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Hydrochemistry of soil water following a slashing and burning of a "Terra Firme" forest parcel in Southern Amazon (Alta Floresta/MT, Brazil)

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Abstract

In this work it is studied the disturbance effects due to slash and burn of a forest plot on the chemical composition of soil water that percolates the soil top layer. The work was conducted at the Fazenda Caiabi ($9^{o}57´42.2´´$S; $56^{o}20´52.05´´$), Mato Grosso, in the Brazilian Arc of Deforestation. Zero-tension lysimeters installed at 20 and 40 cm depth were used to collect soil water samples from a natural forest (F) and from a burned area (B). The samples were collected fortnightly during three rainy seasons named PER-I (September 1999 - January 2000), PER-II (October 2001 - April 2002) and PER-III (September 2002 - January 2003). The slashing and burning were performed in May and August 1999, respectively. The analyzed solutes were: Na^{+}, K^{+}, Mg^{2+}, Ca^{2+}, NH_4^{+}, Cl^{-}, NO_3^{-} and SO_4^{2-}. Factor analysis applied to the forest data set produced three factors, explaining 95% of the variance. Factor one was associated with exchange processes in soil and explains 48% of the variance, while factors two and three were attributed to biological processes (high load on NH_4^{+} and NO_3^{-}) and leaching (high load on Cl^{-}), respectively. In general, for all chemicals except Cl^{-} and SO_4^{2-}, in the burned site, there was a pulse on the concentration values following the burning (PER-I) with a subsequent decay observed on PER-II reaching the forest values in PER-III. The monthly transfer of each ionic species to the soil was estimated at 20-cm depth for both sites and the ratios between the load in the burned site (B) and in the forest (F) varied from 6.9 for Na^{+} to 71.4 for Ca^{2+} for the subsequent period of the burning and between 2.6 for Na^{+} and 0.2 for K^{+} after two years observation. In two years time the solutes content in soil water decay to values near the ones found in the forest or lower. It is most likely that an intense leaching through the soil profile occurs just after the burning followed by absorption due to regrowth.

INTRODUCTION

Studies concerning the impacts derived from forest conversion to pastures as the main economic use of the soils have been frequently reported in the Amazon Region. The formation and maintenance of these pastures involve the felling of the forest, the extraction of economically important wooden, the burning of biomass, and the sowing of the fodder. This is a low cost process because, due to biomass burning, the nutrients become mobilized and, therefore, available to plants. This process can for instance increase the amounts of exchangeable cations such as Mg and K which allow the pasture to be productive during the following five years. However, with the elapsing of time, the pasture undergoes degradation, which is described by Macedo and Zimmer (1993) as a process of vigor and productivity loss, of decrease in the capacity to resist plagues, diseases and invasion of alien species, as well as of decrease or disappearance of the capacity to maintain enough biomass production for the livestock. The practice of slash and burn introduces a significant impact into 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, as well as its cycling through the soil system (root absorption, weathering, leaching, etc.).

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

Although scarce in tropical regions, studies have shown that, some 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 sprouts again.

In the Amazon Region, studies considering the effect of forest slash and burning on the soil solution are rare (Holscher et al., 1997; Piccolo et al., 1994). These authors showed that there exists a significant decline of the solute content in the soil solution after the two subsequent months of forest burning.

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

The slashing and subsequent burning of the forest can also produce pulses of chemical species in the solution in the soil water and in the soil, derived from the wash of the ashes by the first rainfall after the forest fire, thus contributing with 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 soil solution chemical composition and, therefore, modifying the solution that percolates through the soil profile and feeds the ground waters and the water courses.

In this work a comparative study between a natural forested area and burned forest experimental areas was carried out to evaluate the solute content in the soil water that moves under gravity forces through the active zone of the soil, that is, in the zone where the roots are denser. The objective of this study is to evaluate the impact of the slash and burning process on the soil water solutes, comparing them with the equivalent solutes in the soil solution of a natural forest area, assessing the decay time of the solute concentrations to values comparable to the ones found in the forest area, as well as the transfer of chemical species from the ground floor to the top soil (20 cm depth).

To achieve such 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 waters sampled utilizing zero tension lysimeters at 20 and 40 cm depth, during three rainy periods (between 1999 and 2003) subsequent to the experiment of the slash and burning of the forest.

EXPERIMENTAL AREA AND METHODS

The slash and burning experiments were carried out at the Caiabi Farm ($9^o57´42.2´´S$; $56^o20´52.05´´$), located in the town of Alta Floresta, in northern Mato Grosso State (Carvalho et al., 2001).

Considering that the objective this work was to evaluate the losses or gains of solutes in a specific soil layer, the most suitable instruments for sampling the soil free water are zero tension lysimeters (Ranger et al., 2001; Magid and Christensen, 1993). The lysimeters were installed in August 1999 in trenches dug in an almost flat zone of the chosen parcel of both the natural forest and the slashed and burning experimental area, whose characteristics are presented in Table 1. Only the samples collected in trenches G and D were useful for the purpose of this work.

