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How plants of the Amazonian floodplain (Brazil) can affect the geochemical status of trace elements in the Amazon River mainstream?

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Abstract. Multi-element analysis of plant tissue samples increased this last 20 years, in relation to chemical weathering processes. However, if plants play a key role in terms of storage and transfer of elements (major and trace) in natural ecosystems, our knowledge of transfer processes and fluxes are still poor. In the present study, we measured the concentrations of major and trace elements in the leaves of four different species (annual and perennial) of an amazonian floodplain during one hydrological period. The studied site is the "Ilha de Marchantaria"(3°15'S; 60°00'W) located on the Solimões River (Upper Amazon), near the city of Manaus.
The results reveal high concentrations (from 10 to 1000 ppm for Al, Mn and Fe ; from 10 to 100 ppm for Rb, Sr and Ba) in leaves and an annual variation wich is reverse of the river discharge (High concentrations for low water level and low concentrations for high water level). According with datas of net primary production (100 $t.ha^{-1}.y^{-1}$) and of total floodplain area (200000 km^2), we estimate the amount of trace elements stored or recycled in the vegetation of the amazon floodplains. We also observed that the amount of trace metals exported by the amazon [9] is one hundred time less than the amount of trace metals stored or recycled by the vegetation.

1. INTRODUCTION

If we except biological studies dealing with mechanisms of nutrient uptake and transport in plants (i.e., plant physiology), different recent works appear to be focused on element plant analysis in relation to the Earth Science community.

One of these works concerns the role of plants in chemical weathering (e.g.,[1] ; [2] ; [3] ; [4] ; [5]). Indeed, if we want to improve our understanding of the biogeochemical cycles of the elements (major and trace) in natural systems and calculate true chemical weathering rates, we should consider the role of plants. Up to now, mass balance calculations performed on watersheds generally consider a steady state for the vegetation and finally neglects this term. The present paper is an attempt to forecast the role of plant in the cycling of some trace elements (i.e., Al, Mn, Fe, Co, Ni, Cu, Rb, Sr, Ba, Pb) in a floodplain of the Amazon River that is still poorly documented.

Recently, hydrological and geochemical studies have been initiated in these environments in order to evaluate the influence of the floodplains on the Amazon River mainstream (in terms of storage and/or release of elements, geochemical processes). Let us recall that the Amazon is the largest world river in terms of drainage area (6.1 106 km2) and yearly water discharge (5.5 109m3/yr) which represents about 15% of the world's fresh water flux from land to ocean ([6]). For this, we have measured the concentrations of these elements in the leaves of four different plant species from a varzea (Amazonian floodplain) collected at different periods of the year.

In this paper we present a first order calculation to estimate the amount of trace elements stored or recycled by the vegetation.

2. SAMPLING SITE

The studied site is the Ilha de Marchantaria (3°15'S; 60°00W) located on the Solimões River (called the upper Amazon) 20 km south of the city of Manaus (Amazonas state), near the confluence with the Rio Negro (Fig. 1). The island Ilha de Marchanteria is a varzea (floodplain) of the Rio Solimões. The Solimões River is a whitewater wich shows a near neutral pH and is relatively rich in cations and suspended sediments of Andean origin ([7]). A precise description of the site as concerns its hydrology, topography, and climate is given elsewhere ([8] ; [9] ; [10]). A monomodal flood characterizes the Amazon River and its big tributaries, with for illustration an amplitude of 10 m on the rio Negro (Manaus harbor). The lowest water period is in November and the highest water period in July.

Leaves of four species were collected at four different periods of the hydrological cycle (July 2001, September 2001, November 2001, and February 2002). These species are *Pseudobombax munguba*, *Salix humboldtiana*, *Echinochloa polystachya*, and *Eichhornia crassipes*. *Pseudobombax munguba* and *Salix Humboldtiana* are tree perennial species while *Eichhornia crassipes* and *Echinochloa polystachya* are annual herbaceous plants. *Echinochloa polystachya* is a tall C4 grass with an annual life cycle in phase with the water cycle. As water level increases and submerges the floodplain, this species develops adventives roots, which replace the roots of the stem base. *Eichhornia crassipes* is a purely aquatic plant, its root system being never in contact with the sediment.

