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Soils in the Mangrove Forests of the Apar Nature Reserve, Tanah Grogot, East Kalimantan, Indonesia

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Key words

Mangrove forests, *Avicennia* and *Ceriops* substrates, Physical and chemical properties, East Kalimantan, Indonesia

Abstract

The mangrove forest occurring in the Apar Bay, Tanah Grogot is typical of the luxuriant mangrove forest developed in the coastal zone of East Kalimantan province. It has been declared a nature reserve and has an estimated area of about 128,000 ha. This mangrove forest consists mainly of pure stands of *Avicennia officinalis* L. in the seaward zone and *Ceriops tagal* (Perr.) C. B. Robins in the landward zone, both of which grow on similar substrates. Soil samples from pure *Avicennia* and *Ceriops* stands were analyzed in terms of their physical and chemical properties. All soils examined were weakly acidic, high in organic matter and low in available phosphorus. They were also characterized by high bulk density and moderate CEC (cation exchange capacity). The soils covered by the dominant species of *Avicennia* contained less sand and more silt than those covered by *Ceriops*. Generally, the soils covered by *Avicennia* were higher in pH (4.83 ± 0.38 in H_2O), CEC (23.72 ± 0.70 meq/100 g dry soil), exchangeable cation and NH_4-N (453.705 ± 1.031 ppm), and lower in organic matter (6.81 ± 0.14%) than those covered by *Ceriops*. The results suggest that *Avicennia officinalis* L. and *Ceriops tagal* (Perr.) C. B. Robins grow well in their present substrates, as shown by their high biomass and stand density per $100m^2$.

Introduction

The most extensive and luxuriant mangrove swamp forests in Kalimantan, Indonesian Borneo, are found in East Kalimantan province, where their total area is about 266,800 ha, or 69.58% of the total mangrove swamp forest in Kalimantan [Darsidi 1984]. The forests are well developed structurally and floristically along the coast, estuaries, deltas and small islands. Mangrove swamp forests in East Kalimantan province are among the most productive environments [Sukardjo 1993]. They provide tremendous economic benefits to mankind through fishery production (over two-thirds of East Kalimantan fish harvest is linked to the health of mangrove swamp forest areas), maintenance of the water table for agriculture, water storage and flood control.

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Though the mangrove swamp forests in East Kalimantan are extensive, they have been little studied [e. g., Sukardjo 1988; 1993] and are now in the process of wanton exploitation. For these reasons, I feel that there is an urgent need for a thorough ecological study of this important ecosystem. There are many factors which may control or influence productivity and diversity in mangroves. These include climate, geomorphology, tidal range, fresh water input and other factors [Pool *et al.* 1975; Goulter and Allaway 1979; Twilley *et al.* 1986]. However, the substrate characteristics must be considered to exert one of the most direct controls on these systems. It is, therefore, surprising that edaphic factors in mangroves have received relatively little attention [e. g., Soerianagara 1971; Notohadiprawiro 1979; Sukardjo 1982; 1987; Wiranagara and Hardjowigeno 1987]. In this paper, I describe the physical and chemical properties of the soil, and the variation in redox potential, pH, salinity and nitrogen with elevation within the tidal zone, for a mangrove forest in Apar Nature Reserve, Tanah Grogot, East Kalimantan. The results of two months of study from December 1981 to January 1982 are summarized, and important or interesting trends and indications are discussed.

The Study Area

The study area is located at Apar Bay, Tanah Grogot (Lat. −1°56.5′; Long. 116°10.9′), East Kalimantan, about 160 km southwest of Balikpapan (Fig. 1). It is a part of the deltaic coastal swampland that forms a continuous belt on the east coast of Borneo. The coastal swampland at Apar Bay mainly consists of mangrove swamp, peat swamp, freshwater swamp and nipa (*Nypa fruticans*) swamp forests, and gelam (*Melaleuca leucodendron*) forest, each forming a distinct zone.

Apar Nature Reserve (128,000 ha) is one of the main mangrove forests in the East Kalimantan coastal zone. It provides fisheries potential and is essential in the mangrove fauna migration cycle. Fringe and riverine mangrove forests occur as primary features in the coastal zone of Apar Bay, with *Avicennia* spp. and *Sonneratia* spp. which are distributed mainly around the river mouth [Sukardjo 1989]. Four forest types can be identified as mixed forest of *Rhizophora* spp. and *Bruguiera* spp., pure forest of *Avicennia officinalis*, pure forest of *Ceriops tagal* and the non-mangrove plant *Melaleuca leucodendron* forest. Only *M. leucodendron* developed between freshwater swamp and mangrove forests. Physiognomically, the average height of mangrove trees at the seaward and landward edges was 30m and 45m, respectively.

