Concentrations of Chemical Elements in Different Tree Compartments Grown in a Mixed Dipterocarp Forest in Sarawak, Malaysia

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ABSTRACT The distribution of mineral elements in different compartments of trees grown in a mixed dipterocarp forest in the Lambir Hills National Park, Miri, Sarawak was studied. 514 samples mainly of leaves, twigs and trunks, partly of roots, barks and litter were collected from 101 different trees of 62 species of 25 families. The samples were analyzed for 28 chemical elements, i.e. N, K, Ca, Mg, Mn, Na, Al, Br, Fe, B, Sr, Ba, Zn, Rb, Cu, Ni, Co, Ti, Sc, Cr, Pb, Ce, Li, As, Cs, V, Mo and Th. Essential elements as N, K, Mg, Mn, Fe, B and Ni showed higher concentrations in the leaves. Ca, Zn and Cu were found significantly higher in the twigs. These elements are known to be related to the auxin metabolism effective to the induction of the cell lignification. The elements with no characteristic concern to any physiological processes behaved as if they underwent passive uptake. The uptake of elements with toxic or negative effects to plants, e.g., Al, Pb or As seemed to be either blocked by the roots or they were safely stored in those organs as trunks and barks. Taken the fact into account that those elements actively associated with plant physiological processes are accumulated in the living plant organs, due attention should be paid to the high concentrations of Ba (*Gluta oba*), Co (*Koilodepas laevigatum*, *Trigonostemon capillipes*, *Allantosperrum borneense*) or Sr (*Koilodepas laevigatum*).

Key Words: mineral elements / different compartments / accumulation / dipterocarp forest / Sarawak

The distribution of mineral elements in trees of tropical rain forests was reported by several authors (Ashton, 1982; Golley *et al.*, 1975). In view of plant physiological studies leaves are the active and important part of a plant (Vitousek & Sanford, 1986). They work as matter producing factory. But for studies of quantitative accumulations of chemical elements, due attention to the balance between the leaves and stems should be paid, as they represent short- and long-nutrient cycling, respectively (Jayasekera, 1994). Studies of chemical elements in tropical trees were so far mainly restricted to the essential elements, the macro- and micro-nutrients. Some authors (Horovitz, 1988; Markert, 1991) suggested that the metabolic role of several elements has not yet been well recognized and the classification into essential and nonessential elements requires continuous revision. The list of essential micronutrients has expanded as we have become more aware of the biochemistry of physiological processes. Given that only 300 species of the 500,000 or more plant species have been studied on their nutrient requirements, the present list of plant micronutrients is expanding and may well continue to expand in the future. Ni, for example, was added to the list of micronutrients as late as 1992 (Perry, 1994).

The canopies of tropical rain forests are too tall to reach for direct observations or sampling of leaves. In the Lambir Hills National Park, Sarawak, a walkway system was constructed through forest

Fig. 1. Location of the Lambir Hills National Park in the north east of Sarawak, Malaysia.

canopy in 1992 to provide an easy access to the leaves and twigs of tropical rain forest.

In the present study 514 samples of different compartments, mainly of leaves, twigs and trunks, partly of barks, roots and litter, from 101 individual trees of 62 species of 25 families were collected. The identification is still tentative, plant names are subject to further examination. Analyzed were 28 chemical elements as given in Figure 2. The vascular plants develop a system of multiple functions of physiological processes. The root hairs absorb the mineral elements, the vascular system transports them and the living cells in the leaves utilize them. To clarify the distribution characteristics of various chemical elements over the compartments, due attention to the physiological function of each compartment should be paid.

MATERIALS AND METHODS

The Lambir Hills National Park ($4^{\circ} 2'N$, $113^{\circ} 50'E$) is located in the north east of Sarawak, about 30 km south of Miri (Figure 1) and covers an area of 6949 ha. All samples were collected in the central part of a research plot, specifically designed for canopy biology studies. A detailed description of location, sampling procedure and analyses was given in Breulmann *et al.*, (1996).

In total 514 samples were collected from canopy trees as well as from understory trees. The obtained concentrations of the samples from the same tree and compartment but different heights and sampling occasions were averaged. For several elements we performed two measurements for the same sample (Breulmann *et al.*, 1996). We averaged these values when the deviation between the two was less than 10 %. In case the deviation exceeded 10 %, one value was selected referring to the value of the Standard Reference Material. The statistical analyses were performed by SPSS. Because the number of collected samples of barks, roots and litter was small, only the means were calculated in order to show the general trend of the element distributions in these compartments.

