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SOIL AND FOLIAR NUTRIENT COMPOSITIONS AND THEIR INFLUENCE ON THE ACCUMULATED BASAL AREA OF TWO MALAYSIAN TROPICAL RAIN FOREST RESERVES

Amir Husni Mohd. Shariff

Forest Research Institute Malaysia, Kepong, 52109 Kuala Lumpur, Malaysia

&

H. G. Miller

Forestry Department, Aberdeen University, St. Machar Drive AB9 2UD, Aberdeen, United Kingdom

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AMIR HUSNI MOHD. SHARIFF & MILLER, H.G. 1991. **Soil and foliar nutrient compositions and their influence on accumulated basal area of two Malaysian tropical rain forest reserves.** Total K was the main growth limiting nutrient in both reserves based on soil and foliar data. Nutrients N and P also influenced growth but relationships with basal area were only established after removing some out-lying points. Available and exchangeable soil nutrients were found to be poor indicators of growth. Physical properties such as bulk density, clay content, site gradient and available water also exerted some influence on tree growth. Soil data alone is inadequate for nutritional assessments. Foliar data is essential in order to be conclusive.

Key words: Malaysian lowland rain forest - growth limiting nutrients - accumulated basal area

Introduction

Site carrying capacity in Malaysian tropical rain forest under various fertility levels and environmental conditions has not been intensively investigated. This is complicated by the absence of growth rings in tropical trees and paucity of yield data. It is postulated that ecological equivalent sites can make use of accumulated basal area as growth indicator. Limiting physical and or chemical factors influencing site carrying capacity can therefore be determined.

Foliar analysis often correlates well with tree growth (Lau *et al.* 1973, Turner & Lambert 1986, and others). It is highly favoured for diagnosing plant nutritional status and widely applied in rubber and oil palm trees, where samplings were developed by Shorrocks (1962) and Chapman and Gray (1949), respectively. Although using soil for site fertility evaluation is of secondary role in forestry (Ballard 1977), its success has been reported (Shrivastava 1980). Agronomists (Chan & Goh 1978) and those working in forest nutrition (Leaf & Madgwick 1962 and others) welcome the use of both techniques.

This work is designed to study the vital relationship between soil, foliar and basal area so as to have an overview of all factors governing yield. Various components of site carrying capacity are used in this study to represent growth. This is simply to evaluate the response of each guild to soil physical and chemical parameters. This will eventually allow the forest managers to plan the forest resources for optimum productivity.

Pasoh Forest Reserve

Pasoh Forest Reserve (PFR) is located about 140 *km* southeast of Kuala Lumpur. It consists of 650 *ha* of primary lowland mixed dipterocarp forest surrounded by 650 *ha* of buffer zone.

The climate is of Lipis type, characterised by having the lowest average annual rainfall in Peninsular Malaysia (Morgan 1971). Rainfall is about 1800 $mm\,y^{-1}$ (Dale 1959), with annual temperature between 24.5 and 27.2°C.

The geology of this area is mainly sedimentary with igneous outcrops occupying the higher elevation and pockets of alluvial deposits in low lying areas (Loganathan 1980). The topography is flat to undulating, ranging between 75 and 150 *m* above sea level; rising to 600 *m* in the eastern boundary, where it adjoins low granitic hills.

Vegetation was described by Wyatt-Smith (1961) and Salleh (1968) as having a high a percentage of the red meranti group.

Tekam Forest Reserve

Tekam Forest Reserve (TFR) is located at latitude 4° 15' N and longitude 102° 37' E. It is approximately 170 *km* to the northeast of Kuala Lumpur, covering an area of 12400 *ha*.

Precipitation ranges between 2765 and 2980 $mm\,y^{-1}$ (Abdul Rahim 1983), whilst air temperature is between 24 and 29°*C* (Dale 1959).

The geology ranges between upper Triassic and lower Cretaceous, is associated with volcanism (Khoo 1977) and rich in tuffaceous minerals (Ibrahim unpublished). Topography is undulating to rolling to hilly with slopes extremes of 2 and 35°, and elevation between 80 and 325 *m* above sea level.

Poore (1968) described the floristic composition as prevalent to members of *Dipterocarpus* and *Shorea*. At higher elevations (exceeding 300 *m* above sea level), *Shorea curtisii* dominates (Burgess 1972).

Materials and methods

Field procedures

Five dominant soil types were selected from each reserve based on the soil survey carried out by the principle author. The soils were identified using the Soil Survey Manual for Soil Surveyors in Malaysia (after Paramananthan 1986).

The soils of PFR were: Padang Besar (PBR) (Orthoxic Tropudult), Bukit Tuku (BTU) (Aquic Paleudult), Awang (AWG) (Aquic Paleudult), Ulu Dong (UDG) (Typic Paleudult) and Chat series (Typic Paleudult). The soils for TFR were:

Jengka (JKA) (Rhodic Paleudult), Tajau (TJU) (Typic Paleudult), Jeram (JRM) (Typic Paleudult), Bungor series (BGR) (Typic Paleudult) and Jempol (JPL) (Typic Paleudult).

A 2-*ha* north-south oriented plot was laid out on each soil type. All trees 10 *cm* dbh or more were enumerated and identified to species level. For every 2-*ha* plot, the accumulated basal area of all species, preferred species and acceptable species as defined by Wyatt-Smith (1952) was calculated using Fortran 77. Data were sorted into families; and each family into count, basal area, number of species composition and girth class distribution pattern, based on 30 *cm* girth at breast height (gbh) interval.

