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ECOLOGY OF THE JARI-PARU MICROREGION I. CHEMICAL AND PHYSICAL PROPERTIES OF THE SOILS FROM EIGHT PRIMARY FOREST COMMUNITIES

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ABSTRACT - *This paper describes the chemical and physical properties of the soils from eight primary forest communities in the microregion of Jari-Paru, Lower Amazon. Although the Jari soils had the same general properties described for the Amazon soils, a large variation was observed among them. In texture they varied from almost pure quartz sands to heavy clays. The variation in texture paralleled the region's relief and geology. Sandy soils occurred in the alluvial undulating plains such as those found southwest of Monte Dourado, formed by Tertiary sediments. The most clayish soils occurred in 135 to 200 metre terraces made by Plio-Pleistocenic sediments. In chemical terms, the soil found in the "varzea" forest had the highest amounts of Phosphorous and other nutrients, as expected. Among the "terra firme" soils, the most fertile ones were those found at the Jari Ecological Station (IBAMA forest), at 450m altitude, which are formed by Paleozoic sediments.*

KEY WORDS: Lower Amazon; Comparative study; Relief.

RESUMO - *Este trabalho descreve as propriedades físicas e químicas dos solos de oito comunidades de florestas primárias da microregião do Jari-Paru, no Baixo Amazonas. Apesar dos solos do Jari terem as mesmas propriedades gerais descritas para os solos da Amazônia, observou-se uma grande variação entre os mesmos. Em textura eles variaram de areias quartzosas quase puras a solos muito argilosos. Tal variação na textura está ligada ao relevo e à geologia da região. Solos mais arenosos tenderam a ocorrer no relevo ondulado existente a sudoeste de Monte Dourado, os quais são originados de sedimentos do Terciário. Já os solos mais argilosos tenderam a ocorrer nas mesas ou terraços de altitude entre 135 e 200 metros, originados de sedimentos Plio-pleistocênicos. Em termos de nutrientes, o solo da floresta de várzea teve os maiores teores de fósforo e outros elementos químicos, conforme esperado. Dentre as comunidades florestais de terra firme, a que apresentou solos mais férteis foi a floresta da Estação Ecológica do Jari (IBAMA), constituídos por sedimentos do Paleozóico, em terreno de altitude próxima a 450m.*

PALAVRAS-CHAVE: Baixo Amazonas; Estudo comparativo; Relevo.

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INTRODUCTION

There are very few soil studies in the Amazon which were sampled under undisturbed primary forests. The majority of the existing studies were carried out in disturbed areas such as road sides, mines, cattle ranges and plantations. In the microregion of the Jari-Paru the first soil study was carried out by Russell (1983) on nutrient cycling, but it sampled only one pit under the primary forest. Later, an extensive soil survey was carried out by researchers of Companhia Florestal Monte Dourado together with researchers from the Brazilian National Soil Survey and Conservation Service (EMBRAPA/SNLCS) in Rio de Janeiro (Companhia Florestal Monte Dourado 1989), but again, almost exclusively on soils of plantation forestry. Nevertheless, this work is a very important record of Amazon soils due to the soil map produced on a 1:100,000 scale. Without controlled studies of soils occurring under undisturbed vegetation it is not possible to make ecological inferences on the evolution of the soil factors under an environmental impact.

The object of this study was to examine the main physical and chemical properties of the soils found under eight primary forest communities located in the Jari-Paru microregion, where a phenological study was carried out by the author from 1986 to 1990 (Pires 1992). It was thought that knowledge of the soils found under the eight forest communities studied could be of aid in interpreting the phenology data of these forest communities as well as account for their different plant composition (Pires 1991). Some of the data presented here will be used in the next paper of this series.

THE STUDY SITE

The field work was carried out in eight forests located between the rivers Paru and Jari, in the states of Pará and Amapá. These rivers are the two major easternmost tributaries on the northern bank of the Amazon river before it reaches the Atlantic ocean (Figure 1). The area studied includes the town of Monte Dourado, in the county of Almeirim (Pará) and a large area of the county of Mazagão (Amapá). Geographically the studied sites are close to the Equator, ranging from $0^{0}27'$ to $1^{0}6'$ latitude South and $52^{0}51'$ to $52^{0}25''$ longitude West. The economic importance of the area is based on the forestry activities of the Jari Company, formed "Jari Project" whose forest and industrial operations are carried out by the subsidiary Companhia Florestal Monte Dourado.

