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Characteristics of soils under seasonally flooded wetlands (*oshanas*) in north-central Namibia

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Lowland wetlands generally have a high agricultural production potential and can be local hot-spots for biodiversity. Specific seasonal wetland system is largely distributed in north-central Namibia. Seasonal wetlands consist of seasonal river wetlands (locally known as *oshanas*). However, studies on soil fertility, salinity and sodicity in seasonal river wetlands are still limited in this area. The objective of this study was hence to investigate the soil fertility status of seasonal wetlands and evaluate their potential for agricultural production and consider sustainability of the land use system. Soil samples were collected from 102 different spots of the flood plain within 3 major seasonal rivers, and analyzed for their physico-chemical properties and salinity and sodicity. The findings for average soil organic carbon (1.94 g kg^{-1}) and average clay contents (102.3 g kg^{-1}) of seasonal rivers were drastically lower than the wetland of semi-arid Africa regions (organic carbon, 5.8 g kg^{-1}; clay contents, 340 g kg^{-1}), and organic carbon and clay content significantly (p<0.05) decreased at the lower part of each seasonal river. Most of the seasonal river soil's' electrical conductivity of saturated paste extract (ECe) and the sodium adsorption ratio of the saturated paste extract (SAR) were more than 4 dS m^{-1} and 13, respectively. However, there were large differences in electrical conductivity of saturated paste extract (ECe) and the sodium adsorption ratio of the saturated paste extract (SAR) values among the sampling spots. These findings suggest the high agricultural importance to improve the soil organic matter and clay contents, and land selection to avoid the strongly high saline-sodic soil sites in seasonal river.

Key words: Seasonal flooded wetland soil, soil fertility, soil salinity and sodicity, sustainable land use.

INTRODUCTION

Food crisis in Africa is far from over. Among other factors, improper cultivation, uncontrolled burning of vegetation and deforestation have been cited as causes of environmental degradation that result in the general

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critical food situation (Okigbo, 1990). Lowlands with wetlands, generally have a high agricultural production potential (Andriesse et al., 1994; Rodenburg et al., 2014). Lowland soils are usually fertile because they receive transported materials from adjacent uplands. Soil fertility characteristics of lowlands were reported in West Africa (Issaka et al., 1996; Buri et al., 1999; Abe et al., 2010).

Sub-Saharan Africa is endowed with diverse wetland types, including alluvial lowlands and small valley swamps. Wetlands are particularly important assets to rural people as they can fulfil many services (Turner et al., 2000). Apart from agricultural production, these ecosystems supply local communities with a range of goods, including hunting, fishing, forest and forage resources (Roberts, 1988; Scoones, 1991; Adams, 1993) and they are local hot-spots for biodiversity (Chapman et al., 2001).

North-central Namibia is a semi-arid area. The soil in this region is poor with low nutrients and classified as alkali soil or solonetz (Moller, 1997). Specific seasonal wetland system is largely distributed in north-central Namibia, which is called Cuvelai Seasonal Wetland System (CSWS). This seasonal wetland system consists of various types of wetlands; seasonal river wetlands (locally known as *oshana*/*oshana*s), small seasonal ponds and large pans (Mendelsohn et al., 2000). The *oshanas* occupy a large area of the wetland system during the rainy season by receiving local rainfall and flood water from Angola. The *oshana* water gently streams from north to south during December to May. Salinity and sodicity problems are common in low-rainfall regions (Brady and Weil, 2008). Sand and clay mixture with sodic properties are dominant in *oshanas* in north-central Namibia, because sodium and other salts are carried by flood water and accumulate in lowlands (Mendelsohn et al., 2000).

A lot of wetlands in the world have in the past been overutilized, for agricultural expansion and intensification, because with increasing population growth there is a strong need for livelihood support and food security (Halsema and Wood, 2008). Such changes have often led to a gradual degradation of wetland ecosystems and substantial loss in food security (Halsema and Wood, 2008). Therefore, human development and utilisation of wetlands should consider maintenance and sustainability of ecosystems (Ramsar Convention Secretariat, 2007).

There are a few studies conducted so far on physicochemical properties of soils in North-central Namibia (Turner et al., 2014; Hillyer et al., 2006). However, wide area studies on soil fertility, salinity and sodicity in seasonal wetlands, such as *oshanas*, are still limited. Assessing the chemical and physical properties of these soils is necessary to gain information on how to sustain land use, maintain natural resources and adapt to the new environment. The objective of this study was to investigate the soil fertility status of *oshanas* and to evaluate the potential of agricultural production and consider sustainability of the land use system.

MATERIALS AND METHODS

Study area

The study focused on the CSWS in North-central Namibia, which is an ancient depression filled with sediments. During the rainy season, the flood water forms seasonal wetlands which form part of the huge CSWS, which is part of the drainage system originating from southern Angola. Mean annual rainfall in the CSWS ranges from 91.4 to 822.2 mm with an average monthly temperature from a minimum of 9.1°C in June to a maximum of 36.5°C in October, from 2003 to 2015 (a nearest public meteorological station). The vegetation can be broadly classified into five major associations; namely, mixed woodland of the deep aeolian sands, the Palm tree savanna, Mopane woodland and Mopane savanna, Sclerocarya-Ficus savanna, and Various scrub Mopane-Acacia (Moller, 1997). The soils are classified into three major groups: Cambic Arenosols, Eutric Cambisols, and Haplic Calcisols (Mendelsohn et al., 2002). Most of the soils in this region are classified as alkali soil or solonetz (Moller, 1997). Many people benefit from the seasonal wetlands. Fishing and grazing are common practices in the wetland area.