Each of the 2-*ha* plots was divided into 200 sub-plots. Ten sub-plots were randomly chosen for soil sampling. Ten bulk samples were collected from each of the 2-*ha* plot to represent depths of 0 to 15 *cm* and 15 to 30 *cm* using a screw auger. A soil pit was dug for each plot to a depth of 1.5 *m* and described based on the Soil Survey Manual (Anonymous 1951) and the Guidelines for Soil Profile Description (FAO 1977). Samples according to the described horizons were also taken from the soil profile. Undisturbed samples at depths of 0 to 10 *cm*, 25 to 50 *cm* and 50 to 100 *cm* were also collected from the soil pit using circular brass rings for soil physical determinations.

In addition, foliar samples were taken from twelve selected dipterocarp species and two legume species of dominant stature (30 *cm* dbh and over). Only mature leaves 15 *cm* down the shoot were collected.

Soil sample

Samples were dried for 48 to 72 *h* at 60°*C*, passed through the roller mill and sieved through a 2 *mm* sieve. For N and micronutrients determination, finer samples were used (sieved through 60 mesh size).

pH was determined using 1:2.5 of soil to water ratio. Kjedahl digestion procedure was adopted for total N (%) determination (USDA 1972). Available P was determined by Bray and Kurtz's Method No. 2 (1945), measured colorimetrically as the molybdate-blue complex formed in the presence of ammonium molybdate with stannous chloride acting as reductant. Exchangeable cations were determined by leaching with 1*N* NH_4OAc at pH 7. Total elements (P, K, Ca, Mg, Cu and Zn) were prepared by digestion with perchloric: sulphuric acid mixture (1:1) for 2 *h* at 230°*C* (after Lim 1975). Measurements were made following the procedures outlined by Jackson (1956).

Flame photometer was used to determine exchangeable and total K, while Ca, Mg, Cu and Zn were determined by atomic absorption spectrophotometry. For available P, the Hilger Spekker procedure was used and colour was accomplished using the ammonium molybdate-ascorbic acid method (Watanabe & Olsen 1965).

Foliar sample

The technique outlined by Yeoh (1975) was adopted. Samples were ground through a 1 *mm* sieve.

The Kjedahl method (Piper 1950) was adopted for N determination. Macronutrients (P, K, Ca and Mg) and micronutrients (Cu and Zn) were analysed by dry and wet ashing, respectively. Ash P was determined colorimetrically by the formation of yellow vanado-molybdo-phosphate complex, K by flame photometry and Ca and Mg by atomic absorption spectrophotometry (AAS).

Data analyses

Data were tested for normal distribution after transformation using the Box and Cox method (1964). Coded data of drainage class, gradient and soil depth were transformed to a normal distribution using Ridit scores transformation (Bross 1958). In cases of missing data, such as porosity, bulk density and available water, the medians of non-missing observations were used. For this study, it was opted to use the untransformed data which gave results comparable to those of the transformed data. The advantage is that results obtained would be more easily interpreted. Data from the two reserves were combined for statistical analyses.

Correlation and Stepwise Regression Analyses (SRA) were used for statistical interpretation of the data. For SRA, the number of variables were reduced to eight, namely, N, P, K, all the three ranges of available water, gradient and soil depth. All were correlated with accumulated basal area of all species and dipterocarps. Foliar data of N, P and K of the dipterocarps and legumes were also used in this analysis.

Significant level was set at 5% and least significant difference (LSD) calculated on that basis for all tests. However, 1 and 0.1% were also tried for some of the studies where emphasis and greater examination were required. At the same time 10% LSD was used to indicate weak relationships where sample numbers were too small.

Results

The combined accumulated basal area of TFR and PFR showed substantial correlation with total soil nutrients (Table 1) in topsoils and subsoils. The most striking correlation was between all species accumulated basal area and total K in both horizons. Total P and N also showed significant correlation with all species accumulated basal area, provided aberrant points were removed prior to correlation (Table 1). Total Mg also indicated significant influence on all species accumulated basal area of the plots studied in both soil horizons. In addition, correlation between all species accumulated basal area and soil Cu concentration was also established.

The relationships of exchangeable soil nutrients to the accumulated basal area of combined reserves are, however, poor (Table 1).

Amir and Miller (1990) found a significant relationship between accumulated basal area of all species with foliar K of *Shorea* and *Koompassia*. They also found a positive relationship with N and P after removing some aberrant points.

In terms of fertility differences between TFR and PFR, Amir and Miller (1989) indicated that out of fourteen soil chemical properties measured, eleven were found to be significantly different, TFR being more fertile than PFR. This is well supported by high nutrient uptake by forest trees in TFR (Amir & Mona 1990).

As for physical data, only available water and soil gradient could be used to predict the basal area of the acceptable species and dipterocarp species while for all species no variable was correlated (Table 2).

