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RAINFALL CHEMISTRY AND NUTRIENT LOADING IN A PENINSULAR MALAYSIA FOREST SITE

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ZULKIFLI YUSOP, ABDUL RAHIM NIK, ANHAR SUKI & MOHD. FAUZI ZAKARIA. 1989. Rainfall chemistry and nutrient loading in a Peninsular Malaysia forest site. Rainwater collected at the Berembun Experimental Basin, Peninsular Malaysia, was analysed for its chemistry and nutrient loading. The annual weighted mean concentrations of the constituents were as follows ($mg\ l^{-1}$): K^+ - 0.34, Ca^{2+} - 2.64, Na^+ - 0.20, Mg^{2+} - 0.94, Cl^- - 1.64, SO_4^{2-} - 0.31, PO_4^{3-} - 0.02, NO_3-N - 0.08, NH_4-N - 0.07, total-N - 0.54 and alkalinity - 9.11. The pH was 5.98. Solutes in the rainfall were mostly supplied by terrestrial sources on the basis that the ratios of SO_4^{2-}/Na^+, Cl^-/Na^+ and Mg^{2+}/Na^+ were 1.52, 8.06, and 4.62, respectively and generally much higher than the corresponding ratios in seaspray. Concentrations of Ca^{2+} and Mg^{2+} were very high and could be related to sample contamination by local dust. Similarly levels of Cl^- were far in excess to that of Na^+ concentrations. Storm basis as well as monthly solute loads were significantly correlated with rainfall depth for Ca^{2+}, Mg^{2+}, Cl^-, PO_4^{3-}, NO_3-N, NH_4-N and total-N. Annual solute loads were comparable to those obtained from other tropical areas except for Ca^{2+} and Mg^{2+} which were extremely high.

Key words: Rain forest - rainfall chemistry - atmospheric nutrient loading - storm sampling.

Introduction

Various aspects of rainfall chemistry have been widely studied particularly in view of the occurrence of acid rain (McNaughton 1981, Galloway & Likens 1981) and its impact on forest vegetation (Lesinki 1983, Lizon 1986). Rainfall is also a major source of nutrients, which partly substitutes the losses through surface flow. This has been a subject of interest, both in the temperate countries (*e.g.* Likens *et al.* 1970, Feller & Kimmins 1984) and in the tropics (*e.g.* Johnson *et al.* 1975, Dalal 1979, Lewis *et al.* 1981, Kellman & Carty 1986). However, studies in the tropics are often limited in their coverage of chemical constituents and time span. Ma-

nokaran (1980) published the only work in a Malaysian forest environment. Nevertheless, he did not verify the probable sources of the chemical components.

Rainfall chemistry varies in space, time and event, and principally depends on the availability of aerosols or particles in the atmosphere for rain-out and wash-out processes. Naturally, the main sources of atmospheric particles are sea-spray and terrestrial dust. Anthropogenic sources especially from industries and land-use activities also contribute a significant amount of atmospheric solutes.

Considering the high variability of both rainfall chemistry and nutrient loading (Lewis 1981), the present state of knowledge on this matter is still very much lacking, therefore, it will be useful to replicate such work at various sites with different geophysical characteristics. The present study highlights the variation of rainfall solutes concentration and loading in a hill dipterocarp forest at Berembun Experimental Basin, Peninsular Malaysia. The probable sources of the solutes are also alluded.

Site description

Precipitation samples were collected on a storm basis from September 1986 to August 1987 at the Berembun Experimental Basin (BEB), Negeri Sembilan (Figure 1). The site (2°46'N latitude and 102°06' E longitude; altitude of 160 *m*.a.s.l.) is located about 40 *km* east of the Straits of Malacca and 160 *km* west of the South China Sea. Kuala Pilah is the nearest town (population 20,000) at about 20 *km* to the east, whilst Seremban (population 150,000) is about 30 *km* to the west. The two towns are linked by a heavily used highway. The boundary of the forest area comprises mainly rubber and oil palm plantations as well as rice fields. Quarrying and mining activities are also present approximately at 12 *km* to the southwest. A logging road adjacent to the sampling site is being used by local residents.