Soil sampling

Soil samples were collected during 2013 to 2014 from 102 different spots of the flood plain. The three *oshana*s are about 40 km apart along the Angolan border, narrowing to around 20 km distance in the middle, and later converging at Lake Oponono. Each sampling spots along each *oshana* is approximately located 5 km further from the next one. At the soil sampling points, the dominant vegetation were few grass fallow, the slope was gentle (less than 1%), and the average ground water level was less than 5 m. The starting point was near the border of Angola and the end point was at Lake Oponono (Figure 1).

At each spot, 3 sub-samples were collected along topographical setting (lower, middle upper) from 0-15 cm depth and bulked together and a composite sample was used for chemical/physical analysis. Fifteen different soil samples were also collected from upland field (cropland) as a control. Sampling was made with steel cylinder core sampler; with a volume of 100 cm^3. Soil samples were then air-dried and sieved through a 2 mm sieve for physicochemical analysis.

Laboratory analysis

The glass electrode method was used to determine soil pH in water (soil: H_2O, 1:2.5), and here after shown as pH (H_2O). Organic carbon content was measured by the Walkley Black method. Total nitrogen content was measured by the modified Kjeldahl method (salicylic acid added to the sulphuric acid). Available phosphorus (P) was extracted by the Olsen method followed by colorimetric measurement using an Ultraviolet-Visible (UV/VIS) spectro-photometer (Spectrophotometer; UV mini 1240, Shimadzu Corporation, Kyoto, Japan). Exchangeable calcium (Ca), magnesium (Mg), and potassium (K) were extracted from the soil with 1 mol L^{-1} neutral ammonium acetate, and were subsequently determined using an Inductively Coupled Plasma-Optical Emission Spectrometer (ICP-OES; Optima 7000 DV, Perkin Elmer Inc., U.S.A.). The pH, the electrical conductivity (ECe) and the concentrations of soil Ca, K, Mg and Na were determined from the extract from saturated paste of the soil samples and were

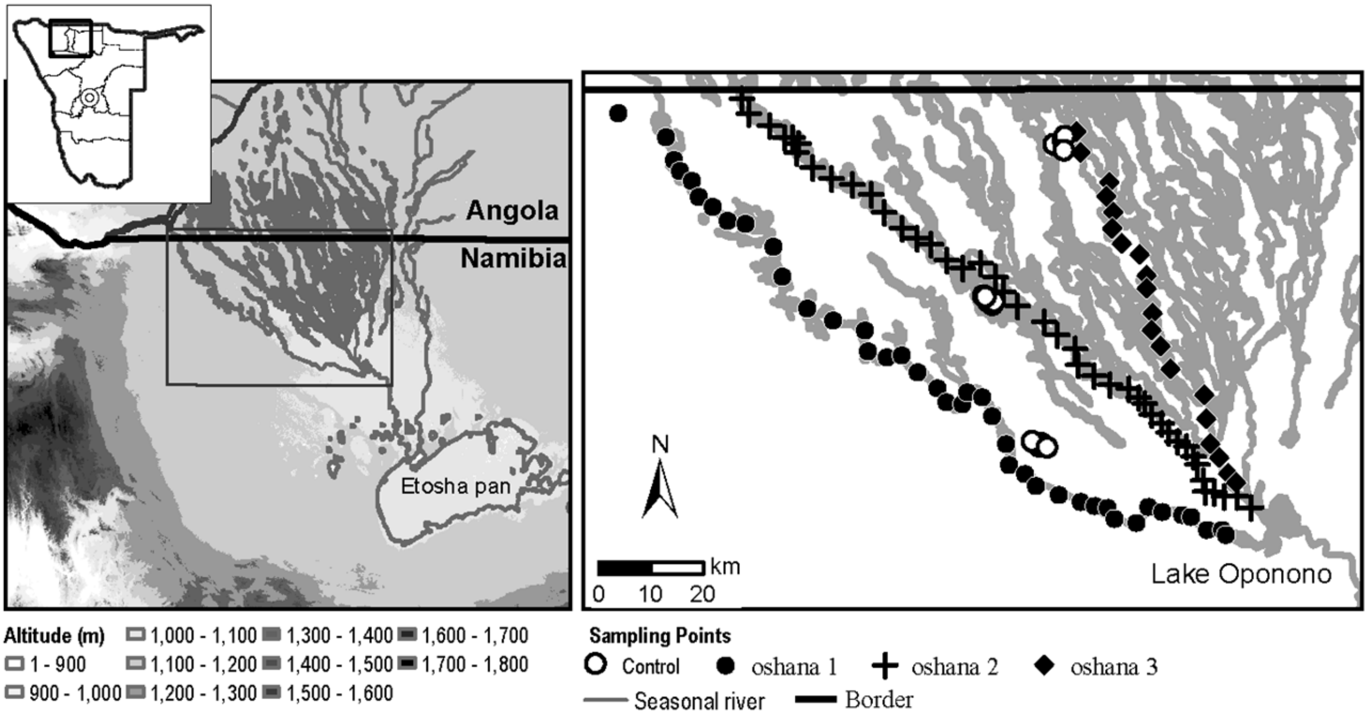

Figure 1. Sampling spots from 3 major *oshanas.* (*oshana* 1= 40, *oshana* 2= 42, *oshana* 3= 20).

