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## SUPERFICIAL EVOLUTION OF AMAZONIAN BAUXITE DEPOSITS

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According to **Bárdossy** [1] »Bauxitization is a surface phenomenon that cannot continue under a cover of later deposited sediments . . . At most surface deposits an »in situ« recent soil is on the top of the bauxite . . . This soil horizon is the best developed where the deposits are covered by a dense tropical humid forest«.

The aim of this paper is to evaluate the contribution of present pedogenetic processes under tropical humid forest of Central Amazonia (Brazil), to the accumulation of aluminum in deep soil horizons.

\* \* \*

### POVRŠINSKA EVOLUCIJA AMAZONSKIH BOKSITNIH LEŽIŠTA

Prema **Bárdossyju** [1], »Boksitizacija je površinski fenomen koji se ne može produžavati ispod pokrova kasnije istaloženih sedimenata . . . Na većem dijelu površinskih nalazišta uvijek se na njima odozgo nalazi in situ recentno tlo . . . Taj je talni sloj najbolje razvijen na ležištima pokrivenim gustim tropskim humidnim šumama«.

Svrha je ove rasprave ocjena doprinosa recentnih pedogenetskih procesa ispod tropskih humidnih šuma brazilske centralne Amazonije akumulaciji aluminija u dubokim talnim slojevima.

(R. M.)

### MATERIAL AND METHODS

This study was realized with the support of »Instituto Nacional de Pesquisas da Amazonia«, of »Centro de Energia Nuclear na Agricultura« (Universidade de São Paulo) and of ORSTOM. The study area is located North of Manaus (2°33'N and 60°02' E). The present climate is equatorial of Amazonian type, with an average rainfall of 2400 mm/y, and a slight dry season.

The vegetation is dense, humid evergreen forest. The annual litter production (0,75 kg/m<sup>2</sup>/y) takes place during the drier period of the year, while decomposition processes (with a marked nitrogen and sulfur loss in the early stages of decomposition) are more accentuated in the wet season [2].

Yellow clayey latosols cover plateaus of sandy loam, clastic, poorly consolidated sediments, which are of the Cretaceous Alter do Chão Formation (according to Putzer [3]).

This yellow clayey latosols are the »latossolos alicos, textura argilosa« of the Brazilian classification. They correspond to the »Acrorthox« of the Soil Taxonomy.

Under a thin bed of dead leaves, the soils have a yellowish brown organic horizon (A) about 20 cm thick, which grade downward into weakly structured plastic horizons, which are first brown yellow, and then yellow. (Fig. 1)

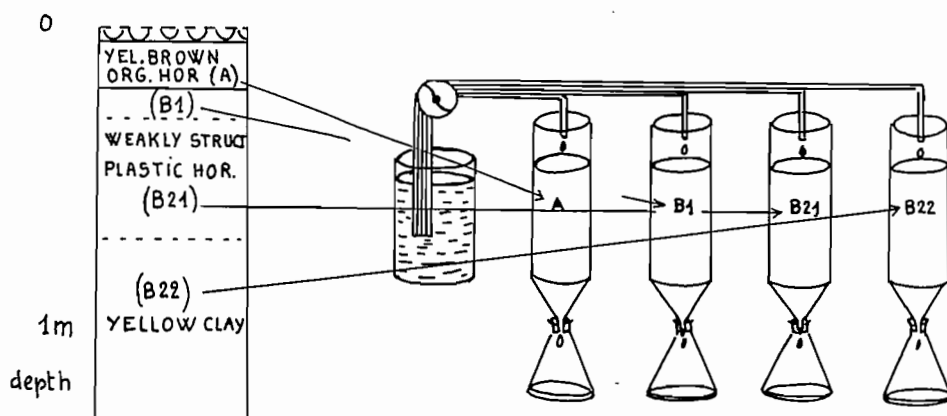


Fig. 1. Soil profile and laboratory experimental apparatus

The soil is clayey from the surface (55 to 75 % of clay in the first 20 cm), and very clayey below down; pH values measured in water is 3.8 to 4.2 down to 20 cm of depth, and go up to 4.9 to 5 in the lower part of the profile.

The sum of exchangeable bases ( $\text{Ca}^{++}$ ,  $\text{Mg}^{++}$ ,  $\text{K}^{+}$ ,  $\text{Na}^{+}$ ) is very low (0.7 meq/100 g in depth). Exchangeable Al is relatively high in the A horizon (3 meq/100 g) and goes down to 0.5 meq/100 g below.

