RESULTS

Recovery of percolated water

The total volume of water recovered in cylinder lysimeters was less than total rainfall during all sampling periods (Table 2). The total rainfall obtained during the 16 months of the experiment was 3,159 mm, of which each humid period represented about one third. During the dry season, the rainfall was 14% of the total, or 21%

Table 2 – Volumes of rainfall and soil solution in samples collected with cylinder lysimeters under native and burned forest. Numbers in parentheses indicate standard errors.

	First humid period 1987	Dry season 1987	Second humid period 1988
Rainfall (L m^{-2})	1035.3	431.8	1119.1
Soil Solution (L m^{-2})			
Native Forest			
0-0.20 m	820.4	294.6	621.2
	(64.2)	(14.3)	(4.1)
0-1.20 m	746.6	301.4	447.5
Burned Forest			
0-0.20 m	1079.2	193.2	438.8
	(369.1)	(4.2)	(107.7)
0-1.20 m	695.4	125.1	349.6

of the annual rainfall. Rainfall was higher in the humid period of 1988 than in 1987, but larger volumes of percolated water were recovered in 1987.

In the native forest, the percolated volumes obtained in the 0.20 m and 1.20 m cylinders represented 79 and 72% of rainfall for the first humid period, 55 and 40% for the second humid period, and 68 and 70% for the dry season. During the first humid period and the dry season, the proportions of collected solutions were similar at the surface and at depth, whereas in the second humid period, they were much lower at 1.20 m.

During the first humid period, the mean volume that percolated through 0.20 m in the burned forest was close to that of the corresponding rainfall, whereas that percolated through 1.20 m represented only 67% of rainfall. During the second humid period, the percentages of percolated volumes were smaller than in the first humid period, and were 39 and 31% at 0.20 m and 1.20 m depths, respectively. During the dry season, the respective percentages at 0.20 m and 1.20 m were 45 and 29%.

Similar volumes of water were recovered at 0.20 m with the cylinder devices during the whole experiment in the native and the burned forest. The percolated volume of water was higher from burned than from native forest only during the first humid period. The volumes recovered at 1.20 m were lower from the burned than from the native forest, with only small differences during the first humid period, and larger differences during the dry season and the second humid period.

pH and ionic concentrations

The pH of solutions from the cylinders in the native forest varied between 3.7 and 5.6 at 0.20 m depth, and between 3.9 and 6.4 at 1.20 m depth. In the burned forest, they varied in a similar way, between 3.8 and 5.6 at 0.20 m depth, and between 4.1 and 6.5 at 1.20 m depth. Solutions collected from plate lysimeters showed the same range of variation as the cylinders, but the pH values in the solutions were generally higher than those of the soils sampled at the respective depths in the cylinders. No specific effect of the burning on the annual variations of pH in the solution was detected.

Average ionic concentrations in the percolated solutions varied considerably from one location to another, as well as with time (Table 3). As a general feature, higher concentrations were found in the samples from the cylinders than in that from the plates, at similar depths. For all ions, at 1.20 m, concentrations two to three times higher were frequently observed in the native forest than in the burned forest. At 1.20 m deep, the concentrations were

Table 3 – Mean concentrations (in mole L^{-1} of cations, anions, silicium and aluminium in the soil solution collected with cylinder and plate lysimeters during the 16 months of the experiment.

	Cations		Anions			
	Monovalents	Divalents	Monovalents	Divalents	Si^{4+}	Al^{3+}
	H^+, Na^+, K^+, NH_4^+	(Ca^{2+}, Mg^{2+}, Mn^{2+})	(NO_3^-, Cl^-)	(SO_4^{-2})		
Cylinder Lysimeters						
Native Forest						
0-0.20 m	0.54	0.13	0.21	0.03	0.06	0.16
0-1.20 m	0.24	0.05	0.08	0.02	0.02	0.02
Burned Forest						
0-0.20 m	0.16	0.09	0.12	0.02	0.06	0.05
0-1.20 m	0.18	0.12	0.11	0.02	0.03	0.01
Plate Lysimeters						
Native Forest						
0.20 m	0.17	0.02	0.07	0.03	0.05	0.03
0.60 m	0.17	0.02	0.04	0.03	0.02	0.01
1.50 m	0.06	0.02	0.01	0.02	0.05	0.03
Burned Forest						
0.20 m	0.11	0.04	0.04	0.05	0.06	0.12
0.60 m	0.11	0.04	0.09	0.02	0.06	0.06
1.50 m	0.12	0.05	0.04	0.16	0.17	0.12