The study area is usually subject to tidal inundation twice daily. During high tide the soil surface is completely covered by sea water. The mean tidal range is about 2.5 m [Anonymous 1981a]. According to the soil map of East Kalimantan province, a part

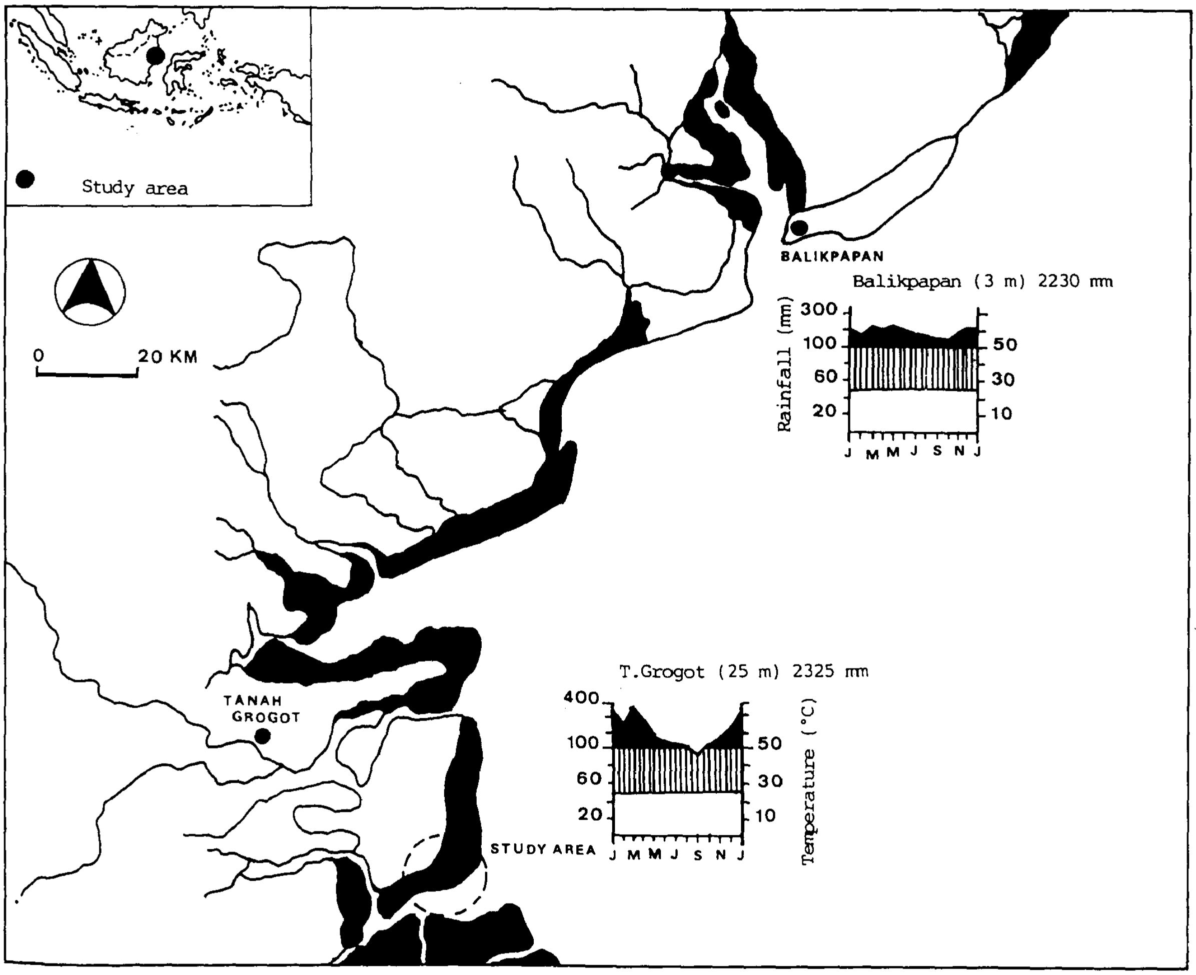

Fig. 1 East Kalimantan Mangroves, Their Climate Diagrams and the Approximate Location of the Study Area

of the area with flat physiography is covered by alluvial deposits of recent origin [Anonymous 1981b], including alluvial soils supporting mangrove forests and organic soil under peat swamp forests [Lembaga Penelitian Tanah 1964].

