Journal of Tropical Forest Science 1 (2): 145 - 161

ESTIMATES OF EVAPORATION IN PLANTATIONS OF *AGATHIS DAMMARA* WARB. IN SOUTH-CENTRAL JAVA, INDONESIA

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Received September 1988, accepted December 1988.

BRUIJNZEEL, L.A. 1988. Estimates of evaporation in plantations of *Agathis dammara* Warb. in South-Central Java, Indonesia. A water balance is presented for a 19-*ha* catchment covered with 11- to 35-*y* old plantation forest of *Agathis dammara* Warb. in central Java.

During the rainy season the ratio (f) between actual evapotranspiration (ET) and Penman open water evaporation (Eo) remained close to 0.79. The study period included an exceptionally severe dry season. Due to the deep nature of the soils, moisture stress did not limit transpiration (Et) until the last month of the drought (November, f = .69). It was inferred that during years with average rainfall ET would be close to 1070 *mm* yr^{-1}. Measurements of throughfall in 11- and 35-*y* old stands of *Agathis* and in *Chromolina* thicket indicated average rainfall interception (Ei) of 23, 14 and 9% of incident rainfall. Subtracting Ei from ET yielded an average rate of Et of about 400 *mm* yr^{-1} for the entire catchment, a rather low value.

The available information on ET and various tropical land-use types is reviewed .briefly. The presently obtained throughfall figures are discussed in the light of results from over twenty throughfall studies in Southeast Asian forests. The use of a roving gauge technique is stressed if reliable estimates are to be obtained.

Key words: Forest hydrology - catchment water balance - evapotranspiration - throughfall - rainfall interception - tropical tree plantations - Indonesia.

Introduction

With concern about environmental degradation in the humid tropics growing, research efforts have increased in the last decade. Much of the work focuses on the description of processes in undisturbed or recently cleared rain forest areas in the hope that a better understanding of these processes will lead to sound management practices. Reviews of rain forest nutrient dynamics and hydrological aspects are given by Jordan (1985), Vitousek and Sanford (1986) and Bruijnzeel (1986, 1988).

Given the extent of severely eroding, hydrologically and ecologically disrupted lands in the humid tropics, massive reforestation programmes seem to be required. On the other hand, as indicated among others by Hamilton and King (1983) and Bruijnzeel (1986), it may be premature to expect that reforesting such degraded lands will fully restore the original hydrological regime. In general, the data base with respect to the hydrological behaviour of tropical plantation forests is small (Bruijnzeel 1987) and to a large extent consists of throughfall studies.

The aim of the present paper is to provide an estimate of annual evapotranspiration for a plantation forest of *Agathis dammara* Warb. in central Java, Indonesia, with trees ranging in age between 11 and 35 years, as obtained with the catchment water balance method. In addition, it presents data on the amounts of throughfall in these plantations. The results are put in perspective by reviewing the available information on evapotranspiration of tropical plantation forests as compared to other types of land use and by comparing them with the findings of a number of throughfall studies conducted in Southeast Asia.

The present work was carried out between December, 1976 and February, 1978 as part of an integrated biogeochemical investigation (*cf.* Likens *et al.* 1977) studying the rate and mode of weathering of volcanic deposits underlying the study site (Bruijnzeel 1983a).

Material and methods

The experimental area

The 18.7 *ha* Mondo catchment is part of the headwater area of the Lokuloh river and is situated in the South Serayu Mountains, central Java, about 5 *km* south of the town of Banjarnegara at an altitude of 508 to 714 *m. a.s.l.* (Figure 1). The study site receives on average (1926-1977) 4770 *mm* of rain per year, distributed among 176 rain days. The variation in annual rainfall is considerable (Figure 2). The principal seasons are associated with a distinct wind regime. The core of the rainy season (north-west monsoon) lasts from November until March, whereas the south-east monsoon (July until September) is associated with drier conditions (Braak 1929). Usually two months experience rainfall totals of less than 60 *mm* during the latter period. The present observation period, however included a more severe dry season. Temperatures at the study site are generally close to 24°*C* during the wet season, dropping to 21.5°*C* in August. Mean annual Penman open water evaporation total amounts to about 1345 *mm* (Bruijnzeel 1983a).

Basin vegetation consists of *A. dammara* plantations ranging in age between 11 and 35 years and exhibiting different degrees of stocking (Table 1). In the more open parts of the forest (37% of the total area) a vigorous shrub thicket is found, dominated by *Chromolina odoratum* L. and *Lantana cammara* L. on the better sites, with *Imperata cylindrica* L. on drier sites.

