VOLUME-BASED NUTRIENT CONTENT OF *ACACIA MANGIUM*, *EUCALYPTUS DEGLUPTA* AND *PARASERIANTHES FALCATARIA* IN INDUSTRIAL TREE PLANTATIONS IN EAST KALIMANTAN, INDONESIA

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MACKENSEN, J., RUHIYAT, D. & FÖLSTER, H. 2001. Volume-based nutrient content of *Acacia mangium*, *Eucalyptus deglupta* and *Paraserianthes falcataria* in industrial tree plantations in East Kalimantan, Indonesia. Nutrient concentrations in stemwood, stembark, branches and leaves of *Acacia mangium, Eucalyptus deglupta* and *Paraserianthes falcataria* were analysed and compared to results by other studies. Nutrient concentrations differed significantly across components. Species-specific differences were profound. The weight-volume ratio for *A. mangium* and *E. deglupta* was described best with an exponential model, while for *P. falcataria* a simple linear model was sufficient. All equations were highly significant ($R^2 > 0.83$). Stand nutrient storage in 200 m^3 ha^{-1} stemwood and stembark ranged between 75–202 kg N, 2.6–9.5 kg P, 73–208 kg K, 85–161 kg Ca and 10–21 kg Mg. Nutrients stored in branches and leaves amounted to 70–223% of the N and P, and 29–164% of the K, Ca and Mg storage in stems.

Key words: Nutrient concentration - *A. mangium* - *E. deglupta* - *P. falcataria* - stand volume - weight-volume ratio - nutrient storage

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MACKENSEN, J., RUHIYAT, D. & FÖLSTER, H. 2001. Kandungan nutrien berasaskan isipadu dalam *Acacia mangium*, *Eucalyptus deglupta* dan *Paraserianthes falcataria* dalam peladangan kayu industri di Kalimantan Timur, Indonesia. Kepekatan nutrien dalam kayu batang, kulit batang, dahan dan daun *Acacia mangium*, *Eucalyptus deglupta* dan *Paraserianthes falcataria* dianalisis dan dibandingkan dengan keputusan kajian yang lain. Kepekatan nutrien untuk semua komponen berbeza dengan bererti. Perbezaan khusus spesies sangat ketara. Nisbah berat-isipadu bagi *A. mangium* dan *E. deglupta* diterangkan dengan baik sekali menggunakan model eksponen, manakala bagi *P. falcataria*, penggunaan model linear yang mudah sudah mencukupi. Kesemua persamaan sangat bererti ($R^2 > 0.83$). Penyimpanan nutrien dirian dalam 200 $m^3 ha^{-1}$ kayu batang dan kulit batang ialah 75–202 kg N, 2.6–9.5 kg P, 73–208 kg K, 85–161 kg Ca dan 10–21 kg Mg. Nutrien yang disimpan dalam dahan dan daun berjumlah 70–223% daripada N dan P, dan 29–164% daripada K, Ca dan Mg yang disimpan dalam batang.

Introduction

Industrial tree plantations are being established at a rapid pace throughout the tropics. They are characterised by a short rotation cycle and intensive site management using few dominant species. Although the differentiation of industrial and non-industrial plantations is not always clear (FAO 1995), the establishment of industrial plantations is obviously increasing. Total plantation area in the tropics increased from 18 million ha in 1980 to 44 million ha in 1990, of which 73% are found in tropical Asia and Oceania (FAO 1995). The importance of plantations in this region has increased even more since then. The plantation sector is given a high priority in the economic development schemes of various nations. Indonesia, for example, plans to establish 10 million ha of mainly industrial plantations by the year 2030 (Kosonen *et al.* 1997).

Plantation management generally causes changes in on-site nutrient fluxes. Management-induced nutrient losses from timber harvest, burning, leaching and erosion result in a significant depletion of nutrients especially at poorly supplied sites (Mackensen 1998). The necessary replenishment of these nutrient losses by fertilisation is costly and requires information on the quantity of nutrients lost (Mackensen & Fölster 2000). However, information on the nutrient content of plantation species is extremely rare. It is, therefore, the objective of this study to supply data on the nutrient content of three major plantation species in Indonesia: *Acacia mangium*, *Eucalyptus deglupta* and *Paraserianthes falcataria*. Nutrient content is often related to weight units (Wise & Pitman 1981, Nykvist *et al.* 1994). A conversion into volume-based units is often impossible because data on the density of stemwood and stembark are scarce. In order to overcome this problem and to allow a direct estimation of the nutrient export through harvesting, we based tree nutrient content on stand volume.

