SOIL, WATER AND CLIMATE OF AMAZONIA:
AN OVERVIEW

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1. INTRODUCTION

In principle, planning the utilization of natural renewable resources for the establishment of agricultural and livestock production is primarily based on types of soils and climatic conditions. When irrigation is necessary, surface and groundwater resources should also be taken into consideration.

In the specific case of colonization projects of the Amazonia region, the planning was initially based on the hypothesis that the exuberant forests lied on fertile soils, and that the humid warm weather did not represent a great problem for the introduction of annual crops and pastures. Subsequently, using data obtained from Project RADAMBRASIL, it was possible to introduce a more technical planning, especially as a result of the already acquired knowledge of chemical and physico-chemical characteristics of the soils. It has been evidenced, through RADAM project that there are only a few spots of good agriculture soils in the Brazilian Amazônia. However, RADAMBRASIL data, in view of the scale with which they were obtained, served only for a pre-planning. Failure of several agricultural and livestock projects showed that a more detailed knowledge was necessary for the implementation of colonization programmes, if the possibility of success was to be considered.

Climate is another limiting factor besides the soil, and probably responsible for the difficulties found in the implementation of sustainable agriculture. THORNTHWAITE (1955) method has been normally used to determine the water balance and the consequent water deficit in the soil.
This method has two serious limitations for this kind of application:
1) The methodology for calculation of potential evapotranspiration, and
2) the water storage capacity of the soil, considered to be of the order of 125 mm.

Actually, after clearance and the beginning of agricultural activity, the capacity of the soil to store water can be quite smaller due to physico-chemical alterations of the soil. Therefore, annual crops and pastures might be subjected to longer periods of water deficit, especially during the drier months.

Besides the methodology problem of agricultural planning based on insufficient data, there are other limiting factors to the success of a development programme, among which it is worth mentioning:
a) lack of adequate technology for agricultural and livestock management programmes in the humid tropics;
b) lack of technical guidance to implement some programmes that could be more successful in more fertile soils;
c) lack of adequate financial resources to make possible for already implemented programmes to determine more appropriate soil management, including control of erosion;
d) impossibility to control the migrating flux to developing areas;
e) lack of institutional infrastructure both in agricultural and livestock management and the environment, to affectively control the soil occupation process.

Experiments carried out in Amazonia States that attempted to establish "agricultural-environment zoning" or "territorial arrangements"
have been recently analysed (SUDAM, 1984). The necessity for methodology improvement has become clear, especially taking into consideration the fluxes of natural processes (water cycle, erosion, nutrients, etc.) as well as population fluxes and the tendency of anthropic transformation activities.

The present paper aims at contributing to a synthetic view of the knowledge on soils, climate and water and of their dependance on a rational planning for the utilization of renewable natural resources.

It is important to stress that erroneous planning might in serious consequences in the management of such resources on a time scale compatible with anthropic activity or in other words "the Amazonia lives once" (LOVEJOY, 1989).

2. EDAPHIC SCENERY

2.1. Nature and soil fertility in Amazonia

At present, the distribution of soil types in the Legal Amazonia (5 millions km²) is known at an exploratory level due to the 1:250,000 scale maps prepared by project RADAMBRASIL. Approximately 45% of the area are Oxisols (Yellow and Red-Yellow Latosol) 30% are Ultisols (distrophic Red-Yellow Podzol) and the Alfisols, represented mainly by eutrophic Red-Yellow Podzol and a small portion of Oxic Paleudalf, contribute with 7%. Young soils (Entisols and Inceptisols), together with Vertisols and Molisols, complete the remaining of the area (DEMATTE, 1988; VIEIRA and
SANTOS, 1987).

Above distribution shows that soils predominating in Amazonia are those containing clay minerals of 1:1 structure, such as kaolinite, and iron and aluminium oxides (KITAGAWA and MULLER, 1979). The predominance of this kind of minerals reflects the advanced weathering stage of the soil of the region (UEHARA and GILLMAN, 1981). Pluviometric indices are characteristically high in tropical regions (see item 4), consequently an intense leaching of the soil profiles occur, with removal of exchangeable bases and silica. Under these conditions, the formation of clay minerals of 1:1 type and iron and aluminium oxides are thermodynamically foreseen (LINDSAY, 1979). Therefore, the nutrients lost due to the intense leaching process, cannot be replaced by the poor geological substrate (KLAMMER, 1984), neither can nutrients derived from organic matter decomposition be retained in the soil (JORDAN, 1987a).

The majority of the Amazonia soils have thus a reduced potential to supply nutrients to plants. According to SANCHEZ et al. (1982), taking into consideration the whole Amazonia extension (around 6.4 million km², 90% of the soils are phosphorus deficient, 73% show aluminium toxicity, 50% water deficit, 24% poor draining and risk of flood. The remaining 7% that do not have great limitations to agriculture, are not, however, in sequence as desirable. Likewise, MALAVOLTA (1987) estimated that around 80% of the Brazilian Amazônia soils show levels of exchangeable basic cations below adequate values for fertility. One of the most "developed" Amazonian region is the Northeastern region, which includes the Great Carajás project (CVRD, 1987) with an area of approximately 1
million km$^2$. FALESI (1987) estimated that about 85% of this area consists of low fertility soils. The phosphorus deficiency observed in Amazonian soils is mainly because this element is on an unavailable state in the soil (SOLLINS et al., 1988). The unavailability of phosphorus is due to its adsorption to the oxides, hydroxides and kaolinite minerals predominating in Amazonia (SANCHEZ, 1976; UEHARA and GILLMAN, 1981).

Inasmuch as phosphorus deficiency, aluminium toxicity, in view of the acidity of tropical soils, is one of the most frequent problems in the region (SANCHEZ, 1976). Both problems are of difficult solution in the tropics. Liming is normally indicated to amend soil acidity and consequent aluminium toxicity, at the same time it helps to improve phosphorus deficiency. However, tropical soils have a high buffer capacity, which make the application of liming or any other amending product, difficult and costly (SOLLINS et al., 1988). Alternatively, phosphorus fertilization might help except for its usual adsorption in this type of soil, and excessive amounts would then be necessary (UEHARA and GILLMAN, 1981).