In the vicinity of the stream isolated *Artocarpus, Ficus* and *Schoutenia* trees are the remnants of a more exuberant vegetation type present in the area before clearing for coffee cultures in the nineteenth century. Further details of site characteristics are given by Bruijnzeel (1983a).

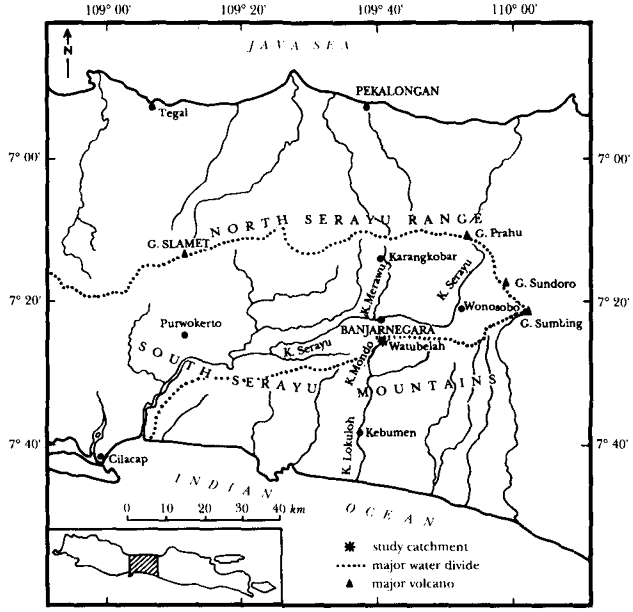

Figure 1. Location of study area

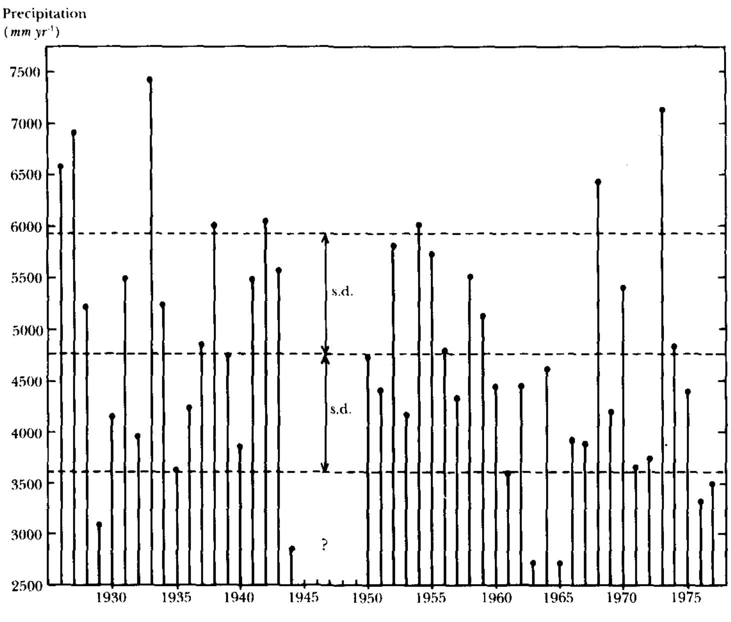

Figure 2. Annual rainfall totals at Watubelah (1926-1944; 1950-1977); s.d. = standard deviation of the mean; source of data: annual publications of the Meteorological Service of Indonesia

Table 1. General characteristics of vegetation in throughfall plots

	Height (*m*)	Average DBH (*cm*)	Number of trees (*/ha*)	Crown cover %	Above-ground living biomass (*t/ha*)
Agathis, 11 years old	14.1 (8-17)	16.6	580	80	58
Understorey (*Imperata*)	0.5-2				
Agathis, 35 years old	27.3 (20-30)	44.6	160	45	180
Understorey (shrubs)	1-2.5				
Chromolina thicket	*ca.* 2-2.5			100	10

Procedures

To compute forest evapotranspiration (ET), use was made of the catchment water balance method (Ward 1975):

$$P = Q + ET \pm \triangle S \pm \triangle G + L \qquad (1)$$

where P = precipitation,
Q = streamflow,
ET = evapotranspiration,
$\triangle S$ = change in soil moisture storage,
$\triangle G$ = change in groundwater storage, and
L = leakage,
with all components expressed in *mm*.

Also, $ET = Ei + Et + Es \qquad (2)$
where Ei = rainfall interception (evaporation from a wet canopy),
Et = transpiration (evaporation from a dry canopy), and
Es = evaporation from the forest flow (neglected here: see Jordan and Heuveldop 1981, Roch 1982).