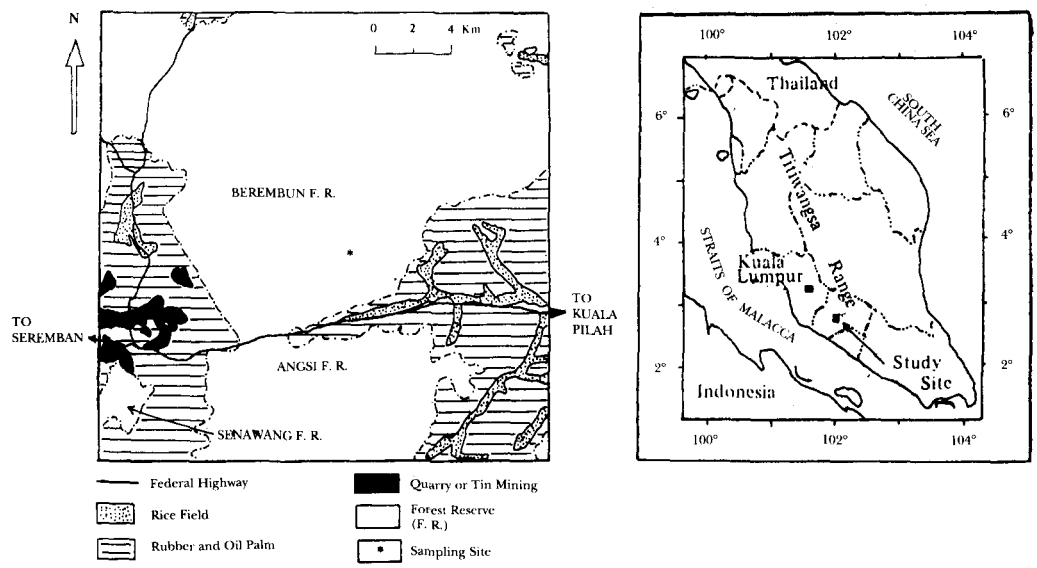

Figure 1. Location of study site

The mean monthly rainfall pattern of seven consecutive years (1981-1987; x = 1979 *mm*) and that observed during the study period (1 year; x = 1967 *mm*) are depicted in Figure 2. As in other parts of Peninsular Malaysia, the area receives two main air streams, namely the southwest monsoon and northeast monsoon from May to September/October and from November/December to March respectively. The transitional periods usually occur in April and also October/early November, often coinciding with the peak in monthly rainfall pattern (Abdul Rahim 1983). The average wind run measured at 2 *m* height was 0.2 ms^{-1}. The value at the canopy height of 50 *m* was 1.13 ms^{-1} (estimated using the Chow's formula, 1964).

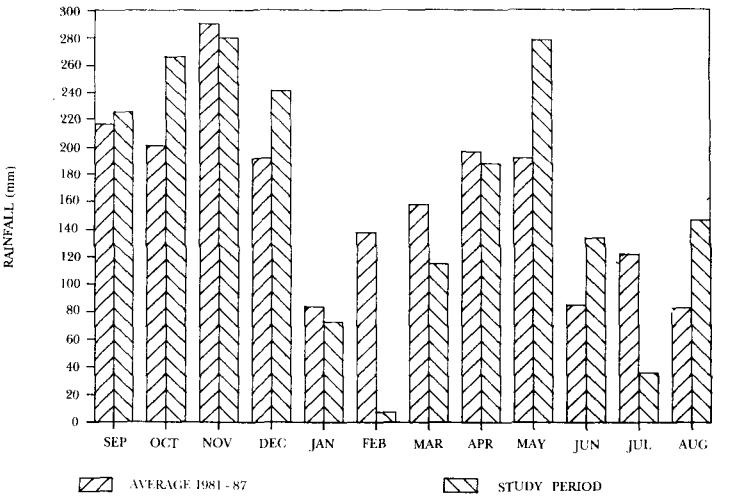

Figure 2. Monthly rainfall pattern at the Berembun Experimental Basin

The area is underlain by undifferentiated granitic rock of upper Triassic age, in which *Typic paleudult* have developed (Adzmi Yaacob, personal communication). The vegetation was originally classified as Red Meranti-Keruing Forest by (Wyatt-Smith 1963), and subsequently as Red Meranti-Balau Forest, due to the abundance of *Shorea laevis* (see Abdul Rahim *et al.* 1985).

