LITTERFALL, LITTER TURNOVER AND SOIL RESPIRATION IN TWO PINE FOREST PLANTATIONS IN CENTRAL JAVA, INDONESIA

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BINTORO GUNADI. 1994. Litterfall, litter turnover and soil respiration in two pine forest plantations in Central Java, Indonesia. Litterfall, litter turnover and soil respiration were studied for one year in two forest plantations of *Pinus merkusii*, one on the slopes of Mount Merapi (at 800*m*) and another on the slopes of Mount Merbabu (at 1050*m*) in Central Java. The dominant component of total litterfall differed per site. At the Merapi site total litterfall was 9 $t\ ha^{-1}\ y^{-1}$, nearly 60% of which consisted of female cones. At the Merbabu site total litterfall was 4 $t\ ha^{-1}\ y^{-1}$ and needles were the dominant component (63%). At the Merapi site, litter turnover during the dry season (K_d=0.08) was four times that in the wet season (k_w = 0.20). Because of litter removal by the local people at Merbabu, derived litter turnover values were not realistic. The removal also decreased litter standing crop and significantly reduced the CO_2 efflux from the litter and soil (0.19 - 0.35 $g\ m^{-2}h^{-1}$). The CO_2 production at Merapi was 0.37 - 0.45 $g\ m^{-2}h^{-1}$. There was no relationship between CO_2 production and rainfall at Merapi because moisture was not limiting to the mulch effect of the litter standing crop. At Merbabu, where the water content of the litter reached very low values by the end of the dry season (7.2%), there was a positive relationship between CO_2 production and rainfall.

Key words: Effects of litter removal - litterfall - liter turnover - *Pinus merkusii* - soil respiration - tropical forest plantation

BINTORO GUNADI. 1994. Guguran sarap, pembalikan sarap dan respirasi tanah dalam dua hutan ladang pine di Java Tengah, Indonesia. Guguran sarap, pembalikan sarap dan respirasi tanih dikaji selama satu tahun di dua hutan ladang *Pinus merkusii*. Kajian telah dijalankan di Bukit Merapi (pada ketinggian 800 *m*) dan Bukit Merbabu (pada ketinggian 1050 *m*), Java Tengah. Komponen dominan jumlah pengguguran sarap berubah mengikut tempat kajian. Pada tapak Bukit Merapi, jumlah gugur sarap ialah 9 $t\ ha^{-1}\ y^{-1}$ yang mana hampir 60% daripadanya terdiri dari kon betina. Di Bukit Merbabu pula, jumlah gugur sarap adalah sebanyak 4 $t\ ha^{-1}\ y^{-1}$ dan komponen dominannya (63%) terdiri dari jejarum. Pembalikan sarap di Bukit Merapi pada musim kering (k_d = 0.80) adalah empat kali lebih banyak di bandingkan dengan pembalikan sarap pada musim hujan (k_w = 0.20). Oleh kerana, aktiviti pengumpulan sarap oleh penduduk tempatan di Merbabu nilai pembalikan sarap yang di perolehi adalah tidak realistik. Kesan pembuangan ini telah mengurangkan sarap dirian tanaman dan mengurangkan effluk CO_2 dari sarap dan tanih (0.19 - 0.35 $g\ m^{-2}\ h^{-1}$). Pengeluaran CO_2 di Merapi adalah 0.37 - 0.45 $g\ m^{-2}\ h^{-1}$. Tidak ada hubungan antara pengeluaran CO_2 dengan penurunan hujan di Merapi kerana tahap kelembapan tidak menghad kesan sungkup pada dirian sarap tanaman. Di Merbabu pula di mana nilai kandungan air sarap menurun pada penghujung semasa musim kering (7.2%) terdapat perhubungan positif antara pengeluaran CO_2 dengan penurunan hujan.

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Introduction

Quantifying fluctuations in amounts of organic matter entering the forest floor is of paramount importance in understanding decomposition processes. Litterfall forms the greatest loss of forest net primary production (NPP), with the exception of heavy exploitation by herbivores during periods of high population densities (Kimmins 1987).

