NUTRIENT FLOW THROUGH NATURAL WATERS IN "TERRA FIRME" FOREST IN CENTRAL AMAZON[1] /

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Resumo

Através de experimento conduzido na Reserva Ducke, foram estimados os teores dos íons Cl^-, NH_4^+, PO_4^{3-}, Na^+ e K^+ contidos na água de chuva, água de precipitação interna (água de lavagem da floresta) e água escoada pelo igarapé Barro-Branco, o qual drena uma bacia hidrográfica de 1.3 km^2 caracterizada por cobertura florestal do tipo terra-firme. Os teores de Ca^{2+}, Mg^{2+} e SO_4^{2-} foram observados somente na água da precipitação interna. Os conteúdos desses íons na água de chuva, em kg/ha/año, foram da ordem de 13.6 de Cl^-, 6.6 de NH_4^+, 0.1 de PO_4^{3-}, 8.4 de Na^+ e 2.4 de K^+. Essas quantidades representaram, respectivamente, 45%, 89%, 37%, 76% e 11% dos totais que chegaram ao piso florestal pela água da precipitação interna, ou seja, pela água de lavagem das folhas, ramos e galhos da floresta. Os aportes de Ca^{2+}, Mg^{2+} e SO_4^{2-} ao piso florestal, através da precipitação interna e em kg/ha/año, foram da ordem de 1.0, 7.8 e 37.0, respectivamente. As perdas de íons observadas na água drenada, mostraram-se muito pequenas quando comparadas aos totais que chegaram ao solo pela água da precipitação interna.

Introduction

It is well known that Amazon soils are generally characterized by poor fertility, acidity and low cation exchange capacity. However, the exhuberance of the forest is due to especial mechanisms of nutrient availability and storage, essential to its maintenance, besides the basic heat and humidity conditions.

Herrera *et al.* (8) noted that nutrient inputs especially from litter, rain water, throughfall (water falling through the canopy, and internal precipitation) and products resulting from the metabolism of certain microorganisms, are sufficient to meet the forest requirements. According to these authors the plant physiology, adapted to the oligotrophic conditions, contributes to the selection of trees with low nutrient requirement, especially for phosphorus, with tolerance to high available aluminium concentration, which represents an important mechanism for nutrient conservation.

In Central Amazon about (kg/ha/yr) 2.2 P, 12.7 K, 5.0 Na, 18.4 Ca, 12.6 Mg and 105.6 N are recycled through litter (9) They point out that these amounts are relatively poor as compared with other tropical forests.

An important portion of nutrients become available to trees by throughfall which transfers sinificant amounts of mineral to the soil (1, 2, 9, 20, 21, 23, 24, 27). These authors mention, in general, the importance of throughfall to forest nutrition and

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that the inevitable losses, which are small in relation to total nutrients recycled, are replaced by minerals from rain water.

As observed by Schubart (25), uncontrolled deforestation represents a complete break-down of mineral recycling mechanisms, since the lack of plant cover will result, among other things, in an increase in leaching and erosion with consequently decreased fertility. According to the author, this can be proven by the inevitable decrease in yield of agricultural product crops occurring in certain deforested areas of the Amazon, the decrease being due to lack of nutrients, associated with other factors.

The objective of the present work is to estimate the flow of certain nutrients in a hydrographic basin with forest cover of the "Terra Firme" type which is characteristic of about 80% of the Amazon Region. Such studies are useful and important as the basic data obtained are necessary to the development of practices for non-predatory exploitation of the existing natural resources, suitable to the local ecology.

Material and methods

The hydrographic basin used in the present study is located at Reserva Ducke, near km 26 of the Manaus-Itacoatiara highway, has an area of about 1.3 km^2. Brinkmann and Santos (2) give detailed description of soil and type of plant cover. Data regarding hydrological characteristics are found in Leopoldo *et al.* (12) and Franken *et al.* (6).

Samples of rain water, throughfall and run-off water through the Barro-Branco stream were collected from October 1976 to September 1977, at one week intervals. A 200 cm^2 surface pluviograph was used in the quantification of rain while three plastic pluviometers, 100 cm^2 surface each, installed at about 20 m from the forest, were used to obtain rain water samples for qualitative analysis. For quantification and qualification of throughfall, i.e. the amount of rain water which reaches the forest soil by passing directly through cover openings and/or through dripping from stem, branches and leaves, 20 plastic pluviometers with 100 cm^2 surface each were installed in the forest.

The stream outflow was determined by using a rectangular weir with 0.98 m gate located at the basin outlet and a limnograph to register the hydraulic flow at the weir. Drainage water samples were collected at the same place for the respective chemical analysis.

As mentioned above, the water samples were chemically analysed for Cl^-, NH_4^+, PO_4^{3-}, Na^+ and K^+ ions, while SO_4^{2-}, Ca^{2+} and Mg^{2+} ions were only determined in throughfall. These analyses were made using a flame spectrophotometer, an atomic absorption spectrophotometer and an ion analyser with specific electrodes. The data obtained were converted into kg/ha/yr as a function of quantification of the water involved in each process.

Results

Table 1 shows the results of ion flux (kg/ha) in a one-year period, besides the percent for each phase of the process. Throughfall values (PI) refer to the addition of ions transported by rain water to those from forest washing and represent the totals which reached the forest soil. Columns P/PI show the percent of ions transported by rain water in relation to throughfall and Q/PI refer to percent from the Basin in relation to totals reaching the forest soil.