Field methods

Rainfall samples were collected using four PVC funnels (20 *cm* diameter) located about five metres from each other at an open area, free from big canopy within a 50 *m* radius. The four funnels ensured adequate sample volumes during light rain, and allowed for discarding of contaminated samples. The funnels were fastened to an iron strap at a height of about 3 *m* and were surrounded by a "bird-off" ring to reduce the possibility of contamination by bird-droppings. A plastic mesh was placed in each funnel to protect the sample from coarse debris. The rainwater from the funnel was conveyed to a polyethylene bottle located about 0.5 *m* above the ground using PVC hoses. All materials were cleaned weekly with distilled water and changed every six months. Only 50 samples out of 133 storms

were collected. The rest were discarded either for being polluted or mixed-up with the subsequent storm. In February the rainfall was low (7.5 *mm*) and the small samples were inadequate for analysis except for pH. Rainfall samples were kept in a container, and cooled with ice before being sent to the Chemistry Department for analysis, usually within 48 *h* following collection. The low temperature (about 4°*C*) stabilizes the concentration of the rainfall constituents (Paden & Skowron 1978, Ridder *et al.* 1985). Analyses for pH and nitrogen constituents were not conducted for samples kept longer than two days because of variation due to microbial activities (Golterman & Clymo 1969).

Laboratory analysis

Prior to analysis the rainwater was filtered using GF/C (1.2 *um*) filter paper. All analyses followed the standard method (APHA 1976). Measurements were done as follows: pH - EDT pH meter (model ECM 200); K^+ and Na^+ - flame photometer (EEL A); Mg^{2+} and Ca^{2+} - atomic absorption spectrophotometer (PYE UNICAM SP191); SO_4^{2-} - the turbidimetric method (HACH 2100 A turbidimeter); PO_4^{3-} - the ascorbic acid reduction method; NH_4-N the distillation and nesslerization method; NO_3-N - the Devarda's alloy reduction method; total-N - the digestion, nesslerization and distillation method; alkalinity - titrimetric (methyl orange) method; and Cl^- - argentometric method.

Results and discussion

Volume-weighted mean concentrations were computed to normalize the averages between light rains (usually having relatively high concentrations) and heavy rains (usually more dilute) (Hendry *et al.* 1984). Table 1 shows the arithmetic mean and volume-weighted mean as well as the observed range in concentrations for the solutes in rainwater at BEB, while Figures 3 to 7 show the variations in monthly weighted mean concentrations. All values were derived from a storm basis except for pH which was measured in weekly bulk rainfall.

Table 1. Weighted and arithmetic mean concentration of major rainfall constituents ($mg\ l^{-1}$) at Berembun Experimental Basin

	pH	K^+	Ca^{2+}	Na^+	Mg^{2+}	Cl^-	SO_4^{2-}	PO_4^{3-}	NO_3-N	NH_4-N	total-N	Alkalinity*
Weighted mean	5.98	0.34	2.64	0.20	0.94	1.64	0.31	0.02	0.08	0.07	0.54	9.11
Arith. Mean	5.90	0.41	2.45	0.28	0.92	1.81	0.41	0.02	0.08	0.08	0.68	9.17
Maximum	6.95	2.00	4.80	1.50	1.90	6.00	3.70	0.19	0.28	0.35	1.80	11.00
Minimum	4.84	0.00	0.60	0.00	0.20	1.00	0.00	0.10	0.02	0.02	0.15	7.00
Std. Error	0.09	0.06	0.14	0.05	0.06	0.15	0.13	0.01	0.01	0.01	0.06	0.65
Sample size	(37)	(50)	(48)	(50)	(50)	(48)	(33)	(48)	(49)	(49)	(48)	(6)

* Expressed in $mg\ l^{-1}$ as $CaCO_3$

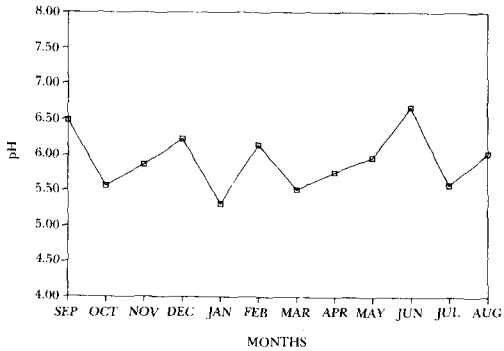

Figure 3. Monthly volume-weighted mean of rainfall pH at the Berembun Experimental Basin