P was measured with three Hellmann-type raingauges (100 cm^2 orifice) and a Thiessen recording gauge (200 cm^2 orifice) (Figure 3). The standard gauges had their funnels at about 1.5 *m* above the ground to avoid splashing. Under similar tropical conditions Koopmans (1969) did not find a significant difference between the catch of a ground-level gauge and of a standard gauge placed at 1.5 *m* above the surface. Care was taken to avoid placing gauges in the rain-shadows of trees. All gauges were inspected daily at 0700 *h* and the arithmetic mean of the readings was used for the areal estimate. The accuracy of the areal estimate was tested using the method described by De Bruin (1977): the standard error of this estimate (as compared to that for a point measurement) amounted to 1.4% for the entire data set (n = 310) and 1.2% for wet-season data alone (n = 283).

Q was monitored continuously at a 90° V-notch weir (W4 in Figure 3) by means of a Leopold & Stevens "type F" stage recorder. Discharges up to 20 ls^{-1} were determined volumetrically, whereas higher flows were generally measured by means of the salt dilution method (Water Research Association 1970) and occasionally with a Gurley number 622 "Teledyne" current meter. No consistent differences between the two approaches were detected during an earlier phase of the present study (Bruijnzeel 1976). In addition, the discharge of a small diversion ditch leaving the catchment was measured daily using a V-notch blade and the volumetric method (W7, Figure 3). The frequent measurements of streamflow revealed that the rating curve of the lower weir W4 showed a tendency to shift due to alterations in streambed configuration during the rainy season. To calculate the amount of flow for a given period, use was made of the appropriate rating curve. Sometimes uncertainty arose as to the extrapolation of a temporary rating to high stages. In such cases refuge was taken to an empirical relationship derived for the catchment by Bruijnzeel (1976) from two months of detailed observations, which related storm flow volume to rainfall. The overall accuracy of the streamflow measurements was estimated to be 6-10% (Bruijnzeel 1983a).

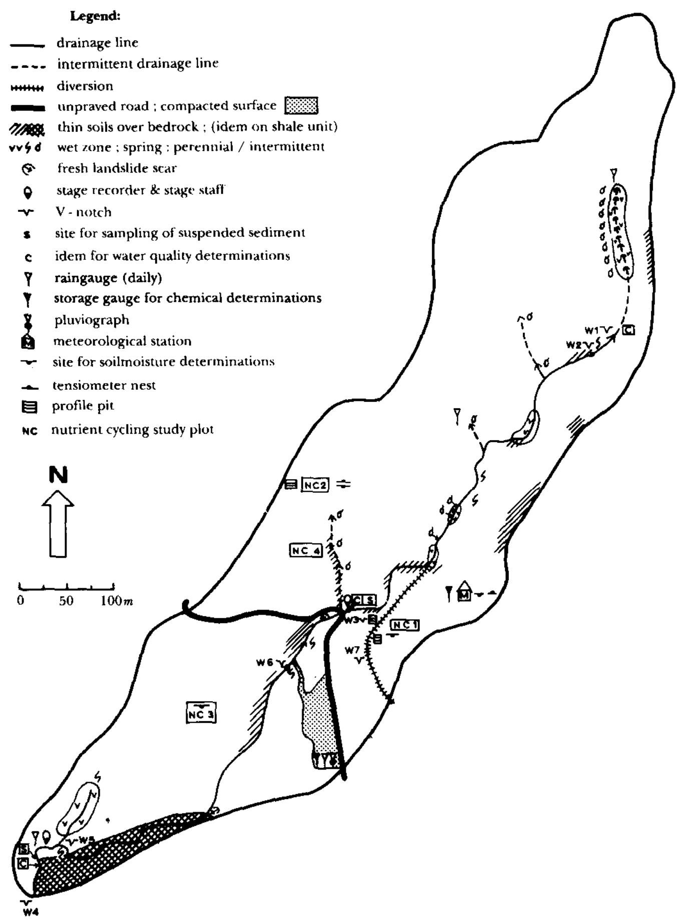

Figure 3. Instrumentation of study catchment

Changes in soil moisture storage ($\triangle S$) were evaluated by sampling three locations (one ridge site and two mid-slope sites, see Figure 3) once a month down to a depth of 225 *cm* for the determination of soil moisture by the thermo-gravimetric method (Reynolds 1970). Values of gravimetric moisture content were converted to volumetric moisture content by multiplication with values for dry bulk density from samples of known volume from walls of nearby soil pits (Figure 3). Although no replicates were taken, later work conducted by Wasser (1987) suggested that spatial variations in bulk density of similar soils in West Java were minor. Although the sampled depth interval covered only a fraction of the total unsaturated zone, the bulk of water extraction by tree roots, at least during the rainy season, must occur in the upper 2 *m* as suggested by observations of root density (Bruijnzeel 1983a). It is recognised that this may present problems during prolonged dry spells such as the one that occurred during the study period.

