conductivity is not an important conductivity

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through the topsoil so that water-mineral tical variation of shape, size, crystallography, and crystal chemistry of the kaolinites attests to the in situ geochemical differentiation of the whole profile (*3, 21*), and gibbsite is currently formed underneath the thick kaolinitic upper horizon (*22*).

We sampled litterfall in conical traps for 2 years (*23*), on a weekly basis during the rainy season and sometimes on a bimonthly basis during the dry season. Samples were sorted into leaves, reproductive parts (flowers, fruits, and seeds), fine woody material, and residue. Animal material and scarce-adhering mineral material were discarded. After sorting, samples were dried, weighed, finely ground, and stored. A bulk sample for the entire 2-year litterfall was used for chemical analysis (*24*). No correction was made for possible mass or element losses during the time the litter was in the trap.

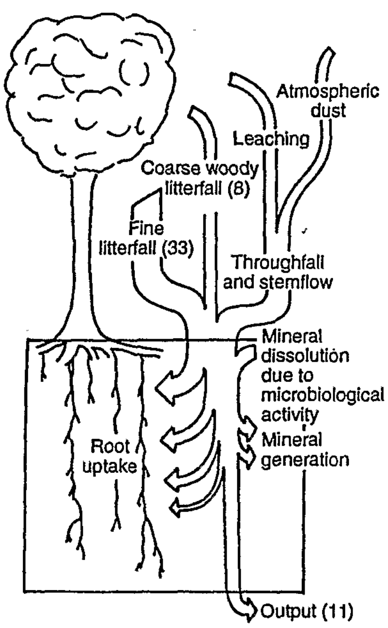

Fig. 2. Silicon cycling in the equatorial rain forest. Numbers in parentheses are in kilograms per hectare per year.

The mean litterfall weight for the 2 years of collection was 8.4 tons ha^{-1} $year^{-1}$. The elements Ca and Si dominated the litterfall element concentrations, 4.4 and 4.0 per mil, respectively, followed by K, Mg, Al, Na, Fe, P, Mn, and Ti, in decreasing order of relative concentration (Table 1). The element Si was mainly concentrated in the leaves, whereas Ca was more evenly distributed among the different components. The elements Al, Fe, and Ti were mainly concentrated in the residue, which may represent soil material brought up to the trees by termites. The annual Ca and Si turnover in the litterfall was 36 and 33 kg ha^{-1} $year^{-1}$, respectively, and the annual turnover of other elements was less (Table 2). The possible recycling by termites of soil material through the residue fraction is <0.8 kg ha^{-1} $year^{-1}$ for Si. The SiO_2/Al_2O_3 ratio of the annual litterfall was >10, whereas in the first meter of soil it was less than 1.3 (bulk soil) or 1.1 (kaolinite plus gibbsite).

We estimated the total Si content of the forest by using existing data on floristic composition, average phytomass of the aerial parts (trunks, branches, and leaves) (*25*), and Si content in trunks and litterfall fractions. The 235 tree species listed in the forest represent a trunk volume of 287 m^3 ha^{-1} (*19*). Wood density and Si content data were available for 39 species (*26*), which represent a trunk volume of 120 m^3 ha^{-1}; the average trunk density is 0.75 ton m^{-3}, and the average Si content is 3.34 per mil. The trunk Si content of these 39 species is 301 kg ha^{-1}, which may be considered a minimum value for Si content of the forest. If we extrapolate to the whole forest, using the average Si content calculated from the 39 species and the average leaf and branch Si content measured in the litterfall, the value is 834 kg ha^{-1} (Table 3). This Si content could be considered a reasonable estimate for the above-ground parts of the forest.

This value is low compared with the Si stock in soil kaolinites, which is >3000 tons ha^{-1} for the top 3 m of soil in our study site. The absolute value of the forest Si stock tells us nothing about the Si turnover by root uptake and input from litterfall, stemflow, and throughfall. The Si turnover in the fine litterfall that we measured was 33 kg ha^{-1} $year^{-1}$. The turnover due to the coarse woody litterfall (trees and branches) is 8 kg ha^{-1} $year^{-1}$, if the annual renewal rate of the aerial parts is 1% (*27*). Negating the Si from stemflow and throughfall, which are important sources of topsoil input for nutrients (*28*), we obtain 41 kg ha^{-1} $year^{-1}$ as the minimum total Si turnover by the rain forest.

This value has to be compared to the amount of Si that is annually leached out of the soils. This content can be calculated from the mean Si concentration in stream waters that drain the studied area, 2.1 mg $liter^{-1}$ (29), and from the amount of water that annually percolates through the soils, 500 mm. The latter value is equal to the annual rainfall minus the evapotranspiration. The surface runoff and the litter washed out of the system by the streams are negligible in plateau areas (*30*). From these data, the amount of Si leached out of the weathering zone is ~11 kg ha^{-1} $year^{-1}$.