Materials and methods

Site description

East Kalimantan is an Indonesian province on the island of Borneo. The study area is within the HTI concession PT.IHM north-west of Balikpapan (0° 22'–1° 00' S; 116° 30'–117° 00' E). The region is characterised by a humid tropical climate. Mean annual precipitation varies between 2000 and 2500 mm. During the drier season (June to October) monthly precipitation often exceeds 100 mm. Mean annual temperature is 26 °C and daily temperature changes cover a range of 6–8 °C. The geology in the region is characterised by Tertiary sand, silt and clay sediments. Miocene limestone occurs in small areas. The topography is undulating with steep but short slopes, narrow valley grounds and crests. Average slope length is 50 to 200 m (Bremen *et al.* 1990, RePPProt 1987).

The major soil types found in 80% of the concession area are Ali and Acrisols (Mackensen 1998, WRB 1994). These soil types, which are comparable to Ultisols (USDA 1994) are characterised by a low pH (H_2O: 4.5–4.8, KCl : 3.5–3.7), high aluminium saturation (56–91% of effective cation exchange capacity (ECEC)), and an ECEC of 18–26 cmol kg^{-1} clay in the top meter. Another 10 to 15% of the soils are sandy and nutrient-poor Ferral and Arenosols with a similar pH, high Al saturation (68–80% of ECEC) and a low ECEC of 9–10 cmol kg^{-1} clay. Calcisols can be found on limestone islands and Fluvisols occur in narrow valley bottoms. Both soil types have a pH(H_2O) of 6.2–7.1, a base saturation of 100% and a very high ECEC (20–100 cmol kg^{-1} clay).

The PT.IHM concession was established in 1992. It covers approximately 200 000 ha of mainly logged secondary dipterocarp forests. In 1993 PT.IHM started to establish 10 000–15 000 ha y^{-1} of industrial tree plantations following some plantation trials dating back to the mid-1970s. During the first few years, *E. deglupta* was the dominant species but *A. mangium* is now planted on 80% of the area. Extended *P. falcataria* stands exist but the species is not planted anymore because of its relatively low pulp yield. The expected mean annual increment (MAI) is 25 m^3 ha^{-1} for all species during a rotation length of 8 y, giving a harvest volume of 200 m^3 ha^{-1}.

Stand volume

Stand volume was measured in a total of 41 plots: 32 plots of *E. deglupta* and nine plots of *A. mangium*. Stand age ranged between 7.5–14.5 y. Topographical position, aspect, degree and length of slopes were recorded for each plot. Plot size was 0.05 ha using a radius of 12.62 m. For an adjustment to slopes equation 1 was used:

$$r' = \frac{r}{(\cos \alpha)^{0.5}} \qquad \text{(equation 1)}$$

where

r' = adjusted plot radius,
r = initial plot radius and
a = slope degree.

Dbh of trees was measured with a diameter tape. Tree heights were measured using a Suunto or, in very dense and high *A. mangium* stands, a Blume-Leiss clinometer. Standing dead and undergrowth trees were not measured. Tree volume was determined by using the standard volume equation for cylinders and applying a species-specific form factor. We used the PT.IHM default values: 0.5 for *A. mangium* and 0.56 for *E. deglupta*.

Nutrient concentration

Following the methodology by Ruhiyat (1989) we analysed the nutrient content of stemwood and stembark of *A. mangium, E. deglupta* and *P. falcataria*. Five average sized trees were sampled per species in 8- to 9-y-old stands on Ali/Acrisols sites. Stem discs were sampled from the base, mean and top (minimum diameter > 7 cm) of sample trees and separated into stemwood and stembark. Samples were dried at 60 °C to constant weight and subsequently analysed for their nutrient concentration at the Institute of Soil Science and Forest Nutrition, Göttingen, Germany. C and N were analysed using a CN-element analyser (CHN-O-Rapid, Heraeus, Germany), while P, S and the cations K, Ca, Mg, Mn and Al were analysed with an inductively coupled plasma-atomic emission spectroscope (ICP-AES, Spectro, Kleve, Germany) after HNO_3-pressure digestion. A detailed methodology is given by König & Fortmann (1 996a, b). A rang-sum test (U-Test) was used for statistical comparison of concentration values with other studies or among species. SAS was used as analytical software package.

