SOME ASPECTS OF THE NITROGEN BALANCE OF THE AMAZON BASIN

E. Salati
R. Sylvester Bradley
R.L. Victória

SOME ASPECTS OF THE NITROGEN BALANCE OF THE AMAZON BASIN

E. SALATI*
R. SYLVESTER BRADLEY**
R.L. VICTÓRIA*

SUMMARY

In order to obtain a basis for determining the relative importance of different ecosystems and nitrogen cycling processes within the Amazon basin, a survey was made of the data available on nitrogen concentrations in water entering and leaving the whole Amazon basin and a waterbasin on oxisol and ultisol near Manaus, Brasil. Biological nitrogen fixation in forests on ultisol, oxisol and entisol ("varzea") in Central Amazonia was also considered. 4 to 6 kg are lost per hectare per year via the Amazon River, and a similar amount enters in the rainfall. Root associated biological nitrogen fixation was considered to contribute 2 kg N ha^{-1} yr^{-1} to forests on oxisol, 20 kg N nh^{-1} yr^{-1} to forests on ultisol and 200 kg N ha^{-1} yr^{-1} to forests on fertile varzea soils. There was 5-10 fold more $N\text{-}NH_4^+$ in the rain and stream water entering and leaving the waterbasin near Manaus than $N\text{-}NO_3^-$. From calculations based on this data, and making certain assumptions, the following nitrogen balance figures were obtained: input through rain: 36×10^5 t yr^{-1}; input through biological nitrogen fixation: 120×10^5 t yr^{-1}; output through the Amazon River: 36×10^5 t yr^{-1}; output through denitrification and volatilization (by difference) 120×10^5 t yr^{-1}.

INTRODUCTION

If the nitrogen balance in a homogeneous ecosystem under controlled management such as sugar cane, rice or corn is a difficult problem to solve, the integrated problem of nitrogen flux in tropical forest, where the principal characteristic is the heterogeneity of the flora and fauna, is even more complex. In addition, the soil variability combined with climatic

Paper presented at the Scope Nitrogen Cycling in Latin American Ecosystems Workshop, CIAT, Cali, Colombia, 16 - 21st March, 1981.

*CENA, Caixa Postal, 96 - Piracicaba, SP, Brasil.
**CIAT, Apartado Aereo 6713, Cali, Colombia.

diversity results in different ecosystems within the Amazon region which range from campina vegetation to tropical rain forest, whose complexity was defined by Humbolt as "Amazonian Hileia". Depending on the degree of detail which is being considered, a greater or smaller number of geobotanic associations can be characterized for the region, and the nitrogen balance should be defined for each one of these. By means of integration the global balance for the Amazon basin could then be calculated. Unfortunately, this detailed information is not available and the measurements of nitrogen flux which do exist are mostly preliminary estimates of the nitrogen gained or lost by a particular mechanism and of the concentrations of certain chemical compounds of nitrogen. Some more complete studies have been carried out on specific ecosystems within the Amazon basin in Venezuela (e.g. Jordan et alii, 1981).

In this study three aspects of the nitrogen balance of the Amazon basin will be considered:

1) A tentative estimate of the nitrogen balance of the whole Amazon basin based on data of the nitrogen concentration and flow rate of the rivers Solimões and Amazonas.

2) Data on the NO_3^- and NH_4^+ fluxes in a waterbasin in Central Amazonia near Manaus.

3) Data on the inputs of nitrogen via biological nitrogen fixation to three Central Amazonian ecosystems and some fertilization and inoculation studies in the three soil representing these three ecosystems.

The study is intended as a basis for identification of suitable sites and topics for further investigations.

We emphasize the great need for the intensification of research projects with the objective of filling some of the gaps in present knowledge and in particular, considering the increasing population pressure in the region, that it is important that these studies should be started as soon as possible before natural environmental conditions are altered by human activities.

1) Nitrogen balance of the Amazon basin

An estimate of the nitrogen balance of the Amazon basin was made using:

a) The flux of the River Amazonas measured by Oltman (1967) at Obidos.

b) NO_3^- concentrations measured by Gibbs (1972) at the mouth of the R. Amazonas.

c) Concentrations of various forms of nitrogen measured by Schmidt(1972) at Manaus.

It was necessary to make some assumptions in order that the existing data could be extrapolated to the whole Amazon basin:

a) That the relative concentrations of the various nitrogen compounds do not vary along the River Amazonas after Manaus.

b) That the flow rate of the River Amazon expressed on an area basis is the same for the area from Obidos to the mouth as that above Obidos.

The data are summarized in Figures 1, 2 and 3 and Tables 1 and 2.

Fig. 1 - Shows the mean monthly concentration of the various nitrogen compounds in the river water, along with the total monthly discharge. It is evident that $N\text{-}NO_3$ is controlled by the river flow; highest discharge is coincident with lower $N\text{-}NO_3^-$ concentrations. This trend is also true for the organic nitrogen, although we have no explanation for the peak that occurred in August. $N\text{-}NO_2^-$ was very low throughout the year.

