Catena 163 (2018) 54–62

Contents lists available at ScienceDirect

Catena

journal homepage: www.elsevier.com/locate/catena

Characterization of the mangrove swamp rice soils along the Great Scarcies River in Sierra Leone using principal component analysis

Idriss Baggie[a,*], Foday Sumah[a], Sander J. Zwart[b,c], Patrick Sawyerr[d], Tamba Bandabla[a], Chernor S. Kamara[a]

[a] Rokupr Agricultural Research Centre (RARC), Sierra Leone Agricultural Research Institute (SLARI), Rokupr, Sierra Leone
[b] Africa Rice Center, Cotonou, Benin
[c] Faculty of Geo-Information Science and Earth Observation (ITC), University of Twente, Enschede, Netherlands
[d] Soil Science Department, Njala University, Njala, Sierra Leone

ARTICLE INFO

Keywords:
Acidity
Hydrogen peroxide
Soil variability
Sulfaquents

ABSTRACT

Mangrove swamp rice cultivation is important for food security in some countries of West Africa including Sierra Leone. In this agro-ecology, rice is cultivated during the rainy season when freshwater flows in the rivers and salt and acidity concentrations have reduced to non-toxic levels. Rice yields in the mangrove ecosystem of Sierra Leone are higher than in other agro-ecologies and weed, disease and pest pressures are minimal. However, salinity, acidity and crabs negatively affect rice productivity in the mangrove swamps. Due to the differences in levels of flooding, salinity and acid sulphate conditions of mangrove swamp soils, it is assumed that there is variability of soil properties of mangrove swamps along the associated river, which may impact the choice of suitable rice varieties and soil management practices. The purpose of this study was to understand the soil physical and chemical properties of mangrove swamp soils along the Great Scarcies River of Sierra Leone. A soil sampling survey was designed and implemented using transects to collect composite soil samples of 1 ha area at 0–0.2 m depth at 11 different sites located from the estuary of the Great Scarcies River to approximately 35 km inland. The soil samples were air-dried, processed and analyzed for selected physical and chemical properties by recommended methods. Statistical analysis generated mean, standard deviations, coefficient of variation, correlation matrix and principal components. The high variability in soil physical and chemical characteristics of mangrove swamp soils along the Great Scarcies River could be attributed to the complex interactions between the twice daily tidal inundations and depositions of soil organic matter, physical particles and nutrients onto the mangrove swamp soils along the river. The result of this is a soil fertility gradient down-stream.

1. Introduction

Sierra Leone is highly dependent on rice, with 104 kg consumed per capita per annum. The Food and Agriculture Organization of the United Nations estimates (IYR, 2004) that 530,000 metric tons of rice is consumed annually in Sierra Leone, and that annual local rice production equals 200,000 tons. Thus Sierra Leone relies heavily on imported rice to satisfy demand. Of a total 5,400,000 ha of arable land area in Sierra Leone, mangrove swamp rice cultivation accounts for approximately 25,000 ha of the total arable (200,000 ha). It is estimated that mangrove rice contributes 12% to the total quantity of rice produced in Sierra Leone (PEMSD/MAFFS, 2014).

Mangrove swamp rice cultivation is important for food security in West Africa from Senegal along the coast to Sierra Leone. The southern mangrove swamps in Guinea and Sierra Leone up to Nigeria receive higher levels of rainfall (2000–4000 mm) than the Sahelian mangrove swamps in the Gambia, Senegal and Guinea-Bissau (600–1600 mm). The southern mangrove swamps include the tidal mangrove swamps, with three 'salt-free' zones, and the associated mangrove swamps. In the Sahelian mangrove swamps, there are some variations in the severity of drought, from Guinea-Bissau to the Casamance region in Senegal. Generally, short- to medium-duration varieties (120–135 days) are grown owing to declining rainfall, resulting in the build-up of adverse soil conditions making it very difficult to grow rice. Rice production is heavily influenced by environmental stresses including salinity, acidity, mineral toxicity (aluminum), diseases, high temperature and drought.

Abbreviations: Av.P, available phosphorus; CEC, cation exchange capacity; CV, coefficient of variation; EC, electrical conductivity; Ex., exchangeable; Org.C, organic carbon; PCA, principal component analysis; SD, standard deviation; SE, standard error

[*] Corresponding author.

E-mail address: idribaggie@gmail.com (I. Baggie).

https://doi.org/10.1016/j.catena.2017.11.026
Received 17 November 2016; Received in revised form 27 October 2017; Accepted 27 November 2017

Therefore, farmers in these regions grow rice on ridges to leach salt and other toxic elements downwards for better environmental conditions at the rooting zone for rice plant growth. Heavy investments are needed in soil and water management to reclaim salinized cropland; hence some of the farmers in the region abandon rice production (Guei et al., 1997).

The low intensity of rainfall in the Sahelian mangrove region results in greater production constraints such as soil stresses and drought. Both climatic factors and the hydrology and tidal regime contribute to the distribution and dynamics of soil salinity and acidification in mangrove swamp soils along the river. Within the same climatic zone, the balance between freshwater river discharge and tidal propagation during the rainy season determines chemical or biochemical processes involved (Van Breemen, 1976).

The tidal rice-cultivation system consists of flooded rice cultivation during the rainy season's freshwater flows of the major rivers, after the salt concentration has reduced to a non-toxic level. Some of the fertile soils benefit from the regular deposits of silt left during tidal flooding. However, the system is tied to the length of this salt-free period. There are generally two classes of mangrove swamp, depending on the salt-free period and flooding conditions: tidal mangrove swamps and associated mangrove swamps. On the basis of the length of the salt-free period, tidal mangrove soils are grouped into three categories based on increasing proximity to the sea (Atlantic Ocean). Category 1 consists of mangroves that have a salt-free period of < 4 months. This requires short-duration rice varieties (< 4 months) in order to escape salinity stress. Mangrove areas in category 2 have a salt-free period of 4–6 months. Medium-duration rice varieties (4–6 months) are usually grown on them. Areas in the third category experience the longest salt-free period of > 6 months.

As a result of the daily inundation of tidal water and silt deposition during the growing season, this ecology produces the highest average rice yields. The major constraints in mangrove swamp rice production include lodging and silting caused by tidal movement, adverse soil conditions of acidity, salinity, Iron, Aluminum and Manganese toxicity; weeds, especially in swamps further from the sea; crabs, stem borers, rice bugs, and diseases especially blast and brown spot (WARDA, 1976, 1977, 1978, 1983, 1984, 1986, 1987; Agyen-Sampong et al., 1988).

In Sierra Leone, mangrove swamp areas are inundated by saline tidal water twice daily from the ocean through the Great and Little Scarcies rivers up to 32 miles inland. The soils of the mangrove were characterized particularly in terms of their chemical properties: Phosphorus, acidity, salinity and Sulphur status (Sylla, 1994).Because of the differences in topography, flooding, salinity and acid sulphate conditions of mangrove swamp soils along the Great Scarcies River (Sylla, 1994), the chemical and physical properties of the soils are expected to vary.

