

Characterization of Soil Nutrients Leaching in Perched Groundwater as Occurring in Bush Fallow of Forest Zone

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ABSTRACT

Geochemical changes can occur in soils exposed to high annual rainfall, even in non cultivated soil of bush fallow as consequence of leaching. Missing data of leached N, P, K and Mg could have lead to erroneous fertilizer practice inducing declining of the crop yields. During the cropping seasons (June, July and August) of 2003 and 2004, 25 mi-piezometers were set (9600 m²) in soil systematically (20 × 30 m) for perched groundwater collection before laboratory analysis of N-NO₃, N-NH₄, P₂O₄, K, Mg and HCO₃. Soil profiles of middle slope (MS), foot slope (FS) and fringe valley (FV) were also sampled by horizon for physic-chemical analysis (particle size, bulk density, C-organic, total-N, exchangeable K and Mg as well as the pH_{water}). Leached concentrations were in decreasing order as HCO₃ > N-NO₃ > K and Mg > N-NH₄ > P₂O₄ and the pH values were higher than 5.5. Although N-NO₃ and P₂O₄ were found to be the main accompanying anions of leached N-NH₄, K and Mg, there was specific anisotropy in leached leaching. Furthermore, the concentrations of N-NO₃ (K and Mg) and P₂O₄ (N-NH₄ and K) in groundwater could be used for the estimation of that of the cations whereas, only Mg concentration could be described by that of HCO₃. Compared with their contents in soil respectively, unavailability of P and Mg was not much concerned by leaching as for total-N and K. We suggested 0.87 g K ha⁻¹ and 0.45 gN ha⁻¹ for 1kg of soil as additional fertilizer practice for sustaining crop production in forest ecosystems.

Key Words: Leaching; Soil Nutrient; Nitrogen; Potassium; Ferralsols; Forest.

INTRODUCTION

In undisturbed ecosystems, the cycling of nutrients through the biomass and soil compartments ensures that leakage of the store of nutrients is negligible (Grierson and Adams 1999). Small amounts leave the ecosystem but may be offset by many processes as accretion in rainfall and nitrogen fixation etc. However, most agricultural systems allow significant nutrient losses through harvested product removal, leaching, gaseous

losses, and erosion (Savat and Poesen 1977, Christianson 1981, Nkonya et al. 2004). Intra-system nutrient cycling is generally, in turn, tied to pathways such as primary productivity and decomposition (Adigbo et al. 2013): When productivity and decomposition rates are high, as in flowing water or pulsing hydroperiod wetlands, nutrient cycling is rapid contrasting with the situation occurring in isolated ombrotropic bogs (Mitsch and Gosselink 1993). Most of these processes have been well documented for undisturbed forest ecosystems of West

Africa (Collinet and Valentin 1979, Stoorvogel et al. 1997, Chakela 1981) with significant contribution to model development for wood forest regeneration (Van Herwaarden 1991; Jansen et al. 1990).

In turn, only nutrient lost due to the exportation by crop and soil erosion was extensively studied in disturbed ecosystem of agricultural lands in the humid forest of West Africa (Roose and Asseline 1978, Roose 1983, Koné et al. 2013a). Meanwhile, aerobic soils are prone to many geo- and biochemical changes in landscape even under bush fallow (Paul et al. 2000), especially after cultivation. The rainfall, soil properties and perched groundwater fluctuation are involved in nutrient leaching (Vartapetian and Jackson 1997, Bell and Seng 2005) as out-flow of nutrients, hence inducing soil nutrient deficiency for crop characterized by shallow rooting profile. Missing knowledge of this process may lead to erroneous estimation of soil fertility and fertilizer recommendation (Berntsen et al. 2003).

Declining yield of cereal crops was observed worldwide (Adepetu and Corey 1977, Beets 1989, George et al. 2002, Bhandari et al. 2002, Melendez et al. 2003) including the humid forest ecosystems of Cote d'Ivoire, where soil nutrient deficiency was increasing (P to P, K, N and Mg) in aerobic condition during successive cropping seasons (Koné et al. 2013b). This threat was occurred in spite of fertilizer even applied at necessary rates to balance the amount of exported nutrients and the outflow induced by erosion. Missing data of nutrient leaching is required as supplement fertilizer recommendation for sustaining agriculture production.

For this purpose, the current study aim to i) characterize leaching nutrient (N, P, K and Mg) patterns and pathway in perched ground water of hydromorphic zone of upland, ii) quantify the outflow of nutrients in perched groundwater and iii) insight knowledge of cation and anion interactions during leaching process. Awareness and advice should be done for maintaining tropical soil fertility of agricultural land.

SITE OF THE STUDY

The study was conducted at Guéssihio (6°06 N, 6° 00 W, 180 m above sea level), located in the Centre Western part of Côte d'Ivoire (West Africa), about ten kilometers from Gagnoa (administrative center). It is a humid forest zone characterized by bimodal rainfall pattern with an annual average rainfall amount of 1200 mm (Figure 1). The annual maximum rainfall was recorded twice in

June and mid-October every year inducing soil saturation with lateral hypodermic circulation of water and water-logging. Cropping season in this region is planned between April to August and the critical period for crop nutritional requirements start from June. The study was preceded by a three years bush fallow dominated by *Chromolaena odorata*.

