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An Assessment of the Physico-Chemical Parameters of Mangrove Soils that Support *Nypa fruticans* and Other Mangrove Species Establishment in the Cameroon Estuary

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Invasion of Nypa palm into mangroves is a problem in the Cameroon Estuary. Soil variability is one of the dominant features that support Nypa palm establishment. The objective was to characterize the soil under the different mangrove stands; Purely Nypa palm stands (A), mixed stands i.e Nypa palm and other mangrove species (B) and other mangrove species i.e Nypa palm free (C), determine the principal soil characteristic critical for Nypa spread. 9 plots of 20 x 20 m were laid in each of the sites. 27 soil samples were collected in the North, West, South East and Center at a depth of 30 cm in these three sites using a soil auger. The results in the three sites indicated that; soils were acidic (3.87- 4.39), pH values did not significantly differ (alpha >0.05), organic matter was low in A (12.32%) and B (16.35%).Soil Organic Carbon ranged from (4.52 to 7.06%). High percentage of organic carbon content was recorded in C (7.06%). Low percentage of organic carbon was found in A (4.52%). Total nitrogen varied from 1.04 g/kg, 1.70g/kg, 1.80 g/kg in sites C, A and B. In all the mangrove stands, the values of Exchangeable Ca content were below 4.0 cmolkg^{-1}. Soil

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texture in the three sites were; sandy, clay and silt. Power test showed no significant different in soil types between the three sites ($p>0.05$). According to the component matrix the factor is positively loaded by soil EC, moisture content, organic matter, organic carbon, N, C/N, CEC, Ca, Mg, K, Na, Clay, Silt, and negatively loaded by the percent sand. This study therefore, suggests that since soil plays key role in Nypa palm establishment, there should be constant monitoring of soil quality to forestall drastic changes that will jeopardize the survival of the mangroves. Nypa palm seedlings should also be physically removed from mangrove forest to prevent colonization. In addition, more mangrove seeds should be planted in deforested mangrove areas to close the window of opportunity for the palms.

Keywords: Invasive species; Nypa palm; physico-chemical parameters; soils; mangrove species; Cameroon estuary.

1. INTRODUCTION

Nypa fruticans is a mangrove palm that grows well in calm estuaries and coastal regions. It is commonly found on the landward side of a mangrove forest subjected to low water salinity. Like many palms, *Nypa fruticans* exhibits a uniform growth pattern with constantly successive leaf production and height increments throughout the year. Mangroves are habitat specialist, and grow only in coastal areas [1]. It is a palm that grows well in areas with average minimum temperature of 20°C and the maximum of 32-35°C. Its optimum climate is sub- humid to humid with more than 100 mm rainfall per month throughout the year [2].

Nypa palm thrives in a brackish water environment. Optimum conditions are when the base and the rhizome of the palm are regularly inundated by brackish water. For this reason, Nypa palm occupies mostly estuarine tidal floodplains. The optimum salt concentration is 1-9 per mil. Nypa palm swamp soils are muddy and rich in alluvial silt, clay and humus [3]. Nypa palm can grow as tall as 10 m, unlike other palms it lacks an upright stem, and instead it has thick, prostrate, rhizomatous stems that branch dichotomously underground [2].

The typical mangrove soil is coffee brown in color, slightly muddy and has a pungent ammonia-like smell, which breathes life into the mangrove forest and accelerates the growth of organisms. Nypa palms grow on a variety of soils such as; muddy soil, sandy soil and algae-infested soils. Studies done using soils from different locations show that growth in height of Nypa palm seedlings were mainly influenced by soils derived from highly polluted forest than soils derived from lowly polluted forest. Another study also indicates that Nypa palm grows better than mangroves in mixed forests (i.e. a combination of mangrove and Nypa palm trees growing together) than in pure forest [4]. This could be one of the reasons why the palms out-compete the mangroves when they infiltrate mangrove forest [5]. Studies had shown that the growth of Nypa palm seedlings in mangroves soils is as a result of the utilization by the palms of the un-used nutrients that are locked within the mangrove soil.

Factors such as altitude, parent rocks, vegetation and anthropogenic activities influence the physico-chemical properties of soil and water (pH, organic matter, cation exchange capacity, soil texture and water chemistry). Soil pH affects nutrients availability and the optimal condition for this is at pH 5 - 7 [6]. The potential for elements present in soils and sediments to be mobilized/ immobilized and be redistributed depends on several factors such as organic matter, type and amount of clay, pH and the prevailing redox conditions and pathways. These elements can easily be mobilized and transmitted through for example, water and the food chain to humans [7].

The mangroves export organic nutrients whereas salt marsh and fringe communities act as nutrient sinks [8]. The above ground mangrove biomass correlated significantly with soil factors [9]. Many marsh soils contain large amount of sulphur which is oxidized to sulphate when exposed to air [10]. Mangrove soils generally were high in clay, organic matter, cation exchange capacity, Al, SO_4 , Fe and exchangeable bases than non-mangrove soils. On the basis of exchangeable Na percentage and electrical conductivity, mangrove soils are classified as saline sodic and the non-mangrove soil, non-saline sodic [11]. Studies of mineral elements in the mangroves from saline and non-saline localities reveal that

potassium uptake is considerably reduced which results in increased uptake of calcium. Potassium and calcium ions build up salt tolerance in mangroves. However sodium concentration affects calcium uptake much more than that of potassium [12].

Nypa palm is amongst the most widespread marine vascular plants along subtropical and tropical coastlines [13]. They grow in swampy soils [14], which originates from weathered sedimentary rocks [15]. The soil is a mixture of litter at different stages of decomposition [16] and serves as carbon sinks [17,18]. Nypa palm is regarded as a member of the mangrove ecosystem and from the nypoid line [19]. However, other studies had shown that Nypa palm is not a true mangrove [20]. In Africa, Nypa palm is an invasive species that was deliberately introduced in Nigeria to curb coastal erosion [5], but have become a major threat to the mangroves. They grow in coastal soils and have their seeds dispersed across the mangrove forest by tidal currents, signaling readiness for full colonization. During low tides the seeds of the palms settle down on the forest floor and start to grow. The growth of Nypa palm within the mangrove forest endangers the mangroves and prevents them from attaining maturity. This is because the palms compete for space and nutrients with the mangroves. The palms use their tiny, permeable and fibrous root system to absorb soil minerals. They also produce allele-chemicals, which prevent the growth of other plants around them [21]. Apart from edaphic factors which affects soil properties, anthropogenic factors also contribute to rapid changes in soil composition and soil chemistry, For instance, oil and gas exploration lead to hydrocarbon pollution [22,20] and affects soil chemistry [23] (Alongi, 2009). In the same vein, deforestation of mangrove trees to pave way for exploration activity [21] impact mangrove growth [24] leading to reduction in species abundance. It is thus postulated that the rapid growth of palms in mangrove forests may signify their affinity and adaptation to coastal soil. Thus, there is great need to investigate the physico-chemical properties of coastal mangrove forest soils that support Nypa palm establishment.