According to Vogt *et al.* (1986), more than 90% of the NPP enters the soil as dead organic matter, with leaves being the major component of above-ground small litterfall in nearly all terrestrial ecosystems. However, other components can be important too, such as bark in eucalypt forest (Kimmins 1987) or cones in pine forests (Sutjahjo 1975).

Based on data of cumulative litterfall and litter standing crop, litter turnover rates can be calculated (Anderson & Ingram 1989). According to Swift *et al.* (1979), litter turnover is relatively high in tropical forest and very low in tundras. Pine litter in Java seems to decompose more rapidly than either the needles shed by *Pinus caribaea* in Nigeria or *P. patula* in Tanzania or *P. radiata* in Australia (Bruijnzeel 1983). In temperate evergreen coniferous forests litter turnover is relatively slow (Kendrick 1959, Kimmins 1987).

Litter turnover is a process in which microorganisms and soil animals play an important role (Verhoef & Brussaard 1990). Carbon dioxide (CO_2) is an end-product of heterotrophic metabolism and its production can be used to measure the metabolic activity in the soil (Edwards 1982, Teuben 1991). However, for this evaluation CO_2 originating from mineral soil should be also taken into account (Cropper *et al.* 1985, Beyer 1991).

This research was performed to study seasonality of organic matter input and turnover in two Indonesian pine forest plantations. In one of the forests in this study, litter was continuously removed by local people and the effects of litter removal on litterfall, litter standing crop, litter turnover, CO_2 production, and concentration of some litter nutrients (K,Ca, Mg) were analysed.

Materials and methods

Study sites

Two plantations of *Pinus merkusii* were studied in Central Java. The first one was situated on the slopes of Mount Merapi, an active volcano, the second one on the slopes of Mount Merbabu, a dormant volcano (Figure 1). The latter site is strongly influenced by human activities, as litter is regularly removed by local people to be used for fuel, compost, and bedding for cattle. Some characteristics of the study sites are given in Table 1.

The plantation at the Merapi site was five years older, and its trees were higher, bigger, and less densely planted than at the Merbabu site. Between 1987 and 1989 annual rainfall was about 15% higher at the Merapi site than that at the Merbabu site. Concerning the nutrient concentration of the organic layer, only Ca was higher at the Merapi site. The pH values of the L layer, humus and soil were similar in both sites; those for the FI and F2 layers were missing for the Merbabu site because of the removal of litter. The pH increased from the L layer to the mineral soil (Table 1).