In contrast with the chemical characteristics, the physical characteristics of Amazonian soils are reasonably good for cultivation (JORDAN, 1987a; DEMATE, 1989). In general, the soils are well drained due to their very stable sand-silt granular structure, originating from the cimenting action of iron oxides, aluminium and organic matter (SANCHES, 1976).
2.2. Land use in Amazônia

2.2.1. Shifting agriculture: ground clearance (roça) by caboclos

The oldest agricultural system developed in Amazônia is known as shifting cultivation (popularly called "roça"). In this system, the primary forest is cut and burned, then the land prepared for planting and when exhausted, abandoned to be naturally recovered. Time of planting and the fallow period vary in accordance with the initial fertility of the soil and local demographic pressure (JORDAN, 1987a; SCOTT, 1987). Generally, the crops planted are: manioc, beans and rice, using mixed cultivation and successive sowings (DEMATTE, 1988). Several authors believe that this kind of exploitation, together with natural extraction, are less aggressive to the environment (SIOLI, 1984a; FEARNSIDE, 1984; HECHT et al., 1988) and are known as ecologically sustainable (JORDAN, 1987b). However this sort of agriculture is meant for areas with small populational density, and it is well known that in areas with density over 25 inhabitants per km², it will undoubtedly fail (SANCHEZ, 1977; cited by DEMATTE, 1988). SCOTT (1987) proved the unfeasibility of this system in the Peruvian Amazônia in a region where demographic pressure was high. In this case, the fallow period of the soil is usually less than 15 years and sometimes only 3 years. Since such period is not enough for recovery, food production depends on the use of mineral fertilizers.

Regarding the nutrient cycling in the soil/plant system, BRINKMANN and NASCIMENTO (1973) and JORDAN (1987a) working with
soils classified as Oxisols, respectively in Manaus, Brasil and San Carlos do Rio Negro, Venezuela, arrived at similar results. Crops established after burning, live at the expenses of nutrients which were in the vegetation and passed to the soil exchangeable complex via ashes. For two to three years the concentration of these nutrients do not drop considerably; however, they become unavailable to the plants, especially phosphorus. This and the invasion of the area by other plants more adapted to the unfavourable environmental conditions, result in the abandonment of the region. SALDARRIAGA (1967) observed that primary forest might be re-established in these areas, however, this process would take about a century to be concluded.

2.2.2. Intensive crop rotation using mineral fertilizers. "Yurimaguas technology"

In 1971 the University of North Carolina and the Peruvian government started a project in the Yurimaguas region in the Peruvian Amazon aiming at determining the feasibility of using tropical soils in continuous cropping with the use of fertilizers and amending minerals, the known "Yurimaguas technology" (SANCHEZ et al., 1982). Evaluation of this technology by the authors themselves and independent researchers (JORDAN, 1987c; DEMATTE, 1988) proved the possibility of using tropical soils in agricultural production. With fertilization and management, the soils of the project maintained adequate concentration of nutrients for eight years, and according to the authors, there was no sign of severe
erosion in the experimental plots. It should be pointed out that there was constant evaluation of the nutritional status of soil and plants and in accordance with NICHOLAIDES et al. (1983) cited by JORDAN (1987c) the success of this technology was due to complete understanding of the soil fertility dynamics. However, this technology can only be used in areas with good infrastructure conditions and with higher economic and social development power (JORDAN, 1987c; DEMATTE, 1988). On the other hand, FEARNSIDE (1987) does not believe in the success of this technology, not even in more developed areas. According to this author the constant necessity to evaluate the nutritional status of crop an soil requires an excessive number of analysis and keeping soil fertility with heavy fertilization, which would make the project not economically feasible. Another point noted by the same author is that the Yurimaguas project was implemented in an even area and, therefore, erosion problems were minimized. He also mentions that Amazonian is not as even as it looks and that in areas where the topography is irregular, under intense precipitation, erosion might become a serious problem.

2.2.3. Low investment crops: "Yurimaguas transient technology"

SANCHEZ and BENITES (1987) proposed an intermediate land use system, between the exploratory agriculture and the Yurimaguas technology. In accordance with these authors, this would be a transient system, because it would be used by those who practice shifting agriculture while waiting for improvement of infrastructure and
marketing conditions. The farmers would then be in a position to use the "Yurimaguas technology". The system is based on selection of rice varieties, resistant to soils high acidity, and a minimum cultivation planning, which includes two rice plantings - green manure (N-fixation) - one rice planting - green manure again and two subsequent rice plantings. The whole planning takes around three years and includes application of herbicides and manual control of invaders. According to the authors, after the three years planting, there was a significant decrease in available phosphorus and potassium, which, however, might be corrected with slight fertilization. Another problem at the end of the three years was the control of invading weed, this being a limiting factor to continue with the project. As mentioned, SANCHEZ and BENITES (1987) considered this system as transient, and offered the following options:

   a) To let the area rest until a second planting;
   b) apply the Yurimaguas technology;
   c) establish pasture, and
   d) establish and agro-forest system.

The authors considered the system economically practicable, with 34% profit in the first year over the capital invested, this percent increasing in subsequent years. On the other hand, they realized that this technology was successful under the specific conditions found at Yurimaguas (soil, selected variety, workmanship, etc.). Although said to be of low costs, this technology required an initial investment of almost 600 dollars/ha, under Yurimaguas conditions. In view of the economic crises now being faced by Amazonian countries, which result in inflation
and financial instability, this initial investment can be considered a limiting factor. Another problem is the control of invaders which makes the use of herbicides necessary, and marketing is difficult in far away areas of the Amazônia. In addition, even in more developed areas of Brasil, such as São Paulo and Paraná, the minimum cropping system was slowly established and required a certain knowledge of the farmer to be successful by employed.

2.2.4. Use of verzeas

The verzea soil can be considered an exception when compared to the poorness of the majority of the Amazonian soils. Sediments fertile from Andean origin are yearly deposited on floodplains of white water rivers during flood. After drainage of the waters, a rich sediment, chemically good for cultivation purposes, remains (MARTINELLI, 1986; VICTORIA et al., 1989).

