

LITTER PRODUCTION OF THE MANGROVE FORESTS IN TIRIS, INDRAMAYU, WEST JAVA, INDONESIA

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ABSTRACT

The Tiris mangrove forest, *Rhizophora apiculata*–*R. mucronata* community, grows in the area with highly human induced stress and typically by silty clay substrate. The litterfall studies in Tiris, Indramayu (Lat. 6° 10'–7° 49' S and long. 107° 25'–108° 25' E), using litterfall trap and plot techniques indicate that the mangrove forest is very productive. Litter productivity, as measured by litter trapping of a *R. apiculata* dominant mangrove forest at Tiris is 1,290.95 dry g/m²/year, and estimated as 12.90 dry t/ha/year and leaf shared is 40.70%. This is a high value when compared with the mangrove forests in the Indo-West Pacific and/or Malesian regions, and even with *R. mucronata* plantation in Tritih, Segara Anakan, Cilacap (Lat. 7° 41'–7° 45' S and Long. 108° 46'–109° E). Correlations between litter components with rainfall, number of rain-day, wind run, mean maximum temperature, mean minimum temperature, and mean monthly temperature, and relative humidity are calculated for understanding their role in litter production. These correlations are discussed and it is suggested that seasonality of mangrove need to be considered in terms of whole tree physiology rather than isolated environmental factors. Also, the high production of litter means an important contribution to support food-webs of many marine organisms. The results suggest that, in terms of litter, the mangrove forests in Tiris may be one of the most productive forest types in Java.

Keywords: Mangrove forests, Tiris, Litter, Seasonality

INTRODUCTION

Globally, amounts of literature on the litter production in the tropical rainforests are impressive, and in tropical region they generally show a higher rate of primary production and litter decomposition than temperate forest ecosystem (Bray and Gorham, 1964). Also, marine fringing communities are normally characterized by high productivity (Mann, 1982). One widely used estimate of productivity, of particular relevance in view of the importance of detritus to consumer organisms which is the total annual litterfall (Clough and Attiwill, 1982). In general, litter production is higher in tropical mangroves than in temperate mangroves although the figures available for tropical region exhibit considerable variation. Estimates of the annual global litterfall from mangroves range from 130 to 1870 g/m² (Kathiresan and Bingham, 2001).

Mangrove forests are thought to be highly productive communities (Lugo and Snedaker,

1974). In some cases they are being important primary producers in estuarine food chains leading to commercial fisheries (Odum and Heald, 1975). Moreover, Snedaker (1978) reviewed important aspects of the mangrove ecosystem and suggested that the value of mangrove forests was accepted and based largely on the production of organic matter as leaf litter that entered the estuarine system, where it formed the basis for a complex food web. Material exported from the mangrove forests could potentially support offshore communities (Robertson and Alongi, 1995).

Mangrove forests reach their greatest structural and floristic diversity in the Malesian region (consists of Indonesia, Singapore, Malaysia, Brunei Darussalam, the Philippines, and PNG) (Jacobs, 1974), and/or Indo-West Pacific region (Steenis 1958, Macnae, 1968). Litterfall studies in the mangrove forests in the region as well as Asia are showing interesting rate of production and very comparable, e.g. in Thailand (Christensen, 1978),

in India (Wafar *et al.*, 1997), in Malaysia (Sasekumar and Loi, 1983), in PNG (Leach and Burgin, 1983), in the Philippines (de Leon *et al.*, 1982), in Srilanka (Amarasinghe and Balasubramaniam, 1992), in Hongkong (Lee, 1989), in Indonesia (Brotonagoro and Abdulkadir, 1979; Sukardjo, 1989, 1995). It seems clear that litter production is higher in Malesian regions, but that considerable variation exists within a given mangrove community. It can be hypothesized that the values vary according to the healthiness and levels of disturbance of the mangrove forests. In addition to species influence, it may be expected that the levels of litterfall could also respond to the effects of site location. Also, clear indications show that litter yields tended to increase with distance up-stream from the mouth and/or sea edge. The present study will deal with this hypothesis.

The mangroves of Indonesia represent one of the largest expanses of unmodified mangroves in the world (Spalding *et al.*, 1997). Although a number of areas have not yet been surveyed and there remain a number of systematic problems, the floristic and to a lesser extent community ecology have been studied (Sukardjo and Kartawinata, 1979). On the productivity, litterfall, litter decomposition, and soil respiration of Indonesian mangrove forests information is not much available, and proceedings of the National Seminar on Mangrove Ecosystem in 1979 to 1999 are particularly pertinent (See: Soemodihardjo *et al.*, 1979, 1984, 1987, 1991, 1995, and 1999).