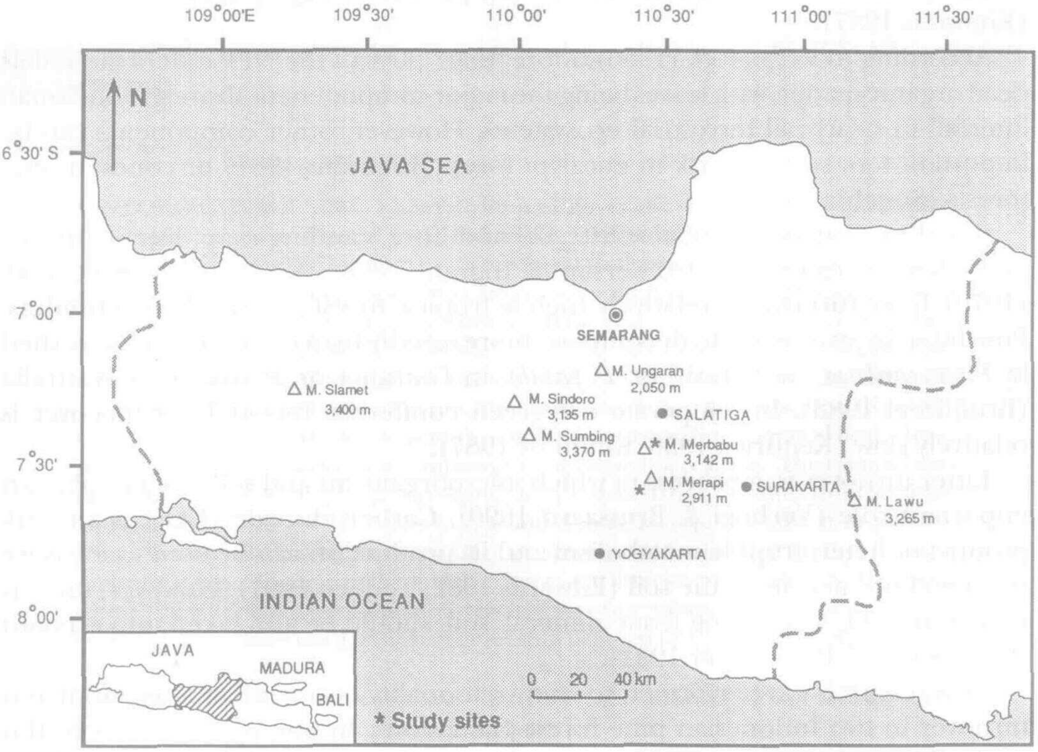

Figure 1. Location of the study sites in Central Java, Indonesia

Litterfall and litter standing crop collection

The method used to collect small litterfall was a modification of Bruijnzeel's (1985). Litterfall was collected at both sites from five randomly distributed littertraps, over monthly time intervals during one year. The research was conducted from September 1988 until September 1989. Traps had a size of 1 m^2 and were made of a wooden frame (board-width 20 *cm*) with a nylon screen (mesh size 2.5 *mm*), placed 15 *cm* above the soil surface. Samples were transported to the laboratory of Terrestrial Ecology, Universitas Kristen Satya Wacana, Salatiga, dried at 50°*C* for three days, sorted into needles, female and male cones and other materials (bark, twigs, seeds, *etc.*), and weighed.

Litter standing crop was collected at monthly intervals for a year from five replicates of 20 × 20 *cm* quadrants. These samples were analysed in the same way as the litterfall, but without sorting. Data was expressed as *g* litter per m^2.

The rate of litter turnover (expressed as k-value) in the wet season was calculated from the cumulative litterfall for six months up to the end of the wet season divided by the litter standing crop at the end of the wet season; the same procedure was followed for litter turnover in the dry season (Anderson & Ingram 1989).

Table 1. Some characteristics of the two study sites on the slope of Mounts Merapi and Merbabu

Parameters	Merapi	Merbabu
Altitude (*m*)	800	1050
Soil type	Andisol	Andisol
Degree of slope (°)	5	5
Size of the plot (m^2)	2000	2000
Year of planting	1958	1963
Number of trees per plot	46	62
Average tree height (*m*)	30.6	20.2
Average tree diameter (*cm*)	39.1	29.3
Min. year air temperature (°*C*)	18.4	16.6
Max. year air temperature (°*C*)	25.2	26.1
Annual rainfall (*mm*)		
1987	3195	2826
1988	3992	3476
1989	3901	3315
Nutrients in the litter ($umg\ g^{-1}$)		
K	41.3	38.9
Ca	343.7	225.5
Mg	43.9	40.4
pH (in H_2O)		
L layer	4.5	4.4
F1 layer	5.3	-
F2 layer	5.5	-
Humus	5.7	5.6
Soil (10 *cm* depth)	5.8	5.7

CO_2 production

CO_2 production from the forest floor (litter and soil) was measured each month from September 1988 until April 1989 using sodalime (NaOH/CaOH) in airtight closed containers (diameter 27 *cm* and height 23 *cm*). All measurements were done at ten randomly chosen sites in each plot. Firstly, sodalime was dried in the oven at 110°*C* for 24 *h*, weighed for about 10 *g* for each measurement and transported to the field in a well-closed glass bottle. Secondly, open-bottom containers were placed in the field about 3 *cm* into the forest floor and the sodalime was put inside the containers on a petri-dish. Subsequently the containers were tightly closed with a lid. After 21 hours in the field, the sodalime was removed, dried and weighed again. The extra weight was a measure of produced CO_2 bound in sodalime and multiplication by 1.4 (a constant) gave the value for CO_2 production expressed in $g\ m^{-2}\ h^{-1}$ (Edwards 1982, Coxson & Parkinson 1987, Beyer 1991).