Changes in groundwater storage ($\triangle G$) were estimated by considering the volume of water needed to arrive from the baseflow level at the start of the period to that at the end of the period, as derived from the master recession curve (Bruijnzeel 1983a). This approach was considered to be more representative than observations of water levels in single boreholes.

The catchment water balance technique only yields reliable results when a catchment is watertight. The present stream was incised into the underlying bedrock and there was very little valley fill at the basin outlet. Leakage underneath the weir is therefore thought to be negligible. Although deep leakage along faults in the area is a possibility, there are two arguments against its importance: firstly, most springs in the catchment are found at the contact between volcanic ash and underlying bedrock, and secondly, the results of the water balance computations are on the low side of the published spectrum.

Open water evaporation (Eo) was computed according to Penman (1956) as an estimate of local evaporation with incoming solar radiation computed with an empirical formula derived from local data (Bruijnzeel 1983a). As for the climatic parameters used in the Penman equation, temperature and relative humidity were continuously recorded by a Thies thermohygrograph placed in a Stevenson screen at the edge of the forest. Data of daily windrun from a freely exposed hilltop of the same elevation were used. Sunshine duration data were obtained from the climatic station at Singomerto, some 5 *km* to the east.

Throughfall was measured with collectors consisting of a polyethylene funnel of 20 *cm* diameter and equipped with a vertical rim of 5 *cm* to reduce effects of splash-out, placed on a 10 *l* container. Four of these were placed randomly in 11- and 35-*y* old stands of *Agathis* and three in a clearing with *Chromolina* thicket.

A roving approach (Lloyd & Marques-Filho 1988) and a sampling frequency of 14 days was used. The measurements were originally performed to obtain an idea of the flux of nutrients carried to the forest floor in throughfall (Bruijnzeel 1983a) and it is recognised that their value for use in the prediction of rainfall interception is limited (*cf.* Bruijnzeel & Wiersum 1987). Despite their improvised character, similar collectors placed in a clearing compared very well with a standard raingauge. Results were adjusted for evaporation from the containers during the dry season.

No attempts were made to measure stemflow as the flaky nature of *Agathis* bark and the drooping habit of the branches did not seem to favour the production of large amounts of stemflow. Blake (1975) reported stemflow for mature *A. australis* in northern New Zealand to be about 1% of incident precipitation.

Results and discussion

Catchment water balance

Monthly and total values for P, Q, △S and △G, with estimates of ET and Eo for the period December 1976 through January 1978 are presented in Table 2. Long-term averages for monthly P have been added for comparison.

Table 2. Water budget for the Mondo catchment, 1 December 1976 - 31 January 1978. All values in *mm*

Month	Precipitation	Long-term mean precipitation	Streamflow	sS+sG*	ET	Eo
December 1976	539	647	455	+72s	84	120
January 1977	460	556	365	- 72s	95	123
February	444	434	416 }	+ 91 }	46	100
March	463	602	354 }	}		117
April	705	556	698	-75	82	117
May	146	384	183	-139	101	109
June	456	213	323	+123	9	100
July	13	125	109	-176	80	103
August	2.5	109	27	-170	145	111
September	9	118	10	-140	102	116
October	39	390	4	- 71	105	135
November	304	634	11	+218	75	109
December	536	647	92	+174	271	104
January 1978	551	556	413	- 12	150	108
Total	4668		3460	-9s	1217°	1572

* changes in soil moisture storage (upper 225 *cm* and groundwater storage respectively
s change in groundwater storage only; overall sS = 0 (see text)
\+ soil moisture data from 10 February onwards
° total P - total Q + sG with sS = 0

A normal amount of rain fell in the wet season of 1976/77, although April and June were distinctly wetter and May considerably drier than average. The dry season started in July and lasted until 20 November, which makes it one of the longest in the history of the rainfall station (*cf.* Figure 2). Although the site receives an average dry-season total of 325 *mm*, it appears that 23 out of 45 *y* had at least two consecutive dry (*i.e.* less than 60 *mm*) months, whereas seven years had at least two months without any precipitation (Bruijnzeel 1983a). Interestingly, six years with four to five rainless months have occurred regularly since 1961.

The total quantity of rain recorded during the period of investigation amounted to 4668 *mm*, which is close to the long-term annual mean of 4768 *mm*. The rain was distributed over 171 rain days, again close to the long-term mean of 176 (Bruijnzeel 1983a).