One of greatest populations densities in Amazônia is in the verzeas (MEGGERS, 1986). The "caboclos" who live in the verzea practice subsistence agriculture similar to the shifting agriculture practice on terra-firme. However, the greatest difference between these two kinds of agriculture does not lie on the productivity, but on the fact that there is no abandonment of the area as in the case of terra-firme (FEARNSIDE, 1984). As mentioned, the soil is fertilized during the yearly flooding. Besides maize, manioc, and rice, malva (Malva rotundifolia) and juta (Corchorus spp.) are also cultivated for fibre production. In addition, close
to the urban centres, like Manaus, the varzeas are being used for vegetable production. In these areas the success depends mainly on adequate control of pests, and insects. According to FEARNSIDE (1984), this type of land use is more profitable and is expanding.

From Manaus down to the estuary of the Amazon river, the varzeas have been used as pasture. Some times natural fields of gramineas (SIOLI, 1984a) are used, while other times planted pastures (JUNK, 1985). FEARNSIDE (1984) state that cattle productivity in these cases is very low, partly due to the quality of the forage and partly due to flooding periods. During flood, the cattle is either removed to terra-firme or placed on rafts, known as "marombas". In the majority of the cases the herds then lose much weight.

2.2.5. The large agricultural and live stock projects in Amazônia

2.2.5.1. Brief background

According to SIOLI (1984) the first large project implemented in Amazônia was in the well-known Zona Bragantina, State of Pará. At the beginning of this Century, the Government of Pará established a settlement for colonizers in an area of approximately 30,000 km². After a few years the project was completely abandoned. In 1926, the also known Fordlândia - a colony aiming at large scale rubber production, was established. The project did not progress due to attack of a single fungi (Microcyclus ulei) that decimated the rubber plantations. A second
attempt was made at Belterra, where the rubber trees were protected against this fungi. However the project failed again due to the poorness of the soil. At the same occasion, there were two Japanese settlements in the Amazônia. One along river Uaicurapa, which was soon abandoned by the Japanese colonizers who were disgusted at not being able to obtain the minimum living from the land. The second was called Tomé-Açu Project and started with a huge plantation of 300,000 trees of cacao, which died in a few years. After the failure with the cacao plantation the Japanese immigrants survived mainly by cultivating vegetables in small areas, which could be sold in the Belém market distant about 150 km. After the second world war, the Japanese started the cultivation of black-pepper and had a period of great development, since the high costs obtained at the black-pepper market compensated for the costs of heavy application of defensives. Nevertheless, also due to a sole fungi (*Fusarium solani*) they failed again. At present, a system of small properties, working on a cooperational basis, has been established. They follow a system of their own, do not use chemical fertilizers and, in accordance with JORDAN (1987c), their principles are:

a) To use trees whose harvesting products are only part of the biomass (fruits and latex, for instance);

b) regarding annual crops, to plant primarily crops that have great commercial value, two crops at the most, then low commercial value crops that do not require much nutrients;

c) keep the soil covered the greatest part of the time to avoid erosion losses;
d) keep large diversity of crops, and
e) try to recycle to the maximum the organic matter both from animals and plants.

According to JORDAN (1987c) the "Tomê-Açu technology" is only viable because it is close to large consuming markets, like Belém. A second factor mentioned by Jordan is that the Japanese nissei are culturally and technologically and prepared for hard and tedious work, such as the work developed in Tomê-Açu.

2.2.5.2 Colonization of Transamazônica and Rondônia

At the beginning of the 70's decade, the Brazilian government authorities initiated a colonization programme along the Transamazônica Highway. At certain points along this highway lots of 100 ha were delimited and practically donated to immigrants arriving mainly from the northeast (drought refugees). Close to the lots small villages (agrovillages with about 60 houses) and larger agropolis (600 houses) and ruropolis (20,000 inhabitants) were established. There should be approximately one agropolis per eight agrovilages, and one ruropolis per four agropolis. There would be medical and technical assistance in these villages or small towns, and a market where the colonizers could sell their products. A similar programme was started in 1975 in Rondônia along highway BR-364.

The type of agriculture adopted in these communities was the traditional shifting agriculture, and at least in theory, there should be
more technical assistance from the government. MORAN (1981) analysed
the progress of one of these settlements near Altamira. The soil there is
an Alfisol, therefore more fertile than the Oxisols and Ultisols found in
San Carlos do Rio Negro and Yurimaguas. MORAN (1981) believes that the
success of the colonizers was due to their previous knowledge of the
region. Therefore, colonists coming from other regions of the country.
Even through, the productivity was low and not encouraging. The reasons
were not different from those that led to the abandonment of thousands of
lots used in this kind of exploitation - loss in soil fertility after 1 - 3
years of cultivation and uncontrolled invasion of weeds. However, in this
case there were two aggravating conditions: the government technical
assistance supplied rice varieties not adapted to the region, and also
failed in the supply of herbicides and insecticides. As a result, of the
planned 100,000 families only around 7,400 families had been settled
there until 1977.

2.2.5.3. Jari Project: agroforest systems

The Jari project, established in an area of 18,000 km², was
primarily intended for paper production and was financed by the American
millionaire Daniel R. Ludwig. RUSSEL (1987) analysed the causes for the
failure of the plantations of Gmelina arborea, the species selected for
cellulose production, and concluded that again due to soil fertility
production was 40% smaller than expected. Besides the fertility factor,
the attack of the fungi Ceratocytis fimbriata and cutting ants (atta sp.) as
noted by FEARNSIDE and RANK (1988) exerted a great influence. Another
factor for failure was the incorrect management since bulldozers were
used (RUSSEL, 1987). DEMATTE (1988) observed that of the various
methods of initial soil preparation the utilization of bulldozers produced
the worst results. Besides soil compaction bulldozers remove soil from
superficial layer which is the richest in nutrients.

In the beginning of 1982 the millionaire Ludwig sold his enterprise
to a Brazilian consortium of 27 firms. This consortium into different
firms: Companhia Florestal Monte Dourado; Agropecuária São Raimundo e
Cauin da Amazônia. The initial failure of the Jari project, according to
the consortium members, was due to administrative problems. Problems
such as soil fertility, attack of pests and diseases were not considered
important (RUSSEL, 1987). However, GARRIDO FILHO (1980), cited by SIOLI
(1984a), stated that the first analysis of the soil was only made by the
project in 1978. New plant species were then used, such as Pinus caribea
var. hondurensis and several species of Eucalyptus. Preparation of the
soil was also changed, aiming at not destroying the soil superficial layer.