Research on characterizing the mangrove swamp rice soils in West Africa has mostly emphasized the pedological and morphological characteristics, but there is limited recent information on the physical and chemical characteristics and spatial distribution relevant to the changing environment. The overall objective of the study was to understand the variations in physical and chemical soil properties of the mangrove swamp soils from upstream to downstream along the Great Scarcies River of Sierra Leone as basis for their sustainable exploitation. The specific objectives were to (1) assess the levels and spatial distribution of key chemical and physical properties; (2) identify their relationships; and the factors (components) that account for most of the variance in soil properties.

2. Materials and methods

2.1. Study area

The study area included mangrove swamps along the Great Scarcies River in the North-western region of Sierra Leone, West Africa (Fig. 1). Rainfall in these mangrove swamps is high (2000–4000 mm). The rainy season is from May to November. The dominant grass species in the mangrove ecology, *Paspalum vaginatum* Sw. (locally called *KereKere*), has robust rhizomes that make plowing a daunting task (Agyen-Sampong et al., 1988).

Soils along the Great Scarcies River have been classified as Sulfaquents which are potential acid sulphate soils (Odell et al., 1974).

The main planting season in the Great Scarcies area, including land preparation and transplanting, is April–August, with harvesting between October and January. Land preparation is usually done manually with hand hoes, and modern production inputs are rarely applied. Traditional farmers in mangrove swamp rice cultivation plant older seedlings (8–10 weeks old) and use more seedlings (six to eight seedlings per hill), compared to other rice growing agro-ecologies, as a means of curbing crab damage.

2.2. Soil sampling and laboratory analysis

Soil samples were collected from 11 locations (Balencera, Gbantoke, Kassirie, Katema in the short salt-free zone; Madora, Kathakireh, Mathanthu in the medium salt-free zone; and Rokupr, Laminaia, Robain, Katalan in the long salt-free zone (Fig. 1).

2.3. Soil sampling and analysis

Composite soil samples were collected during the first week of September in 2013. Low levels of acidity and salinity that are non-toxic to the rice plant are expected around this time. At each location, a 100 × 100 m grid was formed, within which each composite soil sample was taken from randomly selected locations at 0–0.2 m depth. A total of 40 composite soil samples were collected over all 11 locations. Different numbers of composite soil samples were collected per location due to the poor accessibility to some areas as a result of deeper creeks and marshy landscapes. The soil samples were air-dried and sieved to pass through a 2 mm sieve before laboratory analysis was conducted. The physical analysis was performed to ascertain the distributions of sand, silt and clay at the 11 locations along the Great Scarcies River. Percentages of sand, silt and clay were determined by the Bouyoucos Hydrometer method. Textural classes were identified using the textural triangle (Okalebo et al., 1993). The pH was measured in water and in hydrogen peroxide (H_2O_2) had been added at a ratio of 2:1 (Allbrook, 1973; Rahman et al., 1993). The H_20/H_20_2 soil pH test provides a useful indication of the existing and potential acidity of a soil. However, pH in the present study was measured on rewetted air dry soil samples and not on wet soil in the field. Hesse (1971) reported that many researchers air dry wetland soils prior to analysis because of convenience, problems of storing wet soils, subsampling errors in the laboratory etc. and for some analyses such as particle size and total contents it makes little difference whether the samples were air dried or not. For this exploratory study, involving a range of physical and chemical properties, it was practical to air dry prior to laboratory analysis.

Electrical conductivity was carried out using a standardized conductivity meter. Available Phosphorus was determined by the Bray 1 method, and the Kjeldahl digestion method was used in the determination of total Nitrogen. Organic carbon was determined by the modified Walkley–Black method. Exchangeable acidity was measured titrimetrically after extracting the soil with 1 M Potassium chloride followed by analysis of exchangeable Aluminum and Hydrogen. Cation exchange capacity and exchangeable bases of Sodium and Potassium were determined using the Ammonium acetate method (IITA, 1979; Okalebo et al., 1993; Sparks, 1996).

2.4. Statistical analyses

Principal component analysis, a multivariate technique, is a widely used tool to study the variations in soil properties for agricultural studies (Islabao et al., 2013; Kamolchanok et al., 2012; Mahmoodi et al.,

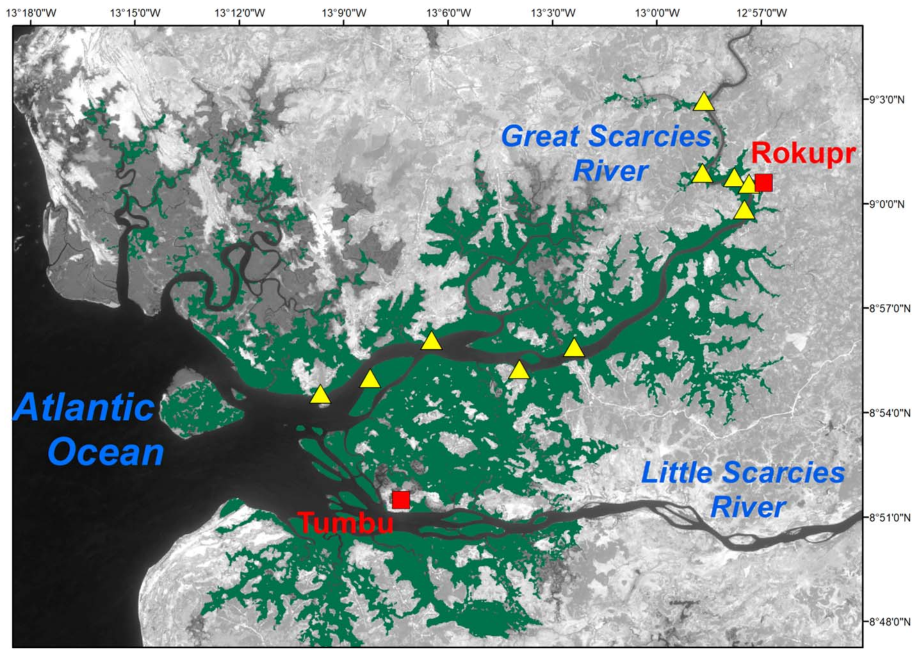

Fig. 1. Location of the sampling sites along the Great Scarcies River (in yellow). The locations are superimposed on a Landsat image dated March 8, 2015 while the mangrove rice cultivation areas, classified by Adefurin and Zwart (2016), are shown in green. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