The area is located within the climatic type A, where the ratio of dry to wet months is 0–98% [Schmidt and Ferguson 1951], with annual rainfall of 2,230 to 2,325 mm [Berlage 1949]. The study area has no dry season throughout the year and mostly no monthly rainfall less than 100mm (Fig. 1). The average monthly temperature does not exceed 29°C. According to the Koppen classification, the climate in this area is a warm temperate rainy climate. Climate diagrams for the meteorological stations at Tanah Grogot and Balikpapan are presented in Fig. 1.

Methods

A transect was established perpendicular to the coastline through the Apar Nature

Reserve, extending inland to the freshwater swamp forest. A pure stand of *Avicennia officinalis* in the seaward zone and one of *Ceriops tagal* in the landward zone were selected for soil study. Soil samples to the depth of 20cm were collected systematically using a cylinder cup with a volume of 1 liter from 25 subplot sites of 10m×10m in 50m ×50m (0.25ha) plots in almost pure stands of *A. officinalis* and *C. tagal.*

The bulk density was measured using a steel cylinder cup with a volume of 1 liter [Allen *et al.* 1974] and the quoted values refer to the dry weight per total volume of wet soil. Redox potential was measured by immediate insertion of a Pt/SCE combination electrode into the soil. The measured potentials were corrected to E_h (vs. hydrogen electrode reference) by addition of+244mV to the reading. The soil salinity was measured by using a refracto-salinometer. Soil analyses were performed by the Chemistry Section of the Department of Natural Sciences, Bogor Agricultural University, Bogor.

In the 50m×50m (0.25ha) plot, the diameter of all trees of more than 2cm DBH (diameter at breast height) was measured 1.30m above the ground using a diameter tape, and their height was measured with a hypsometer. Trunk and branch volume in each 10m×10m subplot was estimated by using the equation $V=0.5\pi r^2h$ [Rochow 1974], where V is volume, r is stem diameter and h is tree height.

Results and Discussion

Soil Description

Physical properties of the soil in the *Avicennia* and *Ceriops* forests are shown in Tables 1 and 2. Table 1 shows that all soil samples have less than 35% of sand particles in the surface layer (0–20cm), which can be classified as a moderate percentage [Soerianagara 1971], indicating that the soil surface mainly was composed of small but newly sedimented particles. The physical properties of soil were similar in the zones of *A. officinalis* and *C. tagal* (Tables 1 and 2); and they were of the same nature as soils classified as clay loam. There was an increase in sand content from 29.96% in the seaward edge zone (*Avicennia* forest) to 31.27% in the interior (*Ceriops* forest). The moderate sand content in both *Avicennia* and *Ceriops* forests can be attributed to the flat topography of the swampland area (Fig. 2), and to the turbulent and churning action of the tidal waters, which permit only the coarse soil fraction to settle out of suspension. *Avicennia officinalis* is the pioneer species in the Apar Bay area, and is able to colonize both muddy and sandy substrates on river banks and the sea edge. At a distance of 300m from the sea edge, the colonization of *A. officinalis* became more stable and a pure stand was formed with an average tree height of 30m. Due to the dense of pneumatophores, the colonization promotes the consolidation and stabiliza-

Table 1 Physical Properties of the Soil in the Mangrove Swamp Forests

Forest Type	Distance from the Sea Edge (m)	Soil Depth (cm)	Soil Fraction (%)			Texture Class	Bulk Density (g/ 100 ml)
			Clay	Silt	Sand		
Avicennia							
	300	0 – 20	30.13	39.91	29.96	Clay loam	103
	310	0 – 20	30.16	39.90	29.94	Clay loam	110
	320	0 – 20	30.05	39.90	30.05	Clay loam	110.5
	330	0 – 20	30.10	39.80	30.10	Clay loam	112
	340	0 – 20	30.04	39.81	30.15	Clay loam	117
	All-site average		30.10	39.86	30.04		110.5
Ceriops							
	510	0 – 20	32.98	35.92	31.10	Clay loam	137
	520	0 – 20	32.93	35.92	31.15	Clay loam	137.5
	530	0 – 20	32.90	35.92	31.18	Clay loam	138.5
	540	0 – 20	33.20	35.60	31.20	Clay loam	139.5
	550	0 – 20	33.23	35.50	31.27	Clay loam	140
	All-site average		32.05	35.77	31.18		138.5