The eight sites of primary forest where the study was carried out are all reserves (Figure 1). Except for the site referred to as Ibama, located at the Jari Ecological Station, all others belong to the Jari Company, being part of a complex of genetic reserves aimed to promote the "in situ" conservation of forest genetic resources. The most important ecological parameters of the eight communities studied area given in Table 1.

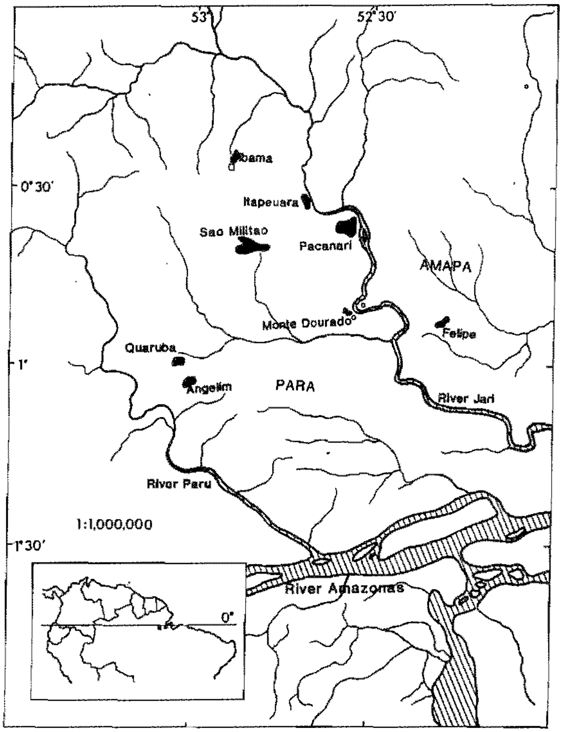

Figure 1 - Map of the Jari-Parú microregion showing the eight forest communities studied

Table 1 - Geographical gradient of the forest sites studied at Jari, Brazil. (Alt. = Altitude).

Site Name	Coordinates	Alt. (m)	Size (ha)	Forest Type	Geology
Angelim	01°06'S 52°25'W	77	400	Savanna	Tertiary
Quaruba	01°02'S 52°20'W	141	987	Savanna	Tertiary
Mt.Dourado	01°01'S 52°33'W	76	150	Semi-open	Tertiary
S. Militão	00°46'S 52°40'W	113	1,973	Semi-open	Tertiary
Pacanari	00°39'S 52°35'W	107	750	Semi-open	Tertiary
Mt. Felipe	00°52'S 52°23'W	150	306	Semi-open	Tertiary
Itapeuara	00°35'S 52°39'W	7	300	Várzea	Quaternary
IBAMA	00°27'S 52°51'W	449	500	Dense	Paleozoic

As far as climate is concerned the area of Jari has a climate formula B1rA'a' on the Thornthwaite system, or 'Amw' on the Köppen system, being hot and humid, with average temperatures in the order of 26.4°C. The average yearly precipitation is 2,115mm. This high precipitation average compensates for a mild dry season which takes place from August to December. The driest months, September to November, contribute with only 8% of te annual volume of rain in the region (Companhia Florestal Monte Dourado 1989). The Jari Company maintains six thermopluviometric stations throughout its area. The information in Figure 2 was taken from these stations during the period when the phenological observations took place.