Fig. 2 - Shows the total monthly fluxes for suspended organic N, Kjeldahl N and total N. Although concentration is inversely correlated to discharge, this is not true for total N fluxes, where the highest quantities are being transported during the highest river discharge.

Figure 3 is derived from Figure 2 and shows that almost 90% of the nitrogen in the River Amazonas is in the organic form, and that this values stays almost constant throughout the year. The second most important loss of nitrogen is in the form of organic nitrogen in suspension, which shows greater variation during the year. The authors cited conclude that soluble $N\text{-}NH_4$ is relatively unimportant in comparison with soluble organic N. The contribution of $N\text{-}NO_2^-$ is also very small.

Table 1 shows a large discrepancy between the data of different authors and emphasizes the need for further research in this ares.

Table 2 shows that the R. Amazonas discharges about 234×10^3 tonnes of nitrogen per month, with a maximun in April of 370×10^3 tonnes, and a minimum in October of 130×10^3 tonnes. The total annual loss of nitrogen from the Amazon basin is 3.1×10^6 tonnes which is equivalent to a loss of approximately 4 to 6 kg nitrogen ha^{-1} yr^{-1}. This is a minimum value considering that the calculation was based on the lowest values found in the literature (see Table 1).

2) $N\text{-}NO_3^-$ and NH_4^+ flows in a Central Amazonian waterbasin

In 1979 water balance studies were initiated in a Central Amazonian waterbasin, through a United Nations project BRA/172/010. This waterbasin is located approximately 60 km north of Manaus, off the road from Manaus to Caracas (BV-8). The basin is about 22 km^2 and supports typical "terra firme" (non-flooded) rain forest growing mainly on oxisol, although ultisols are frequent along the stream beds. Over the last two years precipitation has been measured with 11 pluviometers, the stream flow has been measured at two sites and conventional meteorological measurements have been made at a climatological station which includes a 20 m^2 evaporation pan. Figure 4 indicates the distribution of the instruments utilized and the location of the climatological station.

In 1980 rainwater, throughfall water and stream water were sampled at weekly intervals and analysed for various elements including $N\text{-}NH_4^+$ and $N\text{-}NO_3^-$. In this paper preliminary data for balance of $N\text{-}NH_4^+$ and $N\text{-}NO_3^-$ in May and June of 1980 are presented.

Table 3 shows that the $N\text{-}NH_4$ concentration in rainwater was 0.02 ppm, and $N\text{-}NO_3$ was 0.005 ppm for both months. Total nitrogen input in rainfall was calculated to be 49.0 kg and 44.2 kg for May and June respectively.

Stream water concentrations were 0.043 ppm and 0.025 ppm of $N\text{-}NH_4^+$ for May and June respectively. $N\text{-}NO_3$ concentrations were lower at 0.005 ppm for both months. total outflow was calculated to be $1.1 \times 10^6\ m^{-3}$ and $0.98 \times 10^6\ m^{-3}$ for May and June respectively. Total output was therefore calculated to be 37.8 kg N and 20.2 kg N for each month.

Output rate of $N\text{-}NO_3^-$ was found to be approximately 0.0005 kg ha^{-1} for both months. These values are much lower than the output rate of nitrate calculated for the same months by Schmidt (1972), which was approximately 0.025 kg N ha^{-1}.

3) Nitrogen inputs via biological nitrogen fixation

Nitrogen fixation has been studies in various systems in the vicinity of Manaus, by acetylene reduction, nodule distribution and natural isotope variation methods. Also inoculation experiments have been carried out in the different local soils with some legume crops.

The studies concentrated on three soil types which are significant in the region for different reasons. Firstly, the "varzea" is the fertile alluvial soil which occurs along the banks of white water rivers, such as the Solimões and the Amazonas. The natural forest vegetation on this soil has nearly all been cleared and the land is used for relatively intensive production of vegetables, milk, sorva (*Couma guianesis*), jute, etc., even though it is flooded for three or four months of the year. There are many introduced and native grasses, legumes and other plants growing there, which are often adapted to flooding and some of which can float.

Secondly, the campina and campinarana vegetation grows on white sandy soil covered with a layer of semi-decomposed material and live roots up to one meter thinck. Water in streams draining these areas is tea-coloured due to high concentrations of organic compounds, and forms the black water rivers, such as the Rio Negro. The vegetation in these areas appears xerophytic, although this is in fact an adaptation to the oligotrophic conditions. It is low in stature, is dominated by certain species, some of which are legumes, and the tree trunks, branches and leaf surfaces are colonized by epiphytes and lichens. The sites tend to be small and separated by other types of forest and a certain degree of endemism has been found. The soil is of no use for agriculture, but the sites are being destroyed because the sand is needed for road construction.

Thirdly, and by far the most important in terms of area occupied and problems presented for agricultural development is the rain forest growing on oxisols and ultisols. This forest is more diverse than campina vegetation. Legumes are one of the five most abundant families (~~Rodrigues~~). It has a high biomass (473 tonnes ha^{-1}, Kingle 1976) and is being increasingly used for a wide range of agricultural production including sugar cane, pastures, rubber, cocoa, fruit trees and subsistence crops such as rice, cowpeas and cassava.