Table 2 pH, Redox Potential (E_h) and Soil Salinity in the Mangrove Swamp Forests

Forest Type	Distance from the Sea Edge (m)	pH 1 : 1		E_h (mV) at 5 cm Depth	Soil Salinity (% o)
		H_2O	KCl		
Avicennia					
	300	4.35	4.20	− 115 (− 91 ; − 146)	34
	310	4.44	4.33	− 119 (− 81 ; − 140)	33.75
	320	4.82	4.43	− 120 (− 61 ; − 158)	33.50
	330	5.20	4.54	− 134 (− 105 ; − 158)	32.75
	340	5.29	5.10	− 138 (− 94 ; − 172)	31
	All-site average	4.82	4.52	− 125.2	33
	SD	0.38	0.31	9.06	1.08
Ceriops					
	510	3.70	3.15	− 134 (− 105 ; − 158)	30.50
	520	3.85	3.20	− 138 (− 95 ; − 172)	29.50
	530	3.95	3.25	− 140 (− 119 ; − 197)	28.50
	540	4.05	3.30	− 157 (− 145 ; − 181)	28.50
	550	4.20	3.35	− 162 (− 116 ; − 208)	28
	All-site average	3.95	3.25	− 146.2	29
	SD	0.17	0.07	11.14	0.89

Note: Numbers in parentheses refer to the maximum and minimum.
E_h recorded at each 10 m × 10 m subplot.
SD = Standard deviation

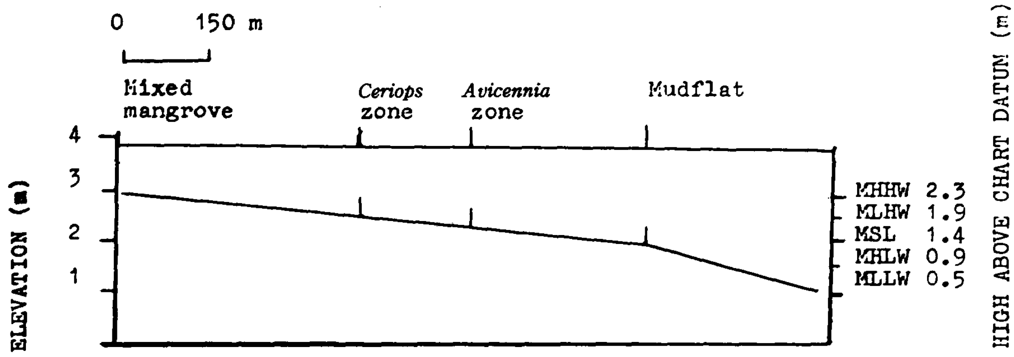

Fig. 2 Physiography of the Study Area Showing the General Vegetation Types and Their Tidal Character

MHHW = Mean High High Water Level
MLHW = Mean Low High Water Level
MSL = Mean Sea Level
MHLW = Mean High Low Water Level
MLLW = Mean Low Low Water Level

tion of the substrate. This is turn permits the accretion of finer sediments such as silt and clay. Once the nature of the substrate is altered sufficiently, not only by *A. officinalis* colonization, but also by crabs and calcareous material brought in from the sea, together with the broken-down shells of mollusca which live within the mangrove, *Bruguiera parviflora* becomes established. Its recorded densities in this zone were as high as 24 trees (DBH more than 10cm) and 128 saplings (trees with diameter 2–9.90cm) per hectare. Further inland, the moderate proportion of the fine soil fraction (silt and clay) in the surface layer of the *Ceriops* forest is probably due to the slow rate of inundation of the forest and the low slope. The particle size distribution suggests that greater deposition of finer sediments is found further from the waters edge.

Bulk density measurements tended to give variable results because of the heterogeneity of the root distribution. The bulk density values were high, varying from 103 to 117g/100ml for *Avicennia* forest and 137 to 140g/100ml for *Ceriops* forest (Table 1). On the average basis, the top 20cm of the soil in the *Avicennia* forest had a bulk density of 110.5g/100ml (SD=4.5) as compared to about 138.5g/100ml (SD=1.5) in the *Ceriops* forest. The bulk density of the soils was 11.5% higher in the *Ceriops* forest than in the pure stand forest of *A. officinalis*. The high bulk density in the surface layer of the *Ceriops* forest was due to the irregularity and decreased frequency of flooding. The low bulk densities in the *Avicennia* forest are a reflection of the moderate clay (30.10±0.05%) and high organic matter contents (6.81±0.12%) (Tables 1 and 3). The moderate clay contents (32.05±0.14%) in the *Ceriops* forest indicates that the soils have a moderate water-holding capacity and poor drainage. These results were supported by the nature and the flat topography of the swamp forest.