Qualitative information on litterfall production of the mangrove forests in Indonesia is little known and limited (See: Proc. of the National Seminar on Mangrove Ecosystem I [1979]–VI [1999]). The study on the production of mangrove litter had been conducted in Rambut Island (Brotonagoro and Abdulkadir, 1979), in Jakarta bay (Sukardjo, 1989), in East Kalimantan (Sukardjo, 1995), in Riau (Kusmana *et al.*, 1997).

The present study concerns with the productivity and phenology of the mangrove forests in the Cimanuk delta complex of the northern coast of West Java where both temperature and rainfall typically show pronounced seasonal variation, and for developing a comprehensive understanding of the mangrove ecosystem in Java.

This paper presents the third report on the large study of the ecology of Tiris mangrove forests, and forms part of the Cimanuk delta complex. The purpose of this paper is to give a general account of the litterfall, seasonal changes in the magnitude of litterfall, and different litter components in a mangrove forest in Tiris as one of important components to support the food-web of many marine organisms.

MATERIALS AND METHODS

The mangrove forests in the Cimanuk delta complex occupy a total area of about 1500 ha or 21.05% of the total area of mangroves in Indramayu (Sukardjo, 1987a; Sukardjo and Yamada, 1992). Tiris, a part of the Cimanuk mangrove forests where litter collection sites were located contain approximately 500 ha of mangrove forest, consists of eight species with *R. apiculata* and *R. mucronata* as the dominant species. This is the most intact mangrove forests found along the coast of Indramayu, comprised of small to medium sized trees of *Rhizophora* spp. The structural characteristics of mangrove forests and its relationship to their environment of Tiris have been described by Sukardjo (1987), and a summary of the study site is given in Table 1.

The nearest meteorological station to Tiris is at Indramayu (Lat. 6° 10'–7° 49' S, Long. 107° 25'–108° 25' E), with the average annual rainfall of 2,539 mm, the maximum and the average daily minimum temperature was 31.5°C and 22.7°C, respectively (Pusat Meteorologi dan Geofisika Departemen Perhubungan 1981–2006). According to Schmidt

Table 1. Structural characteristics of the mangrove forest in litter study site (Site III), Tiris Indramayu West Java

Vegetation Parameter	Tree with DBH > 10 cm	Tree with diameter 2-9.99 cm	Seedling
Density/ha	345 (97.50%)	5,660 (93.64%)	73,500 (53.74%)
Basal Area (m ² /ha)	4.244 (97.86%)	19.016 (97.54%)	-
Average Height (m)	11.50	6.50	0.45
Number of species	3	5	5
Index of Diversity (Shannon)	0.3565	0.4451	0.8154
Complexity Index	3.157	13.664	-
Average Diameter Crown (m)	12.75	9.55	0.35

and Ferguson (1951), the study area belongs to climate type D, in which the annual mean number of wet months (more than 100 mm) is 6.1 and the mean number of dry months (less than 60 mm) is 4.5, where the ratio of dry to wet months is 0–73.70% and almost the entire rainfall occurs during four to six months.

A permanent plot sized 0.25 ha (50 m x 50 m) was established for litter study in the mangrove forest of Tiris which recognized as *R. apiculata* and *R. mucronata* community, located beside river channel and about 250 m interior from the seaward edge. The plot was subdivided into 25 subplots of 10 m x 10 m size. Thirteen litter-traps with 1 m x 1 m x 0.2 m size with 1 mm mesh nylon net at base were systematically suspended diagonally by nylon rope between trees in every 10 m x 10 m subplot with 10 m interval, at a height of 2 m above the ground beyond the reach of high tides (cf. Newbould, 1967).

Sampling was carried out from first of September 2005 to the end of September 2006. A total 48 time collections were made in each traps at four times a month intervals. Total litter within each trap was sorted into its various components and species. The litter was then oven-dried at 105°C for five days and weighed. The total amounts for each sub-plot were converted to daily figures with no correction made for leaching or either losses. Total and leaf litterfalls for 12 months (48 collections) were correlated with mean temperature, evaporation, relative humidity, rainfall, and wind-run data recorded at Indramayu (10 m alt.) meteorological station which is about 15 km north-west of the study site. These meteorological parameters were examined the correlation with litter production (Snedecor and Cochran, 1967; Sokal and Rohft, 1973).

Fallen litter on the forest floor was sampled on twenty-five 1-m² quadrat in each 10 m x 10 m subplot for 12 months (48 collections).