subsequently determined using a pH-mV and conductivity meter (MultiLab 540; WTW Wissenschaftlich- Technische Werkstätten GmbH Weilheim i. OB, Germany), and an ICP (ICP-OES; Optima 7000 DV, Perkin Elmer Inc., U.S.A.). Soil salinity was expressed through the soil electrical conductivity of saturated paste extract (ECe) analysis. The adsorption of sodium by the soil was expressed by the sodium adsorption ratio of the saturated paste extract (SAR). This ratio was used as an indicator of sodicity, and was defined as

$$SAR = Na^{+} / \sqrt{(Ca^{2+} + Mg^{2+})/2} \qquad (1)$$

Soil particles were determined using the pipette method.

Data analysis

All results were reported as the mean ± standard error. One-way ANOVA tests were used to compare the soil physicochemical properties between different land use conditions. Pearson's correlation coefficients were used to compare soil fertility parameters originating from *oshana* soils. All statistical analyses were performed using Excel Statistics Version 2015 software (Social Survey Research Information Co., Ltd., Japan).

RESULTS

General soil fertility

The results of physico-chemical properties that contribute to the general soil fertility of *oshana* soils are shown in Figure 2. Soil pH (H_2O) in *oshanas* ranged from 6.2 to 10.2 with a mean of 7.61. Most *oshana* soils were neutral, but some were alkaline, where the pH was more than 8.5. Organic C and total N ranged from 0.38 to 5.05 g kg^{-1} and 0.10 to 0.60 g kg^{-1}; respectively, with a mean of 1.95 and 0.27 g kg^{-1}, respectively. Clay content in *oshanas* was 0 to 337.6 g kg^{-1} with a mean of 103.3 g kg^{-1}. Those results show that *oshana* soils are sandy with little organic matter. The means of exchangeable Ca, Mg, K, and Na in *oshanas* were 1.49, 0.41, 0.45, and 4.88 cmol$_c$ kg^{-1}, respectively. Sodium was the cation which occupied the greater part of the exchange sites. Available P in *oshanas* ranged from 0.08 to 17.40 mg kg^{-1} with a mean of 3.49 mg kg^{-1}.

Soil chemical properties in *oshanas* varied widely. Comparison of each *oshana*, showed that exchangeable K and Na, silt contents in *oshana*1 were significantly higher than those of *oshana* 2 and 3. Exchangeable Ca and available P were significantly lower for the *oshana* soils than the croplands. Comparing *oshanas* and croplands, exchangeable K and Na, and silt and clay contents were significantly higher in *oshana* 1 than the croplands. Exchangeable Ca and available P were significantly lower in *oshanas* than the croplands.

Comparing *oshanas* and wetlands in other regions, organic C, total N, exchangeable Ca and Mg in the *oshana* soils were lower than those of the flood plains and the inland valleys in West Africa (Figure 2). C/N ratio, exchangeable K, and available P were stable among the regions. Exchangeable Na was higher in *oshana* soils