Each lysimeter is composed of a polyethylene tray with 628 cm^2 area inserted in the soil through the sidewall of the trench in both parcels: natural forest and burned site. Although the trench was locally constructed in a flat area, the wall in which the regional preferential lateral water flow occurred was chosen. In some lysimeters, the sample volume was insufficient or null. This probably happened due to tray faulty installation, waterproofing the soil layer on the top. In this way the water flowed around and not into the tray. The tray was connected with a hose to a 1 L capacity container to collect the soil water samples. The samples were collected fortnightly and, at each collection, the container was substituted by a clean one.

Each collected soil water sample was vacuum filtered to remove suspended solids and microorganisms, using pre-washed Millipore membrane filters with 0.22 μm of pore diameter. After filtering, the samples were separated into three 30 ml aliquots: (i) for the major anions determination, stored in a high-density polyethylene bottle without preserver; (ii) for the transition metals, stored in a polyethylene bottle acidified with 1% volume supra-pure nitric acid, and (iii) 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 and Postma, 1994.

The chemical species were determined with a Dionex DX-500 liquid-ion-chromatograph in the NUPEGEL-ESALQ/USP (Nucleus for Research in Geochemistry and Geophysical of the Lithosphere - Luiz de Queiroz Agricultural Superior School/University of São Paulo). For the

determination of 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 system configuration, on the sample concentrations range and on the analyzed species. Their accuracy was determined using the following certificated samples: TM28 and TM26.2 for the metals and Artificial Rainwater 409 for the anions and major cations, both from Environmental Canada. Primary standards from the UK Natural Environmental Research Council were also employed (Forti et al., 2000). The precision and accuracy results are presented in Table 2.

RESULTS AND DISCUSSIONS

The results are presented in two parts. In the first, the results concerning the time evolution of the major chemical species concentrations (Na^+, K^+, Mg^{2+}, Ca^{2+}, NH_4^+, CL^-, NO_3^- and SO_4^{2-}) during the three sampling periods for both studied sites are presented and discussed. Also, a comparison between the natural forest and the burned site soil-water concentration values at 20 cm depth was performed. In the second, a discussion concerning the species load based on an estimate of the load transferred from the ground to 20 cm depth is presented. The values found for natural forest and for the burned sites are compared.

TIME EVOLUTION OF THE CHEMICAL SPECIES CONCENTRATIONS

Figures a to d and 2a to 2d present the monthly mean concentration values of each ion in solution at 20 cm depth for the soil water in the natural forest and in the burned sites for the three studied periods. The mean values are weighed with the total rainfall height precipitated during the collection interval. As it was not possible to study the soil hydrological properties of the experimental site, this statistical weight was attributed to the concentration values to minimize the dilution/concentration effects that may occur as function of the amount of water circulating in the soil system,

The solute concentration values found in the natural forest site are comparable with others determined in other locations in the Amazon Region, such as the ones in Central Amazon near

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Manaus (Forti, 1989) and in Northeastern Amazon, in the Amapa State (Melfi and Forti, 1997). These values are shown in Table 3.

It was observed a pulse of Mg^{2+}, K^+, Ca^{2+}, NH_4^+ and NO_3^- concentrations for the first observational period that was approximately 2 months after the slashed and burned experiment; these high concentrations remained so until the end of this period. After one year of the slashed and burned experiment, which was the second observational period, the concentration values decayed to values equivalent to the ones found in the natural forest area e.g. for Mg^{2+} and NH_4^+ or lower for K^+ and NO_3^-. 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 in the natural forest as well as in the burned area can be attributed to an evapotranspiration effect due to the growth of vegetation sprouts in the burned area from the second observational period onward. The observed lower concentrations found in the burned area compared with the ones found in the natural forest for the third observational period are attributed to a dilution effect by the rainfall and due to a lower evapotranspiration in the burned area. The observed variations of the soil-water solute concentrations in the natural forest area are comparable with the water amount variability circulating within the soil system and with nutrient cycling processes.

A factor analysis with varimax rotation applied to this data set produced three factors explaining 95% of the weighed mean concentration variance. Factor 1 explained 48% of the variance with high load in the K, Mg and Ca associating it with the exchanges processes with the soil solid phase; factor 2, with high load in ammonium and nitrate, explains 30% of the variance and can be associated with the biological processes of nitrification and denitrification; factor 3 explains 17% of the variance with high load in chloride and sulphate which allowed to associated it with a dilution effect since chloride is a conservative species.

This same analysis carried out with the data set from the burned area produced a factor explaining 77% of the variance, and another explaining 10%. All the species but sodium have high load in factor 1 and sodium has high load in factor 2, the latter presenting low communality with the other species, which could be related to the base exchange capacity of the local soil. For this data set, only one factor explains almost all the variance; therefore, this high load on

such factor is an indication that the forest fire derived chemicals predominates on other factors which could influence the soil water chemical composition.