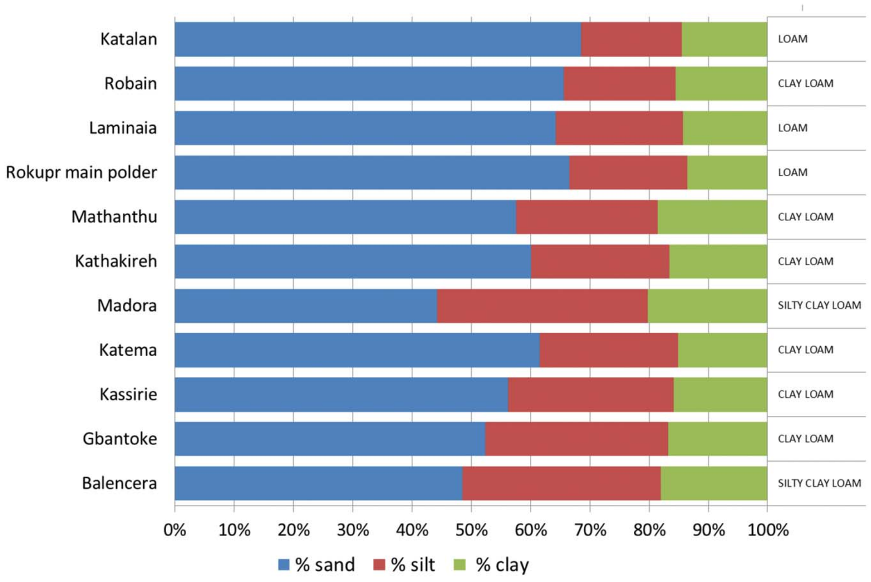

Fig. 2. Percentages of sand, silt and clay and textural classes for 11 sampling locations along the Great Scarcies River in Sierra Leone. The sites are ranged from upstream (Katalan) to downstream (Balencera) (see Fig. 1).

2005; Panishkan et al., 2010; Salehi et al., 2005; Visconti et al., 2009; Yahya et al., 2008). Carvalho et al. (2008) used PCA to measure differences between physical and chemical properties in soils along the Atlantic coastline of Brazil.

Means for all 15 characteristics measured were grouped into statistical factors. Using the PCA method of factor extraction without prior estimates of the amount of variation in each of the soil properties explained by the factors, we standardized variables using correlation matrix to estimate the effect of different measurement units on the determination of factor loadings. The Proc Factor procedure in the Statistical Analysis System (SAS) version 9.3 was used for the PCA (SAS Institute, 2011). Using the PCA approach that allows grouping of variables into statistical factors based on their correlation structure (Brejda et al., 2000) and eliminating the effect of different units of variables, factor analysis was done using the correlation matrix on the standardized values of the measured soil properties (Shukla et al., 2006).

After the extraction of the initial components, the components were rotated using the varimax orthogonal rotation method to obtain orthogonal components so that most of the variables had relatively high factor loadings on only one component, and near zero loadings on the other components, and the components had relatively high factor loadings for some variables, and near-zero loadings. This also helped in the identification of variables that demonstrate high loadings for a given component for the remaining variables to enable easy interpretation. In order for a variable to be uniquely loaded in one component, any variable whose factor loading in a component was not greater than or equal to 0.5 (50%) was excluded from the component. In the literature, 0.30 (or 0.4) and higher values are suggested for items loadings. However, in the present study, a more stringent cut off score (≤ 0.50) was selected in order to avoid having a complex items where a single variable may load in more than one component.

As factor loadings are the simple correlation between properties, eigenvalues were used to explain the amount of variance of each factor. Factors with eigenvalues > 1 (Kaiser, 1960) explained more total variation in the data than individual soil properties, and factors with

Table 1
Mean, standard deviation and coefficient of variation in sand, silt and clay of soils along the Great Scarcies River in Sierra Leone.

Variable	Mean	Standard error	Coefficient of variation
% Sand	56.2	1.23	14.8
% Silt	27.1	0.79	24.4
% Clay	16.7	0.32	15.4

eigenvalues < 1 explained less total variation than individual soil properties. For this reason, factors with eigenvalues > 1 were used for interpretation.

3. Results

Fig. 2 and Table 1 show the percentages of sand, silt and clay in soils along the Great Scarcies River of Sierra Leone. Soil textural class ranges from silt clay loam downstream to loam upstream. Only percentage sand and clay showed a CV below 20%. On average, at all 11 sampling locations, sand consistently shows the higher percentage, followed by silt and then clay from upstream to downstream sampling locations.

The properties of the soils in all 11 locations in mangrove swamp soils along the Great Scarcies River are shown in Table 2. All the soils tested in this study were acidic in nature. A mean pH in water value of 4.7 was recorded for Balencera, downstream, compared with a pH value of 1.9 in Katalan, upstream. The overall mean pH in water along the mangrove swamp soils was 2.7 (SE = 0.17, CV = 44.2%). The pH in Hydrogen peroxide ranged from 1.9 upstream to 2.8 downstream. The mean pH in Hydrogen peroxide of all soil samples collected in the study area was 1.9 (SE = 0.06, CV = 20.6%). Regardless of the medium used, the lowest pH readings were recorded upstream at Mathanthu and Rokupr, and the highest downstream at Balencera (Table 2). Exchangeable acidity that comprises exchangeable Aluminum and Hydrogen recorded a mean of 20.1 (SE = 2.04, CV = 91.3%).The results also show overall higher exchangeable aluminum than exchangeable hydrogen at most locations, with mean values of 11.4 $cmolkg^{-1}$ soil (SE = 1.26, CV = 102) and 8.7 $cmolkg^{-1}$ soil (SE = 0.98, CV = 107), respectively.

The coefficient of variation of total Nitrogen in mangrove swamp soils along the Great Scarcies River was 23.3% while that of Organic Carbon was 39.3%; C:N ratio was 49.6% and available Phosphorus was 30.0%.

Cation exchange capacity ranged from 12.1 to 31.3 $cmolkg^{-1}$ soil (mean = 16.8 $cmolkg^{-1}$ soil, (SE = 0.9,CV = 38.0%). Higher values were recorded for exchangeable sodium (mean = 0.087 $cmolkg^{-1}$ of soil, (SE = 0.01, CV = 73.0) than exchangeable potassium (mean = 0.0091 $cmolkg^{-1}$ of soil, SE = 0, CV = 50.0). The lowest CEC values were recorded at Laminaia and Mathanthu (upstream), and the highest at Gbantoke (downstream).

The correlation matrix (Table 3) shows the initial relationships found between the 15 soil characteristics measured. It is apparent that there are positive and negative associations between soil characteristics. The factor analysis enables us to understand the type and extent of relationships between soil characteristics. The eigenvalues (Table 4) which are the amount of variance explained by each factor of the correlation matrix obtained indicate that only three factors had values ≥ 1. These factors account for 78.7% of the total variation. The three factors were loaded in a rotated matrix using the varimax method. The rotated component matrix is shown in Table 5. The PCA factor extraction indicated positive and negative associations between the characteristics. The first principal component (factor) showed high positive loading with silt (+ 83), clay (+ 67), pH_{water} (+ 87), $pH_{peroxide}$ (+ 79), percentage Nitrogen (+ 67), CEC (+ 82), exchangeable Sodium (+ 73) and exchangeable Potassium (+ 85), but moderately negative loading on sand (− 38), acidity (− 25) and Organic Carbon (− 14). Exchangeable Phosphorus (+ 18) loaded low with the first factor. The second factor showed moderately positive loading with sand (+ 39), clay (+ 28) and electrical conductivity (+ 36); high positive loading with acidity (+ 80), Organic Carbon (+ 89) and C:N ratio (+ 93); and low positive loading with available Phosphorus (+ 3). Others showed low to moderately negative loadings with the second factor. Similarly, the third factor showed moderate to high positive loading with sand (+ 70), exchangeable phosphorus (+ 81), electrical conductivity (+ 84), exchange acidity (+ 48), exchangeable Hydrogen (+ 37), exchangeable Aluminum (+ 49), percentage Nitrogen (+ 44), exchangeable Sodium (+ 30) and exchangeable Potassium (+ 28); and low cation exchange capacity (+ 14).