In 1986 the press announced that the new Jari project was making good
returns. However, according to FEARNSIDE (1988) the silviculture sector
of the project is losing money, which is compensated by the gains with the
kaolin mines. The same author states that sustainable silvicultural
projects in the Amazônia is rather uncertain as proved by the Jari project.
At present, the Grande Carajás project is attempting to establish an area
10 times greater than the area planted in Jari, with species of Eucalyptus
(FeaRNSIDE, 1988). Another large scale activity developed in the Jari
project is planting of irrigated rice in varzeas. According to FEARNSIDE (1988), the primary plan was to cultivate rice an area with 12,700 ha; only 4,150 ha had been effectively used until 1986. The number of harvests in the area varies from 2 to 3 per year. In 1985 approximately 30,000 t were produced, which means about 7 t/ha.yr. FEARNSIDE (1988) calculated that there should have been a loss of almost 100 thousand dollars.

2.2.5.4. Pastures: the Paragominas case

Law no. 51744 creating a number of fiscal incentives aiming at the development of the Amazônia region was approved in October 1966. These incentives could only be utilized by large enterprises due to the characteristics of the subsidies offered (HECHT, 1985). One of the most spread type of exploitation was the establishment of pasture, and the number of such projects greatly increased. Between 1967-72 SUDAM approved about 388 new projects, and in 1978 they increased to 503 projects, 335 new projects and 168 which had been either remodelled or expended from old projects.

Regarding total area, evaluations made in 1982 estimated that the area used in this kind of exploitation should be between 100,000 km² (HECHT, 1985) and 120,000 km² (KOHELHEPP, 1984). The largest part was located in the region of Paragominas, West Amazônia. It is presently widely accepted that the establishment of pastures is one of the worst kinds of large scale exploitation of the Amazon forest (BUSCHABHCER, et
al., 1987; HECHT, 1985; SERRÃO and TOLEDO, 1988; DEMATTE, 1988). HECHT (1985) mentioned that until 1978, 85% of cattle raising farms established in the region of Paragominas had failed. It is now estimated that about 50% of the area with pastures are degraded (SERRÃO and TOLEDO, 1988), which means about 50,000 km². BUSCHABCHER et al. (1987) state that land intensively used with pasture will hardly recover the original plant cover.

Causes for this failure are well known and easily predictable. Once again, after cutting and burning there was an increase in the soil nutrients due to the ashes remaining from the burning. Therefore, the soil enrichment was made at the cost of biomass, with consequent decrease of the stock of nutrients in the ecosystem (BUSCHABCHER et al., 1987). Similary, even though the nutrients are relatively maintained at the same level, they change into a nonavailable form, especially phosphorus (SERRÃO and TOLEDO, 1988). The presence of invaders, perfectly adapted to the region is, therefore inevitable (HECHT, 1985).

3. SURFACE WATER RESOURCES

Since the largest part of the Amazônia is set on low fertility soils, how can the exuberant forest that developed there be explained? Already in 1921 the Swedish anatomist Hans Blunstchli (cited by SIOLI, 1964b) stated the fundamental principle of the ecosystem "wind and plain, forest and water act intrinsicly together, and we understand that all and everything in Amazônia must stand under their influence, from the
smallest living being to the activity and the behaviour of mankind... The circulation of the water from the sea through the air to the wooded earth, and from the forest through the plain of the big river back to the eternal ocean, that is the great momentum which dominates the image of Amazônia, its life and its character. Perhaps there is no other place on earth in which the mighty force of the circulation of the water appears with such transparency and obviousness before the spiritual eye of mankind. As a matter of fact, we know today that the forest survives due to an intrinsic and complex mechanism of interaction between the biogeochemical cycles, supported by its vast genetical diversity. The rivers are an integrated part of this picture and their physico-chemical characteristics are the final expression of the biogeochemical processes that occur in their drainage basins. The knowledge of the hydrodynamics and chemical characteristics of a river are essential parameters for medium term studies of natural or inflicted changes in its drainage basin.

The Amazon basin is formed by five morphostructural zones that differ mainly in altitude and geological formations.

The region with highest altitude is the Andean Cordilheira, followed by the sub-Andean region and by the Amazon pit towards West-East. The Brazilian and Guianas pre-Cambrian cristalline shields margin the basin to South and North respectively, which gives the basin its characteristics horseshoe format with the opening to the Atlantic Ocean. This enormous drainage basin, with about 7.5 million km² (SILLOI, 1984b), or 6.5 million km² not counting the Tocantins basin, and pluviometric annual average of 2,200 mm (SALATI, 1986), is responsible for around 20%
fresh water global flux to the ocean, and is the third largest river in the world as far as sediment fluxes are concerned, with approximate by $1 \times 10^9$ tons/year of suspended sediments (MEADE et al., 1985). With 6,518 km estimated extension (SIOLI, 1964b), the slope of the mainstem of the Amazon river, after leaving the Andean region, is rather low. At Iquitos, approximately 3,500 km from its estuary, the water level during the dry season is only about 100 m above sea level, i.e., a gradient of only about 3 cm/km$^{-1}$ (SIOLI, 1964b). An uncountable number of small rivers and igarapés form its complex drainage net. If both surface and length of these small rivers and igarapés were summed up, the resulting figures would be several orders of magnitude greater than the Amazon proper (FITTKAU, 1967). The Amazonian rivers are different as far as the physical and chemical properties of their waters are concerned. SIOLI (1950), citado por Sioli (1964b) proposed a classification system of the waters of the Amazônia based on their optical properties. In this respect, white water rivers clear water rivers, and black water rivers are considered.

This kind of classification, although keeping a relationship between the water quality and the geological characteristics of the drainage basin of a river, is not good for monitoring changes in the physical structure of the basin. Change in chemical parameters and sediment concentration as well, should be really great to be reflected in the optical properties of the water. Even waters with similar optical characteristics can have quite different chemical composition. In this regard, the classification model proposed by FITTKAU (1971), based on the
ionic composition of the waters, is better. Differences in the water chemistry of a river are closely related with the geological, geochemical and petrographic properties of the region from where they come (GIBBS, 1967; FITTKAU, 1971).