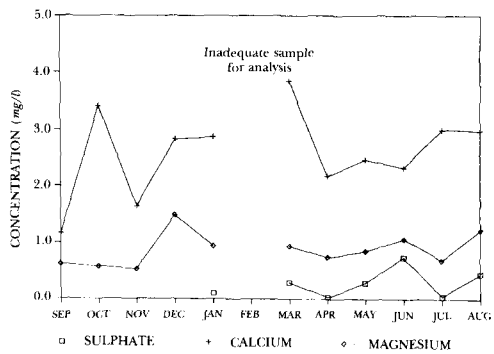

Figure 4. Monthly volume-weighted mean concentrations of SO_4^{2-}, Ca^{2+} and Mg^{2+} in rainfall at the Berembun Experimental Basin

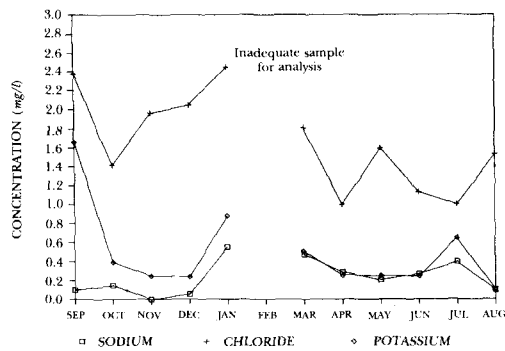

Figure 5. Monthly volume-weighted mean concentrations of Na^+, Cl^- and K^+ in rainfall at the Berembun Experimental Basin

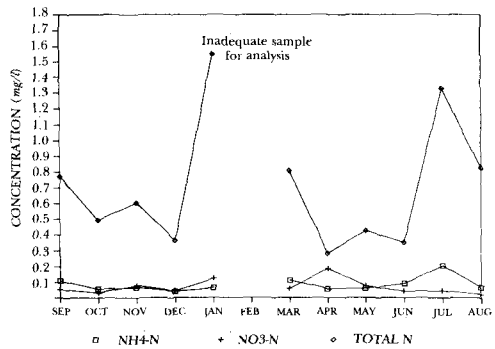

Figure 6. Monthly weighted mean concentrations of NH_4-N, NO_3-N and total-N in rainfall at the Berembun Experimental Basin

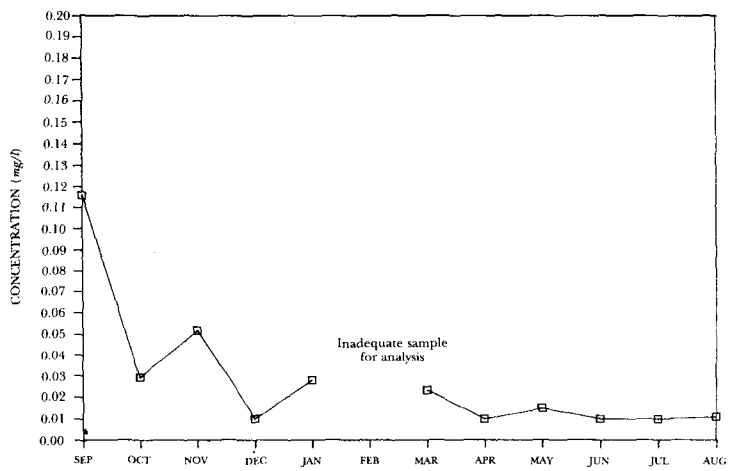

Figure 7. Monthly volume-weighted mean concentrations of PO_4^{3-} in rainfall at the Berembun Experimental Basin

pH

The pH of the rainwater samples ranged between 4.84 and 6.95 (x = 5.98). Less than 10% of the samples recorded pH below 5 while most of the values (60%) were between 5.5 and 6.5. The monthly means of pH varied from 5.13 in the month of January to a maximum of 6.66 in the month of June (Figure 3). Generally, the observed pattern of variations did not consistently follow the rainfall distribution, indicating that variations in H^+ concentrations were not solely dependent on the effect of dilution, but also on other ions present in the rain. Samples might be contaminated by dust, insects, bird-droppings or organic debris, all of which could increase the pH and NH_4-N concentration (Lewin & Torp 1982). In the present case the average pH values were quite close to the equilibrium with atmospheric carbon dioxide (5.6) (Granat 1972). This suggests that such contamination were not major. In addition, concentrations of such acidity related ions as NO_3^- and SO_4^{2-} were quite low, whilst any acidification by these ions will to some extent have been buffered by such ions as Mg^{2+} and Ca^{2+}. This is partly supported with the significant correlation between Mg^{2+} and SO_4^{2-} (Table 2, see also Figure 4). The contribution of the HCO_3^- ion (calculated from alkalinity) on pH could not be ascertained with sufficient accuracy due to limited data (Table 1).