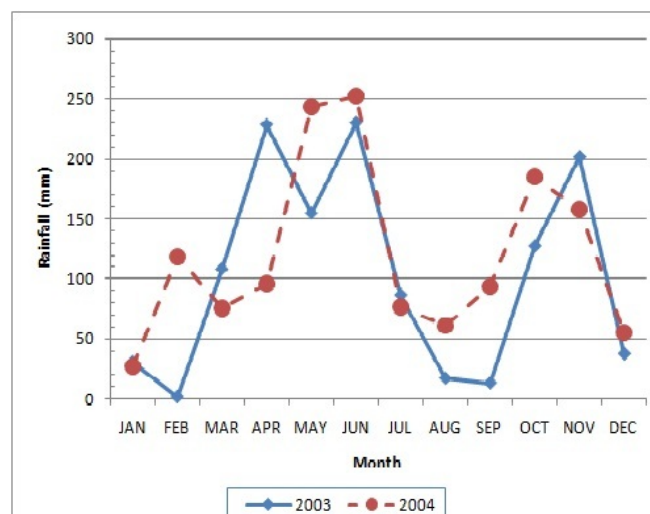


Figure 1. Monthly rainfall during 2003 and 2004 in the study area

METHODS

Setting Mini-Piezometers

Polyvinyl chloride plastic (PVC) pipes of 7cm in diameter with variable length (1-1.5 m) depending on the depth of clayed (impermeable) horizon in soil profile, were used as mini-piezometers. An extremity of PVC was perforated along 20 cm making about 100 holes of 10 mm in diameter. These perforations were recovered by nylon linen, and hand augur was used to dig the soil for setting the piezometers. Gravels composed of crushed Granit were placed around the tube as porous space allowing free circulation of water except for the last 20 cm below the soil surface. This layer was filled up to the soil surface using bentonite as impermeable surface layer. About 30 cm of PVC was left above ground surface as protection against surface water (run-off and flooding), reinforcing bentonite effect. The pipes were permanently closed except during the sampling of groundwater.

Soil and Groundwater Sampling

Mini-watershed (120 × 80 m) extending the middle (MS) and foot slopes (FS) as well as the fringe valley (FV) was considered and groundwater samples collection was done as unequal stratified design (Wester and Olivier, 1990) accordingly. A soil profile of 150 cm depth was described and sampled at each topographic position. Soil horizons were indentified for each profile according to morphological, physical and biotope vertical heterogeneities. Each horizon was sampled for laboratory analysis and classified according to World Reference Base for Soil Resources (ISSS, ISRIC and FAO 1998).

Groundwater collection was done systematically (20 m × 30 m) in mini-piezometers according to routes (longitudinal direction) at each 20 m and transversal distance (each 30 m) across the different topographic sections [Middle slope (0-30 m), Foot slope (30-70 m) and Fringe valley (70-120 m)]. Land surface of 9600 m² (120 m × 80 m) and 25 mini-piezometers were concerned by the study. Every year (2003 and 2004), from June to August, a sample of water was collected in the mini-piezometers by manual suction using a narrow plastic tube adapted to hand operated foot valve pump, 24 hours after rainfall. The samples were stock in order to do a monthly composite sample before laboratory analysis.

Laboratory Analysis

Soil particle sizes and pH water (1:2.5) were determined in laboratory using Robinson pipette (Gee and Bauder 1986) and glass electrode methods respectively. Its contents of total nitrogen (N), available phosphorus (P), and exchangeables potassium (K) and magnesium were determined by the methods described by Pages et al. (1996). Bulk density was also determined for each soil horizon using a cylinder of 100 cm³ and weigh method (Houston et al. 2004, Koné et al. 2011).

The photometric analyses of water samples for determination of phosphate (P₂O₄), ammonia (N-NH₄) and nitrate (N-NO₃) concentrations were applied using a Nova 60 (Merck). Water concentrations of potassium (K), magnesium (Mg) and HCO₃ were also determined with Inductively Coupled Plasma-Optical Emission Spectroscopy (ICP-OES, Perkin Elmer) as described by Heald et al. (2009).

Statistical Analysis

Average concentrations of N-NO₃, N-NH₄, P₂O₄ and

HCO₃ in groundwater as well its pH were determined by repeated measurement analysis defining the route (longitudinal distance) and the transversal distance as repeated and subject variable respectively. Pearson correlation was performed between groundwater anion (N-NO₃, HCO₃ and P₂O₄) concentrations and that of cations (N-NH₄, K, and Mg) for each topographic section. Furthermore, linear regression analyze was also done for the prediction of groundwater concentrations of N-NH₄, K, and Mg according to that of N-NO₃, HCO₃ and P₂O₄. SAS version 8 was used for statistical analysis as well as for doing graph of the pattern of nutrient concentrations in groundwater.