Table 1. Correlation coefficient (rs) of accumulated basal area of preferred, acceptable and all species, on total, exchangeable and available soil nutrients where n=10 unless otherwise stated (PFR & TFR combined)

Species nutrients	Preferred species	Acceptable species	All species
N - topsoil	- 0.676	0.660*	0.014
	(- 0.458)	(0.799**)	(.749*)
- subsoil	- 0.627	0.481	- 0.059
		(0.617+)	(0.629+)
P - topsoil	- 0.563	0.364	0.257
	(- 0.268)	(0.436)	(0.840**)
- subsoil	- 0.503	0.336	0.040
	(- 0.090)	(0.455)	(0.603+)
K - topsoil	- 0.454	0.724*	0.786**
- subsoil	- 0.564	0.611+	0.814**
Ca - topsoil	- 0.369	0.771**	0.283
- subsoil	- 0.362	0.662*	0.173
Mg - topsoil	- 0.178	0.492	0.739*
- subsoil	- 0.385	0.516	0.728*
Cu - topsoil	- 0.235	0.314	0.591+
- subsoil	- 0.393	0.525	0.675*
Zn - topsoil	- 0.058	0.302	0.099
- subsoil	- 0.353	0.029	0.083
Av.P - topsoil	- 0.674	0.140	0.051
- subsoil	- 0.736	0.403	0.226
Ex.K - topsoil	- 0.680	0.227	0.320
- subsoil	- 0.693	0.275	0.417
Ex.Ca - topsoil	- 0.342	0.054	- 0.152
- subsoil	0.145	- 0.150	- 0.615
Ex.Mg - topsoil	- 0.375	0.357	0.598+
- subsoil	- 0.501	0.387	0.592+

Note: Number in parenthesis are those where n=9, except nitrogen for all species where n=8 and +,*,** and *** denote significance levels of 10, 5, 1 and 0.1%, respectively.

Results from simple correlations between physical data and accumulated basal area are further confirmed by SRA (Tables 3 & 4). Available water was positively correlated for both soil horizons while other variables such as soil depth and bulk density are negatively correlated.

Table 2. Correlation coefficient (rs) of accumulated basal area of preferred, acceptable, dipterocarp and all species on topsoil and subsoil physical characteristics of combined reserves

Species soil	Preferred species	Acceptable species	Dipterocarp species	All species
Topsoil				
Porosity	-0.070	0.151	-0.118	0.183
Bulk density	0.060	-0.131	0.082	-0.118
F. sand: C. sand^{++}	0.377	-0.414	0.058	0.274
Silt: Clay	0.177	-0.447	0.385	-0.490
Drainage	-0.008	0.143	0.335	0.406
%Clay	-0.240	0.266	-0.260	-0.011
Available water:				
1/10-1/3 bar	-0.046	0.251	0.207	-0.200
1/3-15 bar	-0.417	0.576+	-0.594+	0.319
1/10-15 bar	-0.207	0.608+	-0.164	0.056
Soil Depth	0.363	-0.536	0.235	-0.100
Gradient	-0.574+	0.521	-0.727*	0.534
Subsoil.				
Porosity	-0.372	0.500	-0.394	0.441
Bulk density	0.312	-0.465	0.318	-0.424
F. sand: C. sand^{++}	0.491	-0.222	0.283	0.248
Silt: Clay	0.436	-0.521	0.579+	-0.271
Drainage	-0.008	0.143	0.335	0.406
%Clay	-0.284	0.414	-0.274	0.022
Available water:				
1/10-1/3 bar	-0.018	0.051	0.155	-0.219
1/3-15 bar	-0.359	0.768**	-0.262	0.452
1/10-15 bar	-0.400	0.750*	-0.262	0.397
Soil depth	0.363	-0.536	0.235	-0.100
Gradient	-0.574+	0.521	-0.727*	0.534

Note: +, *, ** and *** denote significance levels of 10, 5, 1 and 0.1%, respectively; $^{++}$ F and C denote 'fine' and 'coarse' respectively

Eleven selected variables (both physical and chemical data) were chosen to predict the accumulated basal area, using SRA. The influence of K on accumulated basal area is substantiated in both soil horizons (Table 4). The negative influence of gradient on the accumulated basal area of dipterocarp species is also confirmed. However, N showed negative relationship to all species basal area in subsoil, and similarly soil nutrient K to dipterocarp species basal area (Table 4) thus making interpretation more difficult. The significant role of K in controlling growth accumulated basal area of all species is also supported by the foliar data of dipterocarps, legumes (Table 5) and of test species *Shorea leprosula* and *Koompassia malaccensis* (Table 6). However, foliar N of the latter species showed negative relationship (Table 6).

Table 3. Stepwise regression analysis of preferred, acceptable, dipterocarps and all species accumulated basal area of combined reserves on physical characteristics of topsoil and subsoil (where n=10 unless otherwise stated)

Topsoil

a. Acceptable species basal area =8.625 + 0.075 available water (1/10-15 bar) - 6.14 soil depth -7.3 density.
t - ratio for available water is 8.27***
t - ratio for soil depth is - 7.40***
t - ratio for bulk density is - 4.88***

b. Dipterocarp basal area = 10.35 - 9.2 gradient
t - ratio for gradient is -3.00**

Subsoil

a. Acceptable species basal area = 1.467 + 0.069 available water (1/3-15 bar) + 0.050 clay % - 3.2 gradient.
t - ratio for available water is 5.80***
t - ratio for % clay is 3.23**
t - ratio for the gradient is 2.93**

b. Dipterocarp basal area = 10.35 - 9.2 gradient
t - ratio for the gradient is -3.00**