Table 2. Correlation analysis of rainfall components at the Berembun Experimental Basin

	PO_4^{3-}	K^+	Na^+	Ca^{2+}	Mg^{2+}	Cl^-	NH_4-N	NO_3-N	Total-N	SO_4^{2-}
Rainfall	-0.12	-0.17	-0.24	0.02	-0.14	-0.15	-0.22	-0.01	-0.32*	-0.21
PO_4^{3-}		0.47**	0.17	-0.20	-0.07	0.13	0.00	-0.12	-0.02	-0.13
K^+			0.26	-0.01	-0.29*	0.27*	0.14	-0.10	0.34*	-0.23
Na^+				0.20*	0.11	0.07	0.23	-0.08	0.33*	0.09
Ca^{2+}					0.28	0.11	0.05	0.11	0.11	-0.05
Mg^{2+}						-0.01	-0.06	0.08	0.15	0.37*
Cl^-							-0.03	-0.14	-0.01	-0.17
NH_4-N								0.10	0.42**	0.11
NO_3-N									0.02	-0.07
Total-N										0.02

The values shown are correlation coefficients
* Significant at (P<0.05)
** Significant at (P<0.01)

Major ions

Table 3 summarizes the chemical compositions of the rainfall on an equivalent basis. The cationic ranks were dominated by Ca^{2+} (56%) and Mg^{2+} (33%), followed by Na^+ (3.8%), K^+ (3.7%), NH_4^+ (2%) and H^+ (0.5%). The anionic sequence of abundance was HCO_3^- (76%), Cl^- (20%), SO_4^{2-} (2.5%), NO_3^- (2%) and PO_4^{3-}

(0.4%). The same sequence for the anions in the tropical forests have been reported for northern Venezuela (Lewis 1981) and south-central Java (wet season) (Bruijnzeel 1988). The sums of cations (51%) and anions (49%) were about the same, confirming the electroneutrality principle (Hem 1970), and indicating the completeness of the chemical analyses of major ions.

Table 3. Mean ionic composition (*meq* l^{-1}) of rainfall at Berembun Experimental Basin

Cations	*meq* l^{-1}	Anions	*meq* l^{-1}
H^+	0.0011	HCO_3^-	0.1821
NH_4^+	0.0048	Cl^-	0.0464
Ca^{2+}	0.1316	NO_3^-	0.0054
Mg^{2+}	0.0776	PO_4^{3-}	0.0007
K^+	0.0086	SO_4^{2-}	0.0065
Na^+	0.0089		
Total	0.2326	Total	0.2411

Note: H^+ was calculated from the reciprocal of the antilog pH value and the HCO_3^- from alkalinity

Rainfall constituents in the study area were mostly contributed by terrestrial sources as the ratios on molar basis for SO_4^{2-}/Na^+, Cl^-/Na^+, Mg^{2+}/Na^+ and Mg^{2+}/Ca^{2+} were 1.52, 8.06, 4.62, and 0.36, respectively in comparison with the corresponding ratios in sea-spray, which were 0.25, 1.8, 0.12 and 3.16, respectively (Sverdrup *et al.* 1949, Eriksson 1952, Gorham 1976). Chloride concentration in equilibrium unit was five times higher than that of Na^+, indicating that Cl^- was balanced not only by Na^+ but also by other cations.

Monthly mean variations of concentrations of Na^+ and Cl^- did not show meaningful trends to suggest a dominant marine origin, nor were the two elements correlated (Table 2). The Cl^- concentrations seem quite high for an inland area, possibly from nonmarine source. However, it is difficult to think what the Cl^- sources might be since it is not an important constituent of rocks in the region nor are there any major industrial activities or volcanoes in the area. The overestimate of Cl^- could, therefore, be due to i) leachate of Cl^- from the PVC materials of the sampling devices, and/or ii) the failure of the argentometric method in detecting low concentration of Cl^-. On the other hand, the low concentrations of Na^+ could be the result of rain-out, which usually causes decrease in concentrations with distance from sea (Martin & Barber 1975). Because the study site is located at the western side of the Titiwangsa Range, the marine aerosols brought by the northeast monsoon might be depleted at the eastern part of Peninsular Malaysia. Similarly, the southwest monsoon has to pass the Sumatra Island, in the process, depositing some of the element loads as the wind velocity reduces. Consequently, the wind does not have enough strength to

entrain marine aerosols during its transit across the Straits of Malacca.