The most part of the biological activity is concentrated in the A horizon (about 75 % of living organisms: microroots, biomass, fauna... fresh organic material. [4]. Within this superficial horizon of the profile, the proportion of quartz grains progressively increases from the base to the top. According to Scatolini et al. [5] and to Lucas et al. [6] this increasing concentration is a result of the instabilization of the kaolinite which is linked to the increase in the amount of organic matter.

Laboratory and field experiment were carried out by Chauvel, Andreux and Cerri.

*In the laboratory* (Fig. 1) distilled water was made to percolate through several soil samples (sieved but not dried) taken from the different horizons of the soil profile and placed in columns. A constant water flow was obtained with a pump functioning at 1 ml/hour, corresponding to a rainfall of approximately 10 mm/day. Leachates were collected during 40 days. After filtration (millipore) they we-

re analyzed for pH, Si, Al, Fe, Mn, Ca, Na, K, NO<sub>3</sub>, NH<sub>4</sub>, SO<sub>4</sub>. The freeze dried residue of leachates are analyzed by differential thermic analysis and infrared spectrometry. An Nuclear Magnetic resonance spectrum was obtained for one leached by **Bottero** in the laboratory of Nancy.

### Laboratory results

The leachate collected during the first and second day are characterized by pH not different from those of the soil and by very weak concentrations of all elements. Only in column n 1 (containing organic material from A horizon) (see Table 1) was a reduction in pH observed from the third day, which was accompanied by a progressive increase in Al and Si level. The pH turns to 3.8 after 6 days while Al and Si levels reached 25.8 and 4.6 ppm respectively.

Table 1. Leachate characteristics from laboratory experiment

Soil samples leachate characteristics	A		B1		B21		B22	
	1 <sup>th</sup> day	6 <sup>th</sup> day	1 <sup>th</sup> day	6 <sup>th</sup> day	1 <sup>th</sup> day	6 <sup>th</sup> day	1 <sup>th</sup> day	6 <sup>th</sup> day
pH	4,2	3,8	4,2	4,1	4,5	4,5	4,9	4,9
Al (ppm)	0	25,8	0	0,05	0	0,05	0	0,05
Si (ppm)	0	4,6	0	1	0	1	0	1

The leachates from materials taken from the deeper horizons, which are poor in organic material, remained at a constant pH and contained almost no aluminum. Silica levels remains about 1 ppm.

The results of differential thermic analysis and spectrometric infrared analysis showed that aluminum in solution is not found in a form chelated by organic acids. The nuclear magnetic resonance indicates the presence of monomeric forms of aluminum Al(H<sub>2</sub>O)<sub>6</sub><sup>3+</sup> which is explained by the observed pH values.

The cause of this acidification was sought in biological decomposition products of organic material such as weak organic acids (humic acids) and, predominantly, strong nitric (and sulfuric) acids, liberated or excreted by decomposing microorganisms.

Temporal variations of NO<sub>3</sub> and Al<sub>3</sub> concentrations in the leachates is in Fig. 2 which demonstrates:

1. That the evolution of nitrate ions levels is typical of the biological nitrification process: rapid increase after wetting (2 days), maximum level obtained with one week, followed by a progressive reduction through depletion of easily nitrifiable organic constituents.