Table 1. Values (kg/ha) observed for ion flux in a one-year period and the respective proportions.

Ions	Rain (P)	Through-fall (PI)	Outflow flow (Q)	%	
				P/PI	Q/PI
Cl^-	13.60	29.90	3.94	45.5	13.2
NH_4^+	6.60	7.40	0.39	89.0	5.2
PO_4^{3-}	0.10	0.27	$7x10^{-3}$	37.0	2.6
Na^+	8.40	11.10	0.75	75.7	6.7
K^+	2.40	22.10	0.29	10.9	1.3
Ca^{2+}	–	1.00	–		
Mg^{2+}	–	7.80	–		
SO_4^{2-}	–	37.0	–		

During the respective period, total precipitation was of the order of 2 075 mm, throughfall reached 1 847 mm and outflow about 400 mm. Results from such observations are shown in Figure 1, grouped into one month periods.

Figure 2 shows Cl^- flux variation in rain water, throughfall or forest washing and in the Barro-Branco stream outflow, noted during the respective observation periods, while same observations for NH_4^+, PO_4^{3-}, Na^+ and K^+ are shown in Figure 3 to 6. Figure 7 shown SO_4^{2-}, Ca^{2+} and Mg^{2+} flux variations noted only in throughfall.

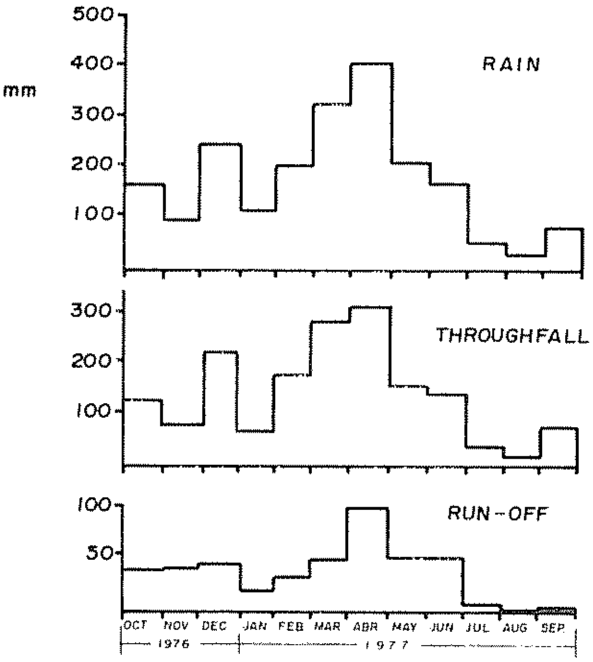

Fig. 1. Rain, throughfall and run-off of the Barro-Branco stream, in milimeters, observed during the respective periods.

Discussion and conclusions

Chlorine – It can be seen from Table 1 that in one year about 29.9 kg chlorine/ha reached the forest soil by throughfall or washing water, as many investigators would prefer to call it. Of this quantity, 13.6 kg representing 45.5% of the total were introduced by rain water, the remaining 16.3 kg being carried by water which removed the soluble chlorine released by leaf, stem and branch surface and, to a certain extent, by the dissolution of products from macro and microorganism. Table 1 also shown that of the total input to the forest soil only 13.2%, i.e. less than 4 kg/ha/yr were lost in solution through water flow.

Since the Amazon forest is in dynamic equilibrium it can be assumed that all external inputs are approximately equal to the losses occuring in the ecosystem, in such a way that the equilibrium is maintained. Therefore, about 9.7 kg chlorine/ha/yr should be lost in other forms, possibly as a complex element in organic matter in decomposition and in suspension in drainage water, or even, as cited by Malavolta (15), adsorbed in soil inorganic minerals, in suspension through "specific adsorption" i.e. by the formation of positive areas for adsorption of negative ions created through the acceptance of protons by aluminium and iron. Following the same principle, chlorine adsorption to colloid organic matter suspended in drainage water would also be feasible. Comparatively, chlorine content in rain and drainage waters was the highest of all ions analysed, followed by sodium.

It was noted that the maximum values or precipitation, throughfall and run-off over the period occurred during the month of April (Figure 1). However, it can be seen in Figure 2 that the Cl^- peak in all three phases occurred in December, i.e. at the beginning of the season considered rainy (December-May). At this peak, of the total Cl^- reaching the forest soil, 60% came exclusively from rain water, and 40% were leached from the forest canopy by throughfall. Figure 2 also shows the minimum values which occurred during August, and it can be noted also that although there was a well characterized seasonal cycle, the greatest amounts of chlorine in the waters under consideration occurred during the humid