FITTKAU (1971) distinguished three geochemical regions in Amazônia:

1) The Andean and pre-Andean regions, producing waters rich in nutrients;
2) the Northern and Southern peripheral areas with waters relatively poor in nutrients; and
3) the Central Amazônia with extremely poor geochemical characteristics.

FURCH (1984) analysed the chemical quality of waters from different geochemical origin in Central Amazônia and agreed with above classification. The author concluded that all waters studies are poor in electrolytes when compared with world average, and that this data proved to be important tools for geochemical studies of drainage basins.

Although there is a reasonable amount of work in the literature on chemical and sediments of Amazonian waters, it is still very little in comparison with the immense size of the region. The majority of the work is specifically situated and have no temporal continuity. Besides, static aspects are focused in the majority of the cases, which although useful for geochemical studies, are of less use for studies of natural and or inflicted changes in the ecosystem. In such case, systematic measurements of outflow and sediment and nutrient concentrations are
necessary.

The drastic changes now occurring in Amazônia are well known. It is estimated that so far 8% of the Legal Amazônia has been deforested, and that critical regions, like Rondônia, have already lost over 20% of their primary forest (FEARNSIDE, in press). Land use changes, especially the change from forest to agriculture and pasture, construction of dams, and mining, will certainly change the environment, which in turn will affect the rivers on a larger or smaller scale. It is practically impossible to evaluate these changes without initial data to serve as a basis and without constant time and space monitoring. Bearing this in mind, a cooperation programme among INPÁ, CENA, and the University of Washington (Projects CAMREX and POLONORDESTE) started in 1982, under which systematic studies aiming at quantitative knowledge of nutrient and sediment dynamics of the Amazonian rivers were carried out. As a result over 40 scientific papers have already been published in national and international specialized journals. An attempt will be made to present in this paper a brief summary of the already existing data on the dynamics of sediments and nutrients.

The Amazon river discharge was measured at Óbidos during the period 1982-1984 and the results indicate an average minimum discharge of 100,000 m³/s and maximum discharge of 220,000 m³/s (RICHEY et al., 1986). The rivers Madeira and Negro showed, for the same period, similar average discharges of approximately 30,000 m³/s. The smallest average discharge was measured in Jutai river, around 15,000 m³/s; in Juruá river, the discharge was double this amount. Then in increasing order river Iça
(7,500 m$^3$/s); Purus (11,000 m$^3$/s) and Japurá (14,000 m$^3$/s) (MARTINELLI et al., 1989).

The main tributaries of the Madeira river basin drain the chrystaline shields of the Brazilian plateau and the Amazonia lowlands, and are therefore rivers with low electrolyte concentration (MARTINELLI et al., 1988). In Rondônia, the main tributaries are Jiparanã and Jamari rivers that cross the State through an area under serious colonization pressure. The discharge of the former, measured in its medium course at Jiparanã city, during the period 1970-1983, was approximately 700 m$^3$/s. Two other measurements were taken during the rainy season, close to the mouth, and showed values of 1,700 m$^3$/s (April, 1984) and 2,700 m$^3$/s (January, 1986) (MARTINELLI et al., in press a). The Jamari river, also in its medium course, showed for the period 1970-1980, an average discharge of 173 m$^3$/s, and the results of two measurements taken at its mouth in April 1984 and January 1986 were 900 m$^3$/s and 1,100 m$^3$/s, respectively. About 780 km from Porto Velho the Madeira river receives the Aripuana river, its largest tributary, which during flood showed an average discharge of approximately 8,500 m$^3$/s (MARTINELLI et al., in press a).

Table 1, taken from MARTINELLI et al. (in press b) and modified, briefly shows the results of nutrient and sediment fluxes from some rivers of the region. More details about analysis and sample collection methods, individual ions and other specific information which do not fit the purpose of the present work, can be found in MEADE (1985), RICHET et al. (1986), MEADE et al. (1985), MARTINELLI et al. (in press a), MARTINELLI
Table 1. TSS, DR, TDS, Daverage, Area and TSS/TDS ratio values on Amazonia rivers.

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<tr>
<th>Main Channel</th>
<th>Uavg (x10^2 m^2/s)</th>
<th>Area (x10^2 km^2)</th>
<th>TSS (x10^3 t/y)</th>
<th>DR (t/km^2.y)</th>
<th>TDS* (x10^3 t/y)</th>
<th>TSS/TDS</th>
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<td>Amazon basin-River cruises</td>
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<th>TSS (x10^3 t/y)</th>
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*Values from Martinelli et al. (em prep.).
**Valores from Martinelli et al. (1985b). Alkalinity not measured for these values. They are therefore approximated values.
et al. (in press b), FERREIRA et al. (1989), RICHEY et al. (in press). The table shows that in general, sediment fluxes are higher than dissolved element fluxes and higher in tributaries of Andean origin. It can also be noted that the lowland areas drained by a river increases while the ratio sediment flux (TSS) to dissolved element flux (TDS) decreases (GIBBS, 1965; STALLARD and EDMOND, 1983; MARTINELLI et al., in press). Maximum and minimum values were obtained for rivers Madeira with ratio TSS/TDS = 12 and Negro with this ratio decreasing to 1.4. In Rondônia rivers the ratio TSS/TDS is quite close as expected, with the maximum observed for the Jaru river, where TSS is greater than TDS (Table 1). It should be pointed out that the TDS values for these rivers might have been under-estimated due to the non-availability of results on alkalinity. In any case, the alkalinity values of the these rivers are generally low and therefore cannot exert great influence on TDS values (J.R. FERREIRA, personal communication).

The greatest "denudation rates" (DR), as expected, are associated with rivers of Andean origin. Discharge and sediment amounts carried by these rivers, especially those of Andean origin, are so great that, even under natural conditions, it is difficult to use them to monitor sediment and nutrient losses through erosion due to changes in their drainage basin. The tributaries of the Madeira river in the Rondônia region, however, with sediment concentration usually low, might be used as indicators of changes now in progress in the basin. It is worth noting that the smallest DR was found at Jaru river, which on the other hand showed the largest export rate of dissolved nutrients (MARTINELLI et al., 1988).
The main difficulties to the execution of such programme would be associated with the generally plane topography of the region and the necessity for an intensive sampling planning of its rivers. GRAHAM JR. (1986) demonstrated that the sediment load transported by the Jamari river has proportionally increased in relation to soil loss due to erosion. However, the ratio of soil loss due to erosion to river sediment load ("delivery ratio") were quite variable proving the necessity for long term studies to confirm these tendencies; these might be stocking zones in the basin, where the sediment from the erosion process may be temporarily stored.