The variable distribution within the variable factor, that is component 1, contrasts exchangeable acidity, exchangeable Aluminum and % Sand to both soil pH of water and Hydrogen Peroxide, % Silt and the cation exchange capacity (CEC) of the soil. Component 2, on the other hand, contrasts available soil Phosphorus and the electrical conductivity (EC) to % Nitrogen, as well as exchangeable Sodium and Potassium plus the clay content of the soil. The third component also contrasts the % organic matter, the electrical conductivity and sand to clay.

Fig. 3a shows the trend of sand, silt and clay content in the mangrove swamp soils along the Great Scarcies River. Generally, the sand content remained high in the soils from down-stream to up-stream; unlike the silt and clay contents, which slightly decreased, sand content increased from downstream to upstream.

Generally, the pH of soils in water and in hydrogen peroxide

Table 2
Chemical properties of mangrove swamp soils along the Great Scarcies River of Sierra Leone.

ite	pH H_2O	E C dSm^{-1}	pH H_2O_2	% N	% Org.C.	C:N	Av.P mg $P_2O_5kg^{-1}$	Ex.acidity cmol kg^{-1}	Ex. H^+ cmol kg^{-1}	Ex. Al^{3+} cmol kg^{-1}	CEC cmol kg^{-1}	Ex. Na^+ cmol kg^{-1}	Ex. K^+ cmol kg^{-1}
Katalan	1.9	0.282	1.9	0.057	2.5	45	20.1	25.4	13.1	12.3	15.6	0.024	0.0049
Robain	2.7	0.365	1.7	0.074	4.0	54	25.9	22.6	14.4	8.2	14.9	0.027	0.0052
Laminaia	2.0	0.339	1.7	0.072	3.2	44	35.3	23.8	5.3	18.6	12.2	0.032	0.0050
Rokupr	1.8	0.454	1.6	0.084	3.3	40	41.7	28.4	15.6	12.9	12.3	0.019	0.0055
Mathanthu	1.9	0.357	1.6	0.093	3.0	32	31.6	22.3	5.5	16.7	12.1	0.012	0.0045
Kathakireh	2.0	0.494	1.8	0.069	4.1	60	31.1	36.8	16.7	20.1	14.8	0.088	0.0097
Madora	3.5	0.233	2.0	0.088	3.5	41	22.9	8.2	3.3	4.9	17.9	0.097	0.0085
Katema	1.4	0.756	1.7	0.096	4.3	46	39.4	39.9	15.2	24.7	13.1	0.074	0.0097
Kassirie	3.5	0.580	1.8	0.116	2.1	19	39.1	2.7	1.0	1.8	17.8	0.231	0.0140
Gbantoke	4.2	0.339	2.5	0.118	1.7	15	31.8	6.9	3.6	3.3	31.3	0.148	0.0158
Balencera	4.7	0.271	2.8	0.098	1.2	12	37.2	4.2	2.1	2.2	22.1	0.207	0.0169
Mean	2.7	0.4	1.9	0.1	3.0	37.1	32.4	20.1	8.7	11.4	16.8	0.087	0.0091
SE	0.17	0.03	0.06	0	0.16	2.48	1.12	2.04	0.98	1.26	0.90	0.01	0
CV	44.2	55.4	20.6	23.33	39.3	49.6	30.0	91.3	107	102	38.0	73	50

Note: The sites are organized from upstream (Katalan) to downstream (Balencera) locations along the river.

Table 3
Correlation matrix of the mangrove swamp soil characteristics.

	%Sand	%Silt	%Clay	pH H_2O_2	EC (dSm^{-1})	Ex. Acidity cmolkg $^{-1}$	pH H_2O_2	Ex. H^+ cmolkg^{-1}	Ex. Al3 + cmolkg^{-1}	% Nitrogen	% Organic Carbon	C:N	CEC (cmolkg^{-1})	Ex Na (cmolkg^{-1})	Ex K (cmolkg^{-1})	Available P ($mgP_2O_5kg^{-1}$)
%Sand	1															
%Silt	−0.669 < 0.0001	1														
%Clay	−0.441 0.003	0.637 < 0.0001	1													
pH H_2O	−0.497 0.001	0.767 < 0.0001	0.498 0.001	1												
EC (dSm^{-1})	0.644 < 0.0001	−0.253 0.101	−0.106 0.499	−0.266 0.085	1											
Ex. Acidity cmolkg^{-1}	0.714 < 0.0001	−0.437 0.003	−0.144 0.357	−0.574 < 0.0001	0.658 < 0.0001	1										
pH H_2O_2	−0.389 0.010	0.685 < 0.0001	0.446 0.003	0.753 < 0.0001	−0.236 0.128	−0.353 0.020	1									
Ex. H^+ cmolkg^{-1}	0.608 < 0.0001	−0.315 0.040	−0.032 0.838	−0.410 0.006	0.515 0.000	0.858 < 0.0001	−0.210 0.176	1								
Ex. Al^{3+} cmolkg^{-1}	0.662 < 0.0001	−0.358 0.018	−0.106 0.499	−0.506 0.001	0.682 < 0.0001	0.924 < 0.0001	−0.313 0.041	0.616 < 0.0001	1							
% Nitrogen	−0.104 0.508	0.467 0.002	0.258 0.095	0.575 < 0.0001	0.342 0.025	−0.234 0.131	0.360 0.018	−0.162 0.299	−0.171 0.274	1						
% Organic Carbon	0.365 0.016	−0.119 0.447	0.106 0.500	−0.382 0.012	0.319 0.037	0.649 < 0.0001	−0.370 0.015	0.568 < 0.0001	0.597 < 0.0001	−0.266 0.085	1					
C:N	0.429 0.004	−0.150 0.337	0.116 0.458	−0.380 0.012	0.247 0.110	0.688 < 0.0001	−0.295 0.055	0.612 < 0.0001	0.640 < 0.0001	−0.455 0.002	0.913 < 0.0001	1				
CEC (cmolkg^{-1})	−0.194 0.212	0.557 0.0001	0.374 0.013	0.759 < 0.0001	0.024 0.880	−0.206 0.185	0.722 < 0.0001	−0.050 0.752	−0.196 0.209	0.641 < 0.0001	−0.292 0.058	−0.287 0.062	1			
Ex Na (cmolkg^{-1})	−0.225 0.146	0.514 0.000	0.291 0.058	0.692 < 0.0001	0.242 0.118	−0.387 0.010	0.515 0.000	−0.277 0.073	−0.325 0.034	0.680 < 0.0001	−0.401 0.008	−0.424 0.005	0.544 0.000	1		
Ex K (cmolkg^{-1})	−0.171 0.274	0.528 0.000	0.337 0.027	0.758 < 0.0001	0.209 0.179	−0.190 0.224	0.676 < 0.0001	−0.085 0.587	−0.149 0.341	0.640 < 0.0001	−0.238 0.125	−0.265 0.086	0.742 < 0.0001	0.782 < 0.0001	1	
Available P ($mgP_2O_5kg^{-1}$)	0.451 0.002	−0.130 0.405	−0.120 0.443	0.047 0.764	0.637 < 0.0001	0.329 0.031	−0.011 0.947	0.223 0.151	0.376 0.013	0.444 0.003	0.034 0.829	−0.020 0.901	0.170 0.276	0.304 0.047	0.325 0.033	1

Table 4
Eigenvalues of the Correlation Matrix.

