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Mangrove Soils of the Creek Town Creek/Calabar River Swamp, South Eastern Nigeria

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Abstract: Soil samples from pure and mixed stands of mangrove species were analysed for their physical and chemical properties. All soils were characterised by high field moisture, ranging from 77.4 ± 18.3% to 124.3 ± 9.5% and low bulk densities, ranging from 0.74 ± 0.04 to 0.96 ± 0.10 g cm^{-3}. Soil acidity was moderate, with a field moist pH range of 5.4 to 6.8. Acidity increased with air drying. Exchangeable acidity ranged from 6.6 to 9.8 me/100 g in *Nypa fruticans/Raphia vinifera* soils. Lower values ranging from 1.2 to 2.8 me/100 g occurred in purely *Nypa fruticans* and *Nypa fruticans/Rhizophora mangle* soils. Cation exchange capacity varied from 25.4 ± 3.7 to 38.3 ± 3.4 me/100 g among the soils, with magnesium and calcium being the predominant cations. Organic carbon values ranged from 2.8% to 6.8% in *Nypa* and *Raphia* soils. Lower values ranging from 3.4% to 4.8% were observed in *Rhizophora* spp. soils. Plant reaction on the soil was mainly reflected in organic carbon contents. There was overlap in the range of soil properties from the seven mangrove stands.

Résumé: Des échantillons de sols d'espèces de mangroves monospécifique et mixte ont été analysés pour leurs propriétés physiques et chimiques. Tous les sols sont caractérisés par une humidité au champ élevée, allant de 77.4 ± 18% à 124,3 ± 9,5% et par une densité extrêmement faible allant de 0,74 ± 0,04 à 0,96 ± 0,1 g cm^{-3}. Le taux d'acidité est modéré, et le pH mesuré au champ sur échantillon humide varie de 5,4 à 6,8. L'acidité augmente avec la sécheresse de l'air. L'acidité échangeable va de 6,6 à 9,8 me/100 g dans les sols à *Nypa fruticans* et *Raphia vinifera* . Les faibles valeurs allant de 1,2 à 2,8 me/100 g apparaissent dans les sols des mangroves monospécifiques à *Nypa fruticans* et des mangroves mixtes à *Nypa fruticans/Rhizophora mangle.* La capacité d'échange en cation varie de 25,4 ± 3,7 à 38,3 ± 3,4 me/100 g, le magnésium et le calcium étant les cations, prédominants. Les valeurs de carbone organique vont de 2,8% à 6,8% dans les sols à *Nypa* et *Raphia.*Des valeurs faibles de 3,4% à 4,8% sont observées dans les sols à *Rizophora* spp. La réaction des plantes aux sols est surtout reflétée dans le taux de carbone organique. Il y a un chevauchement des propriétés des sols des sept peuplements de mangrove étudiées.

Resumen: Se analizaron las propiedades físicas y químicas de muestras de suelo de conjuntos mixtos y puros de especies de manglar. Todos los suelos se caracterizaron por su alta humedad de campo, variando de 77.4 ± 18% a 124.3 ± 9.5% y bajas densidades reales, variando de 0.74 ± 0.04 a 0.96 ± 0.1 g cm^{-3}. La acidez del suelo fue moderada, con un pH húmedo en el campo que varío de 5.4 a 6.8. La acidez incrementó con la sequedad del aire. La acidez intercambiable varió de 6.6 a 9.8 me/100 g en suelos con *Nypa fruticans/Raphia vinifera.* Los valores más bajos variaron de 1.2 a 2.8 me/100 g y ocurrieron solamente en suelos con *Nypa fructicans* y *Nypa fruticans/*

Rhizophora mangle. La capacidad de intercambio catiónico varió de 25.4 ± 3.7 a 38.3 ± 3.4 me/100 g entre los suelos, siendo los cationes predominantes el magnesio y el calcio. Los valores de carbón orgánico variaron de 2.8% a 6.8% en suelos con *Nypa* y *Raphia*. Los valores más bajos variaron de 3.4% a 4.8% y fueron observados en suelos con *Rhizophora* spp.. La respuesta vegetal al suelo se reflejó principalmente en el contenido de carbón orgánico. Hubo un traslapamiento en el rango de propiedades del suelo entre los siete agrupamientos de manglar.