Note: ** and *** are significant at 1 and 0.1%, respectively

Table 4. Stepwise regression analysis of accumulated basal area of all species and dipterocarps of combined reserves on physical plus chemical characteristics of topsoil and subsoil (where n = 10 unless otherwise stated)

Topsoil

a. All species basal area = 22.13 + 1.63K
t - ratio for total K is 3.62**

b. Dipterocarp basal area = 10.35 - 9.2 gradient
t - ratio for the gradient is -3.00*

Subsoil

a. Total basal area = 29.10 + 1.07 K -131N
t - ratio for K is 5.14***
t - ratio for N is - 2.18+

b. Dipterocarp basal area = 9.626 - 0.73K
t - ratio for total K is -3.21**

Note: Eight variables were used: N, P, K, 1/10 - 15 bar, 1/10 - 1/3 bar, 1/3 - 15 bar; soil depth and gradient
+, *, ** and *** are significant at 10, 5, 1 and 0.1%, respectively

Discussion

Relationship of soil and foliar nutrients with accumulated basal area

From correlation analysis (Table 1), significant influence of soil K on growth (accumulated basal area) is illustrated; this is supported by Amir and Miller (1990) with foliar analysis. Further support is found in the SRA (Tables 4, 5 & 6).

Table 5. Stepwise regression analysis of accumulated basal area of all species and dipterocarps of combined reserves on foliar nutrients of dipterocarps, legumes using three nutrient variables; N, P and K, (n =10 unless otherwise stated)

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a. All species basal area =0.992 + 4.1 dipterocarp foliar K
t - ratio for dipterocarp foliar K is 3.66**
b. All species basal area = 17.62 + 10.91 legume foliar K
t - ratio for dipterocarp foliar K is 3.20**
c. Basal area of dipterocarp = 18.9 - 8.5 dipterocarp foliar N
t - ratio for the dipterocarp foliar N is -2.46*
d. Basalarea of dipterocarp = 4.192 - 10.3 legume K + 4.4 legume N
t - ratio for the legume foliar N is 2.56*

Note : * and ** are significant at 5 and 1%, respectively

Table 6. Stepwise regression analysis of all species and dipterocarps basal area of combined reserves on foliar nutrients of four selected test species *Shorea parvifolia, S. leprosula, S. ovalis* and *Koompasia malaccensis* where n equals 7, 9, 6 and 8, respectively

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a. All species basal area = 10.13 + 26.5 S. *parvifolia* foliar K
t - ratio for foliar *S. parvifolia* is 3.90**
b. All species basal area = 26.95 + 11.6 *Koompassia malaccensis* foliar K,
- 3.8 *Koompassia malaccensis* foliar N
t - ratio for *Koompassia malaccensis* foliar K is 6.61***
t - ratio *Koompassia malaccensis* foliar N is - 2.23+

Note : +, *, ** and *** are significant at 10, 5, 1 and 0.1%, respectively

The role of soil exchangeable and available nutrients in controlling growth is poorly exhibited (Table 1), which accords with the observation of Austin *et al.* (1972).

The importance of K as a controlling factor of tropical rain forest trees basal area came as quite a surprise. It is considered as the most mobile element in the plant ecosystem, and easily leached out (Miller *et al.* 1976, Manokaran 1978, and others). Furthermore, it is readily available in the clay minerals, particularly in 2:1 (Van Olphen 1977, Paramananthan 1977, and others).

However, under tropical conditions the clays are mainly kaolinite (1:1) in contrast to temperate soils which are mainly dominated by 2:1 clay type. Hence K poor soils can be expected except when associated with parent materials rich in feldspar and mica, where even then K is strongly bound (Beringer 1982). In addition, the presence of high free Fe content in tropical soils, forms a natural coating on the soil surfaces (cutan layers), which further limit the K release for plant uptake (Soileau *et al.* 1964). There are documented examples of K deficiency in plantation forestry. For example, in Malaysia, Anthony (1971) found that this nutrient, to some extent, influenced the growth of *Pinus caribaea*. Elsewhere O'Caroll (1966), Karani (1976) and others recorded growth responses in forest trees to applied K.

Agriculture experience world wide has shown that K is important for yield and growth (Beringer 1982). In Malaysia, K is dominant in enhancing girth increment of rubber trees (Pushparajah 1969) and similarly in the early growth of oil palm (Ng *et al.* 1968). A synergistic effect on growth of K together with N has been recorded in both these crops. According to Pushparajah (1980), total K in the soil is a very good indicator of the fertiliser K requirement and response of rubber crops. These workers concluded that exchangeable K is considered deficient when the level falls below 0.2 *meq* $100g^{-1}$ soils, provided the level of total K is less than 2 *meq* 100 g^{-1} soils as determined by 6 *N* HCl extractant.

Exchangeable K is 0.18 and 0.10 *meq* 100 g^{-1} soils in topsoils of TFR and PFR, respectively; the levels of total K are 5.05 and 2.47 *meq* 100 g^{-1} soils as determined by H_2SO_4 and $HClO_4$ extractant, respectively (Amir & Mona 1990). This may explain why the all species accumulated basal area in TFR is superior to that of PFR as stated by Amir and Miller (1989) since K is more limiting at the latter reserve than the former. Moreover, K has been suggested to indirectly affect the rate of photosynthesis, accumulation of amino acids and carbohydrates, and regulation of the plant osmotic and diffusion processes (Huber 1985). As K uptake is mainly through mass flow, a low soil K is expected to reduce the uptake and hence growth reduction.