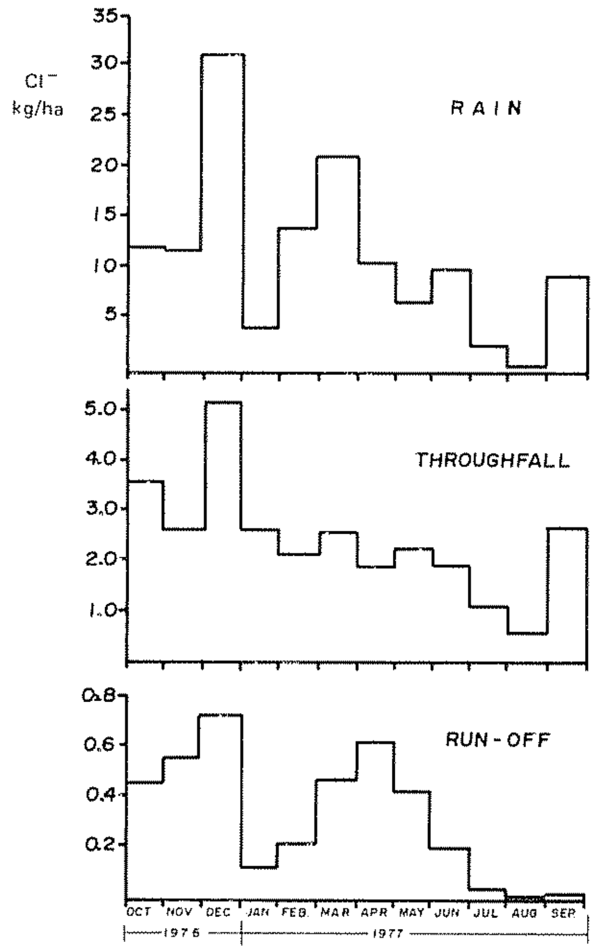

Fig. 2. Cl^- flux in rain waters, throughfall and run-off of the Barro-Branco stream, as a function of the respective observation period.

period or the rainy season (December-May) It is interesting to note that chlorine contribution from rain water and washing water, in this period represented respectively 52% and 48% of the total chlorine transported to the forest soil. However, for the dry period chlorine contribution from rain water and washing water represented respectively 33% and 67% of the total chlorine transported to the forest soil This observation leads us to understand and assume that before leaf-fall of the older leaves, which occurs mainly in the dry season, they release chlorine, similarly to what happens with calcium according to Brinkmann and Santos (2)

Ammonium – In accordance with data in Table 1, about 5.8 kg nitrogen/ha/yr from ammonia reached the forest soil by throughfall Of this amount 5.1 kg were due to rain water and the balance, the small amount of 0.7 kg, leached from the forest canopy

Based on analysis of rain water from different areas of the Amazon region, Salati (22) calculated that approximately 6 kg N/ha/yr are introduced through precipitation He also noted that, in certain cases, the largest part of this amount comes from ammonia as compared to nitrate, which might suggest a recycling of the volatilized nitrogen These values, however, represent a very small fraction – about 6% – in relation to the recycling of nitrogen compounds by litter which, according to Klinge and Rodrigues (9), in "Terra Firme" forest is of the order of 106 kg/ha/yr Similarly, Santos and Ribeiro (23) found that, in the water of the Campina Amazonica ecosystem, the organic nitrogen is in higher concentration than in the other fractions analysed, followed by ammonia-nitrogen

Figure 3 shows that from March to July especially, NH_4^+ input through precipitation was higher than the total in the washing water It was estimated for this period, that only 52% NH_4^+ from rain reached the forest soil This observation reinforces the hypothesis of rapid nitrogen volatilization or else of high foliar absorption or through microflora and other populations normally existing on leaf, stem and branch surfaces which at this time of the year, due to temperature and humidity conditions, whould be in full development

Run-off losses totalled 0.3 kg N/ha/yr, as shown in Table 1 and represent approximately 5.2% of the total that reached the forest soil Evidently other forms of loss ocurred in a way that losses and gains tend to be equal Malavolta (17) noted that NH_4^+ can be lost through particulates, leaching, and above all volatilized, since in aqueous and acid medium through nitrification followed by denitrification, NH_4^+ tends to become N_2O or even N, in which forms it returns to the atmosphere

Phosphate – Figure 4 shows that PO_4^{3-} fluxes can be considered negligible in the phases analysed as compared with the amount of phosphorus in litter, which according to Klinge and Rodrigues (9) totals about 2.2 kg/ha/yr Converting the PO_4^{3-} data in Table 1 into net P values, only $85x10^8$ kg/ha reached the forest soil in one year, through natural waters, which fraction corresponds to less than 4% of the phosphorus returned to soil through litter Of this amount, $32x10^{-3}$ kg/ha originated from rain water, therefore, the balance, i.e. 53.10^{-3} kg/ha came from leaching of the leaves, stems and branches, or even from macro-and microorganisms living on them

Although phosphorus has been analysed only in its soluble form, it is believed that the low values for throughfall result from the adaptation of the Amazon plant species to the low availability of this element as already reported by Herrera *et al.* (8). Even the