Weight-volume ratio

In order to convert the nutrient concentrations [kg kg^{-1}] into volume-based quantities [kg m^{-3}] we derived equations for the weight-volume ratio of the three species. Models were based on the data by Ruhiyat (1989) who measured the dry weight of stemwood, stembark, branches and leaves for 5- to 10-year-old stands of *A. mangium, E. deglupta* and *P. falcataria* on comparable sites in the same plantation estate. We tested the following four regression models (equations 2–5):

$y = a + bx$ (equation 2)
$y = b \times x$ (equation 3)
$y = a + \ln(x)$ (equation 4)
$y = a \times x^b$ (equation 5)

where

y = dry weight (kg) of tree components (stemwood, stembark, branches, leaves),

x = either tree volume (m^3), $dbh^2 \times$ tree height (m^3) or dbh (m) and

a and b = parameters to be estimated.

Estimation of stand nutrient storage

Estimation of stand nutrient storage was based on the volume of the average-volume tree (AVT). AVT values were obtained by dividing a given stand volume ($m^3\ ha^{-1}$) by the corresponding number of trees per hectare. The weight per AVT component was calculated using the weight-volume ratio for individual trees. The weight of each tree component was then multiplied by its corresponding nutrient concentration. Finally, the obtained nutrient storage per AVT was multiplied by the number of trees per ha to get the stand nutrient storage ($kg\ ha^{-1}$). We estimated the attributed error by comparing the stand nutrient storage based on the AVT values. The nutrient storage was obtained by summing up values for individual trees using data from our study plots. The average relative error was 5.4% and the maximum error was 10%.

Results

Stand volume

Mean annual increment for 7.5- to 9.5-y-old stands ($MAI_{7.5–9.5}$) of *A. mangium* stands in the first rotation was higher (35–59 $m^3\ ha^{-1}$) than the expected rate of 25 $m^3\ ha^{-1}$ (Table 1). *Eucalyptus deglupta* stands had a much lower productivity with an average $MAI_{7.5–9.5}$ of 5–33 $m^3\ ha^{-1}$. Stand volume of *A. mangium* stands ranged from 308 to 511 $m^3\ ha^{-1}$, while in *E. deglupta* the volume range was 44–315 $m^3\ ha^{-1}$. Average survival percentage (from an original density of 1111 trees ha^{-1}) ranged from 68 to 74% in *A. mangium* stands and 36 to 71% in *E. deglupta* stands. The high volume in *A. mangium* stands was partly based on the multi-stem habit of the provenance 'Queensland'.

Nutrient concentration

Nutrient concentrations of the various tree components are summarised in Tables 2–4. The results of other studies were given for comparison. There were no significant differences in the concentrations of Ca in the stemwood as well as N, K, Ca and Mg in the stembark (Wilcoxon-test, $p < 0.05$) of *A. mangium* in this study compared to results obtained by Ruhiyat (1989). Generally, concentrations were higher in the bark than in the wood for all nutrients except Al. Nutrient concentrations in stemwood and stembark of 3.6- to 3.8-year-old *A. mangium* stands in Sabah (Nykvist *et al.* 1996) are much higher compared to older

Table 1 Main parameters of surveyed *Acacia mangium* and *Eucalyptus deglupta* stands

Species	Age (y)	n[a]	MAI (m^3 ha^{-1} y^{-1})	Volume (m^3 ha^{-1})	Site index[b] (m)	Survival (%)
Acacia mangium						
	7.5	4	50.5	379	27.5	69
			(43.4–59.2)	(325–444)	(25.5–29.2)	(83–47)
	8.5	2	47.1	404	27.5	74
			(36.2–58.8)	(308–500)	(27–28)	(53–95)
	9.5	3	42.1	400	29.0	68
			(34.9–53.8)	(332–511)	(26.4–31.6)	(58–78)
Eucalyptus deglupta						
	7.5	6	14.3	97	19.7	51
			(6.3–17.7)	(46.9–132.5)	(14.2–24.2)	(24–78)
	8.5	15	16.1	136	20.6	71
			(5.2–23.2)	(44.4–196.9)	(15.4–25.9)	(42–89)
	9.5[c]	4	27.1	257	26.1	69
			(22.8–33.1)	(216.8–314.6)	(24.2–27.6)	(55–78)
	9.5[c]	2	17.0	161	24.2	52
			(15.8–18.2)	(149.8–172.7)	(23.7–24.6)	(51–53)
	14.5	5	20.3	295	31.6	36
			(13.8–28.3)	(200.4–410.3)	(27.9–37.5)	(24–44)