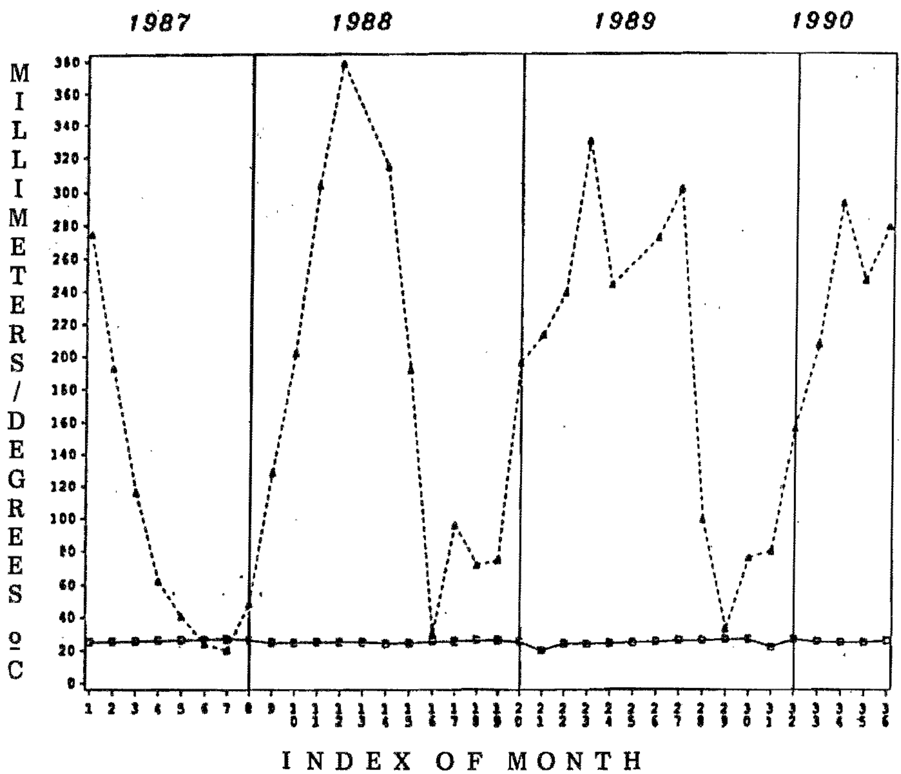

Figure 2 - Rainfall and temperature of the Jari-Parú microregion during the course of the study.

In relation to geology, the microregion of Jari-Paru shares the same geological history of the Amazon Basin. The relevant geological aspect of the Jari-Paru microregion are outcrops of Paleozoic sandstone and siltstone sediments from a sequence known as the Trombetas-Maecuru formation, at an altitude that goes from 430 to over 500m. The resulting pediplane (Pd2) was preserved by the presence of an existing iron duricrust (Pires-O'Brien 1992). As in the rest of the Amazon basin most of the sediments found in the area of Jari are of Tertiary origin being part of the Alter do Chão/Barreiras formation originated from pre-weathered materials of the crystalline shields (Projeto... 1972, 1978). Spread among these Tertiary terrains there are two types of terraces or table-top hills with sediments formed by the Belterra clay (Figure 3). The first type of terrace or pediplane, with altitude between 135 and 200m (Pd1) consists of eroded Pliocene and Pleistocene surfaces. The second type consists of irregular and dissected hills or pediments, of altitude between 68 and 74m (P2), made by sediments of the former (Klammer 1971, 1978).

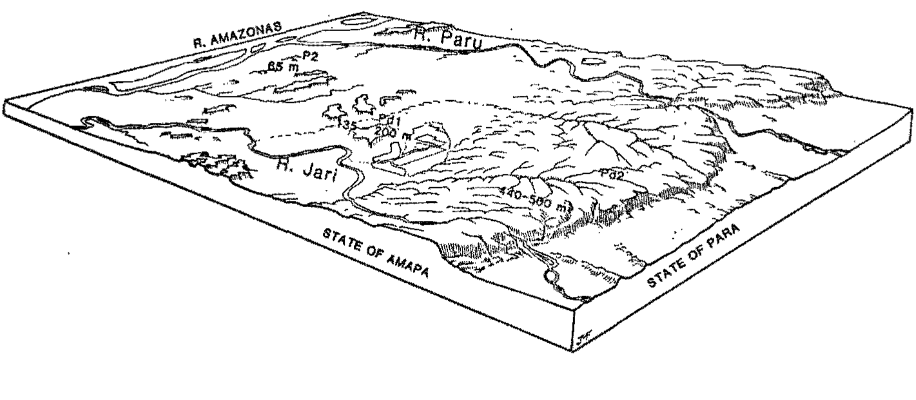

Figure 3 - Diagram showing the relief forms of the Jari-Paru microregion, in Lower amazon.

The presence of at least two geological formations creates a less homogeneous landscape than that found in most parts of the Amazon basin, yielding a variety of soil types and consequently, a less homogeneous vegetation. The relief types found in the area of Jari permits the separation of the various geological formations and consequently the soil types found there. For this reason the altitude of the eight sites studied as well as that of some other important reference points was measured by recording a series of measurements taken by two portable altimeters (Table 1).