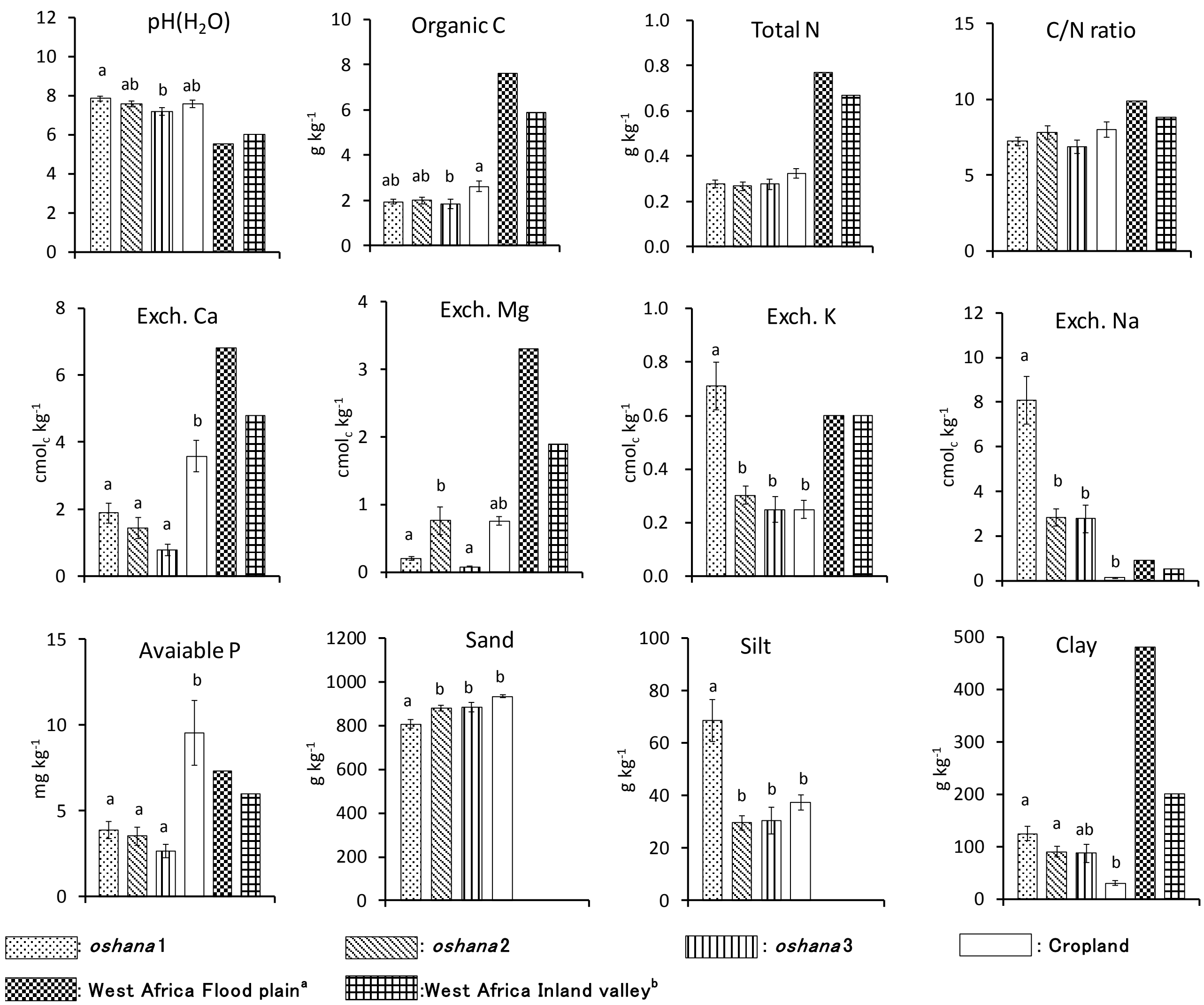

Figure 2. The physicochemical properties of *oshana* and other lowlands in West Africa. Error bears represent the standard error of mean. Different letters indicate significant differences between treatments at 5% significance level using Tukey-Kramer test. [a]Buri et al. (1999) and [b]Issaka et al. (1996). pH, glass electrode method with 1:1 soil:water extraction; organic C and total N, dry combustion method; available P, Bray-2 method; exchangeable cations, neutral ammonium acetate extraction method; clay content, pipette method.

than that of the flood plains and the inland valleys in West Africa.

Soil salinity and sodicity

Some characteristics of soil salinity and sodicity of the *oshanas* are shown in Figure 3. Based on determinations from saturated extract solution, the $pH_{saturated}$ of *oshanas* ranged from 4.70 (acidic) to 8.20 (alkaline) with a mean of 6.55. The ECe and SAR in *oshanas* soil ranged from 0.11 to 32.20 ds m^{-1} and 0.50 to 155.09 with a mean of 6.55 ds m^{-1} and 39.84, respectively. In principle, soils with ECe and SAR of more than 4 and 13 are judged as saline and sodic soils, respectively (Soil Science Society of America, 1997). The mean values for Ca, Mg, K, and Na determined from saturated extract solution were 1.92, 2.08, 1.29, and 54.06 $mmol_c$ l^{-1}. There was a tendency that sodium was very high. ECe, Ca, Mg, Na and SAR for the *oshana* 1 soil were significantly higher than the cropland and *oshana* 2 and 3 soils. However, the soil properties of the cropland and *oshanas* 2 and 3 were not significantly different from each other.

Dynamics of soil physicochemical properties in seasonal stream wetland

Organic carbon was significantly correlated to Total N, Exch. K, Ca, Mg, and Clay (Table 1). Clay was

