Immobilization of Nutrients in Plantation Forests of *Pinus merkusii* and *Agathis dammara* growing on Volcanic Soils in Central Java, Indonesia

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Biomass production and nutrient immbolization over 25 years for plantation forests of Pinus merkusii *and* Agathis dammara *growing on volcanic soils in South Central Java, Indonesia were assessed. Growth of* P. merkusii *was better than* Agathis, *especially during the first 15 years. The effect was species-determined rather than caused by differences in site class. Nutrient uptake by the typically over-stocked pine plantation was significantly less than for the normally stocked* Agathis *stand. It is concluded from a comparison of gains and losses of nutrients for these ecosystems that whole-tree harvesting of* Agathis *should not be practised in Central Java, whilst this would be feasible from a nutrient point of view for the pine foreststite. The limiting nutrient for sustained production of* Agathis *was P and possibly N in the case of* P. merkusii. *Care needs to be taken to control nutrient losses via erosion during taungya.*

The area of forest plantations in the tropics is increasing rapidly: it almost tripled between 1965 and 1980 and the rate of planting in the 1980s is expected to double that of the 1970s (Evans, 1982). Recently, concern has been expressed about the effects that such fast-growing tree plantations with their high nutrient demands may have upon soil nutrient reserves, especially when grown in short rotations (Lundgren, 1978; Chijioke, 1980).

Information on nutrient immobilization by forest plantations growing under tropical conditions is now gradually becoming available: examples are the work on *Pinus caribaea, Gmelina arborea* and *Tectona grandis* in Nigeria by Egunjobi and Baba (1979), Chijioke (1980) and Nwoboshi (1983) respectively, the studies conducted on *P. patula* and *Cupressus lusitanica* on volcanic soils in upland Tanzania (Lundgren, 1978) and work on *P. oocarpa* (Castro *et al.*, 1980) and *Eucalyptus grandis* (Bellote *et al.*, 1980) in eastern Brazil. However, virtually all data on tree growth and nutrient content come from *first* rotation stands. Evans (1982) summarized the sparse evidence available on long-term productivity of tropical forest plantations and suggested that the reduction in productivity which is occasionally reported for second rotation stands, was caused by climatic circumstances (prolongued droughts) or soil erosion rather than too high a nutrient uptake.

In the absence of actual data on **successional** stands one may establish a nutrient balance sheet in which the various gains (bulk precipitation, rock weathering, etc.) and losses (leaching, erosion, harvesting, etc.) for a plantation forest ecosystem are compared in association with soil nutrient reserves. Such computations were recently presented by Bruijnzeel and Wiersum (1984) for plantations of *Agathis dammara* up to 35 years of age growing on andesitic volcanic ashes in Java, Indonesia.

The present paper is an extenstion of the latter in that it compares (preliminary) nutrient immobilization rates for *P. merkusii* plantations up to 21 years of age with those for *Agathis dammara* growing under very similar climatic and edaphic conditions. Some implications for local plantation forest planting and management are discussed as well. The need for this type of information is growing, since nowadays planting of *P. merkusii* is progressing rapidly in southern central Java (usually on lands formerly occupied by teak) to provide pulp for paper manufacturing. Taungya (locally called "tumpangsari") is generally practised for two to three years after planting (Bruijnzeel & Wiersum, 1984).

SITE DESCRIPTION

Observations on biomass were made in August/September 1977 in four plantations of *Agathis dammara* (7, 11, 21 and 35 years old) as well as in a 12-year old stand of (*Pinus merkusii* (Bruijnzeel, 1983a). In May, 1983 additional data were collected on the biomass of 7 and 21-year old pine plantations, whilst measurements of diameter and height were again taken in the pine stand already sampled in 1977. All plantations are managed by the Indonesian State Forest Enterprise Perum Perhutani. The *Agathis* plantations belong to the Midangan complex, located *c.* 5 km south of the town of Banjarnegara, Central Java (7°26′ S; 109°45′ E), whilst the pines constitute the Gunung Pulosari complex, situated 3.5 – 6 km further west. All plantations lie on the main water divided between the Serayu and Lokuloh river basins on deep soils derived from andesitic tuffs underlain by Tertiary volcanic breccias. *Table 1* summarizes some climatic and edaphic data for the sites investigated; further information on soil fertility is given later.