The studies have shown that:

1) Although there is a high proportion of legumes in the primary rain forest on oxisol they are only sparsely nodulated (Norris, ; Sylvester-Bradley *et alii* (~~in press~~). The highest rates of acetylene reduction detected in the root mat extrapolated to 1.5 kg N fixed nh^{-1} yr^{-1}.

2) There is no difference in the $\delta^{15}N/^{14}N$ between legumes and non-legumes in primary forest on oxisols, but there is a significant difference between leaves of legumes and non-legumes in campina vegetation (Victória *et alii*, 1980; Table 4). Nodules were not found on roots of legume plants in campina vegetation, but this may be because they were very deep. (unpublished observation).

3) Epiphytes and lichens in campina vegetation did show acetylene reducing activity but this was difficult to quantify on a per hectare basis. (Leite dos Anjos & Sylvester-Bradley, unpublished).

4) Legumes in rain forest on ultisol were nodulated (Norris,) and their roots reduced acetylene. The highest rates detected extrapolated to 20 kg N fixed ha^{-1} yr^{-1} (Sylvester-Bradley *et alii*, in-press).

5) Legumes in primary forest on varzea soil were very well nodulated. The highest rates of acetylene reduction detected extrapolated to 243 kg N fixed ha^{-1} (Sylvester-Bradley *et alii*, in press).

6) Acetylene reduction activity in roots of aquatic plants and termites (Sylvester-Bradley *et alii*, 1978; ~~1980~~) was also detected. It was found

that acetylene reduction by termites was extremely sensitive to disturbance.

7) Inoculation of cowpeas and winged beans grown in oxisol did not increase their nodulation, but inoculated plants with complete fertilization excepting nitrogen grew much better and were well nodulated (Oliveira & Sylvester-Bradley, submitted).

8) Burning the vegetation before collecting the soil was not as effective as fertilization for increasing plant growth (Oliveira & Sylvester-Bradley, submitted).

Some of these data are summarized in Table 5.

These data on nitrogen fixation, although limited in their scope, have some interesting implications. Firstly, the large difference in the levels of root associated nitrogen fixation in oxisols, ultisols and entisols imply that there must also be large differences in losses of nitrogen from these systems.

Secondly, the limiting factors for growth and nitrogen fixation in each soil type are presumably different. For example, varzea soil contains over 30 ppm phosphorus, whereas oxisols and ultisols contain around 2 ppm. In ultisols losses of nitrogen by leaching are likely to be greater than in oxisols. Thus the potential for nitrogen fixation in the varzea is much greater than in oxisols and ultisols because phosphorus is not limiting. Many more problems would be expected with using biological nitrogen fixation as a source of nitrogen for crops after clearing the forest from ultisols and oxisols than in the varzea. The tenfold greater nitrogen fixation detected in ultisols than in oxisols is presumably due to a greater loss of nitrogen from ultisols by leaching. These soils are considered by local farmers to be easier to cultivate than oxisols, and they support better nodulation in pot experiments. However, they tend to occur on more sloping ground and there fore are more easily eroded. Consequently, oxisols are considered as preferable for agricultural development. There may be several reasons for the low nitrogen fixation in oxisols. It seems most likely to be due to a combination of high soil nitrogen (8000 kg N ha^{-1}; Klinge, 1976), low phosphorus, and possibly toxic substances produced by the vegetation which inhibit nitrogen fixation.

Thirdly the occurrence of greater nitrogen fixation associated with epiphytes in campina vegetation than in primary forest implies that the importance of epiphytes should be assessed in different kinds of tropical rainforest so that their contribution of nitrogen to the system relative to other nitrogen inputs can be determined.

General Considerations

Based on the data presented here and information from other authors during this meeting, especially the working group for tropical rain forest (Jordan, Herrera and Sanhueza) it has been possible to establish a balance of nitrogen for the Amazon basin. The hypotheses and information utilized were:

1) The overall flow of nitrogen at the mouth of the Amazon River is 6 kg N ha^{-1} yr^{-1}.

2) The input of nitrogen via the rain is 6 kg ha^{-1} yr^{-1}.

3) Biological nitrogen fixation was calculated considering that oxisols occupy 50% of the Amazon basin with a rate of nitrogen fixation of 2 kg ha^{-1} yr^{-1}; ultisols occupy 45% with a rate of nitrogen fixation of 20 kg ha^{-1} yr^{-1} and the remaining 5% is occupied by soils with a high potential nitrogen fixation of 200 kg ha^{-1} yr^{-1}. Thus oxisols (3×10^8 ha) fix 6×10^5 kg N yr^{-1}, ultisols (2.7×10^8 ha) fix 54×10^5 kg N yr^{-1} and varzea and other fertile soils (0.3×10^8 ha) fix 60×10^5 kg N yr^{-1}, which works out to an average of 20 kg N fixed biologically ha^{-1} yr^{-1}.