Resumo: As propriedades físicas e químicas de amostras de solo em parcelas puras e mistas de mangal foram analisadas. Todos os solos foram caracterizados por um elevado teor de humidade oscilando entre os 77.4 ± 18% e os 124.3 ± 9.5% e baixas densidades aparentes que oscilaram entre 0,74 ± 0,04 e 0,96 ± 0,1 g cm^{-3}. A acidez do solo era moderada, com um pH no estado húmido entre os 5,4 e os 6,8. A acidez cresceu com a secagem ao ar. A acidez de troca variou entre os 6,6 e os 9,8 me/100 g em solos de *Nypa fruticans /Raphia vinifera*. Valores mais baixos variando entre 1,2 e os 2,8 me/100 g ocorreram em solos de mangal puro de *Nypa fruticans* e *Nypa fruticans / Rhizophora mangle*. A capacidade de troca catiónica entre os solos variou entre os 25,4 ± 3,7 e os 38,3 ± 3,4 me/100 g sendo o magnésio e o cálcio os catiões predominantes. Os valores de carbono orgânico situaram-se entre os 2,8% e os 6,8% nos solos de *Nypa* e *Raphia*. Os valores mais baixos variaram entre os 3,4% e os 4,8 em solos de *Rhizophora* ssp. As reações das plantas ao solo foram fundamentalmente reflectidas nos teores do carbono orgânico. Verificou-se uma sobreposição no quadro da variação de propriedades nas sete parcelas de mangal estudadas.

Key Words : Creek Town/Calabar River, Mangrove vegetation, Mangrove soil, Tidal influence.

INTRODUCTION

Mangrove swamps in southeastern Nigeria are associated with brackish/saline river estuaries. Mangrove vegetation occurs prominently up to the limits of regular tidal inundation in the estuaries, about 20 km up-river from the Atlantic coast. The mangrove species *Rhizophora racemosa* (G.F. May), *Rhizophora mangle* (G.F. May), *Avicennia africana* (Moldenke), *Rhizophora harrisonii* (R. Keay), *Laguncularia racemosa* (G.F. May) and the associes *Nypa fruticans* (Thumb), *Conocarpus erectus* (Gaertn.), *Acrostichum aureum* (Linn.), *Raphia vinifera* (L.), *Acutas afer* (L.) and *Selaginella* spp. (L) reach their northernmost limits of growth in the Creek Town/Calabar River swamp (Fig. 1). The species are in most instances organized into zones arranged from the river channels and creeks inland, to the upland forest margins. However, each zone is often characterised by mosaics of different species due to variation in local topography. Within the mangrove groundlayer, flood tolerant sedges are associated with microdepressions while less flood tolerant species occur on microtopographic mounds (Ukpong 1989).

The relationship between species zones and the corresponding soils in mangrove swamps was reported by Clarke & Hannon (1967); Naidoo (1980); Boto & Wellington (1984) and Boto (1984). Other studies emphasized the chemical characteristics of the surface water (Clough & Sim 1989; Fagbami *et al.* 1988) and subsurface seepage and stratigraphy (Semeniuk 1983). The studies were largely restricted to the distinct zonation in mangroves of littoral areas where species occur in pure stands. In the present study, soils from pure and mixed stands of mangroves from an ever-wet estuarine swamp are characterised for the physical and chemical properties. The aim was to determine the role of the soils in influencing the distribution of species and to investigate the effect of the species on the characteristics of the soils.