Like in other parts of the world, Nypa palm has historically provided useful products to indigenous peoples living near or in the coastal and estuarine mangrove forest area in Nigeria as well as in Cameroon [3, 25]. Matured leaves have been used for roof thatching, wall-partitioning of dwellings, roofs of boats, umbrellas, sun hats, raincoats, baskets, mats and bags, and young leaves are made into cigarette wrappers and to wrap cooked rice [26,27,28,29,3,30,25,31]. Young seeds and buds of the stem are edible [27,3,32].

Several studies have focused on the, distribution, and growth of *Nypa fruticans* [33, 34], but there is limited knowledge on the physico-chemical characteristics of soils under Nypa and other mangrove species. Although the effects of light, soil, salinity and disturbances on the growth of many palms have been studied [35], no such study is available for *Nypa fruticans* specifically.

The purpose of this study was to characterize the physico-chemical parameters of mangrove soils that support; A (pure Nypa stands), B (mixed mangrove stands; Nypa and woody mangroves) and C (pure woody mangrove stands) establishment. The objectives were (1) to characterize the soil under different mangrove stands, (2) to determine the principal soil determinant for Nypa stands distribution.

2. MATERIALS AND METHODS

2.1 Study Site

This study was carried out in the Cameroon Estuary (Fig. 1), located in the South Western part of Cameroon between latitude 3° 83' to 4° 10' N and longitude 9° 25' to 10° 00' E. It is a large forest of approximately 1,750 km^2 and is representative of the bigger mangrove block in Cameroon. The coastal and marine environment of Cameroon forms part of the southern section of the Gulf of Guinea's Large Marine Ecosystem [36]. The coastline stretches from the Equatorial Guinea border at latitude 2° 30' to 4° 67' N at the Nigeria border and it is estimated at about 400 km in length [36].

2.2 Soil Sampling for Physico-chemical Properties

To characterize the physico-chemical parameters of mangrove soils that support Nypa palm establishment, firstly, the geographical locations of sample sites were gotten with the help of a Garmin 62 GPS. 3 sites (A, B and C) were identified and a 20m x 20m plots were established. Within each plot (20 x 20 m) and with the help of a soil auger (Eijkelkamp

Agrisearch Equipment BV, Giesbeek, the Netherlands), soil samples were collected at the North, South, West, East and Centre to a depth of 30cm, given that the roots of Nypa palms do not go beyond 30cm. Before the samples were collected, organic litter was removed from the soil surface at the point of collection. The auger was drilled into the soil at a depth of 30cm; it was twisted at least 6 times clockwise to ensure that the samples were all taken within 30cm. Soil samples were then removed from the auger using a knife and the samples were put into labeled, airtight plastic bags and were taken to the laboratory for analysis. Soil samples were grouped into 3 categories; sites A, B and C. A total of 27 soil samples were collected on the field at low tide. All collected field soil samples were, registered and given a serial number for easy identification. The samples were air dried to reduce the moisture content. In the laboratory they were weighed and oven dried at 105˚C to a constant weight to determine the physical properties of the soil like texture and chemical properties like; Carbon (C), organic matter and Nitrogen (N) as well as; pH, EC, Ca, Mg, P, K and CEC (Cation Exchange Capacity).

2.3 Soil Collection for Moisture Content Determination

The gravimetric method was used to determine moisture content. Here, an empty metal tin of weight (W1) was driven into the soil. The soil around the tin was excavated and the excess removed from the opened end and weighed (W2). The sampled soil were emptied into soil bags and labelled for laboratory analyses.

Data were presented by mean and standard deviation (SD), representing the distribution of data around the mean.

2.4 Laboratory Analysis for Physico-chemical Parameters

Laboratory facilities of University of Dschang, Faculty of Agronomy and Agricultural Sciences (FASA) were used for the analyses of the samples.

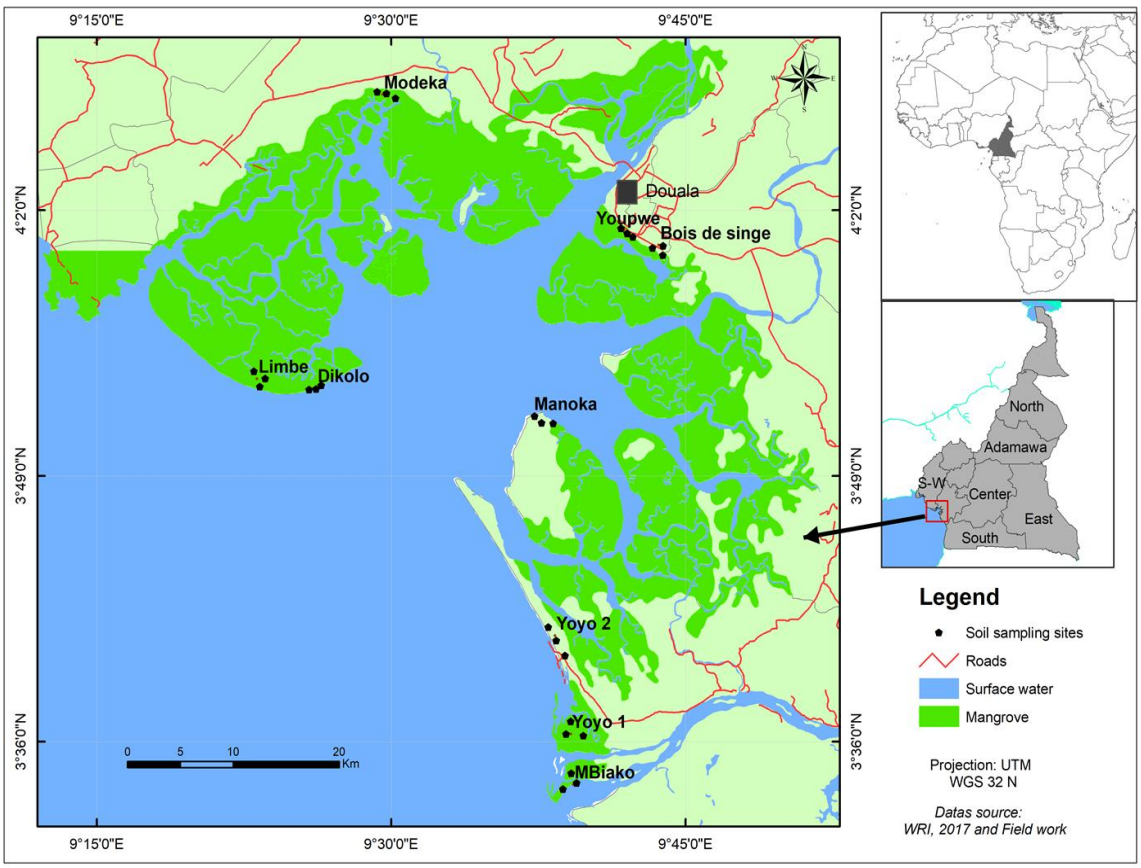

Fig. 1. Map of the study area (INC, 2019)