RESULTS

The floristic and structural parameters of the 0.25 ha study site were summarized in the Table 1, in order to explain the ecological status. There are 45 and 39 trees of *R. apiculata* and *R. mucronata* respectively. The forest type producing a total litterfall which includes twigs, was estimated at about a mean of 3.54 g dry wt./m²/day (Table 2). 1290.5 g dry wt. of litter was collected in the 13 traps over 360 days, allowing the calculation of a mean annual litter was of 12.90 t dry wt./ha/year. Over the whole experiment 40.70% of the material collected was mangrove leaf branch, consisting small branches made up 33.12%. The large quantity of twigs collected on this period due to high wind and rain that might have merely caused premature abscission of that material. Reproductive organs (fruits, flowers, buds) are considered together and shared 26.18%. Thus, non leaf litter account for 59.30% of the total fall. Due to long time for decomposition, their importance cannot be ignored.

The parameters of weather condition particularly relative humidity, rainfall, number of rain-day, and temperature recorded at the meteorological station, Indramayu used for correlation analysis. Correlation analysis with monthly rainfall indicated that total litter, leaf, flower, fruit, bud, and twig litters production was strongly correlated with rainfall recorded at the time of sampling and in the previous months ($r = 0.947$, $r = 0.842$, $r = 0.827$, $r = 0.928$, $P < 0.01$) (Table 3). However, total litter and reproductive materials are negatively correlated with a mean monthly temperature ($r = -0.656$, $r = -0.657$, $P < 0.05$). On the other hand, twigs litter production was best correlated with the mean monthly temperature recorded during the study period ($r = -0.721$, $P < 0.01$). Moreover, plot of litterfall against height (X, m) of the mangrove trees in Tiris is

Table 2. Estimated annual amounts, daily litterfall production by species in the mangrove forest of Tiris Indramayu West Java. Values in mean and Standard Deviation.

Attribute	Litter Component (g dry wt./m ² /day)				% Total	Annual (t dry wt./ha/year)
	Twigs	Fruits + Buds + Flowers	Leaves	Total		
<i>Rhizophora apiculata</i>	0.42 ± 0.11	0.33 ± 0.15	0.60 ± 0.18	1.35	28.14	4.92
<i>R. mucronata</i>	0.45 ± 0.12	0.35 ± 0.22	0.62 ± 0.21	1.42	40.13	5.18
<i>Avicennia marina</i>	0.32 ± 0.11	0.24 ± 0.01	0.21 ± 0.06	0.77	21.73	2.80
Total	1.19	0.92	1.43	3.54	-	-
% Total	33.12	26.18	40.70	-	-	-
Annual (t dry wt./ha/year)	4.27	3.38	5.25	-	-	12.90

shown linear regression line as follows: Y (Litterfall, g/m²) = 0.245 X + 10.059 (r = 0.959, P < 0.001).

The linear regression analysis of the litterfall component with climatic variables and their equations are presented in Table 4. However, further analysis shows that monthly total production of litterfall (Y , kg/ha) correlated significantly with wind run (X_1 , km/hour) and evaporation (X_2 , mm) and the equation of their

multiple regression are as follow, $Y = 252.67 X_1 + 1.24 X_2 - 71.29$ (r = 0.971, P < 0.01).

The variation of litter production and fall during the beginning of rainy season for the first period of September 2005 to the end of January 2006 is shown in Figure 1a, b, and the meteorological data during the period of study was presented in Figure 2a, b. Moreover, it can be shown that during September 2005 to December 2005, the R .

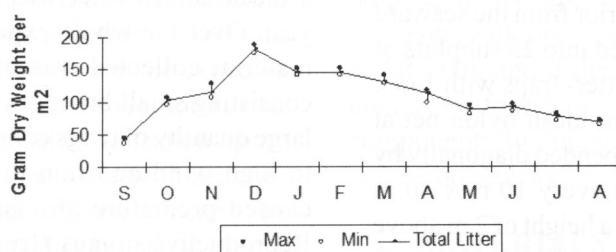


Figure 1a. Total litterfall data for a *Rhizophora apiculata* dominated mangrove forest in Tiris, Indramayu, Indonesia. 95% confidence limits indicated in two directions.