Thus, the Si input (41 kg ha^{-1} $year^{-1}$) from the rain forest on top of the soil is about four times greater than the Si leached

Table 1. Composition of the average annual litterfall. Values in per mil for all elements, in kilograms per hectare for the dry weight. Composition of total fine litterfall was calculated from composition of each fraction related to its dry weight.

Source	Component										
	Si	Al	Fe	Mn	Mg	Ca	Na	K	Ti	P	Dry weight
Leaves	5.5	0.35	0.03	0.10	1.6	3.9	0.73	1.6	0.01	0.11	5.64
Reproductive parts	0.40	0.10	0.21	0.05	1.3	2.5	0.20	5.3	0.01	0.34	0.40
Wood	0.98	0.37	0.06	0.09	1.1	6.0	0.26	1.4	0.05	0.08	1.55
Residue	1.0	1.6	1.0	0.10	1.5	5.5	0.23	2.2	0.13	0.36	0.81
Total fine litterfall	4.0	0.46	0.14	0.09	1.5	4.4	0.57	1.8	0.03	0.14	8.40

Table 2. Annual turnover due to the litterfall. Values in kilograms per hectare per year.

Source	Component									
	Si	Al	Fe	Mn	Mg	Ca	Na	K	Ti	P
Leaves	30.8	2.0	0.19	0.55	9.2	22.0	4.1	8.9	0.04	0.61
Reproductive parts	0.16	0.04	0.08	0.02	0.52	0.99	0.08	2.1	0.00	0.14
Wood	1.5	0.57	0.10	0.14	1.8	9.3	0.40	2.2	0.07	0.13
Residue	0.81	1.3	0.83	0.08	1.2	4.4	0.19	1.8	0.11	0.29
Total fine litterfall	33.3	3.9	1.2	0.79	12.7	36.7	4.8	15.0	0.22	1.2

Table 3. Silicon content of the Amazonian forest. Total Si content was 834 kg ha^{-1}.

	Weight of fraction (ton ha^{-1})	Si content (per mil)	Si content (kg ha^{-1})
Trunks	214	3.3	715
Branches	95	1.0	93
Leaves	4.8	5.5	26

out of the system (11 kg ha^{-1} $year^{-1}$). If we neglect input from forest renewal, stemflow, throughfall, and aerial dust, the annual average concentration of Si and Al in the solution that leaches the litterfall is 5.65 and 0.65 μmol $liter^{-1}$, respectively. In consideration of solubility diagrams (*31*), we find that such a water is supersaturated with Si with respect to kaolinite for a pH of 5.1 or greater.

Thus, geochemical modeling of soil formation and weathering in equatorial areas must be considered (Fig. 2). Topsoil inputs of elements, especially Si and Al, are significant. They are added mainly in fine

rortox (*Soil Taxonomy*, Agricultural Handbook 436 (U.S. Department of Agriculture, Washington, DC, 1975)], or Yellow latossols [(*Sistema de Classifiçao dos Solos*, (Empresa Brasileira de Pesquisa Agropecuária, Rio de Janeiro, 1979)].

21. G. Irion, *Monogr. Biol.* 56, 537 (1984).
22. Y. Lucas, B. Kobilsek, A. Chauvel, *Trav. Com. Int. Etude Bauxites Alum. Alum.* 19, 81 (1989).
23. Fifteen 80-cm conical litter traps were placed at random on the 140-m diagonal of a 1-ha plot. Samples were taken from August 1980 to September 1982.
24. Analyses were obtained at the Centre de Pédologie Biologique, Nancy, France. Samples were calcinated at 500°C and dissolved by strontium metaborate melting. They were then analyzed by plasma emission spectrometry for Si, Al, Fe, Mn, Mg, Ca, Ti, and P and by atomic absorption spectrometry for K and Na. Results were corrected from the loss of weight at 1000°C.

Licaria aurea,* *Nectandra rubra*,* *Eschweilera odora*,† *Eschweilera* sp.,* *Mouriria* sp.,* *Guarea* sp.,* *Inga* sp.,* *Brosimum* sp.,* *Ficus* sp.,* *Helicostylis* sp.,* *Virola calophylla*,† *Minquartia guianensis*,* *Ecclinusa bacuri*,* *Pouteria* sp.,* *Prieurella* sp.,* *Erisma* sp.,* *Qualea paraensis*,† and *Qualea* sp.* Data from species marked with an asterisk are from *Taux de Silice dans Différents Bois Amazoniens* (Laboratoire de Chime du Bois du Centre Technique Forestier Tropical, Nogent-sur-Marne, France, 1990), and those marked by a dagger are from *Estudo de 55 Espécies Lenhosas para Geração de Energia em Caldeiras* (Lab. Quimica da Madeira, Instituto Nacional de Pesquisa da Amazônia, Manaus, Brazil, 1986).

27. F. Hallé, R. A. A. Oldeman, P. B. Tomlison, *Tropical Trees and Forests: An Architectural Analysis* (Springer-Verlag, New York, 1978).
28. M. C. Forti and L. M. Moreira-Nordemann, *J. Geophys. Res.* 96, 7415 (1991).