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IMPACT OF FOREST HARVESTING AND REPLANTING

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SIM, B. L. & NYKVIST, N. 1991. Impact of forest harvesting and replanting. The study monitored the change in biomass and shift of nutrient status before and after harvesting the natural forest, followed by burning and replanting. It concluded that burning should be avoided to reduce nutrient loss and ensure better plantation growth. The loss of inorganic nutrients by harvesting different fractions of the tree biomass is discussed in relation to the losses from burning and leaching.

Key words: Harvesting - burning - leaching - replanting - biomass - nutrients - status - loss

Introduction

The conventional logging operation in Malaysia has been selective cutting where only the larger trees (≥ 50 *cm*) of certain marketable species are felled. With the start of the first pulp and paper mill in Sipitang, Sabah, there is a need for a more intensive use of the forest biomass. The basic forest operation concept of Sabah Forest Industries Sdn. Bhd. would be to clear fell areas under 25° slope to supply pulpwood for the mill, then subsequently replant with fast growing tree species as a renewable source of pulpwood. This intensive log extraction, followed by burning and replanting, will constitute a major change in the biomass and nutrient status, affecting the productivity of the forest site.

This study monitored the change in biomass and shift of nutrient status before and after harvesting logs, burning and replanting with *Acacia mangium.*

The findings from this study, together with the data base generated from complementary studies of stream water chemistry, erosion output, leaching and rain chemistry that are carried out on the same watershed, will be used to construct a complete nutrient budget for the watersheds. The overall cost effectiveness of various forest operations may then be evaluated to provide guidelines for future operational control.

Materials and methods

Trial site

The experimental area is located at 650 to 750 *m* above sea level on the foothill of Gunung Lumaku, 35 *km* southeast of the coast of Sipitang (115 E, 5.0 N) in Sabah, Malaysia. The relief of the terrain is gentle to moderate. The annual precipitation is 4000 *mm* in the experimental area. Six watersheds were set up for the study and treated in different ways (Table 1).

Table 1. The vegetative type and soil types of the watersheds

Catchment number	Area (*ha*)	Soil type	Vegetation before treatment	Treatment	Vegetation after treatment
W1 and W2	6.45	38% gleyic podsol, 62% orthic acrisol	Lowland dipterocarp burnt in 1983	Felled burnt, replanted	*A. mangium*
W3	18.7	Orthic acrisol	Same as W1	Control	Lowland dipterocarp forest
W4	3.4	34% gleyic podsol 66% orthic acrisol	Very lightly logged in 1984	Manual logged replanted not burnt	*A.mangium*
W5	9.67	62% gleyic podsol, 38% orthic acrisol	Same as W4	Tractor logged burnt and replanted,	*A. mangium*
W6	4.47	Gleyic podsol	Same as W4	Control	Lowland dipterocarp forest

Sample of biomass

The experimental area covers an evergreen rain forest which was selectively logged in 1978 and an area where the selectively logged forest was burnt in the "Borneo fire" of 1983.

Sampling of trees > 60 *cm* girth

In the unburnt area, consisting of watersheds number W4, W5 and W6, all trees with a girth of 60 *cm* (about 19 *cm* DBH) or larger were enumerated with respect to girth and tree species. The number of trees was about 145 ha^{-1} with the largest measured girth being 330 *cm* (Table 2). Large trees with buttresses were difficult to measure at breast height and were therefore registered as trees with girth larger than 330 *cm.* The different tree species harvested from W4 and W5 are shown in Table 3.

Table 2. Number of trees per *ha* within different girth classes

Girth classs (*cm*)	Diameter classes (DBH) (*cm*)	Number of trees per *ha*				Number of sample trees within different girth classes	
		W4		W5		W4	W5
60	19.1	0		1.1	14.3		
70	22.3	13.8		13.2		1	1
80	25.5	18.5		20.8		1	1
90	28.6	18.5		20.0		1	1
100	31.8	12.4		9.9	17.0		
110	35.0	7.9		7.1		1	1
120	38.2	18.8		18.0	29.5	1	1
130	41.4	6.8		11.5		1	1
140	44.6	7.1	23.3	3.7	19.9		
150	47.7	15.9		15.8		1	1
160	50.9	0.3		0.4			
170	54.1	1.2	13.6	1.5	14.8		
180	57.3	12.1		12.6		2	2
190	60.5	0.3		0.7			
200	63.7	0.3	7.7	0.6	5.3		
210	66.8	6.8		4.6		1	1
220	70.0	0.3		0.0			
230	73.2	0.3		0.1			
240	76.4	2.9	3.8	2.3	4.7		
250	79.6	0		0		1	
260	82.8	0		0.1			
270	85.9	0.6		1.1			
280	89.1	0		0.2			
290	92.3	0		0			
300	95.5	0.3		0.8			
310	98.7			0			
320	101.9			0			
> 330	105.0			0.2			1
		145.1		146.3			

The great number of different tree species made it unrealistic to investigate the most common species separately. When choosing the sample trees from the different girth classes, all tree species were therefore treated as one group but with preference given to the most common species.

For watershed which were to be clear felled (W4 & W5), ten girth classes were selected (from the 28 different girth classes) (Table 2). The selected girth classes were randomized based on numbered rentices and distances along the rentices. From this point, the nearest tree of the selected girth was chosen and marked.

After the surrounding trees had been felled, the sample tree was felled. The length of the tree was measured and the stem cut at the point where its diameter was 200 *mm* as this is the smallest diameter for the harvesting of wood from the area. The branches and the top of the sample tree were cut at diameters of 50, 20 and 5 *mm*. The biomass of the diffrent diameter classes and all the leaves, which were sampled by hand from the tree, were weighed routinely during the sampling. Small subsamples were taken immediately after weighing of the biomass and stored in plastic bags which were transported to the laboratory and the oven dry weight of the biomass per sample tree were determined. By measuring the area of some leaves from each samples tree and weighing them, the total area of the leaves could be calculated when the total weight of leaves per sample were known. Comparatively few epiphytes were included in the weight of the trees.

Table 3. Inventory of stem volume of different tree species (the inventory was made on tree logs > 60 *cm* girth transported to the landing place)

Tree species	Volume $m^3\ ha^{-1}$ W4	Volume $m^3\ ha^{-1}$ W5
Rubroshorea (Section of *Shorea*)	42.7	17.6
Lauraceae	19.5	13.4
Koompassia malaccensis	7.2	5.4
Richetia (Section of *Shorea*)	6.3	10.6
Parashorea spp.	6.3	9.2
Dryobalanops spp.	4.3	1.6
Shorea superba	4.2	-
Scaphium affine	4.3	1.3
Eugenia spp.	3.7	8.1
Sapotaceae	3.6	8.8
Dipterocarpus ochraceus	3.4	0.2
Cratoxylum spp.	3.2	1.8
Trigonobalanus verticillatus	2.3	7.3
Shorea pauciflora	2.2	0.8
Artocarpus elasticus	2.1	0.4
Annonaceae	1.9	0.5
Shorea spp.	1.6	8.3
Vatica spp.	1.3	1.6
Other identified species (more than 30 species)	17.5	27.3
Unidentified species	8.7	5.5
Total	146.0	129.7

The logs from the sample trees were transported to the pulpmill at Sipitang where the weight and volume were determined. The moisture contents of the logs were determined from drill shavings taken from logs. Thus, the oven dry weight of the logs from the sample trees could be calculated.

Most of the bark was scraped off the logs while they were being transported to the landing place. Bark samples (10 × 5 *cm*) were taken from the most common tree species. These bark samples were then dried and weighed. The areas of the logs from the samples tree were calculated from the lenghts and the diameters of the basal and upper ends of the logs. From these areas and the area of the bark samples, the dry weights of the bark could be calculated.

Sampling of the stumps and coarse roots was very time consuming and therefore such samples were only taken from one of the ten samples in W4 and five of the ten samples in W5. Due to the large trees and especially their large buttresses, the roots were cut 3 *m* from the central part of the stump.

From the dry weights of the different parts of the sample trees, representing different girth classes, and the number of trees per ha in the different girth classes, the dry weight of the total biomass per *ha* could be calculated (for calculation of the coarse roots see below).

Sampling of other vegetation, including trees < 200 *mm* DBH

The biomass from all other vegetation, including trees smaller than 200 *mm* DBH but excluding mosses and lichens which were not investigated, was determined from five samples plots 10 × 10 *m* in watersheds 1, 2, 4 and 5. The stems and branches of the trees and bushes were separated into the diameter classes 200 to 50, 20 to 5, and < 5 *mm* before weighing the samples in the field. Small representative subsamples were taken immediately after the weighing and treated in the same way as the subsamples from the large trees.

From these sample plots, a rough estimation of dead logs was also made by measuring the volume of the dead, more or less decomposed logs, lying on the soil surface. The moisture contents, which varied considerably, were determined for some of the logs. From the average value, the dry weights of the dead logs were calculated.

At 18 *mth* after planting, the *Acacia mangium* plants were sampled separately inspite of their considerably smaller DBH than 200 *mm.* Three trees were sampled representing the mean height, within each watershed. All other vegetation, except mosses and lichens, were sampled from ten sample plots 10 × 10 *m* in each watershed. The sampled vegetation does not represent the total biomass production of the ground vegetation because of the regular weeding (slashing) once every three months during the first year after the planting. However, the investigated ground vegetation gives a good indication of the growth potential of the different treated watersheds.

The roots were investigated in four sample plots of 0.5 × 0.5 *m* from watershed W3 and three sample plots from W6. These watersheds are not felled (controls), W3 corresponding to W1 and W2 and W6 corresponding to W4 and W5. All living roots were sampled from each 10 *cm* down to 50 *cm* below the soil surface. The roots were separated in different diameter classes before they were dried and weighed.

The sample plots 0.5 × 0.5 *m* were placed at least 3 *m* from the central part of the trees > 200 *mm* DBH. When calculating the biomass of coarse roots (> 20 *mm*) ha^{-1}, the average figures from the sample plots were therefore calculated on the hectare area minus the area which the trees occupied (number of trees times $3 \times 3 \times \pi$). The figures from the sample plots 0.5 × 0.5 *m* were then added to figures obtained from the sample trees to get the biomass of the course roots per *ha.*

The finer roots (< 20 *mm*) were not sampled from the sample trees and the hectare figures were therefore calculated over 10,000 m^2 with the assumption that the finer roots were evenly distributed even under larger trees.

Chemical analysis

Composite samples of the biomass were analysed for the following elements : N, P, K, Ca, Mg, S, Fe, Al, B, Ca, Na, Si, Zn and C. The concentrations of nitrogen and carbon were determined by elementary analysis (dry combustion). For all the other elements a wet combustion treatment of the dried and ground biomass samples was used before the analysis using ICP-emission technique (Emteryd 1989).

Biomass and inorganic nutrients in different parts of the vegetation

Results and discussion

The biomass of the evergreen rain forest

The total biomass obtained in this study falls within the lowest range of the values for tropical rain forest (Figure 1 & Table 4). The main reason is probably that the forest was selectively logged in 1978. The biomass of leaves and the leaf area index (LAI) are, however, in the same range as for other investigated tropical rain forests. The root biomass is high due to course superficial roots. The distribution of fine roots with depth is shown in Figure 2.

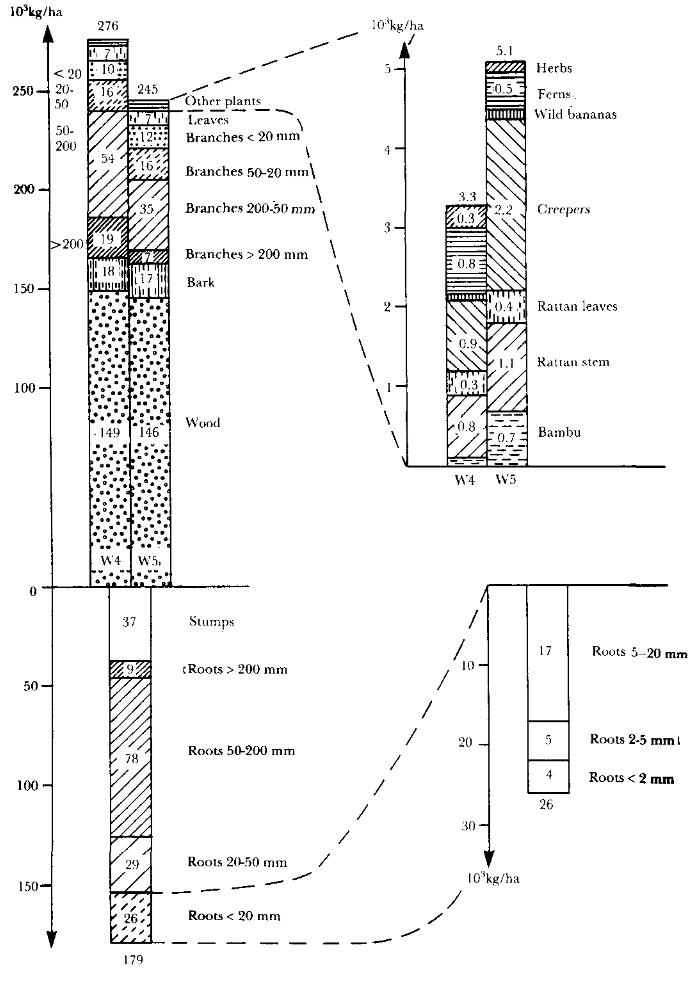


Figure 1. The dry weights of the biomass of trees and other plants (10^3 *kg ha*$^{-1}$)

Table 4. Biomass in some tropical rain forest of the world (in 10^3 *kg* dry weight ha^{-1})

Forest formation	Location	Above ground biomass						
		Boles	Branches	Leaves	Other plants	Total	LAI	Roots
Lowland ever green rain forest	Malaysia Sabah[1]	165	85	7	4	261	6.7	179
	Malaysia Pasoh[2]	346	78	8	0.5-8.8	431	6.9	20[3]
	Malaysia a					250		
	Sarawak[4] b					650		
	Malaysia Sarawak[4] c					470		
Heath forest	Sarawak and Brunei[5]					185		
						747		
						709		
						452		
						765		
						1,158		
						457		
						1,158		
Coastal hill dipterocarp forest	Malaysia Penang[6]					598		
						767		
						1,070		
Lower montane rain forest	New Guinea[7]	385	104	7	9	505		63
	Puerto Rico El verde[8]	153	37	8		198		65
Lowland evergreen rain forest	Venezuela[9]	316		8		324	5	56
Wet evergreen forest	Southern India Karnataka[10]				0.3	463		
Moist semi-deciduous forest	Ghana[11]	109		90	15	214		74

Notes: 1: Boles > 20 *cm* DBH, smaller stems included in branches, roots included stumps, This study;
2: From Kira (1978);
3: Only fine root biomass, from Yoda (1974);
4: a - alluvial forest, b - dipterocarp forest, c - heath forest, from Proctor *et al.* (1983);
5: Roots included, from Bruenig (1969);
6: From Khoon & Eong (1984);
7: Boles ≥ 30 *cm* DBH, alttitude 2400 - 2500 *m* a.s.l., from Edwards (1977);
8: Roots ≥ 5 *mm*, from Ovington & Olsson (1970);
9: From Jordon & Uhl (1978);
10: Boles ≥ 5 *cm*, from Rai (1984);
11: Boles ≥ 30 *cm*, roots included stumps, from Greenland & Kowal (1960).