[a] Number of plots
[b] Site index = height of five tallest trees per plot
[c] Distinguishing two subsites
Figures in parentheses are the range obtained.

stands this study. The N concentrations in stembark and Ca concentrations in stemwood and stembark by Ruhiyat (1989) and Nykvist *et al.* (1996) are comparable to results of this study, while K and Mg concentrations given by Ruhiyat (1989) are higher.

Bark of *E. deglupta* has higher nutrient concentrations than wood (Table 3). There were no significant differences for the concentrations of N, K and Mg in the stemwood and N, Mg and Al in the stembark between the results of this study and Ruhiyat (1989) ($p < 0.05$). Significant differences were found only for the Ca concentration in stemwood and the K concentration in stembark ($p < 0.01$). Nutrient concentrations in leaves found by Ruhiyat (1989) and Syahrinudin (1997) for *E. deglupta* at PT.IHM compared well with data by Lamb (1977) for stands in Papua New Guinea.

For *P. falcataria* nutrient concentrations were higher in stembark than in stemwood (Table 4). Compared to the results by Ruhiyat (1989), all but the Ca values in stemwood were found to be significantly different ($p < 0.01$), while N, K, Ca and Mg concentrations in the stembark did not differ significantly ($p < 0.05$).

A species-specific comparison of nutrient concentrations in stemwood and stembark is given in Figure 1. Species-specific significant differences were found for N, P, K and Mn in the stemwood ($p < 0.1$) while for C, S and Ca no significant differences were found between *A. mangium* and *E. deglupta.* Mg and Al concentrations in stemwood of *E. deglupta* and *P. falcataria* also did not differ

Table 2 Nutrient concentration in stemwood, stembark, branches and leaves of *Acacia mangium*

Component	Reference	Age (y)	n		C (%)	N (%)	P	S	Na	K	Ca	Mg	Mn	Al
										(mg g^{-1} dry matter)				
Stemwood	This study	9	15	x	49.8	0.124	0.0145	0.0989	0.2407	0.3907	0.6459	0.0731	0.0005	0.0548
				std	0.36	0.01	0.02	0.01	0.25	0.24	0.20	0.03	0.00	0.04
	Ruhiyat 1989	5–7	36	x		0.117				1.16	0.68	0.16		
	Nykvist *et al.* 1996	3.6–3.8	40	x		0.24	0.1	0.2		2.5	0.8	0.3		
Stembark	This study	9	15	x	51.4	1.026	0.146	0.622	0.295	4.107	10.553	0.409	0.056	0.004
				std	1.94	0.19	0.03	0.15	0.16	2.19	2.02	0.21	0.02	0.01
	Ruhiyat 1989b	5–7	3	x	47.2	1.100				3.84	10.13	0.52		0.3474
				std	0.98	0.05				0.80	1.67	0.18		0.13
	Nykvist *et al.* 1996a	3.6–3.8	40	x		1.32	0.36	1.16		0.65	10.5	0.93		
Leaves	Ruhiyat, 1989b	5–7	14	x	47.10	2.51	1.630			21.73	5.97	2.09		0.315
				std	4.58	0.93	0.271			5.51	4.91	0.75		0.208
	Pujawanti 1991	5	3	x		2.99–3.42								
	Nykvist *et al.* 1996	3.6–3.8	40	x		3.13	1.3	2.1		15.2	4.5	1.1		
	Amir & Wan. 19946		20	x		2.14–2.35	0.1–1.1			4.0–6.5	3.3–4.7	1.8–1.9	0.2–0.3	
	Srivastava 1993	'critical value'					< 1.3			< 6.0	< 2.0	< 1.1		
		'normal range'				> 3	1.3–1.5			> 10.0		1.5–2.0		
Branches	Ruhiyat 1989	5–7	15	x	45.93	0.33				3.48	2.63	0.63	0.035	
				std	0.18	0.12				1.38	0.65	0.12	0.054	
	Pujawanti, 1991	5	3	x		0.56–0.77								

x = mean, std = standard deviation.