Fig. 2. Mean values of the element concentrations of the leaves, twigs and trunks.

RESULTS

Concentrations of chemical elements in leaves, twigs and trunks

Figure 2 illustrates the element concentrations of the compartments leaves, twigs and trunks. The figures of the means are given in the Appendix. In each column, compartments sharing the same letter were not statistically significant different at the 1 % level. N and K showed significantly higher concentrations in the leaves. They have a primary function in living tissues. Ca was found significantly higher in the twigs. It is known as electrolytic element as well as a structural component of the middle lamella (Perry, 1994). Mg, Mn, Na, Al, Rb, Ti, Pb, Ce and Mo showed no significant differences between the leaves and twigs. Other elements, i.e., Br, Fe, B, Ni, Co, Sc, Cr, Li, As, V and Th showed significantly higher concentrations in the leaves, while Sr, Ba, Zn, Cu and Cs were higher in the twigs.

The concentrations in the trunks were determined in 51 trees. Cr showed a similar concentration in the trunks and the leaves. Pb showed the highest mean concentration in the trunks. It is not essential for plants and the translocation from the roots is reported as very slow (Streit & Stumm, 1993). All other elements showed significantly lower concentrations in the trunks, except Mo (Figure 2).

Several species showed accumulative tendencies for certain elements in the leaves (Breulmann *et al.*, 1996). Most species reflected such a tendency to the twigs but not always to the trunks (Table 1). The accumulations of K, Ni and Co of *Trigonostemon capillipes* (Euphorbiaceae) were reflected to the twigs but not to the trunks, however the twigs showed an accumulation of Zn (84.16 - 173.09 ppm) and the trunks of Na (265 - 645.6 ppm). Zn is essential as a coenzyme in different reactions, e.g., chlorophyll synthesis (Markert, 1993) and auxin metabolism (Berrie *et al.*, 1987). Na is regarded as essential only for C4 - plants (Borriss & Libbert, 1984). However, many tree species accumulate high levels of Na, although in most cases, Na has no clear physiological function (Perry, 1994). *Gluta oba* (Anacardiaceae) and *Mallotus* sp. (Euphorbiaceae) reflected the accumulations of Ba and Mn,

Table 1. List of tree species showing an accumulative characteristic. The letters indicate in which compartment the accumulations were reflected. l = leaves, t = twigs, tr = trunks.

Species	Family	K	Ca	Mn	Na	Ba	Zn	Sr	Ni	Co	Al
<i>Gluta oba</i> (n=2)	Anacardiaceae					l, t, **					
<i>Koilodepas laevigatum</i> (n=8)	Euphorbiaceae		l, t, tr					l, t, tr			
<i>Mallotus</i> sp. (n=2)	Euphorbiaceae			l, t, **							
<i>Trigonostemon capillipes</i> (n=7)	Euphorbiaceae	l, t			tr		t		l, t	l, t	
<i>Allantospermum borneense</i> (n=2)	Ixonanthaceae									l, t	
<i>Memecylon</i> sp. (n=1)	Melastomataceae										l, t, tr

* accumulation corresponds with findings of Masunaga *et al.*, (1995); Markert (1993)

** no trunk samples collected

respectively, in the twigs. Trunk samples were not collected. *Koilodepas laevigatum* (Euphorbiaceae) accumulated Ca and Sr in all compartments, while Co was accumulated only in the leaves. *Allantospermum borneense* (Ixonanthaceae) showed the accumulative tendency for Co in leaves and twigs. The accumulation of Al by *Memecylon* sp. corresponded with Masunaga *et al.*, (1995) and Markert (1993).

Concentrations of chemical elements in barks, roots and leaf-litter

From the compartments barks, roots, and leaf-litter the number of samples collected was small. The means of the concentrations are given in the Appendix. Figure 3 shows the comparison of the means of the barks, roots and litter to the means of all 514 samples, taken as the base-line. The relative deviation was given in percentage.

The barks showed negative deviations for all essential elements but Fe. This suggested that the bark function is less remarkable in plant physiology. High positive deviations were found only for V and Th.

The roots showed high positive deviations of Al, Fe, Pb, As, V and Th. Al and Fe are reported to show higher concentrations in the roots (Hoffmann, 1982), as they occur in relatively higher concentrations in the soil solution under acidic conditions.