In this study the biomass was investigated by harvesting trees of different girth classes at breast height from watersheds 4 and 5 (3.4 and 9.7 *ha*, respectively) and weighing the different part of the trees. From the number of trees in the different girth classes, the figures can be calculated for each hectare. Smaller trees (< 200 *mm* DBH), bushes and other vegetation have been investigated in 10 × 10 *m* samples plots. In the most other biomass investigations of tropical rain forest, small sample plots have been clear felled, all trees weighed and their DBH and height measured. From allometric regressions between the biomass of different parts of the tree and DBH and height, derived from the sample trees, the biomass per *ha* has been calculated from measurement of DBH and height of trees from larger areas (*e.g.* Edwards & Grubb 1977, Kira 1978, Proctor *et al.* 1983).

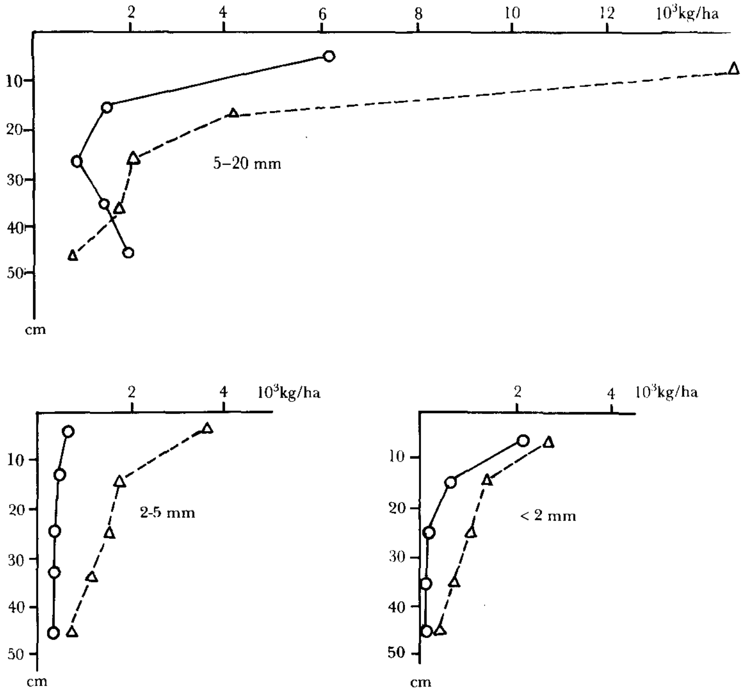
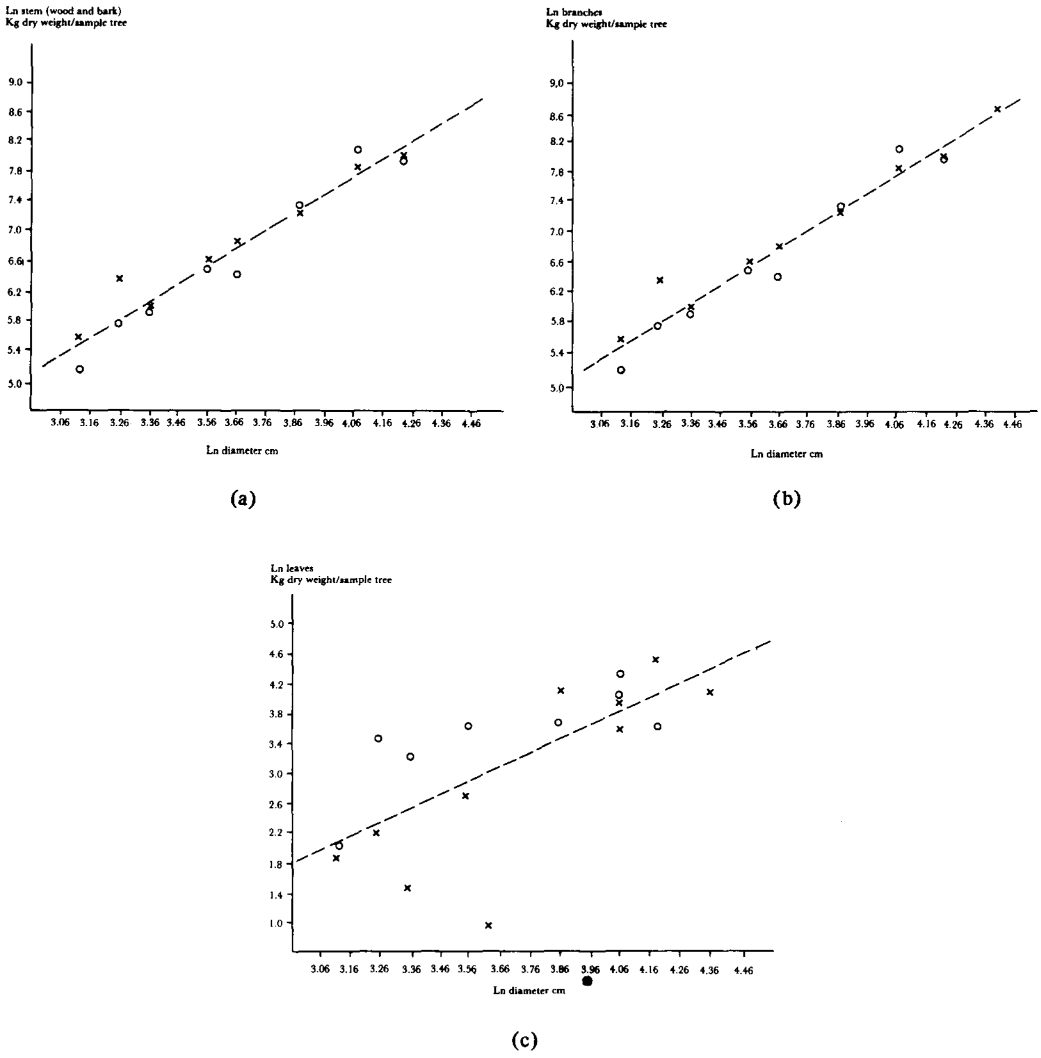


Figure 2. The distribution of small roots with soil depth (dry weights in 10^3 *kg ha*$^{-1}$; average of four sample plots 50 × 50 *cm* from W3 and three sample plots from W6)

Some allometric regressions, worked out for tropical rain forests, have been tested on our diameter measurements of samples trees and compared with the results of the biomass from the harvested trees (Table 5). However, the relative error was great. Therefore the relationships between DBH and dry weights of biomass of stems, branches and leaves of our samples trees were determined (Figure 3).

The allometric regressions between DBH (Ln d) and stems, branches and leaves respectively for the sample trees of this study are also given in the figures. The stem component had a high correlation coefficient ($r = 0.97$) The correlation coefficients were much lower for branches and leaves but surprisingly high considering that the sampled trees were different species except two species which were duplicated. For the equations based on d2, dry weight of branches = $0.7889 \times d2 - 257.70$ and dry weight of branches = $0.4076 \times d2 - 231.26$, the correlation coefficients were slightly lower, $r = 0.97$ and $r = 0.64$, respectively, but for the equation dry weight of leaves = $0.0124 \times d2 + 7{,}589$, the correlation coefficient was slightly higher ($r = 0.73$).



× sample trees from W4
o sample trees from W5

Figure 3. a. Relationship between biomass of stems (ln wood + bark in *kg* dry weight per sample tree) and diameter (ln DBH in *cm*), the equation of the line is: ln y = 2.4184 × ln d - 2.0947 (r = 0.9754). **b.** Relationship between biomass of branches (ln branches in *kg* dry weight per sample tree) and diameter (ln DBH in *cm*), the equation of the line is: ln y = 2.1022 × ln d - 2.2115 (r = 0.7927). **c.** Relationship between biomass of leaves (ln leaves in *kg* dry weight per sample tree) and diameter (ln DBH in *cm*), the equation of the line is: ln y = 1.8551 × ln d - 3.7189 (r = 0.7153)

Table 5. Dry weight and leaf area of actually harvested biomass of trees > 20 *cm* DBH and estimates based on DBH and height of our sample trees calculated from allometric relations from other investigations in tropical rain forest

		Stem (wood + bark) 10^3 *kg* ha^{-1}	Branch 10^3 *kg* ha^{-1}	Leaf 10^3 *kg* ha^{-1}	Total 10^3 *kg* ha^{-1}	Leaf area *ha* ha^{-1}
A	Harvested					
	average W4 and W5	165	57	5	227	6.7
B	Calculated according to:					
	Edwards & Grubb 1977	100[a]	24[b,c]	1[d]	125	-
	rel. error 100(B-A)/A	-39.4	-57.9	-80.0	-44.9	-
C	Kira 1978	228[e]	123f	4[g]	355	3.3[h]
	rel. error 100 (C-A)/A	38.2	115.8	-20.0	56.4	-50.7
D	Anonymous 1978 Tropical forest, ecosystem, pp. 233 - 260	181[i]	-	-	-	-
	rel. error 100 (D-A)/A	9.7	-	-	-	-
E	Proctor *et al.* 1983 pp. 248-250				(392)[j]	-
	rel.error 100(E-A)/A				(72.7)	-

Notes:
a: $\sqrt{Y} = 0.2076 \times \text{girth} - 1.10193$;
b: $\sqrt{Y} = 0.110 \times \text{girth} - 2.0494$;
c: $\sqrt{Y} = 0.0242 \times \text{girth} - 0.3099$ (leaf bearing twigs);
d: $\sqrt{Y} = 0.0228 \times \text{girth} - 0.3024$;
e: $W_5 = 0.313\ (D^2H)^{0.9783}$ (D^2H in dm^3);
f: $W_B = 0.316\ W_5^{1.070}$;
g: $\dfrac{1}{W_L} = \dfrac{1}{0.124W_5^{0.794}} + \dfrac{1}{125}$
h: U (total leaf area) $= 11.4\ W_L^{0.900}$;
i: $W_5 = 0.0396\ (D^2H)^{0.9326}$;
j: $W_{tot} \sim \text{height} \times \text{basal area} \times 0.5 \times 1.1$

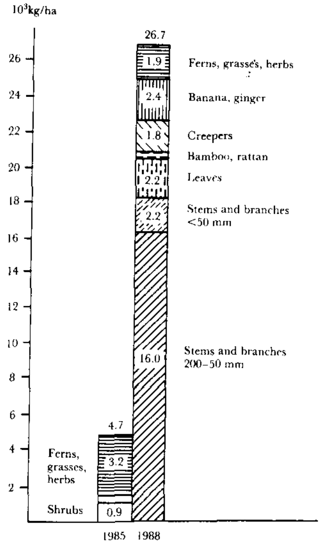


Figure 4. Dry weight of biomass for watershed W1/W2

The biomass of watersheds W1 and W2, which were completely burnt down in the "Borneo fire" of 1983, was investigated in 1985 and 1988. The total biomass was 5 *t* ha^{-1} in 1985 and 27 *t* ha^{-1} in 1988 (Figure 4). The total annual biomass production during the first two years was about 2 *t* ha^{-1} y^{1} and about 5 *t* ha^{-1} y^{1} during the first five years.

The biomass of the *A. mangium* plantations

The biomass of *A. mangium* in plantations W1/W2, W4 and W5 after 17 to 18 *mth* was 2.3, 10.5 and 5.4 *t* ha^{-1} (Figure 5), corresponding to a yearly biomass production of about 1.6, 7.4 and 3.8 *t* ha^{-1}. The biomass of the ground of the ground vegetation in W1/W2, W4 and W5, sampled at the same time as the *Acacia* trees, was 6.2, 1.8 and 3.3 *t* ha^{-1}. The greatest amounts of biomass of ground vegetation were found in the two burnt watersheds (W1/W2 and W5). In these experiments burning had obviously increased the ground vegetation rather than, as commonly believed, decreased it. The grasses seemed to be especially stimulated by burning, as shown in Table 6 where the biomasses of the ten most common species of the ground vegetation for each watershed are given.