Table 2 shows that runoff ratios were less than unity during the wet season, whilst the pattern was reversed during drier spells (*e.g.* May, July - October). The severity of the dry season is well illustrated by the long period necessary for streamflow levels to return to their normal wet season values (Table 2). The high runoff ratios in February and April can be explained by a significantly reduced input of solar radiation (*cf.* the low value for Eo for February) and by residual effects of large amounts of rain falling at the end of March, followed by another 400 *mm* in the first week of April.

△S and △G largely followed similar recharge/drainage patterns (Table 2). The decline in storage starting mid-April was temporarily offset by rains in June, but continued until late November. After the return of the rains considerable recharge took place and it is here that the limitations of sampling only part of the soil profile became apparent (*e.g.* December, Table 2). A lack of representative soil moisture sampling also occurred in June 1977 and in January 1978 due to rainfall patterns prior to sampling. Similarly, negative values for △G were observed for February and April, despite substantial amounts of rainfall. This is due to the fact that in these months most of the rain fell during the first decade, whereafter the combined effect of continued ET and discharge caused the baseflow to fall below its initial level.

The overall value of △S for the entire period presented a problem in that the initial sample batch suffered partial drying during storage in the laboratory. However, since the overall value for △G is relatively small (Table 2) and the amounts of rainfall during the last ten days before the start and the termination of the study differed by less than 10 *mm*, it is believed that the overall value for △S can be assumed to be close to zero.

Monthly values for ET as determined from the foregoing quantities of P *et cetera* looked quite realistic in some cases (*e.g.* December 1976; January, April, May, July 1977), but represented over- or underestimates in other cases (December, August 1977; February, June 1977, January 1978 respectively). Expressing the most realistic monthly estimates of ET as a ratio to Eo (which itself showed only minor fluctuations) yielded an average f of 0.79, which is virtually identical to that found for the entire observation period (0.77, Table 2). This value is considered to be valid for periods during which soil moisture is not limiting Et. In the present case, water stress may have occurred in October and November, as indicated by a corresponding increase in leaf fall from the *Agathis* trees. On the other hand, leaf fall in the presumably shallower rooted *Chromolina* thicket responded much less vigorously to the drought (Bruijnzeel 1985). Values of f for October and November were 0.78 (same as overall mean) and 0.69 respectively (Table 2).

Given the deep nature of the volcanic soils underlying the experimental site no significant soil moisture stress would be expected during years with "normal" amounts of precipitation or with a moderately intense dry season (*cf.* Figure 2). As such the application of a value of 0.79 for f, leading to a "normalised" annual value of ET of 1070 *mm*, seems justified (the higher figure quoted in Table 2 corresponds to a period of 14 months).

Monthly values of Eo almost exactly matched the long-term average pattern as interpolated for the mean catchment height from the generalised data presented by Isnugroho (1975). A minimum occurred in June, a maximum in October and a secondary minimum in February (Table 2), all of which can be explained in terms of incoming radiation and windrun. The belated return of the northwest monsoon in 1977 and the associated high degree of cloudiness in November, December and January is reflected in lower values for these months as compared to the corresponding period the year before (Table 2).

Throughfall

Amounts of throughfall for the period February 1977 through January 1978 are given in Table 3. Despite the small number of gauges per site, total catch for different collectors differed little within stands. This is believed to reflect the technique of regularly re-locating the gauges at random in order to sample as many points in space as possible (*cf.* Lloyd & Marques Filho 1988).

Table 3. Average throughfall totals and standard errors of the mean (1 February 1977 - 31 January 1978)

Agathis, 11 years old	2935 ± 76 *mm* (14 sampling occasions; 4 gauges)
Agathis, 35 years old	3299^{a} ± 148 *mm* (*ibid.*)
Chromolina thicket	3414^{a} ± 85 *mm* (*ibid.*); 3 gauges)

[a] Figures sharing the same superscript are not statistically different at $p < 0.05$

The highest amounts of throughfall occurred below shrubs throughout the observation period (Table 3), which should probably be attributed to their low biomass and sheltered position as compared to that of the tree canopies. However, the possibility of extra contributions of liquid to the collectors through the process of guttation exists (Rutter 1975). Support for the latter hypothesis comes from the very high calcium, magnesium, potassium and silica concentrations in throughfall water from the shrub site as compared to the *Agathis* sites (Bruijnzeel 1983a) and perhaps from leaf anatomical observations: the *Chromolina* leaves possess numerous trichomes close to the transport vessels, which possibly have an excretory function (J. Rozema personal communication).