Table 3 Nutrient concentration in stemwood, stembark, branches and leaves of *Eucalyptus deglupta*

Component	Reference	Age (y)	n		C (%)	N (%)	P	S	Na	K	Ca (mg g^{-1} dry matter)	Mg	Mn	Fe	Al
Stemwood	This study	8.5	15	x	49.7	0.081	0.0354	0.1062	0.0049	1.820	0.710	0.227	0.0276	0.0292	0.014
				std	0.16	0.01	0.04	0.02	0.02	0.53	0.15	0.04	0.01	0.02	0.04
	Ruhiyat 1989	5.1–9	47	x		0.049				1.485	1.108	0.2025			
Stembark	This study	8.5	15	x	47.2	0.495	0.3163	0.5783	0.0732	19.07	8.40	1.367	0.2312	0.0387	0.057
				std	0.50	0.13	0.04	0.10	0.04	3.35	2.85	0.35	0.06	0.02	0.02
	Ruhiyat 1989	5.1–9	4	x	43.3	0.295				11.193	13.848	1.105			0.124
				std	0.83	0.03				2.18	3.90	0.27			0.10
Leaves	Syahrinudin 1997	1–6	15	x		2.03	1.002			12.43	6.32	1.62			
		6	3	x		2.09	0.88			13.21	5.08	1.30			
	Ruhiyat 1989	5.1–9	27	x	48.09	2.03	1.19			14.34	6.56	2.44			0.21
				std	4.82	0.2	0.21			4.6	2.8	0.34			0.30
	Hernawati 1993	5	3	x		1.97–2.02									
	Lamb 1977	1.5	96	x		0.64–2.04	1.0–6.9			4.4–17.8	4.6–14.0	1.3–4.2	0–0.27	0.03–0.15	
			8	x		1.77–3.36	3.6			10.3–14.8					
Branches	Syahrinudin 1997	1–6	15	x			0.643			10.41	8.77	1.46			
		6	3	x			0.337			10.95	6.12	0.85			
	Hernawati 1993	5	3	x		0.39–0.46									
	Ruhiyat 1989	5.1–9	20	x	45.9	0.267				4.16	2.75	1.22			0.006
				std	1.36	0.126				1.07	0.82	1.43			0.026

x = mean, std = standard deviation

Table 4 Nutrient concentration in stemwood, stembark, branches and leaves of *Paraserianthes falcataria*

Component	Reference	Age (y)	n		C (%)	N (%)	P	S	Na	K	Ca (mg g^{-1} dry matter)	Mg	Mn	Fe	Al
Stemwood	This study	4	15	x	48.1	0.179	0.1424	0.3852	0.0296	3.7224	2.5379	0.2047	0.015	0.0218	0.011
				std	0.25	0.06	0.06	0.16	0.04	1.42	0.79	0.07	0.01	0.03	0.01
	Ruhiyat 1989	5–10	34	x	45.4	0.088				1.92	3.01	0.17			0.027
				std	1.24										0.067
Stembark	This study	4	15	x	48.5	1.412	0.7884	1.76	0.0237	8.3484	10.4431	0.5061	0.0869	0.0618	0.026
				std	0.57	0.20	0.18	0.81	0.04	1.31	2.96	0.1	0.02	0.02	0.02
	Ruhiyat 1989	5–10	3	x	44.8	1.473				7.06	13.30	0.74			0.077
				std	0.53	0.13				1.23	2.46	0.20			0.01
Leaves	Ruhiyat 1989	5–10	27	x	45.4	2.94	1.56			17.09	9.66	2.89			0.36
				std	2.38	0.63	0.41			3.35	5.48	0.83			0.32
Branches	Ruhiyat 1989	5–10	3	x	45.75	0.54				4.68	4.48	0.46			0.03
				std	30.34	0.17				1.28	1.87	0.19			0.04

x = mean, std = standard deviation

significantly from each other. All nutrient concentrations in the stembark, except for Ca and S, were significantly different between all species.