RESULTS

Characteristics of Soils

Physico-chemical analyses of studied soils are presented in Table 1. Roughly, soil content of sand was ranging from 30 to 60% with increasing trend in soil depth indifferently to the topographic positions. However, relative accumulations of clay appeared in horizons 20-40 cm (MS), 65-120 cm (FS) and 70-105 cm (FV) as impermeable layer that can stock infiltrated water. Beside the highest content of Mg in the topsoil (0-20 cm) coupled with highest contents of C (organic matter), N, P and K, there was increasing of soil content of Mg, especially in the impermeable layers of soils except for the Ferralsol plinthic in the MS position characterized by decreasing trends of all the others chemical properties in soil depth. We can also notice a lateral variation of soil nutrient contents illustrated by sharpest decrease of soil contents of N, K and Mg in topsoil (0-20 cm) from the hill slope to down slope positions. The difference between studied soils was also illustrated by the profiles of their bulk densities (Figure 2). However, similarities are underlined with the highest values of this property in the enriched clay impermeable layer as also observed in the topsoil at a certain level.

Concentrations and Relationships of Chemical Compounds in Groundwater

Monthly average concentrations of cations (N-NH₄⁺, K⁺ and Mg⁺⁺) and anions (N-NO₃⁻, P₂O₄⁻ and HCO₃⁻) in groundwater as well as the pH values across years are given in Table 2. Except for K⁺, the values recorded were significant (χ^2 Probability < 0.10). Decreasing order

Table 1. Soils' characteristics in the studied site along a toposequence

Topographic Position and Soil	Horizon (cm)	Sand (%)	Silt (%)	Clay (%)	pH _{wat}	C (gkg ⁻¹)	N (gkg ⁻¹)	P (mgkg ⁻¹)	K (cmolkg ⁻¹)	Mg (cmolkg ⁻¹)
Middle slope										
Ferralsol -Plinthic	0-20	24	34	40	6.2	10	1.4	12	0.18	0.60
	20-40	32	16	52	5.7	3.4	0.6	9	0.15	0.38
	40-80	34	24	42	5.4	1.2	0.5	9	0.06	0.72
	80-115	35	28	35	5.1	2.0	0.5	8	0.19	0.28
	115-150	53	33	14	5.1	0.6	0.4	8	0.02	0.19
Foot slope										
Ferralsol- Luvic	0-20	47	39	12	6.7	5.8	0.9	11	0.15	0.25
	20-65	49	25	24	6.8	0.6	0.3	9	0.03	0.05
	65-120	45	29	25	6.8	2.0	0.3	8	0.10	0.23
	120-150	54	23	22	7.2	1.8	0.3	9	0.08	0.14
Fringe valley										
Arenosol	0-20	56	28	13	5.4	7.8	0.6	15	0.10	0.13
	20-40	56	33	10	5.7	1.6	0.3	10	0.08	0.09
	40-70	56	35	9	6.0	1.2	0.1	10	0.06	0.06
	70-105	60	25	15	6.0	1.4	0.3	10	0.06	0.21
	105-150	42	31	26	5.9	1.0	0.2	9	0.05	0.65

Table 2: Monthly concentrations of nutrients and pH in groundwater coupled with their probability (*Pr*) values and that of the studied factors (Root and month) across years

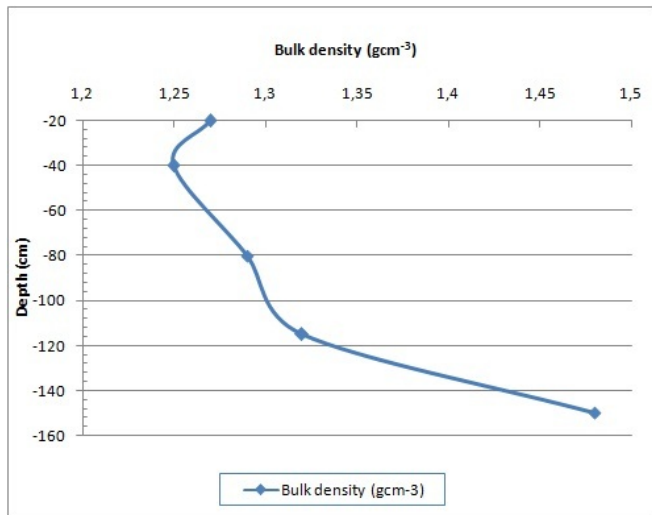
	N-NO ₃		N-NH ₄		P ₂ O ₄		K		Mg		HCO ₃		pH	
	Value	<i>Pr</i> >F	Value	<i>Pr</i> >F	Value	<i>Pr</i> >F	Value	<i>Pr</i> >F	Value	<i>Pr</i> >F	Value	<i>Pr</i> >F	Value	<i>Pr</i> >F
June	8.9	0.007	1.06	0.007	0.04	0.116	1.99	0.0190	2.01	0.003	52.2	0.0004	6.6	<0.0005
July	7.3	0.020	1.36	<0.0001	0.03	0.401	3.51	0.0003	1.89	0.005	32.5	0.0150	5.8	<0.0001
August	11.9	0.001	0.53	0.047	0.04	0.061	2.17	0.0117	2.17	0.002	58.6	0.0002	7.1	<0.0001
<i>Pr</i> > t														
Root	0.103		0.323		0.513		0.178		0.016		<0.0001		0.258	
Month	0.071		0.016		0.878		0.194		0.787		0.0271		<0.001	
<i>Pr</i> > χ^2	<0.0001		0.064		0.0317		0.117		0.0165		0.004		<0.0001	