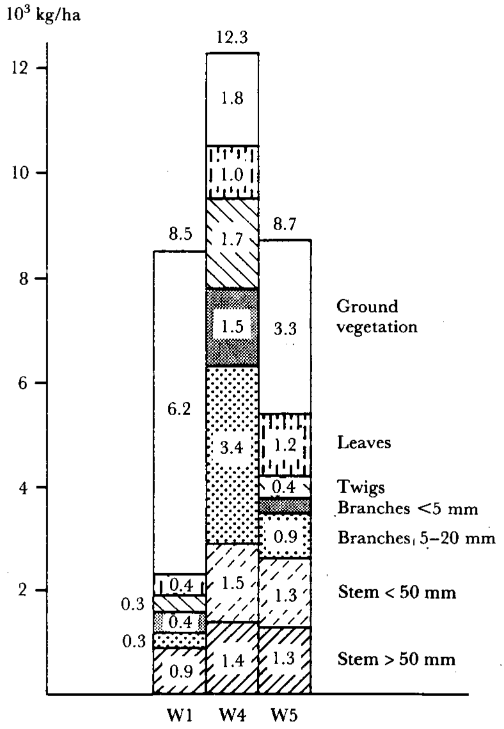


Figure 5. Dry weights of biomass of *Acacia mangium* and ground vegetation

The low productivity of W1/W2 and W5 compared with W4 shown in the biomass figures is also evident from the measurements of diameter and height of the *Acacia* plants (Tables 7 & 8). In Wl and W2 (where the site was burnt by the "Borneo fire" in 1983), there were no living trees to be logged. The land preparation for planting was just felling of dead tress and burning off the slash before planting. The growth of *A. mangium* here was not satisfactory. The accumulated volume of the 22-*mth*-old *A. mangium* on podzol site was 3.4 m^3 ha^{-1} which was about 50% worse than W5 that had been tractor logged and burnt. The volume for the treatments in the more clayey site (Tanjung Lipat), however, was comparable.

Table 6. The biomass of the most common ten species of the ground vegetation for each watershed and the biomass of other species

Species	W1/W2	W4	W5
Imperata cylindrica	636	15	92
Paspalum conjugatum	2546	241	571
Melastoma malabathricum	28	36	225
Erigeron sumathrensis	2	64	-
Ficus stolonifera	28	-	97
Eupatorium odoratum	904	19	-
Glochidion sp.	125	76	-
Hornstedtia scyphifera	39	-	60
Gomphia serratta	-	57	156
Euodia sp.	2	-	-
Nephrolipis bisenata	1155	-	-
Dinochloa sp.	-	90	-
Macaranga sp.	-	37	-
Uncaria	-	14	-
Lycopodium claratum	-	-	19
Smilix sp.	-	-	26
Brookea dasyantha	-	-	23
Blumea balsamifera	-	-	54
Other species	698	1129	1973
Total	6163	1778	3296

It is therefore clear that the fire in 1983 not only destroyed forest wood production, but also degraded the site productivity at least temporarily for subsequent reforestation work. The impact was particularly severe on sandy sites like the podzol which has a lower nutrient retention capacity than the clayey sites.

The conventional method of land clearing by tractor logging and burning was shown to be undesirable. The volune of 22 to 23-*mth*-old *A. mangium*, established in the usual way (W5) was only 11.5 m^3 ha^{-1} in contrast to 23.7 m^3 ha^{-1} for the plantation established without tractor compaction and burning. This represents an improvement of 44% in annual volume increment (MAIV) over the traditional land clearing method.

It is recommended that alternative land clearing method without tractor extraction and burning should be advocated and investigated further.

Table 7. *Acacia mangium* growth in Tanjung Lipat soil

Treatment		Age (*y*)	Stem *ha*^{1}	DG (*cm*)	DOMH (*m*)	BA *m*^{2}*ha*^{1}	MAIG V *m*^{3}*ha*^{1}	MAIH *my*^{1}	V MAIG *m*^{2}*ha*^{1}*y*^{1}	MAIV *m*^{3}*ha*^{1}*y*^{1}
W1& W2	Fell burnt & replant	22	1,010	6.3	8.4	3.2	12.9	4.6	1.7	7.1
W4	Manual log & replant without burning	23	1,090	8.0	8.9	5.5	23.7	4.7	2.9	12.4
W5	Tractor log, burnt & replant	21	1,360	5.3	7.4	3	11.5	4.3	1.8	6.9

Table 8. *Acacia mangium* growth on podzol soil

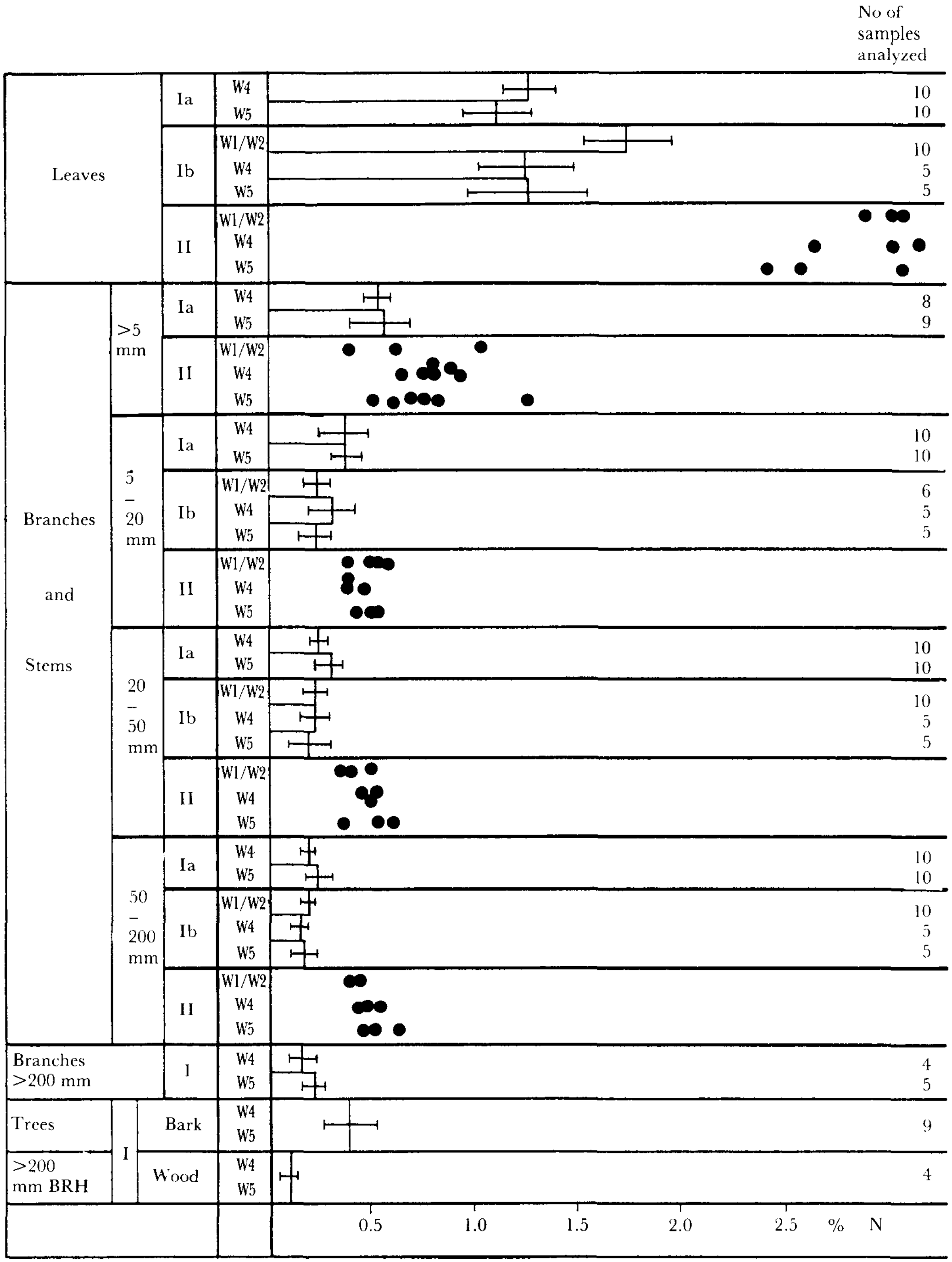
W1 & W2	Fell burnt & replant	22	1,080	3.5	6.3	1.0	3.4	3.4	0.6	1.9
W4	Manual log & replant without burning	23	950	7.3	8.3	4.0	16.9	4.4	2.1	8.8
W5	Tractor log, burnt & replant	21	1,110	5.1	7.3	2.2	7.9	4.1	1.3	4.5

The concentration of inorganic nutrients and some other elements in the biomass

The above ground biomass of trees and the mean concentrations of inorganic nutrients were greatest in the leaves, decreased with increasing diameter of the branches and were least in trunk wood (Figure 6). In the bark, the concentrations were comparatively great and for Ca almost as great as in the leaves. Grubb and Edwards (1982) found in a montane rain forest in New Guinea that the concentration of Ca was even higher in the bark than in the leaves. They also found an increase of N and a trend of increase for Ca and Mg but a decrease of P towards the centre of the trunk.

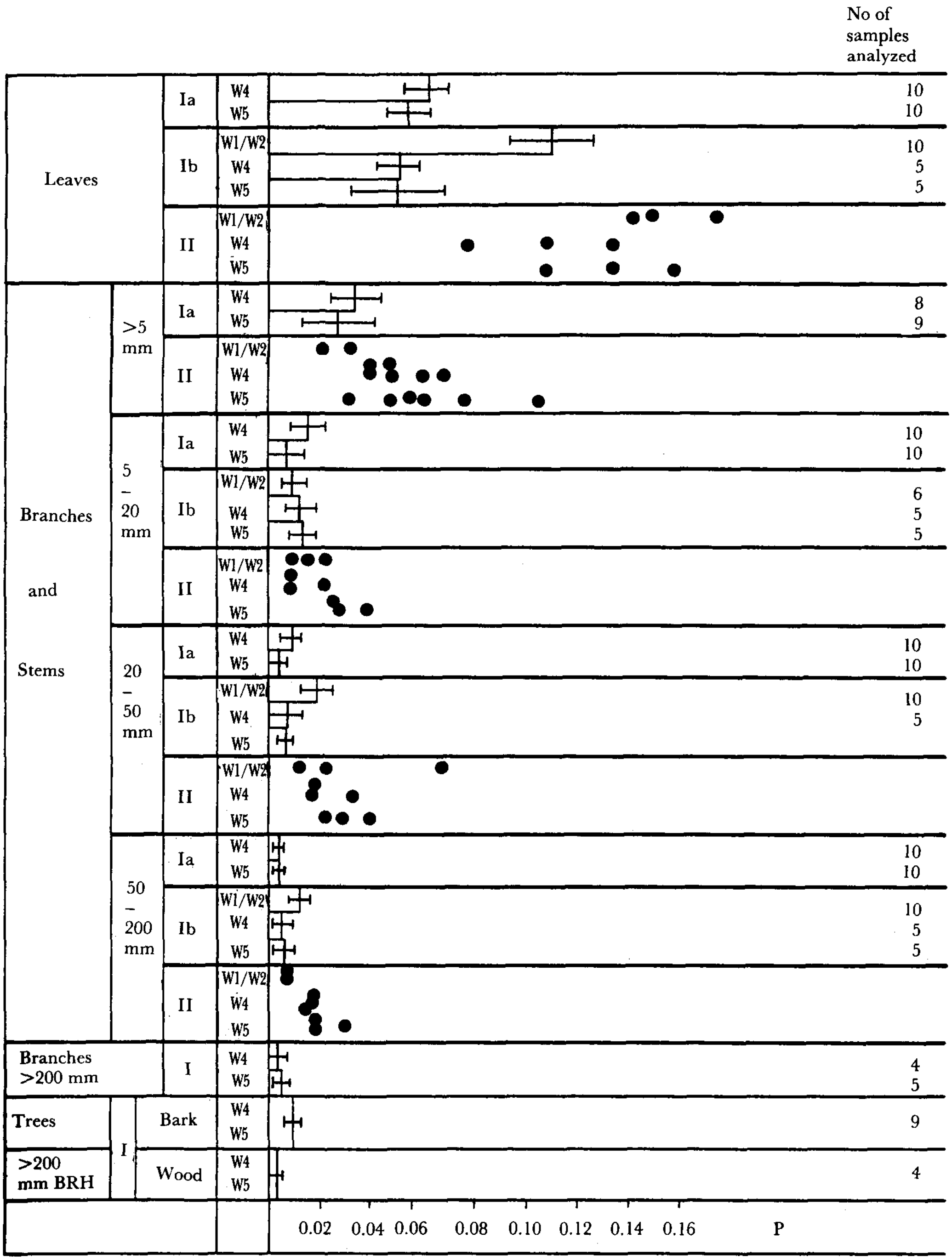
The differences in concentrations of macronutrients between the different parts of the trees are statistically significant in many cases (Figure 6). This is, however, not the case when the concentrations within the same component of the tree but from different trial plots or treatments are compared, except for a few cases. The concentration of N is greater and there is trend of higher concentrations of P and K, along with lower concentrations of Mg and Ca, in the leaves from *A. mangium* compared to the concentrations in the leaves from the tree species before clear felling. The higher concentration of N was expected as *A. mangium* is a nitrogen fixing species.