METHODS

At each forest site studied several pits of 0.8 to 1.0m deep were opened on undisturbed areas on both sides of a transect. Two to three pits of each forest were then selected for the study. Since the profiles were examined and sampled at predetermined depths of 15, 40 and 70-100 cm, they are refered here as A, B and C layers, respectively. The "C" layer was sampled only where it was apparent in the profile. Only the top layer was collected for the "várzea" forest (Itapeuara) since it was beginning to be inundated at the time of sampling.

Each soil sample collected received a sequential number, cross-referenced with field notes. The soils were taken to the laboratory and oven-dried at 40°C as is normal in areas of very high humidity such as those that occur near the Equator. Such procedure is considered equivalent to air drying. After drying, a subsample of the soil was separated and packaged to be shipped to EMBRAPA-SNLCS in Rio de Janeiro, from where it was reshipped to University College London's Biology Department, where the physical analyses took place. The chemical analyses were carried out in the Tropical Soils Analysis Unit of the ODNRI (Overseas Development National Resources Institute), Reading, now in Chatham.

Particle size analysis was carried out by the Hydrometer method. The pH was calculated by immersing the electrode of a previously calibrated pH-meter into a beaker containing a soil solution. The total organic matter determination was carried out by the loss on ignition method. Total nitrogen was determined in an auto-analyzer by the micro-Kjeldahl method. Phosphate was determined by an auto-analyzer, using ammonium molybdate as a reagent. Although the results from the auto-analyzer were given in ppm (parts per million), they were converted into meq./100g in order to allow the comparison with nitrogen. Total phosphorus was determined in on auto-analyzer after digestion of finely ground soil by perchloric acid. The exchangeable sodium, potassium, magnesium and calcium were extracted from the soil samples by leaching them with 1 M ammonium acetate. The determination was carried out in an Atomic Absorption Spectrophotometer (AAS). The percentage of base saturation was calculated by dividing the Total Exchangeable Bases by the CEC (ammonium acetate pH 7) and multiplying the results to one hundred. The CEC was determined by an auto-analyzer following the exchangeable bases extraction on the same funnels of soil and sand. The exchanged ammonium ions were replaced in the soil by leaching it with 1 M potassium chloride at pH 2.5. The ammonia was determined colorimetrically. The exchangeable aluminium was also done on the AAS. 90 ml of the 1M KCl extracting solution was made up to 200 ml with distilled water. Total aluminium was determined by the AAS at 309.3nm, using a nitrous oxide/acetylene blue flame. Ef. CEC was calculated by adding the exchangeable Aluminium to the exchangeable bases (Ca + Mg + K + Na).

RESULTS

Texture - The soils of Jari showed a wide variation in texture, ranging from the almost pure quartz sands to heavy clays. Soil texture was found to accompany landscape features. The sandy soils occurred in the undulating alluvial plains SW of Monte Dourado, consisting of Tertiary sediments. Clay soils occurred on the various 135 to 200m terraces such as those found at the Monte Dourado airport and at the Felipe hills, across the river from Munguba, which are formed by Plio-Pleistocenic sediments. A whole range of soils of intermediate texture fill the gaps between the table-top hills and the sandy soils of the alluvial valleys. The most fertile and best textured soils of the "terra firme" forests are the loams of planation surfaces of the upper Jari-Paru basin, at the Jari Ecological Station (Ibama forest) which consisted of Paleozoic sediments. The floodplain or "vázea" forest had clay to silty-clay soils which were richer in nutrients than the terra-firme soils studied. A serpentine of ferric sandy-clay-loam with ant nests was found among the yellow podzols in both Felipe and Quaruba forests. The major soil textures and the average particle size of the soils studied is shown in Table 2.

Table 2 - Texture classes and particle sizes of the Jari soils under primary forest.