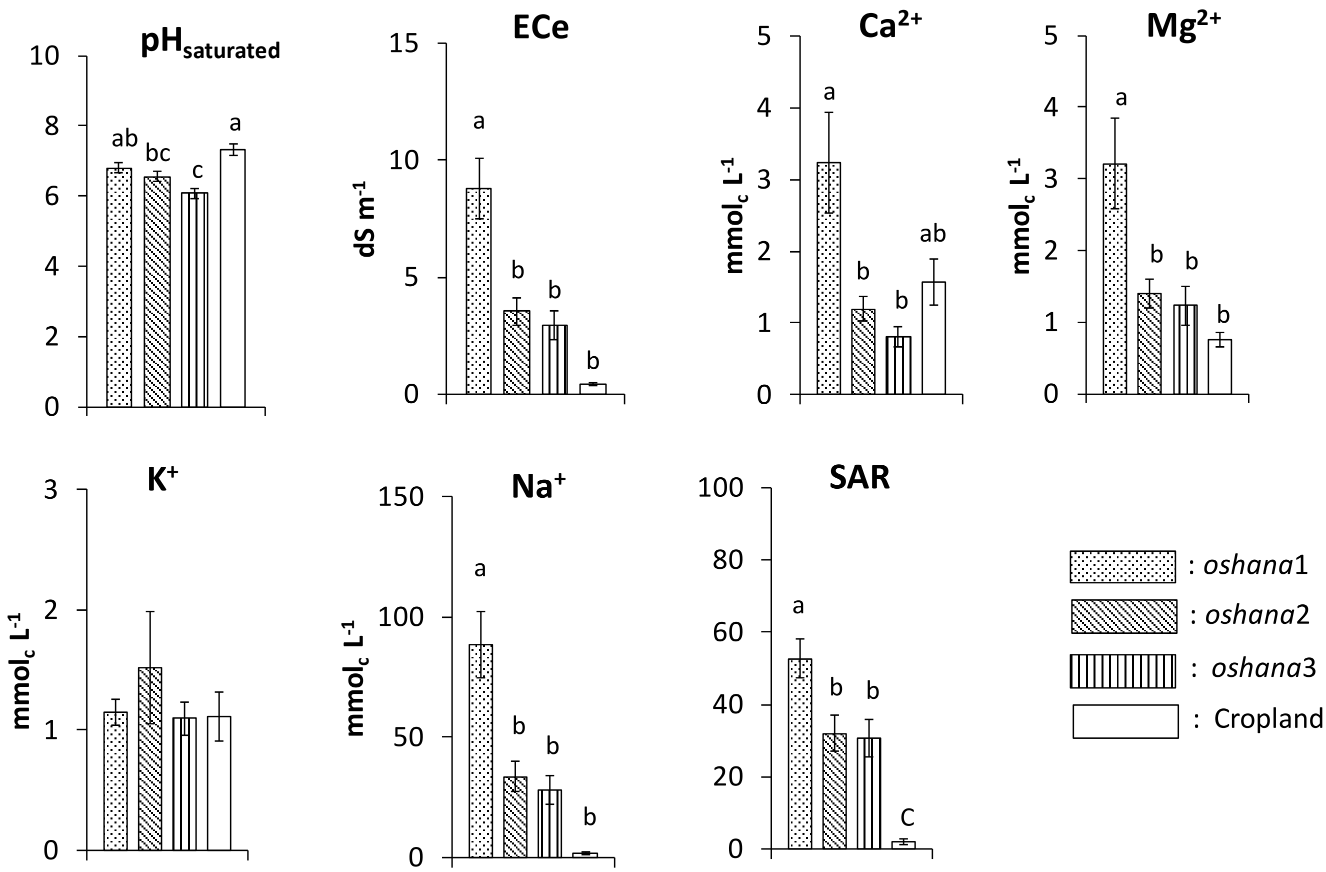

Figure 3. Soil salinity and sodicity of croplands and *oshanas.* Error bears represent the standard error of mean. Different letters indicate significant differences between treatments at 5 % significance level using Tukey-Kramer test.

Table 1. Correlation matrix of selected physicochemical parameters.

	pH (H_2O)	Org. C	Total N	Exch. Ca	Exch. Mg	Exch. K	Exch. Na	Av. P	Clay
pH (H_2O)	1.00								
Org. C	-0.21*	1.00							
Total N	-0.10	0.64**	1.00						
Exch. Ca	0.11	0.51**	0.66**	1.00					
Exch. Mg	-0.09	0.38**	0.56**	0.63**	1.00				
Exch. K	0.02	0.46**	0.56**	0.57**	0.23*	1.00			
Exch. Na	0.17	0.18	0.28**	0.20*	-0.04	0.80**	1.00		
Av. P	0.14	0.17	0.34**	0.36**	0.36**	0.51**	0.44**	1.00	
Clay	-0.01	0.60**	0.72**	0.73**	0.41**	0.78**	0.53**	0.46**	1.00

*p<0.05, **p<0.01 (n=102)

significantly correlated to all soil nutrients that were determined. Therefore, Organic C and clay contents appear to have an important bearing in soil fertility of *oshana* soils.

Dynamics of organic C and clay contents from upper to lower stream in *oshana* 1, 2, and 3 are shown in Figure 4. Organic carbon and clay content significantly decreased at the lower river in *oshana* 1 and 2. Organic carbon and clay content in *oshana* 3 did not so much decrease at the lower stream and were not significantly dependent on stream position. Organic carbon in *oshana* 1 and 2 was higher than that in *oshana* 3. Clay content in upper stream of *oshana* 1 was higher than that in *oshana* 2 and 3.