not always smaller than at 0.20 m. At 0.20 m, and from the native forest, the concentrations of monovalent cations (Na^+, K^+, Na_4^+ and H^+) were about five to ten times higher than those of divalent cations. At 1.20 m, especially under the burned forest, the ratio between mono- and divalent cations was lower than at 0.20 m. The concentrations of Al strongly decreased at 0.20 m under the burned forest (Table 3). Si^{+4} also generally decreased with depth (except in the plate lysimeters at 1.50 m), than can be explained as a consequence of burning.

Seasonal fluxes of solutes

The fluxes of ions in the native and burned forest were calculated from the cylinder lysimeters for the first humid period, dry season, and second humid period (Fig. 2). In the native forest, Al^{3+}, Si^{4+}, NO_3^- and N^+ fluxes were larger in the 0 to 0.20 m lysimeter during the first humid period. During the dry season at 0 to 0.20 m, the dominant ions were NH_4^+, Al^{3+}, NO_3^- and Si^{4+}. During the second humid period at the 0 to 0.20 m depth, the most abundant ions were Al^{3+}, NO_3^-, Si^{+4} and Ca^{2+}. In the deeper 1.20 m lysimeter, Ca^{2+} and Mg^{2+} were more abundant than at the shallower depth during the second humid period. During the dry season, there was a decrease in the amount of Al^{3+}, and an increase in the amount of SO_4^{2-} compared with the shallower depth (Fig. 2).

In the burned forest, the fluxes of most ions were larger when compared with native forest, during the first humid period (Fig. 2). In the 0 to 0.20 m lysimeters, the amount of all soluble ions except Na^+, Cl^-, and Zn^{2+} were higher than in the native forest during the first humid period (Fig. 2). At 1.20 m, the amounts of Al^{3+} and