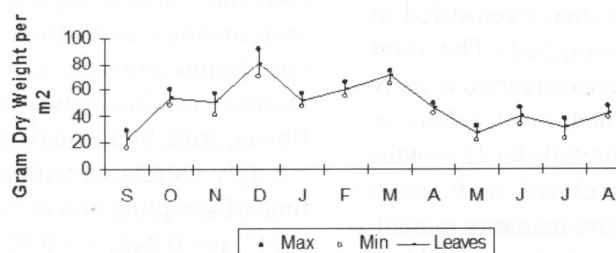


Figure 1b. Leaves component data for a *Rhizophora apiculata* dominated mangrove forest in Tiris, Indonesia. 95% confidence limits indicated in two directions.

Table 3. Simple correlation coefficient (r) matrix for 11 selected climatic and total litterfall and their component variables measured in 13 subplots in site III of the mangrove forest of Tiris (significance level for $p < 0.01$ and 0.05 are 0.661 and 0.532 respectively).

Climatic Variable:	Climatic Variable						Litterfall Component			
	2	3	4	5	6	7	8	9	10	11
1. Rainfall (mm)	0.919	0.137	-0.541	0.367	-0.686	0.795	0.947	0.842	0.827	0.928
2. Number of rain day	-	-0.108	-0.579	0.496	-0.712	0.863	0.935	0.746	0.924	0.935
3. Wind run (m/sec)	-	-	-0.093	-0.251	-0.103	-0.198	0.278	0.122	-0.097	-0.627
4. Mean Max. Temperature (°C)	-	-	-	0.255	0.885	-0.010	-0.533	-0.333	-0.682	-0.616
5. Mean Min. Temperature (°C)	-	-	-	-	-0.994	0.254	0.501	0.419	0.565	0.425
6. Mean Monthly Temperature (°C)	-	-	-	-	-	-0.072	-0.656	-0.462	-0.657	-0.721
7. Relative Humidity (%)	-	-	-	-	-	-	0.854	0.618	0.867	0.911
Litter Component:										
8. Total litterfall	-	-	-	-	-	-	-	0.894	0.887	0.963
9. Leaf litter	-	-	-	-	-	-	-	-	0.609	0.767
10. Flowers + Fruits + Buds litters	-	-	-	-	-	-	-	-	-	0.908
11. Twigs litter	-	-	-	-	-	-	-	-	-	-

apiculata–*R. mucronata* community displayed a marked increase in litter, with a mean of 1.45 (\pm 0.70) g dry wt./m²/day. Also, the litterfall showed marked temporal fluctuations with highest values (more than 4.3 g dry wt./m²/day) in the period of December 2005 to March 2006, and very little litterfall in September 2005 (1.25 g dry wt./m²/day). Figures show the seasonal change of litter including all organs by species (Figures 3, 4, 5). The estimated annual average amounts by species in the mangrove forest of Tiris can be shown in Table 2.

A two-way analysis of variance by the factors of litter traps and months of sampling was done for each component in the litter. Variation by litter

trap was, as expected on an individual species basis, highly significant. For both *R. apiculata* and *R. mucronata*, the variations in all of leaves, reproductive materials (flowers, fruits, and buds) and twigs were all highly significant ($P < 0.01$) by month of sampling. *Avicennia marina* had significant variations ($P < 0.05$) by month of sampling for leaf and reproductive material fall. *R. apiculata* flowers throughout the year, but has a pronounced peak in rainy season in February (493.20 mm) and a minimum in August (9.5 mm). The flower bud fall has a pronounced peak in dry season in June (69 mm) (Figure 3). The fall of floral buds was significantly correlated with rainfall ($P < 0.01$) positively. Leaf fall demonstrated one

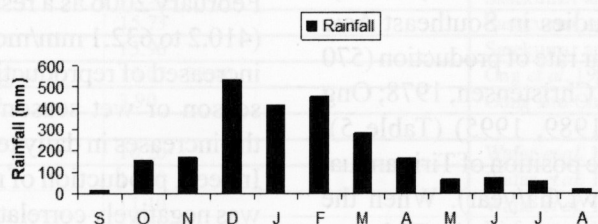


Figure 2a. Meteorological data during the period of the study (September 2005 to August 2006) recorded from Indramayu approximately 15 km from the study area.

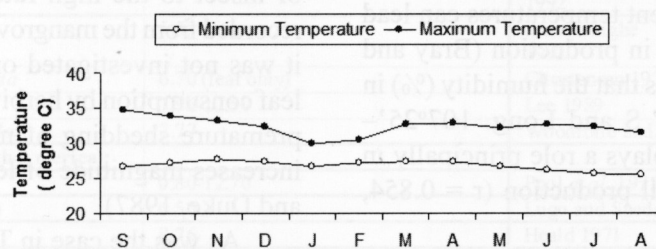


Figure 2b. Meteorological data during the period of the study (September 2005 to August 2006) recorded from Indramayu approximately 15 km from the study area.