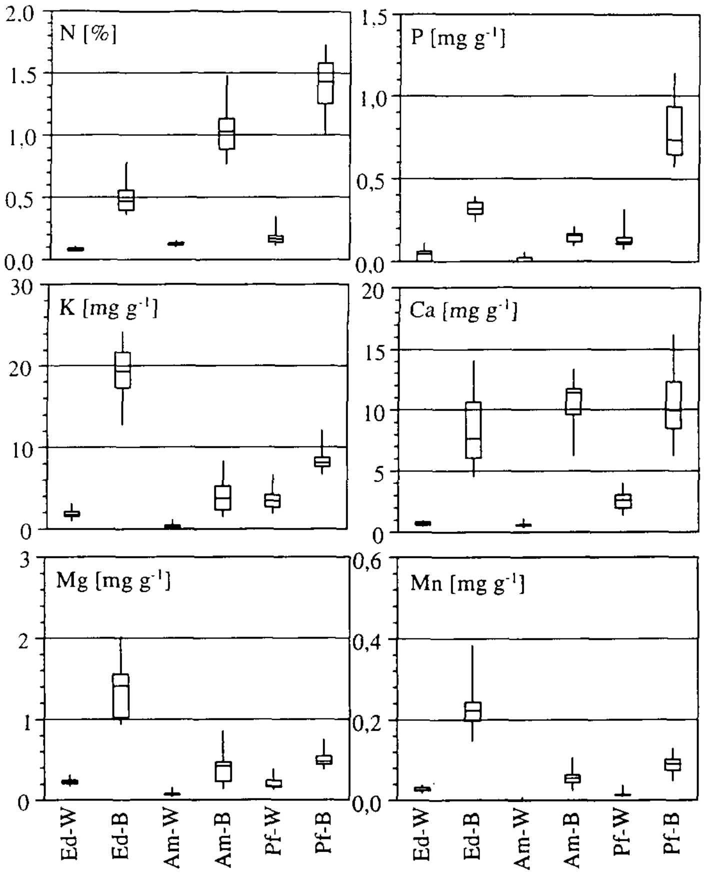

Figure 1 Nutrient concentrations in stemwood (W) and stembark (B) of *Eucalyptus deglupta* (Ed), *Acacia mangium* (Am) and *Paraserianthes falcataria* (Pf). Horizontal line in box indicates median, box indicates 50% range of variation and whiskers indicate 90% range of variation (n per species = 15).

Weight-volume ratio

Results of regression analysis for the weight-volume ratio in different components of *A. mangium, E. deglupta* and *P. falcataria* are summarised in Table 5. Using tree volume as an independent value (x) equations 3 and 5 gave the best fit to the data by Ruhiyat (1989). The R^2 values obtained in this study exceeded 0.82 (Table 5). The weight-volume ratios were only applicable for the range of data tested. A tree volume of 1.2, 2.0 and 4.1 m^3 were the upper values for *A. mangium, E. deglupta* and *P. falcataria* respectively.

Table 5 Correlation between weight of tree component (y) and various tree parameters for *Acacia mangium, Eucalyptus deglupta* and *Paraserianthes falcataria*

Species/ component	n[a]	x = volume (m^3)	R^2	x = dbh × h (m^3)	R^2	x = dbh (cm)	R^2
A. mangium							
Range		1.22–0.01		3.11–0.02		36.8–4.2 cm	
Mean		0.30		0.78		17.1	
Stemwood	14	$y = 369.38x$	0.97	$y = 145.06x$	0.97	$y = 1.1135x^{1.6056}$	0.70
Stembark	14	$y = 29.001x^{0.5204}$	0.89	$y = 17.83x^{0.5204}$	0.89	$y = 0.2368x^{1.4522}$	0.71
Branches	15	$y = 63.264x$	0.83	$y = 25.133x$	0.86	$y = 0.0356x^{2.0777}$	0.75
Leaves	14	$y = 9.9605x^{0.5489}$	0.89	$y = 5.9628x^{0.5489}$	0.89	$y = 0.0755x^{1.4326}$	0.84
E. deglupta							
Range		1.98–0.009		4.51–0.02		37.1–5.1	
Mean		0.82		1.86		23.9	
Stemwood	20	$y = 291.81x^{0.916}$	0.98	$y = 137.43x^{0.9167}$	0.98	$y = 0.0632x^{2.5371}$	0.96
Stembark	20	$y = 15.4x^{0.6671}$	0.97	$y = 8.9035x^{0.6671}$	0.97	$y = 0.0313x^{1.8647}$	0.97
Branches	20	$y = 29.0924x^{1.1912}$	0.86	$y = 11.488x^{1.1312}$	0.86	$y = 0.0005x^{3.2876}$	0.93
Leaves	19	$y = 11.098x^{1.0538}$	0.90	$y = 4.6701x^{1.0538}$	0.90	$y = 0.0005x^{3.0313}$	0.95
P. falcataria							
Range	15	4.12–0.01		7.5–0.02		47.7–5.2	
Mean	15	1.04		1.88		22.6	
Stemwood	15	$y = 241.68x$	0.96	$y = 132.87x$	0.97	$y = 0.104x^{2.3555}$	0.91
Stembark	15	$y = 16.607x$	0.97	$y = 9.13x$	0.97	$y = 0.0102x^{2.2584}$	0.91
Branches	15	$y = 32.578x$	0.91	$y = 17.91x$	0.91	$y = 0.0136x^{2.3268}$	0.78
Leaves	15	$y = 2.2898x$	0.99	$y = 2.289x$	0.99	$y = 0.0034x^{2.1801}$	0.83