There was also a trend of increased concentrations of macronutrients in

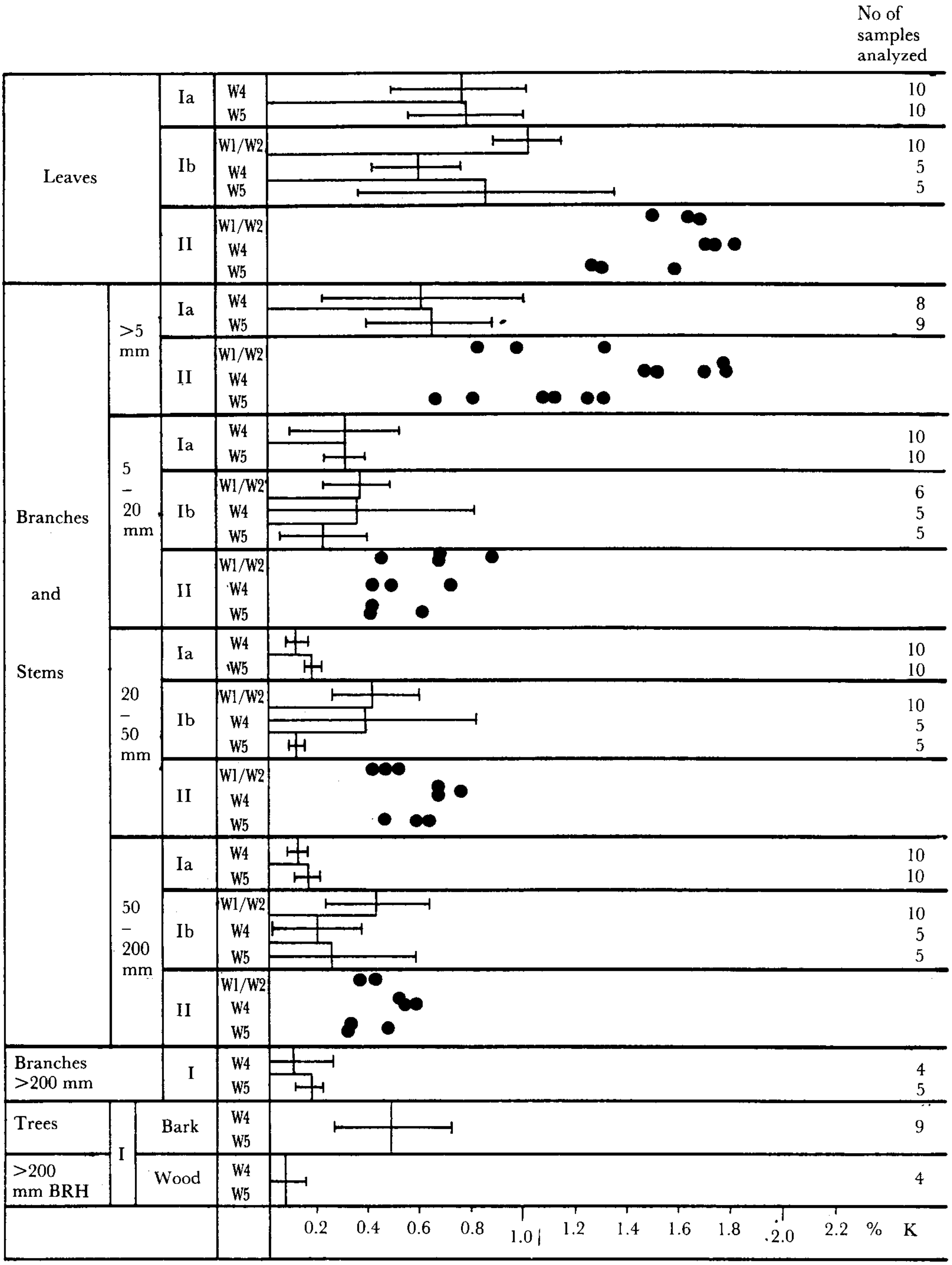


(a)

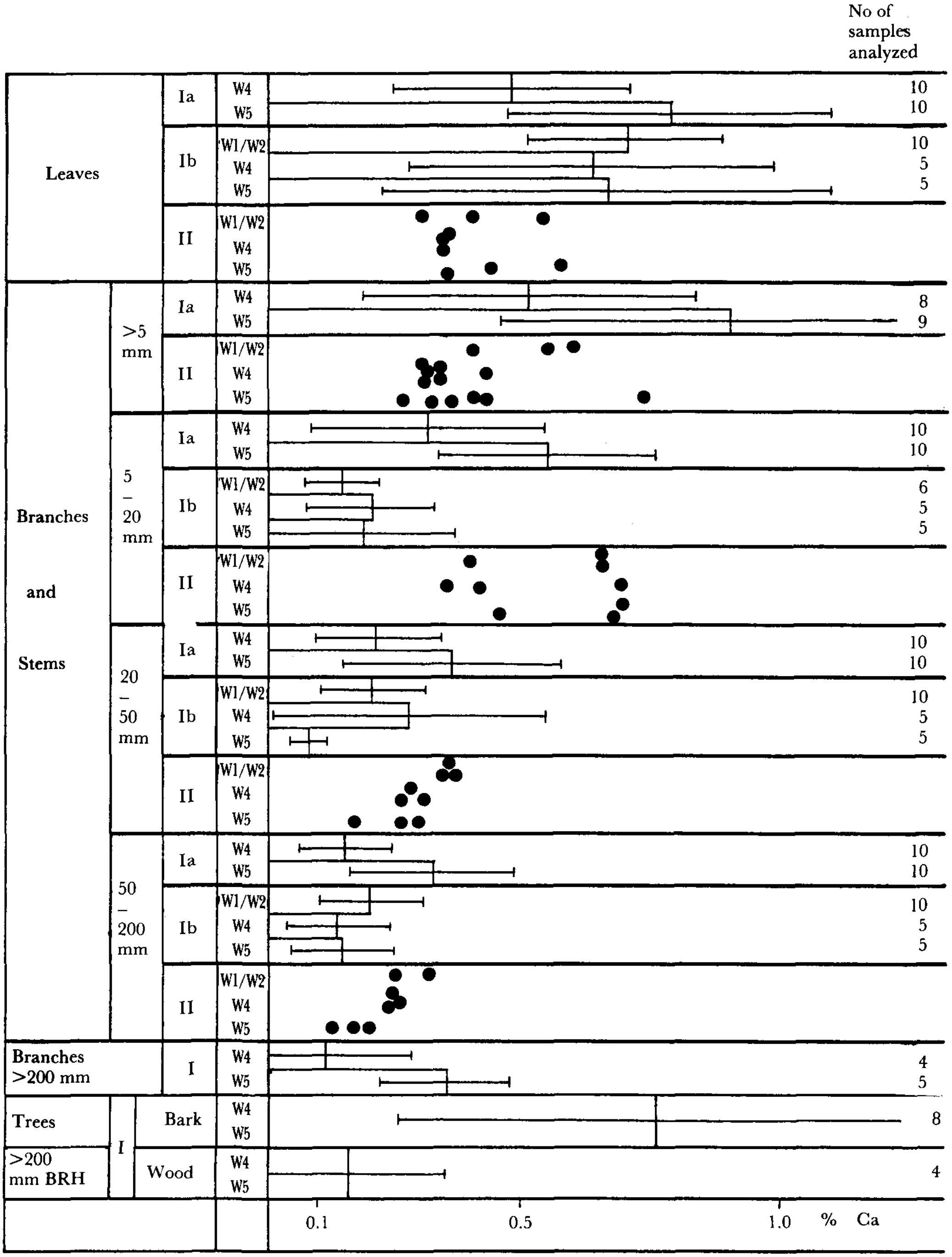
Figure 6. Concentrations of: **a.** nitrogen, **b.** phosphorus, **c.** potassium, **d.** calcium, **e.** magnesium, **f.** sulphur in different parts of the trees (Ia - Rain forest before clear felling, trees > 200 *mm* DBH; Ib - Rain forest before clear felling, trees and bushes < 200 *mm* BRH; mean figures in per cent with least significant differences at the 95% limit; II - Plantation of *Acacia mangium*, 1-y-old, separate samples)


No of samples analyzed
Leaves
Branches and Stems
>5 mm
5 – 20 mm
20 – 50 mm
50 – 200 mm
Branches >200 mm
Trees >200 mm BRH
Bark
Wood
Ia
Ib
II
I
W1/W2
W4
W5
10
10
10
5
5
8
9
10
10
6
5
5
10
10
10
5
10
10
10
5
5
4
5
9
4
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
P

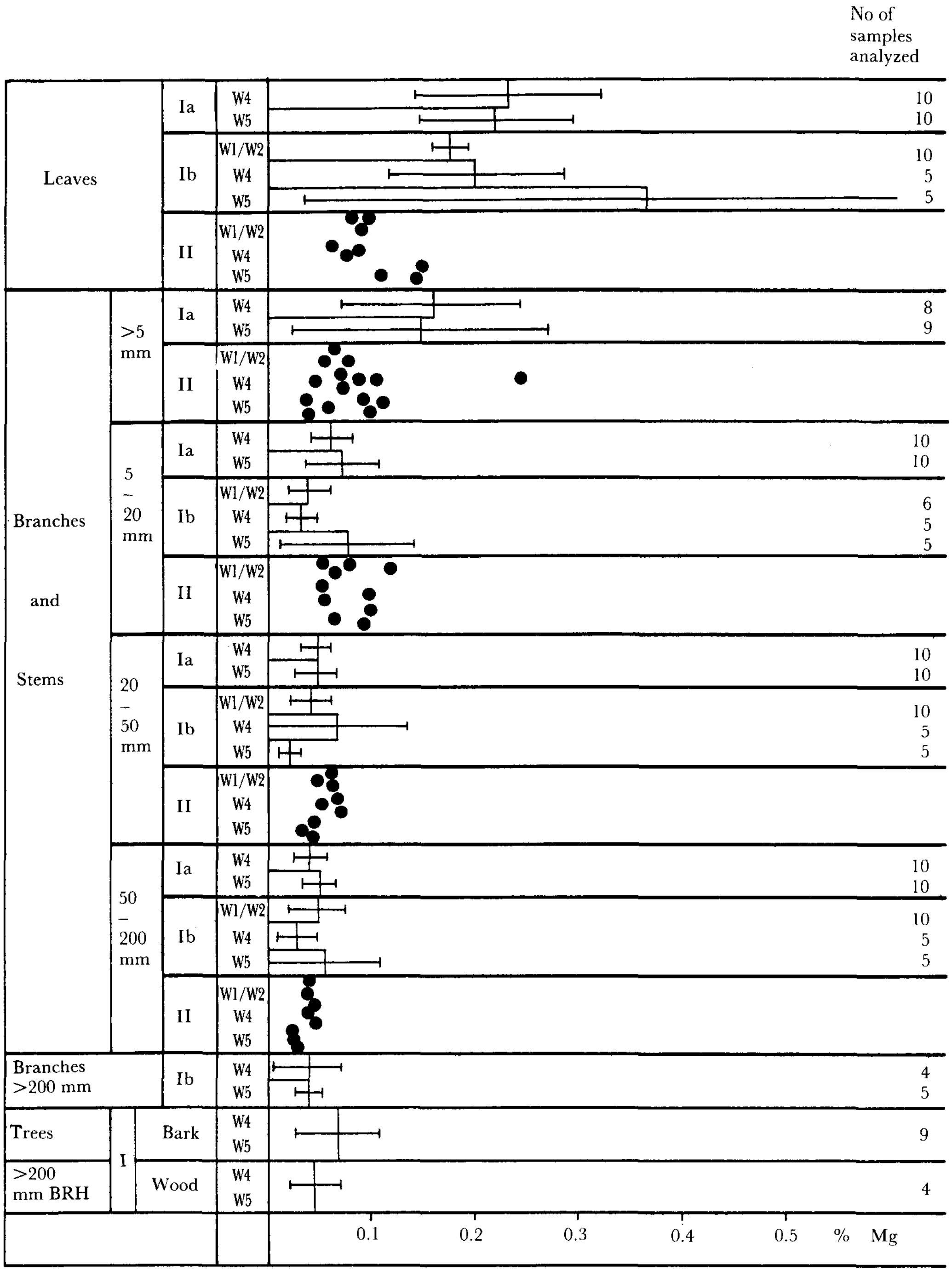
(b)


No of samples analyzed
Leaves
Branches and Stems
>5 mm
5 – 20 mm
20 – 50 mm
50 – 200 mm
Branches >200 mm
Trees >200 mm BRH
Bark
Wood
Ia
Ib
II
I
W1/W2
W4
W5
10
10
10
5
5
8
9
10
10
6
5
5
10
10
10
5
5
10
10
10
5
5
4
5
9
4
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
% K

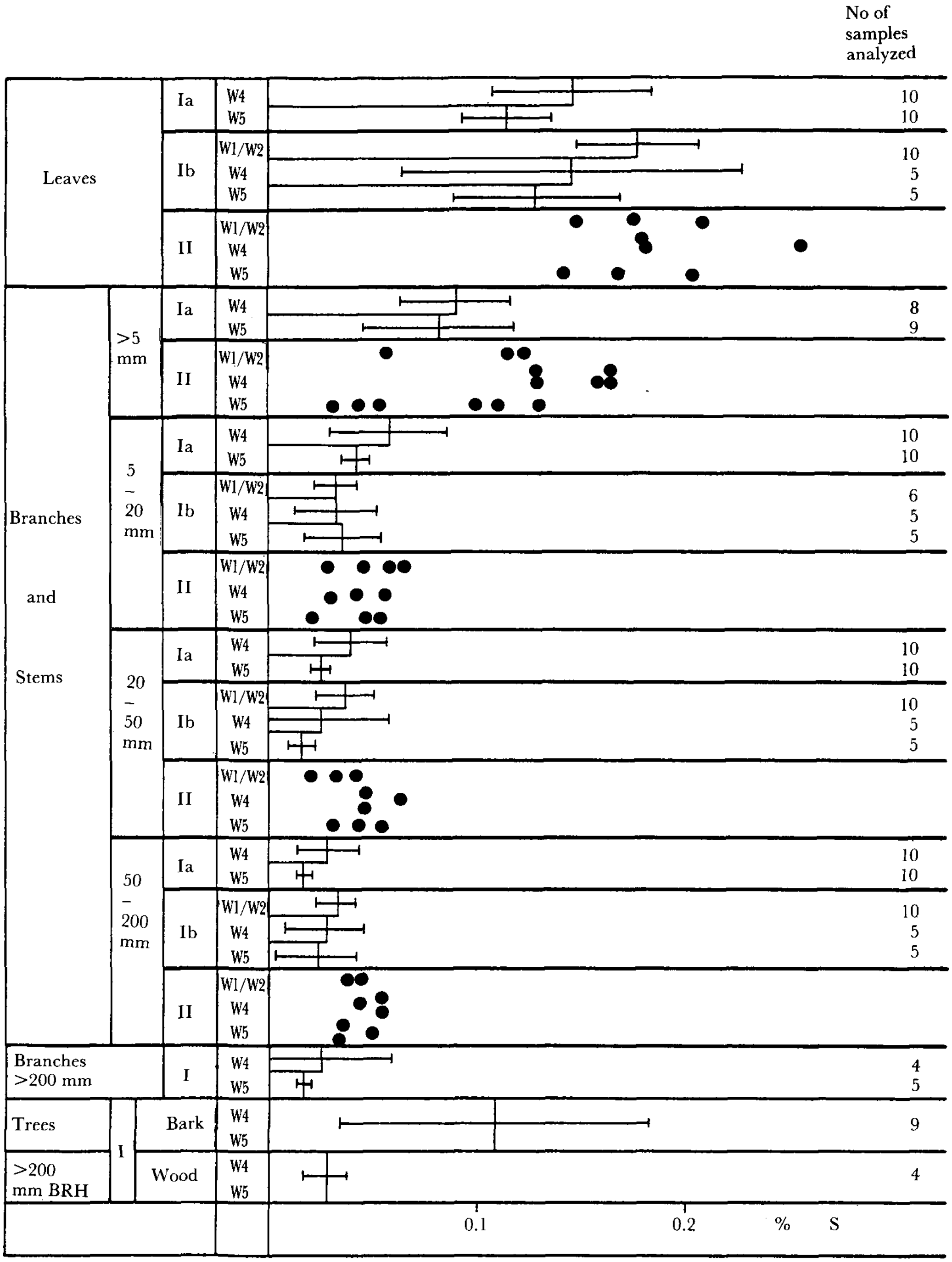
(c)