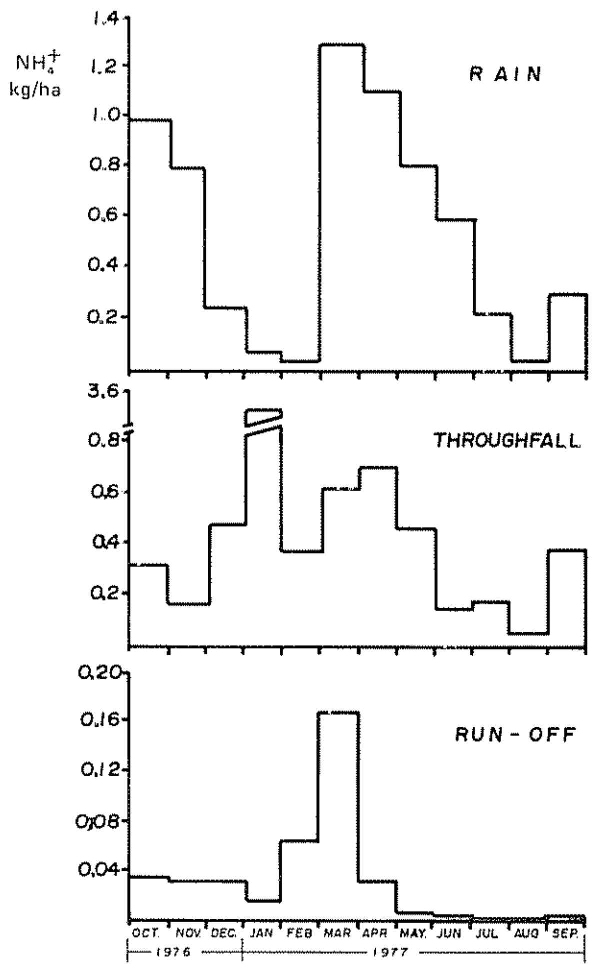

Fig 3. NH_4^+ flux in rain waters, throughfall and run-off of the stream, as a function of the respective observation period

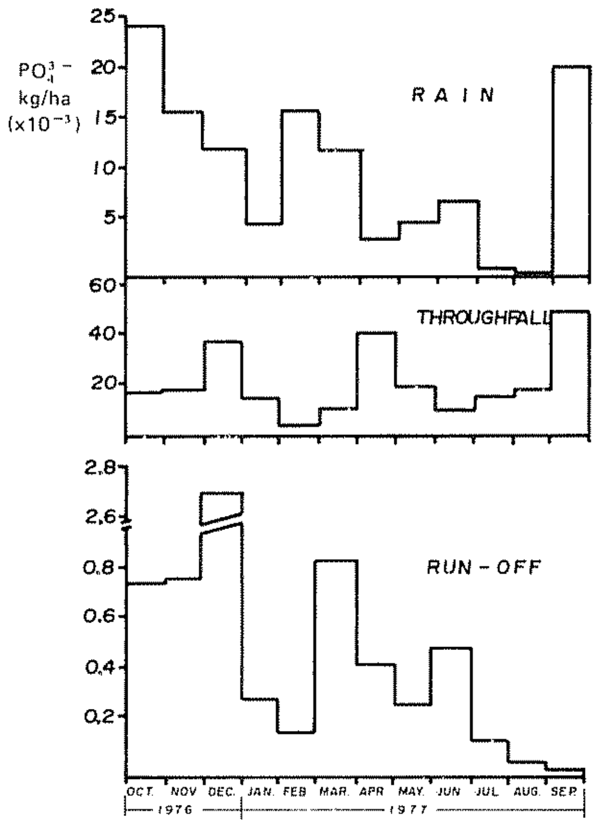

Fig. 4 PO_4^{3-} flux in rain waters, throughfall and run-off of the stream, as a function of the respective observation period.

phosphorus amount in litter can be considered poor as compared with other regions or species. For conifers, Will (28) concluded that throughfall contains the same amount of phosphorus as that observed for the litter of such populations, which in part means larger demands of the species in relation to this nutrient.

Thus, besides the physiological plant adaptation to the phosphorus availability, it can also be concluded that the Amazon ecosystem has developed an efficient conservation system of this nutrient.

Sodium – Brownell and Wood (3) cited by Malavolta (15) observed that sodium effect on plants varied from essential in only one species, *Atriplex versicaria* Heward, to toxic for many others.

According to citation by Malavolta (15) many plants accumulate sodium, while others tend to eliminate it from aereal parts and accumulate in the roots. Letey *et al.* (13) showed that the quantity of sodium translocated to the aereal parts of certain plants in increased by the low oxygen supply to the roots, which leads us be believe that the elimination process is metabolic.

Lehr (11) also cited by Malavolta (15) developed a scheme for the Na/K ratio in higher plants, in which there are 4 categories:

a) plants that show a great response to sodium at high levels of potassium, and in these cases they can substitute part of the potassium for sodium;

b) plants that show a small response to sodium under good K supply conditions, there being in these cases substitution of K for Na but in a lesser scale than in the previous case;

c) species that show moderate to great response to Ka deficiency; and

d) plants which show little or no response, with or without K deficiency conditions.

As to absorption, Harding *et al.* (7) and Ehlig and Bernstein (4) showed that sodium can be absorbed through the leaves and that this absorption is relatively quick, so that toxicity symptoms appear within a few weeks is plants sensitive to Na^+.

Table 1 shows that about 8.4 kg Na^+/ha/yr reached the region through precipitation, which amount is higher than the sodium content in litter proper. To this amount, about 2.7 kg Na^+/ha/yr from tree top washing were added, so that a total of 11.1 kg Na^+/ha/yr reached the forest soil.

Table 1 also shows that soluble sodium loss was of order of 6.7% of the total that reached the forest soil through water. This is, evidently, a paradoxical result, since it should be supposed that the greatest sodium losses occur through leaching, if we consider that this element is more weakly adsorbed by soil colloids than K, Mg and Ca most probably colloidal organic matter. However, considering that losses tend to equal external gains; that Ca and Mg losses are minimal (1,2) as well as losses of K, probably the excess sodium was exported as particulates, i.e. adsorbed to the inorganic and organic matter suspended in run-off water, or else similar to the other ions observed, through decomposing organic matter.