The leaf-litter samples showed high positive deviations for Br and As. Essential elements in the leaf-litter samples were found more or less within the range of the overall means, except K, which showed a negative deviation.

DISCUSSION

Accumulations of chemical elements into different compartments

The process of assimilation occurring in a plant undergoes complex biochemical reactions. The mineral nutrients are translocated to the various parts of a plant for utilization in various biological functions. For example, nitrate (NO_3^-) is reduced to ammonia (NH_3), then introduced into the intermediary metabolism through a series of enzyme-mediated steps (Taiz & Zeiger, 1991). Other elements, especially those rated as macro- and micro-nutrient cations, are taken up by plants forming complexes with organic compounds, e.g., Ca^{2+} -pectate associated with the cell wall. It is widely accepted that chemical elements occur in the greatest concentrations in the living tissues, e.g., foliage, cambial layers, growing root tips, etc., and in the lowest concentrations in the woody stem. Perry (1994) gave base-line data for element concentrations in small branches and small roots to be 50 - 70 % of those accumulated in the foliage, large branches and roots to be 20 - 30 % and stems to be 10 - 20 %. Our data of mineral concentrations in the leaves, twigs and trunks, as given in the Appendix follow this trend in general.

Fig. 3. Mean values of the element concentrations of the barks, roots and litter in comparison with the means of all 514 samples taken as the base-line.

Functions of chemical elements in plants

N is known as a very important element in the physiologically active compounds present in plant cells (Taiz & Zeiger, 1991). It is an element compulsory in forming proteins, nucleic acids and other nitrogen-containing components of the cell (Berrie *et al.*, 1987). N normally does not occur in the structural components of plants, it is readily remobilized from aging organs. K also is involved in numerous physiological functions, e.g., osmotic regulation, stomatal movement or photosynthate

transportation.

Ca is required as an electrolytic and as a structural element. It acts as a coenzyme and is a constituent of the middle lamella (Berrie *et al.*, 1987). It is also required for the cell elongation and is possibly related to the auxin action (Taiz & Zeiger, 1991). Among the micronutrients, Zn is involved in the chlorophyll synthesis and the auxin metabolism (Berrie *et al.*, 1987). Cu containing enzymes hold key positions in lignification, protein synthesis and auxin regulation (DKI, 1988). The biological effect of auxin is said to promote or inhibit cell elongation (Berrie *et al.*, 1987), but it also induces the lignification of cells (Borriss & Libbert, 1984). The higher concentrations of Ca, Zn and Cu in the twigs might be related to the auxin production and lignification.

Fe, Mn, Mo and Ni are essential for certain enzyme activities (Perry, 1994). Fe and Mn, which readily change their valence state, mediate electron transfer within cells. Fe is also an essential constituent of the cytochrome system. Mo is involved in the nitrogen metabolism. It can be toxic to grazing animals at a level not toxic for plants (Streit & Stumm, 1994). Ni is related to N-fixation and in some plants it is a constituent of Urease (Markert, 1993). The function of B is still unknown (Perry, 1994). The translocation rate of Fe, Mo, Ni and B is reported as low to moderate. Mn is translocated easily (Borriss & Libbert, 1984; Streit & Stumm, 1993). The uptake rate of all these elements is promoted by low pH values.

The status of Co as a micro-nutrient is not yet certain, however, it has been shown, that deficiency of Co can lead to chlorosis and leaf-drop (Berrie *et al.*, 1987). It is also counted as a necessary element in the N-fixation of symbiotic *Rhizobium* bacteria. Na is not regarded as essential or necessary, however, it is accumulated at high levels by many tree species (Perry, 1994). Sr can be used as a substitute for K and Ca when these elements are short (Kimmins, 1987). Al is regarded as toxic in high concentrations, especially in the rhizosphere (Ulrich, 1981).

Compartments as a reflection of element functions

As the mineral concentrations in the different compartments of the rain forest trees of the Lambir Hills National Park followed the trend discussed by Perry (1994), the concentrations of N, K, Mg, Mn, Fe, B and Ni in the leaves were higher and became lower to the twigs and trunks. Ca, Zn and Cu showed significantly higher concentrations in the twigs.

The concentrations of physiologically active elements were comparatively low in the trunks. This may reflect the trunks main function as a storage organ, composed largely of dead cells. They showed remarkably higher concentrations of Pb whose translocation rate from the roots is said very slow (Streit & Stumm, 1993). Co is accumulated in the vegetative parts and less in the storage organs (Streit & Stumm, 1993), which corresponded well to our results (Appendix). This can be regarded as element specific characteristic.