Accordingly the losses of nitrogen by denitrification and volatilization should be of a similar magnitude, unless the system is accumulating nitrogen, or agricultural development is causing losses of nitrogen and not replacing them by fertilization or nitrogen fixation.

The overall nitrogen balance for the Amazon basin therefore works out to input from rain: 36×10^5 t yr^{-1}; input from biological nitrogen fixation 120×10^5 t yr^{-1}; ontput from the Amazon River 36×10^5 t yr^{-1}; ontput by denitrification and volatilization (by difference) 120×10^5 t yr^{-1}.

Table 1 - Mean nitrate-nitrogen concentration obtained by various authours and the mean monthly discharge of $N-NO_3^-$.

Discharge Obidos (x $10^9 m^3$) (Oltman 1967)	Oltman (1967) $N-NO_3^-$ (ppm)	Oltman (1967) (mass x 10^3 ton)	Gibbs (1972) $N-NO_3^-$ ppm (mass flow)	SCHMIDT 72 $N-NO_3$ ppm	SCHMIDT 72 mass flow (x 10^3 ton)
JAN......295				0,065	19,2
FEB......349				0,064	22,3
MAR......455			Max. conc. 0,3 ppm	0,043	19,6
APR......557			Min. conc. 0,1 ppm	0,035	19,5
MAY......643			Mean 0,2 ppm	0,023	14,8
JUN......622				0,018	11,2
JUL......549	0,1	54,9	Total year 0,99 x 10^6 ton	0,028	15,4
AGO......442	0,1	44,2		0,024	10,6
SEP......311			Mean (Month) 82,5 x 10^3 ton	0,040	12,4
OCT......241				0,084	20,2
NOV......220				0,076	16,7
DEC......254				0,071	18,0

TOTAL 199,9
MEAN (MONTH) 16,7

Table 2 - Total nitrogen discharge at Obidos (SCHMIDT, 1972) and the calculated discharge at the month.

DISCHARGE	SCHMIDT (1972) N-TOTAL (x10³ ton) (OBIDOS)	MOUTH (CORREC.)	
		TOTAL (x 10³ ton)	Kg/ha
JAN.....295	237.8	266.8	0.4
FEB.....349	291.6	314.8	0.5
MAR.....455	269.8	301.2	0.5
APR.....557	332.0	370.1	0.6
MAY.....643	229.0	254.9	0.4
JUN.....622	285.5	318.1	0.5
JUL.....549	235.0	261.9	0.4
AGO.....442	338.6	377.6	0.6
SEP.....311	134.0	149.6	0.2
OCT.....241	117.3	130.5	0.2
NOV.....220	154.0	172.2	0.3
DEC.....254	189.2	211.6	0.4
TOTAL YEAR	2.813.8	3.129.3	5.0
MEAN (MONTHLY)	234.5	234.5	0.42

Table 3 - Preliminary nitrogen balance of $N-NH_4^+$ and $N-NO_3^-$ at the water basin for the months of may and june 1980.

INPUT

	Mean prec. (mm)	Total ppt. (m^3)	NH_4^+ ppm	NO_3 ppm	NH_4 kg	NO_3 kg	TOTAL in
MAY	133,3	2.9×10^6	0,02	0,005	45,7	3,3	49,0
JUNE	132,6	2.6×10^6	0,02	0,005	41,2	3,0	44,2

OUTPUT

	IGARAPE TOTAL FLOW (m^3)	NH_4 ppm	NO_3 ppm	NH_4 kg	NO_3 kg	TOTAL OUT
MAY	$1,1 \times 10^6$	0,042	0,005	36,6	1,2	37,8
JUNE	$0,98 \times 10^6$	0,025	0,005	19,1	1,1	20,2

$N-NO_3$ OUTFLOW RATE (Kg/ha)

	"Bacia Modelo"	SCHMIDT (1972)
MAY	0,00055	0,0296
JUNE	0,00050	0,0224

Table 4 - $\delta^{15}N^{o}/oo$ in leaves of legume and non-legume trees growing on two soil types in Central Amazônia, Brazil, relative to $^{15}N/^{14}N$ of atmospheric N_2 (Victoria et alii, 1979).

COMMON NAME OF PLANT	$\delta^{15}N^{o}/oo$	
	R. Ducke (clayey soil)	Campina (sandy soil)
Legume		
Macucu (*Aldina latifolia*)	-	- 1.9
Faveira (*Pithecolobium Sp*)	+ 3.9	-
Angelim (*Pithecolobium Raceniorum*)	+ 7.8	-
Muirapiranga (*Caesalpinoidae*)	+ 6.5	- 1.6
Visgueiro (*Pankia Sp*)	+10.0	-
Copaiba roxa (*Caesalpirinoidae*)	+ 8.1	-
Tento (*Paspilionidae*)	-	- 2.2
Non-legume		
Mata-mata (*Lecitidaceae*)	+ 5.8	-
Ucuuba branca (*Virola Surinasuensis*)	+ 5.9	-
Casca doce (*Glycoxylon Inophiluru*)	-	- 7.0
Andiroba (*Carapa Guianensis*)	+ 7.0	-
Pitomba de macaco (*Sapotaceae*)	-	- 7.0