It can also be noted in Figure 5 that the sodium content in rain water was influenced by the season, the largest amounts having been introduced from December to April, while those noted for the May-September interval can be considered negligible. Making a mass-balance for each period it is noted that in

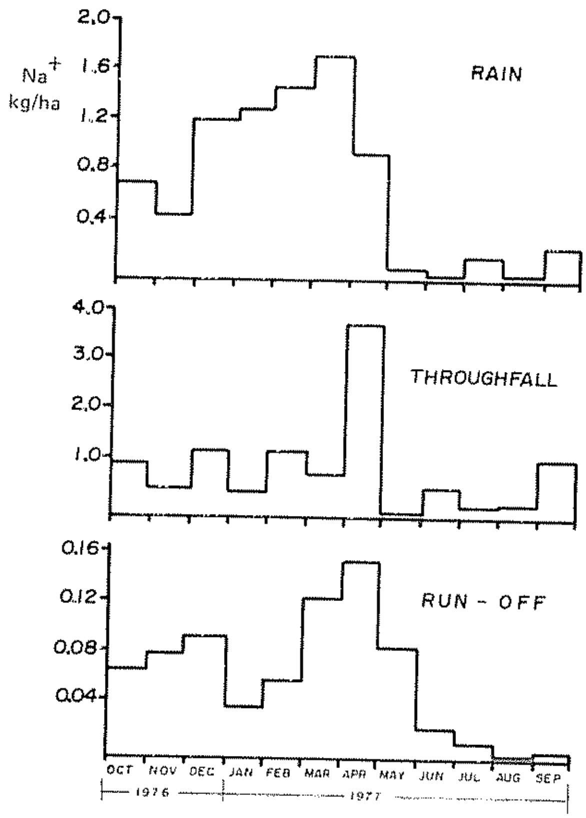

Fig. 5 Na^+ flux in rain waters, throughfall and run-off of the stream, as a function of the respective observation period.

the November-March interval, only a portion of 63% of total sodium introduced by rain water reached the forest soil. Part of it (37%) was retained by tree tops, the washing water thus becoming poor in relation to its original content. Therefore, as far as mass is concerned, from November to March about 6.2 Na^+/ha/yr entered the ecosystem through rain water,of which 3.9 kg were transported to the soil by throughfall, approximately 2.3 kg Na^+/ha having been retained on the leaf surfaces, or even by other organs and/or by microflora. The portion retained is most likely to have been absorbed by plants through the leaves, according to research by Harding *et al.* (7) and Ehlig and Bernstein (4).

In this period losses amounted to about 0.4 kg Na^+/ha, therefore, hypothetically there should be available in the soil 3.5 kg Na^+/ha. For the following period, April-October, the situation was relatively reserved: the soil received about 7.2 kg Na^+/ha through natural waters, of which 31% or 2.2 kg originated from rain and the balance, about 4.9 kg/ha were taken from the forest canopy by washing water; losses of Na^+ were of the order of 0.3 kg/ha, which should give a net availability in the soil of 6.8 kg Na^+/ha.

For the first period it can be noted that between the amount of sodium absorbed by the vegetation and that supposed to be available in the soil we had a total of approximately 5.8 kg Na^+/ha/yr. On the other hand, it can be noted that in the following period there was an elimination of sodium through water of 4.9 kg/ha which represented a difference of only 0.9 kg/ha between the two periods; this leads to the supposition that, besides foliar absorption there was also an intensive absorption by roots to maintain the sodium equilibrium in the plant.

The following considerations are made in an attempt to explain such behavior, in which during a certain period sodium was absorbed by the plant, followed by another period when it was eliminated:

–It is noted that the sum of potassium content in washing water (Table 1) and litter is higher than Ca and Mg, therefore there is an adequate supply of potassium to the plants. Thus the vegetation studied can be included in the first category, or even the second, established by Lehr (11) where plants whow a certain affinity to sodium in spite of good potassium supply conditions, there being in these cases substitution of K for Na in order to maintain the ratio Na/K within adequate limits for the plants.

–Of the total sodium eliminated by the vegetation (4.9 kg/ha) during the period April-October, it was noted that the greatest portion 57%, was in April and May. It is assumed that this procedure is possibly due to excess water in the soil, especially in March, April and/or even May (Figure 1) thus causing low oxygen supply to the roots, which according to Letey *et al.* (13) results in translocation of sodium to the aereal parts, which is later eliminated by metabolic process. Subsequent elimination, on a much lesser scale, probably occurred to eliminate the excess sodium absorbed in the previous period.

Finally, all of the above remarks are only conjectures on a little studies subject.

Potassium – Results in Table 1 show that potassium was the cation most leached from tree tops and was the main cation in washing water. This was probably due to the fact that the largest proportion of potassium in the plant is in soluble form, contrary to Ca^{2+} and Mg^{2+}, and consequently is more easily removed by water.

Nye (19) working in a tropical forest in Costa Rica came to similar conclusions, observing that the potassium reincorporated in the washing water represented, under those conditions, about three times the amount in litter. In conifer populations in New

Zealand, Will (28) observed a lesser proportion i.e. twice as much; while in the present work and based on results by Klinge and Rodrigues (9) this proportion was less still, of the order of 1.7.

Table 1 also shows that external inputs of potassium represented 10.9% of the total reincorporated into soil by washing water, which amount is relatively inferior to the other ions studied. Considering, however, the potassium contained in litter, 12.7 kg/ha/yr according to Klinge and Rodrigues (9) it can be noted that the external contribution will be reduced to 6.9% of the total pottasium involved in the ecosystem.