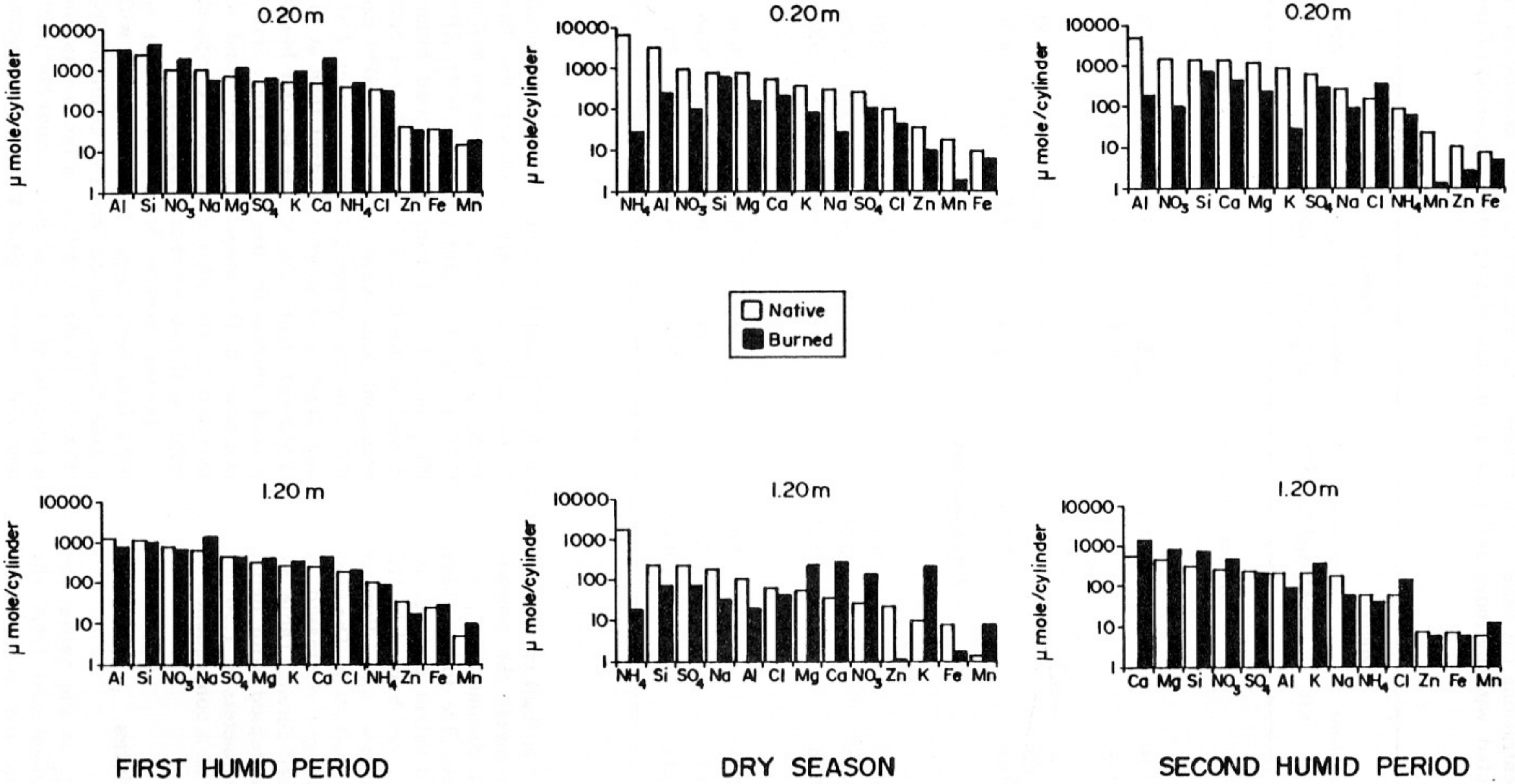

Figure 2 – Flux of main anions and cations in soil solutions collected with cylinder lysimeters on 0.20 m and 1.20 m deep during the first humid period (1987), dry season (1987) and second humid period (1988) under native and burned forest.

Zn^{2+}, measured during the first humid period, were slightly lower than in the 0 to 0.20 m lysimeter.

During the dry season and the second humid period, the fluxes were generally larger from the natural forest than in the burned forest (Fig. 2). It is observed a strong decrease in the fluxes of elements at the two depths, with the exception of K^+, Ca^{2+}, Mg^{2+}, NO_3^- and Mn^{2+}. For the entire duration of the experiment, fluxes of major ions were higher at 0.20 m under the native forest than under the burned forest (Fig. 2).

DISCUSSION

In spite of existing data on nutrient dynamics in the Amazon forest, no long-term experiments have been conducted to study variations in concentrations and seasonal fluxes of soluble elements under the native forest, nor following forest clear-cutting and burning. In this experiment, cylinder lysimeters were artificial soil columns in which the water fluxes were forced vertically. Although they represented a major disturbance of the soil system, they had the advantage of making possible calculations of water balance and solute fluxes. The plate lysimeters were open systems which introduced less disturbance, did not modify the structure of the soil layers, and had minimal effect on the plant root systems. However, the plate lysimeters allowed determination of seasonal changes in solute concentrations under undisturbed soil, but did not provide water balances.

Greater concentration of all ions at similar depth found in cylinder lysimeters compared with plate lysimeters, suggested that a disturbance associated with the installation of the cylinder lysimeters or the absence of plant roots and plant element uptake increased solute concentrations relative to undisturbed soil. In the plate lysimeters, root growth and nutrient uptake was not affected.