Table 4. Linear regression for litterfall production vs. climatic variable (rainfall, number of rain day, mean maximum and mean monthly temperatures, and relative humidity)

Litterfall (L) compared	r	Regression equation
L total vs. rainfall	0.947	Y, g dry wt. = 64.293 + 0.169X
L total vs. number of rain-day	0.935	Y, g dry wt. = 45.164 + 3.855X
L total vs. relative humidity	0.854	Y, g dry wt. = -352.873 + 5.660X
L total vs. mean maximum temperature	-0.533	Y, g dry wt. = 592.885 - 15.133X
L total vs. mean monthly temperature	-0.656	Y, g dry wt. = 844.409 - 27.693X
L leaf vs. rainfall	0.842	Y, g dry wt. = 29.587 + 0.066X
L leaf vs. number of rain-day	0.746	Y, g dry wt. = 39.130 + 0.679X
L leaf vs. relative humidity	0.618	Y, g dry wt. = -118.720 + 2.027X

peak annually in association with the wet season (March = 280.10 mm). The leaf fall was also significantly correlated with the number of rain-day and relative humidity ($P < 0.01$).

DISCUSSION

Annual amount of litter production in the *R. apiculata* – *R. mucronata* community in Tiris (1291 g dry wt./m²/year) was very close to the value of 1430 g dry wt./m²/year recorded in Papua New Guinea of the Malesian region (Leach and Burgin, 1985). Southeast Asia region has reported similar rate of production (570 to 830 g dry wt./m²/year) (Christensen 1978; Ong *et al.*, 1982; Sukardjo 1989, 1995) as well as those of Southern Florida (Pool *et al.*, 1974). Hinchinbrock Island, Queensland Australia (Duke *et al.*, 1981). Significantly, litterfall studies in Southeast Asia region have reported similar rate of production (570 to 830 g dry wt./m²/year) (Christensen, 1978; Ong *et al.*, 1982; Sukardjo, 1989, 1995) (Table 5). Globally, Table 5 shows the position of Tiris annual production (12.90 t dry wt./ha/year). When the litterfall figures from mangroves in Tiris are compared to studies in mangrove forests elsewhere, especially in the tropical region, thus value can be classified high (Cf. Kathiresan and Bingham, 2001; Saenger and Snedaker, 1993). Moreover, comparison of weights of litter which has been dried at different temperatures can lead to apparent differences in production (Bray and Gorham, 1964). It means that the humidity (%) in Tiris (Lat. 6°10'–7°49' S and Long. 107°25'–108°25' E) study area plays a role principally in the total annual litterfall production ($r = 0.854$, $P < 0.01$).

The litterfall in Tiris peaked during the high rainfall of the rainy season or wet season (November 2005 to April 2006), reflecting the pattern of leaf fall, the major litter component (40.70%) (Figure 1a, b). The fact that leaf fall in Tiris is more strongly correlated with number of rain-day, rainfall ($P < 0.01$), and relative humidity ($P < 0.05$) than temperatures suggests that the total litter production be largely controlled by the former parameter which is climatologically the region has high annual rainfall (2,661 mm). Table 3 suggests that further observation in dry season are required to established seasonal fluctuation in nature and to maintain a level of productivity indicated by litterfall every year. Heavy rain in the period of

observation of September 2005 to January 2006 coincided with increased litterfall, this is especially marked in the collection of November 2005.

Previous attempts to correlated rainfall and litterfall in Malesian forests yielded contrasting results; a significant correlation between rainfall and leaf fall has been recorded by Sukardjo (1989, 1995), Kusmana (1995), Sasekumar and Loi (1983) and Leach and Burger (1985). Similar studies in the effects of temperature on the litterfall production of *R. mucronata* plantation in Tritih, Cilacap (Sukardjo, 1996) suggests that in the absence of moisture stress, leaf fall showed short terms response to change in temperature.

The reproductive organs consisted mainly of fruits, buds, and flowers. Reproductive organs production peaked during December 2005 to February 2006 as a result of high monthly rainfall (410.2 to 632.1 mm/month). This indicates that the increased of reproductive activity during the rainy season or wet season, was probably caused by the increases in daily temperature ($26.9^{\circ} \text{C} \pm 0.86$). Indeed, production of reproductive organs in Tiris was negatively correlated with temperatures (mean maximum temperature and mean daily temperature) (Figure 2a, b) and positively correlated with mean minimum temperature and relative humidity (Table 3). In connection with the peaked leaf fall production, no apparent contribution of insect to the high rate of litterfall has been recorded from the mangrove forest in Tiris although it was not investigated on an annual basis. The leaf consumption by herbivores possibly causes to premature shedding of mangrove leaves which increases magnitude of leaf fall (Cf. Roberstson and Duke, 1987).