In conclusion, in spite of the efforts being exerted to characterize the distribution of sediment and nutrients in the Amazon basin, the existing data are still very scarce. Its spatial and temporal distribution is small, making difficult any definite conclusion on the influence of anthropic activity in Amazônia. They are, however, sufficient to determine the areas that should be more intensively investigated, such as Rondônia, where change in land use is increasing at an alarming speed.

4. CLIMATE

Climatic classification was one of the earliest concerns in climate studies of Amazônia. BASTOS (1972) made a review of the climatic type classifications for Amazônia based on Kuppen and Thornthwaite classification. In 1984, SUDAM published a climatological Atlas of the Brazilian Amazônia (SUDAM, 1984).
Such works, with were meant to serve as basis for planning the use of natural resources, were not concerned, in view of its own nature, with the dynamics of the processes that regulate the present dynamic equilibrium of the atmosphere. A number of papers have been published during the 70' and 80 decades, summarized by SALATI (1986) and HENDERSON SELLERS (1987), in an attempt to learn and relate the present dynamic equilibrium of the atmosphere in the Amazon area with the type of plant cover. Such work, developed at different scales, including microclimatic and mezoclimatic observations with studies of the water balance in hydrographic and regional basins, permitted a series of conclusions among which are outstanding:

4.1. **Solar radiation**

Estimates of solar radiation balance in Amazônia were made using especially data on hours of insolation obtained by heliograph. From these data a correlation between the ratio of insolation to incident solar radiation on top of the atmosphere was determined (VILLA NOVA and SALATI, 1978).

This study proved that the incident solar radiation at tree canopy level is fundamentally controlled by cloudiness, which depends on the atmospheric water vapour.

The average cloudiness in the Central Amazônia is of the order of 50%, varying in Manaus from 30% in March to 70% in July-August. More exact measurements with radiometer type EPPLEY, were taken initially in
Manaus (SALATI and MARQUES, 1984; RIBEIRO et al., 1982) and values showed an average of 400 cal/cm² day. VILLA NOVA and SALATI (1976) studied the water balance in the Amazon basin and concluded, from the solar radiation balance, that 73% or the net radiation are used in the process of water vapour production through evaporation when there is no direct water restriction, and from tree transpiration (latent heat); 24% are used in other processes, such as 1% in photosynthesis, 26% in air heating (sensible heat). MOLION (1987) investigating microclimatic data obtained by SHUTTLEWORTH et al. (1984a, 1984b and 1985) concluded that about 75% of absorbed solar energy are consumed in the evapotranspiration process, and that 25% are used to heat the air. When there is water restriction, these percentages vary considerably, the fraction for heating the air should greatly increase due to the smaller consumption in the change of phase (evapotranspiration).

4.2. Temperature

The average temperature does not vary much during the year in the central strip of land characterized by the Amazon plain. The values tend to increase towards West. In Belém, (1°20'S, 48°30'W), the mean temperature of the warmest month occurs in November, 26.9°C while the smallest occurs in March 24.5°C. In Manaus (3°07'S, 60°2'W) the greatest monthly mean temperature occurs in September, 27.9°C and the smallest in February, 25.8°C. In Iquitos (3°46'S, 73°11'W) the greatest monthly mean temperature occurs in November, 32.0°C and the smallest in July,
In regions of highest altitude, both north and South of the Amazon plain, the thermic amplitude increases and there is a well defined period with smaller temperatures related with precipitation and the movement of air masses from higher latitudes.

In some regions of the Brazilian Amazon a strong orographical effect is also noted in regions where the relief exceeds 500 m, as the typical case of Serra dos Carajás, where the temperatures are 2-3°C below the areas around the mountain range.

Existing studies on temperature are almost always directed towards establishing climatic classifications.

No detailed studies on temporal tendency of maximum, medium and minimum temperatures are available.

According to existing studies and others in progress it is expected that deforestation might result in changes in temperature due to the change in radiation balance.

The expected changes are especially in thermic amplitudes and in increase of maximum temperatures.

4.3. Winds and water vapour

The amount of water vapour in the atmosphere is fundamental to determine climate characteristics. Therefore special attention has been to identify the origin of the water vapour, its spatial and temporal variation, and the fluxes involved. The amount of precipitable water
vapour found in Amazônia is on average 40 mm (MARQUES et al., 1979). This means that there is a water vapour mass over the Amazon region of the order of $24 \times 10^{10}$t. This water vapour or the absolute humidity varies, increasing from East to West; the largest values measured were found in the city of Iquitos. The primary origin of the water vapour is the Atlantic Ocean, being brought into the region by the Trade Winds that blow from the East quadrant (MARQUES et al., 1979b).

Quantification of water vapour flux demonstrated that total precipitation in the region cannot be explained only by direct precipitation of this primary water vapour. The possible second source of the water vapour is the generation of vapour by plant cover through direct evaporation of the water retained in the tree leaves and plant transpiration.

FRANKEN et al., 1982, showed that in a dense forest up to 25% of the precipitation can be retained by the tree canopy and that 50% of it is used for plant transpiration. The data indicate that up to 75% of the precipitation returns to the atmosphere in the form of vapour by plant activity. The outflow through rivulets (igarapés) is about 25%.

Mean values for the Amazon basin indicated that evapotranspiration corresponds to 48.4% and the outflow to about 51.6% (VILLA NOVA et al., 1976). Works of DALL'OLIO 1976; SALATI et al., 1979, evidenced through isotope fractionation techniques ($^{18}O/^{16}O$ and D/H) the existence of a recycling mechanism of the water in the region.

The study of the divergence of the water vapour and its comparison with the Amazon river at Obidos, indicates a 2-3 months
residence time of the water in the Amazon ecosystem. (MARQUES et al., 1980). These studies also indicated the possibility of using radiosonding analysis in the coastal region, especially in Belém, to foresee flooding in the low Amazon.