Nutrient content of the organic layer

Analyses for K, Ca, Mg of the organic layers (L, F1, F2) were performed using flame Atomic Absorption Spectrophotometer model PE 4000. Dry litter samples were flown to the laboratory of Ecology and Ecotoxicology, Vrije Universiteit, Amsterdam. The samples were first completely digested in a $HNO_3/HClO_4$ mixture (7:1 Ultrex Grade, Baker) using a block heater. There were ten replicates for each location.

Abiotic factors

Acidity of the L, F1 and F2 layers, humus and mineral soil was measured with a pH meter Consort P907 in 10 replicates for each location in a soil/water mixture (2:5) (Anderson & Ingram 1989).

The rainfall data for the study year were derived from the meteorological stations at Gunung Maron (960 *m*), which is about 1 *km* (NE) from the study site at Merapi, and at Kopeng (1300*m*), which is about 5 *km* (NW) from the study site at Merbabu.

Statistical analyses

Student's t-test was used to compare the parameters of both sites. The relationship between CO_2 production and rainfall was analysed by Pearson correlation. Both analyses were performed using computer software available in Cricker Graph 1.3 and StatWorks 1.2a, with the assumption that the data sets could be described by a bivariate normal distribution (Parker 1980).

Results

Litterfall

Monthly amounts of litterfall are presented in Figures 2a,b, for the Merapi and Merbabu sites respectively, with the input divided into needles, female and male cones, and other materials (bark, twigs, seeds, *etc.*). Female cones formed the dominant organic matter input (about 60%) at the Merapi site, whereas needles accounted for about 35% of total litterfall (Figure 2a). The input of female cones showed a gradual increase throughout the wet season (October-March) into the dry season (April-September) with a maximum around July. Needle fall was more or less constant, although a maximum can be seen just before the start of the dry season. At the Merbabu site (Figure 2b) female cones constituted only 29% of the total input of organic matter to the forest floor whereas needles made up 63% of the total. Total annual litterfall in this forest plantation was much lower than that at the Merapi site (422 $g\ m^{-2}\ mth^{-1}$ vs. 903 $g\ m^{-2}\ mth^{-1}$). However, needle litter input was similar for both sites at about 20 - 30 $g\ m^{-2}\ mth^{-1}$. The removal of litter by the local people was confined to the standing crop and did not include the litterfall.

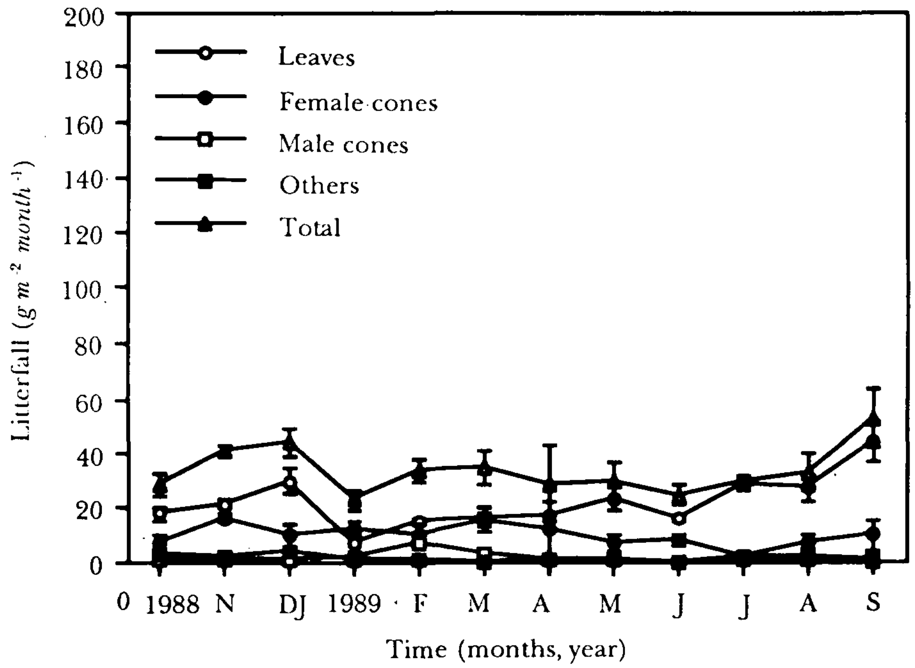

Figure 2a. Monthly fluctuation of litterfall at the Merapi site. The results are ± SE (n = 5)