Pr > χ^2 : Probability related to Likelihood ratio

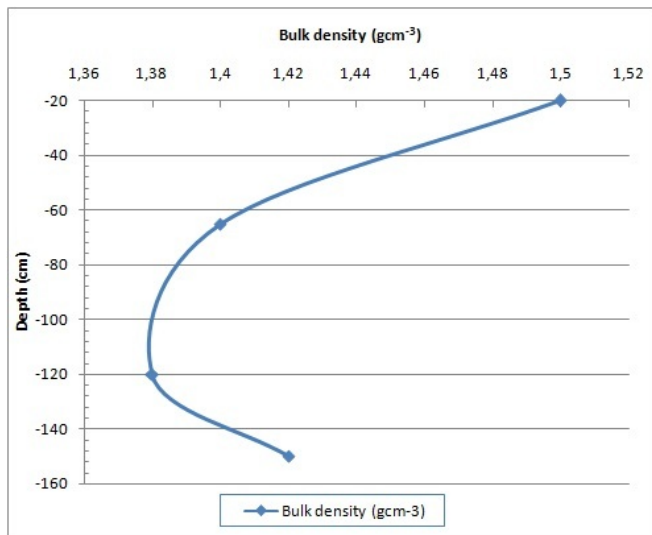
of ionic concentrations was determined as HCO₃>N-NO₃>K and Mg>N-NH₄>P₂O₄ and the pH values were greater than 5.5. The ratio of N-NO₃/N-NH₄ was ranging from 7 to 20 reflecting the dominance of nitrate. Lowest variability of phosphate concentration (0.03-0.04 mg L⁻¹) concentration can be noticed with highest value recorded in June and August similarly to that of most of the chemical compounds except for N-NH₄ and K resulting

a neutral pH while lowest pH (5.5) was coupled with lowest concentrations of N-NO₃ (7.3 mg L⁻¹), P₂O₄ (0.03 mg L⁻¹), Mg (1.89 mg L⁻¹) and HCO₃ (32.5 mg L⁻¹).

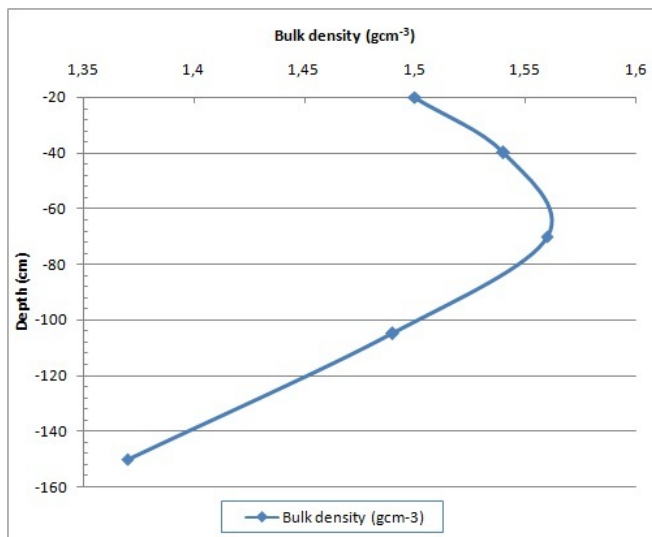
Significant correlation values (1) are observed between P₂O₄ and cation concentrations in groundwater for MS position with negative value (-1) for K concentration (Table 3). Positive correlation (0.578) is also between N-NH₄ and P₂O₄ in groundwater of FS position



a



b



c

where no significant correlation accounts for HCO₃ and K concentrations exceptionally. Indeed, N-NO₃ is negatively correlated with Mg and K concentrations in groundwater of FS position. Only Mg and HCO₃ concentrations in the groundwater of FV position are significantly correlated (0.605). But, no significant correlation is observed between HCO₃ and K concentrations contrasting with that of HCO₃ and Mg. Increase of HCO₃ concentration in groundwater is coupled with that of Mg while, N-NH₄ concentration can decrease significantly in FS position as consequence of their correlations respectively. But, no significant linear regression of N-NH₄ concentration was determined with that of HCO₃ as descriptive variable contrasting with the prediction of Mg concentration using HCO₃ and N-NO₃ concentrations (Table 4). In turn, K and N-NH₄ concentrations in groundwater can be significantly predicted by linear expressions of P₂O₄ and N-NO₃ with positive and negative slope values respectively.