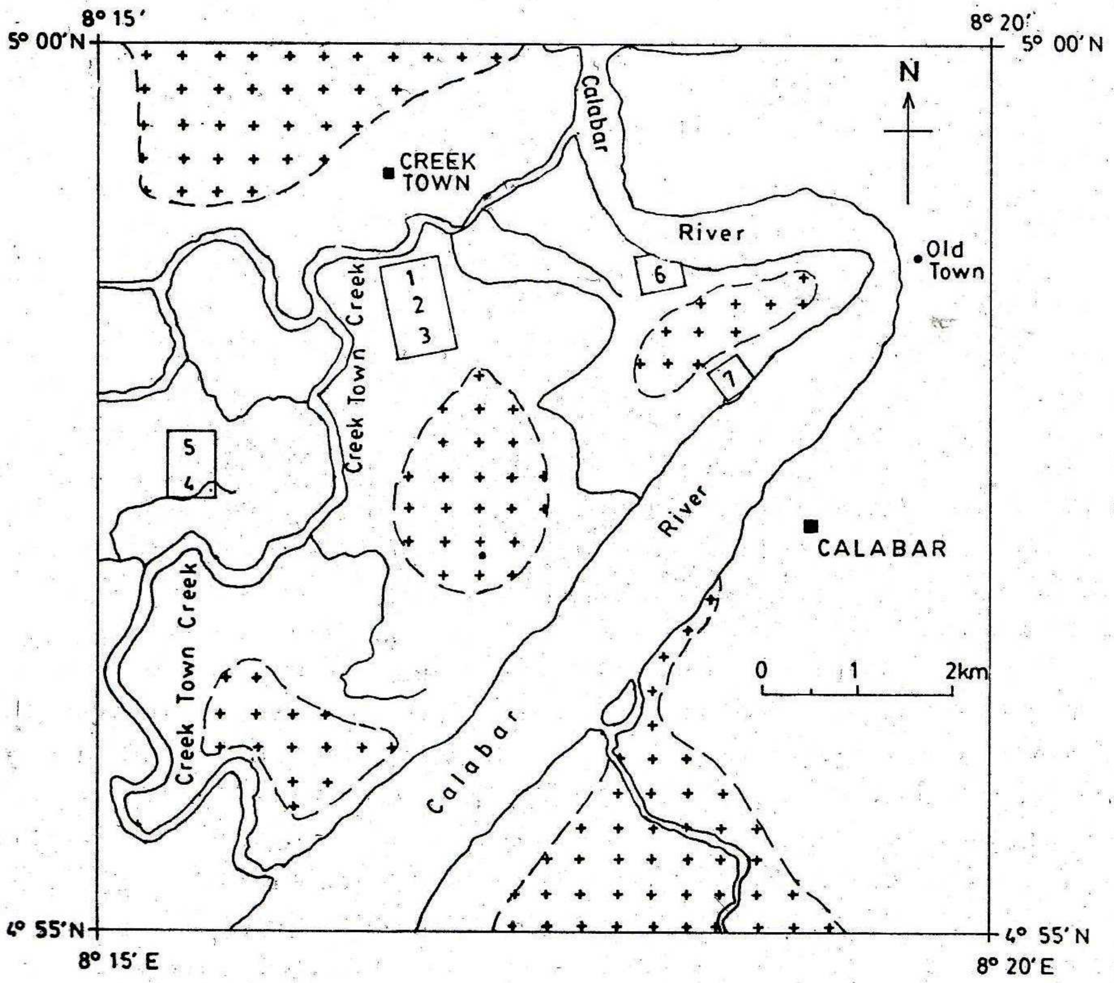

Fig. 1. Map of the mangrove swamps of the Creek Town/Calabar area: (++++ = non-mangrove high forest species on elevated segments; 1, 2, 3 . . . 7 = sampling areas).

THE STUDY AREA

The study area for this investigation was the Creek Town/Calabar River swamp located about 20 km up-river from the Atlantic beachridge coast in southeastern Nigeria (Fig. 1). Physiographically, mangroves occur on tributary creek habitats, interdistributary basin habitats and on wooded levee habitats. Each mangrove habitat is of variable elevation. However, the swamp as a whole varies by less than 1 in 500 metres in elevation except on the upland forest ecotone where abandoned levees may exceed 1 in 500 metres.

The swamp experiences regular diurnal tides with a mean amplitude of 0.75 m at Creek Town. The climate of the area is humid tropical, with a mean annual rainfall of 4021 mm (Nig. Met. Serv. 1980). Although rainfall occurs throughout the year, there are peaks from May to August (1880 mm); lowest values (240 mm) occur from December to February. Temperatures are uniformly high with a maximum of 30°C and minimum of 23°C. High salinity (3.8 ± 0.4%) is limited to the dry season while lower salinity (0.5 ± 0.6%) occurs in the rainy season (Ukpong 1991).

MATERIALS AND METHODS

The mangrove soils were collected during low tide at or close to the centre of seven 100 m^2 quadrats located within the least disturbed mangrove stands in the Creek Town/Calabar River area. To qualify a quadrat for sampling, there had to be evidence of regular diurnal flooding as indicated by the accumulation of wrack beyond the landward limits of the quadrat. The 100 m^2 quadrats were considered most appropriate. Although a larger quadrat would have raised the number of mangroves encountered, it would also have demanded a much longer sampling time. Further, a larger quadrat would probably have mixed up micro-environmental differences that could otherwise have been restricted within the area of a smaller quadrat. The quadrats were numbered consecutively according to distance of location from each other and from the water channels (see Fig. 1). In each quadrat, all species present were recorded and estimates of crown cover and stem density, by species, were made. Importance values of the species were derived as the summation of relative density and relative coverage (Lindsey 1956).

Soil sampling was performed during the relatively dry period of the year (December - February). Where a profile pit was hampered by the high water table, a soil corer (Giglioli & Thornton 1965) enabled one profile core, to a depth of 100 cm, to be obtained from each quadrat. From the profile core, five soil samples at 20-cm vertical intervals irrespective of natural horizons were extracted for laboratory analysis. Portions of the soils were sealed in plastic bags for field moist pH determinations immediately on arrival at the laboratory. The rest of the samples were air dried, ground with mortar and pestle and stored in glass bottles.