As was the case in Tiris, rainfall coincident peaks in mangrove litterfall have been recorded on *R. mucronata* plantation in Tritih Segara Anakan, Cilacap (Sukardjo, 1996), and on a small mixed stand of mangroves with *R. stylosa* as a dominant species in Papua New Guinea (Leach and Burgin, 1985), Malay Peninsula (Sasekumar and Loi, 1983). In the tropical regions, dry season induces in abscission (e.g., Daubenmire, 1972; Gong and Ong, 1983), but leaf fall peak in mangrove forest in Tiris, Indramayu showed coincidence with the onset of the wet season. Based on the result of the statistical analysis presented in Table 3, it can be concluded that maximum leaf fall in the mangrove forest of Tiris Indramayu coinciding with the periods of high

Table 5. Regional comparison of litter production in the mangrove forests

Locality/Forest Type	Yield (t dry wt./ha/year)	Refer ence
Indonesia:		
1. <i>Rhizophora</i> forest:	12.90	This study
1.1. <i>R. apiculata</i>	4.92	This study
1.2. <i>R. mucronata</i>	5.18	This study
1.3. <i>Avicennia marina</i>	2.80	This study
2. <i>Rhizophora</i> forest	4.94	Sukardjo 1989
3. <i>Avicennia</i> – <i>Rhizophora</i> forest	13.99	Sukardjo 1989
4. <i>Avicennia</i> forest	15.81 – 17.50	Sukardjo 1989
5. <i>R. apiculata</i> – <i>A. marina</i> forest	20.50 – 21.10	Sukardjo 1995
6. <i>Ceriops tagal</i> – <i>R. apiculata</i> forest	25.92 – 29.35	Sukardjo 1995
7. <i>A. officinalis</i> – <i>A. marina</i> forest	28.82	Sukardjo 1995
8. <i>R. mucronata</i> plantation	7.06 – 10.40	Sukardjo 1996
9. <i>Bruguiera</i> – <i>Rhizophora</i> forest	10.96 – 12.69	Kusmana <i>et al.</i> 1997
Philippines:		
1. <i>Rhizophora apiculata</i>	4.77 (leaf only)	De Leon <i>et al.</i> 1992
2. <i>R. mucronata</i>	7.87 (leaf only)	De Leon <i>et al.</i> 1992
PNG:		
1. <i>Rhizophora</i> forest	14.30	Leach and Burgin 1985
2. Mixed mangrove forest (Fly river estuary)	8.00-14.00	Twilley <i>et al.</i> 1992
Malaysia:		
1. <i>Avicennia</i> forest	15.36	Sasekumar and Loi 1983
2. <i>Rhizophora</i> forest	15.73	Sasekumar and Loi 1983
3. <i>Sonneratia</i> forest	13.96	Sasekumar and Loi 1983
4. <i>Rhizophora</i> (S. Merbok - Matang)	10.07 - 23.40	Ong <i>et al.</i> 1982
5. Mixed mangrove forest (Matang)	3.90	Gong and Ong 1990
India:		
1. <i>Avicennia officinalis</i>	10.20	Wafar <i>et al.</i> 1997
2. <i>Rhizophora apiculata</i>	11.70	Wafar <i>et al.</i> 1997
3. <i>R. mucronata</i>	11.10	Wafar <i>et al.</i> 1997
4. <i>Sonneratia alba</i>	17.00	Wafar <i>et al.</i> 1997
5. Mixed mangrove forest (Andaman islands)	7.10-8.50	Mall <i>et al.</i> 1991
7. <i>Bruguiera gymnorrhiza</i> (Andaman islands)	5.11-7.09	Dagar and Sharma 1993
8. <i>R. apiculata</i> (Andaman islands)	8.08-10.30	Dagar and Sharma 1991
Sri Lanka:		
1. <i>Avicennia spp.</i>	3.74	Amarasinghe and Balasubramaniam 1992
2. <i>Rhizophora spp.</i>	4.41-6.24	Amarasinghe and Balasubramaniam 1992
3. Mixed mangrove forest	5.53	Amarasinghe and Balasubramaniam 1992
Thailand: <i>Rhizophora apiculata</i>	6.70 (leaf only)	Christensen 1978
Hongkong: <i>Kandelia candel</i>	7.96-12.59	Lee 1989
South Pacific: <i>Rhizophora stylosa</i>	7.77	Woodroffe and Moss 1984
USA (Southern Florida, North America):		
1. Mixed mangrove forest	0.80-12.70	Pool <i>et al.</i> 1975
2. <i>Avicennia germinans</i> (basin)	6.50	Lugo and Snedaker 1975
3. <i>Rhizophora mangle</i>	8.76	Heald 1971
4. <i>Avicennia spp.</i>	4.69-5.38	Twilley <i>et al.</i> 1986
5. Mixed mangrove forest	7.51	Twilley <i>et al.</i> 1986
6. Mixed mangrove forest (Bermuda)	9.40	Ellison 1997
Mexico:		
1. Mixed mangrove forest	8.34-12.52	Day <i>et al.</i> 1987
2. Mixed mangrove forest	14.17	Flores-Verdugo <i>et al.</i> 1990
2. <i>Avicennia germinans</i>	6.14	Lopez-Portillo and Ezcurra 1985
3. <i>Laguncularia racemosa</i>	11.00	Flores-Verdugo <i>et al.</i> 1987
South Africa:		
1. <i>Avicennia marina</i>	7.15	Steinke and Charles 1984
2. <i>Bruguiera gymnorrhiza</i>	8.61	Steinke and Charles 1984
3. Mixed mangrove forest	4.50	Steinke and Ward 1990
Australia and New Zealand:		
1. <i>Avicennia marina</i>	15.98	Bunt 1995
2. <i>Ceriops tagal</i>	12.90	Bunt 1995
3. <i>Rhizophora stylosa</i>	23.69	Bunt 1995
4. Mixed mangrove forest	3.70 – 28.40	Bunt 1978
5. <i>A. marina</i> forest	5.80	Goulter and Allaway 1979
6. <i>A. marina var. resinifera</i> (low-tall)	3.65-8.10	Woodroffe 1982