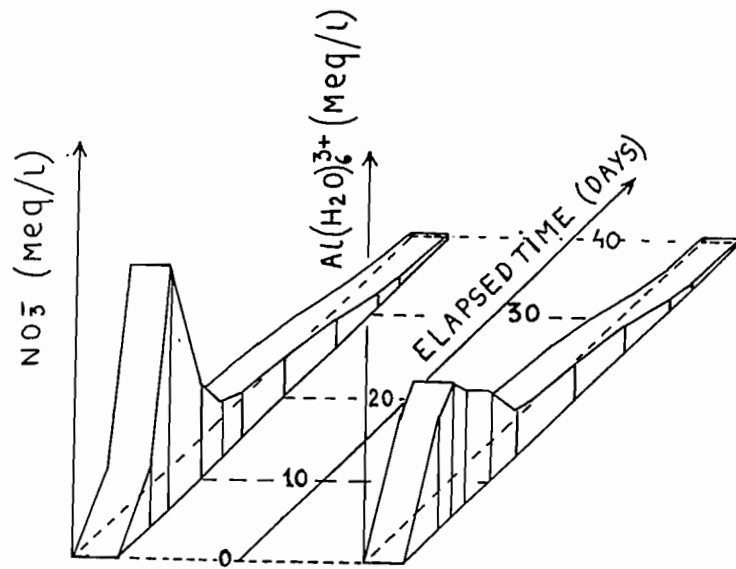


Fig. 2 Temporal variations of  $\text{NO}_3^-$  and  $\text{Al}(\text{H}_2\text{O})_6^{3+}$  concentrations (Meq/l leachate) out of the soil sample during column percolation.

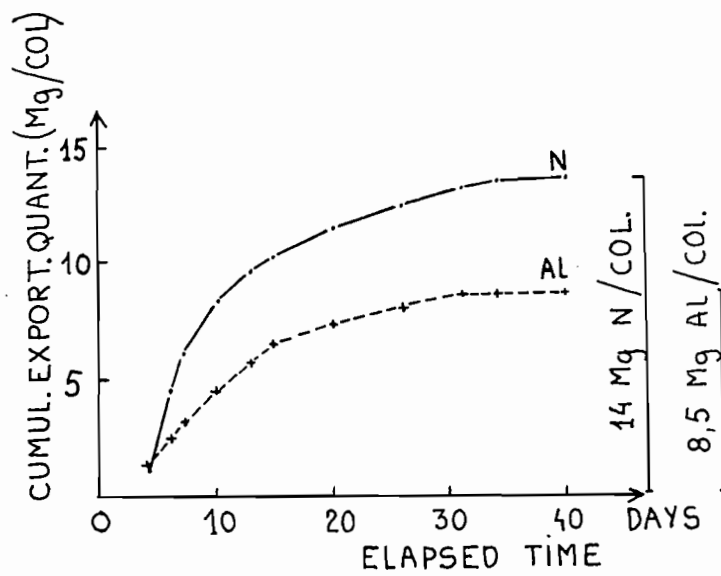


Fig. 3. Cumulative  $\text{NO}_3^-$  (NMg/column) production, and aluminum dissolution (Al Mg-/column) curves

2. The evolution of aluminum level in solution of aluminum, in this case, is linked to production of strong nitric acid by the decomposition of plant organic matter. Therefore, this is a mineral reaction governed by the biological process.

The cumulative  $\text{NO}_3$  production curves and dissolution of Al (Fig. 3) shows the development of a phase of nitrification process. The quantity of aluminum in solution coming from one column containing 300 g of dry earth from the horizon A is approximately 8 mg, or 27 mg/kg of earth, corresponding to 5 g/m<sup>2</sup> in the soil.

### LYSIMETRIC FIELD EXPERIMENT

Our objective was to approach natural conditions which characterize the Amazonian forest. Fig. 4 presents the experimental apparatus. Cylindrical lysimeters containing undisturbed soil samples and collectors in form of plates have been settled on the edges of one pit.