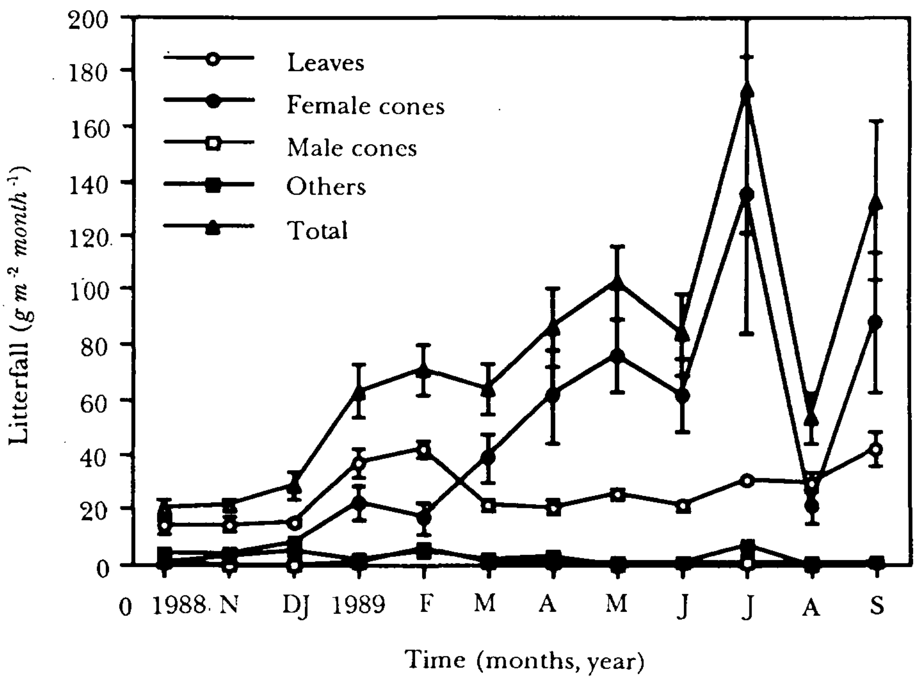

Figure 2b. Monthly fluctuation of litterfall at the Merbabu site. The results are ± SE (n = 5)

Litter standing crop and water content

Amounts of litter standing crop and water content throughout the study period are given in Table 2. As could be expected, the standing crop was much higher for the Merapi site than for the Merbabu site. This was mainly due to active removal of litter by the local people, and also because of the lower input of litterfall in the plantation at Merbabu. The reduced standing crop of the Merbabu site also had a strong impact on the water content of the organic layer. The litter standing crop at the Merapi site decreased during the dry season but remained relatively constant at Merbabu (Table 2). The mean litter water content was about 29% at Merbabu and about 61% at the Merapi site.

Table 2. Dry weight of litter standing crop and water content for two pine forest plantations in Central Java. The results are ± SE (n=5)

Month	Litter standing crop ($g\ m^{-2}$)		Water content (%)	
	Merapi	Merbabu	Merapi	Merbabu
Wet season				
October 1988	1759 ± 271	109 ± 21	56.7 ± 2.8	28.6 ± 2.3
November	1480 ± 349	86 ± 22	57.8 ± 2.7	33.7 ± 2.9
December	1315 ± 269	73 ± 16	47.7 ± 5.9	15.5 ± 0.5
January 1989	1939 ± 204	103 ± 50	57.8 ± 3.9	48.3 ± 2.4
February	1088 ± 244	67 ± 12	66.3 ± 2.1	50.4 ± 1.9
March	1353 ± 273	82 ± 9	64.7 ± 1.3	19.3 ± 1.2
Dry season				
April 1989	1257 ± 184	92 ± 27	63.6 ± 2.1	25.5 ± 2.1
May	1240 ± 143	102 ± 61	63.2 ± 1.6	32.9 ± 1.7
June	790 ± 239	46 ± 12	63.1 ± 2.5	25.3 ± 1.8
July	887 ± 119	78 ± 27	60.6 ± 1.6	36.7 ± 1.7
August	903 ± 154	99 ± 24	67.3 ± 0.7	23.6 ± 2.5
September	790 ± 150	109 ± 24	58.4 ± 0.7	7.2 ± 0.2