rainfall is common, and litterfall peaks coinciding with either high or low precipitation. Unlike the study of Pool *et al.* (1974), however, those results could not be attributed to an increase in mean wind velocity associated with the rain as was not observed to be related to litterfall either in total or by component, except twigs litter (Table 3). With regard to nutrient concentration especially leaching from fallen litter, the occurrence of maximum litterfall in a wet season would appear to be adaptive. However, in the mangrove forest in Tiris Indramayu which has wet season (October to April), litterfall peaks are characterized by lower species diversity. Only three species was recorded

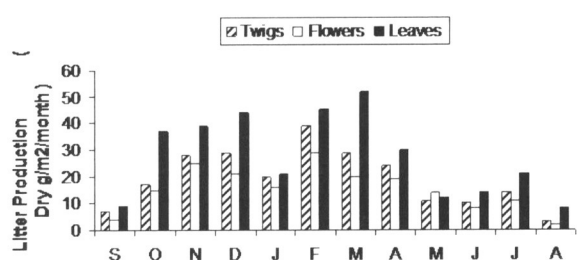


Figure 3. Litterfall data for *Rhizophora apiculata* BI. in Tiris, Indramayu from September 2005 to August 2006.

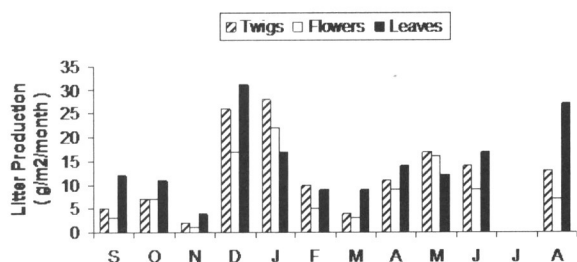


Figure 4. Litterfall data for *Rhizophora mucronata* Lmk. in Tiris, Indramayu from September 2005 to August 2006.

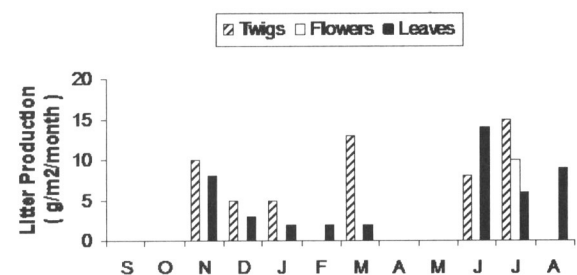


Figure 5. Litterfall data for *Avicennia marina* (FORSK) Vierh. in Tiris, Indramayu from September 2005 to August 2006.

as litter contributors viz, *R. apiculata*, *R. mucronata*, and *A. marina* (Table 2).