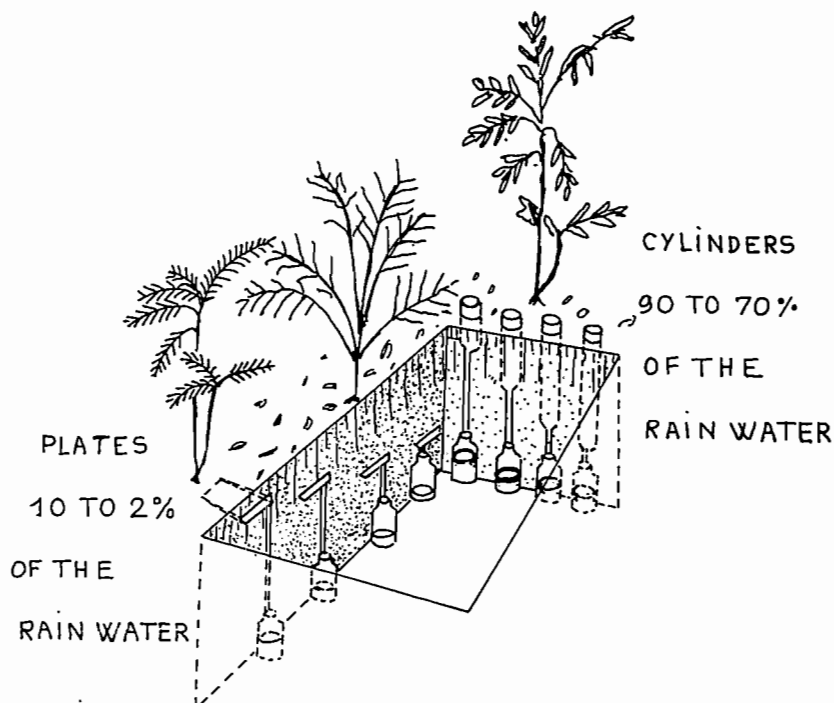


Fig. 4. Lysimetric experimental apparatus

Leachates were collected during the humid season and analyzed after filtration.

Experimental conditions change according to the type of lysimeter:

— On one hand, the undisturbed samples placed in the cylinders are isolated from surrounding soil. So: first these samples are not penetrated by roots which

then cannot absorb water and nutritive elements such as nitrates; and secondly 80 to 95 % of the rainwater is drained vertically (and collected), the remaining being evaporated.

— On the other hand, the plate collectors, which are open laterally, firstly do not prevent the root penetration and then their absorption activity, and, secondly, collect only rapid circulating water, that is to say 2 to 10 % of rain water.

### *Lysimetric experiments results*

#### 1. Cylinder

In the top soil (0 to 20 cm) analytical results show that acidity is mainly related to organic matter decomposition and usually exceeds  $100 \mu\text{eq H}^+ \cdot 1 \div 1$  of percolating solution.

Consequently the concentration of soluble Al is about  $75 \div 30 \mu\text{mol} \cdot 1 \div 1$  at 20 cm, which corresponds to  $3.2 \div 1.3 \text{ g Al/m}^2/\text{y}$  collected in solution (not very different from the evaluation in laboratory, that is to say  $5 \text{ g/m}^2/\text{y}$ ).

As in laboratory experiment, it can be seen a good linear correlation between  $\text{NO}_3$  and  $\text{Al}_3$  molecular concentrations (Fig. 5); likewise it can be seen that the  $\text{NO}_3$  content is high when not absorbed by roots. Then, the aluminum dissolution raised a maximum.

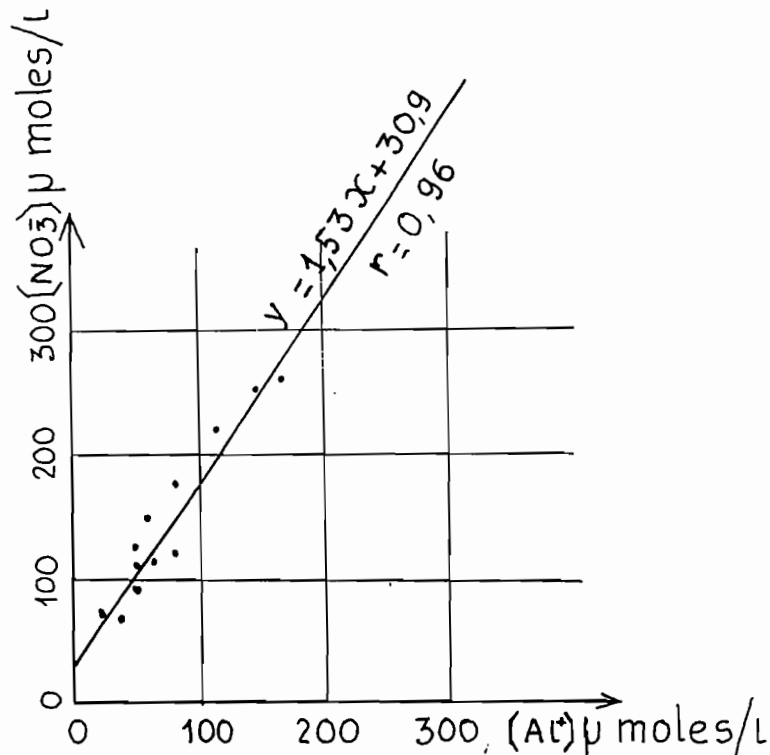


Fig. 5. Correlation between nitrates and aluminium concentrations in the leachates collected from cylindrical lysimeters