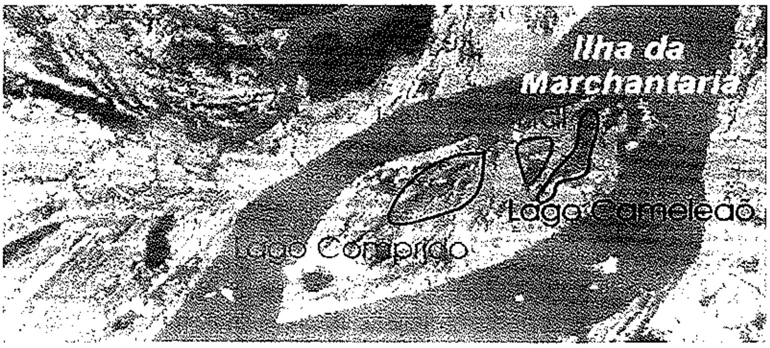

Fig. 1. Location of the studied site : the Ilha de Marchantaria

3. SAMPLES AND METHODS

Before to be finely ground with a hammer mill, plant materials were first cleaned with ultrapure water to remove particles from the surface and dried at 95°C in a oven during 24 hours. All these procedures (cleaning, drying, and homogenization) have been carefully reviewed by Markert (1995). Each powder sample was submitted to hydrogen peroxide digestion (H_2O_2) and acid digestion (HNO_3 + HF). Blank tests were performed to estimate the level of contamination induced by the acid digestion. The contamination is found to be less than 1% of the less concentrated sample. The international geostandard NIST-SRM 1515 (Apple Leaves) were used to check the validity and the reproducibility of both the acid digestion and ICP-MS analyses. Trace elements concentrations were measured using a quadrupole-based ICP-MS (Elan 6000, Perkin Elmer SCIEX). For the trace elements reported in this study (Table 1) we obtained a good agreement between our values and the certified data (relative difference below 10%).

4. RESULTS

The figure 1 presents the concentrations of the different trace elements measured in the leaves of the four species and at different time periods. Undoubtedly, we observe that there is large differences in the level of concentration for these elements. The four plant species appear to have high concentrations of Al, Mn, and Fe with values ranging from 10 to 1000 ppm. Rb, Sr and Ba are also strongly concentrated in those plants (between 10 and 100 ppm) with the exception of the *Echinochloa polystachya* that exhibits lower values (below 10 ppm) notably for Sr and Ba. The four species present homogeneous concentrations for Ni and Cu with values generally below 10 ppm. Finally, Co and Pb are the less concentrated elements with values close to 0.1 ppm. Considering the seasonal variation of concentration for the different elements, it appears that the highest concentrations are measured in the samples collected in September and November when the water level is low. This is shown by the figure 2 where we ploted the variation of Mn concentration in the *Eichhornia crassipes* and *Pseudobombax munguba* as a function of time. For information we have reported on the same graph, the variation of the Solimões river water discharge measured at Manacapuru ([11])

	Salix humboldtiana				*Pseudobombax munguba*				*Eichhornia crassipes*				*Echinochloa polystachya*			
	7/18/01	09/11/2001	11/22/01	02/06/2002	7/18/01	09/11/2001	11/22/01	02/06/2002	7/18/01	09/11/2001	11/22/01	02/06/2002	7/18/01	09/11/2001	11/22/01	02/06/2002
Al	93,54	165,40	363,92	163,05	8,16	24,82	44,89	31,31	93,54	165,40	363,92	163,05	25,08	18,66	21,82	-
Mn	269,71	888,25	1232,64	887,12	40,95	24,76	87,75	144,41	269,71	888,25	1232,64	887,12	40,25	123,58	172,05	-
Fe	142,01	503,82	470,24	172,60	53,89	83,72	160,08	191,65	142,01	503,82	470,24	172,60	357,42	82,39	138,72	-
Co	0,08	0,32	0,19	0,21	0,12	0,07	0,08	0,11	0,08	0,32	0,19	0,21	0,11	0,04	0,11	-
Ni	2,78	1,54	1,06	0,59	2,24	1,80	2,43	3,92	2,78	1,54	1,06	0,59	2,04	2,02	1,28	-
Cu	7,37	7,74	8,12	3,40	7,23	6,07	5,81	8,39	7,37	7,74	8,12	3,40	3,52	5,96	3,45	-
Rb	20,06	31,96	31,00	24,72	36,63	51,15	20,00	21,38	20,06	31,96	31,00	24,72	26,98	67,53	50,67	-
Sr	93,51	100,72	82,44	33,58	34,98	34,15	86,39	97,52	93,51	100,72	82,44	33,58	2,36	5,06	3,72	-
Ba	70,05	71,18	58,24	19,29	35,43	33,65	90,88	80,84	70,05	71,18	58,24	19,29	2,71	0,42	1,15	-
Pb	0,20	0,15	0,26	0,19	0,09	0,04	0,14	0,14	0,30	0,15	0,26	0,19	0,17	0,09	0,13	-