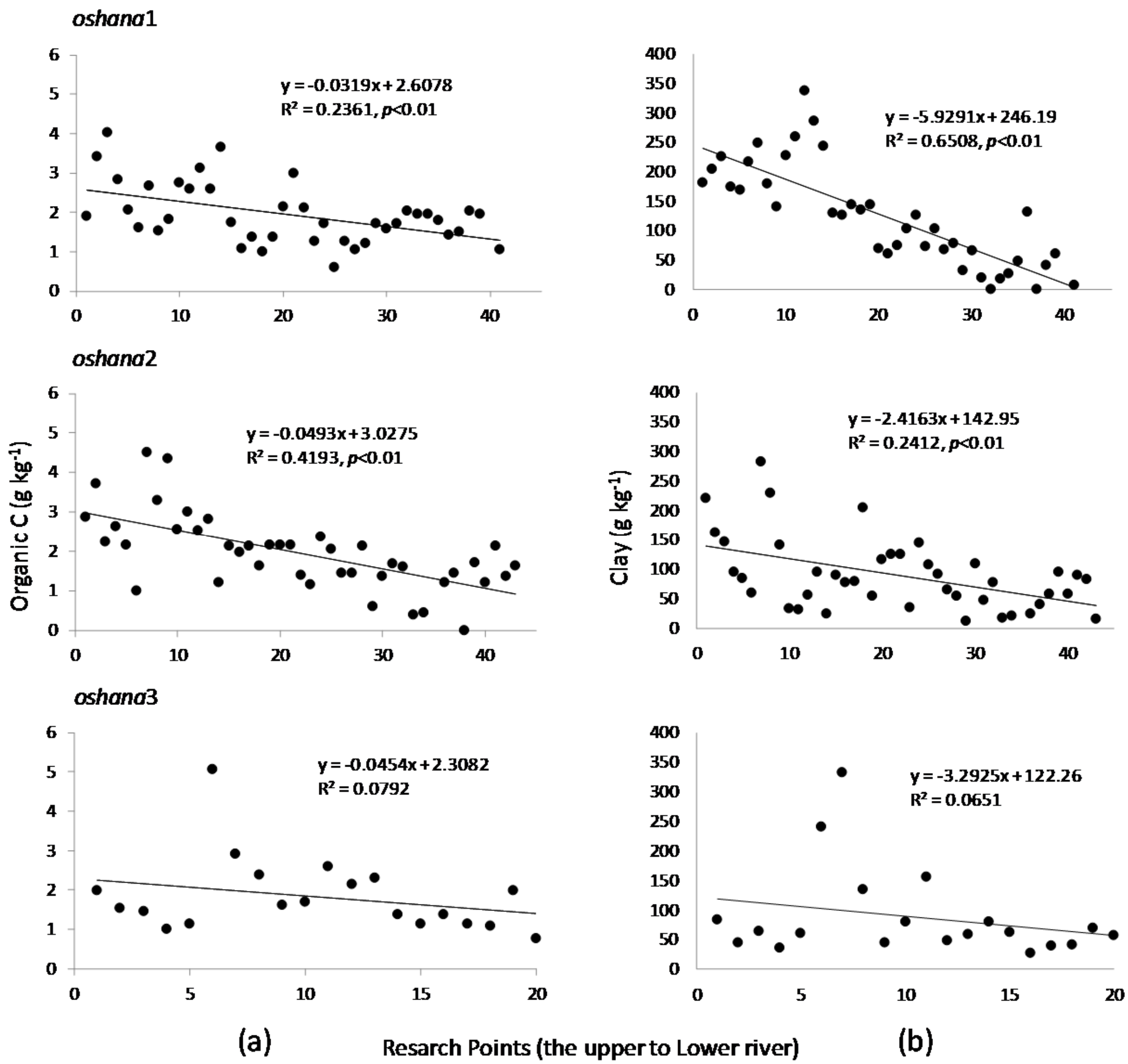

Figure 4. Simple liner regression between (a) organic carbon and research points, (b) clay contents and research points from 3 major *oshanas.* (*oshana* 1= 40, *oshana* 2= 42, *oshana* 3= 20).

ECe and SAR quality were not dependent on stream position (Figure 5). ECe and SAR were less than 10 ds m^{-1} and 50 in most of sampling points, respectively, although some points had strongly high values. In general, ECe and SAR in *oshana* 1 were higher than that in *oshana* 2 and 3.

DISCUSSION

General soil fertility conditions of *oshanas*

Since on the average most of the *oshana* soils were neutral to slightly alkaline, the soil reaction conditions in this region was favorable for producing a wide range of crops. However, the organic carbon and nitrogen contents were much below average that unless organic matter or fertilizer amendments were added, these soils could be regarded as extremely poor in soil fertility. The situation was even more compounded by the very low contents of phosphorus and exchangeable cations, which rendered these soils as unproductive. Additionally, the clay content of the *oshanas* was so low that it would be difficult for these soils to retain sufficient plant nutrients under the present natural condition.