Table 5 - Nitrogen fixation (C_2H_2 reduction) in various systems in Central Amazonia, Brackets indicate an approximate estimate.

	kg N $ha^{-1}yr^{-1}$
roots of primary forest on clayey soil	1.50
roots of secondary forest on clayey soil(no cultivation)	2.45
roots of secondary forest on sandy soil	20
roots of primary forest on alluvial soil	243
epiphytes on campina vegetation	(5-20)
epiphytes on primary forest on clayey soil	(0-5)
aquatic macrophytes	(100)
termites	(0-5)
grassroots in oxisol in "improved pastures"	(very low)
grass roots in alluvial ("varzea" soil	(much higher)

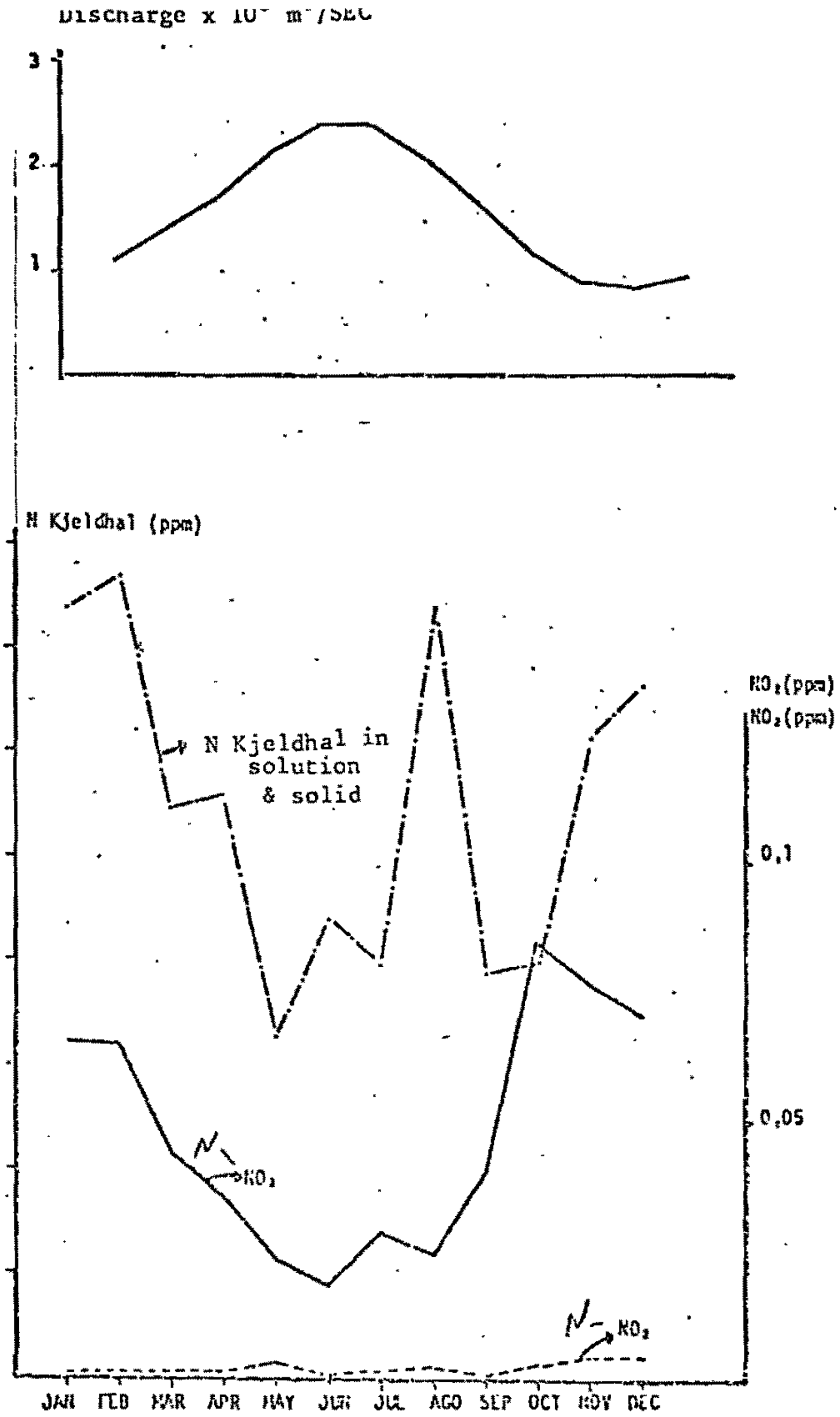

Fig. 1 - Monthly discharge of the Amazon river at Obidos (OLTMAN, 1967) and mean monthly concentration of the various nitrogen compounds (SCHMIDT, 1972).