In the SRA some relationship was also recorded between nutrient N in the subsoil, and foliar N in *K. malaccensis*, with all species accumulated basal area. In both cases, however, the relationship was negative. In the case of accumulated basal area of dipterocarp species, significant relationships were observed with subsoil K and with its own foliar N concentration, both being negative. The negative relationship between the subsoil N and the all species accumulated basal area (Table 4) has to be approached with considerable caution. Such negative results could be brought about by the rigidity of the statistical analysis and the effect of two outlying points (one from JPL and the other from JRM sites), similarly observed by Austin *et al.* (1972). A similar explanation can be offered in the case of dipterocarp species relationship with soil K.

It is interesting to note that N concentration sampled by described horizons (soil profiles) tend to be higher than the composite random sampling. It is postulated that the selected depth of sampling for N in this study obscured the true N concentration since its availability is governed by decomposition and mineralisation of organic matter. By contrast, the negative relationship between foliar N of dipterocarp species and their accumulated basal area may suggest dilution effects at higher growth rates while high accumulation of N in the lower accumulated basal area may suggest some toxicity effects that may well suppress the intake of some vital elements such as K. With regards to the negative effect of foliar nutrient K on the accumulated basal area of the dipterocarp species, the same theory as above is forwarded. The accumulation of K at lower basal area could be due to some other limiting factors.

In this study, some of the measured foliar nutrient concentrations exceeded the optimum range reported by Stark (1971) and Golley (1986) as shown in Table 7. This is especially so for Cu and Zn which have toxic effects if in excess. However, the levels of Cu (10-14 ppm) and Zn (23-30 ppm) all lie within the normal expected range of concentrations as reported by Stone (1968). Unfortunately no measurements of Mn and Al were attempted for either soil or foliar in this study.

Table 7. Foliar nutrient concentrations of some tropical rain forests

Location	Authority	Nutrient mean concentration						
		N	P	K	Ca	Mg	Cu	Zn
		% (oven dry basis)					ppm	
Brazil +	Stark (1971)	2.30	0.19	0.65	0.25	0.27	7.93	16.4
Columbia*	Golley (1986)	-	0.06	1.02	0.39	0.32	6.00	19.0
Malaysia++	Amir & Mona (1990)							
	i) Dipterocarpaceae	1.55	0.07	0.67	0.43	0.23	12.16	27.0
	ii) Leguminosae	2.58	0.09	0.97	0.51	0.41	11.85	24.8

Note: + tierra firme, ++ mixed dipterocarp forest, * tropical wet forest

Most tropical crop plants are subjected to aluminium toxicity (Goedert 1983). According to Tanaka *et al.* (1987), Al in the soil increases as pH decreases. However, between pH 4.2 and 4.8 the amounts of Al concentration in the soil are insignificant. For this study, the soil pH is between 4.2 and 5.1; therefore it is not expected to be associated with Al toxicity. Manganese toxicity, in particular, has rarely been reported in forest trees (Stone 1968). In Malaysia, Mn toxicity is only associated with soils are high pH. For example, Paramananthan (1977) cited an amount between 0.3 and 0.4% in serpentinite derived soils where pH ranges between 5.7 and 6.4, while *Hevea* has been found to suffer from Mn toxicity when grown on Segamat series soils (soils derived from ultra basic rock). Based on exhaustive review on Mn toxicity in forest trees, Stone (1968) suggested that concentration exceeding 0.2% in the foliar has to be considered as possibly toxic.

It has been widely reported that N and P are the most common limiting nutrients for growth (Miller *et al.* 1976, Vitousek 1984, and others). Recently, attention has been centered around P. It was found to be efficiently recycled under tropical rain forest environments, and, if this cycle is disturbed, deficiencies may result (Herrera *et al.* 1978, Vitousek 1984). N is less likely to be limiting in tropical rain forests (Vitousek 1984), as compared to forests of the temperate regions, since mineralisation of N is efficient.

However, this study showed some suggestion of soil N and P influencing growth, as revealed by simple correlation analysis (Table 1). Significant relationships between soil and foliar levels of these nutrients with accumulated basal area of all species were only obtained after removing some out-lying points. In the case of foliar P, SRA indicates non-significant relationship. Although an effect of N was expected, no support was found in this study. The SRA indicated negative correlations except between accumulated basal area of the dipterocarp species (Table 5) and foliar N of *K. malaccensis* (Table 6).

Thus, it seems likely that K is the most limiting nutrient for growth of tropical rain forest, based on the soil investigated. The role of N, and to a lesser extent P, has to be viewed with caution. The support for Mg as influencing growth (Table 1) is even less convincing; there being no support for such ideas from foliar data (Amir & Miller 1990). Soil Mg was simply covarying with soil K, an observation which accords with that of O'Carroll (1966) in Ireland.

Relationship between soil physical characteristics and accumulated basal area

Based on simple regression analyses (Table 2), some degree of influence of available water (1/10-15 bar and 1/3-15 bar) on the accumulated basal area of the acceptable species was observed. and further supported by SRA (Table 5). The importance of water on growth and yield has been well acknowledged in plantations in Malaysia. The decision to plant rubber, oil palm and cocoa is based on the examination of climatic variables, with rainfall being one of the important criteria in clone selection.