		LAYERS								
FOREST CODE	TEXTURE CLASS	A % SILT	B % SILT	C % SILT	A % CLAY	B % CLAY	C % CLAY	A % SAND	B % SAND	C % SAND
ANG	Loamy-Sand Sandy-loam	03	02	02	11	24	19	87	74	79
QUA	Loamy-sand Sandy-loam	02	00	00	09	13	21	89	87	79
DOU	Sandy-loam	00	17	04	18	20	23	82	63	73
SML	Sandy-clay-loam Sandy-loam	08	04	12	19	24	20	73	72	69
PAC	Clay	05	06	-	57	68	-	38	26	-
FEL	Clay	16	07	-	48	63	-	36	29	-
ITA*	Silty-clay	21	-	-	61	-	-	18	-	-
IBA	Sandy-clay-loam Sandy-loam	08	19	-	21	25	-	71	56	-

note: * Floodplain forest

Soil pH - As shown in Table 3, the Jari soils are very acidic, with pH ranging from 4.0 to 4.7 for the top soil. This table also shows pH values in relation to the three layers.

Table 3 - pH of the Jari soils under primary forest.

FORESTS	SOIL LAYERS A	B	C
ANGELIM	4.2	4.5	4.5
QUARUBA	4.3	4.4	4.6
MT. DOURADO	4.4	4.2	4.8
S. MILITÃO	4.0	4.4	4.7
PACANARI	4.2	4.5	-
FELIPE	4.7	4.9	-
ITAPEUARA	4.0	-	-
IBAMA	4.7	4.7	-

Soil Organic Content - The organic content of the Jari soils, are summarized in Table 4. This table allows one to visualise the decrease of organic matter with the increase in soil depth. The first four sandy type soils had a distinctly lower organic content than the last four clay ones.

Table 4 - Soil type and percentage of organic content in the Jari soils under primary forest.

FORESTS	SOIL TYPE	LAYERS A	B	C
ANGELIM	Loamy-sand	4.3	3.8	3.0
QUARUBA	Loamy-sand	8.0	5.1	4.7
MT. DOURADO	Sandy-loam	5.7	5.1	5.4
S. MILITÃO	Sand-clay-loam	5.0	3.8	19.4*
PACANARI	Clay	16.6	8.6	-
FELIPE	Clay	22.2	21.1	-
ITAPEUARA	Silty-clay	17.4	-	-
IBAMA	Sandy-clay-loam	14.4	15.5	-

* The data for this soil layer is clearly an outlier from what was expected. Samples of charcoal were found within this layer suggesting that it could have been top soil at some point in the past.

Nitrogen - The values of total nitrogen are summarized in Table 4. The nitrogen content found in the top soil of the eight forests studied varied fron as low as .09 meq/100g in the sandy soils of Angelim forest to .34 meq/100g in the heavy clay soils of Felipe. However there was no clear tendency for soil texture to be associated with nitrogen content. The amount of nitrogen also diminished with soil depth (Table 5).

Table 5 - Total Nitrogen of the Jari soils under primary forest (meq/100g Kjeldahl method).

FORESTS	LAYERS		
	A	B	C
ANGELIM	.09	.06	.03
QUARUBA	.34	.27	.10
MT.DOURADO	.13	.13	.07
S.MILITÃO	.20	.01	.04
PACANARI	.33	.18	-
FELIPE	.34	.21	-
ITAPEUARA	.23	-	-
IBAMA	.29	.22	-

Phosphorus - The results of the present study showed that only two of the eight forest sites studied had a phosphorus fraction higher than 50 percent of the total organic content. In the Jari soils studied, the available phosphorus was only 3 - 50 percent of the total amount. Table 6 contrasts the total and the extractable forms of phosphorus. The results for each soil layer were kept distinct to show the influence of soil depth on phosphorus content. One can see that the IBAMA forest, which had the highest amount of organic P showed the least amount of it in extractable forms. This can be explained by the high levels of iron found in this soil as shown through visible iron pellets and smaller particles.

Table 6 - Occurrence of Phosphorus in Jari soils under primary forest in meq./100 g of soil. (P=phosphorus, T = total P, E = exchangeable P).

FORESTS LAYERS:	A		B		C	
	T	E	T	E	T	E
ANGELIM	7.1	2.9	8.5	1.3	7.6	1.0
QAURUBA	8.9	6.0	7.4	2.0	7.4	1.3
MT.DOURADO	10.0	5.3	10.7	4.4	12.2	1.5
S.MILITÃO	42.6	14.1	34.3	5.1	33.0	2.0
PACANARI	39.5	5.3	32.8	1.9	-	-
FELIPE	26.0	4.6	20.2	2.3	-	-
ITAPEUARA	79.8	22.1	-	-	-	-
IBAMA	68.6	2.0	39.5	1.7	-	-

Exchangeable Bases: Ca, Mg, K, Na - The values for the exchangeable bases are summarized in Table 7, below.