Table 4. Linear regression of positive charged ions (N-NH₄, K and Mg) concentrations to that of negative charged ions (HCO₃, P₂O₄ and N-NO₃)

	N-NH ₄	K	Mg
<i>Pr</i> > <i>F</i> for model	0.0015	0.0028	<0.0001
Intercept (mg L ⁻¹)	0.476	1.067	0.700
HCO ₃			
<i>Pr</i> > <i>t</i> / Slope	0.0012	0.002	0.010
<i>Pr</i> > <i>t</i> / Slope	-0.001	0.0009	0.027
<i>Pr</i> > <i>t</i> / Slope	0.218	0.771	<0.001
P ₂ O ₄			
<i>Pr</i> > <i>t</i> / Slope	0.009	0.041	0.227
<i>Pr</i> > <i>t</i> / Slope	4.727	-8.878	-4.038
N-NO ₃			
<i>Pr</i> > <i>t</i> / Slope	0.009	0.129	-0.059
<i>Pr</i> > <i>t</i> / Slope	0.527	0.001	0.049
Root MSE	0.498	1.220	0.944

Spatial Anisotropy of Chemical Compounds in Groundwater

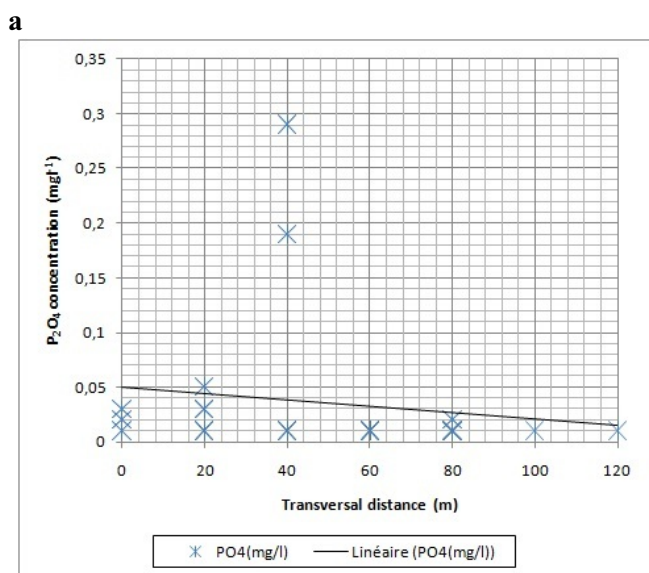
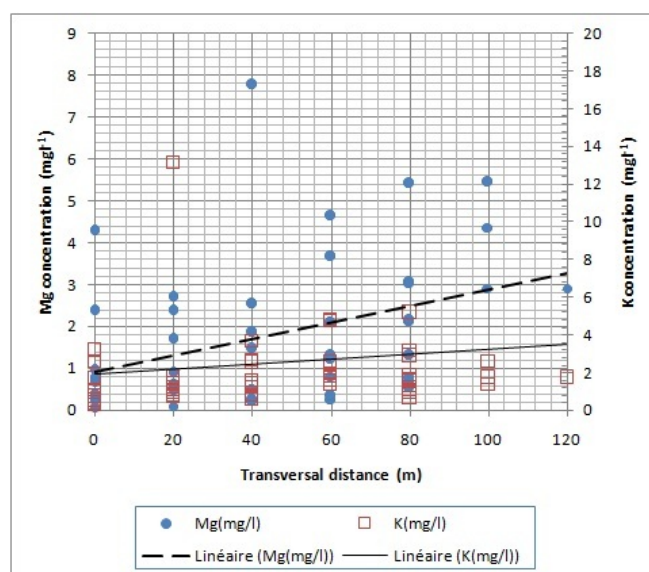
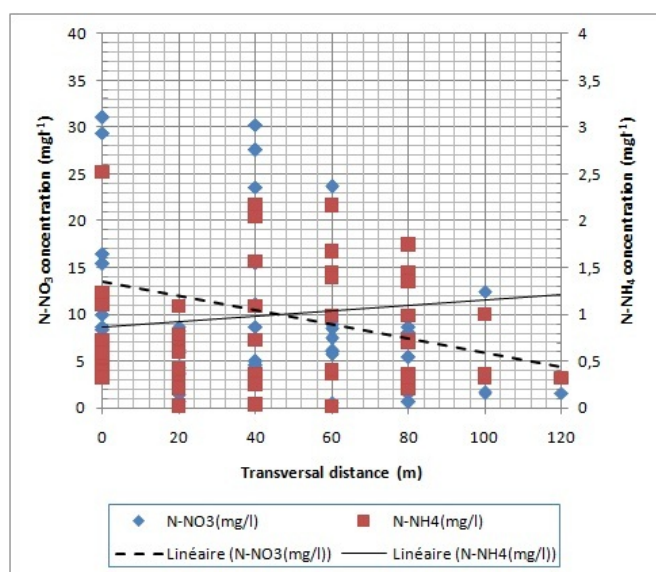
There is difference between the special distributions of groundwater concentrations as recorded for N-NO₃, N-NH₄, P₂O₄ and K according to Figure 3: opposite positions of highest concentrations of N-NO₃ and N-NH₄ are observed in the MS (0-30 m) topographic section and the