Factor	Eigenvalue	Percentage variation
1	6.843	42.77
2	3.650	22.81
3	2.096	13.10
4	0.823	5.14
5	0.498	3.11
6	0.445	2.78
7	0.426	2.67
8	0.353	2.20
9	0.288	1.80
10	0.207	1.30
11	0.141	0.88
12	0.109	0.68
13	0.053	0.33
14	0.045	0.28
15	0.018	0.11
16	0.002	0.01

Table 5
Rotated component matrix using the varimax method in principal component analysis.

Variable	Components		
	1	2	3
Sand (%)	− 38	39	70[a]
Silt (%)	83[a]	− 5	− 39
Clay (%)	67[a]	28	− 38
pH H_2O	87[a]	− 33	− 16
Electrical conductivity 1:5 (dSm^{-1})	5	36	84[a]
Exchangeable acidity (cmolkg^{-1})	− 25	80[a]	48
pH H_2O_2	79[a]	− 17	− 16
Exchangeable H^+ (cmolkg^{-1})	− 11	74	37
Exchangeable Al^{3+} (cmolkg^{-1})	− 20	73[a]	49
N (%)	67[a]	− 30	44
Organic C (%)	− 14	89[a]	− 2
C:N	− 16	93[a]	− 7
CEC (cmolkg^{-1})	82[a]	− 13	14
Exchangeable Na (cmolkg^{-1})	73[a]	− 38	30
Exchangeable K (cmolkg^{-1})	85[a]	− 15	29
Bray 1 P (mg $P_2O_5{}^{-1}$ kg)	18	3	81[a]

[a] Indicates high positive loading.

decreased slightly from downstream to upstream (Fig. 3e). At all locations along the Great Scarcies River, pH values in water were higher than in hydrogen peroxide, except at Katema, in which case the soil may not be truly potential acid sulphate soil (Table 3).

The percentage Organic Carbon content in soils of the mangrove swamps along the Great Scarcies River of Sierra Leone increased slightly from downstream up to Katema, and remained at a relatively steady thereafter (Fig. 3b). Percentage total nitrogen (Fig. 3f), CEC (Fig. 3c), exchangeable Sodium (Fig. 3g), exchangeable Potassium (Fig. 3d) and exchangeable Phosphorus (Fig. 3h) all decreased from downstream to upstream.

4. Discussion

The high CV values observed for most of the measured soil properties suggest spatial variabilities. With the exception of sand and clay content, all other characteristics showed high soil variations ranging from 23.3 to 107%. The very high CV observed for most of the chemical and biological soil properties (exchangeable acidity 91.3%, exchangeable Al^{3+} 101%, exchangeable H^+ 107% and exchangeable Na 72.7%) and moderately high variations (electrical conductivity 55.4%, exchangeable K 50.0%, C:N ratio 49.6%, pH water 44.2% and available P 30.0%) demonstrate complex chemical and biological interactions influenced by acidity and salinity in the mangrove swamp soils along the Great Scarcies River. Olorunlana (2015) suggested for Akoko region of Nigeria that a CV of $< 20\%$ be regarded as low variability; 21–50% as moderately variable; 51–100% as highly variable; and above 100% as of very high variability. This suggests that mangrove swamp soils along the Great Scarcies River are moderately to highly variable.

The measuring of pH in water and then H_2O_2 is based on a method of assessing acid sulphate soil status (Green-Dublin and Ojanuga, 1988; Hey et al., 2000; Konsten et al., 1988; Rahman et al., 1993; Allbrook, 1973). However, the test is only qualitative and does not give any quantitative measure of the amount of acid that has been or could be produced through the oxidation process. The rapid reaction with concentrated peroxide fast-forwards the breakdown of pyrite and provides an indication of the potential acidity that could be released from the soil (Allbrook, 1973; Rahman et al., 1993).

The principle of the method is that when the pH of a normal soil is measured in hydrogen peroxide solution, the pH is similar to that in water. However, when the pH of an acid sulphate soil is measured in hydrogen peroxide, the pH will be lower than that measured in water. This is because hydrogen peroxide is a strong oxidising agent. When it comes into contact with acid sulphate soils containing iron sulfides, it breaks down the minerals very quickly, releasing the iron and sulphuric acid. It is well known that acidity of sulphate soils is directly or indirectly caused by sulphuric acid formed by the oxidation of pyrite (FeS_2) (Allbrook, 1973; Hart, 1959; Metson et al., 1977; Van Breemen, 1982).

The occurrence and nature of potential and actual acid sulphate soils have been reviewed by Van Breemen (1976), Goldhaber and Kaplan (1982), and Dent (1986). However there is relatively limited recent information on their status and management under West African conditions.

Sylla (1994); C. A. Dixon – personal communication, 2016) reported that the soils of the Great Scarcies are potential acid sulphate. According to Sylla (1994), potential acidity is high at all sites along the Great Scarcies river but much lower along the Casamance river in Senegal (Actual acid sulphate). He also reported very high actual acidity in top soils along the Great Scarcies river, similar to the Casamance river, Potential acid sulphate soils like those along the Great Scarcies river are undrained soils because of the twice daily tidal inundations and rainfall. It has also been reported that potential acid sulphate soil environments in West Africa are generally characterized by saline and brackish-water tidal swamps and marshes. That acid saline soils can occur in some coastal areas (Hesse, 1971), explains why salinity correlates with acidity in this study but it is not a cause and effect relationship. Hesse and Jeffrey (1963), Jordan (1964), Dent (1986), and Dost (1986) highlighted that mangrove swamp soils, including those of the Great Scarcies river are rich in pyrites and therefore potentially acid sulphate soils with weakly differentiated horizons. Once cleared of the original mangrove vegetation, the salt tolerant grass *Paspalum virginatum* become the predominant vegetation. On empoldering and drying, *Rhizophora* soils tend to become too acidic from oxidation of pyrite for rice growing (Agyen-Sampong, 1985), but with the twice daily tidal influence drying is minimized. These literature support the argument that the soils of the Great Scarcies River are mainly potential acid sulphate.