The high value observed for throughfall in the older *Agathis* stand reflects its rather open character, which is not only due to the low number of trees per hectare

(Table 1), but also to the shape of the tree crowns, which becomes narrower with age.

Neglecting stemflow (*cf.* Blake 1975) (maximum) estimates of rainfall interception of 23, 14 and 9% were derived for the 11- and 35-*y*-old *Agathis* forests and for *Chromolina* respectively. As the throughfall plots had been selected to represent catchment vegetation, these site-specific interception values were used to compute an overall mean value for the catchment, based on the distribution of the three vegetation types (occupying 40, 19 and 37% of the total area respectively). Assuming a stemflow figure of 1%, a weighted mean interception loss of about 14% of incident rainfall was found. Substracting this from the 1070 $mm\,y^{-1}$ for total forest ET yielded an annual value for Et of about 400 *mm*, which must be considered as rather low compared to the values for lowland (885-1285 $mm\,y^{-1}$) and montane (560-830 $mm\,y^{-1}$) rain forests quoted by Bruijnzeel (1988). It would seem, therefore, that in this high rainfall environment evaporation from the wet forest canopy (Ei) exceeds evaporation from a dry canopy (Et). This phenomenon is well documented for rainy temperate zone climates, such as Wales (Calder 1977) and New Zealand (Pearce & Rowe 1979). It is usually ascribed to the fact that evaporation rates from a wet forest canopy are considerably higher than from a dry one due to the absence of stomatal controls in the former case (Steward 1977, Calder 1982).

Alternatively one could argue that the high proportion of land occupied by shrubs might cause the rather low value for Et. However, the observations of Wasser (1987) in upland West Java suggested the rate of water use (according to the Penman-Monteith equation) of this vigorously growing pioneer vegetation to be somewhat higher than that of the present forest.

Comparison with other studies in the tropics

Annual totals for ET of tropical plantation forests seem diverse (Table 4). However, several of the studies quoted suffered methodological problems, such as a leaky catchment area (numbers 5 & 8; f well above unity) or an overstocked lysimeter (numbers 3 & 4). As such, these high values must be considered overestimates. The studies in Kenya and Indonesia reported upon by Blackie (1979) and Bons (personal communication) respectively were done on presumably watertight catchments and the results suggest an f for mature pine forest in the tropics very close to that found for mature *Agathis* in the present study. Although ET for young pine trees was much lower (f = 0.6), the effect of increased water yield following tree planting disappeared upon canopy closure after about six years, when ET became again very similar to that for nearby natural forest (Blackie 1979, Table 4). Similar values of f were found for lowland rain forests in the Philippines (0.77, Baconguis 1980) and central Amazonia (0.8, Shuttleworth 1988) as well as for well-watered *Paspalum* grass in the Congo (0.75, Riou 1984).

These few comparative results suggest the opportunities for influencing

Table 4. Evapotranspiration (ET), interception loss (Ei), transpiration (Et) and "crop factors" for coniferous plantation forests and selected other types of land use in the humid tropics

Location	Species	Stand age (*y*)	ET (*mm y⁻¹*)	Ei (%)	Et[a] (*mm y⁻¹*)	ET/Eo	Rainfall (*mm y⁻¹*)	Elevation (*m. a. s. l.*)
Watubelah Central Java[1]	*Agathis dammara*	11-35	1070*	14	405	0.79	4770	635
Genteng, West Java[2]	*Pinus merkusii*	29	900*	23	445	0.84	1965	1375
Ciwidey, West Java	*Pinus merkusii*	1-8[3]	1975°			ca.2	3110	1750
		9-17[4]	1665°			ca.1.7		
	Bare soil[3]		420°			0.43[b]		
	Montane forest[5]		1170*	20	510	1.23[b]	3310	1875
Bogor, West Java	Lowland Rain Forest[6]		1480[+]	21	885		2850	80
	Bare soil[5]		1085°			0.70[b]	3410	250
Angat, Philippines[7]	Lowland Rain Forest		1230			0.77	3235	300
Blue Mts., Jamaica[8]	*Pinus caribaea*	18	1850*	17	1300	>1	3230	700
	Montane forest		2000*	19	1285	>1	3750	1020
Minas Gerais, Brazil[9]	*Pinus caribaea*	4-6	615[△]	7	545		1120	820
	Eucalyptus grandis	4-6	785[△]	12	650			
	Grassland		480[△]					
Manaus, Brazil[10]	Lowland Rain Forest		1315	12	980	0.8	2720	80
Kimakia, Kenya[11]	*Pinus patula*	1-3				0.60	2200	2440
		10-16	1160*			0.77		
	Montane forest		1155*	20[12]	685	0.76	2310	2440
Manankazo, Madagascar[13]	*Pinus patula*	4-10	1610[△]				1715	1475
	Natural grassland		1425[△]					
Brazzaville, Congo[14]	*Paspalum* grass		1070			0.75	1800	low