Table 3 Organic Matter, C Organic, Nitrogen and Phosphorus in the Soils of the Mangrove Swamp Forest

Forest Type/ Distance from the Sea Edge (m)	Soil Depth (cm)	Organic Matter (%)	C Organic (%)	N Total (%)	C/N	NH_4-N (ppm)	NO_3-N (ppm)	P_2O_5 Total (ppm)	Available P_2O_5 (ppm)
Avicennia									
300	0-20	6.65	3.73	0.345	10.81	452.310	29.960	575.225	20.15
310	0-20	6.70	3.85	0.355	10.85	452.927	30.950	575.125	20.05
320	0-20	6.85	3.90	0.375	10.40	453.718	31.020	574.985	19.90
330	0-20	6.90	4.09	0.385	10.62	454.320	31.950	574.653	19.65
340	0-20	6.95	4.23	0.390	10.85	455.250	32.150	573.987	19.60
All-site average		6.81	3.96	0.370	10.71	453.705	31.206	574.795	19.87
SD		0.12	0.18	0.020	0.18	1.031	0.787	0.448	0.22
Ceriops									
510	0-20	19.35	10.50	0.955	10.99	229.780	30.883	472.795	61.575
520	0-20	19.47	10.95	0.960	11.40	230.475	31.384	472.508	61.025
530	0-20	19.68	11.45	0.965	11.86	230.880	31.682	472.306	60.525
540	0-20	19.75	11.75	0.975	12.05	231.675	31.986	472.010	59.769
550	0-20	19.80	12.35	0.980	12.60	232.075	32.145	471.702	58.946
All-site average		19.61	11.40	0.97	11.78	230.977	31.616	472.264	60.272
SD		0.17	0.64	0.01	0.55	0.823	0.450	0.381	1.034

SD=Standard deviation

E_h, pH and Salinity

Redox potential (E_h) measurements made during exposure of the soils at low tides showed that the soils were consistently anaerobic at all sites (Table 2). The soils surface became slightly more oxidized during exposure, but even then the E_h at the surface (0–5cm depth) was usually less than 100mV. The relationship between E_h and location is shown in Fig. 3. The feature of these results is that soils were consistently anaerobic. The plant biomass estimated in terms of average trunk volume per $100m^2$ for subplots along the transect is also shown. The soils of subplots with less plant biomass tended to be more anaerobic. Also, the maximum E_h values at each subplot coincided with a period of high plant activity (new shoot growth). These findings suggest that the mangrove may translocate oxygen to the root zone, as proposed by Scholander *et al.* [1955]. Oxygen diffusion from the roots or release of metabolites [Howes *et al.* 1981] could then create aerobic zones within the soil root system.

Table 2 shows the soil pH of mangrove forests at Apar Bay. All soil samples were acidic. Soil pH (in H_2O) in the *Avicennia* forest varied from 4.35 to 5.29, while in the *Ceriops* forest the range was 3.70 to 4.20. These pH values was less than 4.30, and such acidity might be partly due to humic acid [Swift *et al.* 1979]. Soils were generally slighty more acidic in the *Ceriops* forest (3.95±0.17) than in *Avicennia* forest (4.85± 0.38). Furthermore, very small differences were found between the pH (H_2O) and pH (KCl) in the soils of *Avicennia* forest and also in the *Ceriops* forest (Table 2), and this