Table 7 - Exchangeable bases of the Jari soils under primary forest in meq./100 g of soil.

FORESTS	SOIL LAYERS											
	A				B				C			
	Ca	Mg	K	Na	Ca	Mg	K	Na	Ca	Mg	K	Na
ANGELIM	.1	.3	.2	.1	.1	.2	.1	.2	.1	.1	.1	.1
QUARUBA	.2	.1	.1	.2	.2	.1	.1	.2	.1	.1	0	.1
MT.DOURADO	.2	.1	.1	.2	.2	.2	.1	.2	.2	.1	.1	.1
S.MILITÃO	.2	.3	.3	.1	.2	.1	.2	.1	.1	.3	.2	.1
PACANRI	.4	.3	.4	.1	.2	.2	.3	.1	-	-	-	-
FELIPE	.2	.3	.3	.2	.2	.3	.2	.2	-	-	-	-
ITAPEUARA	.2	1.4	.6	.2	-	-	-	-	-	-	-	-
IBAMA	.2	.2	.2	.2	.2	.2	.1	.2	-	-	-	-

Cation Exchange Capacity (CEC) - The CEC of the top soils under primary forest examined varied from 3 to 47 meq./100g. (Table 8) CEC seemed to be closely related to texture, with the lowest values occurring in sandy soils and the highest occurring in heavy clay soils.

Table 8 - Cation exchange capacity (CEC) of the Jari soils under primary forest (meq./100g of soil).

FORESTS	SOIL LAYERS:	A	B	C
ANGELIM		3.1	2.3	1.6
QUARUBA		6.3	3.5	1.7
MT.DOURADO		4.9	5.0	3.4
S.MILITÃO		8.3	4.6	3.0
PACANARI		12.9	7.1	-
FELIPE		17.2	7.2	-
ITAPEUARA		47.8	-	-
IBAMA		9.8	6.8	-

The values for CEC shown in Table 8 are slightly different in soils of high aluminium content and low pH (Table 3), due to the fact that the acidic environment allows a high amount of extractable aluminium ions.

The effective CEC (ef. CEC), that is, the field value is given in Table 9, which also the pH and the total aluminium content of the various soils studied. These results confirm what was indicated above, the effect of pH on available aluminium.

Table 9 - pH, Aluminium and the effective cation exchange capacity (meq./100g soil) of the Jari soils under primary forest.

FORESTS	pH	T. Al(mg/g)	Ef. CEC SOIL LAYERS A	B	C
ANGELIM	4.2	17	1.4	1.3	1.0
QUARUBA	4.3	26	2.4	1.7	.7
MT.DOURADO	4.4	25	1.8	2.0	-
S.MILITÃO	4.0	41	2.5	2.5	2.3
PACANARI	4.3	132	4.7	2.9	-
FELIPE	4.7	172	3.0	.8	-
ITAPEUARA	4.0	106	10.9	-	-
IBAMA	4.7	83	1.8	1.1	-

Base Saturation Percentage - The results of base saturation percentage for the Jari soils are given in Table 10.

Table 10 - Base saturation percentage of the Jari soils under primary forest (meq./100 g soil).

FORESTS	SOIL LAYERS A	B	C
ANGELIM	20.5	24.4	30.3
QUARUBA	16.7	18.1	18.1
MT.DOURADO	10.8	13.6	14.7
S.MILITÃO	9.6	14.4	23.3
PACANARI	8.5	18.6	-
FELIPE	5.3	10.2	-
ITAPEUARA	5.0	-	-
IBAMA	7.9	12.7	-

Aluminium - Aluminium is a major element in the Amazon soils, where it is commonly found in the extractable form due to the low pH of these soils. The Brazilian system of soil classification utilizes the adjective "allic" to those soil types with high aluminium content. Almost all the soils of Jari have extremely high amounts of aluminium (Table 11). A contrast between the total and the extractable aluminium can also be observed in the same table. Due to its excessive ocurrence in tropical soils, aluminium is seen as a problem to plant growth rather than as a nutrient (various, Lathwell & Grove 1986). For this reason, CEC is considered a better estimate of the nutrient status of tropical soils than Ef.CEC.

Table 11 - Amounts of total and extractable Aluminium of the Jari soils under primary forest (T.Al mg/g; Ex.Al meq./100g).