Tables 4 and 5 present the factor matrix and the communality values for the natural forest and the burned areas, respectively.

The Pearson coefficients of the correlation matrix with linear association (Tables 6 and 7) confirm the factor analyses results for both sites. This matrix show high correlation coefficients among the base cations K^+, Mg^{2+}, Ca^{2+} and moderately high with the NH_4^+, a correlation between NH_4^+ and NO_3^- and a low, although significant, correlation between Cl^- and SO_4^{2-}. For the burned site the correlation matrix shows coefficients with high significance level for all ions but Na^+.

The time evolution of the solute contents in soil water at 20 cm depth is shown in Figures 3a to 3d and 4a to 4d. It is observed that in the first rainy period after the slashed and burn experiment all chemical species are leached from the soil system, except Na. In the other two subsequent periods there is no evidence that leaching has occurred.

THE TRANSFER OF CHEMICAL SPECIES

For a better comparison among the solutions which are the object of this study, the chemical species transfer from the ground to soil at 20 cm depth were estimated assuming that all the water that reaches the ground floor is transferred to this soil depth through infiltration. The amount of water reaching this soil depth at the natural forest site was estimated as the difference between the rainfall (P) and the sum between the evapotranspiration (ET) and the interception (INT), being the utilized values for ET and INT 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 same as the rainfall amount during the first period (PER-I) because the soil was bare during this period. Owing to the fact that during the second (PER-II) and third (PER-III) periods the vegetation sprouts in the area, the amount of water that infiltrated was assumed to be the difference between the rainfall and the evapotranspiration, being the utilized evapotranspiration value the one calculated for a pasture area (Alves, 1997). The rainfall, evapotranspiration and interception values for the different areas are presented in Table 8.

The chemical transfer calculations were done by grouping the data by monthly mean values for the two sites. The results are presented in the Table 9. The monthly values of these calculations for the total observational period are presented in Table 10.

The observed monthly variation in the transfers among the different observational periods for the natural forest site can by attributed mainly to the hydrological condition of each period because the concentration variations has an important component derived from the amount of water circulating within the soil system. It is also observed that the monthly variations of the transfers of each ion have the same order of magnitude, except NO_3^- for the natural forest, indicating that these are natural variations for this soil system.

After the slash and burn of the forest, a pulse of load for all ions was observed for the first sampling (one month later), which was attenuated along of the time, leading to a decay. The decay elapsed time can be evaluated through the ratios between the burned and the natural forest loads whose values are shown in Table 11.

These ratios indicate that in two years time the chemical composition of the soil water solution at 20 cm depth decays to values equivalent to the ones found in the natural forest soil water for Mg^{2+} and NH_4^+ and lower for K^+ and Ca^{2+}. The Na^+ ratio is approximately constant for the second and third periods. A decay elapsed time equivalent to the one observed in this work was observed by Uhl and Jordan (1984) in San Carlos de Rio Negro, in the Venezuelan Amazonia.

In general, an intense leaching into the first 20 cm soil depth of the considered solutes is observed during the first rainy season after the slash and burn. In the following seasons these chemicals were absorbed by the re-growing vegetation thus their transfer to the soil profile decayed.

GENERAL COMMENTS

In this study, it was shown that the solute contents in the soil water present a concentration peak soon after the slash and burn of the forest, with values up to 60 times larger than those observed in the natural forest. After this pulse, in two years time the solute content decay to values lower than the ones observed in the natural forest soil water. This happens because the

burned area, which is surrounded by forest, is recolonized by regrowth secondary vegetation that most likely has high production and storage rate. The observed annual variations in the leaching of solutes through soil water at 20 cm depth for the natural forest is due to the hydrological variations within the soil, while in the burned area, even considering the uncertainties in the estimated values, the solute content variations can be attributed to the substratum degradation. From these results it can be concluded 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 with an abnormal input of nutrients to the ground water table as well as to water courses. However, this process is attenuated and, in two years time, the soil water chemical content reaches values equivalent to the ones observed in the natural forest soil water.

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TABLES

Table 1 – Trench characteristics in bold the ones from which the soil water samples were taken.

Trench	Site	Soil level (cm)	Sample number	Comments
G	**Forest site**	**20**	**37**	**Built in August 1999. Recovered; level 40 cm added in August 2001.**
		40	**05**	
F	Forest site	20	10	Built in August 1999. Litter accidentally burned, abandoned in January 2000
		40	07	
		80	00	
D	**Burned site**	**20**	**47**	**Built in August 1999.**
		40	**42**	
		80	**00**	
TR1	Burned site	20	40	Built in August 2001
		40	14	
		80	02	
TR2	Burned site	20	12	Built in August 2001.
		40	22	
		80	04	

Table 2 – Analytical Precision (PR) and accuracy (AC) in % for each 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

Table 3 –Concentration values of the solutes in the soilwater for the location of the present study and other locations in the Amazon: Caiabi - this study; Duke - Duke Reserve, Central Amazonia (Forti, 1989) and SNV - Serra do Navio, Northeastern Amazonia (Melfi and Forti, 1997).