Despite some disturbance effect associated with installation of the cylinder lysimeters, there were clear differences in the dynamics of water and losses of nutrients in native forest and burned forest sites. The most immediate effect in the water balance was related to the removal of the forest cover. The soil under native forest probably received a lower input of water, since the forest canopy generally intercepts and evaporates approximately 16% of total rainfall (Greenland & Kowal, 1960). In the burned site, the direct impact of raindrops and of sunlight is responsible for a loss of surface soil structure (Martins et al., 1991). At the beginning of the experiment (first humid period), percolation was enhanced in the newly created soil column, it then decreased with time, because of increasing compaction of the subsoil inside the cylinders. Similar effects have been observed in lysimeters in temperate forests (Gras et al., 1988).

Patterns of nutrient concentrations suggest other changes associated with forest burning. Soil solutions were more acidic at 0.20 m than at 1.20 m in both systems, probably due to the higher organic acidity in the surface layer (Andreux et al., 1987). A temporary neutralization of acidity in the surface soil by alkaline ash material probably occurred following burning (Martins et al., 1990), but this was not detected in soil water. Other studies have reported increased soil pH immediately following forest cutting and burning (Nye & Greenland, 1964; Brinkmann & Nascimento, 1973; Sanchez et al., 1983; Martins et al., 1990). These effects of forest clearing and burning on soil pH may be short-lived, however, if the forest is allowed to regrow. Uhl et al. (1982) found only slightly greater soil pH (<0.5 unit) in regrowing forest three years after burning. There are few data on the pH of soil solution following burning. Uhl & Jordan (1984) reported similar soil solution pH in natural forest and 5-year-old successional site on a cut and burned forest.

The larger fluxes of most cations and anions in soil water in the burned forest, compared with the natural forest that were measured in this study during the first humid period following the burning, were consistent with the results of a number of other studies that found increases of soil Ca^{2+}, Mg^{2+} and K^+ following forest burning (Nye & Greenland, 1964; Brinkmann & Nascimento, 1973; Ewel et al., 1981; Sanchez et al., 1983). Uhl et al. (1982) and Uhl & Jordan (1984) observed an increase in Ca^{2+}, Mg^{2+}, K^+ and NO_3^- concentrations in soil solution, during approximately three years following forest burning and they concluded that the larger fluxes came from the burned forest; an increase in concentrations and fluxes of soil cations and anions following disturbance also occur in temperate forests (Likens et al., 1977).

In contrast to other studies that observed a continuous increase in ionic concentrations in soil solution, for a period of approximately three years following burning (Uhl & Jordan, 1984), the fluxes measured in this study in the dry season (six to ten months following burning) and in the second humid period (ten to sixteen months following burning) were larger in the natural forest than in the cut and burned forest. The possible explanations for this result were: 1) a destruction of soil structure with time, especially in the burned forest, which reduced water fluxes, and 2) absence of new litter, and hence, ionic inputs to the burned forest soil. Also, there is a probability that larger fluxes of elements from the burned forest may not have been sampled, due to the fact that sampling in this study began in January, approximately one month after forest burning.

Natural forest vegetation plays an important role in the cycling of minerals, maintaining the mineral composition of surface soils and preventing mineral losses in soil solution (Lucas et al., 1993). Our results indicated that losses of elements from surface soil to the soil solution, during the dry season and second humid period, following forest cutting and burning, were higher in natural forest, when compared with cut and burned forest. Continuous litter input to the soil surface, which occur in natural forest but not in cut and burned forest, may be critical to regulate the concentrations of most ions in soil solution.

ACKNOWLEDGMENTS

The authors wish to thank the CNPq (Brazil), ORSTOM (France), and EEC-STD2 Program for supporting this research. They are indebted to the Fundação "FUCADA" (Manaus-Brazil) for the help provided during the field work. They are grateful to the Soil Chemistry and Analytical Chemistry Departments of CENA for their assistance with the chemical analyses. Advice received from Drs. F. Sondag (ORSTOM, Bondy, France), J.L. Probst (CNRS-CGS, Strasbourg, France) and C. Neil (The Ecosystems Center, Woods Hole, Massachusetts, USA) was also greatly appreciated.