FORESTS	SOIL LAYERS					
	A		B		C	
	T.Al	Ex.Al	T.Al	Ex.Al	T.Al	Ex.Al
ANGELIM	17	0.8	36	0.8	36	0.5
QUARUBA	26	1.9	36	1.2	51	0.4
MT.DOURADO	25	1.5	27	1.4	44	1.2
S.MILITÃO	41	3.0	50	1.9	38	1.5
PACANARI	132	3.6	158	2.3	-	-
FELIPE	172	2.1	260	0.3	-	-
ITAPAUARA	106	7.5	-	-	-	-
IBAMA	83	1.0	97	0.6	-	-

The major soil types found under the natural forests of Jari, is given in table 12 below. Most of them are variations of the soil referred to as "Latossolo Amarelo Alico", according to the Brazilian soil classification system.

Table 12 - Major soils types found at Jari under primary forest (Translation of the Brazilian classification system).

FORESTS	SOIL TYPES
ANGELIM	Allic Red-yellow Latosol, Allic Yeollow Podzol
QUARUBA	Allic Yellow Latosol with podzoic A
MT. DOURADO	Allic Yellow Podzol*, quartz sands
S. MILITÃO	Allic Red-yellow Latosol
PACANARI	Allic Concretionary Latosol
FELIPE	Allic Yellow Latosol
ITAPEUARA	Allic Hunic Glei
IBAMA	Eutrophic Structured "terra roxa"

* Although the area of cultivated forests nearby had mainly Allic Yellow Latosols, the physical properties of the sample examined under the forest suggested a podzol.

CONCLUSION AND DISCUSSION

The most commonly occurring soil type in the Amazon is the so-called Red-yellow Latosol or "Latossolo Amarelo Alico" (Brazilian system), or Oxisol (U.S.A. system), or even Ferrasol (FAO system) (Falesi 1976; Cochrane 1984). These soils vary in the amount of and type of clay (Falesi 1976; Cochrane & Sanchez 1982). Their chemical properties are usually very poor. They tend to have low pH levels, poor ion exchange capacity, poor total bases and high aluminium levels (Cochrane 1984;

Lathwell & Grove 1986). It ("Latossolo Amarelo Alico") is also the most common order found at Jari. The second most commonly occurring soil type in the Jari forests studied was the "Podzol Hidromorfico" (Brazilian system) also called Tropaquod (U.S.A. system), or even Gleyic Podzol (FAO system), which are derived from coarse sandy materials.

Although the Jari soils examined fell in the same great orders of the Amazon soils they varied extensively among the eight forest communities studied, mainly in function of geology and the altitude. In texture they ranged from almost pure quartz sands to heavy clay soils. The forests Monte Dourado, Angelim and Quaruba had considerable amounts of quartz sands and their soils were more weathered and poor than the soils from the remaining "terra firme" forests. Such forest occurred in alluvial terrains of Tertiary origin, and had the lowest plant diversity. The forests Pacanari and Felipe had fine clay soils and occurred over the table-top hills formed of Plio-Pleistocenic sediments. The highest plant diversity of all the "terra firme" forests studied was the Ibama forest, which had sandy clay loam soils, formed by Paleozoic sediments. The subsequent paper by this author in this same volume utilizes some of the soil properties described in this paper to draw an ecological classification of the forest communities studied in the Jari-Paru microregion.

Finally, it is interesting to compare the soils of the native forests studied with the most similar and nearest occurring soils from the cultivated forest described by Companhia Florestal Monte Dourado (1989). All but one (Ibama forest) of the native forest soils studied matched the soil units described by the former. Although the Eutrophic Structured "terra roxa" found in the Ibama forest was similar to the Unidade "Pacanari" described by Companhia Florestal Monte Dourado (1989) its texture was of a sandy-clay-loam to sandy-loam, whilst 'Unidade Pacanari' had a clay texture. Furthermore, the soil found in the IBAMA forest had higher organic content and CEC, and lower pH than the former.

The comparison of the chemical properties of the soils under cultivated forests nearest the native forests studied, with the soils from such native forests revealed that the latter had a lower pH and a much higher organic content and cation exchange capacity than the former. This is expected due to the environmental impact suffered by these soils resulting from deforestation and subsequent crop rotations.

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