The barks showed negative deviations for all essential elements but Fe (Figure 3). The barks seemed less physiologically active than any other parts of a plant. High positive deviations were recorded for V and Th. But not much is known of these elements' uptake and distribution.

The roots showed positive deviations for Al, Fe, Pb, As, V and Th (Figure 3). Al and Fe occur relatively high in the soil under acidic conditions (Scheffer & Schachtschabel, 1989). The soil pH in the Lambir Hills National Park was reported as ranging between 4.2 and 5.2 (Hirai *et al.*, 1995). Nultsch (1982) reported that in front of the endodermis congestions of Al were observed frequently. It probably is because the Casparian bands build a barrier to Al-inflow. The uptake of Pb and As seems to be passive (Streit & Stumm, 1993). The Pb translocation rate from the roots to other plant parts is low. Arsenic is translocated to many other plant parts, however, high concentrations are normally

found in the roots (Streit & Stumm, 1993).

In the leaf-litter Br and As showed positive deviations (Figure 3). The reason for this positive deviations was not clarified yet. K showed a negative deviation. Leaching might be a cause.

From what was found from the element concentrations in the different compartments, it was verified that those elements associated with physiological processes were positively taken up and accumulated in the living organs of a plant. The elements with no characteristic concern to any physiological process behaved as if they underwent passive uptake. While the elements toxic or with negative effect to a plant may be absorbed, but their invasion into the plant body was inhibited or they were transported to those organs as trunks and barks for safe storage.

Specific characteristics of element accumulations

Out of 62 species, several species showed specific characteristics of accumulations to certain elements as shown in Table 1. In case of Co three species, e.g., *Koilodepas laevigatum*, *Trigonostemon capillipes* and *Allantospermum borneense* were determined as accumulators. But the three species did not accumulate into the trunks. Ca and Sr were accumulated by *Koilodepas laevigatum* in all three compartments. *Gluta oba* and *Mallotus* sp. accumulated Ba and Mn, respectively. These accumulations took place in the leaves and twigs. Trunk samples were not collected from those species. *Trigonostemon capillipes* accumulated K, Na, Zn, Ni and Co. K, Ni and Co were accumulated in the leaves and twigs. The accumulation of Na and Zn took place only in the trunks and twigs, respectively. In case of *Memecylon* sp. the accumulation of Al in all compartments corresponded with Masunaga *et al.*, (1995) and Markert (1993).

Generally speaking an accumulation can not be equated with a physiological benefit for the organism (Markert, 1992). Some of the trees of the Lambir Hills National Park showed such an anomaly or specific characteristic of element accumulation to certain compartments. Little is known yet on such specific anomaly, its causes, its functions or its results. However, it is important to remember that organisms are quite diverse and highly adaptive in their nutrient requirements and particularly in their tolerances (Perry, 1994). We do not know again the richness of biodiversity of component tree species of tropical rain forests. But the results of our study of element accumulations by various tree species to different compartments gave a suggestion to clarify the functions and results of biodiversity. Due attention should be paid to the genetic variation of the inter- and intra-population in relation to plant function, requirements for nutrients and uptake. It may give us an important key of niche and specific differentiation as discussed by Ernst (1990).

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G. BREULMANN, 二宮生夫, 荻野和彦 サラワク混交フタバガキ林に生育する樹木の各部位における化学元素濃度の分布

マレーシア連邦サラワク州にあるランビル国立公園の、混交フタバガキ林に生育する樹木の異なった部位における無機元素濃度分布を調べた。25 科 62 種 101 個体の葉、梢端付近の小枝、幹、根から 514 個のサンプルを採集した。構成元素の分析は N, K, Ca, Mg, Mn, Na, Al, Br, Fe, B, Sr, Ba, Zn, Rb, Cu, Ni, Co, Ti, Sc, Cr, Pb, Ce, Li, As, Cs, V, Mo および Th の 28 種についておこなった。このうち必須元素である N, K, Mg, Mn, Fe, B および Ni はとくに葉に高濃度の蓄積がみとめられた。Ca, Zn および Cu については梢端付近の小枝で有意に高い濃度を示した。これらの元素は、細胞の木化の誘導に影響を及ぼす植物ホルモンであるオーキシンの代謝に関係していることが知られている。これに対して、いずれの生理過程にも特徴的な影響をもたないような元素は受動的な取り込みというべき濃度分布を示した。植物にとって有毒もしくは生育に負の影響をもつ元素、例えば Al, Pb, As などは根の部分で吸収を遮断されたり、幹や樹皮などの組織に安全な形で貯蔵されるようにみえた。植物の生理過程に積極的に影響を及ぼす元素が植物の生きた組織に蓄積されているという事実から、*Gluta oba* に Ba が、*Koilodepas laevigatum*, *Trigonostemon capillipes*, *Allantospermum borneense* に Co が、*Koilodepas laevigatum* に Sr が高濃度に集積されるという事実はこれらの元素の植物体内での生理的活性の有無という点で注意すべきと考えられる。