Litter turnover

The litter turnover values are presented in Table 3 as k-values for the wet (k_w)and for the dry season (k_d). For the Merapi site k_d = 0.08, a relatively high value (see discussion), but in the wet season k_w decreased to 0.02. As "k" represents the ratio of litterfall to litter standing crop, both factors may play a role. The low value of k in the wet season at the Merapi site was caused both by low litterfall (Figure 2a) and a large amount of litter standing crop (Table 2). Litter decomposition rates at the Merapi site were apparently higher during the dry season than the wet season, based on the decrease in standing crop during the dry season even though litterfall was also greater during the dry season (Figure 2a and Tables 2 and 3). Because of the removal of litter at the Merbabu site, the derived "k"- values were not realistic and hence not considered further.

Table 3. Litterfall (LF, $t\ ha^{-1}\ 6\ mth^{-1}$), litter standing crop (SC, $t\ ha^{-1}$) and litter turnover (wet season = k_w, dry season = k_d, 6 mth^{-1}) of the locations

Parameters	Merapi	Merbabu
Wet season		
LF	2.7	2.0
SC	13.0	0.8
K_w	0.2	2.5
Dry season		
LF	6.3	2.0
SC	8.0	1.0
K_d	0.8	2.0
Annual LF	*9.0*	*4.0*

CO_2 *production and rainfall*

As shown in Table 4, CO_2 production from the soil at the Merapi site was significantly higher than that at the Merbabu site, especially during the transition from dry to early wet season (September and October 1988).

Table 4. CO_2 production from the litter and soil. The results are ± SE (n=10)

CO_2 production $g\ m^{-2}\ h^{-1}$	Merapi	Merbabu	
September 1988	0.40 ± 0.04	0.19 ± 0.01	***
October	0.44 ± 0.04	0.21 ± 0.02	***
November	0.38 ± 0.01	0.30 ± 0.03	*
December	0.37 ± 0.01	0.28 ± 0.01	*
January 1989	0.37 ± 0.01	0.30 ± 0.01	ns
February	0.44 ± 0.01	0.33 ± 0.01	**
March	0.45 ± 0.01	0.35 ± 0.01	**
April	0.40 ± 0.03	0.33 ± 0.02	**
Average values	0.41	0.29	

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, ns = not significant.

It can be seen from the monthly rainfall data for both locations (Figure 3) that during the dry season rainfall decreased but was not reduced to zero, although values were very low during August and September. The relationships between CO_2 production and rainfall for the Merapi and Merbabu sites are shown in Figure 4. There was no relationship between CO_2 production and rainfall at the Merapi site ($r = 0.0$), but there was a positive relationship ($r = 0.7$, $p < 0.001$) for the Merbabu site.

Discussion

The dominant component of litterfall differed for the two forest plantations. At the Merapi site nearly 60% of annual litter input consisted of female cones. However, this was a seasonal phenomenon: most cones fell in July, just before the start of the dry season (Figures 2a and 3). Pines usually show a peak in litterfall at the end of the wet season or during the dry season (Bruijnzeel 1983, Kimmins 1987). This seasonal phenomenon did not happen on the Merbabu site possibly because the trees were in a stressed condition, or because the plantation at the Merbabu site was five years younger. Pine forest plantations in Java usually grow on poor soil (Bruijnzeel 1984). Peak biomass production during the wet season followed by increased litterfall, as the dry season approaches, appears useful for immobilizing and conserving nutrients within the forest.

According to Crawford (1989), seed production in many trees takes place typically at irregular intervals which are called "mast years". For example, in Norway spruce (*Picea abies*) mast years occur at favourable sites every 4 - 5 years. In such a year the tree has to support a large production of flowers, fruits and seeds. It is suggested here that the research period in this study can be classified as a mast year for the pine forest plantation at the Merapi site, although it is acknowledged that a longer observation period would be needed to substantiate this. Mainly because of the high input of cones, total annual litterfall at the Merapi site was twice that for the Merbabu site. The production of needle litter, however, was not significantly different between sites, although production on a per tree basis was higher on the Merapi. This might be due to the fact the plantation at the Merapi site was five years older and the trees were higher and bigger than at the Merbabu site.