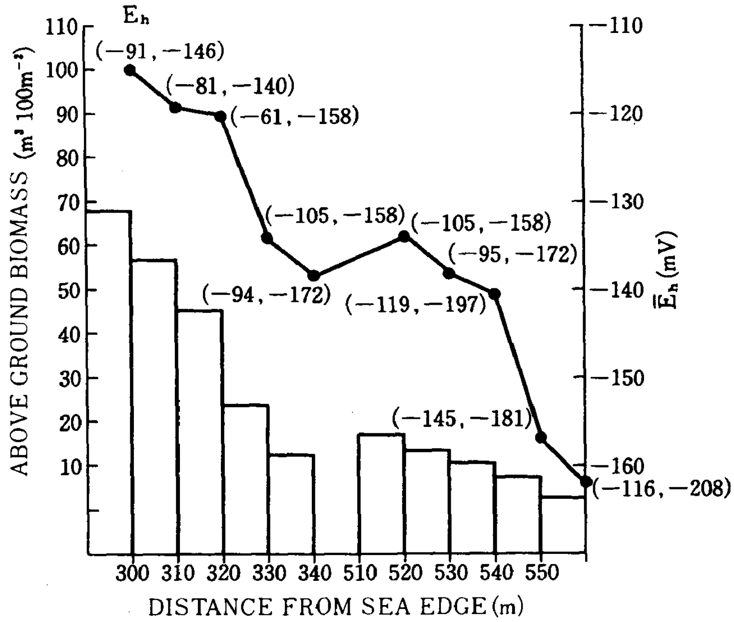

Fig. 3 Variation in Soil Redox Potential (E_h) for Each 10 m × 10 m subplot Site

Numbers in parentheses refer to the maximum and minimum E_h recorded at each site. The above ground biomass per 100 m^2 along the transect is also shown.

indicates that most of the cations in the soils are in a readily exchangeable form.

During the period of high plant activity as evidenced by the rate of new leaf shoot appearence of *A. officinalis* and *C. tagal*, the pH was consistently low (4.35 for *Avicennia* forest and 3.70 for *Ceriops* forest) in the 20-cm depth zone. This indicates that root exudates during the high activity period may influence the soil pH [Motomura 1962]. It was found that the forests are flooded by sea water twice daily [Anonymous 1982]. Among the major factors governing the pH of flooded soils are the concentrations of reduced iron and manganese hydroxides and carbonates, carbonic acid and humic acid [Patrick and Milkelsen 1971 ; Ruttner 1963].

The values of soil salinity show considerable change at boundary between species zones, overall decreasing inland from a maximum of 34‰. The soil salinity in *Avicennia* forest (33‰±1.08) was higher than that of the pure *Ceriops* forest (29‰±0.89) at 20cm depth (Table 2). Measurements in each 10m×10m subplot site showed that the soil salinity was generally constant at 33‰ for *Avicennia* forest and 29‰ for *Ceriops* forest. Restricted exchange between the tidal water and the stagnant water in the *Avicennia* forest, combined with the effects of evapo-transpiration, account for the increase in salinity. Changes in soil salinity along the transect suggested that the soil salinity was a major factor and tide a subsidiary factor controlling the mangrove zones or gradient in the Apar Nature Reserve. These findings support Haan's postulate [Haan 1931].

Organic Matter and C Organic

The surface layers of 20cm depth of mangrove forests were high in organic matter (Table 3). Organic matter content generally increased with distance inland, from 6.65% in the *Avicennia* forest to 19.80% in the *Ceriops* forest. The high quantities of organic matter present in the soils of both *Avicennia* and *Ceriops* forests are due to high elevation coupled with the high density of trees. The dense pneumatophores (*Avicennia*) and kneeroot systems (*Ceriops*) also contribute by trapping leaves and other debris during tidal inundation. The litter fall of *Avicennia* and *Ceriops* forests also contributes significantly to the higher organic matter contents in the soils. It was found here that the *Ceriops* forest produced much more litter fall than *Avicennia* forest [Sukardjo 1993]. The increasing darkness of soil which is observed with distance inland is probably a reflection of the high organic matter contents. High soil organic matter in mangrove forest is usually associated with a slow rate of silting [Moorman and Pons 1974]. Based on the results, it can be concluded that rich organic matter associated with soft mud sediments of fine silt and clay supports the development of mangrove forests in the Apar region, as shown by the high population density of *A. officinalis* (144 trees/ha and 128 saplings/ha) and *C. tagal* (168 trees/ha and 112 saplings/ha) along the transect, and the increasing height of trees toward the interior (30.05±1.75m to 45.09±1.01m).