Thus, like the observations made by Brinkmann and Santos (1, 2) for calcium and magnesium, and phosphorus in the present work, potassium can also be included as a closed cycle elements since the gains are relatively low as compared to the total K involved in the cycle. The potassium incoming flux followed a certain seasonal variation as can be seen in Figure 6, with minimum quantities being introduced in the months July-September, followed by a period when these quantities tended to increase until April.

Contrary to what was observed for sodium, Figure 6 shows that potassium content in washing water, for the whole period, was always higher than that of rain water. These contributions were minimal in July and August, while from January to June the quantities introduced showed little relative variation, with a mean value of about 1.3 kg K^+ ha/yr. The greatest contribution, however, ocurred in the period September-December, i.e. middle to end of the dry season and the beginning of the rainy season, when washing water transported to the forest soil a total of 11.0 kg K^+/ha, corresponding to 49.8% of the total per annum.

It is known that potassium is an element easily redistributed in the plant, and according to Malavolta (15) when the leaf matures part of the potassium adsorbed to the proteins is released. Therefore, the greatest concentrations of K^+ in washing water, during the period September–December could be explained assuming that before and during falling of older leaves there would be an increase in the potassium, susceptible to leaching by water action

On the other hand, it is also known that potassium absorption depends directly on its availability, being also affected by aeration and soil moisture. Lawton (10) cited by Malavolta (15) working with maize, found that the K content in the plant decreases with the decrease in soil moisture. Similarly, when aeration is lessened the element's rate of absorption also decreases. Furthermore, Loué (14)

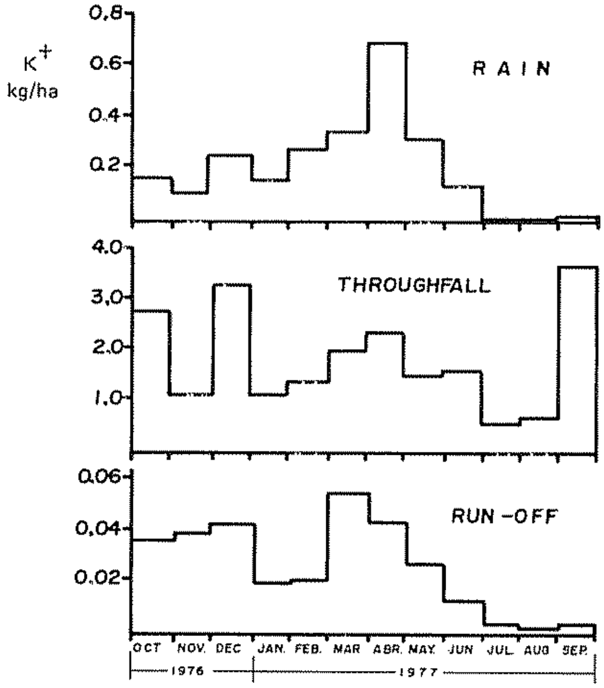

Fig. 6. K^+ flux in rain waters, throughfall and run-off of the stream, as a function of the respective observation period.

mentions that potassium absorption indirectly depends, as a general rule, on Ca^{2+} and Mg^{2+} concentration in soil solution, according to the ratio $(K)/(Ca+Mg)^{1/2}$. Low ratios would generally indicate a smaller K absorption by the plant, while for high ratios there would be higher amounts of K in the leaves and a decrease in Ca and Mg.

Studying this ratio in the present work for washing water which introduced into the soil the majority of the referred to elements, a mean value of 106 was found the period September-December and a mean of 71 for January-June. For the months of July and August this ratio was of the order of 54 and 57, respectively.

Therefore, it can be concluded that the results obtained for potassium are in accord with the general observations: from January-June (part of the rainy season, beginning of the dry season) K^+ flux in washing water was smaller since during this period there is supposedly a high content of moisture in the soil with consequent low aeration, besides the observed low ratio $(K)/(Ca+Mg)^{1/2}$; the peak observed in April was probably due to the occurrence of high amounts of precipitation, increasing therefore the leaching capacity by water, not only of K but of other elements as well; for July/August besides the smaller ratio observed $(K)/(Ca+Mg)^{1/2}$ the total water involved was very little in comparison with other periods; and from September to December the conditions were reserved, resulting in greater K availability, susceptible to leaching process.

Sulphur – Table 1 shows that the amount of SO_4^{2-} in washing water, about 37 kg/ha/yr (12.3 kg S) was higher than the other ions analyses. Although not determined in rain water, it is assumed that the external contribution was relatively large, as has been concluded for chlorine and ammonium. Thus, of the amount of 37.0 kg/ha/yr a large portion must have been introduced by rain water, and recalling that of the total sulphur in the plant the greatest part is in organic from, leaching is not so likely compared to certain other elements. These indications, together with the characteristic that SO_4^{2-} can be lost by volatilization through microbial activity which reduces the SO_4^{2-} to S^{2-}, suggests that recycling of the volatilized SO_4^{2-} should occur, as described by Salati (22) for NH_4^+.

