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

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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

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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.,