Figure 2. Bulk density by soil depth in the upper (a), middle (b) and foot slopes (c) position

Table 3.: Pearson correlation coefficient (R) and probability (Pr) between positive (N-NH₄, K and Mg) and negative charged ions (HCO₃, N-NO₃ and P₂O₄) concentrations in groundwater of different topographic sections

		N-NH ₄			K			Mg		
		MS	FS	FV	MS	FS	FV	MS	FS	FV
HCO ₃	R	-0.229	-0.498	-0.163	-0.047	0.233	0.141	0.812	0.677	0.605
	Pr>/t/	0.391	0.035	0.228	0.862	0.350	0.298	<0.0001	0.002	<0.0001
N-NO ₃	R	0.457	0.558	-0.158	0.508	-0.570	-0.010	-0.451	-0.516	-0.051
	Pr>/t/	0.056	0.015	0.225	0.0312	0.013	0.934	0.059	0.028	0.700
P ₂ O ₄	R	1	-0.579	0.547	-1	0.598	-0.094	1	0.299	-0.269
	Pr>/t/	<0.0001	0.079	0.001	<0.0001	0.067	0.617	<0.0001	0.400	0.165

MS: Middle slope; FS: Foot slope; FV: Fringe valley



c
 Figure 3. Average concentrations of N-NO₃ and N-NH₄ (a) in groundwater along the toposequence (0-120 m) as well as for P₂O₄ (b) and that of Mg and K (c)

groundwater in FS (30-70 m) position is also enriched in N-NH₄ overlapping lowest concentration of N-NO₃. However, the FV (70-120 m) groundwater is characterized by lowest concentrations of both nutrients. Highest concentration of P₂O₄ is also characterizing the groundwater in FS position of landscape, while its lowest concentration and variability are observed else-where in the watershed. Similar pattern is also partially observed for K concentration, especially in the FS topographic position.

Highest concentrations resulting to wide variability of N-NO_3 , N-NH_4 and Mg are respectively observed, especially in the groundwater of FS (Figure 3). This observation is limited for P_2O_4 (Figure 3b) and K (Figure 3c) concentrations. Increasing trends of cations (N-NH_4 , Mg and K) concentrations are also observed from hill to down slopes (0 to 120 m) of the watershed contrasting with anions (N-NO_3 and P_2O_4) concentrations of groundwater. Lowest slopes of linear trends were observed for N-NH_4 , P_2O_4 and K concentrations as consequence of their overall variability.

DISCUSSION

Geochemistry of Perched Groundwater

Soil and rain fall are key factors of perched groundwater occurrence accounting for quantitative and qualitative contributions. After downward circulation through porous spaces in the soil matrix, rainfall water can be accumulated as perched-water body above an impermeable or very low permeable layer corresponding to clayed soil horizon (Peterson 1972). Therefore, the amount of rainfall as well as its' chemical component concentrations (Fischer et al. 2008) are contributing to the input of the system likewise the chemical component in soil. However, soil physical properties (texture, bulk density, permeability, porosity) are the most important parameters when referring to perched groundwater characteristics. Indeed, the difference in bulk densities as observed for different soils of the study (Figure 2) could have induced difference in water infiltration rates. Meanwhile, it was documented that substance (colloid and ion) mobilization in soil was not controlled by hydrodynamic shear, but was time-dependant and possibly, diffusion limited process (Schelde et al. 2002). Thus, we assert that the highest bulk densities (1.5 g cm^{-3}) in the enriched chemical components observed in topsoils (0-20 cm) of the Ferralsol luvic (FS) and the Arenosol (FV) could slowdown water infiltration, and thereby, improving the condition of dissolution process (Quaggio 2000). As consequence, highest concentrations of leached nutrients were determined in the samples of groundwater of corresponding topographic positions (Figure 3) contrasting with their variability in topsoil (Table 1). But, this process was limited for anion (N-NO_3^- and P_2O_4^-) concentrations that were low in the groundwater of FV position. Highest infiltration rate resulting to sandy texture of soil with lowest bulk density

(1.3 g cm^{-3}) in soil depth ($> 80 \text{ cm}$), nutrient losses (N and P) from the systems as consequence of waterlogging inducing discharge of groundwater in subsequent lowland (USGS 2008) and its effect on P- bounding by Ca^{++} (Abekoe and Tiessen 1998) can account for this results.

Therefore, the land of FV position may have low suitability for rainfed crops in spite of the high availability of moisture and no mechanic limitation of rooting zone. Such contrast can justify further investigations for developing new index of soil productivity (Riquier et al. 1970, Neill 1979) in tropical ecosystems.