The *Agathis* plantations showed average growth for Javanese conditions (*Table 1*) and belong to site class III according to local yield tables (Suharlan *et al.*, 1975). This corresponds to an average annual increment of 20–22m^3/ha/year (20- and 35-year periods respectively). Undergrowth in these plantations is dominated by *Eupatorium sp.* and *Melastomataceae* (moister sites) and by *Imperate cylindrica with Melastoma, Eupatorium* and *Stachytarpheta* on drier and more open sites.

By contrast, the pine plantations all showed excellent growth (*Table 1*) according to local tables and classified as site class V (older stands) or even better (7-year old stand). Ideally this would imply average annual increment rates of 19–20 m^3/ha/year over a 20-year period (Suharlan *et al.*, 1975). On average *Agathis* exhibits slower initial growth than does *P. Merkusii* under Central Javanese conditions, but generally productivity (per hectare) of the former starts to exceed that of the latter after about 20 years (Suharlan *et al.*, 1975).

Undergrowth in the overstocked pine plantations is poorly developed and dominated by ferns, grasses, *Eupatorium* and *Clidemia hirta.* Further information on the sites investigated in 1977 is given by Bruijnzeel (1983a).

METHODS

The above-ground living biomass of all plots has been estimated as follows: diameter at breast height (DBH) and height of all trees in sampling plots ranging from 0.125 to 0.30 ha were measured after a general structural vegetation description had been made (Team Vegetation and Erosion, 1979). The DBH of each tree was transferred to basal area (BA) and the mean BA of each plot (MBA) calculated. This again was transferred to diameter to arrive at the diameter (DBA) of the "average" tree. Inserting the latter value in the corresponding diameter/height curve yielded the height of the "average" tree.

TABLE 1. SITE AND STAND CHARACTERISTICS

Parameters	*Agathis dammara* I	II	III	IV	*Pinus merkusii* I	II	III
Elevation (m.a.s.l.)	560 ± 20				435	550	
Precipitation (mm/yr)	4770 ± 1150[a]				*c.* 4000	*c.* 4500	
Evaporation[b] (mm/yr)	1345				1430	1375	
Soil type[c]	Humic Andosol				Humic Cambisol[d]		
Pre-planting history	All plantings at least second rotation-stands; former crops include teak, mulberry of coffee				Sites I & II were preceded by a least 35 years of teak growing; site III by 30 years of mahogany, possibly preceded by a rotation of teak		
Age (yr)	7	11	21	35	7	12	21
Average height (m)	9.2	14.1	22.1	27.3	11.9	19.8	26.9
Average diameter (cm)	9.5	16.6	32.0	44.6	15.4	23.7	33.1
Mean basal area (cm2/tree)	71	217	803	1564	185	441	861
Stocking (no/ha)	2110	580	450	160	1355	720	595
Optimum stocking (no/ha)[e]	1830	1040	455	320	665	370	245

[a] 1926–1977

[b] Penman open-water estimate

[c] FAO/UNESCO (1974) classification

[d] classification for Pinus III still tentative

[e] according to Suharlan *et al.* (1975).

Trees having dimensions as close as possible to the "average" trees were selected for felling to obtain information on stem-, branch-, twig-, cone- and leaf/needle weights. For various reasons only two sample trees could be taken during the 1977 investigation (Bruijnzeel, 1983a). Four trees were sampled in the 21-year-old pine stand and five in the 7-year-old plantation (1983 investigation).

Branches, twigs, seed cones, smaller stems (7-year old stands) and needles/leaves (*Agathis* has elliptic, leathery leaves) were weighted directly in the field with a precision of 0.05 kg. Dry weight biomass was computed by drying samples of known wet weight in the laboratory for 24 or 48 hours at 70° C in duplo. Stemwood volume (diameter >7 cm including bark) was estimated in the field by dividing the trunks in 1 m sections and determining the diameter of each section at midpoint; sectional volumes were summed to give total stem volume. In some cases (usually the lower parts of the pine trunks) the perimetric measurements were corrected for the irregular shape of the bark through factors obtained from discs taken at various heights along the stems. Trunk volumes were converted to oven-dry weights by weighing sample discs of known volume. Average specific gravities (including bark) for the two species were very similar: 0.42 ± 0.02 for *Agathis* (7–21 years old), 0.434 ± 0.045 for 7-year old pines and 0.446 ± 0.058 for 21-year old pine. Total above-ground tree biomass was obtained by adding the oven-dry weights of the various components.