According to results, most *oshana* soils can be

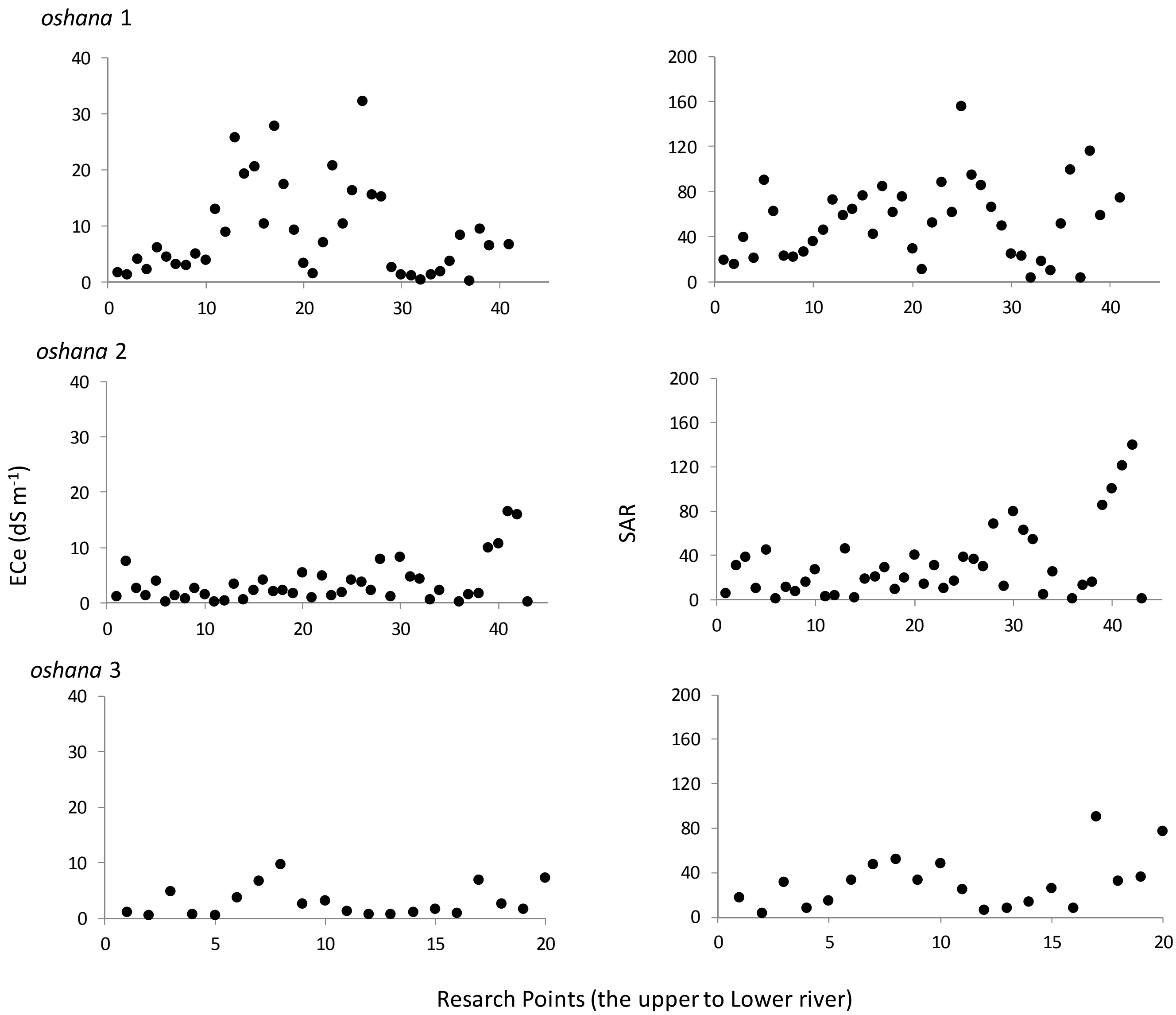

Figure 5. ECe and SAR quality of the upper to lower stream of 3 major *oshanas.* (*oshana* 1= 40, *oshana* 2= 42, *oshana* 3= 20).

regarded as saline and sodic. In a few instances lower ECe and SAR values have been observed. From this research one can derive that soil salinity and sodicity properties in *oshanas* vary widely. Among the *oshanas*, exchangeable K and Na, silt, ECe and SAR in *oshana*1 were significantly higher than those of *oshana* 2 and 3 (Figures 2 and 3). According to Mendelson et al. (2000), there is clay distribution in the west to south part of the CSWS, close to *oshana* 1 compared to the other *oshanas*. The presence of clay in the vicinity can hence play a role in enriching the fertility status of oshana 1 over the other *oshanas*. Since most of the *oshana* soils had high Na^+ ions on the exchange spots and mean pH of 7.7, they could be classified as saline-sodic soils. Saline-sodic soils exhibit physical conditions intermediate between those of saline soils and sodic soils.

There are some similarities in lowland wetlands in West Africa and *oshanas*. Lowlands in West Africa consist of inland valleys and flood plains. Inland valleys can be defined as seasonally flooded wetlands comprising valley bottoms (fluvial) and hydromorphic fringes (phreatic) but excluding river flood plains (Rodenburg et al., 2014). Inland valley is a swamp and the position is the upper reach of river systems in the gentle slope of a peneplain.

In the seasonal regimes of rivers in semi-arid Africa high water levels cause extensive inundation. The area, flooded then by the rivers can be reduced to pools of water separated by dry land (Adams, 1993). In West Africa, flood plains are distributed at the Senegal River Delta, the Inner Niger Delta, the lake Chad Basin (Buij and Croes, 2013). Those lowlands, inland valleys and flood plains are seasonal wetlands and of low soil fertility (Issaka et al., 1996; Buri et al., 1999; Abe et al., 2006).

Compared to lowland wetlands of West Africa, the *oshanas* in north-central Namibia happen to be much less fertile due to lower contents of the essential plant nutrients. The West African lowland wetlands in turn have lower fertility status compared to other tropical wetlands. Therefore, this indicates how poor the *oshanas* of north-central Namibia.

Even the cropland soils which appeared to have better soil fertility than the *oshanas* (Figure 2), when cultivated with pearl millet were reported to yield only between 0.1 to 0.5 ton per hectare (Shifiona et al. 2016). Through personal communication with some farmers, it was recognized that yields of maize, sorghum and other crops also appeared to be generally low. The situation therefore calls for the need of some strategic fertility options such as inclusion of legumes in the crop rotation, proper soil management practices such as mulching, and organic matter additions to improve the fertility condition of these soils.

Characteristics of soil physicochemical properties

Oshana soils generally were sandy with low organic matter content, and these soils were classified as Arenosols. The results of our study indicated that organic C and clay contents were major indicators of soil fertility (Table 1). Soil organic matter and clay influence soil physicochemical properties. Soil organic matter reduces the plasticity and cohesion of soils, and increases water holding capacity (Brady and Weil, 2008). Soil organic matter and clay hold nutrient cations (Brady and Weil, 2008). These results suggested that *oshana* soils are easily affected by environmental changes.