REFERENCES

ANDREUX, F.; CERRI, C.C.; MELLO, E.; KRUG, F.J. (1987) Composição mineral da água livre de um latossolo sob floresta Amazônica e após a queimada. In: Proc. Congr. Bras. Ci. Solo, Campinas, SP, 19-25/07, **123**: 118-119.

BRINKAMNN, W.L.F. & NASCIMENTO, J.C. (1983) The effects of slash and burn in agriculture on plant nutrients in the Tertiary region of Central Amazônia. Turrialba, **23**: 284-290.

CAMARGO, M.N.; KLAMT, E.; KAUFFMAN, J.H. (1987) Sistema Brasileiro de Classificação de Solos. B. Inf., Soc. bras. Ci. Solo, Campinas, **12**(1): 11-33.

CERRI, C.C.; VOLKOFF, B.; ANDREUX, F. (1991) Nature and behaviour of organic matter in soils under natural forest and after deforestation, burning and cultivation near Manaus. Forest Ecol. Manag., **38**: 247-257.

CHAUVEL, A.; ANDREUX, F.; CERRI, C.C.; LUCAS, Y. (1989) Superficial Evolution of Amazonian Bauxite Deposits. In: 6th International Congress of ICSOBA, Poços de Caldas, Brasil. May 11-20, 1989, Académie Yougoslave des Sciences et des Arts, **19**: 45-53.

DEMATTE, J.L.I. (1988) Manejo de solos ácidos dos Trópicos Úmidos, Região Amazônica. Fundação Cargill, Campinas, Brasil.

DIAS, A.C.P.; NEVES, A.D.S.; BARBOSA, R.C.M. (1980) Levantamento de solos da Estação Experimental Rio Negro. Boletim Técnico CEPLAC, **71**, 13p.

EWEL, J.; BERISH, C.; BROWN, B.; PRICE, N.; RAICH, J. (1981) Slash and burn impacts on a Costa Rican wet forest site. Ecology, **62**: 816-829.

FAO-UNESCO (1988) Soil map of the world. Revised legend. World Resources Report 60. Food and Agriculture Organization, Rome.

FEARNSIDE, P.M. (1984) Agriculture in Amazônia. In: G.T. Prance and T.E. Lovejoy, Eds., Key Environments: Amazônia. Pergamon Press, Oxford, pp. 393-418.

FEARNSIDE, P.M.; TARDIN, A.T.; MEIRA FILHO, L.G. (1990) Deforestation rate in Brazilian Amazônia. National Secretariat of Science and Technology, Manaus, 8p.

GOSZ, J.R.; LIKENS, G.E.; BORMANN, F.H.

(1976) Organic matter and nutrient dynamics of the forest and forest floor in the Hubbard Brook Forest. Oecologia, **22**: 305-320.

GRAS, F.; MERLET, D.; ROUILLER, J.; BECQUER, T.; BARTOLI, F. (1988) Effet des apports acides sur la libération de l'aluminium dans les sols forestiers du Massif Vosgien. In: Rapport Programme DEFORPA, No. 86319, C.P.B.-C.N.R.S., Vandoeuvre, France, 38p.

GREENLAND, D.J. & KOWAL, J.M.L. (1960) Nutrient content of the moist tropical forest of Ghana. Plant and Soil, **12**: 154-174.

GUILLAUMET, J.L. & KAHN, F. (1982) Structure et dynamisme de la forêt. Acta Amazônia, **12**: 61-67.

HERRERA, R.; JORDAN, C.F.; KLINGE, H.E.; MEDINA, E. (1978) Amazon ecosystems: Their surface and functioning with particular emphasis on nutrients. Interciência, **3**: 223-232.

IPEAAOc (1971) Solos do Distrito Agropecuário da Suframa, Manaus (AM). Boletim do Instituto de Pesquisas e Experimentação Agropecuária da Amazônia Ocidental, **1**, 99p.