In mangrove swamp soils along the Great Scarcies, the predominant vegetation is *Rhizophora species*. Some authors (Tomlinson, 1957; Hesse, 1961; Jordan, 1964; Giglioli and Thornton, 1965 and Kalawec, 1977) have observed differences in the amount of pyrite between soils having been influenced either by *Rhizophora* or *Avicennia* or *Phragmite* vegetation during genesis, with the latter having lower potential acidity. When soils that were under Rhizophora dry up, their pH (water) falls to below 2.0 (Tomlinson, 1957, cited in Hesse, 1971; Odell et al., 1974) due to the activity of sulphur-oxidising bacteria. With regards to the very low pH values reported in this study for surface soils (a characteristic usually associated with pyrite rich subsoils getting exposed and oxidized to produce extreme acidity), it can be suggested that decades of cultivating the soils of the Scarcies after clearing from

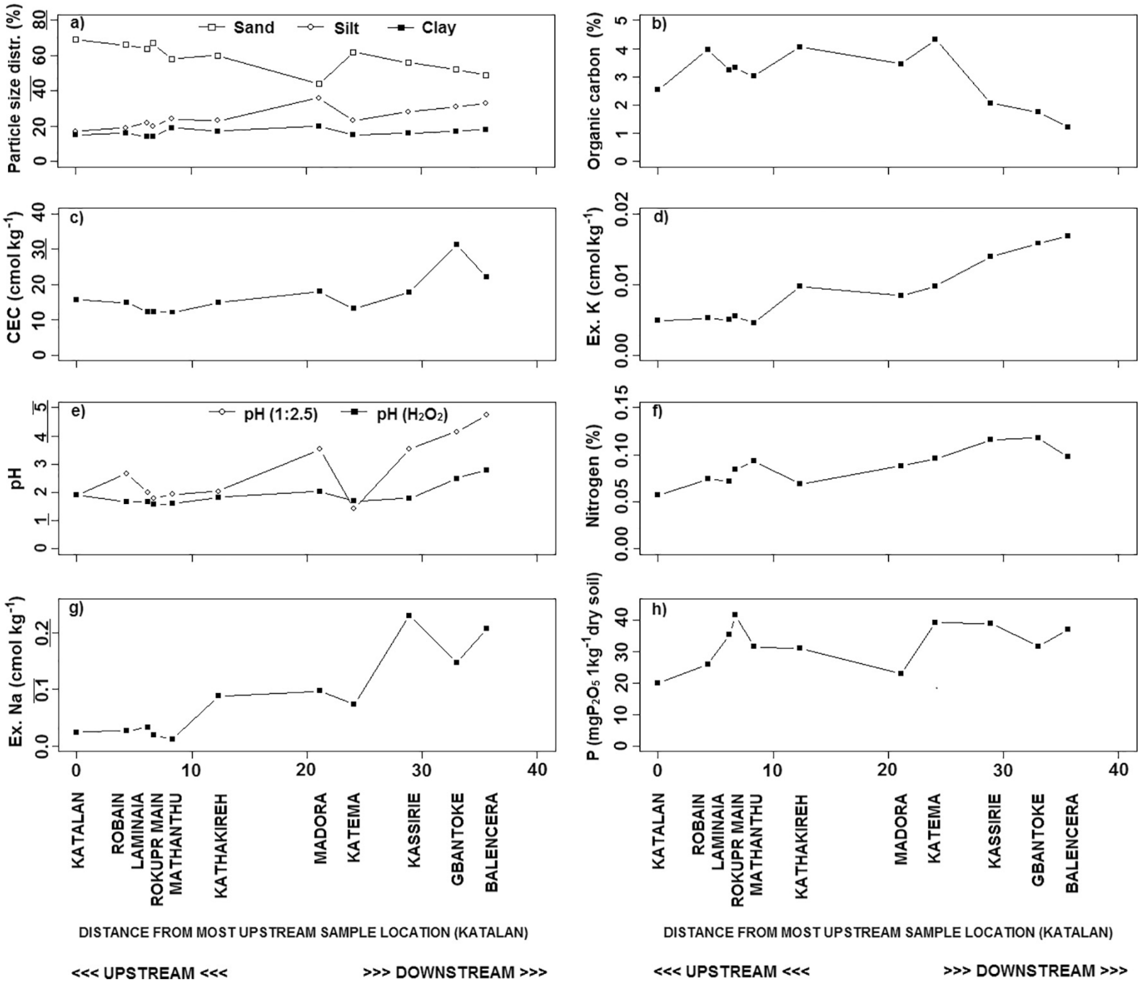

Fig. 3. Trends in eight selected soil parameters along the Great Scarcies River from the upstream section (Katalan) to the estuary (Balencera): (a) particle size distribution of sand, silt and clay (%), (b) Organic Carbon content (%), (c) Cation exchange capacity (cmolkg^{-1}), (d) exchangeable K (cmolkg^{-1}), (e) pH, (f) nitrogen (%), (g) exchangeable Sodium (cmolkg^{-1}), and (h) phosphorus (mg P_2O_5kg^{-1} dry soil).

Rhizophora, activity of crabs and/or the occurrence of pyrites at shallow depths may have resulted in subsurface materials being mixed with top soils.

Principal component analysis is a variable reduction procedure that reduces a large number of variables into smaller number called components that accounts for most of the variance in the observed variables. This is because with a large number of variables, there may be some redundancy in that some of the variables are correlated possibly because they are measuring the same construct. In PCA the variables measuring the same constructs will have high loadings (coefficients) in the same principal component (Stevens, 1986).

Correlation was done to determine which variables would have high loadings in the same principal component; the variables with high correlation should have high loadings in the same principal component. The high correlations among variables in Table 3 were confirmed in Table 5 that is the correlation were high among Silt, Clay, pH H_2O, pH H_2O_2, N, CEC, Ex Na + and Ex. K + therefore they had high loadings in component 1. Similarly, the other variables that had high correlation among them had high loading in components 2 and 3.

Component 1 contributes immensely to soil pH of water and peroxide as well as both exchangeable acidity and Aluminum. Component 2, on the other hand, contributes strongly to the electrical conductivity and percent Nitrogen content of the soil while the third component contributes to the clay and organic matter content of the soils. The implications of such variations are that the first component can be limited to acidity, the second to salinity and the third to organic matter deposition and silting. This also means that an increase in pH improves the cation exchange and minimizes the activity of acidity and hence the performance of the rice crop. Siltation through tidal movement improves the soil physical and chemical characteristics responsible for water and nutrients retention. The waterlogged condition of the mangrove swamp soil minimizes the rapid oxidation of the pyrites present in this soil to Sulphuric acid which is typical of sandy soils. In effect, reducing the sand content minimizes acidity accumulation and improves the cation exchange capacity especially where more clay is observed. It also implies that a reduction in the clay content of the mangrove swamp soil results from an increase in the electrical conductivity and exchangeable Sodium and Potassium from saline sea water. During tidal movement, the basic cations of Sodium and Potassium in tidal water replace the acid-forming cation of Aluminum and Hydrogen. The data sets also imply that the availability of soil phosphorus is enhanced when the pH is increased due to natural liming from salinity-related flooding. The implication of the third component is that increasing the organic matter content through soil deposition by tidal movement decreases the sand content in the soil. For this reason, the clay content of the soil increases with the amount of organic matter content of the soil which improves the cementation of soil physical particles (Wolanski, 1992; Hossain and Nuruddin, 2016).