Undergrowth and litter on the forest floor were sampled in three 1-m^2 quadrats in August, 1977 (*Agathis*, 12-year old pines) and in five 1-m^2 quadrats in May, 1983 (7, 18 and 21-year-old pines). Oven-dry weights were established again by weighing and drying of subsamples.

Branches, twigs, cones and foliage were sampled in duplo from each sample tree for chemical analysis. Needle/leaf- and twig samples were taken after thoroughly mixing large volumes of material, whilst branches were sampled on a basis of representativity. Stemwood discs were taken at 50 cm (1977) or at three to four heights along the stem (1983). All oven-dried samples (including litter and undergrowth) were shipped to the Netherlands, ground to pass a 1 mm sieve and subsequently analyzed for Ca, Mg (applying a 1% $LaNO_3$ solution), Fe, Mn (atomic absorption flame photometry), Na, K (emission flame photometry) and P (colorimetrically) after wet ashing with $HNO_3/HClO_4$. Nitrogen was determined with an azotometer by burning in a pure oxygen stream. Further analytical details can be found in Bruijnzeel (1983a).

Nutrient gains and losses to the plantations (as coupled to the hydrological cycle) were estimated by means of the small-watershed mass-balance technique, which involves computation of the water balance of a drainage basin in conjunction with regular analysis of the chemical composition of precipitation and streamflow (Bruijnzeel, 1983b). Erosion rates associated with taungya cultivation were estimated from local observations and data from comparable locations elsewhere on Java, as summarized by Bruijnzeel and Wiersum (1984). The corresponding nutrient losses were computed by inserting on-site soil chemical concentrations.

RESULTS AND DISCUSSION

Biomass Accretion

Above-ground biomass for *Agathis* and pine trees up to 21 years of age is summarized in *Table 2*.

Crown and stem weights for *P. merkusii* appear to be much higher than for *Agathis* trees of the same age, except for the 21-year old pine stand, whose crown mass had been reduced by villagers in search of firewood. More realistic estimates of needle- and branch masses for these trees, based on some of the pine biomass studies listed in the introductory section and the younger two stands presently investigated, would amount to 30 and 130 kg/tree respectively (i.e. again higher than for *Agathis* of that age).

With *Agathis*, the increase in biomass with age for the various components shows regular trends, which are well described by quadratic curves (Bruijnzeel, 1983a). As for *P. merkusii*, this proved possible only for stemwood mass, due to the exceptional nature of the oldest stand with respect to crown mass. Stemwood growth curves for both species are presented in *Figure 1*.

Pine stemwood mass per tree is seen to be larger throughout the period considered (25 year). The observed difference, however, cannot entirely be ascribed to differences in

TABLE 2. ABOVE-GROUND LIVING BIOMASS[a] FOR *AGATHIS* AND *PINUS MERKUSII*

Item	*Agathis dammara*[b]			*Pinus merkusii*[c]		
	I[d] *7 Years*	*II*[d] *11 Years*	*III*[d] *21 Years*	*I*[d] *7 Years*	*II*[e] *12 Years*	*III*[f] *21 Years*
Leaves	2.8 ± 0.4	9.7 ± 0.1	26.0 ± 8.0	7.1 ± 0.8	16.6 ± 0.3	12.9 ± 0.9
Branches	5.0 ± 0.1	11.4 ± 0.9	41.6 ± 4.7	7.8 ± 0.7	38.2 ± 3.3	30.8 ± 2.6
Twigs		8.1 ± 3.5	17.6 ± 2.3	5.3 ± 0.8	7.2 ± 1.2	18.0 ± 4.0
Cones	–	–	–	1.3 ± 0.5	–	1.7 ± 0.9
Bark	15.0 ± 3.0	70.5 ± 3.7	364.2 ± 46.3	7.9 ± 1.2	24.6 ± 1.3	46.9 ± 4.4
Stemwood				35.2 ± 3.0	128.2 ± 6.9	420.8 ± 30.4
Total	22.8 ± 3.5	100.3 ± 8.0	449.4 ± 61.3	64.9 ± 3.8	214.8 ± 12.4	531.2 ± 23.8