2.5 Soil Analyses

2.5.1 Sample preparation and analyses

The soil samples were air-dried in a ventilated room. The samples were then ground using a ceramic mortar and passed through a 2 mm sieve. Portions of the samples were oven dried at 105 ^{o}C for the moisture correction factors. The other less than 2 mm fraction was collected and homogenized for subsequent analyses. Part of it, was used to analyse routine parameters (like; organic carbon, total nitrogen, CEC and available phosphorus.) in the Environmental and Analytical Chemistry Laboratory of the University of Dschang.

2.6 Chemical Analyses

2.6.1 Soil pH determination

Soil pH was determined using a 1:2.5 soil solution ratio using a PD 300 series pH meter. Real acidity (pH H_2O) was measured in a soil water suspension of ratio 1:2.5 (10 g of soil and 25 ml of distilled deionized water), 16 hours after the mixture to ensure complete homogenisation. Potential acidity (pHKCl) was determined in a well homogenized soil-KCl suspension of ratio 1: 2.5, 10 minute after preparation [37].

2.6.2 Electrical Conductivity (EC)

Electrical conductivity was determined using a 1:5 soil solution ratio using 10 g of < 2 mm soil in a 50 ml distilled deionized water. The mixture was agitated for 1hour. The value of electrical conductivity was read from a conductivity meter calibrated with 0.01 N KCl [38].

2.6.3 Percentage soil moisture

A small portion of the less than 2 mm fraction of the air dried soil was weighed and introduced into a well-ventilated oven regulated at 105 ^{o}C for 1 day. The samples were then removed, placed in desiccators to avoid the absorbance of moisture while cooling [39].

$$\mathrm{M}(\%) = \frac{A-B}{\mathrm{B}} X100$$

Where M = soil humidity
A = mass of the air-dried soil
B = the mass of the oven dried soil

The moisture correction factor was obtained from the relationship

$$\mathrm{MCF} = \frac{100 + M(\%)}{100}$$

Where MCF = Moisture correction factor
M (%) = Soil humidity

2.6.4 Percentage organic carbon

Organic carbon was determined by the Walkley and Black method using acidified potassium dichromate as the oxidizing agent [40]. The method was based on the principle of organic carbon oxidation in an acidic medium. As such, 2 g of each soil sample was introduced into a 500 mL of round bottom flask, followed by 10 mL $K_2Cr_2O_7$, and 2 mL of H_2SO_4 in a fume cupboard. The mixture was allowed to digest for 30 minutes and successively, 150 mL of distilled H_2O and an indicator (diphenylamine) was added. The solutions was then put on a magnetic stirrer and titrated with $FeSO_4.7H_2O$ to obtain the end point when the colour changes from violet to green. The percent organic carbon was obtained as indicated by the formula below.

% OC = 4 (Vo-V) x 100/V.P

Where OC = organic carbon
Vo = Volume of $FeSO_4.7H_2O$ added to the control
V = Volume of $FeSO_4.7H_2O$ added to the sample
P= Amount of soil sample taken.

The percentage organic matter (% OM) was calculated by multiplying the % C with a factor of 1.724.

2.7 Available Phosphorus

The Olsen (NaHCO3) method was used for available phosphorus (Quesada, 2009) analysis. The available phosphorus in the soil sample was extracted with 0.5M sodium hydrogen carbonate (pH 8.5) solution. To lower the pH of the $NaHCO_3$ to about 5.0 and to remove cloudiness due to the presence of organic matter in the soil sample, 1.0 mL of 2.5M sulphuric acid was added to the mixture. To develop colour for the extracts, a solution (labeled A) was prepared by mixing thoroughly solutions of 12 g ammonium molybdate in 250 cm^3 of distilled water and 100 cm^3 of 5 N sulphuric acid. The whole mixture was topped to 2000 cm^3 volume with distilled water.

From solution A, another solution (labelled B) was prepared by dissolving 1.056 g ascorbic acid in 200 cm^3 of solution A and used for colour development.

A 15 cm^3 aliquot of the extract containing about 20 µg of orthophosphate was pipetted into a 50 cm^3 volumetric flask, and its pH was adjusted by adding a few drops of p-nitrophenol indicator and a few drops of 4N – NH_4OH until the solution turned yellow. About 8cm^3 of solution B was added to the yellow solution developed above and topped with distilled water to volume and left for some time for colour development. Also, a 50 cm^3 blank solution was prepared with distilled water and 8cm^3 of solution B.

A standard phosphorus solution containing 25 µg phosphorus was also prepared by pipeting 5 mL of a standard phosphorus and blank solution into a volumetric flask and made up to 50 mL with distilled water. This was also left for some time to develop colour. The standard phosphorus and blank solutions were used to calibrate the colorimeter at 712 nm wavelength (Quesada, 2009). After the calibration of the spectrophotometer (Spectronic 301) with standard solutions, the available phosphorus in the extracts were measured and calculated as:

(3) Phosphorus in soil sample (µg/g) = RxE / AxW

Where *R* = colorimeter reading in (µg/g), *E* = volume of extractant (cm^3), A = volume of aliquot (cm3) and W = weight of soil (g).

2.8 Total Nitrogen

The Kjeltec Auto 1030 Analyzer (distillation) method (also called the Kjeldahl procedure) was used. In this method, NH+4-N was liberated by distillation of the soil digest with 40 % NaOH solution and absorbed in unstandardized boric acid to form ammonium borate. The borate was then titrated against 0.01M hydrochloric acid (HCl) using a mixture of bromocresol green and methyl red solutions as indicator.

About 2 grams of soil sample were weighed into Kjedahl flask and a few drops of distilled water were added to moisten the soil. A scoop of digestion accelerator mixture and later 5 ml of concentrated sulphuric acid were added to the moistened soil in the flask. The result mixture was digested to obtain a clear solution; after which it was cooled with distilled water and transferred into a 50 mL volumetric flask and topped up with distilled water.