Ion	Na^+	K^+	Mg^{2+}	Ca^{2+}	NH_4^+	Cl^-	NO_3^-	SO_4^{2-}
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

Table 4 – Factor Matrix with varimax rotation calculated for the solutes in the soil water of the natural forest and communality values between the variable

Species	Factor			Communality
	1	2	3	
Na^+	0.39385	0.1162	0.48318	0.38871
K^+	**0.83806**	0.32702	0.11196	0.82182
Mg^{2+}	**0.92076**	0.15631	0.02020	0.87264
Ca^{2+}	**0.95589**	-0.12926	-0.05425	0.93338
NH_4^+	0.35282	**0.79654**	-0.11322	0.77178
Cl^-	-0.13704	**0.58703**	**0.66667**	0.80783
NO_3^-	-0.00473	**0.65866**	0.13925	0.45324
SO_4^{2-}	-0.03352	0.01358	**0.90184**	0.81462

Table 5 – Factor Matrix with varimax rotation calculated for the solutes in soil water for the burned site and communality values between the variable

Species	Factor		Communality
	1	2	
Na^+	0.6997	**0.76128**	0.58445
K^+	**0.77504**	0.29577	0.68816
Mg^{2+}	**0.94393**	0.08846	0.89882
Ca^{2+}	**0.92349**	0.10469	0.86379
NH_4^+	**0.77441**	0.44621	0.79882
Cl^-	**0.81656**	0.45005	0.86932
NO_3^-	**0.91593**	0.02468	0.83954
SO_4^{2-}	**0.90389**	0.15311	0.84046

Table 6 - Matrix of correlation with Pearson coefficients with linear association for the solute concentration in the natural forest.

	Na^+	K^+	Mg^{2+}	Ca^{2+}	NH_4^+	Cl^-	NO_3^-	SO_4^{2-}
Na^+	1	0.3039	0.3382	0.3585	0.1978	0.2314	0.0358	0.4162
	(0.0000)	(0.3138)	(0.1842)	(0.1576)	(0.4467)	(0.3714)	(0.8914)	(0.0966)
K^+		1	**0.8244**	**0.7649**	**0.5446**	0.1405	0.2258	0.186
		(0.0000)	(0.0000)	(0.0003)	(0.0238)	(0.5906)	(0.3835)	(0.6229)
Mg^{2+}			1	**0.8750**	0.4395	0.0214	0.0753	-0.0185
			(0.0000)	(0.0000)	(0.0775)	(0.9350)	(0.7738)	(0.9437)
Ca^{2+}				1	0.1987	-0.2560	-0.0483	-0.0940
				(0.0000)	(0.4445)	(0.3213)	(0.8539)	(0.7198)
NH_4^+					1	0.3364	**0.4989**	-0.1539
					(0.0000)	(0.1868)	(0.0415)	(0.5553)
Cl^-						1	**0.5094**	**0.6541**
						(0.0000)	(0.0368)	(0.0044)
NO_3^-							1	0.1355
							(0.0000)	(0.6041)
SO_4^{2-}								1
								(0.0000)

Table 7 - Matrix of correlation with Pearson coefficients with linear association for the solute concentration in the burned site.

	Na^+	K^+	Mg^{2+}	Ca^{2+}	NH_4^+	Cl^-	NO_3^-	SO_4^{2-}
Na^+	1	0.2599	0.1721	0.2072	0.3368	0.3462	0.1368	0.1298
	(0.0000)	(0.3138)	(0.5089	(0.4248)	(0.1863)	(0.1734)	(0.6007)	(0.6212)
K^+		1	**0.8346**	**0.8082**	**0.6103**	**0.8350**	**0.6051**	**0.6269**
		(0.0000)	(0.0000)	(0.0001)	(0.0093)	(0.0000)	(0.0101)	(0.0071)
Mg^{2+}			1	**0.9833**	**0.6758**	**0.7873**	**0.8093**	**0.7564**
			(0.0000)	(0.0000)	(0.0029)	(0.0002)	(0.0001)	(0.0004)
Ca^{2+}				1	**0.6405**	**0.7722**	**0.8188**	**0.7142**
				(0.0000)	(0.0056)	(0.0003)	(0.0001)	(0.0013)
NH_4^+					1	**0.8321**	**0.7488**	**0.9257**
					(0.0000)	(0.0000)	(0.0005)	(0.0000)
Cl^-						1	**0.7008**	**0.8125**
						(0.0000)	(0.0017)	(0.0001)
NO_3^-							1	**0.8992**
							(0.0000)	(0.0000)
SO_4^{2-}								1
								(0.0000)

Table 8 –Rainfall (P) measured values in the experimental area, natural forest evapotranspiration (ET-F) and, interception (INT-F) from Leopoldo et al. (1995) pasture evapotranspiration (ET-P) from Alves (1997) and calculated infiltration values for the natural forest (INF-F) and burned area (INF-B) all in mm.