Sulphate concentrations were also low, ranging from undetectable values to 3.7 $mg\ l^{-1}$ (x = 0.31 $mg\ l^{-1}$), similar to those found for other humid tropical locations (Bruijnzeel 1988). Thermal power stations and industries have been mentioned as the major sources of SO_2 in Peninsular Malaysia especially in Penang and southern part of Johore. Low concentrations of SO_4^{2-} in rainfall can be directly related to the low concentration of SO_2 in the atmosphere, which is below 0.01 (2.6 $ug\ m^{-3}$) for urban and residential areas, except for Johor Bahru and Prai (DOE 1984). The mean concentrations of SO_4^{2-} in rainwater at urbanized areas of Kuala Lumpur and Petaling Jaya (10 *km* north of Kuala Lumpur) and residential areas of Serdang (30 *km* southwest of Kuala Lumpur) were 3.95, 2.87 and 3.10 $mg\ l^{-1}$, respectively (Lee & Low 1984); this is about ten times higher than the values presently observed in the forest area. It is likely that anthropogenic SO_4^{2-} is subjected to wash-out by rain or diluted in atmosphere before reaching remote areas.

Nitrogen and phosphorus

Generally, the levels of these nutrients were quite low: the volume-weighted means for total-N, NH_4-N and NO_3-N were 0.541 $mg\ l^{-1}$, 0.076 $mg\ l^{-1}$ and 0.068 $mg\ l^{-1}$, respectively. As shown by Bruijnzeel (1988), all are within the lower part of the range for tropical regions; 0.22 - 3.60 $mg\ l^{-1}$ for total-N, 0.05 - 0.67 $mg\ l^{-1}$ for NH_4-N and 0.01 - 0.46 $mg\ l^{-1}$ for NO_3-N. High lightning activity has been accepted as an important means for nitrogen fixation in the tropics producing NO_3^- in rainwater (Visser 1964). Monthly mean variation of total-N concentrations generally followed the pattern for NH_4-N (Figure 6), whereas NO_3-N showed an inverse pattern compared to both the other nitrogen constituents especially between the months of March and August. This suggests nitrification of ammonia might be important in producing NO_3^- in the present case.

Phosphate concentrations ranged between 0.01 to 0.19 $mg\ l^{-1}$ (x = 0.021 $mg\ l^{-1}$). In contrast to nitrogen, phosphorus is generally a non-volatile element, and therefore, its cycle is limited to the rock-soil-water phase. Hendry *et al.* (1984) suggested that the atmospheric deposition of phosphorus represented a recycling of local input rather than an external source and is injected into the atmosphere by such activities as agriculture, mining and burning. The uniform monthly mean concentrations especially between March and August (Figure 7), seem to support the hypothesis that outside contributions by anthropogenic sources are not so important. Furthermore, almost all (75%) of the individual samples were within a very narrow range of concentrations (0.00 - 0.01 $mg\ l^{-1}$).

Variation of solutes concentrations with rainfall

Although correlation analysis showed no statistically significant relationships, the trends indicated that concentrations of solutes decreased with increasing

rainfall amount due to dilution except for Ca^{2+} (Table 2). The weak correlation might be due to inadequate number of samples taken during heavy rain. Nevertheless, the increasing trend of Ca^{2+} concentration could be due to contribution of dustfall, which bears little relationship with rainfall amounts. Total-N was the only constituent that showed a significant correlation ($p < 0.05$) (Table 2), probably because nitrogen in the atmosphere is often associated with organic particulates. Lewis (1981) suggested that due to their lower specific gravity, organic components would exhibit lower settling rates than mineral particles and thus organic particles could stay in suspension for a longer time until they are washed-out by precipitation. In contrast the settling of nonorganic mineral particles may be governed by gravity as well.