Organic C in the *oshana* soils was lower than that of the flood plains and the inland valleys in West Africa (Figure 2). Most of the particle size was sand, and the clay content was very low in *oshana* soils. The other soil nutrients in *oshanas* were lower than in West Africa except for exchangeable K (Figure 3). Soil fertility in the West African lowlands is much less than other tropical regions (Abe et al., 2010). These results indicate that soil fertility of *oshanas* is lower than other tropical wetlands in the world.

Organic C and clay content decreased with topography at the lower river (Figure 4). In the northern part of this study area shrub vegetation dominated while in the south part it was mainly grass vegetation (Mendelsohn, 2000).

The shrub vegetation was higher in biomass than grass lands. The grasslands in this study area may face high grazing stress; thereby resulting in low organic matter from the grasses. Organic C content in this study decreased at lower positions of the *oshanas* (Figure 4). Cambisols and Calcisols covered the northern part of the study area with relatively higher clay contents than the Arenosols which covered the southern part of the study area (Mendelsohn et al., 2002). Arenosols had sandy texture, and contained more sand than Cambisols and Calcisols. Therefore, clay content decreased at lower stream (Figure 4). Organic C and clay contents in the *oshana* soils varied widely among the sampling points (Figure 2 and 4). The correlation of clay and organic matter was very high (Table 1). Shrub planting increased the quantity of silts + clay content and organic matter (Rathore et al., 2014). There were a lot of soil organic matter and clay contents at the spots where there was high plant biomass. Clay contents in *oshanas* were significantly higher than that of cropland field (Figure 1). The clay is transported through runoff from the surrounding uplands to inland valley in West Africa (Ogban and Babalola, 2003). Our results suggested that clay materials are eroded from upland fields and flow into *oshana*.

Soil organic matter and clay content can protect soil erosion and maintain soil fertility. Soil organic C and clay contents were drastically low in *oshanas* (Figure 4), and hence the soil was vulnerable to erosion. However, those organic C and clay contents varied widely in topographical positions. Therefore, it is suggested that major agricultural activities should focus on selected high organic C and clay content positions for sustainable land use. Maintenance and improvement of soil organic matter content could result in sustainable food production in Sub-Sahara Africa. Seasonal wetlands (dambos) are cultivated in southern Africa by applying cow manure as organic amendment to sustain crop yields (Nyamadzawo et al., 2014). Applying plant residues or animal manure increases soil organic carbon in Vertisols (Hua et al., 2014). It is also useful to prevent clay removal by erosion. In addition to increasing organic matter, organic amendments could reduce the effect of salts and alkalinity by releasing organic acids. Saline sodic conditions may equally affect ground water quality in the long run. Clay content is an important factor for land productivity and drought tolerance (He et al., 2014). The clay content can be reduced by erosion (Rejman et al., 2014). Applying biochar prevents erosion due to rainfall in sandy clay loam soils (Sadeghi et al., 2016).

Soil salinity and sodicity

ECe, Na^+, Mg^{2+}, and SAR of *oshana* 1 soils were significantly higher than the cropland (Figure 3). Especially, Na^+ content was drastically higher in the *oshana* 1 soil than the cropland soil. However, ECe of *oshana* 2 and 3 soils were not significantly different from those of croplands. The average of ECe and SAR in the cropland were 0.42ds m^{-1} and 2.08, respectively (Figure 3). Those values did not pose any problem of salinity and sodicity on the farmlands. The likely reason for this is because croplands are situated in the upper slope positions, whereas *oshanas* are found in lower slope positions and sodium is dissolved by ground water and moved to lower slope positions. Mendelsohn et al. (2000) reported that total dissolved solid in ground water is above 2600 mg l^{-1} under a lot of sites in north-central region.

ECe and SAR quality were not affected by stream position (Figure 5). ECe and SAR were less than 10 ds m^{-1} and 50; respectively, in most of the sampling points. However, some points had strongly higher values. Saline-sodic soil affects plant growth and contributes to soil structure deterioration. Increased osmotic pressure of soil water, which impedes its uptake by the roots, and nutrient imbalances, which in turn lead to toxicities and differences, are the major causes for the adverse effects of salinity and sodicity on plant growth. ECe was significantly correlated with SAR ($r = 0.74$, $p < 0.01$). ECe is good indicator of agricultural site selection. It is imperative to manage the saline-sodic conditions in the *oshana* soils of the CSWS for improved crop productivity. In a seasonal wetland in California, the river salt loads were managed and the water and salinity mass balances were regularly monitored (Quinn et al. 2010).

Conclusions

Soil fertility of *oshanas* is generally low. Especially, soil organic C and clay contents are drastically lower than other wetlands in other tropical regions. Most *oshana* soils are saline-sodic soils. However, the values of salinity and sodicity are very different at each research points. Land selection is very important, and agricultural land should avoid the strongly saline and sodic sites. *Oshana* soils are very vulnerable to erosion and are easily prone to salinity and sodicity. Such changes have led to degradation of wetland ecosystems and substantial loss of crops; thereby threatening food security. Therefore, it is important to adjust and sustain wetland ecosystems, such as *oshana* ecosystems. In order to prevent erosion and problems related to saline-sodic conditions in the agricultural land, it is important to keep natural vegetation in some areas.

Conflict of Interests

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

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