Particle size distribution (% sand, silt, clay) was determined by the hydrometer method (Bouyoucos 1962). Soil texture was classified according to USDA (1960). Bulk density was determined from samples collected using steel cores of volume 550 cm^3, while field moisture content was determined gravimetrically. Soil pH was measured in 1:2 soil to water suspensions using a glass electrode (Jackson 1962); aluminium concentration, by the aluminon method (Yuan & Fiskell 1959), and acetate soluble sulphate by the method of Bardsley & Lancaster (1965). Exchangeable acidity was determined by extraction with barium acetate and titration with NaOH, while organic carbon content was obtained using the Walkley-Black wet oxidation method (Jackson 1962). Available phosphorus was determined by the Bray NO. 1 Method (Jackson 1962). Exchangeable cations were extracted in 1 N ammonium acetate at pH 7 from which the concentrations of potassium, magnesium and calcium were determined by atomic absorption and sodium by flame photometry; cation exchange capacity (CEC) was obtained as the summation of the exchangeable cations and exchange acidity. Soil colours were compared with a Munsell Soil Colour Chart (USDA 1960).

RESULTS

Vegetation characteristics of the sample profiles

Table 1 shows the characteristics of vegetation in the seven quadrats from which soil prfile samples (P_1 - P_7) were obtained. *Nypa fruticans* (I.V. 200) was dominant in P_1, located 10 m from Creek Town Creek (see Fig. 1). *Rhizophora mangle* (I.V. 200) and *Rhizophora racemosa* (I.V. 200) were also dominant in P_5 and P_6 located 100 m and 40 m, respectively, from water channels. The occurrence of pure monodominant stands corresponds with the zonation of major species from the channel margins, inland. In P_2, located 40 m from Creek Town Creek, *Nypa fruticans* (I.V. 103) occurred in association with *Rhizophora mangle* (I.V. 81) and *Raphia hookeri* (I.V. 15), while in P_3 located 130 m inland, *Nypa fruticans* was associated with *Raphia hookeri* (I.V. 81) and *Drepanocarpus lunatus* (I.V. 26). *Rhizophora racemosa* (I.V. 106) also associated with *N. fruticans* and *R. mangle* in P_4. The mixed stands represent interface consocies where one species zone grades into another. Also, due to local variation in topography, mosaics of different species tend to occur together and achieve relative mix. A transitional (ecotonal) vegetation is represented in P_7 where *Triumfetta rhomboideae, Acutas afer* and *Selaginella* spp. are dominants. These species primarily occur in upland forest areas but have become adapted to the mangrove swamps due to increasing salt tolerance. The occurrence of large numbers of mangrove and *Nypa* saplings and propagules appeared to be a seasonal phenomenon as the understorey was relatively open.

Bulk density, field moisture and soil colour

Bulk density for all profiles ranged from 0.72 to 1.08 g cm^{-3} (Table 2). The values tend to increase with profile depth. The lowest values ranging from 0.72 to 0.79 g cm^{-3} occurred in soils associated with *Nypa fruticans* in P_1 and *Nypa fruticans/Rhizophora mangle* in P_2. Slightly higher values ranging from 0.81 to 0.89 g cm^{-3} occurred in *Rhizophora mangle* soil (P_5) and ecotonal soil (P_7). The ecotonal soil, although flooded daily by high tides supported only non-mangrove species, e.g. *Acutas afer, Selaginella* spp. and *T. rhomboideae* due to the higher elevation which prevents prolonged inundation. The highest bulk densities occurred in *Nypa fruticans/Raphia* soil (P_3) and *Rhizophora racemosa* soil (P_6). The relatively high values were clearly related to the high sand content in these soils. Low bulk densities correlated with high silt, high organic carbon and clay contents of soil profiles.

Field moisture content represented conditions at low tide during the relatively dry period of the ecological year (December-February). The values ranged from 56% in *Nypa fruticans/ Raphia* soil (P_3) to 144% in the ecotonal soil (P_7). There was a sharp decrease in values with profile depth (Table 2). The highest mean profile values (123%; 124%) occurred in *Rhizophora racemosa* soil (P_6) and *Nypa fruticans* soil (P_1), located close to the main tidal channels. High field moisture was an indication of the regular tidal flooding of soils and retention of water by silt and clays.

TABLE 2. Bulk density, field moisture, particle size distribution, texture and colour values of mangrove soils.