Variation of solute load value with rainfall

The solute load of each storm was obtained by multiplying the concentration of solute with rainfall volume over a 1 m^2 area and expressed in $mg\ m^{-2}$. The H^+ concentrations were calculated from the reciprocal of the antilog pH values and computed for load on a weekly basis. These load values were then regressed against rainfall depth and the results are presented in Table 4. With the exception of Na^+ and SO_4^{2-}, the loads of all parameters were significantly correlated with rainfall depth (per storm).

Table 4. Regression analysis between evently nutrient load ($mg\ m^{-2}$) and rainfall depth (mm)

	Equation	No. of Samples	r^2
H^+	$Y=3.933x10^{-9}X^{0.915}$	37	0.45**
K^+	$Y=0.211X+2.963$	48	0.40**
Ca^{2+}	$Y=1.645X^{1.118}$	48	0.87**
Na^+	$Y=0.036X+4.404$	48	0.03ns
Mg^{2+}	$Y=0.664X^{1.076}$	49	0.84**
Cl^-	$Y=1.711X-1.633$	47	0.81**
SO_4^{2-}	$Y=0.009X+7.869$	32	0.00ns
PO_4^{3-}	$Y=0.019X^{0.926}$	48	0.60**
NO_3-N	$Y=0.048X^{1.056}$	48	0.66**
NH_4-N	$Y=0.092X^{0.876}$	48	0.64**
Total-N	$Y=1.055X^{0.776}$	47	0.68**

Notes:
Four types of simple regression were tested; linear (Y=bX+a), power ($Y=aX^b$), exponential (Y=Exp (bX+a)) and reciprocal (1/Y=bX+a). Y represents evently nutrient load and X is rainfall depth. The best correlation is presented here.

** Significant at ($p<0.01$)
ns Not significant

Monthly nutrient inputs were computed by multiplying the various monthly weighted mean concentrations by rainfall volume of each particular month (during the study period) over an area of one *ha*, whereas the annual load was the product of annual weighted mean and the average rainfall volume of seven years

(1981-1987). Correlation between monthly nutrient loading and monthly rainfall depth is also significant with the exception of K^+, Na^+ and SO_4^{2-} (Table 5). A comparison of the annual loads with other studies are also presented in Table 6. Generally, the nutrient inputs were within the published range except for Ca^{2+} and Mg^{2+} which were very high, especially so when the relatively low rainfall total at BEB is taken into account. Annual accession rate of K^+ and N-constituents at the BEB were similar to those of nearby Pasoh (Manokaran 1980) but those for Ca^{2+} and Mg^{2+} were much lower at Pasoh, which again suggest more or less serious pollution of the sample at BEB.

Table 5. Regression analysis between monthly nutrient load (*kg ha* $^{-1}$) and monthly rainfall depth (*mm*) at Berembun Experimental Basin

	equations	No. of Samples	r^2
PO_4^{3-}	$Y=Exp(1.047x10^{-2}X-5.359)$	11	0.58**
K^+	—NS—		
Na^+	—NS—		
Ca^{2+}	$Y=0.148X^{0.619}$	11	0.52*
Mg^{2+}	$Y=0.012X^{0.934}$	11	0.78**
Cl^-	$Y=7.309x10^{-3}X^{1.155}$	11	0.86**
NH_4-N	$Y=Exp(4.034x10^{-3}X-2.867)$	11	0.57**
NO_3-N	$Y=2.350x10^{-4}X^{1.223}$	11	0.49**
Total-N	$Y=0.477+3.181x10^{-3}X$	11	0.36*
SO_4^{2-}	—NS—		

Notes:
Four types of simple regression were tested; linear (Y=bX + a), power (Y=aXb), exponential (Y=Exp(bX+a)) and reciprocal (1/Y=bX+a). Y represents the monthly nutrient load and x is rainfall depth. The best correlation is presented here.
NS Not significant; * Significant at ($p<0.05$); ** Significant at ($p<0.01$)

Monthly nutrient loading for major elements; Ca^{2+}, Cl^-, Mg^{2+}, K^+, Na^+ and total-N are shown in Figure 8. Calcium was abundant during most of the months except in September, October and November in which Cl^- exceeded it. Higher Cl^- loading during the three months coincided with high monthly rainfall during the northeast monsoon.