An aliquot of 5 ml was taken into a Markhan distillation apparatus. About 2 mL of 40% sodium hydroxide was added and distilled. The distillate was collected into a flask containing 5 mL of 2% boric acid. Three drops of a mixture of bromecresol green and methyl red solutions were added to the distillate as indicator and titrated against 0.01M HCL. A change from green to pink end point was observed [41]. The procedure was repeated twice and the average titre computed was used to calculate the percentage nitrogen:

(4) %N in Soil= (Vs – Vb) x Molarity of Standard HCL x 1.401/ Weight of sample digested

Where Vs = Volume (mL) of standard HCl for titration of sample and Vb = Volume (ml of standard HCl for titration of blank. The percentage nitrogen was converted to gkg by multiplying by a factor of 10 (Rayment and Higginson, 1992) [41].

2.9 Determination of Exchangeable Bases and CEC

The exchangeable bases and CEC were determined following the procedures proposed [40]. Here, the soil samples are saturated with ammonium acetate buffered at pH 7 to displace the exchangeable bases. Sodium and potassium concentration in the extract were determined by flame photometry while the concentrations of magnesium and calcium were determined by complexiometry.

For CEC determination, the column of each sample was then thoroughly washed with 95% alcohol to get rid of all the excess ammonium acetate that saturated the complex. This was verified by the use of Neslar reagent. Sixty mL of KCl was then introduced into each tube to let potassium replace ammonium ions that saturated the complex. The tap was opened and the filtrate collected slowly into a 100 mL volumetric flask. This was finally brought to the 100 mL mark by the addition of KCl. 25 mL of each sample were transferred into a distillator's tube and NaOH added followed by 2-3 drops of phenolphthalene. 40mL of boric acid were placed into a conical flask and distilled water added to the 100 mL level. Each sample was distilled and the distillate in the conical flask used for titration

with 0.01MH_2SO_4 from a burette. The CEC was calculated using the following formula:

$$CEC\ (100g)_{soil} = (V\text{-}Vo) \times 1.6$$

Where V and Vo are the volumes of sulfuric acid added to the sample and control, respectively.

$$CEC_{clay} = (CEC_{soil} - 1.724 \times 2x\ \%\ OC)100 / \%clay$$

Exchangeable acidity ($H^+ + Al^{3+}$) meq/100g of soil = $40\times t \times (Vx - Vo)$

Where: t = exact molarity of NaOH used
Vx = the volume of NaOH added to the sample
Vo = Volume of NaOH added to the control

The exchangeable aluminium was determined after the colour development following the procedure described [40]. The concentration was then determined using the UV spectrophotometer, regulated at a wavelength of 530 nm. The concentration of hydrogen was simply obtained by the difference between that of exchangeable acidity and aluminium.

Base Saturation ECEC (BS –ECEC)

The base saturation ECEC was calculated using the following formula.

$$\text{BS} - \text{ECEC} = \frac{\text{Sum of exchangeable bases}}{\text{ECEC}} \text{ X } 100$$

2.10 Exchangeable Cations

The concentrations of calcium (Ca), potassium (K), and magnesium (Mg) in the sediment samples were determined by using a single extraction with silver-thiourea for measuring exchangeable cations. The exchangeable cations were extracted for 4 hrs from 5 g samples by 30 mL of silver-thiourea reagent, and analysed by inductively coupled plasma optical emission spectrophotometer (Optima S300 DV, Perkin Elmer) [42].

2.11 Physical Analysis

2.11.1 Determination of soil texture

Particle size determination allows us to know the percentage of different textural classes (sand, silt, and clay), found in a < 2 mm mineral fraction of soil [43]. It was determined by the Pipette method. Hydrogen peroxide (H_2O_2, 35% p/p) was added to the samples placed on a hot plate to eliminate organic cementing materials on a hot plate. This was followed by the addition of hydrochloric acid (HCl, 0.02 N) to destroy sesquioxides binding the colloidal fraction. The samples were then washed with distilled water. Sodium hexametaphosphate was added to the samples for dispersion. The clay, silt and sand fractions were separated using the Robinson – Köhn pipette. The time and depth of pipetting was determined by Stocks law. Textural classes were determined using the USDA textural triangle.

For the chemical analyses, soil samples from the respective study plots were analysed for their moisture content (%), cation exchange capacity ($cmolckg^{-1}$), organic carbon (gkg^{-1}), total nitrogen (gkg), available phosphorus ($mgkg^{-1}$) and exchangeable Ca, Mg and K as follows:

2.11.2 Principal component analysis

The data of the 22 variables reported in this study were subjected to R-mode factorial analysis using the six-factor model. Before this was done the data were subjected to two test statistics for inspection (Table 1) that is, the Bartlett test of sphericity and the Kaiser-Meyer-Olkin Measure of Sampling Adequacy (usually called the MSA). The Bartlett Test of Sphericity compares the correlation matrix with a matrix of zero correlations (technically called the identity matrix, which consists of all zeros except the 1's along the diagonal). From this test we are looking for a small *p*-value indicating that it is highly unlikely for us to have obtained the observed correlation matrix from a population with zero correlation. However, there are many problems with the test, for a small *p* value indicates that you should not continue but a large *P*-value does not guarantee that all is well. The MSA does not produce a *P*-value but we are aiming for a value greater than 0.8 and below 0.5 considered to be unacceptable. Good values for all variables for the MSA were obtained but the overall value was a bit low (0.672). However, Bartlett's Test of Sphericity had an associated *P*-value of <0.001 as by default SPSS reports *p*-values of less than 0.001 as 0.0001. So from the results, a valid factor analysis can be performed. To take care of multiple multi collinearity the determinant was checked to see if it is greater than 0.00001. In the study, it was 0.0653.

Table 1. Test statistics (KMO and Bartletts's test for data impaction prior to principal component analyses

KMO and Bartlett's Test		Value
Kaiser-Meyer-Olkin Measure of Sampling Adequacy (KMO)		0.672
Bartlett's Test of spericity	APPro. Chi-square	178.431
	Df	20
	Sig	0.000!

3. RESULTS

3.1 pHKCl (Soil pH)

Soil pH varied between 3.87 ± 0.17 in site A, 4.16± 0.47 in site C and 4.39 ± 0.25 in site C. The sites with A recorded the lowest mean Soil pH 3.87±0.17. The highest mean value of Soil pH 4.39±0.08 was found in site B, followed by site C, with mean value of 4.16±0.16 (Table 2). However, power test revealed that this difference was not statistically significant $p<0.05$.