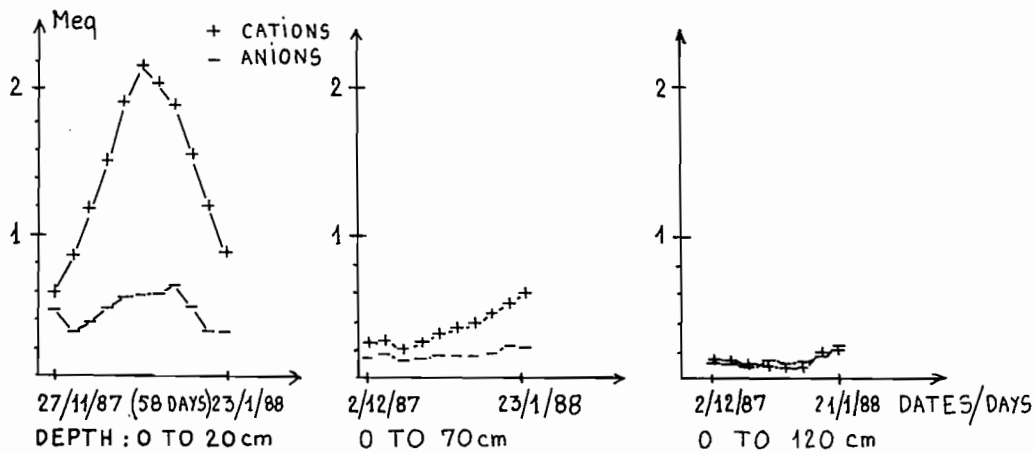


Fig. 6. Temporal variations of a ionic balance in leachates from the cylindrical lysimeters.

In Fig. 6 it can be seen that the evolution of a ionic balance, which takes into account all the anions and cations including Al, is all the more unbalanced as the aluminum content is high. This can be interpreted either as an effect of chelating weak organic acids or as the presence of non ionic aluminum which could be in a mineral form in the experimental conditions.

Deeper in the soil, the disequilibrium remains and the most of the aluminum precipitates in the cylindrical lysimeters.

## 2. Plate Collectors

The main results concern the solutions collected at two depths: first near the surface under organic matter accumulations, secondly at 20 cm depth.

In this conditions, which are not far from the undisturbed forest environment, the ionic balance is almost equilibrated (Fig. 7).

Moreover, a good correlation can be seen between silica and aluminum (Fig. 8). At the beginning of the testing silica content is relatively high and decreases pro-

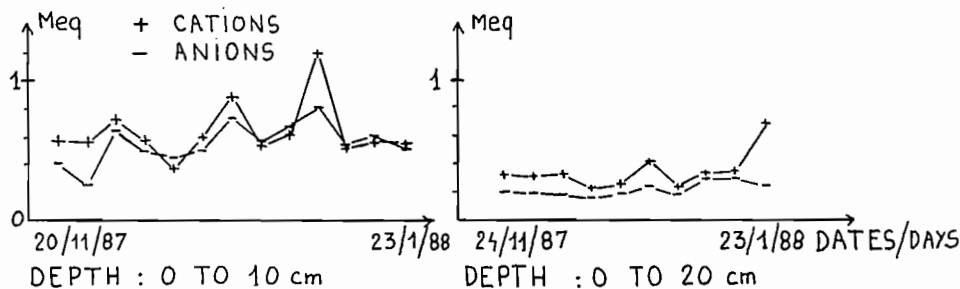


Fig. 7. Temporal variation of a ionic balance in leachates from the plate collectors

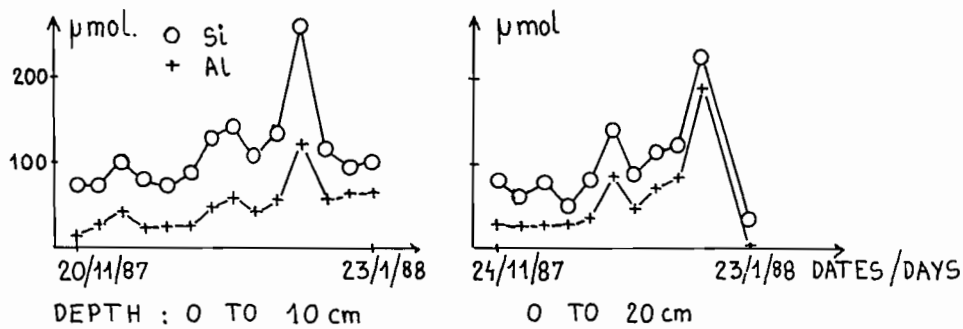


Fig. 8. Correlation between silica and aluminium in leachates from the plate collectors