Table 1. Concentrations of trace elements in sampled plants (ppm)

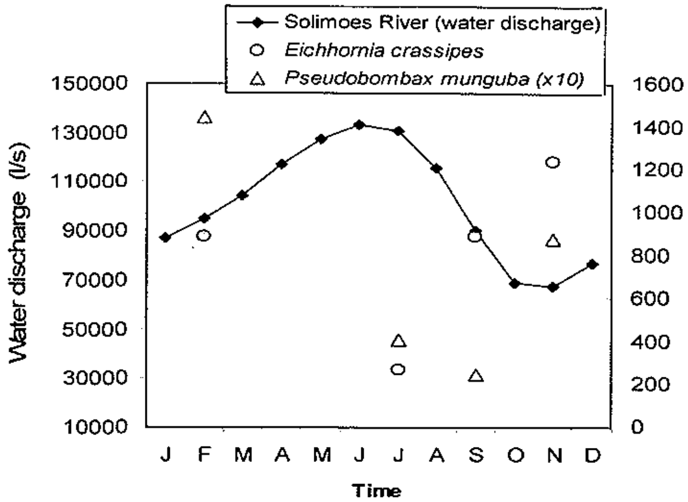

Figure 2. Seasonnal variation of Mn Concentration in *Eichhornia Crassipes* and in *Pseudobombax Munguba*

5. DISCUSSION

Data about concentration levels for the selected elements show that these species present high concentrations and should be considered as a potential and significant geochemical reservoir.The results we obtained as concerns seasonal variation show that both perrenal and annual species exhibit the same temporal variations with high values in October and November (Low water level) and low values in July (high water level).

As annual species have their roots in the lake water, we expected trace elements concentrations in the leaves of thes species do follow the corresponding concentration in the lake water. Unfortunately, we do not have temporal variation of trace elements concentrations in the lake of the varzea. However, according to Furch ([8]), the concentrations are 20 times higher in October and November wich seems to be in agreement with our hypothesis. The seasonal variation obtained for tree species is surprising because of their roots wich are in the sediment and not directly related to lake water. Further investigations should be done to propose an explanation. Our results do not follow ion any case the tendency reported by Piedade et al. [10] for some major elements. They analyzed the nitrogen (N), phosphorus (P) and potassium (K) contents in the different plant organs (i.e., leaves, stems, roots) of the C4 macrophyte *Echinochloa polystachya*. One of the main results of their study is the concurrent increase of N and P concentrations together with the water level. Beyond the seasonnial variation, data presented hereshould demonstrate the potential role of vegetation in the geochemical cycles of elements. This is particularly true when considering the species present in the site. One of the species considered in this study, *Echinochloa polystachya*, is one of the most productive herbaceous species with a maximum net primary production in dry weight (NPP) of 100 t.ha-1 during one year. In large rivers floodplain such those of the Amazon, the predictable and prolonged flood pulse allow the development of seasonality in the biotic communities. Animal and vegetal develop adaptation and strategies for an efficient utilization of habitats and nutrients. As defined by Junk et al. ([13]), those floodplain areas are called "aquatic/terrestrial transition zone" (ATTZ) because they alternate (according to the river hydrological cycle) between aquatic and terrestrial environments. During terrestrial phase (dry period: October, November), biomass collapses, and then we have an intense and rapid decomposition on the sediment when exposed to oxygen. This allows a rapid nutrient turnover. According to Junk and Howard Williams ([14]), the half-life of dead of *Echinochloa polystachya* is estimated to be 14 days. So, perennial grasses like Echinochloa polystachya are very important for the nutrient status of the Amazon. Finally, floodplains represent environments where the physical and chemical conditions supporting various biotic communities (animals, vegetal) differ strongly and may act as sink or source with respect to elements.