In mixed mangrove stands in Tiris *A. marina* produced litterfall amounted to be 2.8 t dry wt./ha/year (or only 21.73% of the total litterfall). In New Zealand, litterfall beneath *A. marina* as single stand (3.5–4 m tall) near its latitudinal limit (36°48'S, 174°45'E) can be as high as 8.10 ± 2.74 t dry wt./ha/year (Woodroffe 1982). *R. apiculata* and *R. mucronata* contributed 38.14 and 40.13% of the total litter production, respectively (Table 2). It can be concluded that no much inter-specific differences in leaf shedding time between those two species (Figures 3, 4). As results, despite relatively high litterfall during the heavy rain, dry season (< 100 mm/month) litterfall (May to September) (Figure 2a, b) is still considerable in the mangrove forest in Tiris, accounted to be 27.75% of the annual total litter production (Figure 1a, b). A year-round production of slow-nutrient-releasing woody litter in the mangrove forest of Tiris (1.17 g dry wt./m²/day) could also be adaptive features, tending to maximize nutrient conservation and utilization. The difficulties involved in making generalizations about patterns of litterfall in the mangrove forest reflect differences within and between mangrove forest ecosystems. This is complicated by the possibility that leaf abscission may have wider ecological significance than merely the contribution on litter to nutrient cycling. Overall, litterfall is probably best considered as a dynamic process shaped by different selective forces under different circumstances, those patterns which enhance nutrient utilization and conservation tending to persist.

A mean yields of total litterfall by species (see Table 2) show remarkably little inter-specific variation and are closely comparable with the mean value 1.65 and 1.54 g dry wt./m²/day reported by Duke *et al.* (1981) for *R. apiculata* and *R. stylosa* forests, respectively, in Coral Creek Walkway, Missionary Bay, North Eastern Australia. Values for each of the Tiris species, although lower, bear comparison with a mean value of 3.97 g dry wt./m²/day from a *R. stylosa* forests in Papua New Guinea (Leach and Burgin, 1985) and with global estimates of primary production in mixed forests in Queensland (1.03–7.70 g dry wt./m²/day) reported by Bunt (1978) (See also Table 4 for another areas in the world). Further, within species local condition may act to shift seasonal patterns in litterfall in time to some extent and perhaps also

in character. There is indication of such effects in the data for *A. marina* (Figure 5). Accordingly, these possibilities should be taken into account when detailed ecological studies are undertaken elsewhere in Indonesia. It is clear that distinctive seasonal patterns of growth from species to species must be reflected in difference in the nature of litterfall input in mangrove forests of differing floristic composition through annual cycles. Figures 3, 4, and 5 suggested that the causes of seasonality in the phenological cycles of mangroves will be the result of a combination of factors including external environmental variables; internal tree phenology, and the ecological aspects of pollination and propagule dispersal (cf. Duke, 1988).

In conclusion, estimates of litter production from Tiris, Indramayu may be applied to mangroves elsewhere in Indonesia provided that the influence of those differences in mangrove biomass, canopy height and density, and nutrient availability, and the effect that might have on mangrove productivity are taken into account (Cf. Lugo and Snedaker, 1974, Onuf *et al.*, 1977, Rochow, 1974). These results serve to strengthen the importance attached to mangroves in Tiris as well as the Cimanuk delta complex and their contribution to the estuarine food web, and enhance the desirability of protecting these mangrove forests. Also, litter from Tiris mangroves represents a significant organic input into the Java Sea, to form the major source of nutrients and energy for the shallow water marine system. Non-leaf components of litter (59.30%) constitute a significant input in organic matter to the mud floor in Tiris mangrove forests. As tidal activity decreases in the study area (site III), surface litter becomes less susceptible to export (cf. Twilley, 1985, Twilley *et al.*, 1992), suggesting that in situ litter decomposition should have more influence on litter dynamics and nutrient cycling. Overall, litterfall is probably best considered as a dynamic process shaped by different selective forces under different circumstances, those patterns which enhance nutrient utilization and conservation tending to persist. Further studies on the litter decomposition and turnover in the mangrove forests in Tiris (include the Cimanuk delta complex) are strongly urged. Also, Indonesia possesses magnificent mangrove forests which are not only the most extensive, but they also contain the largest number of species and communities.

The present study supports thus statement and the above hypothesis.

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