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<th>Title</th>
<th>Soils in the Mangrove Forests of the Apar Nature Reserve, Tanah Grogot, East Kalimantan, Indonesia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Author(s)</td>
<td>Sukardjo, Sukristijono</td>
</tr>
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<td>Citation</td>
<td>東南アジア研究 (1994), 32(3): 385-398</td>
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<td>Type</td>
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Soils in the Mangrove Forests of the Apar Nature Reserve, Tanah Grogot, East Kalimantan, Indonesia

Sukristijono Sukardjo*

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 H₂O), CEC (23.72±0.70 meq/100 g dry soil), exchangeable cation and NH₄-N (458.705±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 100m².

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
of the area with flat physiography is covered by alluvial deposits of recent origin [Anonymous 1981 b], 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 $V=0.57r^2h$ [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

<table>
<thead>
<tr>
<th>Forest Type</th>
<th>Distance from the Sea Edge (m)</th>
<th>Soil Depth (cm)</th>
<th>Soil Fraction (%)</th>
<th>Texture Class</th>
<th>Bulk Density (g/100 ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avicennia</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>300</td>
<td>0 - 20</td>
<td>30.13</td>
<td>39.91</td>
<td>29.96</td>
<td>Clay loam</td>
</tr>
<tr>
<td>310</td>
<td>0 - 20</td>
<td>30.16</td>
<td>39.90</td>
<td>29.94</td>
<td>Clay loam</td>
</tr>
<tr>
<td>320</td>
<td>0 - 20</td>
<td>30.05</td>
<td>39.90</td>
<td>30.05</td>
<td>Clay loam</td>
</tr>
<tr>
<td>330</td>
<td>0 - 20</td>
<td>30.10</td>
<td>39.80</td>
<td>30.10</td>
<td>Clay loam</td>
</tr>
<tr>
<td>340</td>
<td>0 - 20</td>
<td>30.04</td>
<td>39.81</td>
<td>30.15</td>
<td>Clay loam</td>
</tr>
<tr>
<td>All-site average</td>
<td></td>
<td>30.10</td>
<td>39.86</td>
<td>30.04</td>
<td>110.5</td>
</tr>
<tr>
<td>Ceriops</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>510</td>
<td>0 - 20</td>
<td>32.98</td>
<td>35.92</td>
<td>31.10</td>
<td>Clay loam</td>
</tr>
<tr>
<td>520</td>
<td>0 - 20</td>
<td>32.93</td>
<td>35.92</td>
<td>31.15</td>
<td>Clay loam</td>
</tr>
<tr>
<td>530</td>
<td>0 - 20</td>
<td>32.90</td>
<td>35.92</td>
<td>31.18</td>
<td>Clay loam</td>
</tr>
<tr>
<td>540</td>
<td>0 - 20</td>
<td>33.20</td>
<td>35.60</td>
<td>31.20</td>
<td>Clay loam</td>
</tr>
<tr>
<td>550</td>
<td>0 - 20</td>
<td>33.23</td>
<td>35.50</td>
<td>31.27</td>
<td>Clay loam</td>
</tr>
<tr>
<td>All-site average</td>
<td></td>
<td>32.05</td>
<td>35.77</td>
<td>31.18</td>
<td>138.5</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Forest Type</th>
<th>Distance from the Sea Edge (m)</th>
<th>pH 1:1 H₂O</th>
<th>pH 1:1 KCl</th>
<th>$E_h$ (mV) at 5 cm Depth</th>
<th>Soil Salinity (% o)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avicennia</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>300</td>
<td>4.35</td>
<td>4.20</td>
<td>-115 (-91; -146)</td>
<td>34</td>
<td></td>
</tr>
<tr>
<td>310</td>
<td>4.44</td>
<td>4.33</td>
<td>-119 (-81; -140)</td>
<td>33.75</td>
<td></td>
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<tr>
<td>320</td>
<td>4.82</td>
<td>4.43</td>
<td>-120 (-61; -158)</td>
<td>33.50</td>
<td></td>
</tr>
<tr>
<td>330</td>
<td>5.20</td>
<td>4.54</td>
<td>-134 (-105; -158)</td>
<td>32.75</td>
<td></td>
</tr>
<tr>
<td>340</td>
<td>5.29</td>
<td>5.10</td>
<td>-138 (-94; -172)</td>
<td>31</td>
<td></td>
</tr>
<tr>
<td>All-site average</td>
<td>4.82</td>
<td>4.52</td>
<td>-125.2</td>
<td>33</td>
<td></td>
</tr>
<tr>
<td>SD</td>
<td>0.38</td>
<td>0.31</td>
<td>9.06</td>
<td>1.08</td>
<td></td>
</tr>
<tr>
<td>Ceriops</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>510</td>