Sample depth (cm)	Bulk density ($g cm^{-3}$)	Field moisture (%)	Particle size distribution(%) Sand	Silt	Clay	Texture	Colour
P_1 : *Nypa fruticans*, 10 m from Creek Town Creek							
0-20	0.72	134	32	44	24	Loam	2.5Y3/2
20-30	0.78	133	32	48	20	Loam	2.5Y3/2
40-60	0.76	123	30	48	22	Loam	2.5Y3/3
60-80	0.79	118	30	56	14	Silt Loam	5Y2.5/2
80-100	0.75	112	40	30	30	Clay Loam	5Y2.5/2
P_2: *Nypa fruticans/Rhizophora mangle*, 40 m from Creek Town Creek							
0-20	0.73	125	26	46	28	Clay Loam	2.5Y3/2
20-40	0.68	105	24	52	24	Silt Loam	2.5Y3/2
40-60	0.72	98	24	40	36	Clay Loam	2.5Y3/2
60-80	0.79	98	34	34	32	Clay Loam	2.5Y3/2
80-100	0.78	86	32	44	24	Loam	2.5YN2/0
P_3: *Nypa fruticans/Raphia*, 130 m from Creek Town Creek							
0-20	1.02	94	46	28	26	Sandy Loam	2.5Y3/2
20-40	0.84	96	42	32	26	Loam Sandy	2.5Y3/2
40-60	0.88	77	48	20	32	Clay Loam	10 YR3/1
60-80	1.08	56	50	22	28	Sandy Clay Loam	10 YR3/1
80-100	1.00	62	52	21	27	Sandy Clay Loam	10 YR/3/1
P_4: *Rhizophora racemosa/N. fruticans*, 40 m from tributary Creek							
0-20	0.72	120	29	59	12	Silt Loam	2.5Y3/2
20-40	0.75	125	29	63	8	Silt Loam	2.5Y3/2
40-60	0.82	100	33	59	8	Silt Loam	2.5Y3/2
60-80	1.00	98	49	41	10	Loam	5Y2.5/1
80-100	0.98	86	48	43	9	Loam	5Y2.5/1
P_5 : *Rhizophora mangle*, 100 m from tributary Creek							
0-20	0.85	137	46	16	38	Sandy Clay Loam	2.5Y3/2
20-40	0.88	137	40	24	36	Clay Loam	2.5Y3/2
40-60	0.89	128	46	42	12	Loam	2.5Y3/2
60-80	0.81	113	38	44	18	Loam	2.5Y3/2
80-100	0.84	96	46	38	16	Loam	5Y3/1
P_6 : *Rhizophora racemosa*, 40 m from Calabar River Channel							
0-20	0.74	140	32	50	18	Loam	5Y3/1
20-40	0.86	142	45	35	20	Loam	5Y3/1
40-60	0.88	120	43	33	24	Loam	5Y3/1
60-80	1.01	115	49	27	24	Sandy Clay Loam	5Y3/1
80-100	1.04	98	49	23	28	Sandy Clay Loam	5Y3/1
P_7 : Transition (ecotonal) levee, 40 m from Calabar River Channel							
0-20	0.85	138	36	42	22	Loam	2.5Y3/2
20-40	0.82	144	34	44	22	Loam	2.5Y3/2
40-60	0.88	100	38	44	18	Loam	2.5Y3/2
60-80	0.84	92	40	40	20	Loam	2.5Y3/2
80-100	0.88	78	44	30	26	Sandy Clay Loam	2.5YN2/0

The texture of soils varied between the sample profiles. The surface layers of *R. racemosa* soils (P_6), the transition ecotonal soils (P_7) and *N. fruticans* soils (P_1) consisted of loam. With increasing depth, increase in sand and clay fractions resulted in sandy clay loam texture. While *N. fruticans/R. mangle* soils (P_2) and *R. racemosa/N. fruticans* soil (P_4) were clay loam/silt loam at the surface layers, a decrease in silt fractions, with increasing profile depth, resulted in loamy texture. Profiles located inland, away from the tidal channels, e.g. P_3 *(N. fruticans/Raphia)* tend to have sandy loam/sandy clay loam texture.

The colour values of soils were dominantly dark greyish brown (2.5 Y3/2 - 5Y3/1) at all depths (Table 2), an indication that the soils, being regularly flooded, were very weakly differentiated into horizons. Since the effects of tides and water table level show little variation during the year, there is no distinct segregation of basic ferric sulphate and other feruginous materials in the profiles. Consequently the mangrove soils remain in an almost permanently reduced condition, resulting in greyish chroma.