a = Accuracy of kg dry wt. not to last digit.
b = *Agathis* at site class III.
c = *Pinus* at site class V.
d = Mean of 2 trees.
e = Mean of 5 trees.
f = Mean of 4 trees.

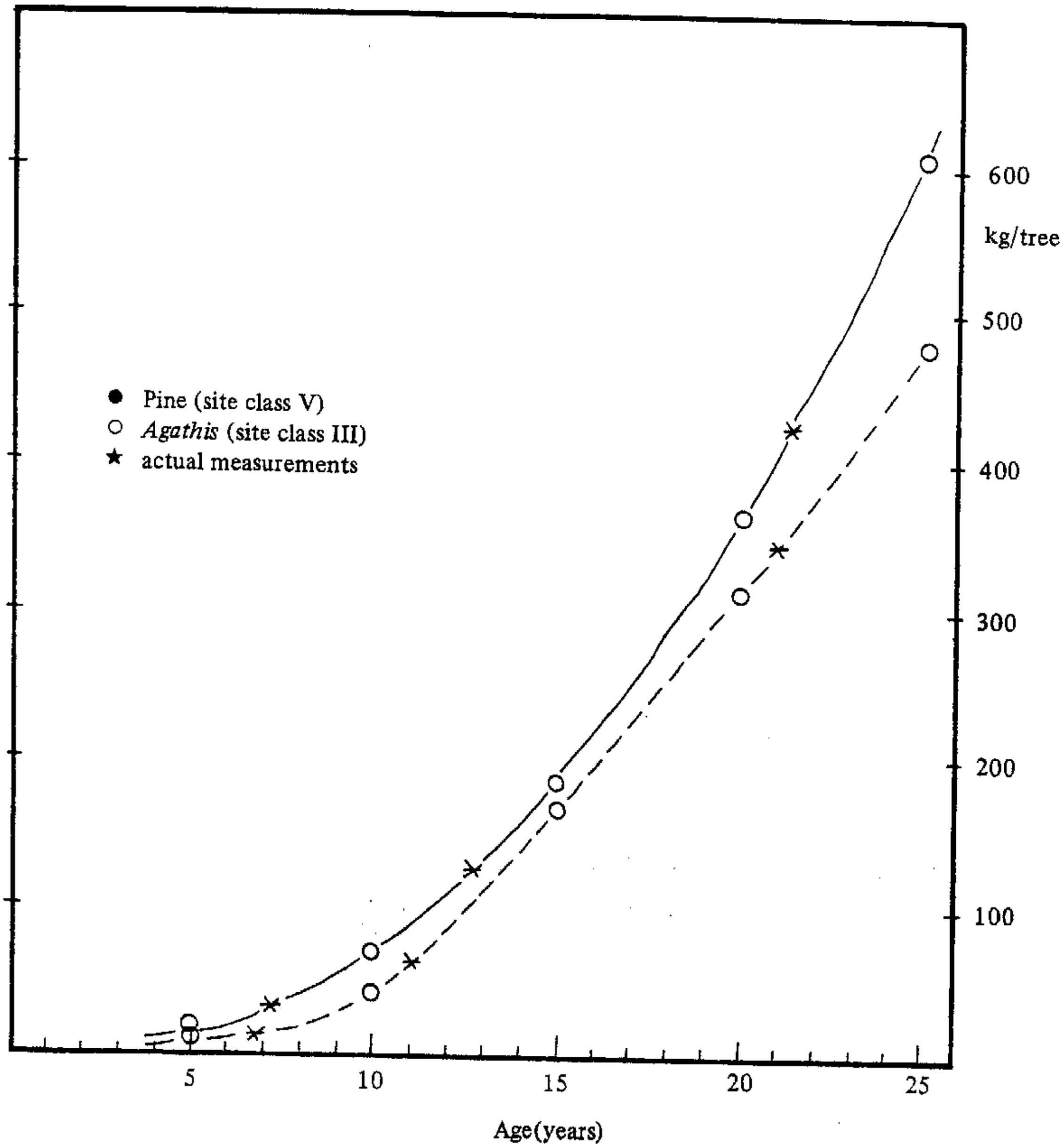

Figure 1. Stemwood growth curves for P. merkusii (site class V) and A. dammara (site class III)