4.4. Precipitation

Precipitation in the Amazon region has been studied and there are several publications showing spatial and temporal distribution (SUDAM, 1984, among others). SALATI et al., 1978, presented a temporal and spatial distribution and discussed the origin of rain in Amazônia.

To explain the level and distribution of precipitation based on present information it is necessary to accept the recirculation of water vapour in the region, i.e., primary water vapour in part is precipitated as rain, which returns to the atmosphere in the form of vapour, mixes with the primary vapour and again precipitates. An attempt to define a recycling coefficient $R$ has been made by analysing as a whole the information obtained so far:

$$R = \beta \frac{E}{P}$$  \hspace{1cm} (1)

where $E$ is the evapotranspiration, $P$ the precipitation and $\beta$ defined as:

$$P = 0.9o + \beta E$$  \hspace{1cm} (2)
where $Q_o$ is the primary vapour flux from the Ocean.

DALL'OLIO (1976) and SALATI et al. (1979) estimated that 50-60% precipitation comes from recycling, and work in progress (VILLA NOVA et al., in review), indicate that the maximum recycling is around 62% and minimum recycling around 38%. The error in these estimates depends on how accurate the hydrological cycle components are known.

4.5. The present water and energy dynamic equilibrium depend on the forest

The water balance is closely linked to the energy balance. Any change in water cycle will influence the energy cycle and vice-versa. The fundamental problem is to know which changes can be introduced by deforestation in the present equilibrium of these cycles, and how would they influence to meteorological parameters. There is no simple answer to this complex problem due to the several interaction among factors to be evaluated under the present different equilibrium conditions.

The present equilibrium shows that in a dense forest 75% precipitation returns to the atmosphere as vapour, 25% through evaporation of the water retained by the leaves and 50% through plant transpiration. Obviously, in case of total deforestation as it is done in several colonization schemes, the ecosystem will change. If annual crops are planted, there will be one or two plant species to substitute the thousand that originally existend in the forest. This change in flora with time will imply in change in fauna and soil micro-fauna. Therefore the
biogeochemical cycles are altered right from the beginning.

With respect to the water cycle, the tendency will be greater runoff, as the water quantify retained by the plants will be smaller. On the other hand, unless high technology is used in agriculture, including soil conservation, the loss of runoff water will be greater, and even with such techniques the cleared forest soil is liable to compaction, which reduces the permeability (SCHUBART, 1982). As a result, total precipitation will be divided into two different fractions, with tendency to an increase in water runoff through the igapós during the rainy season, mainly heavy rains and a decrease in the amount of water available for evapotranspiration.

This will change both the water and the energy cycles. Since the amount of water available for evapotranspiration will decrease, the relative humidity of the air will drop, and this alone will change the energy equilibrium. Then the incident solar energy instead of being used for evaporation of the water, will be used to heat the air. This phenomenon has been observed by RIBEIRO et al. (1975) in a "campo cerrado" near Manaus, where temperatures higher than in the forest have been recorded.

Other aspects should be raised besides those mentioned above. Change in plant cover involves a change in albedo or a variation in the reflecting power upon the considered surface. This change in albedo involves changes in the energy balance.

It is clear that changes in small areas, surrounded by forest, should neither influence the energy and water balance, nor the regional
climate as a whole. The problem is to know how the summing up of a large
of number of small clearings can influence the regional climate on a large
scale, or else how annual agriculture and stock breeding (out of total
small projects) can bring changes into regional climate parameters.

It is also necessary to draw the attention to the evidence of water
vapour recycling in the Amazon basin. The existence of a large amount of
water vapour in the atmosphere, which is partially due to forest activity,
besides controlling the energy balance, also leads to the formation of
clouds and therefore rain. It is, thus, possible that a decrease in forested
area results in a decrease in atmosphere water vapour and there might be
a consequent change in distribution of precipitation. What will not change,
at least on a first approximation, is the amount of water vapour from the
Ocean that tends to form rain in the region. However, it is probable that
rain distribution, which in part is due to recycling of water vapour, will
change and the total precipitation in relation to present levels will also be
different. The extension of this influence will depend on the level of
disturbances that will occur.

Another important point to be considered is the water vapour
transport from the Amazônia to adjacent areas. Practically all year round
the water vapour flux in the latitudes of Vilhenas and Brasília vary in
intensity from north to south. There is also a flux towards the central
zone of South America, including part of the Brazilian Central plateau.
Nevertheless, considering that the flux is always from the Amazon basin
into these regions, it is clear that there is a dependence relationship,
which should be systematically analysed and quantified. Bearing this in
mind, it is important that this doubt is cleared before the deforestation level becomes very high because once such alterations are introduced it will be difficult to control forest recovery programmes.

According to existing information there is a clear necessity for a better knowledge of the water vapour dynamics in the Amazon region and its interaction with adjacent areas before establishing other colonization projects. The experience has shown that once occupation of an area is started it is impossible to control the migrating fluxes and the consequent deforestation. The most recent experience has been the excessive deforestation rate in Rondônia, due to colonization programmes which had at the beginning certain aims and dimensions, but in reality have become an uncontrolable devastation.

From a global view of climate change due to the "greenhouse effect", Amazônia represents a reservoir of carbon equivalent to $50 \times 10^{15}$ g (FEARNSIDE 1987). The deforestation in Amazônia has contributed with transference of C from the biosphere reservoir to the atmosphere, which has been estimated to vary between 0.24 to $1.6 \times 10^{15}$ g C/year, and which represents 7 to 25% of total CO$_2$ annual contribution to the atmosphere (MARTINELLI et al, in review).

5. CONCLUSION AND RECOMMENDATIONS

The shifting agriculture practiced all over "the Amazônica", the so-called Yurimaguas technology, the Tranzamazon colonization, the Jari
project, and the Paragominas pastures are agricultural and livestock activities totally diverse as far as their social and especially economic situation are concerned. However, they all have something in common: they have been developed on unfertile tropical soils, and soil poorness was the main limiting factor for all of them.