Prediction of Leached Nutrient Concentrations

Although depleted in July, there was increasing of leached nutrient concentrations during the study (Table 2), particularly for N-NO_3 , P_2O_4 , Mg, and HCO_3 coupled with the increasing of water pH. In contrast, highest concentrations of N-NH_4 and K were determined in the samples collected in July as a similarity also described by the overlapping of their highest concentrations in the groundwater occurring in the FS (Figure 4). Moreover, the concentrations of these cations were not correlated with that of HCO_3 , except in FS position for N-NH_4 contrasting with the result observed for Mg. Indeed, base cation mobility in the soil profile is depending to the valence of accompanying anions as documented for SO_4^{2-} (Chaves et al. 1991) for establishment of electrochemical equilibrium in soil solution (Lindsay 1979). Our finding revealed the importance of HCO_3 for cation leaching, especially for Mg in undisturbed soil of bush fallow resulting from forest clearing. However, Mg average concentration was close to that of K (monovalent cation) contrasting with the normal condition of leaching under influence of organic acids (Rosolem et al. 2004). In turn, N-NO_3 and P_2O_4 looked like to be the main accompanying leached anions for that of N-NH_4 , K and Mg with positive or negative influence depending to topographic positions (Table 3). Furthermore, the concentrations of N-NO_3 (K and Mg) and P_2O_4 (N-NH_4 and K) in groundwater can be use for the estimation of that of the cations whereas, only Mg concentration can be describe by that of HCO_3 (Table 4).

In the light of these analyses, organic agriculture can be of interest in reducing nutrient loss by leaching process: The reduction of N-pool leaching (Laegreid, Bockman, and Kaarstad 1999) will similarly affect that of K and P, while that of Mg is still questioned. If confirmed by further study, we can attest ecological consequence of this practice already subjected to contro-

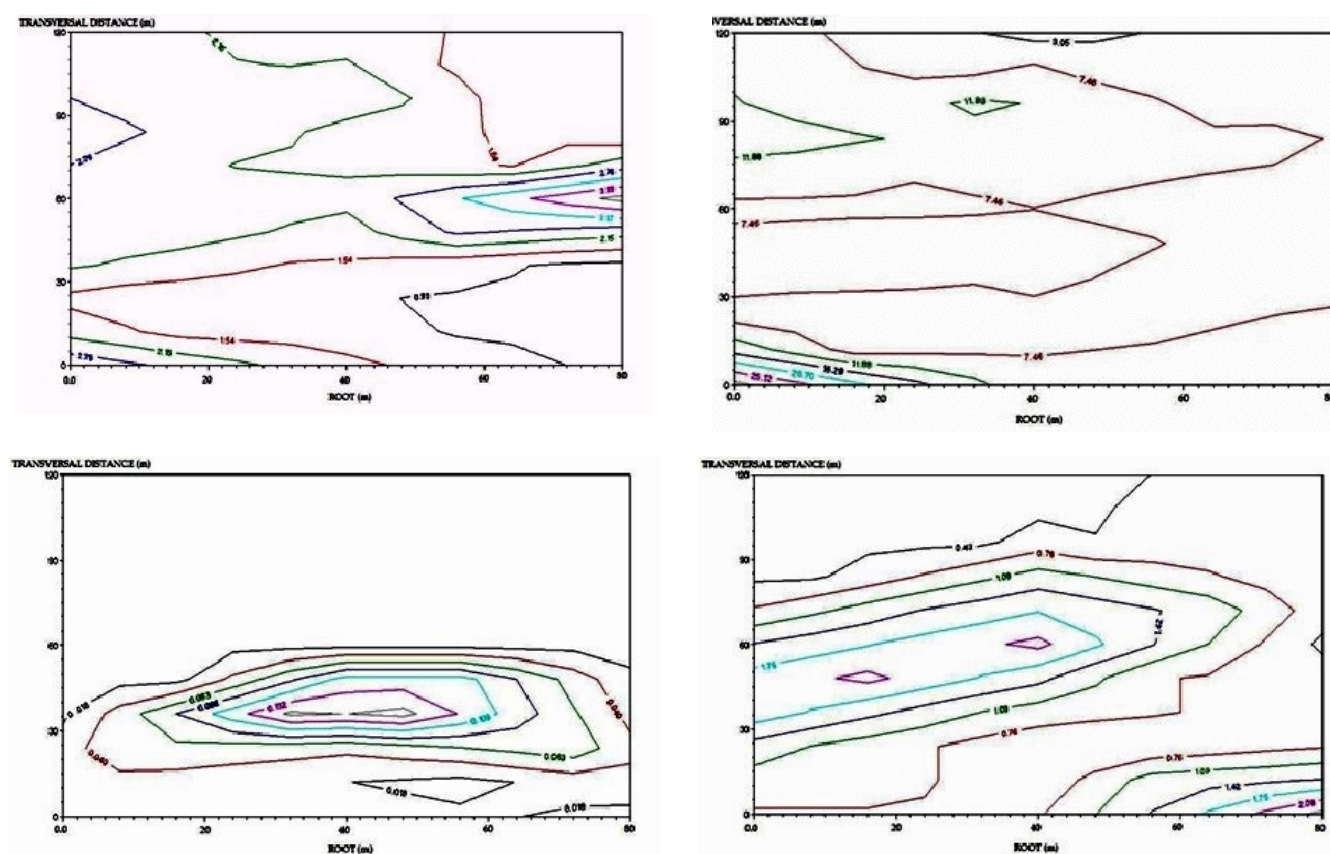


Figure 4. Patterns of major nutrient (N, P and K) concentrations in perched groundwater