No of samples analyzed
Leaves
Branches and Stems
>5 mm
5 – 20 mm
20 – 50 mm
50 – 200 mm
Branches >200 mm
Trees >200 mm BRH
Bark
Wood
Ia
Ib
II
I
W1/W2
W4
W5
10
8
9
6
5
4
0.1
0.5
1.0
% Ca

(d)

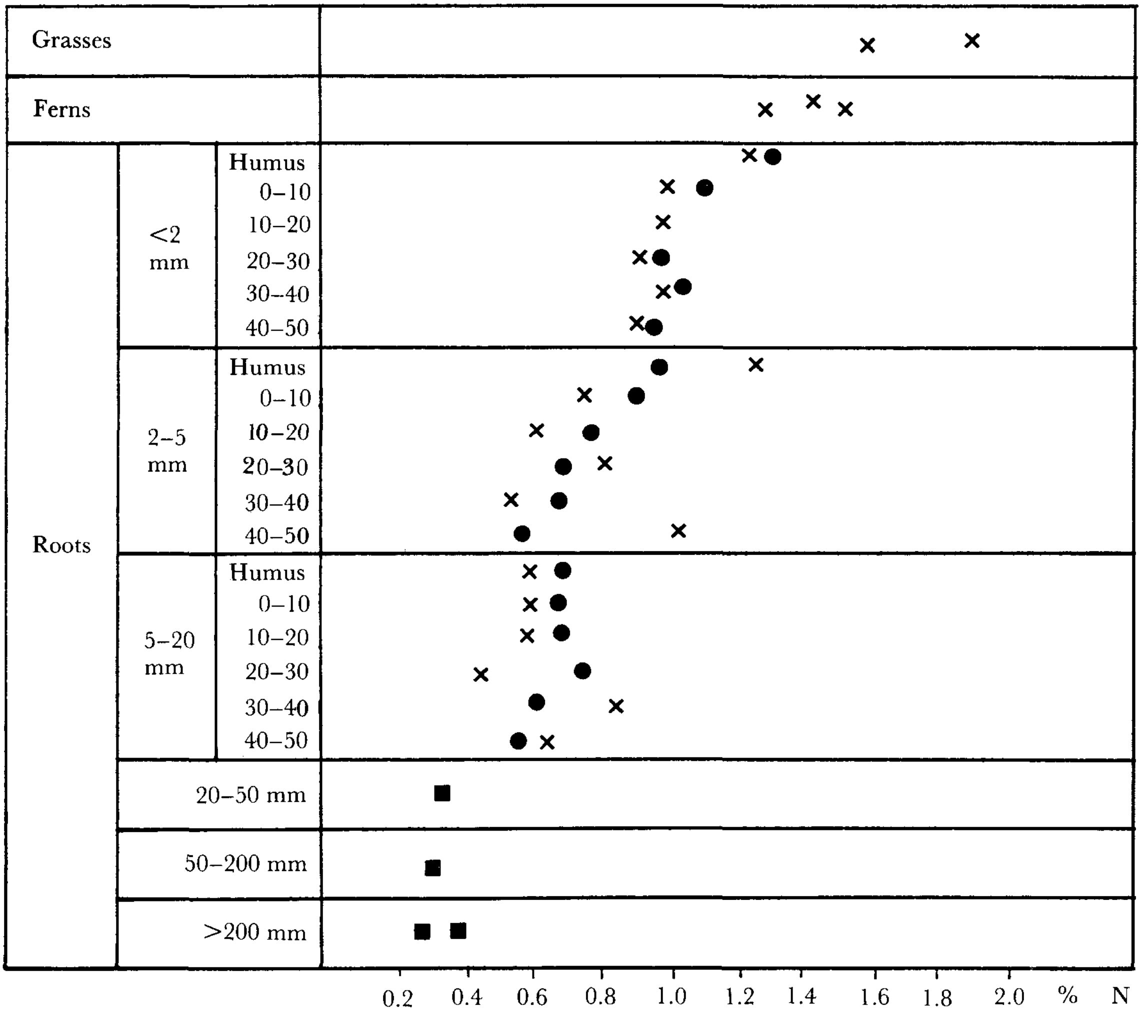

No of samples analyzed
Leaves
Branches and Stems
>5 mm
5 – 20 mm
20 – 50 mm
50 – 200 mm
Branches >200 mm
Trees >200 mm BRH
I
Bark
Wood
Ia
Ib
II
W1/W2
W4
W5
10
10
10
5
5
8
9
10
10
6
5
5
10
10
10
5
5
10
10
10
5
5
4
5
9
4
0.1
0.2
0.3
0.4
0.5
% Mg

(e)


No of samples analyzed
Leaves
Ia
W4
W5
10
10
Ib
W1/W2
W4
W5
10
5
5
II
W1/W2
W4
W5
Branches and Stems
>5 mm
Ia
W4
W5
8
9
II
W1/W2
W4
W5
5 – 20 mm
Ia
W4
W5
10
10
Ib
W1/W2
W4
W5
6
5
5
II
W1/W2
W4
W5
20 – 50 mm
Ia
W4
W5
10
10
Ib
W1/W2
W4
W5
10
5
5
II
W1/W2
W4
W5
50 – 200 mm
Ia
W4
W5
10
10
Ib
W1/W2
W4
W5
10
5
5
II
W1/W2
W4
W5
Branches >200 mm
I
W4
W5
4
5
Trees >200 mm BRH
I
Bark
W4
W5
9
Wood
W4
W5
4
0.1
0.2
% S

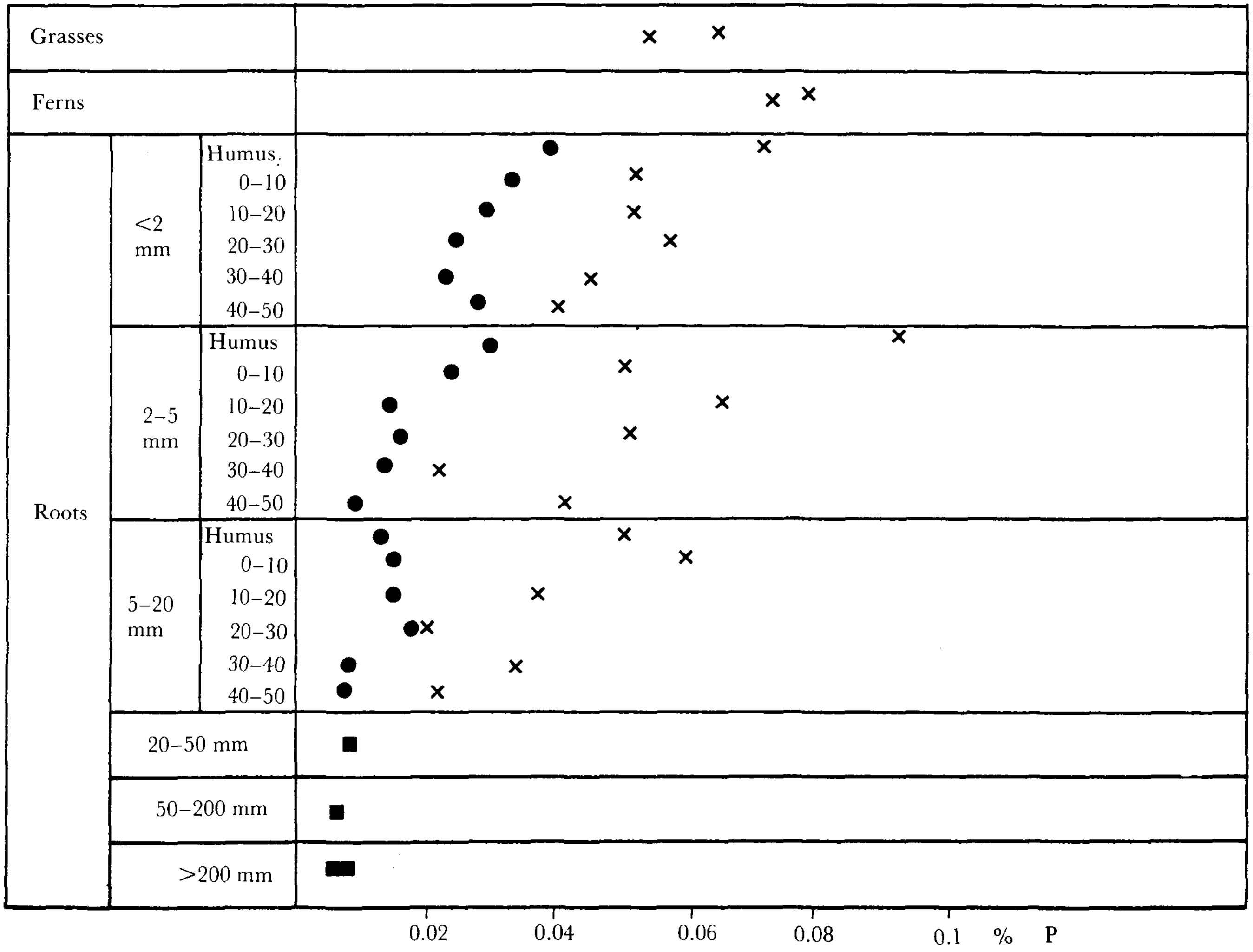
(f)

the leaves from W1/W2 before clear felling compared with W4 and W5, except for Mg and Ca. One difference between the two areas is that the biomass of W1 and W2 was completely burnt down in the "Borneo fire". But this could scarcely explain the higher concentrations of N and lower concentrations of Mg and Ca in W1/W2 compared to W4 and W5.

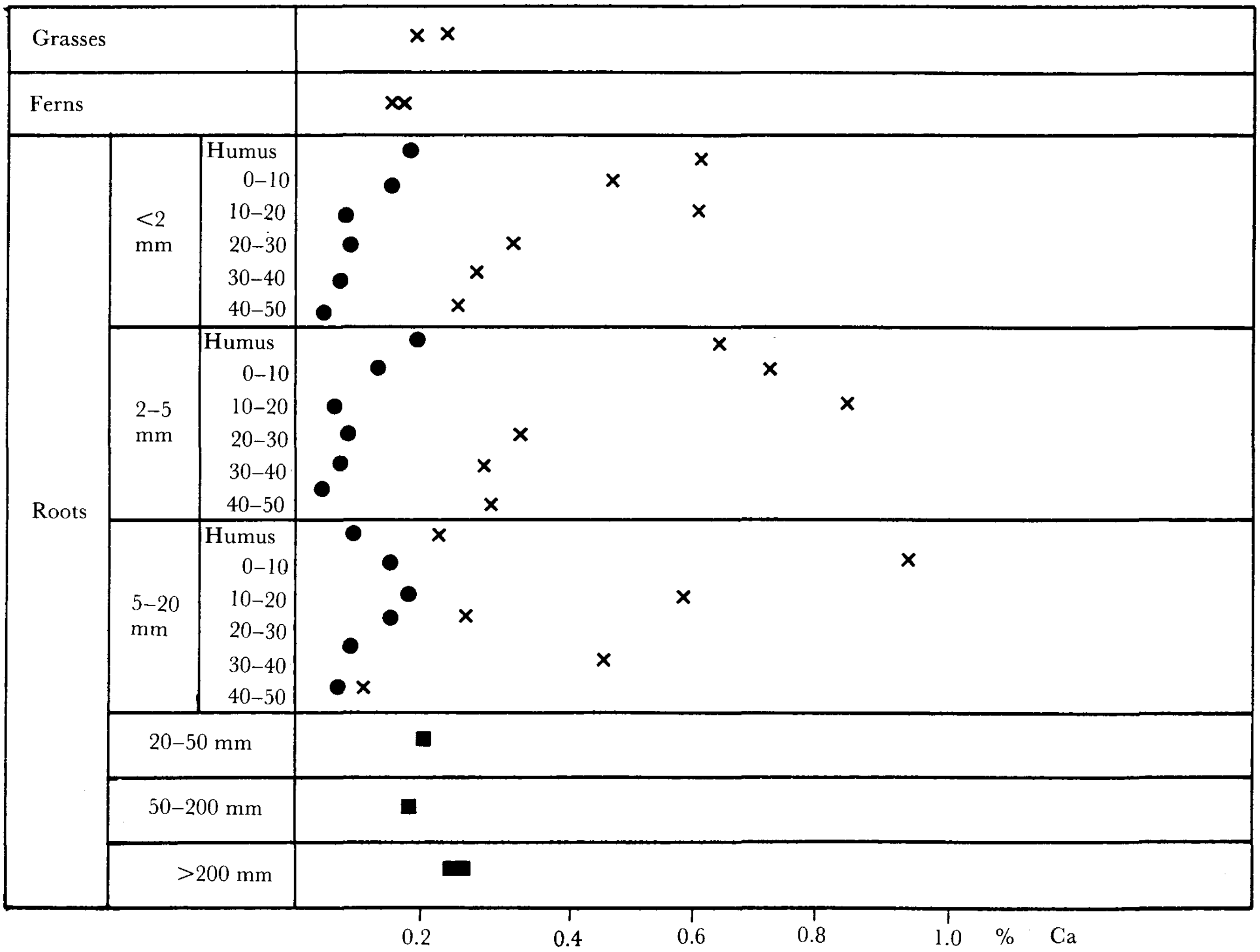


(a)