Table 2. Comparing soil parameters among sites (A, B and C)

Soil Parameters		Sites			Power Test
		Purely Nypa (A)	Mixed (B)	No Nypa (C)	
pHKCl	Mean	3.87	4.39	4.16	Difference not
	Std. Error of Mean	0.17	0.08	0.16	significant
	Std. Deviation	0.52	0.25	0.47	
EC(ms/cm)	Mean	1.01	2.20	0.77	Difference not
	Std. Error of Mean	0.39	0.56	0.04	significant
	Std. Deviation	1.18	1.67	0.13	
Moisture(%)	Mean	91.22	92.89	91.78	Difference not
	Std. Error of Mean	0.94	0.42	0.46	significant
	Std. Deviation	2.82	1.27	1.39	
Exch acidity	Mean	2.84	1.89	2.46	Difference not
(méq/100g)	Std. Error of Mean	0.31	0.34	0.39	significant
	Std. Deviation	0.94	1.01	1.16	
Carbon (%)	Mean	4.52	6.00	7.06	Difference not
	Std. Error of Mean	0.89	0.49	0.38	significant
	Std. Deviation	2.66	1.47	1.13	
Org matter (%)	Mean	12.32	16.35	19.23	Difference not
	Std. Error of Mean	2.41	1.34	1.02	significant
	Std. Deviation	7.24	4.01	3.07	
Nitrogen (g/kg)	Mean	1.70	1.80	1.04	Difference not
	Std. Error of Mean	0.28	0.25	0.31	significant
	Std. Deviation	0.85	0.74	0.92	
C/N	Mean	24.44	40.67	40.22	Difference not
	Std. Error of Mean	4.68	7.53	7.83	significant
	Std. Deviation	14.05	22.58	23.50	
Phos(mg/kg)	Mean	26.02	39.22	25.09	Difference not
	Std. Error of Mean	5.94	11.39	7.92	significant
	Std. Deviation	17.81	34.18	23.77	
Cationexch	Mean	40.93^{ab}	75.78 ^{a}	89.88^{b}	Difference is
capacity	Std. Error of Mean	5.94	6.31	8.38	significant
(meq/100g)	Std. Deviation	17.82	18.94	25.14	
Ca(méq/100g)	Mean	0.09^{ab}	0.18 ^{a}	0.25 ^{b}	Difference is
	Std. Error of Mean	0.03	0.01	0.01	significant
	Std. Deviation	0.08	0.04	0.04	
Mg(méq/100g)	Mean	0.09	0.12	0.11	Difference not
	Std. Error of Mean	0.02	0.01	0.01	significant
	Std. Deviation	0.07	0.04	0.03	

Soil Parameters		Sites			Power Test
		Purely Nypa (A)	Mixed (B)	No Nypa (C)	
K(méq/100g)	Mean	5.46	3.65	5.83	Difference not significant
	Std. Error of Mean	0.86	0.40	0.59	
	Std. Deviation	2.58	1.21	1.76	
Na(méq/100g)	Mean	0.13	1.48	0.19	Difference not significant
	Std. Error of Mean	0.05	0.71	0.04	
	Std. Deviation	0.16	2.13	0.11	
Clay(%)	Mean	17.89	16.61	13.33	Difference not significant
	Std. Error of Mean	2.98	1.16	0.61	
	Std. Deviation	8.95	3.47	1.84	
Silt(%)	Mean	2.06	3.28	4.94	Difference not significant
	Std. Error of Mean	0.64	1.43	1.27	
	Std. Deviation	1.93	4.28	3.81	
Sand(%)	Mean	80.06	80.22	81.72	Difference not significant
	Std. Error of Mean	3.17	1.75	1.28	
	Std. Deviation	9.50	5.24	3.85	

[a,b]: Means with the same subscripts are significantly different at 0.05 Level.

3.2 Electrical Conductivity

Sites B recorded the highest mean electrical conductivity 2.20±0.56 ms/cm, followed by sites A with mean value 1.01±0.39 ms/cm. Sites C had the lowest mean electrical conductivity 0.77±0.04 ms/cm (Table 2). Completing Power Text on EC indicated that there was no significant difference between the three sites (p<0.05).

3.3 Soil Moisture

The lowest mean soil moisture 91.22± 0.94% was found in sites A, followed by sites C, with mean moisture 91.78 ±0.46%. The highest mean soil moisture 92.89± 0.42% was recorded in sites B. (Table 2). Through the Power test, it was found that the difference were not statistically significant among the sites (p>0.05).

3.4 Exchangeable Acidity

The highest mean exchangeable acidity 2.84 ± 0.31 meg/100g was found in sites A, followed by sites C with mean exchangeable acidity 2.46±0/39 meg/100g. Sites B had the lowest mean exchangeable acidity 1.89±0.34 meg/100g (Table. 2). Consequently, Power test showed no significant difference (p>0.05).

3.5 Organic Carbon

Sites A was found with the lowest mean carbon 4.52±0.89%, while sites C and B were recorded with the highest mean carbon 7.06±0.38% and 6.00±0.49% for C and B respectively (Table 2). The low organic carbon in Nypa palm was as a result of low supply of organic matter derived from litter. Upon conducting Power test, it was revealed that the difference was not statistically significant p>0.

3.6 Organic Matter

Organic Matter of soil was found with a low mean 12.32±2.41 % in sites A and to a high mean of 16.35±1.34 % in sites B and 19.23±1.02% in sites C (Table 2). Power test showed a no significant different between the three sites p>0.05.

3.7 Total Organic Nitrogen Available Phosphorus and C/N

Mean values of Nitrogen content varied between 1.04±0.31g/kg in sites C, 1.70±0.28g/kg in A and 1.80±0.25g/kg in sites B (Table 2).

The Maximum mean C/N ratio was observed 40.67±7.53 in sites B, while the minimum mean C/N 24.44 ±4.68 was found in sites A (Tab. 2). Power test showed no significant difference between the sites (p>0.05).

The mean values of phosphorus fluctuated between 25.09±7.92 mg/kg in site C, 26.02±5.94 mg/kg in site A and 39.22±11.39 mg/kg in sites B (Table 2)

3.8 Cation Exchange Capacity

Site A recorded the lowest mean value of Cation Exchange Capacity 40.93±5.94 meg/100g, while

the highest mean value of Cation Exchange Capacity 89.88±8.38 meg/100g was found in sites C with mean value 75.78±6.31 meg/100g (Table 2). Though, this difference was statistically significant at (p<0.05). Power test reveals a significant difference between the sites (p<0.05).