Chemical Properties

Chemical properties of the soil in pure stands of *A. officinalis* differ from those in pure stands of *C. tagal* (Tables 3 and 4). The cation exchange capacity (CEC) of soils also differs between the forests. CEC generally increased with distance inland in both forest types, which is probably a reflection of the trends in organic matter and clay contents. Soils had lower CEC in the *Ceriops* forest (12.21–16.30 me 100 g^{-1} than the *Avicennia* forest (22.60–24.60 me 100 g^{-1}). The average CEC of soils was 23.72 me 100 g^{-1} (SD=0.70) for *A. Officinalis* and 14.15 me 100 g^{-1} (SD=1.42) for *C. tagal* (Table 4). The high CEC may reflect the large amount of organic matter in the *Avicennia* (6.81±0.12%) and *Ceriops* (14.15±14.15±1.42%) forests. It also suggests that the soils represent a potentially large sink for cations. All soils contained large amounts of exchangeable sodium, calcium and magnesium (Table 4). The acidic nature of the soils suggests that the source of much of the calcium and magnesium needs to be studied in detail. Nickerson and Thibodeau [1985] reported that the distribution of *Avicennia* and *Rhizophora* was closely correlated with the concentration of hydrogen sulfide in the soil. Therefore, measuring H_2S in the soils will indicate whether a similar correlation exists with regard to the distribution of *A. officinalis* and *C. tagal* in the region. Here, the soils in the *Ceriops* forest were lower in sodium, calcium, magnesium

Table 4 CEC and Exchangeable Cations in the Mangrove Swamp Forest

Forest Type/Distance from the Sea Edge (m)		Soil Depth (cm)	CEC (meq/ 100 g dry soil)	Exchangeable Cation (meq/ 100 g dry soil)			
				Ca	K	Mg	Na
Avicennia							
	300	0－20	22.60	79.25	0.27	41.15	88.75
	310	0－20	23.30	80.05	0.28	40.88	88.28
	320	0－20	23.90	80.25	0.29	40.06	87.96
	330	0－20	24.20	81.05	0.30	39.66	87.47
	340	0－20	24.60	82.15	0.31	38.86	86.95
	All-site average		23.72	80.55	0.29	40.12	87.88
	SD		0.70	0.98	0.02	0.83	0.63
Ceriops							
	510	0－20	12.21	65.85	0.15	27.10	75.65
	520	0－20	13.21	66.35	0.16	25.90	75.38
	530	0－20	14.01	66.75	0.17	25.20	74.96
	540	0－20	15.03	67.05	0.18	24.40	74.52
	550	0－20	16.30	67.25	0.19	23.50	74.20
	All-site average		14.15	66.65	0.17	25.23	74.94
	SD		1.42	0.50	0.02	1.24	0.53

SD=Standard deviation

and potassium than those in the *Avicennia* forest (Table 4). This is primarily due to the proximity of *Avicennia* forest to the sea. The soils in the *Avicennia* forest are more frequently inundated by salt water than those in *Ceriops* forest. In the inland areas at distances of more than 500m from the sea edge, there is also greater dilution from freshwater sources. This suggests the urgent need to measure the concentration of hydrogen sulfide in the soils, as an important factor regulating both primary production and forest structure of *Avicennia* and *Ceriops* forests in Apar Nature Reserve.

N and P

Table 3 shows the values of phosphate and nitrogen in the soils of the mangrove forests in the study area. The two soils show marked differences in NH_4-N and NO_3-N. The higher amount of nitrogen in the form of NH_4-N indicates a lack of nitrate and nitrite bacteria due to the anaerobic conditions.

NH_4-N was higher in the soils in the *Avicennia* forest (453.705±1.031ppm) than in the pure stands of *Ceriops tagal* (230.977±0.823ppm). This is due to the frequent tidal inundation of the soils in the *Avicennia* forest. The presence of NO_3-N in the soils supports the presence of aerobic zones within the soil-root system of both *A. officinalis* and *C. tagal* [cf. Kaplan *et al.* 1979 ; Valiela and Teal 1979].

The level of available phosphate (P_2O_5) varies greatly with position along the transect as shown in Table 3. However, it does not vary significantly with subplot site position in each forest type ($r=0.692$ for *Avicennia* forest, $r=0.690$ for *Ceriops* forest). The available phosphate content in the soils is three times higher in the *Ceriops* forest than the *Avicennia* forest, but the total phosphate content is lower. The values in the soils of the *Ceriops* forest were only 60.272±1.034ppm and 472.264±0.381ppm, respectively (Table 3). The levels of available phosphate in the study area were generally low, being higher in the soils of *Ceriops* forest. However, phosphorus should not limit the growth of mangroves.