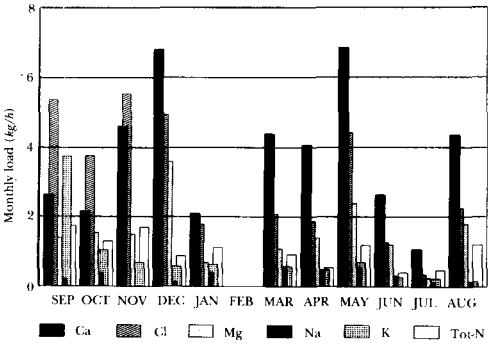

Figure 8. Monthly loads of major solutes via rainfall at the Berembun Experimental Basin

Table 6. Annual atmospheric nutrient loading of some tropical areas (*kg ha*$^{-1}$)

Location	Annual rainfall (*mm*)	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	NH_4-N	NO_3-N	Total-N	PO_4^{3-}	Cl^{-}	SO_4^{2-}
Queensland[a][1]	8631	17.1	19.4	158.0	8.1	-	-	-	-	-	-
Java[2]	4670	9.8	4.0	13.3	9.6	6.5	2.8	15.4	1.2	41.4	14.5
Papua N. Guinea[3]	3800	3.6	1.3	-	7.3	-	-	6.5	0.5	14.3	3.3
Puerto Rico[4]	3750	21.8	4.9	57.2	18.2	-	-	-	-	-	-
Costa Rica[5]	2820	1.4	1.0	5.8	2.5	1.15	0.5	5.0	0.1	11.8	9.2
Amazonas[b][6]	2545	3.8	3.2	-	-	4.3	2.7	10.3	0.1	<0.1	-
Queensland[c][1]	2520	2.3	2.9	20.8	4.5	-	-	-	-	-	-
Taiwan[7]	2420	17.7	3.0	8.8	7.3	3.5	6.1	-	-	2.6	6.8
Malaysia[8] (Pasoh)	2380	4.2	0.7	22.9	6.4	2.3	3.9	13.5	-	-	-
Amazonas[d][9]	2050	-	-	9.3	3.4	4.7	-	-	0.1	17.6	20.5
Ghana[10]	1850	12.7	11.3	-	17.5	11.5	2.5	14.0	0.4	65.0	6.0
Queensland[e][11]	1650	3.2	5.9	50.0	3.4	-	<0.1	60.0	<0.2	85.0	3.2
Venezuela[12]	1575	5.6	5.2	3.3	2.6	-	-	9.9	1.1	-	-
Present Study	1979	52.2	18.6	4.0	6.7	1.4	1.6	10.7	0.4	62.4	6.1#

1) Brasell & Gilmour 1980
2) Bruijnzeel 1988
3) Edward 1982
4) Jordan *et al.* 1972
5) Hendry *et al.* 1984
6) Anonymous 1972
7) King & Yang 1984
8) Manokaran 1980
9) Franken & Leopoldo 1984
10) Nye 1961
11) Westman 1978
12) Steinhardt 1979

#: Limited data
a: Bellenden Kerr site
b: Manaus
c: Gadgarra site
d: Ducke Reserve and Bacia Modelo site
e: Coastal site

Summary

(1) The rainfall in a forested area of Peninsular Malaysia generally contained low levels of anthropogenic pollutants, with SO_4^{2-} and NO_3^{-} concentrations being 0.30 and 0.08 *mg l*$^{-1}$, respectively.

(2) The pH values were generally greater than 5.6, which indicate the absence of major acidifying constituents and the presence of metal ions (especially Ca^{2+} and Mg^{2+}) as neutralizing agents.

(3) Rainfall chemistry at the BEB was dominated by terrestrial rather than maritime sources, with cationic contents following the order: $Ca^{2+} > Mg^{2+} > Na^{+} > K^{+} > NH_4^{+} > H^{+}$; and anions : $HCO_3^{-} > Cl^{-} > SO_4^{2-} > NO_3^{-} > PO_4^{3-}$.

(4) Storm basis as well as monthly atmospheric nutrient loads were significantly correlated with rainfall depth, except for Na^{+}, K^{+} and SO_4^{2-}.

(5) Both annual mean concentrations and annual nutrient accession rates were comparable to those obtained in other tropical areas, except for Ca^{2+} and Mg^{2+} which were extremely high and suggestive of an external source providing particulate matter rich in Ca^{2+} and Mg^{2+}. Similarly Cl^{-} levels were far in excess of Na^{+} levels, a feature which is difficult to explain.

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