site class between the investigated stands (i.e. average growth for *Agathis* and above average performance for *P. merkusii*), at least not for the younger plantations. Standard yield tables (Suharlan *et al.*, 1975) suggest a 30% increase in stem volume per tree when going from average conditions to site class V. On the other hand, the stem biomass ratio for 21-year old *Agathis* and pine trees equals the site class effect (1.27) predicted by the yield tables, perhaps marking the beginning of more serious competition in the over-stocked pine stand.

It is concluded, therefore, that under the field conditions covered by the present study, yields of merkusii pine plantations may be significantly higher than those for *Agathis*, especially when grown in well-stocked short rotations (e.g. 15 years).

Nutrient Immobilization

The data on tree biomass presented in *Table 2* have been used to calculate cumulative production for an ideally stocked plantation of *Agathis dammara* (site class III) grown in a rotation scheme of 25 years. Assuming tree stockings for the three investigated pine plantations (*Table 1*) to be representative for the various stages of one (typically over-stocked) pine stand, then cumulative production over 25 years can be computed as for *Agathis*. Inserting the appropriate nutrient concentrations yields the associated nutrient immobilization over the rotation period (*Table 3*).

TABLE 3. CUMULATIVE PRODUCTION AND ASSOCIATED NUTRIENT IMMOBILIZATION FOR AN OVER-STOCKED PLANTATION OF *P. MERKUSII* (SITE CLASS V) AND A NORMALLY STOCKED PLANTATION OF *AGATHIS DAMMARA* (SITE CLASS III) OVER A ROTATION PERIOD OF 25 YEARS

Parameters	*Production (t/ha)*		*Nutrients (kg/ha)*[a]				
	Crop	*Thinnings*	*Ca*	*Mg*	*K*	*P*	*N*[b]
	Pinus merkusii						
Needles	27	10	401	87	272	26	529
Branches	81	18	259	30	55	10	90
Twigs	5	12	322	35	88	13	145
Bark	43	15	163	17	32	12	163
Wood	400	87	413	97	219	73	435
Total tree	*602*	*142*	*1558*	*266*	*666*	*134*	*1362*
Litter	16.1		132	29	34	5	103
	Agathis dammara						
Leaves	25	20	865	165	341	49	569
Branches	35	26	262	55	248	43	146
Twigs	18	16	294	91	239	48	178
Bark	16	10	409	61	67	17	79
Wood	271	175	423	98	281	75	758
Total tree	*365*	*247*	*2253*	*470*	*1176*	*232*	*1730*
Litter	5.3		90	14	12	2.5	40

[a] unrounded values

[b] concentrations from 35-year old sample trees for *Agathis.*

[c] actually sampled in 21-year old stands.

Before drawing conclusions from *Table 3,* the following should be considered: :

- To-date chemical concentrations for the 21-year-old pine trees are not available and those for the 12-year-old stand have been used instead. In the case of Agathis no trends with age in concentration levels could be observed (Bruijnzeel, 1983a) and the substitution referred to will probably not influence the results to a great deal.

- Crown biomass for 21-year old pine trees was estimated from literature data in combination with observations in the younger two stands; proportional contributions of needles, branches and boles for 10-year-old *P. patula* trees growing under similar conditions in Tanzania (Lundgren, 1978) were virtually identical to those for 12-year old *P. merkusii.* Proportions observed for 20-year-old patula pines should therefore be applicable to 21-year old merkusii pines without causing serious deviations.

- Nutrient uptake rates are generally better expressed on an area basis (Evans, 1982). It is unknown too what extent the high degree of over-stocking so typical for these pine plantations (BA 51:1 m^2/ha vs 27.9 m^2/ha "normally") may influence the results.