versarial assertions referring to nutrient management in agricultural lands (Kirchman and Bergström 2001, Sileika and Guzys 2003).

Nutrient Outflows From the System

According to Fischer et al. (2008), some nutrients including phosphate ($0.8 \text{ kg P}_2\text{O}_4/\text{ha}/\text{year}$), N ($4.9 \text{ kg NO}_3/\text{ha}/\text{year}$), M ($0.1 \text{ kg Mg}/\text{ha}/\text{year}$) and potassium ($0.3 \text{ kg K}/\text{ha}/\text{year}$) could be imported to the system (watershed) through rainfall in forest ecosystem of West Africa. The overall input flux was exceeding surface runoff (output) which was responsible for decreasing trend of studied nutrient contents in topsoil along toposequence (Table 1) as early documented by Koné et al. (2009) for ferralsol environment. Furthermore, K and HCO_3 are supply by the canopy of vegetation, but N, P, K and Mg deficiencies were observed in the studied agro-ecology coupled with the declining of rice grain yield over cropping seasons (Koné et al. 2013a, 2014). Studied chemical compounds were loss from the rooting

zone in decreasing order as $\text{HCO}_3 > \text{N-NO}_3 > \text{K}$ and $\text{Mg} > \text{N-NH}_4 > \text{P}_2\text{O}_4$ during this experiment (cropping season of 3 moths). The conversion (Tekalign et al. 1991) of the lowest leached concentration of P_2O_4 was equivalent to $0.017 \text{ mg P L}^{-1}$ (0.017 mg kg^{-1}) which was negligible compared with the topsoil contents of P ($11\text{--}15 \text{ mg kg}^{-1}$) likewise for Mg (0.02 g kg^{-1}). If understandable for P because of polyvalent cations (Al^{+++} and Fe^{+++}) bounding in soil, limiting the solubility of P-compounds (Koné et al. 2010), that of Mg is confused when referring to Hermans *et al.* (2004): Because of high hydrated radius, Mg was supposed to sorbs less strongly to soil colloid than by other cations, hence supposed to be most prone to leaching. Therefore, insight should done for Mg dynamic in tropical forest soil in order to understand more its contribution to declining crop yield across cropping seasons (Koné et al. 2013a). Nevertheless, leaching look likes to be a minor factor concerning P and Mg availabilities for crops mineral nutrition in the studied ecosystem.

In turn, leached K and total-N (N-NO_3 and N-NH_4)

account for $0.0895 \text{ cmol kg}^{-1}$ and 0.13 g kg^{-1} respectively, were sometime greater than the amounts determined in subsoil horizons (0-70 cm), especially, in the soil of FV position. As consequence, we can attest that N and K are most concerned by leaching process in the soil beside of organic acid which is not a mineral compound however. Furthermore, it was known that N is affected by chemical changes as conversion to nitrite, nitrous oxide and nitrogen gas (denitrification) rendering nitrate unavailable to roots in facultative aerobic condition (Vartapetian and Jackson 1997). But these aspects were not concerned by the current study.

Similar results were early documented for the studied ecosystem using in situ lysimeters (Charreau 1972) as consequence of fertilizers application. But, the actual study pointed out ecological ability of losing soil N and K by leaching process even under bush fallow. Roughly, the losses of K and N for 1kg of soil can be determined as 0.87 g K ha^{-1} and 0.45 g N ha^{-1} which are required as additional fertilizer practice in forest ecosystems according to the rooting depth of crops and soil particle density.

CONCLUSIONS

Carbonic acid is the most leached chemical compound in the studied ecosystem but, N-NO₃ and P₂O₄ looked like to be the main accompanying leached anions for that of N-NH₄, K and Mg with positive or negative influence depending to topographic positions. Furthermore, the concentrations of N-NO₃ (K and Mg) and P₂O₄ (N-NH₄ and K) in groundwater can be use for the estimation of that of the cations whereas, only Mg concentration can be describe by that of HCO₃. Nevertheless, leaching look likes to be a minor factor concerning P and Mg availabilities for crops mineral nutrition in the studied ecosystem contrasting with that of N and K respectively. For 1kg of soil, 0.87 g K ha^{-1} and 0.45 g N ha^{-1} are required as additional fertilizer practice for sustaining crop production in forest ecosystems.

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