[1] present study
[2] C.A. Bons, personal communication; data preliminary and for 9/1985 -8/1986
[3] Pudjiharta (1986a); lysimeter 3x4x2*m*, 12 trees
[4] Pudjiharta (1986b); lysimeter 3x4x2*m*, 2 trees
[5] Gonggrijp (1941); bare soil ET estimated from small lysimeters
[6] Calder *et al.* (1986)
[7] Baconguis (1980)
[8] Richardson (1982)
[9] Zakia (1987)
[10] Shuttleworth (1988)
[11] Blackie (1979)
[12] Pereira (1952)
[13] Bailly *et al.* (1974)
[14] Riou (1984)
* catchment water balance
° lysimeter
[+] Penman Monteith equation
△ soil water balance
[a] approximate values obtained by subtracting Ei from ET
[b] Eo from Bruijnzeel (1987)

streamflow totals in the wet tropics permanently through a change from natural forest or indeed grassland to be rather limited. In the more seasonal tropics, however, some rather dramatic reductions in (especially dryseason) streamflow following afforestation of grassland with pines have been reported (Bailly *et al.* 1974, Kammer & Raj (1979) in Hamilton and King 1983). Converting forest to permanent cropping on the other hand generally produces a significant reduction in ET, reflecting changes in energy balance and aerodynamic characteristics (Bruijnzeel 1986, Monteny 1986). However, in view of the potential danger of soil erosion associated with grazing or agricultural cropping any changes in cover aimed at increasing water yield should be accompanied by strict soil conservation measures (Bruijnzeel 1986, 1987).

In Table 5, results from over 20 throughfall studies in Southeast Asian forests, both natural and manmade, have been collated. The variation in average interception values is large and again the results need to be interpreted with care.

Table 5. Mean rainfall interception values for man made and natural forests in Southeast Asia

Location	Vegetation type	Age *(y)*	Basal area $(m^2\ ha^{-1})$	Interception (%)*	Annual precipitation *(mm)*	Site elevation *(m.a.s.l.)*
Indonesia						
Watubelah, Central Java[1]▲	*Agathis dammara*	11	13	≤23	4770	560
		35	25	≤14		
	Chromolina odoratum	3		≤ 9		
Watubelah, Central Java[2]▲	*Tectona grandis*	25	15	≤13	4770	550
	Pinus merkusii	12	32	≤12	4000	430
Ubrug, West Java[3]	*Acacia auriculiformis*	4	12	11	3075	115
		5	15	18		
Jatiluhur, West Java[4]	*Albizzia falcataria* }	5-6	32	≤18	3075	100
	Antocephalus. chinensis }			≤20		
Ciwidey, West Java[5]	*Alttingia excelsa*	7 }	*ca.*18	31	3110	1750
	Schima wallichii	7 }		38		
Gunung Walat, West Java[6]	*Pinus merkusii*	15	-	14	3000	560
	Schima wallichii	10	-	17		
Lembang, West Java[7]	*Pinus merkusii*	10	833^{+}	16	2825	1350
		15	556	22		
		20	303	31		
Genteng, West Java[8]▲	*Pinus merkusii*	31 }	240^{+}	25	2120	1375
			400	27		
			560	28		
Janlappa, W. Java[9]■	Lowland Rain Forest		49	21	2850	80

Table 5. continued

Location	Vegetation type	Age (*y*)	Basal area ($m^2\ ha^{-1}$)	Interception (%)*	Annual precipitation (*mm*)	Site elevation (*m.a.s.l.*)
Ciwidey, W. Java[10]■	*Montane Rain Forest*		*ca.*50	20	3310	1875
Riam Kanan, Borneo[11]▲	*Pinus merkusii*	9	21	18	2100	80
	Peronema canescens	9	11	11		80
	Lowland Rain Forest		21	16		100
Philippines						
Baguio[12]▲	*Pinus kesiya*	10-15	704[+]	10	3525	*ca.*1500
			512	11		
			352	10		
			176	7		
Benguet[13]▲	*Pinus kesiya*	30	26	13	3600	1370
			17	11		
			10	11		
			7.5	8		
Benguet[14]	*Pinus kesiya*	20-25	-	0.1	3345	1200
Mt. Province[14]	Mossy forest		-	11	3910	2200
Agusan del Norte[15]▲	*Tectona grandis*	8	-	20	2220	<1000?
	Swietenia macrophylla	15	-	20		
	Albizzia falcataria	12	-	21		
Malaysia						
Pasoh[16]	Lowland Rain Forest		*ca.*27	22	1885	100
Ulu Gombak[17]	Hill Rain Forest		*ca.*26	≤18	2000	275
Negeri Sembilan[18]▲	*Hevea brasiliensis*					
	RRIM	6	1065[+]	32	<2000	<100
	Ibidem		555[+]	24		
	Ibidem		300[+]	20		
	Ibidem		210[+]	15		
Singei Buloh[19]▲	*Hevea brasiliensis*					
	RRIM 600	23	536[+]	18	*ca.*2000	<100
	GI1			26		
	RRIM 605			35		
Gomali[20]	*Elaeis guineensis*	12	148[+]	23	1930	<100