On the other hand, chemical concentrations in the normally stocked 21-year old *Agathis* stand (BA 36.1 m^2/ha) did not differ significantly from those observed for an understocked 11-year old stand (BA 66% of "normal" value) next to it (Bruijnzeel, 1983a). The effect is therefore thought to be moderate at most.

Despite a higher organic production by the pine stand (site class V) as compared to the *Agathis* plantation (of average site class) nutrient immobilization by the latter is distinctly higher *(Table 3)*, mainly as a result of generally higher nutrient concentrations (Bruijnzeel, 1983a). Amounts of Mg, K and P incorporated by the pines are about 57% of those taken up by *Agathis*; for Ca and N these figures read 69% and 79% respectively.

Table 3 also gives information on the distribution of nutrients over the various tree components, which can be used to estimate possible effects of various harvesting intensities. The two species show distinctly different distribution patterns: with *Agathis* 19–21% of the totally incorporated Ca and Mg is found in stemwood; with pines the corresponding values are 27–36%. Potassium and N in *Agathis* stemwood make up 24% and 44% of the total, in pinewood 33% and 32% respectively. Also, relative immobilization of P in stemwood differs considerably: 54% for *Agathis* vs. only 32% for *P. merkusii.*

Considerable amounts of nutrients can therefore be conserved during harvesting or thinning by leaving foliage, bark and branches on-site. However, this is not a feasible option in view of the critical local firewood situation.

Indeed, it is now common practice to have the larger branches taken away for firewood when harvesting or thinning these forests (Bruijnzeel and Wiersum, 1984). Associated nutrient losses differ between species again: for *Agathis* values range from 8% (N) via 12% (Ca, Mg) to *c.* 20% (K, P). Corresponding losses for pine branch removal make up 7–8% (N, P, K) to 11% (Mg) and 17% (Ca).

Another aspect in which the two plantations differ is in the amounts of nutrients temporarily locked in the litter layers on the forest floor (*Table 3*), amounts in the 21-year old pine stand being considerably higher. This not only reflects the higher tree density (and therefore litter production) of the latter, but also a difference in decomposition rate. Observations of nutrient dynamics of the litter layers in these forests (Bruijnzeel, 1983a) showed nutrient residence times in pine litter to be about twice as long as for *Agathis* litter.

Although nutrients stored in the litter layer may theoretically become available to a subsequent rotation and as such would require careful treatment during harvesting operations (Carey *et al.*, 1982), current practice (burning of slash) destroys much of it.

Towards a Nutrient Balance Sheet for *P. Merkusii* Plantations

It is of interest to put the above findings into the perspective of overall nutrient gains via bulk precipitation, weathering, etc.) and losses (deep seepage, harvesting, erosion during intercropping) for these plantations over a full rotation period as has been done for *Agathis dammara* by Bruijnzeel and Wiersum (1984).

Table 4 is an attempt to do so for an overstocked pine plantation grown on a rotation scheme of 25 years. Since both geological substratum and climatological situation (*Table 1*) as well as bulk precipitation quality (Bruijnzeel, 1983a) for the 21-year-old pine forest plot are very similar to those for the *Agathis* sites, weathering data and deep seepage losses have been adapted from Bruijnzeel (1983b). Losses associated with intercropping were taken from Bruijnzeel and Wiersum (1984) and immobilization rates from *Table 3.*

Without going into too much detail here, it can be readily seen from *Table 4* that amounts of nutrients involved in total-tree harvesting are about balanced by nutrient inputs. This is in contrast to the situation for the *Agathis* plantations where total-tree harvesting losses exceeded inputs considerably, especially for P (Bruijnzeel and Wiersum, 1984). There seems to be less danger of productivity decline in the case of *P. merkusii.* Interestingly enough, however, N levels in foliage and branches (but not in stemwood) of *P. merkusii* are lower than those found for *P. patula* in upland Tanzania (Lundgren, 1978) or *P. oocarpa* growing on poor soils in Brazil (Castro *et al.*, 1980). Also, N reserves in the upper metre of soil under pine amounted to *c.* 90% of those found under *Agathis* (Bruijnzeel, 1983a). However, in the absence of data on N-fixation rates it is not possible to make any meaningful statements.