These factor loadings with soil characteristics, measured in conjunction with the trends of most of the elements measured in mangrove swamp soils along the Great Scarcies River, show high variability in nutrients from downstream to upstream. Sylla (1994) reported variabilities in acidity and salinity of mangrove swamp soils in West Africa including Sierra Leone. There was a general decrease of pH, percentage nitrogen, CEC, exchangeable Sodium and exchangeable Potassium, and an increase in acidity, from downstream to upstream of the mangrove swamp soils along the Great Scarcies River. These results demonstrate the effects of the twice daily tidal movement that influences the environment, and indicate the increasingly favorable growth conditions (soil nutrients and fertility status) from upstream to downstream. This results from the chemical and biological interactions (as manifested in the C:N ratio) at various degrees along the river.

When the pH of a normal/non-acid sulphate soil is tested in hydrogen peroxide medium, the value is very similar to the pH measured in water; but the pH of a potentially acid sulphate soil will have a much lower pH in hydrogen peroxide than in water. The chemical characteristics of the soils in this study indicate that the soils are strongly acidic in reaction. The changes in pH values are negative, which indicates that the soils contain a considerable quantity of reserved potential acidity. The reasons for this decrease of pH with H_2O treatment may be due to the production of sulphuric acid (H_2SO_4) by oxidation of pyrite. Van Breemen (1982) reported that acidity in acid sulphate soils is directly or indirectly caused by sulfuric acid formed by the oxidation of pyrite (FeS_2). The increasing sand content and slight decrease of silt and clay from downstream to upstream suggest that most of the sand carried away by tidal movement upstream is not returned downstream. The higher sand content upstream confirms the relatively higher soil fertility status observed downstream.

5. Conclusions

Statistical and graphical interpretations of soil characteristics demonstrate considerable variation in the mangrove swamp soils along the Great Scarcies River of Sierra Leone. With the descriptive statistics and PCA approach used in this study, high CVs and ranges of loading indicate spatial variations. The high variabilities in physical and chemical characteristics of mangrove swamp soils could be attributed to the complex interactions between twice daily tidal inundations and depositions of organic matter, physical and chemical elements of the mangrove swamp soils along the Great Scarcies River. Area-specific management practices will be required for sustained rice production. Additional research on the characterization of the acidity of these soils is required to determine precisely these practices.

Acknowledgements

This research was conducted within the framework of the West Africa Agricultural Productivity Program (WAAPP) funded by the World Bank and the Japanese Government (Grant Numbers: IDA Grant Number H654-SL and Japan PHRD TF Grant Number TF099510-S, respectively). The contributions of laboratory and field technicians in the implementation of the research are highly appreciated. The authors also thank Drs Ali Toure (Agricultural Economist) and Olupomi Ajayi (Rice Research Coordinator), out-posted by AfricaRice to Sierra Leone, for contributing greatly to the implementation of this study and for editorial comments on the manuscript. We are grateful to Prof. Edward R. Rhodes for his valuable comments on the manuscript. We also thank Mr. Guy Manners for revising the English of the manuscript.

Appendix A. Supplementary data

Supplementary data associated with this article can be found in the online version, at doi: https://doi.org/10.1016/j.catena.2017.11.026. These data include a Google Earth kmz file of the sampling locations and mangrove rice areas in the study area as shown in Fig. 1.

References

Adefurin, O., Zwart, S.J., 2016. A detailed map of rice production areas in mangrove ecosystems in West-Africa. AfricaRice GIS Report – 2. Africa Rice Center, Cotonou, Benin. http://dx.doi.org/10.13140/RG.2.2.32544.58889.

Agyen-Sampong, M., 1985. Mangrove Swamp Rice Production in West Africa. pp. 185–188.

Agyen-Sampong, M., Prakeh-Asante, K., Fomba, S.N., 1988. Rice improvement in mangrove swamps of West Africa. In: Selected Papers of the Dakar Symposium on Acid Sulfate Soils, Dakar, Senegal, 6–11 January 1986. International Institute of Land Reclamation and Improvement (ILRI), Wageningen, The Netherlands.

Allbrook, R.F., 1973. The identification of acid sulphate soils in Northwest Malaysia. In: Dost, H. (Ed.), Proc. Int. Symp. Acid Sulphate Soils ILRI Publ. 18(II), pp. 131–140 (Wageningen, The Netherlands).

Brejda, J.J., Moorman, T.B., Karlen, D.L., Dao, T.H., 2000. Identification of regional soil quality factors and indicators: I. Central and Southern High Plains. Soil Sci. Soc. Am. J. 64, 2115–2124.

Carvalho Jr., W., Schaefer, C.E.G.R., Chagas, C.S., Fernandes Filho, E.I., 2008. Análise multivariada de Argissolos da faixa atlântica brasileira. R. Bras. Ci. Solo 32, 2081–2090.

Dent, D., 1986. Acid Sulphate Soils: The Baseline for Research and Development. ILRI. Publ. No. 44. Wageningen, The Netherlands.

Dost, H., 1986. Selected Papers of the Dakar Symposium on Acid Sulphate Soils. ILRI Publ. No. 44, Wageningen, The Netherlands.

Giglioli, M.E.C., Thornton, I., 1965. Mangrove swamps in the Gambia. J. Appl. Ecol. 2 (81–103 and 257–269).

Goldhaber, M.B., Kaplan, I.R., 1982. Controls and consequences of sulfate reduction rates in recent marine sediments. In: Acid Sulfate Soils Weathering. SSSA special Publ. 10. Wise, Madison.

Green-Dublin, C.O., Ojanuga, A.G., 1988. The problem of acid sulphate soil in brackish water aquaculture: a preliminary study of the soils Niomr/Arac Fix farm, Bugum Rivera State, Nigeria. In: Technical Paper No. 45.

Guei, R.G., Dixon, C.A., Sampong, M.A., 1997. Strategies and approaches to mangrove swamp rice varietal improvement in West Africa. Afr. Crop. Sci. J. 5, 209–217.

Hart, M.G.R., 1959. Sulphur oxidation in tidal mangrove soils of Sierra Leone. Plant Soil 11 (3), 215–236.

Hesse, P.R., 1961. Some differences between the soils of *Rhizophora* and *Avicennia* mangrove swamps in Sierra Leone. Plant Soil 14 (4), 335–346.

Hesse, P.R., 1971. A Textbook of Soil Chemical Analysis. John Murray, London.

Hesse, P.R., Jeffrey, J.W.O, 1963. Some properties of Sierra Leone mangrove soils. L'Agronomie Tropicale 8, 803–805.

Hey, K.M., Ahern, C.R., Watling, K.M., 2000. Using chemical field tests to identify acid sulfate soils likelihood. In: Ahern, C.R., Hey, K.M., Watling, K.M., Eldershaw, V.J. (Eds.), Acid Sulfate Soils: Environmental Issues, Assessment and Management, Technical Papers. Department of Natural Resources, Indooroopilly, Queensland, Australia Brisbane, 20–22 June, 2000. (16-9–16-12).