[a] number of sample trees

Based on the data reported by Ruhiyat (1989), stemwood contributed between 71–85% of total above ground phytomass while stembark, branches and leaves accounted for 5–11, 8–14 and 2–4% respectively (Table 6). The relative proportion of the different components differed with tree age and species. Generally, relative percentage of stembark, branches and leaves decreased with increasing age (Table 6). While *P. falcataria* and *E. deglupta* had similar distributions of component weights, *A. mangium* had a much smaller stemwood component.

Above-ground nutrient storage

Calculated nutrient storage per stand depended on both stand volume and species (Table 7). For a stand volume of 200 m^3 ha^{-1}, N storage in stemwood and stembark was much higher in *A. mangium* stands (202 kg ha^{-1}) than in *P. falcataria* (133 kg ha^{-1}) or *E. deglupta* stands (75 kg ha^{-1}). Similar patterns were observed for Ca. The P and S stock in stemwood and stembark were high in *P. falcataria* (9.5 and 25 kg ha^{-1} respectively) compared to the other species. Both Mg (21 kg ha^{-1}) and Mn (2.8 kg ha^{-1}) stocks in stems of *E. deglupta* stands were high compared to *P. falcataria* and *A. mangium.*

Having a stand volume of 200 m^3 ha^{-1} resulted in a residual phytomass of 16.2 Mg ha^{-1} for *A. mangium* and approximately 7 Mg ha^{-1} for *E. deglupta* and *P. falcataria* stands (Table 8). Nutrient storage in the slash was generally lower compared to the timber. Exceptions occurred for N and Mg in *P. falcataria* and P and K in *A. mangium.* N and P storage in residual phytomass ranged from 75 to 220% of storage in timber. K, Ca and Mg storage in slash ranged from 29 to 164% of specific nutrient storage in timber.

Table 6 Absolute amounts and proportion of total tree weight in stemwood, stembark, branches and leaves for *Acacia mangium, Eucalyptus deglupta* and *Paraserianthes falcataria*

Age	Stemwood		Stembark		Branches		Leaves	
(y)	(Mg ha^{-1})	(%)	(Mg ha^{-1})	(%)	(Mg ha^{-1})	(%)	(Mg ha^{-1})	(%)
A. mangium								
7	76.7	79.5	7.9	8.2	9.7	10.0	2.3	2.3
6	45.7	67.8	7.5	11.0	11.6	17.1	2.7	4.0
5	39.2	66.5	8.4	14.3	8.3	14.1	3.1	5.2
Mean		71		11		14		4
E. deglupta								
9	73.9	84.0	3.86	4.4	7.7	8.8	2.5	2.9
9	94.0	86.2	4.64	4.3	7.9	7.2	2.5	2.4
7	64.4	83.6	3.39	4.4	6.7	8.6	2.6	3.4
Mean		85		4		8		3
P. falcataria								
10	85.9	81.4	7.0	6.6	11.1	10.5	1.6	1.5
9	69.1	80.5	3.4	3.9	12.0	13.9	1.4	1.7
5	69.9	82.7	5.0	5.9	8.3	9.8	1.3	1.5
Mean		82		5		11		2