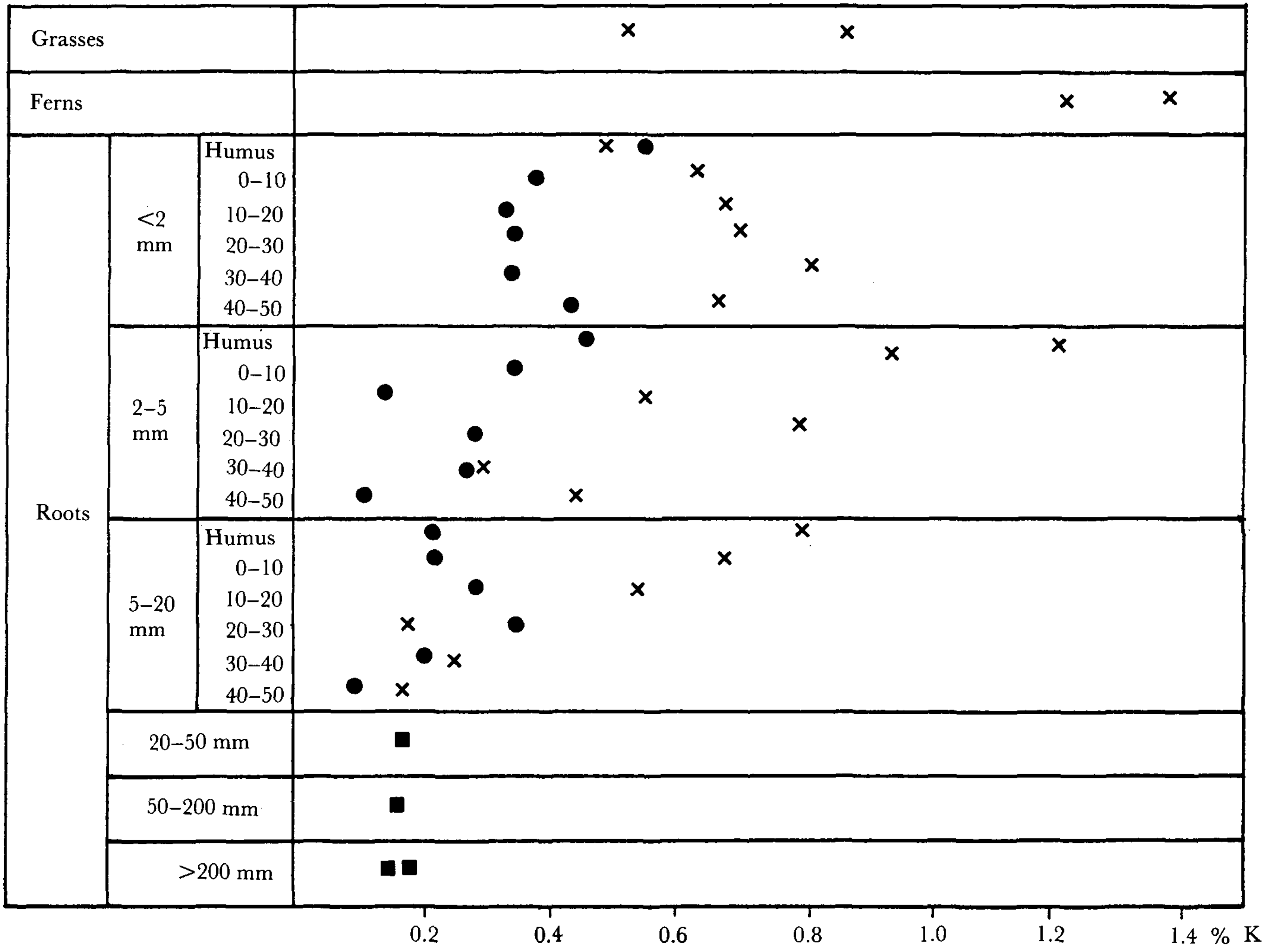
Figure 7. Concentrations of: **a**. nitrogen, **b**. phosphorus, **c**. potassium, **d**. calcium, **e**. magnesium, **f**. sulphur in grasses, ferns and roots of different diameter classes; rain forest, Sabah, Malaysia (× W3, • W6, - W5)


Grasses
Ferns
Roots
<2 mm
Humus
0–10
10–20
20–30
30–40
40–50
2–5 mm
Humus
0–10
10–20
20–30
30–40
40–50
5–20 mm
Humus
0–10
10–20
20–30
30–40
40–50
20–50 mm
50–200 mm
>200 mm
0.02
0.04
0.06
0.08
0.1
% P

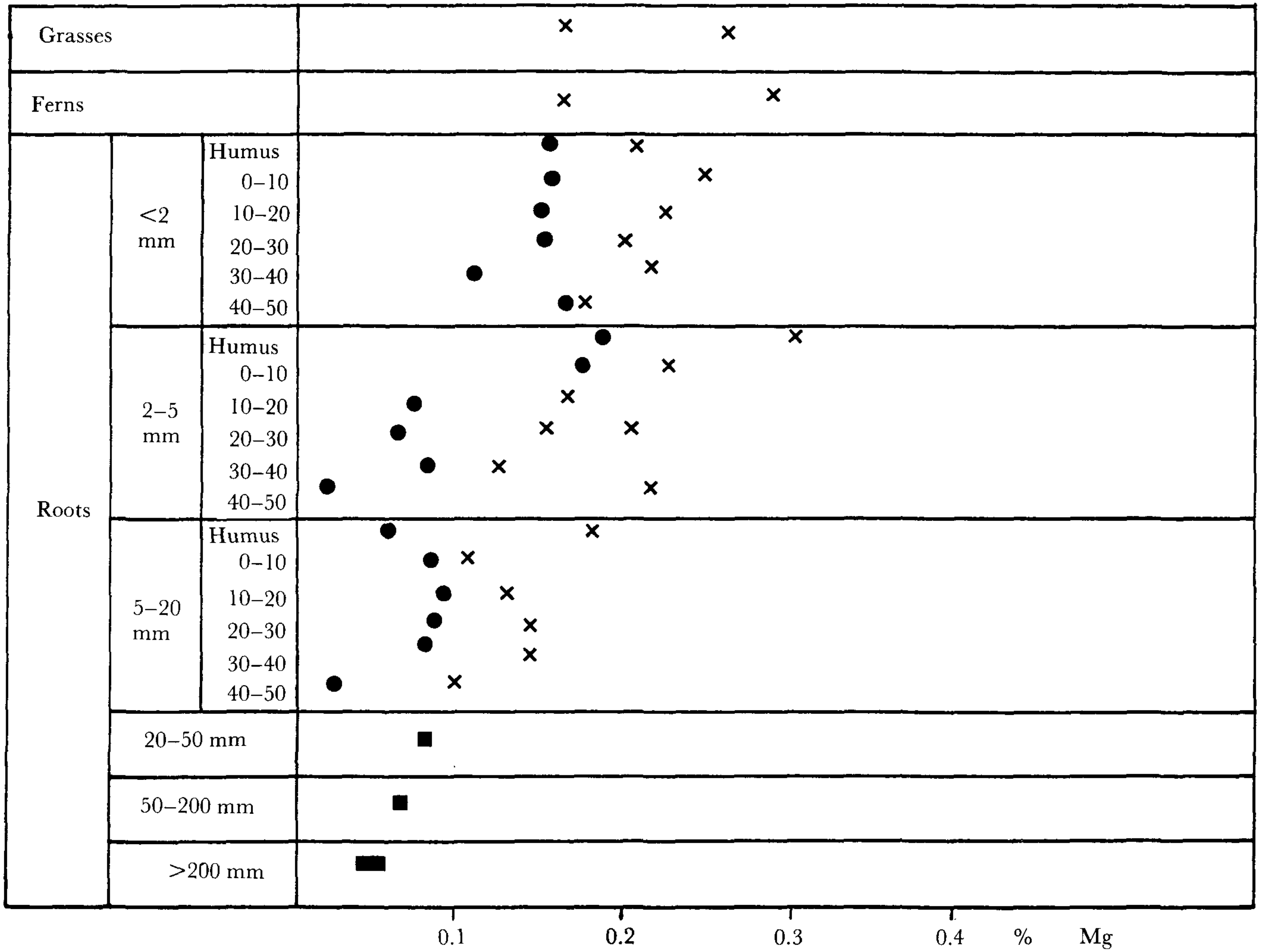
(b)


Grasses
Ferns
Roots
<2 mm
2–5 mm
5–20 mm
Humus
0–10
10–20
20–30
30–40
40–50
20–50 mm
50–200 mm
>200 mm
0.2
0.4
0.6
0.8
1.0
% Ca

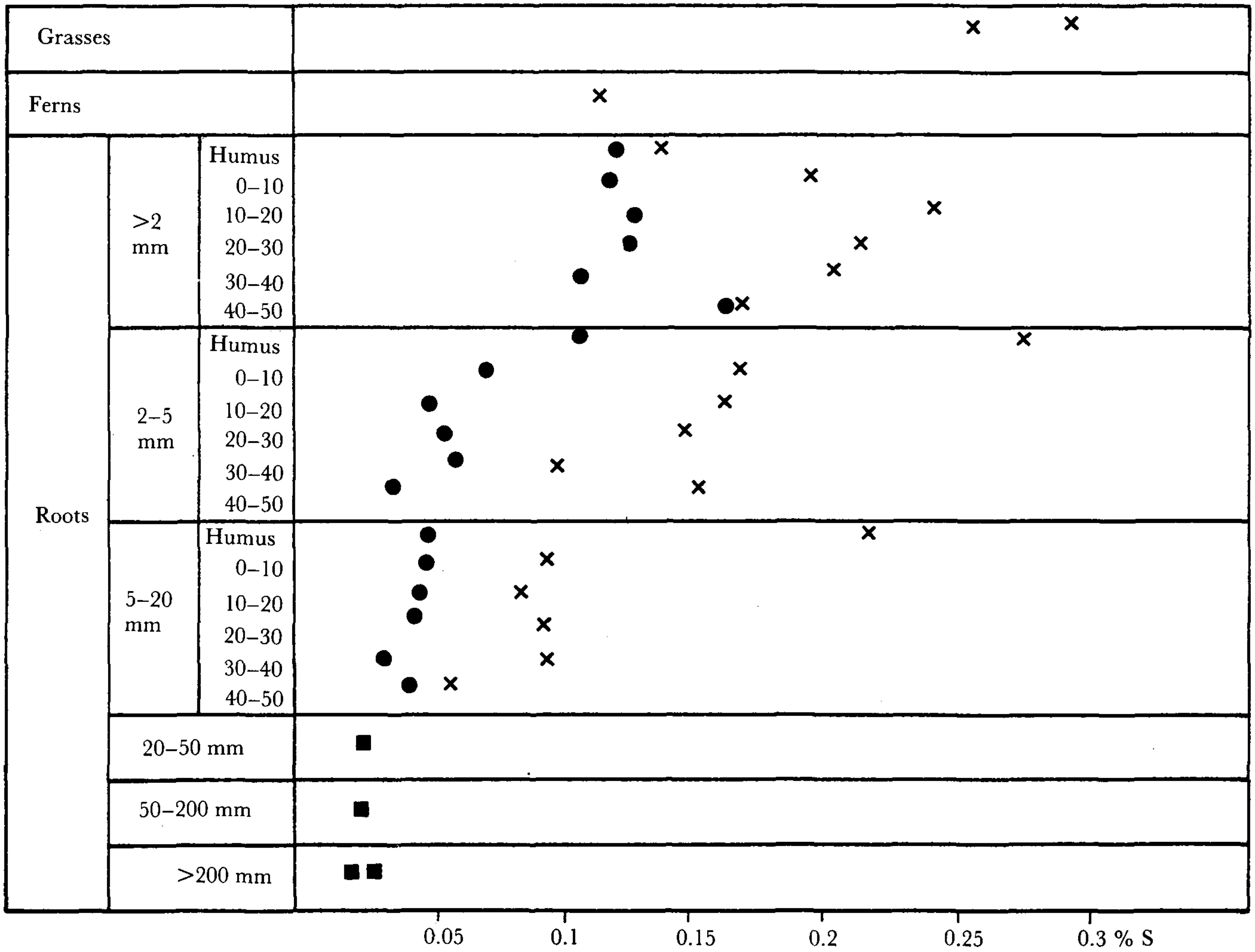
(c)


Grasses
Ferns
Roots
<2 mm
2–5 mm
5–20 mm
Humus
0–10
10–20
20–30
30–40
40–50
20–50 mm
50–200 mm
>200 mm
0.2
0.4
0.6
0.8
1.0
1.2
1.4
% K

(d)


Grasses
Ferns
Roots
<2 mm
2–5 mm
5–20 mm
Humus
0–10
10–20
20–30
30–40
40–50
20–50 mm
50–200 mm
>200 mm
0.1
0.2
0.3
0.4
% Mg

(e)


Grasses
Ferns
Roots
>2 mm
2–5 mm
5–20 mm
20–50 mm
50–200 mm
>200 mm
Humus
0–10
10–20
20–30
30–40
40–50
0.05
0.1
0.15
0.2
0.25
0.3 % S

(f)

scarcely explain the higher concentrations of N and lower concentrations of Mg and Ca in W1/W2 compared to W4 and W5.