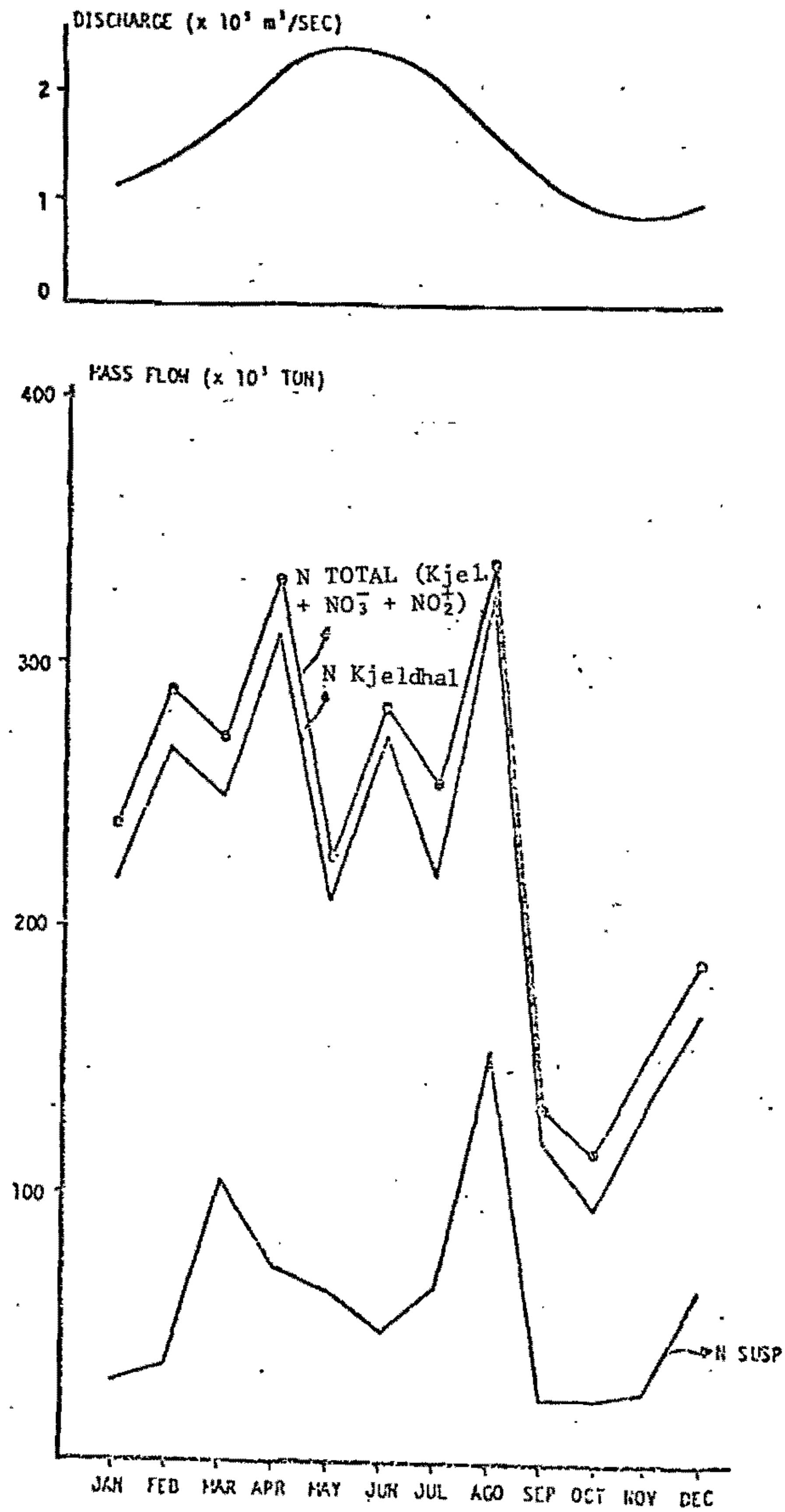

Fig. 2 - Monthly river discharge (OLTMAN, 1967) and total monthly fluxes of nitrogen, calculated with SCHMIDT (1972) data.