Períods	P (mm)	ET-F (mm) (67.6%)	INT-F (mm) (11.3%)	ET-P (mm) (51%)	INF-F 20 cm (mm)	INF-B 20 cm (mm)
Per-I	1080	686	115	518	214	1015
Per-II	1870	892	149	673	279	647
Per-III	1281	563	94	425	175	407

Table 9 –Mean concentration values in mg.L^{-1} of solutes in the soil water at 20 cm depth for the three periods and the two areas.

	Na^+	K^+	Mg^{2+}	Ca^{2+}	NH_4^+	Cl^-	NO_3^-	SO_4^{2-}
					mg.L^{-1}			
Natural Forest								
Per-I	0.29	6.94	0.58	0.42	1.57	4.09	23.3	1.85
Per-II	0.32	4.28	0.55	0.94	1.74	1.86	19.62	0.48
Per-III	0.24	8.85	0.87	2.58	1.69	1.28	13.2	0.46
Burned site								
Per-I	0.42	51.85	7.08	6.36	7.72	3.38	95.6	7.19
Per-II	0.49	7.71	0.48	0.85	2.04	1.42	20.6	0.91
Per-III	0.27	0.71	0.44	0.60	0.88	0.23	3.43	0.15

Table 10- Solutes transfer average values (total for each period and monthly for the corresponding period), in kg.m^{-2}, for 20 cm soil depth for the two areas.

	Na$^+$	K$^+$	Mg^{2+}	Ca^{2+}	NH$_4^+$	Cl$^-$	NO$_3^-$	SO$_4^{2-}$
Natural Forest								
Per-I								
Total Transf. kg.m^{-2}	0.07	1.67	0.14	0.11	0.32	1.03	4.93	0.54
Monthly Transf. kg.m^{-2}.month^{-1}	0.02	0.39	0.03	0.02	0.09	0.23	1.32	0.11
Per-II								
Total Transf. kg.m^{-2}	0.12	1.51	0.24	0.37	0.69	0.75	6.72	0.17
Monthly Transf. kg.m^{-2}.month^{-1}	0.02	0.24	0.03	0.05	0.10	0.10	1.10	0.03
PER-III								
Total Transf. kg.m^{-2}	0.06	1.76	0.19	0.56	0.34	0.39	4.04	0.13
Monthly Transf. kg.m^{-2}.month^{-1}	0.01	0.48	0.05	0.14	0.09	0.07	0.71	0.02
Burned site								
PER-I								
Total Transf. kg.m^{-2}	0.40	57.1	7.38	6.99	8.15	3.59	106	7.48
Monthly Transf. kg.m^{-2}.month^{-1}	0.11	14.0	1.91	1.72	2.09	0.91	25.8	1.94
PER-II								
Total Transf. kg.m^{-2}	0.41	4.16	0.48	0.84	1.74	1.33	12.7	0.54
Monthly kg.m^{-2}.month^{-1}	0.06	0.90	0.06	0.10	0.24	0.17	2.40	0.11
PER-III								
Total Tranf. kg.m^{-2}	0.17	0.39	0.25	0.33	0.47	0.12	2.26	0.10
Monthly Transf. kg.m^{-2}.month^{-1}	0.03	0.09	0.06	0.08	0.11	0.03	0.43	0.02

Table 11 –Transferred load ratios between the values found for burned site (B) and natural forest (F) for the three observational periods for each ion.

Ratio B/F	Na$^+$	K$^+$	Mg^{2+}	Ca^{2+}	NH$_4^+$	Cl$^-$	NO$_3^-$	SO$_4^{2-}$
Per-I	6.9	36	59	71	23	3.9	20	19
Per-II	3.2	3.7	1.8	1.9	2.4	1.6	2.2	4.0
Per-III	2.6	0.2	1.2	0.5	1.2	0.4	0.6	0.8

FIGURES CAPTIONS

Figure 1 – Monthly variation of Na^+, K^+, Mg^{2+} and Ca^{2+} in solution ($\mu Mol.L^{-1}$) in soilwater (20 cm) for the natural forest and burned site during the three observational periods (PER-I: Sep1999-Jan2000, PER-II: Aug2001-Apr2002 and PER-III: Sep2002-Feb2003). The rainfall heights (mm) for the same three periods are plotted in the second axis.

Figure 2 – Monthly variation of NH_4^+, NO_3^-, Cl^- and SO_4^{2-} in solution ($\mu Mol.L^{-1}$) in soilwater (20 cm) for the natural forest and burned site during the three observational periods (PER-I: Sep1999-Jan2000, PER-II: Aug2001-Apr2002 and PER-III: Sep2002-Feb2003). The rainfall heights (mm) for the same three periods are plotted in the second axis.