Nutrient losses through harvesting agricultural produce during taungnya appear to be minor (except perhaps for N), but losses associated with erosion occurring during this period may be sizeable. It can be concluded that care should be taken to minimize such losses, especially under a total-tree harvesting regime. The removal of branches for firewood does not seem to pose any serious nutrient problems.

CONCLUSION AND RECOMMENDATIONS

Although the data set is preliminary with respect to chemical aspects for pines, the following conclusions emerge:

- Production of densely stocked plantations of *P. merkusii,* both per tree and per hectare, is significantly higher than for *Agathis dammara*, especially during the first 15 years.
- During this period the effect is species-inherent rather than caused by differences in site class between investigated stands.
- Despite higher biomass production nutrient immobilization in densely stocked pine stands is significantly lower than in normally stocked plantations of *Agathis* when grown on a 25-year rotation scheme.

TABLE 4. NUTRIENT INPUTS AND OUTPUTS FOR AN OVERSTOCKED PLANTATION OF *P. MERKUSII* (SITE CLASS V) OVER A ROTATION PERIOD OF 25 YEARS

Inputs & Outputs	*Nutrient (kg/ha/rotation)* Ca	Mg	K	P	N
Inputs					
atmospheric	245	70	180	70	430
weathering	1870	965	1015	82	–
fixation					?
total inputs	*2115*	*1035*	*1195*	*152*	?
Outputs					
leaching	690	720	520	22	280
stemwood harvest	413	97	219	73	435
stemwood & branch harvest	672	127	274	83	525
total-tree harvest	1558	266	666	134	1362
agricultural intercropping[a] grain only	12	5	27	14	95
(upland rice + maize) grain only + straw	20	8	62	18	115
erosion[ab] during intercropping "available"[c]	210	50	90	3	6
"total"				160	610
nutrient reserves[c] in upper metre of soil[d]	7650	2200	5600	345	180

[a] two-year period

[b] 1 cm/year

[c] "readily available", i.e. extractable by NH_4 acetate at pH = 7 (bases) or a 2% solution of citric acid (P); 1% of total (N)

[d] 12-year old pine stand.

- In contrast to *Agathis* where whole-tree harvesting may cause serious depletion of soil nutrient reserves, there does not seem to be such a great danger in the case of *P. merkusii* (as concluded from a comparison of nutrient gains and losses from the ecosystem.
- The critical element for sustained production of *Agathis* is P; for pine it may be N.
- Nutrient losses associated with erosion during taungnya are considerable as are losses due to deep seepage.

These findings suggest that:

- Total tree-harvesting should be avoided in the case of *Agathis*.
- The recommendation for *Agathis* plantation sites suggested by Bruijnzeel and Wiersum (1984). i.e. to leave nutrient-rich material, such as foliage, twigs and bark, on-site after harvesting, is not strictly necessary for *P. merkusii* sites: h wever, to facilitate local extension work it would be better to extend the above practice to all plantations in the region.
- Care should be taken to minimize nutrient losses from erosion during taungnya, especially with *Agathis* forest plantations.
- The N economy of these forest requires further investigations; fertilizer trials (P,N) should be included in such studies.

ACKNOWLEDGEMENT

The author gratefully acknowledges financial support from the Netherlands Foundation for the Advancement of Tropical Research (WOTRO) under project no's W76-45 (1977 investigations) and WR 84-221 (1983 study). Assistance in the field by Mr. A. Riyadi and Mr. Sutono and in the laboratory by Messrs. H.F.M. Nelissen, H. Wesselman, Miss J.A. Isaaks and Miss R. Vooijs under supervision of Prof. Dr. W.H.O. Ernst, is greatly appreciated. Perum Perhutani is thanked for permission to work in the forests and for support at all levels. Special thanks are due to Mr. J.W. Hildebrand, Ir. P.P.C. van Meer, Dr. Soenardi, and Miss T. Baer. Romee de Vries typed the manuscript and Saskia Kars helped with *Figure 1*.

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