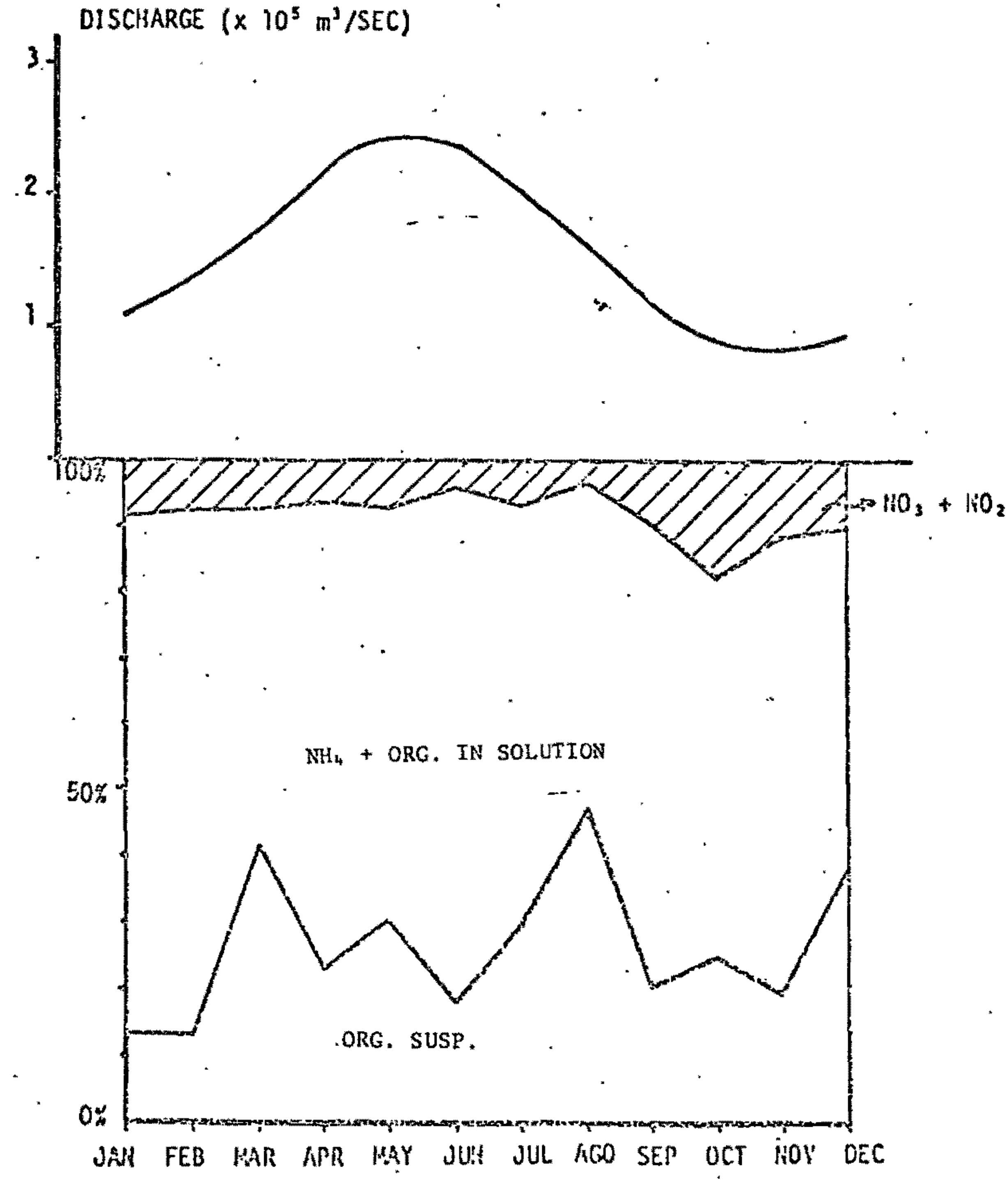

Fig. 3 - Monthly river discharge (OLTMAN, 1967) and relative distribution of the various nitrogen compounds.