Appendix Mean concentrations of the different compartments. In each column, compartments sharing the same letter were not statistically significant different at the 1 % level. The barks, roots and litter were not tested because of the low number of samples.

	%				ppm										
	N	K	Ca	Mg	Mn	Na	Al	Br	Fe	B	Sr	Ba	Zn	Rb	
leaves ¹	1.47 ^a	1.42 ^a	0.38 ^a	0.22 ^a	340.76 ^a	117.71 ^a	62.39 ^a	45.12 ^a	38.93 ^a	25.16 ^a	19.56 ^a	18.10 ^a	13.83 ^a	13.48 ^a	
twigs ²	0.78 ^b	1.14 ^b	0.61 ^b	0.20 ^a	305.62 ^a	118.03 ^a	50.75 ^a	14.93 ^b	17.67 ^b	11.03 ^b	33.06 ^b	32.44 ^b	33.02 ^b	12.97 ^a	
trunks ³	0.25 ^c	0.29 ^c	0.18 ^c	0.04 ^b	49.38 ^b	98.98 ^a	15.35 ^a	9.22 ^{ab}	11.23 ^c	2.42 ^c	9.07 ^c	13.12 ^c	8.53 ^c	3.64 ^b	
	ppm														
	Cu	Ni	Co	Ti	Sc	Cr	Pb	Ce	Li	As	Cs	V	Mo	Th	
leaves ¹	5.96 ^a	4.99 ^a	3.73 ^a	2.46 ^a	0.61 ^a	0.54 ^a	0.38 ^a	0.287 ^a	0.19 ^a	0.15 ^a	0.07 ^a	0.03 ^a	0.02 ^a	0.004 ^a	
twigs ²	9.37 ^b	3.09 ^b	0.82 ^b	2.27 ^a	0.17 ^b	0.27 ^b	0.34 ^a	0.015 ^{ab}	0.07 ^b	0.05 ^b	0.09 ^b	0.02 ^b	0.03 ^a	0.002 ^b	
trunks ³	1.56 ^c	0.55 ^c	0.26 ^c	0.34 ^b	0.03 ^c	0.53 ^a	0.68 ^b	0.004 ^a	0.02 ^b	0.03 ^{ab}	0.03 ^c	0.01 ^c	0.03 ^a	0.001 ^c	

¹n=237 ²n=158 ³n=55

	%				ppm									
	N	K	Ca	Mg	Mn	Na	Al	Br	Fe	B	Sr	Ba	Zn	Rb
barks ⁴	0.58	0.77	0.30	0.16	34.46	62.28	233.50	18.40	122.00	6.56	21.94	42.49	9.06	9.96
roots ⁵	0.68	0.60	0.24	0.17	89.91	58.64	685.44	95.74	482.80	6.59	17.96	20.13	12.03	13.70
litter ⁶	1.00	0.39	0.49	0.34	414.73	133.09	150.39	189.07	167.40	25.41	27.87	23.59	19.65	3.15
	ppm													
	Cu	Ni	Co	Ti	Sc	Cr	Pb	Ce	Li	As	G	V	Mo	Th
barks ⁴	6.29	0.38	0.18	4.40	0.25	0.66	0.69	0.03	0.12	0.25	0.11	0.26	0.01	0.06
roots ⁵	5.48	2.78	1.42	6.43	0.46	1.20	3.81	0.12	0.28	0.77	0.15	0.72	0.04	0.19
litter ⁶	10.55	3.74	0.45	3.48	1.17	1.82	1.11	0.03	0.06	1.11	0.05	0.22	0.05	0.02

⁴n=24 ⁵n=26 ⁶n=14