Acid properties of the mangroves soils

The mangrove soils were moderately acid (Table 3). The lower field moist pH, ranging from 5.3 to 5.9, occurred in *Rhizophora* spp. soils while the higher values, ranging from 6.3 to 6.8, occurred in soils associated with *Nypa fruticans* and the ecotone (P_7). These values indicated greater alkalinity in soils where *Nypa fruticans* is not associated with *Rhizophora* spp. than in soils where *Nypa* and *Rhizophora* are associates. On air drying, pH of soils decreased appreciably, particularly in soils associated with *Rhizophora* spp., with values ranging from 4.1 in P_6 to 4.9 in P_4. Other soils had higher air dry values, ranging from 5.2 in P_1 *(N. fruticans)* to 5.9 in P_7 (ecotonal). This confirms the observation by Hesse (1961) that drainage, reclamation and exposure of *Rhizophora* swamps produce acid soils.

The exchangeable acidity increased with sample depth (Table 3). Higher values, ranging from 6.8 to 9.8 me/100 g, occurred in *Nypa/Raphia* soil (P_3). Lower values, ranging from 1.0 to 2.8 me/100 g occurred in *N. fruticans/R. mangle* soil (P_2). Exchangeable acidity increased with distance from the channels as indicated for P_3 and P_5 located 130 m and 100 m, respectively, from the water channels (see also Fig. 1).

The aluminium content of soils was similar for most profiles, showing a decrease with depth (Table 3). In *Rhizophora* spp. soils (P_5, P_6), aluminium levels ranged from 0.21 to 0.29 me/100 g while in soils associated with mixed stands of *Nypa*, *Rhizophora* spp. and *Raphia* the values ranged from 0.18 to 0.38 me/100 g. Highest values occurred in *N. fruticans* soil (P_1) while the lowest values occurred in the ecotonal soil (P_7).

Soluble sulphate levels were similar for all profiles, showing increases with sample depth (Table 3). In *Nypa fruticans* soil (P_1), values increased from 0.05 me/100 g at the surface to 0.07 me/100 g in the last layer, while in the ecotonal soil (P_7), the values increased with depth from 0.07 me/100 g to 0.10 me/100 g. . Mangrove subsoils (40-100 cm) have been observed to contain higher levels of sulphate than the surface layers (Naidoo1980). Since the sulphate levels were low, ranging from 0.03 to 0.10 me/100 g for all profiles, the main contributors to exchange acidity in the swamp appeared to be aluminium and hydrogen ions.

TABLE 3. Chemical Properties of mangrove swamp soils.

Sample depth (cm)	pH Field moist	pH Air dry	Exchange acidity (me/100 g)	Al (me/100 g)	SO_4 (me/100 g)
P_1: *Nypa fruticans*, 10 m from Creek Town Creek.					
0-20	6.5	5.6	1.2	0.29	0.05
20-40	6.5	5.5	1.2	0.25	0.05
40-60	6.6	5.2	1.4	0.40	0.08
60-80	6.6	5.0	3.4	0.29	0.07
80-100	6.8	5.5	2.4	0.18	0.07
P_2: *Nypa fruticans/Rhizophora mangle*, 40 m Creek Town Creek					
0-20	5.6	4.7	1.1	0.28	0.04
20-40	5.4	4.8	1.1	0.22	0.04
40-60	5.5	4.5	1.0	0.25	0.05
60-80	5.6	4.3	2.3	0.38	0.06
80-100	5.8	4.4	2.8	0.20	0.08
P_3: *Nypa fruticans/Raphia*, 130 m from Creek Town Creek					
0-20	6.4	5.6	6.8	0.26	0.03
20-40	6.4	5.4	6.6	0.27	0.03
40-60	6.7	5.3	9.0	0.36	0.03
60-80	6.6	5.3	9.6	0.22	0.08
80-100	6.2	5.3	9.8	0.19	0.08
P_4: *Rhizophora racemosa/N. fruticans*, 40 m from tributary Creek					
0-20	5.8	4.7	2.5	0.32	0.05
20-40	5.8	4.8	2.5	0.31	0.08
40-60	5.7	4.4	3.6	0.26	0.09
60-80	5.9	4.6	3.8	0.18	0.09
80-100	5.9	4.9	3.8	0.22	0.10
P_5: *Rhizophora mangle*, 100 m from tributary Creek					
0-20	5.4	4.8	3.7	0.26	0.03
20-40	5.7	4.6	3.8	0.26	0.04
40-60	5.5	4.8	4.1	0.25	0.05
60-80	5.8	4.6	4.2	0.29	0.07
80-100	5.6	4.7	4.6	0.21	0.10
P_6: *Rhizophora racemosa*, 40 m from Calabar River Channel					
0-20	5.7	4.1	2.4	0.27	0.06
20-40	5.9	4.4	2.3	0.21	0.06
40-60	5.8	4.2	2.4	0.21	0.06
60-80	5.9	4.1	2.4	0.22	0.07
80-100	5.6	4.5	2.6	0.27	0.07
P_7: Transition (ecotonal) levee, 40 m from Calabar River Channel					
0-20	6.3	5.6	2.9	0.22	0.07
20-40	6.4	5.9	2.7	0.18	0.08
40-60	6.6	5.7	3.0	0.18	0.09
60-80	6.6	5.6	3.2	0.19	0.08
80-100	6.7	5.6	2.9	0.18	0.10

TABLE 4. Organic carbon, cation exchange capacity, exchangeable cations and available phosphorus of mangrove swamp soils.