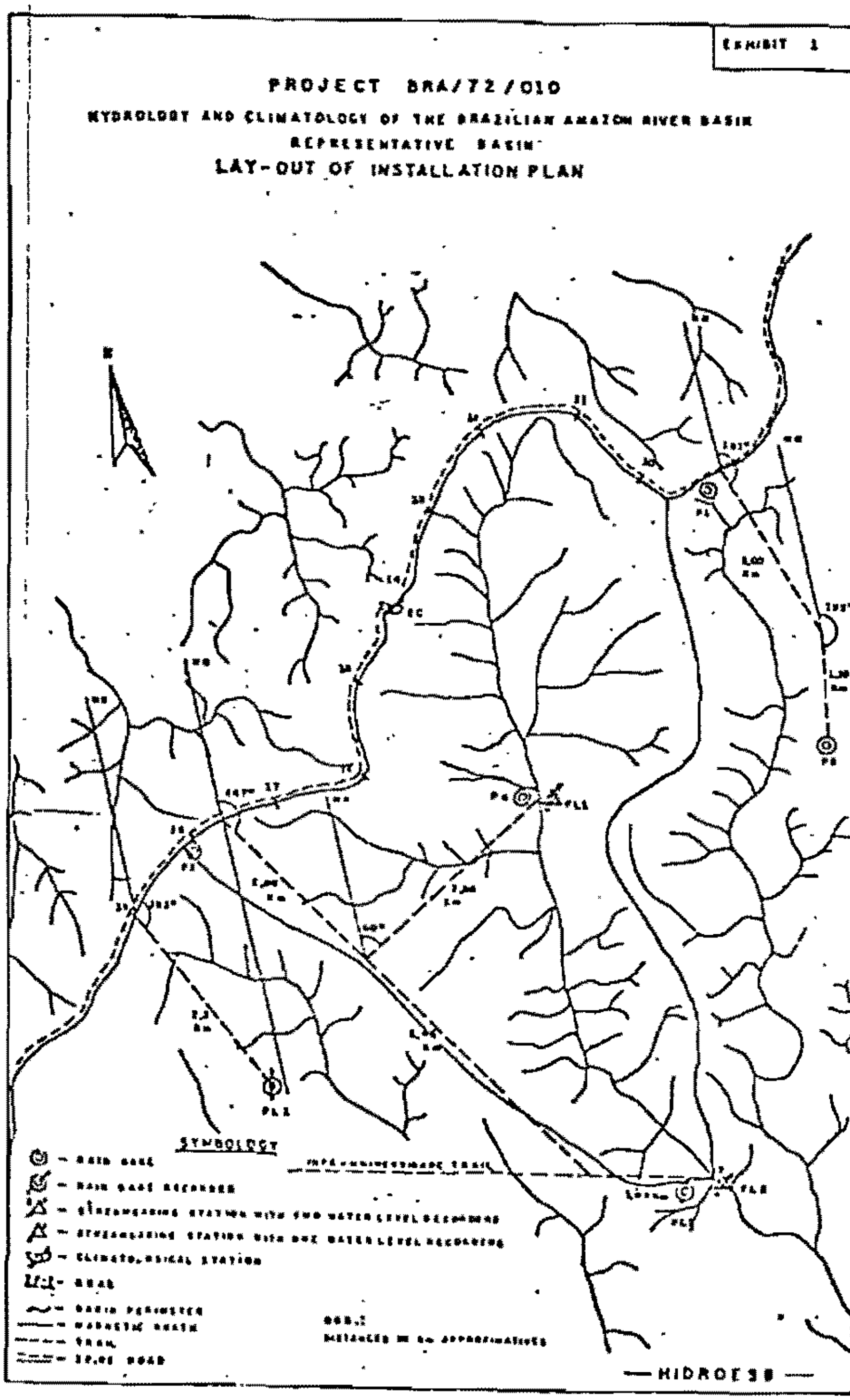

Fig. 4 - Esquematic of the water basin under study.

REFERENCES

1. Black, G.A., Dobzhansky, Th.& Pavan, C. (1950) some attempts to estimate species diversity and population density of trees in Amazonian forests. Bot. Gaz. 3: 413-425

2. De Oliveira, L. A. & Sylvester-Bradley, R.(submitted to Turrialba) Effect of different Central Amazonian soils on growth, nodulation and occurrence of N_2fixing Azospirillum spp in roots of some crop plants.

3. Gibbs, R.J. (1972) Water chemistry of the Amazon River.Geoch Cosmoch Acta 36: 1061-1066.

4. Herrera,R. & Jordan,C.F.(1980) Nitrogen cycle in a tropical Amazonian rain forest: The caatinga of low mineral nutrient status. In Clark F. E. & Rosswall. T (eds) Terrestrial Nitrogen Cycles Ecol Bull (Stockholm) 00.000.000.

5. Jordan,C.F. ,Caskey, W., Escalante, G., Herrera, R., Montagnini,F., Todd,R. and Uhl, C.(1981) The nitrogen cycle in a "tierra firme rain forest" on oxisol in the Amazon territory of Venezuela (this volume).

6. Klinge,H.,(1976) Bilanzierung von Hauptnährstoffen im Ökosystem tropischer Regenwald (Manaus)-vorläufige Daten. Biogeografia 7:59-77.

7. Norris, D.O.(1969)Observations on the nodulation status of rain forest leguminous species in Amazonia and Guyana. Trop.Agric (Trinidad) 46: 145-151.

8. Oltman,R.E.,(1967)Reconnaissance investigations of the discharge and water quality of the Amazon. Atas do Simposio sobre a Biota Amazônica.3:163-185.

9. Prance, G. T. (1978) The origin and evolution of the Amazon Flora : Interciencia 3: 207-222

10. Schmidt, G.W., (1972). Amounts of suspended solids and dissolved substances in the middle reaches of the Amazon over the course of one year (August,1969-July,1970). Amazoniana (Kiel, Germany),3(2):208-223.

11. Sylvester-Bradley,R.,de Oliveira, L. A. & Bandeira. A.G. (in press) Nitrogen Fixation in Nasutitermes in Central Amazonia. Proceedings of the International Symposium on Social Insects in the Tropics.9-13. November 1980 Cocoyoc,Mexico.

12. Sylvester-Bradley,R., de Oliveira, L.A.,de Podestá.Filho,J.A. and St. John T.V. (1980) Nodulation of legumes, nitrogenase activity of roots and occurrence of nitrogen-fixing Azospirillum spp in representative soils of Central Amazonia. Agro-Ecosys,6: 249-266.

13. Sylvester-Bradley,R., Bandeira,A.G. & de Oliveira, L.A. (1978) Fixação de nitrogênio (redução de acetileno) em cupins (Insecta:Isoptera)de Amazonia Central. Acta Amazonica, 9: 621-627.

14. Victoria R.L., Stewart, J. W. B., Matsui,E. & Salati,E. (in press) Variação natural de ^{15}N em plantas e solos da região amazônica. Proceedings of the XVII Congresso Brasileiro de Ciência do Solo. Manaus, July 1979.