<td>3.70</td>
<td>3.15</td>
<td>-134 (-105; -158)</td>
<td>30.50</td>
<td></td>
</tr>
<tr>
<td>520</td>
<td>3.85</td>
<td>3.20</td>
<td>-138 (-95; -172)</td>
<td>29.50</td>
<td></td>
</tr>
<tr>
<td>530</td>
<td>3.95</td>
<td>3.25</td>
<td>-140 (-119; -197)</td>
<td>28.50</td>
<td></td>
</tr>
<tr>
<td>540</td>
<td>4.05</td>
<td>3.30</td>
<td>-157 (-145; -181)</td>
<td>28.50</td>
<td></td>
</tr>
<tr>
<td>550</td>
<td>4.20</td>
<td>3.35</td>
<td>-162 (-116; -208)</td>
<td>28</td>
<td></td>
</tr>
<tr>
<td>All-site average</td>
<td>3.95</td>
<td>3.25</td>
<td>-146.2</td>
<td>29</td>
<td></td>
</tr>
<tr>
<td>SD</td>
<td>0.17</td>
<td>0.07</td>
<td>11.14</td>
<td>0.89</td>
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</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Forest Type/Distance from the Sea Edge (m)</th>
<th>Soil Depth (cm)</th>
<th>Organic Matter (%)</th>
<th>C Organic (%)</th>
<th>N Total (%)</th>
<th>C/N</th>
<th>NH₄N (ppm)</th>
<th>NO₃-N (ppm)</th>
<th>P₂O₅ Total (ppm)</th>
<th>Available P₂O₅ (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Avicennia</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>300</td>
<td>0-20</td>
<td>6.65</td>
<td>3.73</td>
<td>0.345</td>
<td>10.81</td>
<td>452.310</td>
<td>29.960</td>
<td>575.225</td>
</tr>
<tr>
<td></td>
<td>310</td>
<td>0-20</td>
<td>6.70</td>
<td>3.85</td>
<td>0.355</td>
<td>10.85</td>
<td>452.927</td>
<td>30.950</td>
<td>575.125</td>
</tr>
<tr>
<td></td>
<td>320</td>
<td>0-20</td>
<td>6.85</td>
<td>3.90</td>
<td>0.375</td>
<td>10.40</td>
<td>453.718</td>
<td>31.020</td>
<td>574.985</td>
</tr>
<tr>
<td></td>
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<td>0-20</td>
<td>6.90</td>
<td>4.09</td>
<td>0.386</td>
<td>10.62</td>
<td>454.320</td>
<td>31.950</td>
<td>574.653</td>
</tr>
<tr>
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<td>0-20</td>
<td>6.95</td>
<td>4.23</td>
<td>0.390</td>
<td>10.85</td>
<td>455.250</td>
<td>32.150</td>
<td>573.987</td>
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<td>All-site average</td>
<td>6.81</td>
<td>3.96</td>
<td>0.370</td>
<td>10.71</td>
<td></td>
<td>453.705</td>
<td>31.206</td>
<td>574.795</td>
<td>19.87</td>
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<tr>
<td>SD</td>
<td>0.12</td>
<td>0.18</td>
<td>0.020</td>
<td>0.18</td>
<td></td>
<td>1.031</td>
<td>0.787</td>
<td>0.448</td>
<td>0.22</td>
</tr>
<tr>
<td><em>Ceriops</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>510</td>
<td>0-20</td>
<td>19.35</td>
<td>10.50</td>
<td>0.955</td>
<td>10.99</td>
<td>229.780</td>
<td>30.883</td>
<td>472.795</td>
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<tr>
<td></td>
<td>520</td>
<td>0-20</td>
<td>19.47</td>
<td>10.95</td>
<td>0.960</td>
<td>11.40</td>
<td>230.475</td>
<td>31.384</td>
<td>472.508</td>
</tr>
<tr>
<td></td>
<td>530</td>
<td>0-20</td>
<td>19.68</td>
<td>11.45</td>
<td>0.965</td>
<td>11.86</td>
<td>230.880</td>
<td>31.682</td>
<td>472.306</td>
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<tr>
<td></td>
<td>540</td>
<td>0-20</td>
<td>19.75</td>
<td>11.75</td>
<td>0.975</td>
<td>12.05</td>
<td>231.675</td>
<td>31.986</td>
<td>472.010</td>
</tr>
<tr>
<td></td>
<td>550</td>
<td>0-20</td>
<td>19.80</td>
<td>12.35</td>
<td>0.980</td>
<td>12.60</td>
<td>232.075</td>
<td>32.145</td>
<td>471.702</td>
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<tr>
<td>All-site average</td>
<td>19.61</td>
<td>11.40</td>
<td>0.97</td>
<td>11.78</td>
<td></td>
<td>230.977</td>
<td>31.616</td>
<td>472.264</td>
<td>60.272</td>
</tr>
<tr>
<td>SD</td>
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<td>0.64</td>
<td>0.01</td>
<td>0.55</td>
<td></td>
<td>0.823</td>
<td>0.450</td>
<td>0.381</td>
<td>1.034</td>
</tr>
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</table>