On the other hand, as seen in Figure 7, the largest part of the SO_4^{2-} in washing water occurred during the period September-December, i.e. middle and end for the dry season and the beginning of the rainy season. The amount of SO_4^{2-} in washing water in these four months was of the order of 20.8 kg/ha, representing 56.2% of the total per year. Thus, the largest concentration found for the period September-December seem to the correlated with release of SO_4^{2-} by older leaves before falling, as noted for potassium. Besides this possibility, and as previously mentioned, the highest K^+ concentrations in washing water occurred during the identical period as for SO_4^{2-} which would imply, according to Simon-Sylvester (26) a greater speed of sulphate absorption. Such coincidence permits the establishment of another hypothesis, in which it is noted that when there is an ample supply of SO_4^{2-} its absorption can be quicker than its own reduction and assimilation of organic compounds, resulting in a considerable fraction of the absorbed sulphur remaining as SO_4^{2-} which is easily leached (Epstein, (5) cited by Malavolta (16).

The month in which the maximum value of SO_4^{2-} in washing water, 6.8 kg/ha, occurred was April (Figure 7). This must have been due to concentration of this element in rain water together with the characteristic rainy events in that month. These characteristics, high intensity and high precipitation, evidently confer on the water a high leaching capacity.

Calcium – In accordance with the results in Table 1, about 1.0 kg calcium/ha/yr was reincorporated into the forest soil through washing water. This value represents only a small portion, 5%, of the total cal-

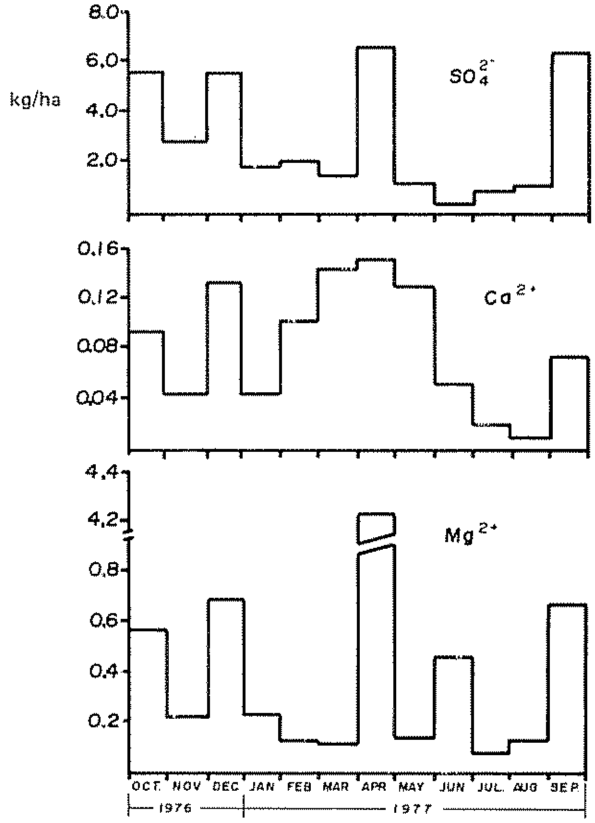

Fig. 7 SO_4^{2-}, Ca^{2+} and Mg^{2+} in throughfall, as a function of the observation period.

cium returned via litter, which reached 18.4/ha/yr (9). Such a proportion indicates that calcium is an immobile element, especially in older leaves (2). This shows that calcium content in washing water and litter was smaller than K and Mg in view of the fact the high concentration of these two elements in the medium decreases Ca absorption (15).

Figure 7 shows that the greatest amount in washing water occurred during the period December-May, coinciding with the period of greatest precipitation. According to data obtained, 0.71 kg Ca^+/ha, corresponding to 71% of the total year, were transported during this period.

Brinkmann and Santos (2) working in Central Amazon found traces of soluble calcium in rain, soil and drainage waters, which lead them to consider it as a circulating element in a closed system. Similar remarks were made by Santos *et al.* (24). Yet, according to Brinkmann and Santos (2), the largest concentration of calcium in washing water was found in the dry season, a period in which the element is released from the older leaves due to their decomposition before falling. Besides this main source of soluble calcium, these authors mention two others: the solubilization process in leaves and microflora, and sporadic leaching of residues and excretion of non-photosynthesic macro– and microorganisms on leaf surface.

The results presented in Figure 7, however, are not entirely in accord with those cited by the above authors, if we consider that in the present case the largest amount of the element in internal precipitation occurred during the rainy season, i.e., when the forest is in vegetative development. Evidently, larger concentrations can be found at leaf fall (2) during the dry season, since a smaller dissolution of leached calcium should occur at such time because of the lesser amounts of washing water involved in the process. From the results presented it appears that the processes which originate calcium in washing water, are more efficient in the rainy season when there are greater amounts of calcium leached from the forest canopy.

Magnesium – The forest soil received during one year about 7.8 kg soluble magnesium through washing water (Table 1). As shown in Figure 7, 4.2 kg/ha, corresponding to 53.8% of the total, during the month of April alone, probably as a consequence of high and intense precipitation which occurred in that month.

Magnesium is a mineral that translocates easily in plant tissue as already observed by (1). According to these investigators, leaching of released magnesium by oxidizing and solubility processes in leaves, stems and branches or even epiphytes, constitutes a very important source of the element, besides the already cited calcium sources. The possible solubility of magnesium present in leaf surface and stems by strong acids, such as nitric and organic acids, has been suggested by Santos *et al.* (24). It can be seen in Figure 3 that the greatest NH_4^+ availability introduced by rain water was in March-April, and this can be correlated with the magnesium peak in April.