Physiognomically, the mangrove forest in the Apar Nature Reserve is well developed with an average tree height of 30m for *Avicennia officinalis* and 45m for *Ceriops tagal*. The estimated above ground biomass of *Avicennia* forest was 22.03 to 77.12m^3 $100m^{-2}$, and that of *Ceriops* forest was 13.69 to 27.01m^3 $100m^{-2}$. It appears that mangrove growth in this area may be related to soil salinity, redox potential, available phosphate and soil nitrogen (NH_4-N and NO_3-N). This hypothesis was tested by simple correlation analyses using the data in Tables 2 and 3. The correlation matrix, where the values are the linear product-moment correlation coefficients (see Table 5), shows a number of significant correlations at the $p<0.01$ level. Most notable are the significant correlations between biomass and (i) available phosphate, (ii) soil salinity, (iii) redox potential, and (iv) soil nitrogen (NH_4-N and NO_3-N) (negative correlation). In addition, it is apparent that many of the soil parameters are inter-correlated. A possible explanation is that a common causative factor, such as frequency of tidal

Table 5 Correlation Matrix for the Estimated above Ground Biomass (trunk volume in m^3/ 100 m^2), Redox Potential (mV), Available Phosphate (ppm), NH_4-N (ppm), NO_3-N (ppm) and Soil Salinity (% o)

	Redox Potential	Available P_2O_5	NH_4-N	NO_3-N	Soil Salinity
Avicennia soils					
Biomass	− 0.983**	0.994**	− 0.986**	− 0.968**	0.920**
Redox potential	—	− 0.973**	0.938**	0.950**	− 0.921**
Available P_2O_5		—	− 0.971**	− 0.964**	0.876**
NH_4-N			—	0.949**	− 0.933**
NO_3-N				—	− 0.845**
Ceriops soils					
Biomass	− 0.958**	0.999**	− 0.990**	− 0.969**	0.929**
Redox potential	—	− 0.969**	0.964**	0.909**	− 0.813**
Available P_2O_5		—	− 0.988**	− 0.954**	0.913**
NH_4-N			—	0.987**	− 0.936**
NO_3-N				—	− 0.975**

Key to table : ** =significant at the $p<1\%$ level inundation and/or degree of sediments exchange, is responsible for the variations in many of these properties. Furthermore, the presence of large amounts of C organic in the soil results in a higher consumption of oxygen [Swift *et al.* 1979]. These effects will lead to the formation of highly anaerobic soils in mangrove forests of the Apar Nature Reserve.

Conclusion

The soils covered by mangrove forest in the study area are well sorted fine silt containing large quantities of organic matter, mainly fine, fibrous root materials. Redox potential and pH were typical of flooded anaerobic soils. Physical and chemical properties of soil samples in the 0.25–ha plots from the *Avicennia* forest to the *Ceriops* forest show very definite correlations between the vegetation and the soil supporting it. The most obvious change in the surface soil (0–20cm depth) is that due to silt accumulation.

The data obtained for Apar Nature Reserve soils differ markedly from those for the soils covered by mangrove forests in Tiris and Cimanuk delta complex, West Java, which have been reported by Sukardjo [1982; 1987]. The soils in Tiris (*Rhizophora* forest) and in the Cimanuk delta complex (*Avicennia* forest) were predominantly clay, which comprised more than 35%. In Apar Nature Reserve, sand content was 30.04% (in *Avicennia* forest) and 31.18% (in *Ceriops* forest). Soerianagara [1971] reported that mangrove soils in Cilacap were predominantly clayey in texture. Mangrove soils on the north coast of West Java were also found to be clayey [Sukardjo 1980]. Physiographically, the coastal area around Apar Nature Reserve was flat, which could explain the moderate sand content in the study area. Moreover, the bulk density in the *Ceriops* forest was greater than in the *Avicennia* forest. It is considered that *C. tagal* trees contribute more organic debris to the soil than does *A. officinalis*. This study has revealed important differences between the soils in *Avicennia* and *Ceriops* forests at the significance level of 1%. These mean that such variables of habitat as physiography, climate, salinity, soil drainage, water currents and salt–spray play an important role in determining the differences between soil properties. This conclusion is supported by the findings of Diemont and van Wijngaarden [1974] that a close relationship exists between vegetation and frequency of flooding, physiography and soil properties in the tidal areas of West Malaysia. The combined effects of physical and chemical properties and soil salinity appear to be the major factors responsible for the high standing crop biomass of the *Ceriops* and *Avicennia* forests in the Apar Nature Reserve in East Kalimantan.

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