SD=Standard deviation

Eₜ, pH and Salinity

Redox potential (Eₜ) 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 Eₜ at the surface (0–5cm depth) was usually less than 100mV. The relationship between Eₜ 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 100m² for subplots along the transect is also shown. The soils of subplots with less plant biomass tended to be more anaerobic. Also, the maximum Eₜ 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 H₂O) 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 slightly 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 (H₂O) and pH (KCl) in the soils of *Avicennia* forest and also in the *Ceriops* forest (Table 2), and this
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 appearance 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 H₂S 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

<table>
<thead>
<tr>
<th>Forest Type/Distance from the Sea Edge (m)</th>
<th>Soil Depth (cm)</th>
<th>CEC (meq/100 g dry soil)</th>
<th>Exchangeable Cation (meq/100 g dry soil)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Ca</td>
<td>K</td>
</tr>
<tr>
<td>Avicennia</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>300 0-20</td>
<td>22.60</td>
<td>79.25</td>
<td>0.27</td>
</tr>
<tr>
<td>310 0-20</td>
<td>23.30</td>
<td>80.05</td>
<td>0.28</td>
</tr>
<tr>
<td>320 0-20</td>
<td>23.90</td>
<td>80.25</td>
<td>0.29</td>
</tr>
<tr>
<td>330 0-20</td>
<td>24.20</td>
<td>81.05</td>
<td>0.30</td>
</tr>
<tr>
<td>340 0-20</td>
<td>24.60</td>
<td>82.15</td>
<td>0.31</td>
</tr>
<tr>
<td>All-site average</td>
<td>23.72</td>
<td>80.55</td>
<td>0.29</td>
</tr>
<tr>
<td>SD</td>
<td>0.70</td>
<td>0.98</td>
<td>0.02</td>
</tr>
<tr>
<td>Ceriops</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>510 0-20</td>
<td>12.21</td>
<td>65.85</td>
<td>0.15</td>
</tr>
<tr>
<td>520 0-20</td>
<td>13.21</td>
<td>66.35</td>
<td>0.16</td>
</tr>
<tr>
<td>530 0-20</td>
<td>14.01</td>
<td>66.75</td>
<td>0.17</td>
</tr>
<tr>
<td>540 0-20</td>
<td>15.03</td>
<td>67.05</td>
<td>0.18</td>
</tr>
<tr>
<td>550 0-20</td>
<td>16.30</td>
<td>67.25</td>
<td>0.19</td>
</tr>
<tr>
<td>All-site average</td>
<td>14.15</td>
<td>66.65</td>
<td>0.17</td>
</tr>
<tr>
<td>SD</td>
<td>1.42</td>
<td>0.50</td>
<td>0.02</td>
</tr>
</tbody>
</table>

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$_2$O$_5$) 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 \( 60.272\pm1.034\) ppm and \( 472.264\pm0.381\) ppm, 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 (\( \text{NH}_4\text{-N} \) and \( \text{NO}_3\text{-N} \)). 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 (\( \text{NH}_4\text{-N} \) and \( \text{NO}_3\text{-N} \)) (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>
<thead>
<tr>
<th>Table 5 Correlation Matrix for the Estimated above Ground Biomass (trunk volume in m(^3)/100 m(^2)), Redox Potential (mV), Available Phosphate (ppm), ( \text{NH}_4\text{-N} ) (ppm), ( \text{NO}_3\text{-N} ) (ppm) and Soil Salinity (% o)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Avicennia soils</strong></td>
</tr>
<tr>
<td>Biomass</td>
</tr>
<tr>
<td>- 0.983(^<em>)</em></td>
</tr>
<tr>
<td>Redox potential</td>
</tr>
<tr>
<td>-</td>
</tr>
<tr>
<td>Available ( P_2\text{O}_5 )</td>
</tr>
<tr>
<td>-</td>
</tr>
<tr>
<td>( \text{NH}_4\text{-N} )</td>
</tr>
<tr>
<td>-</td>
</tr>
<tr>
<td>( \text{NO}_3\text{-N} )</td>
</tr>
<tr>
<td>-</td>
</tr>
</tbody>
</table>

| **Ceriops soils**                                  |
| Biomass                                           |
| - 0.958\(^*\)*     | 0.999\(^*\)* | - 0.990\(^*\)* | - 0.969\(^*\)* | 0.929\(^*\)* |
| Redox potential                                   |
| -                  | - 0.969\(^*\)* | 0.964\(^*\)* | 0.909\(^*\)* | - 0.813\(^*\)* |
| Available \( P_2\text{O}_5 \)                     |
| -                  | - 0.988\(^*\)* | - 0.954\(^*\)* | 0.913\(^*\)* |
| \( \text{NH}_4\text{-N} \)                        |
| -                  | - 0.987\(^*\)* | - 0.936\(^*\)* |
| \( \text{NO}_3\text{-N} \)                        |
| -                  | - 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 con­
taining large quantities of organic matter, mainly fine, fibrous root materials. Redox
potential and pH were typical of flooded anaerobic soils. Physical and chemical pro­
PERTIES 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 (0–20 cm 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]. Physio­
graphically, 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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