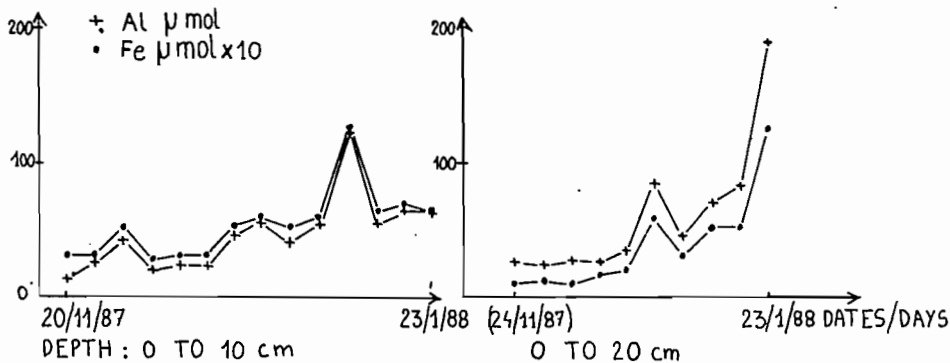


Fig. 9. Correlation between the iron and aluminium contents from the plate collectors.

gressively as a function of time, the Si/Al ratio tending to 1. Silica in excess could be due to quartz dissolution, while the other part could be linked to kaolinite dissolution.

Finally, the Fig. 9 shows the close relationship between the iron and aluminum contents evacuated from the organic horizon. This relation would emphasize that the Al, Si and Fe transfer in solution is due to dissolution of kaolinite and associated iron oxides in the superficial organic horizon.

*In conclusion*, it appears that significant quantities of aluminum, as well as silicon and iron are released by decomposition and dissolution of soil material in the organic horizon that covers bauxite deposits found under native Amazonian forest.

This process depends on the production of strong acid by the biological decomposition of plant material. The nitrate anions are normally quickly assimilated by plant roots, but an excess of this nitrates, and thus acidolysis process, may result of experimental conditions and under conditions of disequilibrium due to climatic stress, fire . . .



For the moment, research continues on this biochemical cycle of the forest under undisturbed natural conditions with the purpose of quantify the surface biological weathering.

#### REFERENCES

1. *Bárdossy, Gy.*: A comparison of the main lateritic bauxite regions of our globe. Lateritization processes, São Paulo 1983, Proc. 15/51.
2. *Luizao, F. J., Schubart, H. O. R.*: Litter production and decomposition in a terra firma forest of Central Amazonia. Birkhauser Verlag, Basel, *Experientia*, 43 (1987), 259/265.
3. *Putzer, H.*: The geological evolution of the Amazon Basin and its mineral resources. In: *The Amazon: limnology and landscape ecology of a mighty tropical river and its basin. Monographiae biologicae*, 56 (1984), 15/46.
4. *Chauvel, A., Guillaumet, J. L., Schubart, H. O. R.*: Importance et distribution des racines et des êtres vivants dans un »latossol« argileux sous forêt Amazonienne. *Rev. Ecol. Biol. Sol*, 24 (1987), 1, 19/48.
5. *Scatolini, F., Soubies, F., Chauvel, A.*: Destruição superficial da caulinita nos solos de uma toposequencia sobre a formação Later de Chão na região de Manaus. XX. Congr. Bras. Ci. Solo., Belem 1985.
6. *Lucas, Y., Chauvel, A., Ambrosi, J. P.*: Processes of aluminium and iron accumulation in latosols developed on quartz-rich sediments from Central Amazonia (Manaus, Brazil). *Geochemistry and mineral formation in the earth surface. Granada 1986*, 289/299.
7. *Andreux, F. G., Cerri, C. C., Mello, E. B., Krug, F. G.*: Composição mineral da agua livre de um latossolo sob floresta amazonica e apos queimada. XXI. Congr. Brasileiro de Ciencia do Solo. Campinas 1987, Resumo 123.