Hossain, M.D., Nuruddin, A.A., 2016. Soil and mangrove: a review. J. Environ. Sci. Technol. 9, 198–207.

IITA, 1979. Selected Methods for Soil and Plant Analysis. IITA Manual Series No. 1. International Institute of Tropical Agriculture, Ibadan, Nigeria.

Islabao, G.O., Pinto, M.A.B., Selau, L.P.R., Vahl, L.C., Timm, L.C., 2013. Characterization of soil chemical properties of strawberry fields using principal component analysis. R. Bras. Ci. Solo 37, 168–176.

IYR, 2004. International year of rice. In: Rice Round the World – Sierra Leone. FAO, pp. 2004. www.fao.org/ag/irc/.

Jordan, H.D., 1964. The relation of vegetation and soil to development of mangrove swamps for rice growing in Sierra Leone. J. Appl. Ecol. 1, 209–212.

Kaiser, H.F., 1960. The application of electronic computers to factor analysis. Educ. Psychol. Meas. 20, 141–151.

Kalawec, A., 1977. La genèse et l'évolution des sols sur alluvions marines. Varsovie, Poland.

Kamolchanok, P., Kanokporn, S., Natdhera, S., Daoroong, S., 2012. Principal component analysis for the characterization in the application of some soil properties. Int. J. Environ. Chem. Ecol. Geol. Geophys. Eng. 6, 279–281.

Konsten, C.J.M., Andriesse, W., Brinkman, R., 1988. A field method to determine total potential and actual acidity in acid sulphate soils, p. 106–134./n H. In: Dost (Ed.), Selected Papers of the Dakar Symposium on Acid Sulphate Soils. ILRI Publ. No. 44, Wageningen, The Netherlands.

Mahmoodi, J., Zahedi Amiri, G.H., Adeli, E., Rahmani, R., 2005. An acquaintance with the relationship between plant ecological groups and the soil characteristics in a Kelarabad plain forests (in North of Iran). Iran. J. Nat. Resour. 58, 351–362.

Metson, A.J., Janica, G.E., Cox, J.E., Gibbs, D.B., 1977. The problem of acid sulphate soils with examples from north Auckland, New Zealand. New Zealand J. Sci. 20, 371–394.

Odell, R.T., Dijkerman, J.C., van Vuure, W., Melsted, S.W., Beavers, A.H., Sutton, P.M., Kurtz, L.T., Miedema, R., 1974. Characteristics, Classification,& Adaptation of Soils in Selected Areas in Sierra Leone, West Africa. Bulletin 748, Agricultural Experiment Station, College of Agriculture, University of Illinois at Urbana-Champaign/Bulletin 4, Njala University College, University of Sierra Leone.

Okalebo, J.R., Gathua, K.W., Woomer, P.L., 1993. Laboratory Methods of Soil and Plant Analysis: A Working Manual. Tropical Soil Biology and Fertility Programme, Nairobi.

Olorunlana, F.A., 2015. Factor analysis of soil spatial variability in Akoko Region of Ondo State, Nigeria. J. Geogr. Reg. Plan. 81, 12–15.

Panishkan, K., Mayuva, A., Natdhera, S., Kanokporn, S., 2010. Soil classification based on their chemical composition using principal component analysis. Environ. Asia 3, 47–52.

PEMSD/MAFFS, 2014. Agricultural Statistics Bulletin Volume 3. Project Evaluation, Monitoring and Statistics Division, Ministry of Agriculture, Forestry and Food Security, Freetown, Sierra Leone.

Rahman, S., Islam, A., Hussain, M.S., Parveen, Z., Mohiuddin, A.S.M., 1993. Identifying characteristics of potential and actual acid sulphate soils. Bangladesh J. Soil. Sci. 24, 41–49.

Salehi, A., Zarinkafsh, M., Zahedi Amiri, G.H., Marvi Mohajer, M.R., 2005. A study of soil physical and chemical properties in relation to tree ecological groups in Nam-Khaneh district of Kheirood-Kehar forest. Iran. J. Nat. Resour. 58, 567–577.

SAS Institute, 2011. The SAS System for Windows. Release 9.2. SAS Institute, Cary, NC.

Shukla, M.K., Lal, R., Ebinger, M., 2006. Determining soil quality indicators by factor analysis. Soil Tillage Res. 87, 194–204.

Sparks, D.L., 1996. Methods of Soil Analysis. Part 3: Chemical Methods. Soil Science Society of America, Madison, WI.

Stevens, J., 1986. Applied Multivariate Statistics for the Social Sciences. Lawrence Erlbaum Associates, Hillsdale, NJ.

Sylla, M., 1994. Soil salinity and acidity: spatial variability on rice production in West Africa's mangrove zone. In: PhD Thesis. Wageningen University, Wageningen, The Netherlands.

Tomlinson, T.E., 1957. Relationship between mangrove vegetation, soil texture and reaction of surface soil after empoldering saline swamps in Sierra Leone. Trop. Agrc. 34 (1), 41–50.

Van Breemen, N., 1976. Genesis and Solution Chemistry of Acid Sulfate Soil in Thailand. Agricultural Research Reports 848. PUDOC, Wageningen, The Netherlands.

Van Breemen, N., 1982. Genesis, morphology, and classification of acid sulphate soils in coastal plains. In: Kittrick, J.A., Fanning, D.S., Hosner, L.R. (Eds.), Acid Sulphate Weathering. Soil Science Society of America Special Publication 10. SSSA, Madison, WI, pp. 95–108.

Visconti, F., Miguel de Pal, J., Luis, R., 2009. Principal component analysis of chemical properties of soil extracts from an irrigated Mediterranean area: implications for calcite equilibrium in soil solutions. Geoderma 151, 407–416.

WARDA, 1976. Special Project. Annual Research Report. West Africa Rice Development Association, Freetown, Sierra Leone.

WARDA, 1977. Annual Report. Regional Mangrove Swamp Rice Research Station, Rokupr, Sierra Leone.

WARDA, 1978. Annual Report. Regional Mangrove Swamp Rice Research Station, Rokupr, Sierra Leone.

WARDA, 1983. Research Highlights. West Africa Rice Development Association.

WARDA, 1984. Research Highlights. West Africa Rice Development Association.

WARDA, 1986. Annual Report. West Africa Rice Development Association.

WARDA, 1987. Annual Report. West Africa Rice Development Association.

Wolanski, E., 1992. Transport of sediment in mangrove swamps. In: Asia-Pacific Symposium on Mangrove Ecosystems pp 31-42; Part of the Developments in Hydrobiology Book Series (DIHY, volume 106).

Yahya, K., Jalilyvand, H., Ali Bahmanyar, M., Pormajidan, R.M., 2008. The use of principal component analysis in studying physical, chemical and biological soil properties in Southern Caspian Forest (North of Iran). Pak. J. Biol. Sci. 11, 366–372.