3.9 Exchangeable Ca

The lowest mean value of Exchangeable Ca content was 0.09±0.03 meg/100g and 0.18±0.01 meg/100g in sites A and B respectively .The highest mean value 0.25±0.01 meg/100g was found in sites C (Table 2). Using Power test, it showed that there was significantly difference between the sites (p<0.05).

3.10 Exchangeable Mg

The average value of Exchangeable Mg varied between 0.09±0.02 meg/100g in A, 0.11±0.01 meg/100g in site C and 0.12±0.01 meg/100g in sites B. The Maximum value of Exchangeable Mg was 0.12±0.01 meg/100g and the minimum 0.09±0.02 meg/100g (Table 2). However, this difference was not statistically significant at (p>0.05). Comparing the three pairs, Power test revealed no significant difference among the sites (p>0.05).

3.11 Exchangeable K

The mean value of Exchangeable Potassium (K) was 5.46±0.86 meg/100g, 3.65±0.40 meg/100g and 5.83±0.59 meg/100g for A, B and C respectively. Site C had the highest mean 5.83±0.59 meg/100g, followed by site A 5.46±0.86 meg/100g (Table 2). Sites B was found with the lowest mean 3.65±0.40 meg/100g. Power test indicate that there was no significant difference among the three sites (p>0.05).

3.12 Exchangeable Na

Site A had the lowest mean exchangeable Na 0.13±0.05 meg/100g which was followed by site C with mean value 0.19±0.04 meg/100g, sites B had the highest exchangeable Na 1.48±0.71 meg/100g (Table 2). This difference was not statistically significant (p>0.05) and power test as well revealed no significant difference between the three sites (p>0.05).

3.13 Soil Texture

Sand along the Cameroon mangrove ranged between 81.72±1.28% in sites C to 80.22±1.75% in sites B and 80.06±3.17% in sites A. The lowest mean 80.06±3.17 % of sand was found in sites A, while sites C had the highest mean 81.72±1.28% (Table 2).

Clay was most abundant in sites A (17.89±2.98%) and site B (16.61±1.16%). Sites C had the lowest mean clay 13.33±0.61% (Table 2).

Silt was relatively abundant in sites C (4.94±1.27), followed by sites B. The minimum mean value of silt (2.06±0.64%) was found in sites A (Table 2). On the other hand, Power test revealed that the difference was not statistically significant at (p> 0.05).

3.14 Principal Soil Characteristic Critical for Nypa Palm Spread in the Mangroves

3.14.1 Factor determining the spread of Nypa palms

From the Principal component analysis, four (4) soil factors critically explain the dominance of Nypa palms as single stands (Table 3). The four factors explain 89% of the total variance.

Factor one: explains 50.8% of the total variance (Table 3). According to the component matrix (Table 4), the factor is positively loaded by soil EC, moisture content, organic matter, organic carbon, N, C/N, CEC, Ca, Mg, K, Na, Clay, Silt, and negatively loaded by the percent sand. This shows that Nypa palms thrive well in environment with good soil quality factors but do not thrive well in sandy environments given that the percent sand is negatively loaded (-0.698). Sandy soils do not give good anchorage to Nypa palms. This is worsens by the fact that Nypa palms have fibrous roots systems. They will thus be easily dislodged in sandy environments with high tides impacts. This factor could be term as a soil quality factor.

Factor two: This is the negative loads of pH water, clay content but a positive load of sand, EC and exchange acidity. The negative load of pH means that Nypa palms will prefer acidic environments where the concentrations of H^+ ions are high (Table 4). Similarly, the factor is positively loaded by the high exchange acidity (Al^{3+} and H^+ concentrations). From the results pH loads negatively which means that positive load of exchange acidity comes from exchangeable Al^{3+}.Therefore low pH (or high concentrations of

H^+) and high concentrations of Al^{3+} will favour the survival of Nypa palms. This factor could be termed an acidic factor.

Factor three: is a two component factor composed of only silt and P. It is positively loaded by P meaning Nypa palms will thrive well in environments with high concentrations of P (Table 4).

Factor four: is mineralization factor. It is positively loaded by N and negatively loaded by high C/N. This means that when the concentration of N is high, Nypa palms will establish and grow well but when the ratio of C/N is high mangrove do not thrive well. This could be attributed to the fact that with high C/N ratio, the mineralization of organic matter to it component mineral ions needed for plant growth is limiting (Table 4).

3.14.2 Factor determining the spread of purely woody mangroves stands

For the principal soil characteristics determining the spread of purely woody mangroves stands, four principal components were extracted (Table 5), explaining 87.9% of the total variance.

Table 3. Total Variance explained for principal determinants of soil factors influencing the dominance of Nypa palms within the Cameroon Estuary

Total Variance Explained						
Component	**Initial Eigenvalues**			**Extraction Sums of Squared Loadings**		
	Total	**% of Variance**	**Cumulative %**	**Total**	**% of Variance**	**Cumulative %**
1	9.156	50.866	50.866	9.156	50.866	50.866
2	4.044	22.466	73.332	4.044	22.466	73.332
3	1.716	9.531	82.862	1.716	9.531	82.862
4	1.122	6.234	89.097	1.122	6.234	89.097
5	.955	5.306	94.403			

Extraction Method: Principal Component Analysis.

Table 4. Component matrix for the four principal components explaining the principal soil characteristics influencing the spread of Nypa palms

Component Matrix[a]	**Component**			
	1	**2**	**3**	**4**
pH_Water	.369	**-.878**	-.137	-.090
pH_KCl	.186	-.399	.494	.004
EC	**.841**	**.521**	-.014	-.046
Moisture	**.790**	-.457	.155	.135
Excg_Acidity	-.055	**.937**	-.073	.169
Org_Carbon	**.931**	.166	.212	-.014
Org_Matter	**.932**	.166	.211	-.014
N	**.567**	.334	-.354	**.500**
C_N_Ratio	**.531**	.064	.399	**-.697**
P	-.004	.239	**.719**	.391
CEC	**.843**	-.478	-.014	.061
Ca	**.932**	.327	-.036	-.037
Mg	**.904**	.385	-.101	-.034
K	**.993**	-.002	.046	.023
Na	**.883**	.445	.069	-.037
clay	**.630**	**-.676**	-.060	.235
silt	**.515**	.108	**-.687**	-.291
sand	**-.698**	**.614**	.196	-.163

Extraction Method: Principal Component Analysis.[a]

a. 4 components extracted.