After one century after the first colonization attempt in Amazônia, it seems that lesson has not been learned. MEAGERS (1971), cited by Russel (1987), believes that these successive failing attempts to colonize Amazônia are among the greatest paradoxes of our times. JORDAN (1987d), however, thinks that this paradoxes can be explained by the immediatism that directs politicians and governors between elections and by “easy and immediate profitting” perspective on the part of certain entrepreneurial sectors.

From an economic view it should be considered that agricultural or environmental failure do not always mean financial failure. As mentioned by HECHT (1985), in the case of Paragominas pastures, due to the fiscal incentive and subsidy politics, what cared less was the soil fertility or adequate management. The over-appraisal of land alone constitutes a highly profitable business. Analysing the evaluation made in 1985 on fiscal incentives granted by SUDAM, GASQUES and YOKOMIZO (1985) confirm the trueness of above information. In item VII (pg. 27) of the their report, the authors cite a number of problems in projects which make them totally inviable in technical terms. However, such project continue to exist and to be approved. HECHT (in press) has recently shown that one of the most profiting ways of exploring agriculture and livestock
breeding is overcrowding of pastures for a few years until total degradation. This practice is the most profitable even without fiscal incentives. On the other hand, this kind of exploitation leaves even more degraded areas and increase the pressure for deforestation. Therefore, if this tendency continues, EMBRAPA efforts to recover degraded pastures (SERRÃO and TOLEDO, 1988) and other efforts to find the best way of using Amazonian soils, will be in vain. Because the overappraisal of the land, together with fiscal incentives, alone much more profitable than the agricultural and livestock activities to be developed.

In social and not purely economic terms, the attempt to use Amazônia as an escape valve for no-land populations of the Northeast and South/Southeast has proved disastrous. Colonization of the Transamazônica and Rondônia in the years 70’s and 80’s is the best example. HECHT (unpublished) has shown that the financial return for colonizers has been lower than the national minimum wage. Therefore, small farmers change their working force into private firms. Their lands are considered a secondary source of income, or else are cleared and they appraised and sold for a better price to be used as pasture. Several government settlements in Rondônia, seem to be recently following this way. Luiz Antonio Martinelli had the opportunity of working with about 8 fellers at Samuel Dam in November 1988. Of these, six had plots that had been donated by the extinct INCRA. They now have left their families in Jiparanã and are making living on pay roll work.

In ecological terms it has been apparently proved that rational utilization of the Amazônia requires much more study yet. The most
evident conclusion is that the researchers know what should not be done with Amazonian soils. However, they have not yet found a rational exploiting manner. Assuming that "Yurimaguas technology" is efficient, in spite of the subject being under discussion (FEARNSIDE, 1987), this intensive technical assistance and a regular market are required. Well now, in the colonization of Transamazon the government was not even capable of supplying rice variety adequate for planting. At present, colonists are being set in accordance with information obtained from soil maps at exploratory level, which are known to be inadequate for the purpose. More detailed mapping has proved that of the 90% of soils considered fertile according to the former maps only 32% are really fertile (BROWN, data not yet published). Therefore, assuming that there is adequate technology for Amazônia exploitation, there is a need for improvement of the institutions in charge of colonization programmes in order that they can be implemented without the leastest chance of failure.

In summary, there is still a long way to follow towards finding a better manner of rationally exploiting the Amazônia. On the other hand, almost one century has elapsed and politicians, governors, entrepreneurs still insist in applying a land occupation model which brings degradations to the environment and is not economically viable neither at medium nor at long term.

Along this way however, some steps indispensable should be taken with maximum urgency as we see it. Among them we can cite:

- Ecological-economic zoning of the region. In this regard, the primary and essential activity should be a knowledge of the natural
renewable resources at a level compatible with the size of the region. For example, the soil maps prepared by RADAMBRASIL project, which are the primary source of information for projects of agricultural settlements, are the most detailed up to now, and were made on a 1:250000 scale, i.e., at an exploratory level. It is therefore necessary that detailed soil surveys (1:25000) or semi-detailed (1:50000) be encouraged before proceeding with the zoning. It should also be stressed that such zoning should not be based on classical parameters used in agricultural zoning, but rather take into account the dynamic processes and the equilibrium of the ecosystem. From there, to define, implement and guarantee the areas that should consist of: untouchable ecological reserves, areas to be used as extraction reserves, and areas capable of supporting management that can assure at long term the maintenance of renewable natural resources.

- Encourage research on agricultural utilization of varzeas, avoiding incentive to terra-firme agriculture, especially in Central Amazônia.

- To continue and encourage basic monitoring of sediment and quality of the waters of rivers of the region, which is essential for better understanding at medium term of the anthropic activity in the region.

- Avoid, as much as possible, contamination of the waters by mercury, heavy metals and agrochemicals from mining, industrial and agricultural activities.

- Encourage studies on environmental impact caused by the installation of dams in the region. Such studies should be carried out and concluded before such work starts. Constant monitoring of the water
quality of the reservoir and control of occupation processes both downstream and upstream are essential in already existing dams.

- Increase the density of the meteorological observation net work in the region.
- Promote and encourage activities aiming at systematic study of the water vapour flux in the Amazon region. It is necessary to increase the number of radiosonding stations in the region and make more detailed study of the already existing information in this field as well.
- Promote and encourage activities aiming at the study of the water and energy balance in deforested areas.
- Study biogeochemical cycles and maintenance processes of the high photosynthetic rates in the region (the greatest in the planet).
- Multi-disciplinary analysis of recently colonized areas in an attempt to understand ecological limitations to different forms of utilization of renewable natural resources. It should be stressed that depending on the occupation process the biological resources cannot be considered renewable.

- The vital point, however, is the complete elimination of fiscal incentives and government subsidies. Such incentives and subsidies have, without doubt, resulted in an erroneous land development in the region encouraging real state speculation of large cleared areas, already degraded and hardly recoverable.

The analysis of such problems in an area corresponding to half the national territory will be difficult without capable personnel, trained and willing to work hard in the region. The strengthening of universities and
research institutes should precede the social-economic development to avoid leaving to technicians the responsibility of correcting already made mistakes, which under the conditions described above might be sometimes technically and economically unsolvable within a time span of social interest. Therefore, research work should be speeded up, specialized workmanship prepared, to enable careful planning in order to lessen failure risks.

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