A great difference is the concentrations of macronutrients, except that N, however has been found between biomass samples of fine roots from the burnt (W3) and unburnt (W6) reference watersheds (Figure 7). It is not possible to say whether this is an effect of the fire in 1983, since there are different soil types within certain areas of the two watersheds.

Concentrations of macronutrients in different components of biomass from tropical forests have been investigated by Grubb and Edwards (1982), from a montane rain forests in New Guinea (Andriesse & Schelhaas 1987), from young forest in Sarawak, Sri Lanka and Thailand (Ovington & Olson 1970), from a lower montane rain forest in Puerto Rico and by Greenland and Kowal (1960) from a moist tropical forest in Ghana. All figures obtained in this study from Sabah fell between the maximum and minimum ranges for different macronutrients found in more than 100 different trees by Ovington and Olson (1970). The P concentration for leaves was near the maximum value given by them. The Ca concentration for branches was also near their minimum value.

The concentrations in the Sabah study were low for Ca and P in leaves, branches and boles compared to figures given by Grubb and Edwards (1982) and also low for N in leaves, K in trunks and leaves compared to figures given by Andireese and Schelhaas (1987) for 12 to 15-y-old forest in Sarawak.

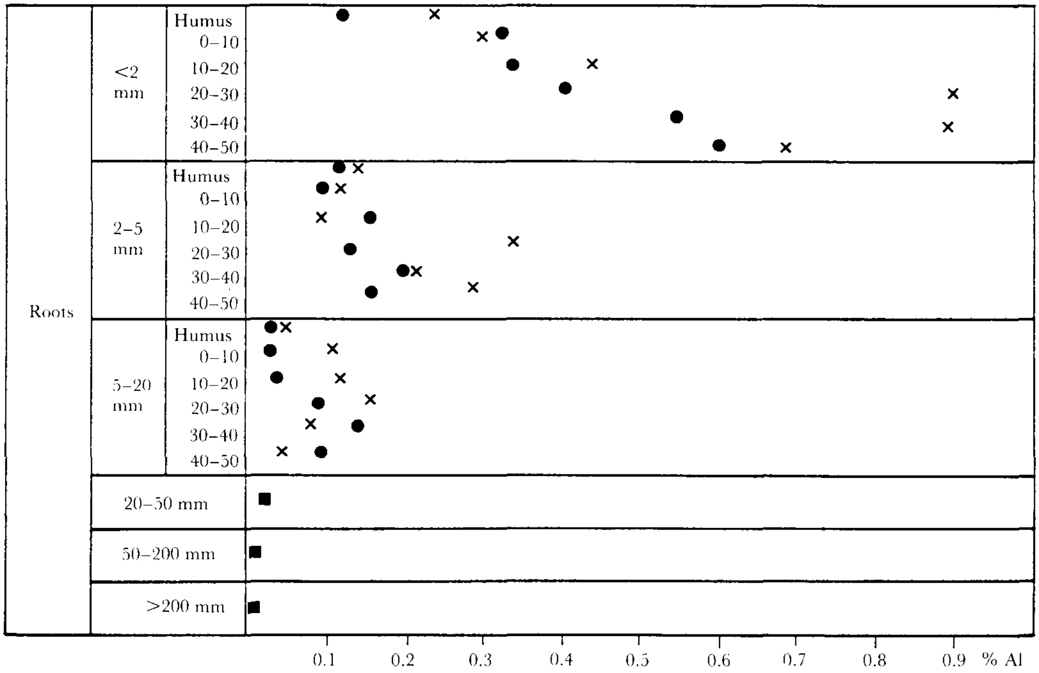


Figure 8. Concentration of aluminium in roots of different diameter classes, rain forest, Sabah, Malaysia (otherwise as in Figure 7)

Except for the macronutrients N, P, K, Ca, Mg and S the concentrations of Mn, Fe, Al, Si, Zn, Cu, B, Na and carbon have been analyzed. Very great differences in concentrations of aluminium have been found between different species. Most of the figures for concentration of Al were lower than 0.02% of the dry weight of the biomass. However in the leaves of trees < 200 *mm* DBH, the mean figures from five samples were 0.23 with a least significent difference of 0.20 at the 95% limit for W4 and 0.18 ± 0.26 for W5. Aluminium concentrations of 0.4, 0.7 and 0.8% were found for single samples of *Melastoma malabathricum* samples from *A. mangium* plantations in W1/W2, W4 and W5, respectively. It is known from earlier reports (Goodland 1971, Haridasan & Monteirode de Arauja 1988) that many species of Melastomataceae, Vochysiaceae and Rubiaceae could be Al accumulators (a minimum foliar concentration of 0.1% Al). Apparently, the species *Melastoma malabathricum* is an Al-accumulator as well as some unknown species among the trees < 200 *m* DBH. In the fine roots, the Al concentration was often higher than 0.1% and for roots < 2 *mm* diameter it increased with depth (Figure 8).

Amounts of inorganic nutrients in biomass

In the evergreen forest

Owing to the low biomass in this study of a selectively logged rain forest in Sabah in relation to other investigated rain forest, the amounts of inorganic nutrients were comparatively low (Figure 9 & Table 9). To compare the contents of macronutrients in biomass obtained from other investigations, the amounts of different macronutrients in the above ground biomass have been calculated as a percentage of the dry weights of above ground biomass (Table 10). From this comparison it is obvious that rain forests in Sabah and New Guinea have a very low content of P. The highest contents of most macronutrients are found in young forest in Sarawak, Sri Lanka and Thailand which is probably accounted for by the fact that the wood with low concentrations of macronutrients constitutes a comparatively small part of the biomass in young forests.

In the 18-*mth*-old plantation of *A. mangium*

The biomass of all above ground parts, of those plants 18 months after plantation, contained 94 to 115 *kg* K, 41 to 47 *kg* Ca, 11 to 22 *kg* Mg, 14 to 16 *kg* S and 6 to 8 *kg* P. Compared to the above ground parts of the evergreen rain forest before clear felling, these figures represent for N, about 19%, K 32%, Ca 7%, Mg 11%, S 16% and P 39% of the total contents of macronutrients. The corresponding figures were for Mn about 6%, Na 3%, Zn 21%, Fe 10%, Al 14% and Si 1%. The very fast uptake of macronutrients during the early stages of plant growth after clear felling has also been shown in the coniferous forests of Sweden (Nykvist unpublished).

Table 9. Amounts of nitrogen, phosphorus, potassium, calcium and magnesium in biomass of different tree components ($kg\ ha^{-1}$)

		a	b	c			d	e	f	g
				S	SL	Th				
N	Leaves	88.0	90	46.0	122	46.0	118	514	220	76
	Branches	198.0	182	29.0	276	36.0	213		280	88
	Trunks (wood + bark)	233.0	342	44.0	111	110.0	483	731	270	131
	Other vegetation	28.0	69	13.0	37	2.0		170	0	11
	Total	547.0	683	132.0	546	194.0	814	1415	770	306
	Stumps	53.0						186	50	27
	Roots > 20 *cm*	363.0						214	20	69
	Roots < 20 *cm*	204.0							20	
P	Leaves	4.1	6	2.2	6	4.0	7	34	22	12
	Branches	6.6	9	1.1	10	5.0	15		37	11
	Trunks (wood + bark)	5.4	16	2.2	13	15.0	21	45	28	12
	Other vegetation	1.3	5	0.7	1			8	0	2
	Total	17.4	36	6.2	30	24.0	43	87	87	37
	Stumps	1.2						20	2	6
	Roots > 20 *cm*	6.3						11	2	8
	Roots > 20 *cm*	7.0							1	
K	Leaves	55.0	45	34.0	128	31.0	62	204	122	41
	Branches	163.0	169	37.0	186	33.0	111		143	39
	Trunks (wood + bark)	202.0	388	108.0	59	122.0	344	424	172	79
	Other vegetation	24.0	62	29.0	15	2.0	63		0	7
	Total	444.0	664	208.0	388	186.0	517	691	437	166
	Stumps	47.0						93	51	20
	Roots > 20 *cm*	176.0						87	8	33
	Roots < 20 *cm*	88.0							6	
Ca	Leaves	47.0	82	20.0	98	29.0	56	530	84	69
	Branches	193.0	469	31.0	632	79.0	257		92	128
	Trunks (wood + bark)	398.0	638	57.0	189	225.0	581	1005	283	177
	Other vegetation	4.0	92	9.0	62	2.0		280	0	6
	Total	642.0	1281	117.0	981	335.0	894	1815	459	380
	Stumps	93.0						186	23	58
	Roots > 20 *cm*	213.0						146	14	79
	Roots < 20 *cm*	73.0							8	
Mg	Leaves	18.0	18	5.0	29	8.0	20		10	10
	Branches	42.0	45	6.0	67	12.0	51	72	21	11
	Trunks (Wood + barks)	76.0	107	10.0	35	26.0	269	167	39	28
	Other vegetation	4.0	14	2.0	5	0.4		21	0	1
	Total	140.0	184	23.0	136	46.0	340	260	70	50
	Stumps	18.0						35	7	7
	Roots > 20 *cm*	66.0						44	2	8
	Roots < 20 *cm*	29.0							2	

Notes:

a - This study; b - Grubb & Edwards 1982, New Guinea; c - Andriesse & Schelhass 1987 (S - Sarawak 12 to 15- y-old secondary forest, annual rain fall 4000 *mm*; SL - Sri Lanka 25 to 40- y-old secondary forest, annual rain fall 900 - 1200 *mm*; Th - Thailand 10-y-old secondary forest, annual rain fall 1600 *mm*); d - Ovington & Olson 1970, Puerto Rico;e - Greenland & Kowal 1960, Ghana; f - Nihlgard 1972, Spruce forest, South Sweden; g - Nykvist 1974, Spruce forest, South Sweden.