	Stored in the floodforest	Stored annually by the floodforest	Recycled annually by the floodforest	Recycled annually by the herbaceous plants	*Exportation fluxes from the Amazon River**
	10^3 kg	10^3 kg.yr^{-1}	10^3 kg.yr^{-1}	10^3 kg.yr^{-1}	10^3 kg.yr^{-1}
Al	296495	8951	16783	10916	-
Mn	1184420	35756	67043	46569	*416*
Fe	588966	17780	33338	25751	-
Co	393	12	22	15	*9*
Ni	5416	163	307	164	*47*
Cu	17931	541	1015	548	*39*
Rb	78473	2369	4442	3766	*50*
Sr	186591	5633	10562	4064	*438*
Ba	152230	4596	8617	2806	*430*
Pb	401	12	23	16	-

Table 2 . amount of trace elements stored or recycled by the vegetation of the amazonian floodplain

Amazonian floodplains are submitted to different hydrological regime (monomodal regime, unespectable polymodal regime, costal regime) and occupy an area of about 1,350,000 km^2 wich is about 25 % of the whole amazon river basin.

Among this maximum floodplain area, 200,000 km2 are dominated by the monomodal hydrological regime with prevailing vegetation composed of forest and grassland similar to the vegetation we have at the Ilha de Marchantaria. Using data of piedade et al. [15] obtained on the varzea de Marchantariafor the vegetation(i.e., net primary production, wood increment, biomass) we have calculated the amount of trace elements stored or recycled by the vegetation of the amazonian floodplain. Of course we should note that this is a first order calculation.For this estimation we extrapolated the data obtained on the varzea of Marchantaria to the whole amazon floodplains submitted to a monomodal hydrologic regime.

The net primary production of the varzea forest varies with the distribution of the species which depends on the age of the forest. Piedade et al. ([16]) proposed an estimated net primary production of the varzea forest between 23.8 and 33.6 t.ha-1.yr-1 for the Ilha de Marchantaria (40 years old forest). Wood increment for this forest is estimated to be around 8 6 t.ha-1.yr-1. About one/third is the production of leaves which contribute to about 80% of the litterfalls. For the herbaceous plants, we used the net primary production calculated for the *E. polystachya* species (100 t.ha-1.yr-1). Our calculations depend a lot on the areas occupied by openwater, herbaceous macrophytes and flooded forest. This is still a challenge for the Amazon ([17]). To perform these calculations, we considered that 50% of the floodplain area (200,000 km2) is occupied by flooded forest and the remaining surface by open lakes. 10 % of the open lakes are covered by herbaceous plants such as *Echinochloa polystachya* and *Eichhornia crassipes* ([18]). Finally, we use the average concentrations measured in the two tree species and in the herbaceous species. Calculations are reported in table 2.

First, we observe that the amount of trace elements recycled annually by the flood forest is similar to the amount of trace elements recycled annually by the herbaceous plants. These values are of the same order to the amount stored annually by the flood forest (wood increment). We have reported on the table 2 the exportation fluxes from the Amazon River (at Manacapuru) calculated by Seyler and Boaventura ([7]). These authors have proposed the first quantitative estimate of natural fluxes of trace metals in the Amazon basin, on both the dissolved and particulate form for Mn, Sr, Ba, Co, U, Cu, Pb, Rb, V, As, and Ni. The amount exported by the Amazon River is negligible compared with the amount recycled or stored by the vegetation.

This has major implication because when deforestation increases due to the expansion of cities or for agriculture (farms and pasture lands), this will be a major potential source of elements. The same may occur when forest decays following hydroelectric dams establishment. This signifies that on a small scale time, vegetation may deliver to the oceans amount of element highly superior to the amount delivered by chemical or physical weathering.

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