Table 7 Nutrient content in stemwood and stembark of *Acacia mangium, Eucalyptus deglupta* and *Paraserianthes falcataria* for different stand volumes

Stand volume (m^3 ha^{-1})	N	P	K	Ca (kg ha^{-1})	Mg	S	Mn
A. mangium							
200	202	2.6	73	161	9.8	14	0.6
300	274	3.5	98	211	13.5	19	0.8
400	341	4.4	121	257	17.1	24	0.9
E. deglupta							
100	42	2.1	118	48	11.7	5.3	1.6
200	75	3.7	206	85	21.0	9.5	2.8
300	106	5.2	286	117	29.5	13.4	4.0
P. falcataria							
200	133	9.5	208	157	11.6	25	1.0
300	200	14.3	312	236	17.4	37	1.5
400	267	19.0	415	315	23.2	49	2.0

Values normalised to a stand density of 800 stems ha^{-1}.

Table 8 Nutrient content in residual slash of *Acacia mangium, Eucalyptus deglupta* and *Paraserianthes falcataria* for different stand volumes

Stand volume ($m^3 ha^{-1}$)	Phytomass ($Mg\ ha^{-1}$)	N	P	K ($kg\ ha^{-1}$)	Ca	Mg
A. mangium						
200	16.2	152	5.8	111	47	14.0
300	23.4	202	7.2	150	67	19.5
400	30.5	247	8.4	186	87	25
E. deglupta						
100	3.2	28.3	1.3	22.7	11.5	4.6
200	6.9	58.1	2.6	47.9	24.7	9.7
300	10.9	88.6	3.9	74.3	38.6	15.0
P. falcataria						
200	7.4	224	10.2	112	64	19
300	11.0	336	15.2	168	96	28
400	14.7	448	20.3	224	127	38

Values normalised to a stand density of 800 stems ha^{-1}.

Discussion

The nutrients accumulated in stemwood and stembark of plantation crops are exported during harvest and represent a loss to the site. Whether this loss endangers sustainable production will depend on the soil stores of plant-available or total nutrients. On a global scale, soils of the humid tropics are ill supplied with such stores; thus plantation managers cannot afford to neglect this nutrient loss. In fact, compensation of this loss by fertilisation may become an economic necessity in order to maintain the required production level.

The information required to estimate the nutrient loss are expected production volume, nutrient concentration and the weight-volume relation. The information on expected production is generated locally. The estimation of the other two data demands a higher investment of labour and costs so that a transfer of information may be warranted. This is why we presented data from our case study. At the present state of knowledge, however, the transfer of data poses a problem as they can be expected to vary with species, age and site conditions. In our study, nutrient concentrations in the different tree components differed significantly between the three plantation species. Comparing our results with other studies of the region (Ruhiyat 1989, Nykvist *et al.* 1996, Syahrinudin 1997) revealed a reasonable similarity between species-specific data.

Our study provided no indication of a possible site influence on nutrient concentration. Nykvist *et al.* (1996) found no correlation between soil nutrient status and nutrient concentrations in *A. mangium* leaves, stemwood and stembark. Amir & Wan (1994) encountered a significant correlation between K concentration in leaves of the same species as well as the total and exchangeable K storage in the soil.

Our results emphasised the importance of nutrients in the bark and slash for plantation management (Fölster & Khanna 1997). Bark is usually exported while slash is frequently burnt. The actions imply total or partial loss of nutrients which could at least be substantially reduced by appropriate management practices (Mackensen *et al.* 1996, Mackensen 1998).

Conclusion

Despite the popularity of industrial plantations in Southeast Asia, little is known about the nutrient content in above-ground tree components. Significant differences in the nutrient content of the different species indicate that the replenishment of nutrient losses through timber harvest must refer to species-specific conditions. The necessity to estimate the nutrient content of above-ground tree components for an improved nutrient management requires further regional studies on nutrient concentration of plantation species and its correlation to site conditions.

Information on nutrient concentration in plantation tree components should be collected and evaluated for the humid tropics on a global scale. Our own attempt at such a task have not yet yielded a satisfactory framework of data applicable to different constellations. This is why we consider examples from case studies a tentative remedy. A regional or global data bank should simultaneously solve the problem of transferring nutrient concentration data from a weight to a volume base. Wood density data differ even within the same species and age group. Bark density data are rare.

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