Sample depth (cm)	Organic carbon (%)	CEC (me/100 g)	Exchangeable cations (me/100 g)				P (μg ml^{-1})
			Ca	Mg	K	Na	
P$_1$: *Nypa fruticans*, 10 m from Creek Town Creek							
0-20	6.8	34	14	19	0.10	0.20	1.95
20-40	5.9	36	13	21	0.07	0.30	1.15
40-60	5.9	36	15	19	0.06	0.37	0.99
60-80	4.1	41	15	22	0.05	0.40	0.56
80-100	2.8	42	15	23	0.07	0.43	0.90
P$_2$: *Nypa fruticans/Rhizophora mangle*, 40 m from Creek Town Creek							
0-20	5.6	29	9	18	0.07	0.18	1.36
20-40	4.9	26	6	18	0.09	0.26	0.64
40-60	4.0	23	8	13	0.06	0.29	1.14
60-80	4.4	33	9	20	0.04	0.43	1.22
80-100	4.4	40	11	24	0.08	0.46	0.90
P$_3$: *Nypa fruticans/Raphia* , 130 m from Creek Town Creek							
0-20	6.2	22	5	9	0.10	0.28	1.49
20-40	6.8	21	5	8	0.09	0.31	1.04
40-60	5.6	25	6	10	0.08	0.34	0.96
60-80	3.4	28	5	12	0.14	0.44	1.32
80-100	3.8	29	6	13	0.06	0.44	1.44
P$_4$: *Rhizophora racemosa/N. fruticans*, 40 m from tributary Creek							
0-20	4.4	30	12	15	0.14	0.16	2.86
20-40	4.2	25	12	10	0.08	0.20	2.36
40-60	4.2	32	12	16	0.10	0.28	1.08
60-80	3.6	34	11	19	0.05	0.39	2.36
80-100	3.8	44	13	21	0.09	1.22	2.36
P$_5$: *Rhizophora mangle*, 100 m from tributary Creek							
0-20	3.4	31	12	12	0.14	0.38	2.93
20-40	3.8	28	10	13	0.07	0.42	1.18
40-60	3.6	36	12	19	0.09	0.07	2.36
60-80	3.8	32	13	15	0.06	0.11	2.68
80-100	3.8	31	11	21	0.03	0.28	1.93
P$_6$: *Rhizophora racemosa*, 40 m from Calabar River Channel							
0-20	3.8	27	8	17	0.10	0.60	2.06
20-40	4.2	27	8	15	0.14	0.88	2.36
40-60	3.6	23	7	13	0.07	0.70	2.08
60-80	4.8	33	9	20	0.05	0.92	2.41
80-100	3.6	36	8	25	0.06	0.51	1.64
P$_7$: Transition (ecotonal) levee, 40 m from Calabar River Channel							
0-20	3.8	29	11	14	0.10	0.36	1.67
20-40	4.2	37	11	22	0.12	1.26	1.09
40-60	4.0	32	14	13	0.10	1.35	1.77
60-80	4.0	41	14	24	0.08	1.22	1.86
80-100	3.6	45	16	24	0.09	1.22	1.93

Organic carbon

Organic carbon content of soils ranged from 2.8% to 6.8% (Table 4). Values decreased with sample depth and with distance inland in *Rhizophora* spp. soils (P_4, P_5). *Nypa fruticans* soil (P_1) and *Nypa fruticans*/*Raphia* soil (P_3) had high mean profile values (5.1 ± 1.6%; 5.2 ± 1.5%), presumably due to the extensive fibrous roots of *Nypa* and *Raphia* palms. High soil organic carbon in intertidal swamps is also associated with a slow rate of silting (Moorman & Pons 1974). Lower organic carbon occurred in *R. racemosa*/*N. fruticans* soil (P_5, P_6) and in the ecotonal soil (P_7), corresponding with low species density or crown cover in these stands (see Tabe 1).