Except for the transference which occurred in April, it can be noted in Figure 7 that a representative portion of magnesium was leached during the period September-December, i.e. the middle and end of the dry season and beginning of the rainy season, identical to what was observed for certain other ions. The high throughfall concentration, strongly reduced for rain water and run-off, shows that magnesium, as stated by Brinkmann and Santos (1) can be considered an element of internal recycling.

Comparing the three cations, K^+, Mg^{2+} and Ca^{2+} the order of preference was given by the sequence $K^+ > mg^{2+} > Ca^{2+}$ since the high relative availability of potassium and magnesium induces a smaller rate of calcium absorption, and in turn potassium causes a decrease in magnesium (15).

It can be noted that the water running down the trunk has not been analysed, which would complete the nutrient balance in the ecosystem in question. However, according to Franken *et al.* (6) it is known that the portion of trunk-water is very small as compared to the total water reaching the soil by throughfall. Similar remarks are found in McColl (18).

The nutrient flux in the waters of tropical forests is very complex and little studied, suggesting that research should continue with the objective of defining practices and policies for a non-depredatory explotation of this immense and important ecosystem.

Summary

In an experiment conducted at Reserva Ducke, Cl^-, NH_4^+, PO_4^{3-}, Na^+ and K^+ ions were estimated in rain water, throughfall and run-off water of the Barro Branco Igarapé which drains a 1.3 km² watershed characterized by "Terra Firme" forest cover. Ca^{2+}, Mg^{2+} and SO_4^{2-} were found only in throughfall. Ion contests in rain water were (kg/ha/yr) 13.6 Cl^-, 6.6 NH_4^+, 0.1 PO_4^{3-}, 8.4 Na^+ and 2.4 K^+. This represented 45%, 89%, 37%, 76% and 11% respectively of the totals reaching forest soil by throughfall. Ca^{2+}, Mg^{2+} and SO_4^{2} reaching the forest soil by throughfall (kg/ha/yr) were 1.0, 7.8 and 37.0 respectively. Run-off ion loss was relatively small as compared with total ion content reaching the soil forest by throughfall.

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Reseña de libros

STANHILL, G. (ed.) Energy and Agriculture. Springer-Verlag. 1984. 192 p. (Advanced Series in Agricultural Sciences 14).

A partir de 1973 el mundo llegó a tener un mejor conocimiento del valor de los recursos energéticos, a raíz del vertiginoso aumento en los precios del petróleo decretado por la Organización de Países Exportadores de Petróleo. Esta situación de verdadera crisis, que puso en jaque aún a los países más ricos, tuvo como un resultado positivo el desarrollo de un marcado interés por el estudio del flujo de la energía en diversos sistemas, tanto agrícolas, industriales como también naturales, así como la búsqueda de formas de un mejor aprovechamiento de la energía y de nuevas fuentes de este recurso.

Precisamente, el material que se presenta en esta obra procede de los trabajos sometidos a la consideración de una conferencia internacional celebrada en Kiryata Anavim, Israel, en marzo de 1983, dedicada al análisis del tema de la energía. En esta conferencia, organizada por el Consejo Nacional para la Investigación y el Desarrollo de Israel, un distinguido grupo de científicos presentó un enfoque multidisciplinario del problema energético en los agroecosistemas. El contenido de los 9 capítulos, que a continuación se transcriben, incluye aspectos no sólo agronómicos sino también biológicos y económicos.

Capítulo 1. Introducción: el papel de la energía en la agricultura.

Parte I. Principios y procesos.

Capítulo 2. Impacto económico de los precios de la energía en la agricultura.

Capítulo 3. Análisis energético del papel del ambiente en la agricultura.

Capítulo 4. El papel de la ingeniería genética en la modificación del flujo de energía en la agricultura.

Parte II. Fuentes de energía para la agricultura.

Capítulo 5. Energía en diferentes sistemas agrícolas: fuentes renovables y no renovables de energía.

Capítulo 6. Mano de obra en agricultura: desde fuentes de energía a centros de consumo.

Capítulo 7. Uso de la energía en el sector productivo de alimentos de la Comunidad Económica Europea.

Capítulo 8. Energía en la agricultura australiana: consumo, producción y políticas de acción.

Capítulo 9. Uso de la energía y su manejo en la agricultura de los Estados Unidos de Norteamérica.

Aunque todos los capítulos de este libro están muy bien presentados en cuanto a contenido, forma y sustento bibliográfico, se nota un sesgo hacia el análisis de los problemas en los países de mayor desarrollo científico y tecnológico, en especial en el estudio de casos. Hubiese sido interesante que se incluyera por lo menos un país del tercer mundo, en donde se haya logrado progresos en el estudio de los problemas energéticos, como es el caso de Brasil. Los capítulos 3, 4 y 5 son los que tienen un carácter más general y por lo tanto podrían ser de mayor interés para los estudiosos del problema en cualquier parte del mundo. El capítulo 4 es bastante innovador en cuanto al enfoque del problema, ya que muestra cómo la ingeniería genética, y en general la biotecnología, pueden ser de importancia en la modificación de los diversos elementos que intervienen en el flujo de energía en los agroecosistemas.

Por el interés y la vigencia del tema y por el buen contenido de la obra considero que ésta debe ser lectura obligada de todos aquellos que se interesan por los problemas energéticos en especial los investigadores en el campo de los agroecosistemas.

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