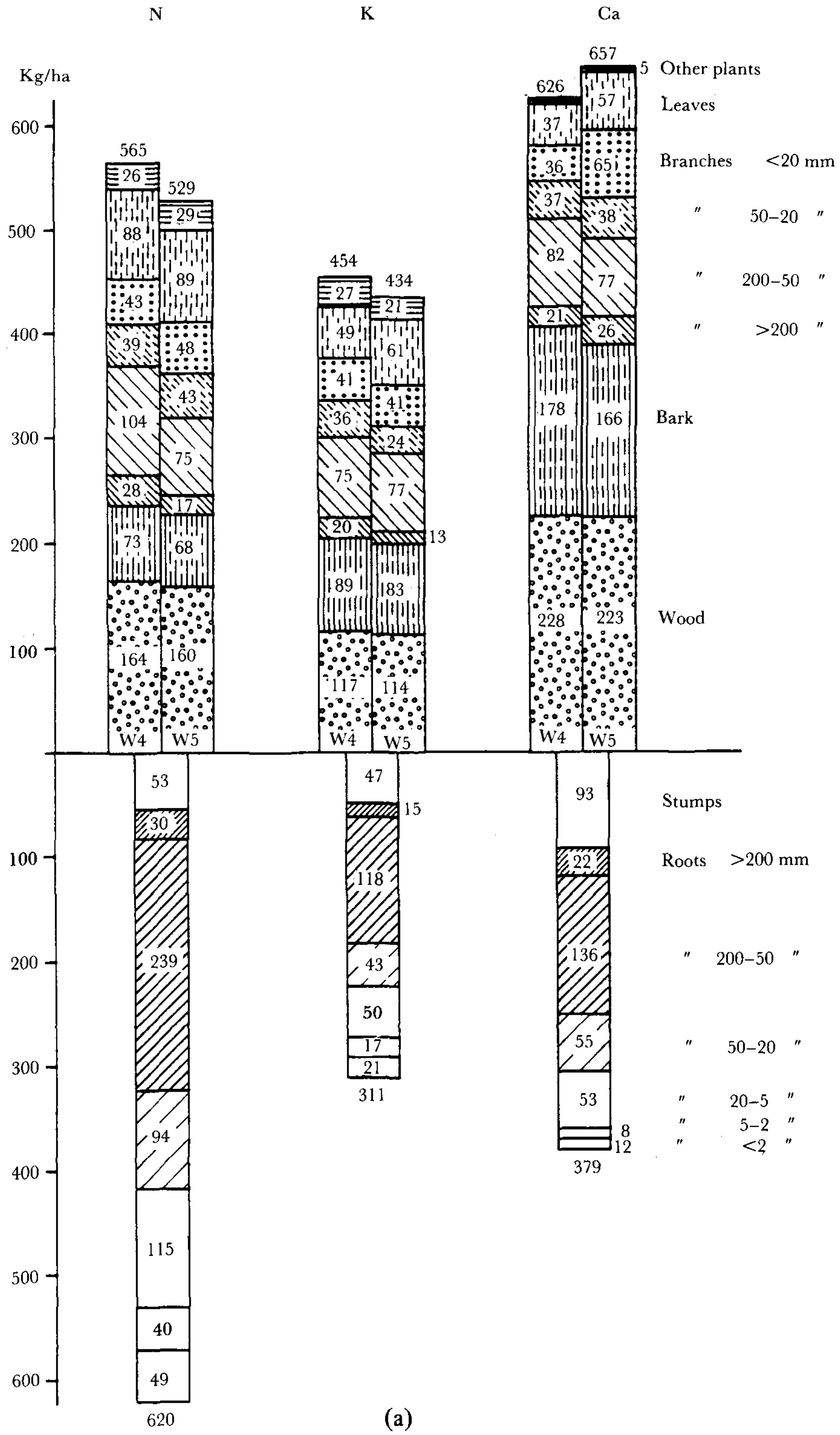
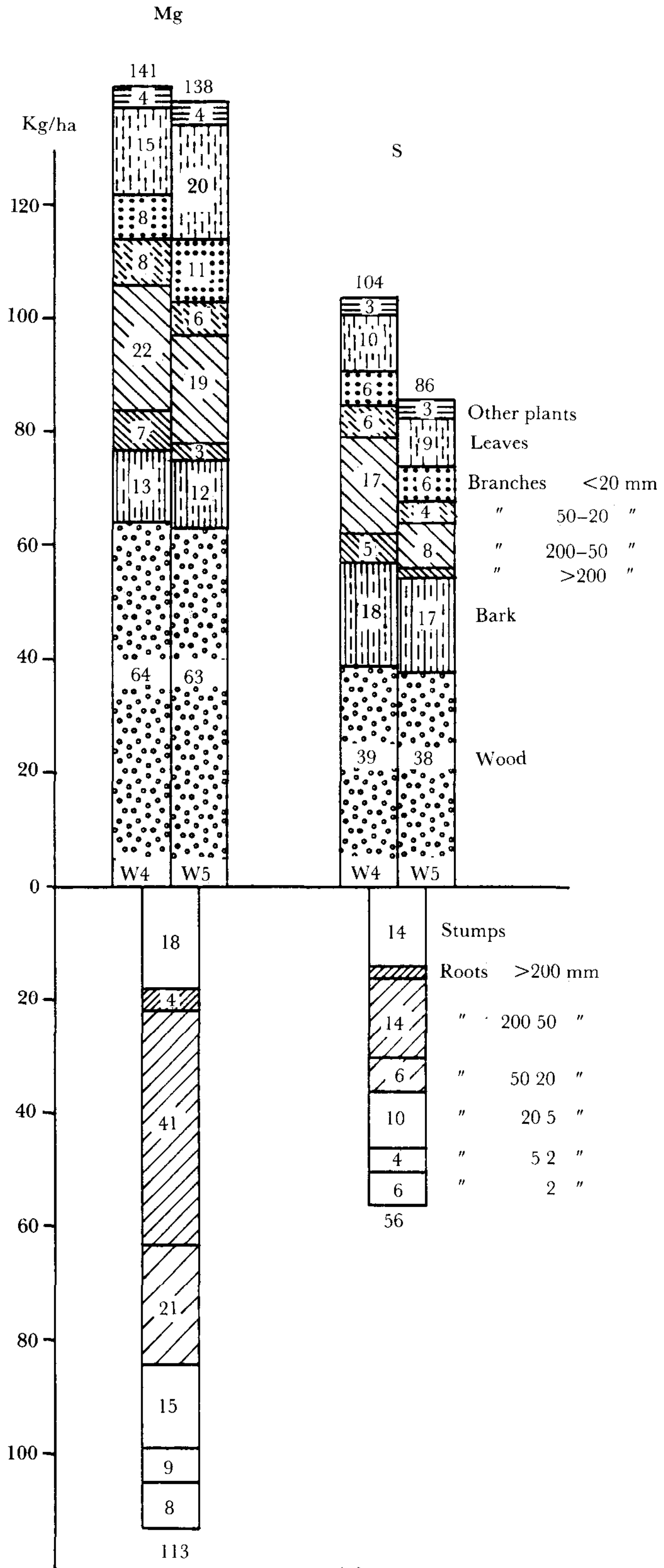
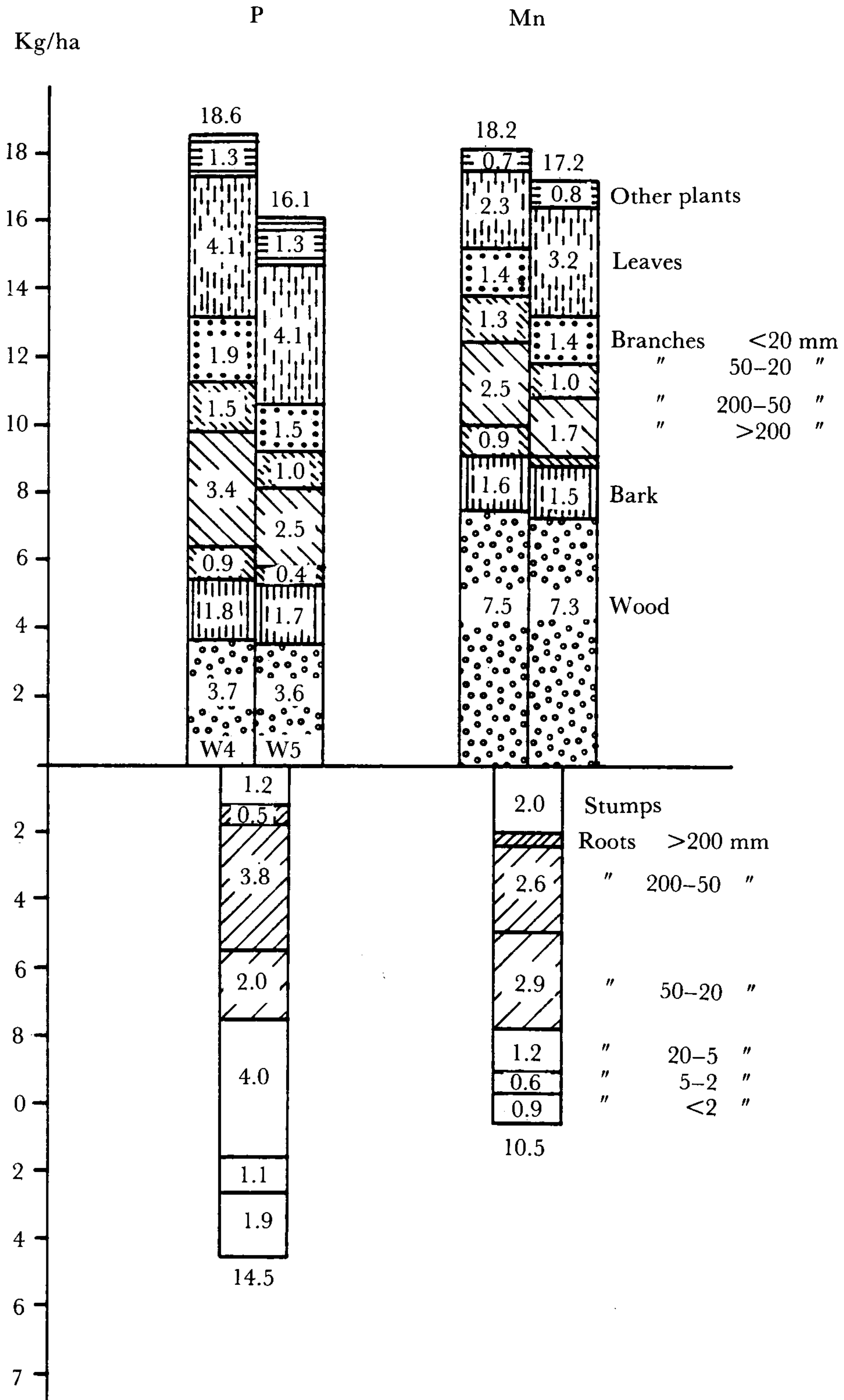


Figure 9. Amounts of: **a**. **nitrogen, potassium and calcium**, **b**. magnesium and sulphur, **c**. phosphorus and manganese, in different constituents of the biomass (*kg ha*$^{-1}$)


Mg
S
Kg/ha
0
20
40
60
80
100
120
141
138
4
15
8
8
22
7
13
64
4
20
11
6
19
3
12
63
W4
W5
104
3
10
6
6
17
5
18
39
86
3
9
6
4
8
17
38
Other plants
Leaves
Branches <20 mm
" 50–20 "
" 200–50 "
" >200 "
Bark
Wood
18
4
41
21
15
9
8
113
14
14
6
10
4
6
56
Stumps
Roots >200 mm
" 200 50 "
" 50 20 "
" 20 5 "
" 5 2 "
" 2 "

(b)


P
Mn
Kg/ha
18
16
14
12
10
8
6
4
2
2
4
6
8
0
2
4
6
7
18.6
1.3
4.1
1.9
1.5
3.4
0.9
1.8
3.7
W4
16.1
1.3
4.1
1.5
1.0
2.5
0.4
1.7
3.6
W5
18.2
0.7
2.3
1.4
1.3
2.5
0.9
1.6
7.5
17.2
0.8
3.2
1.4
1.0
1.7
1.5
7.3
Other plants
Leaves
Branches <20 mm
" 50–20 "
" 200–50 "
" >200 "
Bark
Wood
1.2
0.5
3.8
2.0
4.0
1.1
1.9
14.5
2.0
2.6
2.9
1.2
0.6
0.9
10.5
Stumps
Roots >200 mm
" 200–50 "
" 50–20 "
" 20–5 "
" 5–2 "
" <2 "

(c)

Table 10. The amounts of different macronutrients in the above ground biomass as a percentage of the dry weights of biomass (For description of the forest types, see Tables 4 & 9)

N	P	K	Ca	Mg		Source
0.21	0.007	0.17	0.25	0.05		This study
0.14	0.007	0.13	0.25	0.04		Grubb & Edwards 1982
0.41	0.019	0.65	0.36	0.07	S	Andriesse & Schelhaas 1987
0.67	0.037	0.48	1.2	0.17	SL	
0.37	0.046	0.36	0.64	0.09	Th	
0.41	0.022	0.26	0.45	0.17		Ovington & Olson 1970
0.66	0.041	0.32	0.85	0.12		Greenland & Kowal 1960
0.25	0.028	0.14	0.25	0.02		Nihlgard 1972
0.21	0.028	0.11	0.26	0.03		Nykvist 1974

Conclusions

The most common method of silviculture in Malaysia as well as in most other tropical countries is tractor logging and slash burning planting of monocultures. Our experiments in two watersheds have shown a very serious reduction in growth of *A. mangium* with this method when compared to manual logging and no burning of slash before planting. The stunted growth of the plants in the tractor tracks indicate that compaction and disturbance of the soil may be one of the main reason for this. In the tractor tracks, which covered 24% of the mechanically logged watershed, the steady state infiltrability was only 0.28 $mm\ h^{-1}$ on clay soils compared to 36.7 *mm* on extraction tracks covering only 4% of the manual logged watersheds. The corresponding figures for sandy soil were 1.26 and 11.6 *mm.*

Another reason for the reduced growth in the tractor logged watershed may be the burning of slash before the planting of *A. mangium.* Burning means a great loss of nitrogen stored in the slash and a washing out of other inorganic nutrients from the ash into the streams before plants revegetate the burnt area. An increase of inorganic nutrients and conductivity in the stream water running off the watershed after burning also indicates such a loss in our experiments (Malmer personal communication).

The great amount of slash clear felling and logging in a tropical rain forest makes the subsequent planting difficult and expensive. The most common way of reducing the amounts of slash is to burnt it. Burning is generally said to reduce the weed problem. However, this is dependent on the vegetation in the forest and in the adjacent areas. One of the worst weeds in this area is *Imperata cylindrica* which is stimulated by burning (*c.f.* Table 6). Burning of slash after clear felling has decreased the plant growth in many temperate forest plantations. This is the main reason for the method being abandoned about 30 years ago in many countries, example Sweden.

It is therefore very important to find preparation methods that do not involve burning. The methods used in temperate forests are not applicable in tropical rain forests mainly because of the great amounts of slash, especially coarse branches. In the watersheds with manual logging and no slash burning (W4), planting rows were cleared from slash. This method is, however, too expensive to use in practical forestry. Another method is to harvest not only the stems but also the coarse branches. The extra costs for this harvesting could then be paid by selling fuelwood or making charcoal of it for sale. However, a harvest of a greater part of the tree biomass also mean a greater loss of inorganic nutrients from the sites. A trial in Sweden has shown that harvesting all the stems, branches and needles from coniferous forests resulted in a decrease of the forest growth in young plantations almost equivalent to the effect of burning before planting. For spruce, the growth in trial plots with slash removed was only about 60% of the growth in trial plots where the slash was left (Nykvist 1989). It is therefore important not to take out more biomass than is necessary.

In a lowland rainforest similar to that in this study, it should probably be necessary to also harvest the branches and stems with a diameter > 50 *mm* to make the clear felled area accessible for planting. This means an extra loss of 112 *kg* N, 3.6 *kg* P, 93 *kg* K, 103 *kg* Ca, 26 *kg* Mg, and 16 *kg* S added to the loss of 232 *kg* N, 5.4 *kg* P, 202 *kg* K, 398 *kg* Ca, 76 *kg* Mg and 56 *kg* S by harvesting the stems > 200 *mm* diameter, barks included (see Figure 9 a, b and c).

These figures are not greater than corresponding figures from temperate forest. Compared with spruce forest in southern Sweden, the loss in inorganic nutrients by harvesting the boles is greater for K, Ca and Mg but lower for N and considerably lower for P due to the low content of P in the strongly weathered soil in Sabah.

The loss of inorganic nutrients from harvesting branches > 50 *mm* diameter should be compared with the loss incurred by burning when nitrogen and sulphur compounds, mainly from the leaves and smaller branches, are lost from the site. Other inorganic nutrients such as phosphorus, potassium, calcium and magnesium can be leached out from the ash into the streams. These amounts are also investigated in this watershed study but the results have not yet been calculated.

The loss of inorganic nutrients by the harvest causes a decrease of the forest growth, the size of which depends on the type and amount of biomass being harvested. The loss can be compensated for by returning the ash from the fuelwood to the plantations. The ash does not contain any nitrogen compounds but as long as *A. mangium* or any other nitrogen fixing tree species is planted, there is no need for any extra supply of nitrogen fertilisers.

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