[1] present study; [2] Bruijnzeel (1983a); [3] Bruijnzeel & Wiersum (1987); [4] Wiersum *et al.* (1979); [5] Kudeng Sallata *et al.* (1984); [6] Solo (1980); [7] Pudjiharta & Kudeng Sallata (1985); [8] C.a. Bons, personal communication; values of Ei considered over-estimates by the investigator himself; [9] Calder *et al.* (1986); [10] Gonggrijp (1941); [11] Ruslan (1983); [12] Florido & Saplaco (1981); [13] Veracion & Lopez (1976); [14] Mamanteo & Veracion (1985); [15] Castillo (1984); [16] Manokaran (1979); [17] Kenworthy (1969); [18] Teoh (1977); [19] Teoh (1973); [20] Maene *et al.* (1979)

* if data on stemflow are lacking Ei coputed as gross rainfall minus throughfall

[+] number of trees per hectare

▲ regular re-locating of gauges

■ large collecting surface (plastic sheeting, sheet metal)

Lloyd and Marques Filho (1988) showed that regular relocating throughfall gauges to new random positions on the forest floor greatly reduced the standard error of the mean throughfall estimate in Amazonian rain forest. Similarly, Bruijnzeel and Wiersum (1987) concluded that the largely different interception values found for a young plantation forest in Java during two consecutive rainy seasons (number 3 in Table 5) had to be ascribed to the fact that two different fixed gauge arrangements were used. Bruijnzeel (1988) observed that the highest throughfall figures were often recorded by those studies in which the gauges were randomly relocated at regular time intervals. This probably reflects the inclusion of a representative number of "drip points", where throughfall is concentrated and exceeds gross precipitation (Shuttleworth 1988).

Several of the studies quoted in Table 5 have practised gauge relocation and may therefore be relatively reliable. The data suggest that average interception values for broad-leaved forests in the region lie close to 20% of gross precipitation. Somewhat lower values have been reported for scrub (present study) and light-canopied species such as *Peronema* (number 11) or *Pinus kesiya* (numbers 12 & 13), although altitudinal effects (increased cloud cover, lower temperatures) may also have been important in the latter case. The effect of fog incidence ("cloudstripping") is illustrated by the low interception loss recorded in some studies in the Philippines (*P. kesiya*, number 14).

Effects of stand density (thinnings) are relatively minor in the case of upland pine forests in the Philippines and Indonesia (numbers 12, 13 & 8 respectively, all of which employed a roving gauge technique), but significant in other cases (rubber in Malaya, number 18; *Agathis* in central Java, this study).

Interception loss as determined by several studies in the mountains of west Java was surprisingly high (often close to 30%), despite the frequent relocation of a large number of gauges in some of these studies (number 8). As such these high values can hardly be explained in terms of methodological bias. Despite the large number of throughfall studies conducted to date in the region, only one (Calder *et al.* 1986) has attempted to link rainfall interception to above-canopy climatic conditions. More work of this type (*cf.* Shuttleworth 1988) is needed if any apparently anomalous results are to be explained (*cf.* Bruijnzeel & Wiersum 1987).

Acknowledgements

Financial support for the field investigation was provided by the Netherlands Foundation for the Advancement of Tropical Research (WOTRO) under project W 76-45. A. Riyadi, S. Sumartono and I. Sieverding assisted with the field measurements. M. Karmono, H. Speelman and Th. J. Beukeboom kindly made available laboratory and transport facilities within the freamework of the "Serayu Valley Project". W. de P. Lima (University of Sao Paulo), J.H.C. Gash (IH Wallingford), C.A. Bons (Free University Amsterdam) and S. Manan (Bogor Agricultural University) provided unpublished or in press materials. G.B. Engelen is thanked for useful comments at an early stage, whilst the manuscript greatly benefited from comments by J.R. Roberts.

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