Figure 3 – Monthly variation of Na^+, K^+, Mg^{2+} and Ca^{2+} in solution concentrations ($\mu Mol.L^{-1}$) in the soil water (20 and 40 cm depth) for the burned area during the three observational periods (PER-I: Sep1999-Jan2000, PER-II: Aug2001-Apr2002 and PER-III: Sep2002-Feb2003). The rainfall heights (mm) for the same three periods are plotted in the second axis.
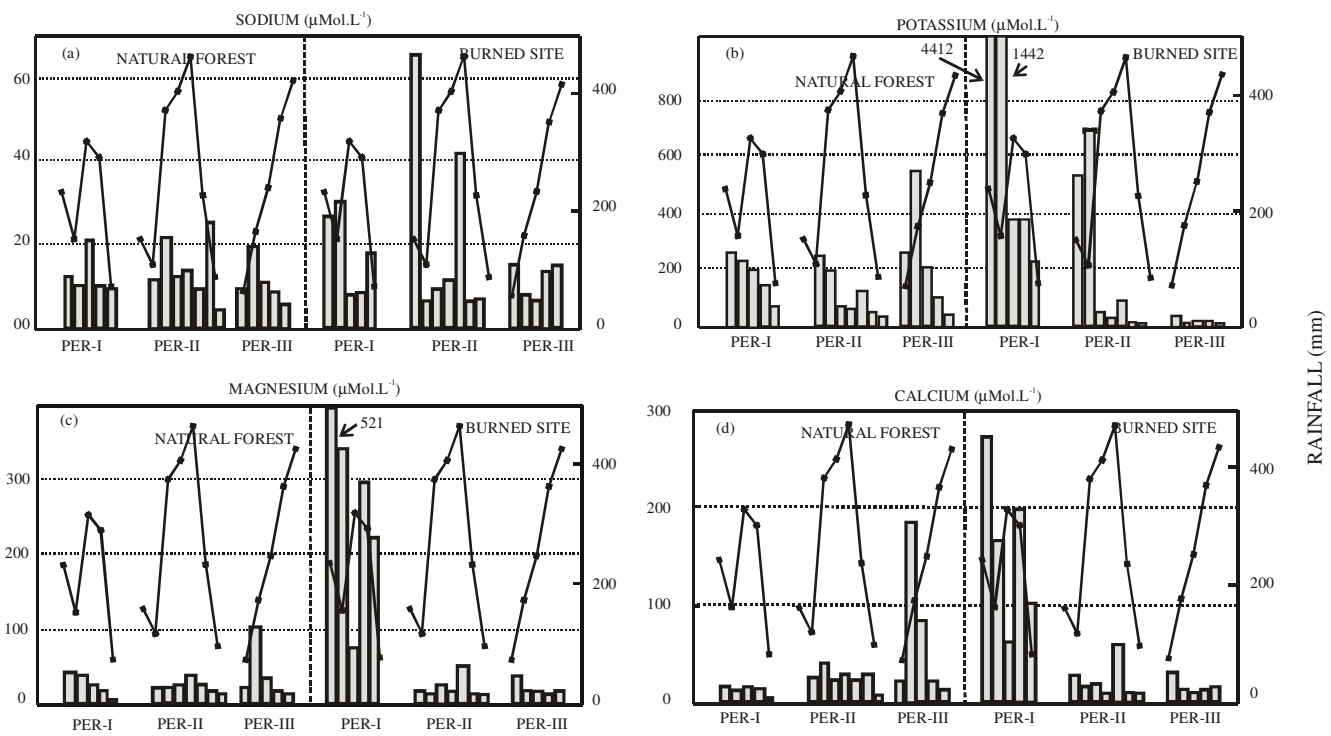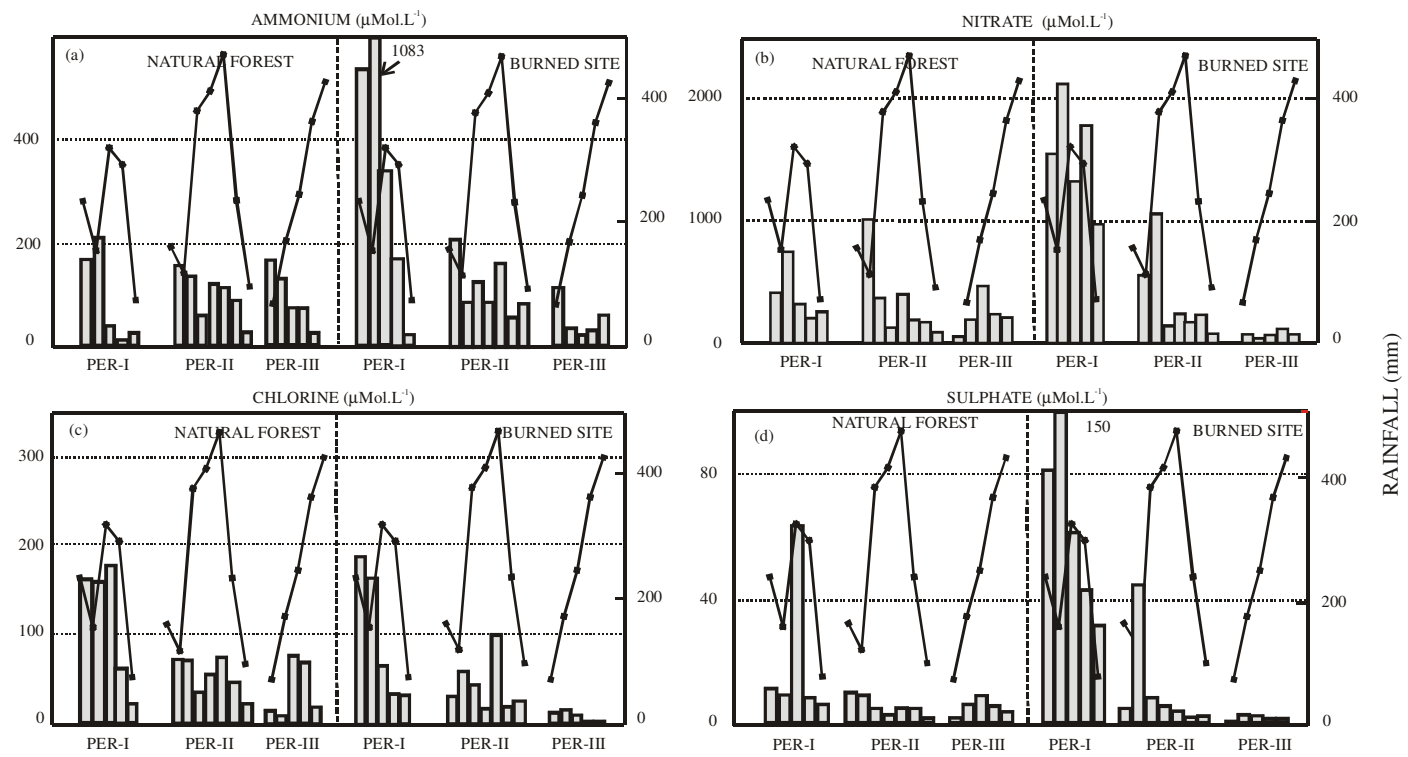
Figure 4 – Monthly variation of NH_4^+, NO_3^-, Cl^- and SO_4^{2-} in solution concentrations ($\mu Mol.L$-1) in the soil water (20 and 40 cm depth) for the burned area during the three observational periods (PER-I: Sep1999-Jan2000, PER-II: Aug2001-Apr2002 and PER-III: Sep2002-Feb2003). The rainfall heights (mm) for the same three periods are plotted in the second axis.
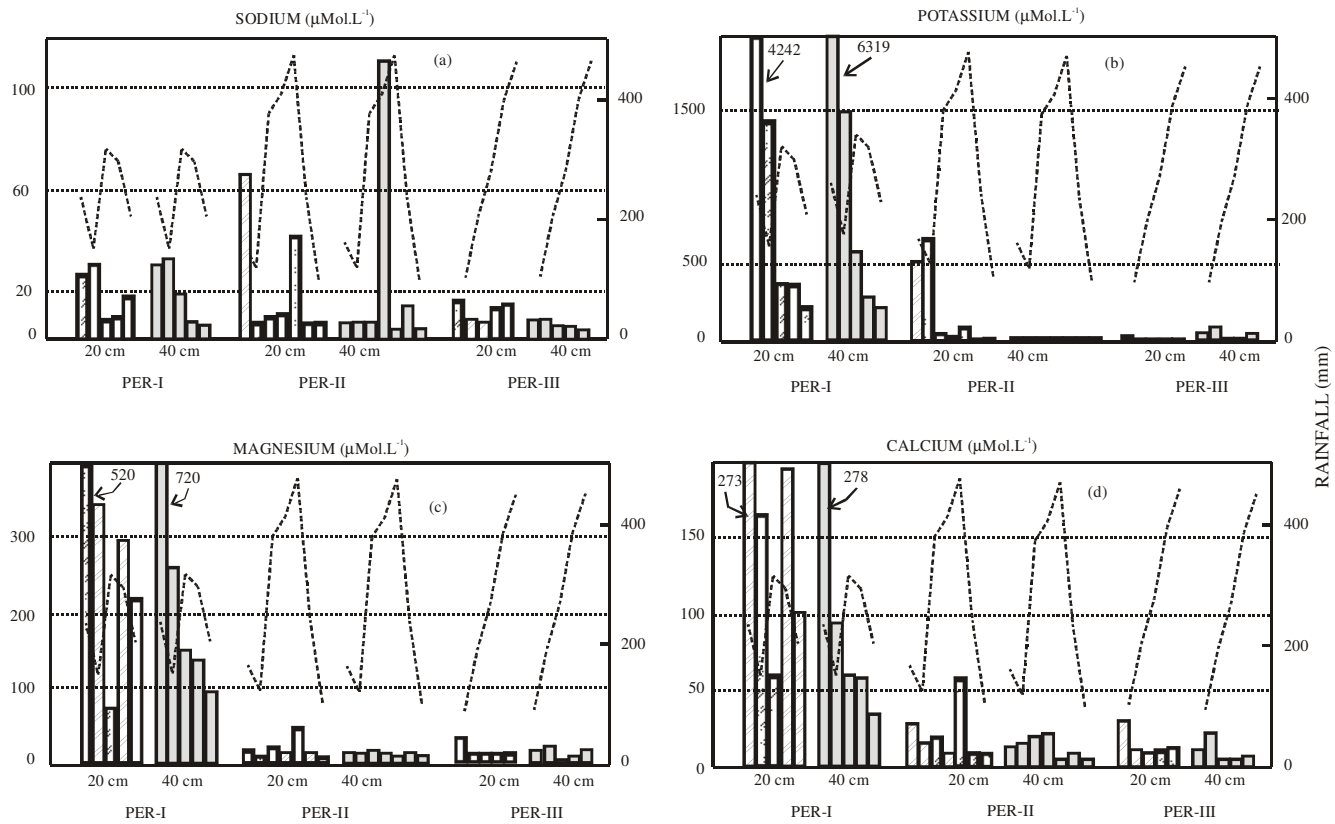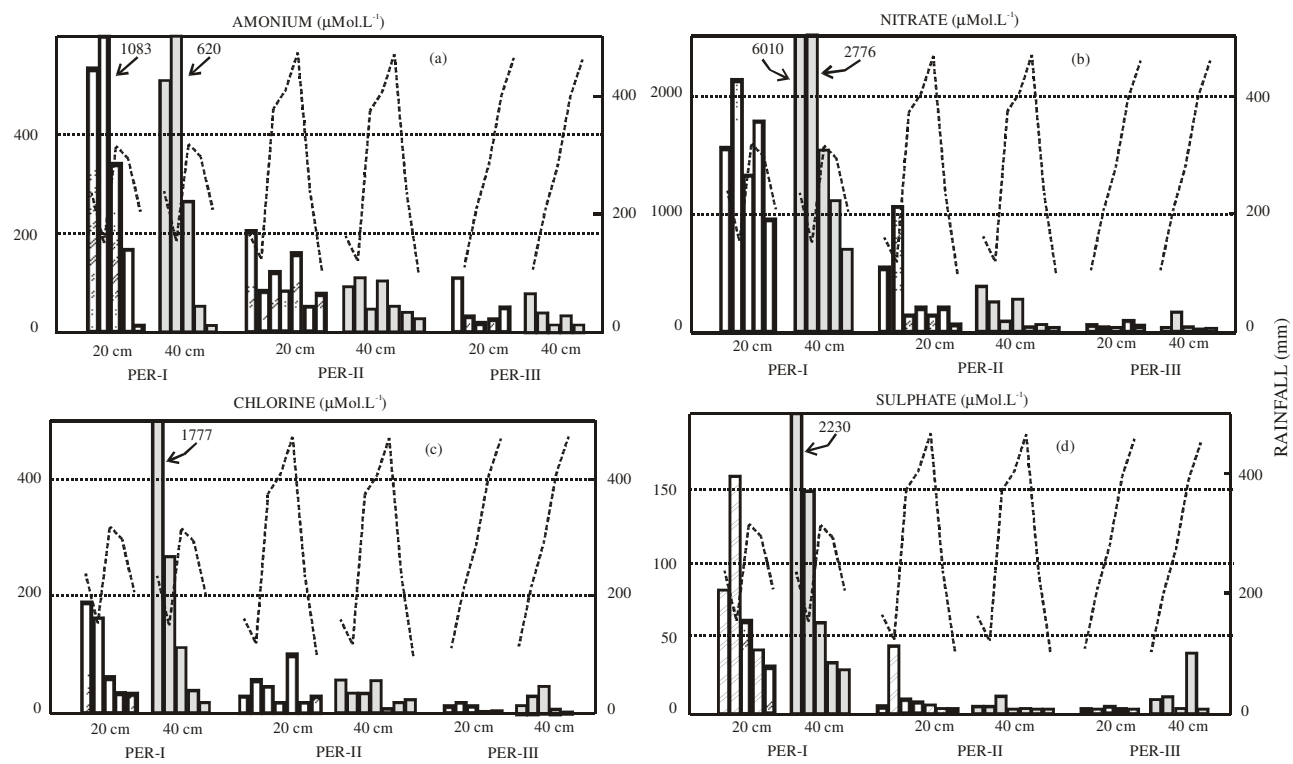
Figure1

Figure 2

Figure 3

AMONIUM (μMol.L⁻¹)

CHLORINE (μMol.L⁻¹)

NITRATE (μMol.L⁻¹)

SULPHATE (μMol.L⁻¹)

Figure 4

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