In addition to the available water, soil depth and bulk density may exert an important influence; but in both cases the relationships were negative. In the case of subsoil, besides available water, the percentage of clay was positively correlated with growth. The preference for clay soils when seeking sites for agriculture plantation crops further highlights the influence of available water. Moreover, the influence of clay soils in relation to soil chemical properties, such as higher CEC and base saturation values has been suggested by Wong (1977) to be important. On sandy soils, there could also be nutritional problems, since most of the nutrients and a bulk of the feeding roots lie close to the surface horizon as illustrated by Stark and Jordan (1978). This is further supported by Baillie and Mammit (1983), working in East Malaysia.

By contrast, shallow soils enable roots to ramify in the loose weathered parent material. This may be the case in TFR, where the profiles are mostly shallow and the rocks are highly weathered and fragmented, thus enabling penetration of roots. The greater basal area on friable soils, especially of the topsoil, as indicated by the negative relationship between acceptable species and bulk density suggests that the rich organic matter content in this layer may have improved the soil structure and thus its aeration. This creates a more friable environment for fine root growth as well as a larger surface area of soil for exploitation. Ashton (1965) acknowledged soil friability as a significant factor in relation to species composition in North Borneo.

In this study, gradient had a negative relationship with basal area of the dipterocarps, suggesting a preference of these species for lower gradients. This accords with the observation by Wyatt-Smith (1963). At this physiographic location, the soils are less severely eroded, nutrients are accumulated and the soils are usually deep.

By contrast, dipterocarp species composition of high economic value are found invariably on ridge tops (Burgess 1972). Here the slopes are fairly stable, erosion less severe and soils shallower. The main species that flourishes here is *Shorea curtisii*, which contributes enormously towards the basal area and grows in clumps. The roots tend to graft (Ng 1975) allowing effective retranslocation of nutrients and moisture availability within the tree. This particular species is genotypically a large growing tree and drought resistant (Khamis *et al.* 1981). All these inherent physiological traits may explain why this particular species is so successful in dominating such areas.

Conclusion

In this study, accumulated basal area of subgroups representing all species, preferred species, acceptable species and also dipterocarps, was used as growth indicator to identify the critical nutrient influencing growth. These three subgroups were tried with the aim of exploring the possibility of any relationship with the measured soil and foliar nutrient chemical variables; but it is perhaps not surprising that the relationships found were very inconsistent, even between the soil and foliar data. The success of using these sub-groups as growth indicators was limited because the species composition of each guild has no rationale in terms of physiological, morphological or biological features. In fact, they varied drastically within themselves. Some species are shade tolerant while others are light demanders and some tend to have both characteristics. By contrast, all species accumulated basal area is an ecological representation. Therefore, this study gave heavy emphasis for this particular composition as a growth indicator. However, the subgroups growth parameters were also noted when consistent results were displayed.

Based on this study, K is suggested as the limiting nutrient for the growth of tropical rain forest trees, of the studied soils. Physical variables such as available water, bulk density, soil depth, percentage of clay and gradient, showed some degree of relationship with the accumulated basal area of dipterocarps and acceptable species. The role of N and P in controlling growth is approached with caution. Further testing is required, and this study does not rule out other variables that are not quantified here.

The use of soil analysis alone is inadequate to predict site carrying capacity of tropical rain forest. The tropical rain forest soils are too heterogenous even over small areas. Foliar data are essential to obtain a more conclusive result.

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References

ABDUL RAHIM, N. 1983. Rainfall characteristics in forested catchment of Peninsular Malaysia. *Malaysian Forester* 46: 233-243.

AMIR, H.M.S. & MILLER, H.G. 1989. Influence of soil chemical properties on site carrying capacity of two Malaysian lowland rain forests. Paper presented at the *Fourth Round Table Conference on Dipterocarps*. 12 - 15 December 1989. Bogor, Java, Indonesia.

AMIR, H.M.S. & MONA, Z. 1990. Soil and foliar nutrient relationships of some selected *Shorea* and *Koompassia* spp. in two forest reserves, Peninsular Malaysia. *Journal Tropical Forest Science* 2(4) : 320-330.

AMIR, H.M.S. & MILLER, H.G. 1990. *Shorea leprosula* as indicator species for site-fertility evaluation in tropical lowland rain forest of Peninsular Malaysia. *Journal Tropical Forest Science* 3(2):101-110.

ANONYMOUS. 1951. Soil Survey Manual. *United States Department Agriculture (USDA) Handbook 18.*

ANTHONY, J. 1971. Growth and development of potted seedlings of *Pinus caribaea* mor. hondurensis under different combinations and levels of nitrogen, phosphorus and potassium. *Malaysian Forester* 34: 182-202.

ASHTON, P.S. 1965. Notes on the formation of a rational classification of floristic and structural variation within the mixed dipterocarp forests of Sarawak and Brunei, for forestry and land use planning. Pp. 185-197 in *Proceedings UNESCO Symposium on Ecological Resources in Humid Tropical Vegetation.* Forestry Department, Kuching, Malaysia.

AUSTIN, M.P, ASHTON, P.S. & GREIG-SMITH, P. 1972. The application of quantitative methods to vegetation survey. III. A re-examination of rain forest data from Brunei. *Journal Ecology* 60: 305-324.