Table 5. Total Variance explained for principal determinants of soil factors influencing the dominance of purely woody mangroves within the Cameroon Estuary

Total Variance Explained						
Component	**Initial eigenvalues**			**Extraction sums of squared loadings**		
	Total	**% of variance**	**Cumulative %**	**Total**	**% of Variance**	**Cumulative %**
1	8.375	46.527	46.527	8.375	46.527	46.527
2	4.176	23.202	69.729	4.176	23.202	69.729
3	2.019	11.216	80.945	2.019	11.216	80.945
4	1.249	6.937	87.883	1.249	6.937	87.883
5	.966	5.366	93.249			

Extraction Method: Principal Component Analysis.

Principal component 1 explained 46.5% of the total variance (Table 5) and from the component matrix it is loaded by; silt, Na, EC, Organic Matter, OC, K, P, pH water, Sand, Ca, Mg, exchange acidity, pHKCl. This indicates that other mangroves thrive well in environment with high pH values having less acidic environments i.e following the positive load of pH (Table 6). They would not thrive well in environments with high exchangeable acidity (high $Al^{3+)}$. They also prefer environments with silty soils.

Principal component 2 explains 23.2% of the total variance. It is loaded by K, pH water, Ca, Mg, exch acidity, C/N, clay, and N. It is positively loaded by K (0.602) and pH water. Purely woody mangroves will therefore thrive well in environments with high concentrations of K^+. K is necessary for seed formation and ion exchange in the rhizomorphic roots.

Principal component 3 explains 11.2% of the total variance. It is loaded by pH Kcl and CEC.

Principal component 4 is dominated by moisture alone. It explains 6.93 percent of the total variance. Therefore other mangroves thrive well under inundation.

Table 6. Component matrix for the four principal components explaining the principal soil characteristics influencing the spread of purely woody mangroves stands

Component Matrix[a]				
	Component			
	1	**2**	**3**	**4**
Silt	**.920**	.103	.177	.070
Na	**.860**	.474	-.090	-.152
EC	**.843**	-.482	.012	.074
Org_Matter	**-.835**	.068	.436	-.120
OC	**-.834**	.067	.437	-.121
K	**.768**	**.602**	-.063	-.162
P	**.753**	.131	.168	.121
pHwater	**.741**	**.563**	-.284	.033
Sand	**-.735**	-.376	-.377	-.290
Ca	**.697**	**-.636**	-.198	.207
Mg	**-.597**	**.719**	.090	.055
Excg_Acididy	**-.674**	**-.717**	.098	-.010
CN_ratio	.483	**-.704**	.390	.071
Clay	-.368	**.572**	.422	.462
Tot_N	-.402	**.537**	-.464	-.456
pHKCl	**.580**	.261	**.670**	-.369
CEC	-.277	.038	**-.540**	.400
Moisture	-.449	.496	.026	**.540**

Extraction Method: Principal Component Analysis.[a]
a. 4 components extracted.

3.14.3 Factor determining the spread of Mixed stands (Nypa palm and other mangroves species)

Four principal components explained 90% of the total variance (Table 7).

Principal component 1 explained 40.4% of the total variance (Table 7). It constituents soil characteristics are; moisture, Org C, Org matter, C/N, P, Ca, Mg, K, and silt. This environment has contrasting characteristics such as; high C/N ratio and percent silt that can favour other mangroves but low moisture favouring Nypa palms (Table 8).

Principal component 2 contributing 22.4% of the total variance was made of EC, CEC, Ca and Clay.

Principal component 3: negatively loaded exchange acidity favouring Nypa palms. This component contributed 15.7% of the total variance (Table 7).

Principal component 4 was dominated by a single soil characteristic (pHKCl) and contributed 11.3% of the total variance.

In fact, mixed mangrove environments depict some characteristics that favours Nypa palm and some that favours other mangroves. It is thus intermediate in character.

Table 7. Total Variance explained for principal determinants of soil factors influencing the dominance of mixed mangrove stands within the Cameroon Estuary

Total Variance Explained						
Component	**Initial Eigenvalues**			**Extraction Sums of Squared Loadings**		
	Total	**% of variance**	**CUMULATIVE %**	**Total**	**% of variance**	**Cumulative %**
1	7.272	40.398	40.398	7.272	40.398	40.398
2	4.086	22.700	63.098	4.086	22.700	63.098
3	2.830	15.722	78.820	2.830	15.722	78.820
4	2.027	11.263	90.083	2.027	11.263	90.083
5	.768	4.265	94.348			

Extraction Method: Principal Component Analysis.

Table 8. Component matrix for the four principal components explaining the principal soil characteristics influencing the spread of mixed mangroves

Component Matrix[a]				
	Component			
	1	**2**	**3**	**4**
pHwater	-.283	.189	**.837**	.203
pHKCl	.121	.387	.198	**.865**
EC	-.009	**.912**	.224	-.329
Moisture	**-.724**	.324	.058	-.249
Excg_Acidity	.290	.212	**-.846**	.229
Org_C	**.927**	.105	.239	-.171
Org_matter	**.926**	.105	.239	-.171
N	-.459	-.268	**.679**	.139
C_N_ratio	**.754**	.289	-.481	-.231
P	**-.956**	.089	-.069	-.235
CEC	.119	**-.915**	-.189	.324
Ca	**.629**	**-.527**	.420	.098
Mg	**-.606**	.358	.193	.344
K	**-.898**	.300	-.240	-.027
Na	.368	**.815**	.282	-.307
Clay	.079	**-.701**	.280	-.586
Silt	**-.946**	-.063	-.210	.015
sand	**.733**	.492	.004	.396

Extraction Method: Principal Component Analysis.[a]

a. 4 components extracted.

4. DISCUSSION

Soil pH in the current study was acidic, which agreed with the predictions of Ashton & Macintosh [44] on soil and water pH in the Sematan mangrove forest in Sarawak. Similarly, Davies and Abowei [45] reported 4.22 ± 0.27 pH in Okpoka creek sediment where the most dominated species were Nypa palm and white mangrove. The low soil pH might be attributed to fauna and tree root respiration, to oxidation and vegetation, to the higher topographical level of mud lobster mounds with good drainage and also to less frequent tidal inundations [46]. Mangrove vegetation is significantly correlated with soil moisture content [44] and soil pH, because of their significant role in mobilizing both beneficial and toxic elements to plants [47].