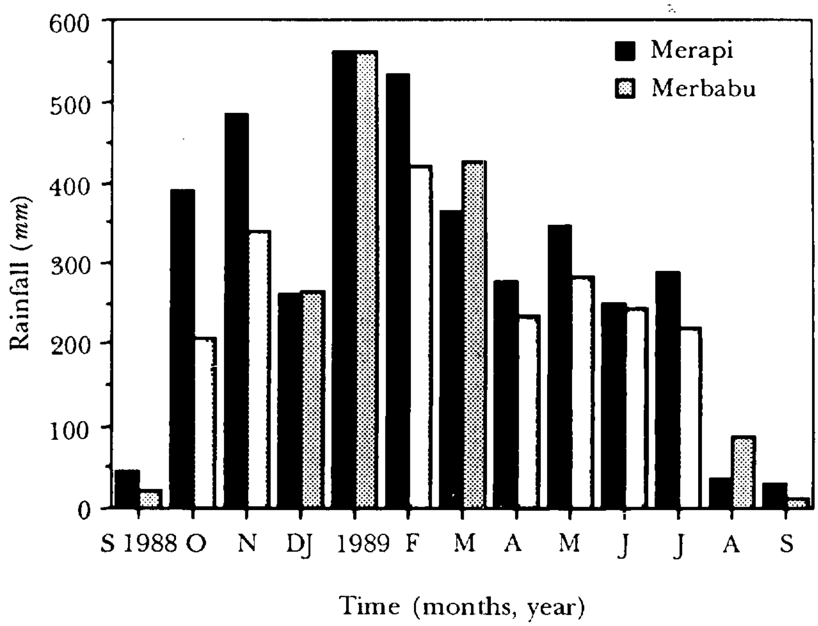

Figure 3. Monthly rainfall at the Merapi and Merbabu sites

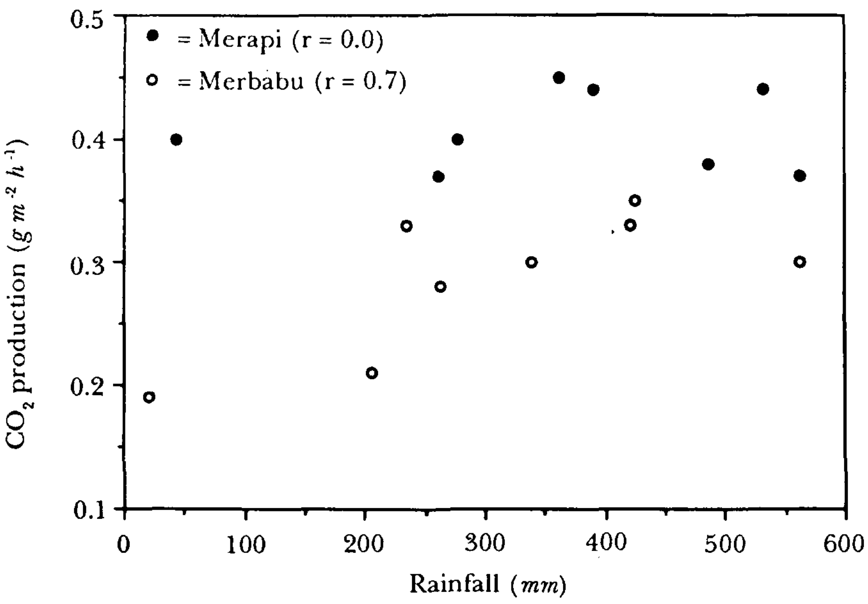

Figure 4. The relationship between CO_2 production and rainfall in both sites

The annual litterfall in the 31-*y*-old pine forest plantation of the Merapi site was about 9 $t\,ha^{-1}$, of which about 3 $t\,ha^{-1}$ were needles. These differ from the data for a 12-*y*-old pine plantation, also in Central Java (435 - 580 *m*), of which the annual litterfall was 10 $t\,ha^{-1}$, with 5 $t\,ha^{-1}$ as needles (Bruijnzeel 1985). This may be caused by differences in stand density, as these are man-made forests, the occurence of an exceptionally long dry season during the latter study, or the vitality of the stands. The presently studied forest plantation was much older than the one reported on by Bruijnzeel (1985). Gholz *et al.* (1985) observed a decline in litter production with stand age for a series of slash pine (*P. elliottii*) plantation in Florida, after a peak had been reached at age 15 - 16 years. However, it is difficult to compare the present findings with results obtained elsewhere because of the use of different types and numbers of collectors, the definition of the size limits of the small-wood component, differences in sampling period and intensity, and differences in species and environmental conditions (Proctor 1983).

The litter turnover in the wet season at Merapi (k_w = 20) was similar to the year value found for temperate evergreen coniferous (k = 0.28, Kimmins 1987) However, there is a clear seasonal effect on the k-value at the Merapi site. In the dry season litter turnover (K_d; litterfall/standing crop) was four times higher than in the wet season (k_d = 0.80 and k_w = 0.20). The decomposition rate was faster in the dry season. This can be explained by the fact that during the wet season rain may saturate the whole forest floor (including the upper mineral soil) for several days on end, rendering the situation anaerobic and less favourable for decomposition. At these elevations in Java the soil remains moist during the dry season.

During this study the driest period occurred in September with less than 50 *mm* rainfall per month. At that time the water content of the litter standing crop at the Merapi site was still high (about 58%, Table 2). Thus the high litter turnover in the dry season was due to the greater bioactivity arising from the generally high water content of the litter in the absence of saturation of the forest floor. In general, the annual litter turnover rate in the pine forest plantation at the Merapi site (k = 0.50) was faster than in *P. caribaea* in Nigeria (k = 0.31, Egunjobi & Bada 1979, Egunjobi & Onweluzo 1979), *P. patula* in Tanzania (k=0.20, Lundgren 1978) or *P. radiata* in Australia (k = 0.29, Forrest & Ovington 1970). The value of k = 0.50 in this research is about two times higher than the average litter turnover rate in temperate evergreen coniferous forests (k = 0.28, Kimmins 1987). This result is in line with the suggestion of Jordan (1989) that process rates are higher in the tropics than in temperate regions, as long as the sites examined on the tropical-temperate gradient have comparable moisture regimes and soil fertility.

Monthly CO_2 production was significantly higher at the Merapi site than at the Merbabu site. The higher CO_2 production on the Merapi was partly because of the larger volume of litter standing crop and probably partly because of a more active decomposer community. Here the lowest CO_2 production occurred mainly in the middle of the wet season (November 1988 - January 1989) when the soil was thoroughly wetted, suggesting an anaerobic situation with lower bioactivity (Gunadi, unpublished data). The thick litter standing crop in the merapi site retained the water during the dry season and during these "optimal" conditions litter turnover was comparable to the year value found for temperate deciduous forests (k = 0.77, Swift *et al.* 1979). But in the wet season the situation becomes too humid. CO_2 production at the Merapi site showed a good correlation with corresponding k values (also smaller in the wet season). It can be concluded that decomposition processes at the Merapi site were faster during the dry season than during the wet season.

As mentioned above, there was no relationship between CO_2 production and amount of rainfall at the Merapi site (r = 0.0) whereas there was a positive relationship at the Merbabu site (r = 0.7). This can be explained by the fact that at the end of the dry season the water content of the litter was very low: 7.2% at the Merbabu site. With increasing water content the soil biota become more active and may produce more CO_2. Besides microorganisms, the most dominant soil fauna in the wet season at the Merbau site are earthworms, which occur in much lower densities than at the Merapi site at the same time (Gunadi *et al.* 1991).

Finally, it can be concluded that due to litter removal by the local people at the Merbabu site, decreasing the litter standing crop and the soil fauna density, derived litter turnover values at this site were not realistic. The CO_2 efflux from the litter and soil were also reduced. The lowered biotic activity at the Merbabu site may reduce the soil fertility.

Acknowledgements

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