BAILLIE, I.C. & MAMIT, J.D. 1983. Observation on rooting in mixed dipterocarp forest, central Sarawak. *Malaysian Forester* 46: 369-374.

BALLARD, R. 1977. Predicting fertilizer requirements of production forests. Pp. 33-44 in Ballard, R. (Compiler) *Proceedings of Symposium on Use of Fertilizer in New Zealand Forestry, No. 19.* Forest Research Institute, New Zealand.

BERINGER, H. 1982. Potassium requirements of tropical crops and physiological functions of potassium. Pp. 271-284 in Pushparajah, E. & Sharifuddin, H.A.H. (Eds.) *Proceedings International Conference on Phosphorus and Potassium in the Tropics.* Malaysian Society Soil Science, Kuala Lumpur,

BOX, G.E.P. & COX, D.R. 1964. An analysis of transformation. *Journal Royal Statistic Society Bulletin* 26: 211-252.

BRAY, R.H. & KURTZ, L.T. 1945. Determination of total organic matter and available forms of phosphorus in soils. *Soil Science* 59 : 39-45.

BROSS, I.D.J. 1958. How to use ridit analysis. *Biometrics* 14: 18-38.

BURGESS, P.F. 1972. Silviculture in the hill forests of the Malay Peninsula. *Malaysian Forester* 35: 103-123.

CHAN, K.W. & GOH, M.K.H. 1978. Interpretation of the soil and leaf data for oil palm. Pp. 60-77 in Mokhtaruddin, A.M. & Aminuddin, H. (Eds.) *Proceedings Seminar on Soil and Leaf Analytical Methods: their Techniques and Interpretations.* Malaysian Society Soil Science and Universiti Pertanian Malaysia.

CHAPMAN, G.W. & GRAY, H.M. 1949. Leaf analysis and the nutrition of oil palm *(Elaeis guineensis Jacq.). Annal Botany* 13: 415-433p.

COLE, D.W. & RAPP, M. 1981. Elemental cycling in forest ecosystems. Pp. 301-409. in Reichle, D.E. (Ed.), *Dynamics Properties of Forest Ecosystems.* Cambridge University Press, New York.

DALE, W.L. 1959. Rainfall of Malaya, Part 1. *Journal Tropical Geography* 13: 23-37.

FAO. 1977. *Guidelines for Soil Profile Description.* Soil Research Development and Conservation Services Land and Water Development Division (2nd edtn.) FAO.

GOEDERT, F.B. 1983. Management of the cerredo soils of Brazil: A review. *Journal Soil Science* 34: 405-428.

GOLLEY, F.B. 1986. Chemical plant-soil relationships in tropical forest. *Journal Tropical Ecology* 2: 219-229.

HUBBER, S.C. 1985. Role of potassium in photosynthesis and respiration. Pp. 369-396 in *Potassium in Agriculture.* American Society Agronomy, Crop Science Society America and Soil Science Society America.

JACKSON, M.L. 1956. Soil chemical analysis. Sodium carbonate fusion of silicates. *Handbook of Chemistry and Physics* 302. Department of Soil Science, University of Wisconsin, Madison, Wisconsin. 302 pp.

KARANI, P.K. 1976. The response of *Pinus* species to inorganic fertiliser in Uganda. *East Africa Agriculture Forestry Journal* 42: 28-38.

KHAMIS, A., BASRI, M.H. TAJUDDIN, B. & SHAIR, O. 1981. Effects of some environmental factors on the growth of three hill forest dipterocarps. *Seminar on Forest Regeneration in S.E.A., Biotrop Special Publication 13*: 10-22.

KHOO, H.P. 1977. The geology of Sungai Tekai area, Pahang. Pp. 93-103 in *Annual Report for 1976,* Geological Survey of Malaysia, Ministry of Primary Industries, Malaysia.

LAU, C.H., PUSHPARAJAH, E. & YAP, W.C. 1973. Evaluation of various soils-K indices in relation to nutrition, growth and yield of *Hevea brasiliensis*. Pp. 239-247 (Vol. II) in *Proceedings of the 2nd. ASEAN Soil Conference*. The Soil Research Institute, Bogor, Indonesia.

LEAF, A.L. & MADGWICK, H.A. 1962. Evaluation of chemical analyses of soils and plants as aids in intensive soil management. Pp. 554-556 (Vol. 1) in *Proceedings Forest Ecology and Soils - 5th. World Forestry Congress*. Seattle.

LIM, H.K. 1975. Working manual for soil analysis. *Soil and Analytical Services, Manual No. 6*. Division of Agriculture, Ministry of Agriculture and Rural Development, Malaysia.

LOGANATHAN, P. 1980. The geology of southwestern part of the Durian Tepus area (Sheet No. 96), Negeri Sembilan. Pp. 147-158 in *Annual Report for 1979*. Geological Survey of Malaysia, Ministry of Primary Industries, Malaysia.

MANOKARAN, N. 1978. Nutrient concentration in precipitation, throughfall and stemflow in a lowland rain forest in Peninsular Malaysia. *Malaysian Nature Journal* 30: 423-432.

MILLER, H.G., COOPER, J.M. & MILLER, J.D. 1976. Effect of nitrogen supply on nutrients in litterfall and crown leaching in a stand of Corsican pine. *Journal Applied Ecology* 13: 233-248.