It was observed that, all the soils in the three sites (A, B and C) were acidic with mean pH values 3.87, 4.16, 4.39 for sites A, B and C respectively. The optimal range for plant availability of nutrients is 5 to 7 [6]. This could be suggesting that fertilizer application is needed for its maintenance. The pH values in soils in the three sites did not significantly differ (alpha >0.05). The pH in water was higher than the pH in KCl, being the variation of ΔpH [pH (KCl) – pH (H_2O)] negative throughout. This indicates that the net charge on the exchange complex is negative, and thus exhibits cation exchange capacity [48]. The relative low pH levels observed in these soils are attributable to the presence of pyrites upon oxidation and hydrations generally produce hydrogen sulphide which hydrolyses into sulphuric acid to reduce the soil pH [49]. In addition, soil acidity may have resulted also from decomposition of mangrove litter [50]. The results obtained in this study corroborate the findings of other studies [51,52].

Soil moisture is important for plant growth, and varies depending on soil topography, soil disturbance, rainfall, frequency of tidal inundation and soil quality [44]. In wet conditions, soil porosity, hydraulic conductivity, vegetation canopy, shaded condition, root action and transpiration, particularly after rainfall, all effectively increase the soil moisture [43]. In this study, the percentage of moisture content had little variation, and depended on the time the samples were taken. The soil moisture content in the study area was high (91.22%, 91.78% and 92.89%) in the three sites (A, C and B) respectively. These findings agreed with that of [44] who found a high moisture values in Sematan mangrove forests with large areas of *Nypa fruticans* along the riverbanks of Sungai Sematan. The homogeneous soil moisture content could be related to saturated water of the upper soil layer after rainfall having the same soil porosity, water retention, and similar vegetation cover on the study area.

The relatively high percentage of Organic Matter recorded in sites C (19.23%) could be attributed to input from the mangrove form of dead leaves and decaying stilt roots [53,49]. Organic matter is low in sites A (12.32%) and B (16.35%). The low percentage is as a result of the fact that, Nypa palm leaves/fronds prevent or trap the leaves of other mangrove species from reaching the ground.

Soil Organic Carbon ranged from 4.52 to 7.06%. High percentage of organic carbon content was recorded in sites C (7.06%). This could be attributed in the high supply of organic matter derived from litter. The low percentage of organic carbon was found in sites A (4.52%). This could be attributed to the low supply of organic matter derived from litter. According to the rating established by Hazelton and Murphy [54], the soil organic carbon contents were in the low to high range. The effect on soil quality is the existence of degraded or severely eroded topsoil with poor structural condition and stability [54]. Soil organic carbon not only affects soil fertility, but also has influence on releasing or holding CO_2 from the atmosphere through various channels, thereby possibly affecting the atmosphere-soil carbon balance [55,56]. The low values could be attributed to the sandy nature of most of the soils, as indicated in a similar study [57]. Particle size was dominated by sand 80.06% to 81.72%, followed by clay (13.33% to 17.89%) and then silt (2.06% to 4.94%), which revealed coarse soils with low supply of nutrients and moisture [58].

Total nitrogen varied from 1.04 g/kg to 1.80 g/kg. In the present study, total nitrogen in soils was high (1.08g/kg) in sites B due to the oxidation of dead plant organic matter, which has settled on the top layer. The lower value of total nitrogen (1.04g/kg) in sites C may be ascribed to low level of organic matter. In Swartkops estuary in Africa, Dye [59] observed high nitrogen content in finer substrate and suggested that it was probably due to trapping of detritus by finer particles, resulting in an increase in bacterial population which may also be a reason for the high level of nitrogen encountered in the present study. Reddy and Hariharan [60] attributed the high values of

nitrogen to release from the decay of a large number of phytoplankton in Netravathi–Gurupur estuary. The sediment detritus may be a rich source of nitrogen as shown by lower C/N ratios and regular ingestion by crabs.

Fragmenting leaves by crabs may be elevating the nutritional quality of the substrate detritus [61]. The low values of total nitrogen observed may be ascribed to the low level of organic matter along with high level of sand.

Exchangeable Cation exchange capacity (ECEC) and base saturation have been used to indicate the fertility status of the soils. According to FAO [62] soils with ECEC of > 20 cmol/kg are indicative of high suitability of the soils for crops production [62,63]. From the results of this study, the soils are more fertile. Values of cation Exchange capacity reflect the overall influence of regular replenishment by seepage and tides. In all the mangrove stands, the value of Exchangeable Ca content were below 4.0 camolkg-1 regarded as critical level for fertile soils [64,62,51].

Phosphorus ranged between 25.09 mg/kg and 39.22 mg/kg. The capacity of sediment to retain or release phosphorus is one of the important factors, which influence the concentration of inorganic/organic phosphorus in the overlying waters. In the present study, high value of inorganic phosphorus was recorded in sites B (39.22mg/kg) and low values (25.09mg/kg) in sites C. The high values observed may be due to dead organic matter from the top layer and low values may be related to removal of top layer of sediments by heavy floods.

The soils generally have narrow C/N ratios; this implies that microbial activities which are necessary for the release of nutrient element may not be hindered. This is in consonant with the report of Allotey [49] that plant residues with C/N ratios of 20:1 or narrower have sufficient N supply micro-organisms responsible for decomposition and also to release N for plant use while residues with C:N ratios of 20:1 to 30:1 supply sufficient N for decomposition but enough to result in much release of N for plant use.

Soil texture in the three sites was dominated by sand, followed by clay and silt though to different extents. 81.72%, of the soils in sites C was sandy, followed by 80.06 % in sites A. While 13.33% was clay and 4.94% was silt. This showed that the predominant texture in the three sites was sandy.

4. CONCLUSION AND RECOMMENDATIONS

Nypa palm can be established in areas with mixed mangrove forest stands and in areas with acidic soils due to its high salt content. The growth of Nypa palm seedlings in mangroves soils was as a result of the utilization by the palm of the un-used nutrient that are locked within the mangrove soil. High abundance and distribution of Nypa seedlings in deforested mangrove forest signify early stage of colonization, which is facilitated by propagule pressure. This is as a result of the window of opportunity created by the deforestation of mangroves. This situation has been a major factor in the overall decline of mangrove forest in the Cameroon estuary. Thus, this study suggests that; since soil plays a key role in Nypa palm establishment, there should be constant monitoring of soil quality to foresee all drastic changes that will jeopardize the survival of the mangroves. Nypa palm seeds and seedlings should also be physically removed from mangrove forest to prevent colonization. In addition, more mangrove seeds should be planted in deforested mangrove areas to close the window of opportunity for the palms. The outcome of this study implies that soil quality is very significant to Nypa palm establishment in deforested and polluted areas globally. There is an urgent need for research to be undertaken into the effects of the Nypa palm on the ecology of the West and Central African mangrove ecosystem. Additional research is also needed into possible means of developing biological control methods to supplement human control through harvesting and utilization.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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