KLINGE, H.; RODRIGUES, W.A.; BRUNIG, E.; FITTKAU, E.T. (1975) Biomass and structure in a central Amazonian rain forest. In: F.B. Goley & E. Medina, Eds., Tropical Ecological System, Ecological Studies, 11, Springer Verlag, New York, pp. 115-120.

LIKENS, G.E.; BORMANN, F.H.; PIERCE, R.S.; EATON, T.S.; JOHSON, N.M. (1977) Biogeochemistry of a forested ecosystem. Springer-Verlag, NY, 146p.

LUCAS, Y.; CHAUVEL, A.; BOULET, R.; RANZANI, G.; SCATOLINI, F. (1984) Transição latossolos-podzois sobre a formação Barreiras na região de Manaus-Amazônia. Rev. Bras. Ci. Solo, **8**: 325-335.

LUCAS, Y.; LUIZÃO, F.J.; CHAUVEL, A.; ROUILLER, J.; NAHON, D. (1993) The relation between biological activity of the rain forest and mineral composition of soils. Science, **260**: 521-523.

LUIZÃO, F.J. (1989) Litter production and mineral element input to the forest floor in a central Amazonian forest. GeoJournal, **19**: 407-417.

MALINGREAU, J.P. & TUCKER, C.J. (1988) Large-scale deforestation in the southeastern Amazon Basin of Brazil. Ambio, **17**: 49-55.

MARQUES FILHO, A.O.; RIBEIRO, M.N.G.; SANTOS, H.M.; SANTOS, J.M. (1981) Estudos climatológicos da reserva Ducke (AM). Acta Amazônica, **11**: 579-68.

MARTINS, P.F.S.; CERRI, C.C.; VOLKOFF, B.; ANDREUX, F. (1990) Efeito do desmatamento e do cultivo sobre características físicas e químicas do solo sob floresta natural na Amazônia Oriental. Rev. IG, São Paulo 8-10, **11**(11): 21-33.

MARTINS, P.F.S.; CERRI, C.C.; VOLKOFF, B.; ANDREUX, F.; CHAUVEL, A. (1991) Consequences of clearing and tillage on the soil of a natural Amazonian ecosystem. For. Ecol. Manage., **38**: 273-282.

NORTHCLIFF, S. & THORNES, J.B. (1978) Water and cation movement in a tropical rainforest environment. Acta Amazônica, **8**: 245-258.

NYE, P.H. & GREENLAND, D.J. (1964) Changes in the soil after clearing tropical forest. Plant and Soil, **21**: 101-112.

RUZICKA, J. & HANSEN, E.H. (1981) Flow injection analyses. Wiley Interscience, NY, 271p.

SANCHEZ, P.A.; VILLACHIA, J.H.; BANDY, D.E. (1983) Soil fertility dynamics after clearing a tropical rainforest in Peru. Soil Sci. Soc. Am. J., **47**: 1171-1178.

SANTOS, A. & RIBEIRO, N.M. (1975) Nitrogênio na água do solo de ecossistema de Campina Amazônica. Acta Amazônica, **5**: 173-85.

SINGH, K.P. (1968) Litter and nutrient turnover in deciduos forest of Varanasi. Proc. Symp. Adv. Trop. Ecol., 655-665.

STANDARD Methods for the Examination of Water and Wastewater 1975. APHA/AWWA/WPCE, 1193p.

UHL, C. & JORDAN, C. (1984) Succession and nutrient dynamics following forest cutting and burning in Amazônia. Ecology, **65**: 1476-1490.

UHL, C.; JORDAN, C.; CLARK, K.; CLARK, H.; HERRERA, R. (1982) Ecosystem recovery in Amazon coatings forest after cutting, cutting and burning, and bulldozer clearing treatments. Oikos, **38**: 313-320.

VAN RAIJ, B. (1991) Fertilidade do solo e adubação. Piracicaba, SP. CERES, POTAFOS, 343p.