MORGAN, R.P.C. 1971. Rainfall of West Malaysia. A preliminary regionalization using principle analysis. *Area* 3: 222-227.

NG, F.S.P. 1975. A note on natural root grafts in Malaysian trees. *Malaysian Forester* 38 (2) : 153-159.

NG, S.K., THAMBOO, S. & de SOUZA, P. 1968. Nutrient content of oil palm in Malaysia. II. Nutrient in vegetative tissues. *Malaysian Agriculture Journal* 46: 332-390.

O'CAROLL, N. 1966. Growth check of Norway spruce and Scots pine due to potassium deficiency. *Ireland Forestry* 23:36-41.

PARAMANANTHAN, S. 1977. *Soil Genesis on Igneous Rock and Metamorphic Rocks in Malaysia*. DSc. thesis. State University of Ghent, Belgium. 302 pp.

PARAMANANTHAN, S. 1986. *Field Legend for Soil Surveys in Malaysia*. Universiti Pertanian Malaysia and Malaysian Society Soil Science, Kuala Lumpur, Malaysia.

PIPER, C.S. 1950. *Soil and Plant Analysis*. University of Adelaide, Adelaide, Australia.

POORE, M.E.D. 1968. Studies in Malaysian rain forest. I. The forest on triassic sediments in Jengka forest reserve. *Journal Ecology* 56: 143-196.

PUSHPARAJAH, E. 1969. Response in growth and yield of *Hevea brassiliensis* to fertiliser application on Rengam soils. *Journal Rubber Research Institute Malaysia* 21: 165-174.

PUSHPARAJAH, E. 1980. Joint discussions, Session I. P. 76 in Pusparajah, E. & Lock, C.S. (Eds.). *Proceedings Conference on Soil Science and Agriculture Development in Malaysia*. Malaysian Society Soil Science, Kuala Lumpur, Malaysia.

SALLEH, M.N. 1968. Forest Resources Reconnaissance Survey of Malaya. Jelebu District, Negeri Sembilan. *Report 21*. Department of Forestry, Malaysia.

SHORROCKS, V.M. 1962. Leaf analysis as a guide to the nutrition of *Hevea brasiliensis* V. A leaf sampling technique for mature rubber trees. *Journal Rubber Research Institute Malaysia* 17: 167-173.

SHRIVASTAVA, M.B. 1980. Site fertility evaluation. Needle versus soil analysis. *Indian Journal* 3: 95-102.

SOILAEU, J.M., JACKSON, W.A. & McCRACKEN, R.J. 1964. Cutans (clay films) and potassium availability to plants. *Journal Soil Science* 15: 117-123.

STARK, N. 1971. Nutrient cycling II. Nutrient distribution in Amazonian vegetation. *Tropical Ecology* 12: 177-201.

STARK, N. & JORDAN, C.F. 1978. Nutrient retention by the root mat of an Amazonian rain forest. *Ecology* 59: 434-437.

STONE, E.L. 1968. Micronutrient nutrition of forest trees. A review. Pp. 132-175 in *Forest Fertilization. - Theory and Practice*. Tennessee Valley Authority, Natural Fertilizer Centre, Muscle Shoals, Alabama, 35660.

TANAKA, A., TADANO, T., YAMAMOTO, K. & KANAMURA, N. 1987. Composition of toxicity to plants among Al^{3+}, $AlSO_4$+ and Al-F complex ions. *Soil Science Plant Nutrition* 33: 43-55

TURNER, J. & LAMBERT, M.J. 1986. Nutrition and nutritional relationships of *Pinus radiata*. *Annal Review Ecology Systems* 17: 325-350.

USDA 1972. Soil survey laboratory methods and procedures for collecting soil samples. *Soil Survey Investigations Report 1.* United States Department Agriculture and Conservation Services, Washington, D.C.

VAN OLPHEN, H. 1977. *An Introduction to Clay Colloid Chemistry.* (2nd edtn.). John Wiley and Sons.

VITOUSEK, P. M. 1984. Litterfall, nutrient cycling, and nutrient limitation in tropical rain forests. *Ecology* 65: 285-298.

WATANABE, F.S. & OLSEN, S.R. 1965. Test of ascorbic acid method for detecting phosphorus in water and $NaHCO_3$ extracts from the soil. *Soil Science Society of America Proceedings* 29: 677-678.

WONG, C.B. 1977. A toposequence on granite and its influence on the performance of *Hevea brasiliensis.* Pp. 74-83 in Pushparajah, E. & Lock, C.S. (Eds.) *Proceedings on Classification and Management of Tropical Soils.* Malaysian Society of Soil Science.

WYATT-SMITH, J. 1952. Pocket check list of timber trees. *Malayan Forest Record 17.* Forestry Department, Peninsular Malaysia. 362 pp.

WYATT-SMITH, J. 1961. A note on the fresh water swamps, lowland and hill forests of Malaya. *Malayan Forester* 24: 110-121.

WYATT-SMITH, J. 1963. Manual of Malayan silviculture for inland forests. *Malayan Forest Record 23.*

YEOH, H.F. 1975. *Working Manual for Plant Analysis.* Soils and Analytical Services Branch, Division of Agriculture, Ministry of Agriculture and Rural Development, Malaysia.