CEC, exchangeable cations and phosphorus

Cation exchange capacity (CEC) in the mangrove soils ranged from 21 to 45 me/100 g (Table 4). In the ecotonal soil (P_7), CEC ranged from 29 to 45 me/100 g. There was a clear decrease in CEC concentrations from the channels inland and with profile depth.

In all soils, exchangeable magnesium and calcium were higher than exchangeable sodium (Table 4). Magnesium levels were highest in profiles associated with *N. fruticans*, *R. racemosa* and the ecotonal species (*Selanginella* spp, *A. afer, T. rhomboideae*), all located within 40 m from creeks and channels. Calcium levels also decreased inland. The ecotonal and *R. racemosa* soils (P_6, P_7) inundated by Calabar River tides, had the highest sodium concentration, ranging from 0.51 to 1.35 me/100 g. The high ratio of exchangeable magnesium and calcium and the low ratio of sodium to the extractable bases indicate a strong influence of overland and subsurface freshwater inputs in the swamps. Soils inundated mainly by tidal waters usually have higher concentrations of exchangeable sodium than upland soils, due to the concentration of sodium in sea water (Coover *et al.* 1975). As the soils were moderately acidic, with mean profile pH values ranging from 5.6 to 6.6, it is probable that much of the magnesium and calcium occurred in the form of sulphates.

Table 4 shows that the lowest phosphorus values ranged from 0.56 $\mu g\ ml^{-1}$ to 1.95 $\mu g\ ml^{-1}$ in pure stands of *N. fruticans* (P_1). Highest values occurred in profiles associated with *Rhizophora* spp. (1.08 $\mu g\ ml^{-1}$ to 2.93 $\mu g\ ml^{-1}$). The acid pH values observed for the mangrove soils suggest that phosphorus was probably fixed by iron and aluminium. The phosphorus levels presumably increased with decrease in pH of soils on air drying, due to increased fixation (Huynn-cong-Tho & Egashira 1976).

DISCUSSION AND CONCLUSION

Although some differences exist among soils from different mangrove stands, there is also considerable overlap in the range of values for most soil properties. Species distributions are not restricted to exclusive ranges of the soil property values. However, it is observed that mixed stands of *Nypa* and *Rhizophora* tend to favour soils that are clay loam in texture while mixed stands of *Nypa* and *Raphia* favour sandy loam/sandy clay loam soils. Higher acidity conditions tend to occur in soils associated with *Rhizophora* spp. than in soils associated with *Nypa fruticans* and ecotonal species.

Low bulk density in the mangrove soils reflects the high silt, clay and organic carbon contents of the soils, while high field moisture reflects the extent to which the soils are saturated by tides. High silt and clay proportions increase the water holding capacity of the soils, resulting in poor drainage. The soil physical properties appear to relate more to the physiographic and fluvial aspects of the swamps, where substrates differ due to local flocculation, consolidation and sedimentation patterns. Considering the high water-holding capacity of the soil, the poor drainage and seasonal salinity in the swamps (Ukpong 1991), the soils do not appear to have much agricultural potential. Drainage and reclamation of the swamps would result in highly acid soils.

Plant reaction on the soil is mainly reflected in organic carbon contents. High organic carbon contents correlate with relatively high species density and coverage (see Tables 1 & 4). In addition, the stilt roots of the mangroves probably trap leaves and other organic debris thereby contributing to the high organic carbon. Therefore, much of the organic materials may have been derived from tidal imports.

There are no clear relationships between soil properties and species distribution. The spatial location of stands relative to terrestrial and marine influences affects the physical and chemical properties of soils. Soil texture is influenced by proximity to tidal channels, which determine the pattern of sedimentation. Proximity to the ocean and availability of freshwater supply are important determinants of CEC concentrations.

The findings from this study differ from those reported for other mangrove swamps. In Australia, Clarke & Hannon (1967) reported predominantly sandy (>75%) surface and subsurface soils in mangroves, with pH values ranging from 5.5 to 7.3. This contrasts with the results of the present study where sand proportions range from 26% to 52% and the field moist pH values range from 5.5 to 6.8. In Australia, CEC was extremely low, ranging from 0.38 to 0.84 me/100 g while in the present study, CEC ranged from 21.00 to 45.71 me/100 g. In South America, Moorman & Pons (1974) reported clayey texture in soils from different mangrove zones, which contrasts with the dominantly loamy texture observed for the Creek Town swamps.

It is concluded that the physical and chemical properties of mangrove soils are related more to geogenetic factors, e.g. soils of adjacent areas or hydraulic characteristics of channels and tidal influence, than to the occurrence of species. However, soils do influence vegetation distribution, but the extent to which they determine the occurrence of mangrove species remains unclear.

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