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Soil fertility status of seasonally closed wetland ecosystem (*ondombe*) in north-central Namibia

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In the Cuvelai Seasonal Wetland System (CSWS) of North-central Namibia, there are widespread manifestations of seasonally flooded river and seasonally closed wetland ecosystems (ponds). These wetlands are called *oshana* (seasonally flooded river wetland) and *ondombe* (seasonally closed wetland) according to the local language. This study was initiated to find out the soil fertility status of *ondombe*s and whether they could be utilized for agricultural purposes unlike the present situation. Soil salinity and sodicity were determined to find out impact of such adverse conditions on possibility of food production. A total of 70 representative *ondombe*s were identified from three selected villages. A total of 210 soil samples were collected from upper, middle and lower positions adjacent to *ondombe*s, and 15 soil samples from each 5 upland fields in the three villages and 102 soil samples from different spots of the flood plain in the three *oshana*s for comparison. The results indicated that the mean soil pH (H_2O) in *ondombe* was 6.3, the means of organic C and total N were 6.28 and 0.41 g kg^{-1}; respectively, the mean of available P was 4.81 mg P kg^{-1}. The means of exchangeable Ca, Mg, K, and Na in *ondombe* were 2.31, 1.44, 0.21, and 0.61 cmol$_c$ kg^{-1}, respectively. Most soil nutrients were higher in lower *ondombe* positions than on upper and middle positions. Organic C, exchangeable Mg, and clay at the *ondombe* soils were significantly higher than those at the croplands. The means of electrical conductivity of saturation extract (ECe) and sodium adsorption ratio (SAR) in *ondombe* soils were 0.62 ds m^{-1} and 7.32, respectively; even though most of the *ondombe* soils did not exhibit salinity and sodicity problems. Hence, one can conclude that an *ondombe* soil has an appropriate condition for agriculture, and may only be prone to sodicity whenever the sodium content is high, as sometimes observed.

Key words: Soil fertility, seasonal wetland, soil salinity, sodicity, Cuvelai Seasonal Wetland System (CSWS).

INTRODUCTION

Semi-arid ecosystems in tropical regions exhibit high climatic variability, where food security is threatened by frequent drought (Steiner and Rockström, 2003). North-central Namibia is a semi-arid area in southern Africa

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which is dry through most of the year receiving very little rainfall. There is frequently occurring drought, and performance of cereal production fluctuates greatly (Shifiona et al., 2016). In north-central Namibia, during the rainy period, a specific seasonal wetland system is usually experienced, which is commonly referred to as Cuvelai Seasonal Wetland System (CSWS).

In the CSWS, there are widespread manifestations of seasonally flooded river and seasonally closed wetland ecosystems (ponds). These wetlands are called *oshana* (seasonally flooded river wetland) and *ondombe* (seasonally closed wetland) according to the local language (Figure 1). The *ondombe* water is shallow and the water level fluctuates during December to May. *Ondombe*s include different-scale seasonal ponds. Most of them usually range between 500 and 1000 m^2 in size and the water depth of *ondombe* is less than 1.0 m. Efficient utilization of *oshanas* and *ondombes* during rainy seasons, may alleviate problems associated with drought and food production in Namibia. *Ondombe*s are usually situated on a gentle slope having some vegetation. Closer examination has also revealed the prevalence of different soil types at different slope positions.

In principle, the local farmers do not often utilize *ondombe* for irrigation purposes because they lack water pumps to draw the water from *ondombe*. The area surrounding *ondombe* is usually left for grasses to grow, for livestock grazing, or for obtaining roof materials and the *ondombe* water is used for livestock drinking and washing clothes. Through the Rice-Pearl Millet Namibia-Japan project, efforts have been made to utilize *ondombe* for rice production and other crops such as pearl millet and sorghum (Iijima et al., 2016a). Iijima et al. (2016b) found that mixed-planting pearl millet or sorghum with rice improved the photosynthetic and transpiration rates and biomass under O_2 deficient solution culture conditions. Awala et al. (2016) reported that mixed planting with rice could alleviate flood stress under field flood conditions.

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). Although limited studies on soil fertility of seasonally flooded wetlands (*oshana*s) are available (Watanabe et al., 2016), there appears to be significant paucity of information on *ondombe*s.

A lot of croplands in arid areas have a problem of soil salinity and sodicity. It is well established that salinity reduces water availability to plants and sodicity results in sealing of soil pores and reduction of air and water exchange. Semi-arid catchments usually experience salinization and are degraded by intensive agricultural use (Moreno-Mateos et al., 2010). The irrigation and drainage mass balance is important for control of salinity effects on agriculture in semi-arid areas (Tedeschi et al., 2001; Causapé et al., 2004). Therefore, reclamation and utilization of arid wetlands should consider salt accumulation, and maintenance of food production.

This study was hence initiated to find out the soil fertility status of soils around *ondombe*s and whether the *ondombe* could be utilized for agricultural purposes unlike the present practices. The investigation of the soil physicochemical properties and salt accumulation was done to confirm the possibility of crop production from the seasonal wetlands.

MATERIALS AND METHODS

Study area

The study focuses on *ondombe* wetlands in CSWS area in north-central Namibia. Mean annual rainfall where *ondombe*s are observed, ranges from 269 to 914 mm, and an average monthly temperature from a minimum of 9.1°C in June to a maximum of 36.6°C in October, from 2003 to 2015 (Ondangwa station, Metrological service division Namibia). The vegetation can be broadly classified into the following major associations; 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). Many people benefit from the seasonal wetlands. Fishing and grazing are common practices in the wetland areas. Three villages, two in Omusati (Oshiteyatemo; 17°28'29.57"S, 15°20'19.41"E and Onamundindi; 17°45'59.17"S, 15°15'0.25"E) and one in Oshana (Afoti; 18° 0'55.20"S and 15°19'58.76"E) regions, with altitudes ranging from 1090 to 1110 m above sea level, were selected for the study of *ondombe* (Figure 2). A total of 70 representative *ondombe*s (Oshiteyatemo, 24; Onamundindi, 24; Afoti, 22) were identified in the three villages.

Soil sampling

Soil samples were collected from the plow layer (0-15 cm) during 2014 to 2015. Soil samples were collected from upper, middle and lower positions adjacent to *ondombe*s. Fifteen soil samples from 5 representative upland fields in the three villages, and 102 soil samples from different spots of the flood plain in the three *oshana*s were collected for comparison (Watanabe et al., 2016). At each spot of *oshana*, 3 sub-samples were collected along topographical setting (lower, middle upper) from 0-15 cm depth and composite sample was used for chemical/physical analysis (Watanabe et al., 2016). At the soil sampling points, the vegetation observed were few grasses, and the prevailing slope was gentle (less than 1%). The soil samples were collected and stored in plastic bags. The soil samples were air-dried and were ground and sieved to remove all materials above 2 mm diameter, before laboratory analyses.

Laboratory analysis

The samples were subjected to different physical and chemical analyses. The physical analysis involved particle size determination using the pipette method. The glass electrode method was used to

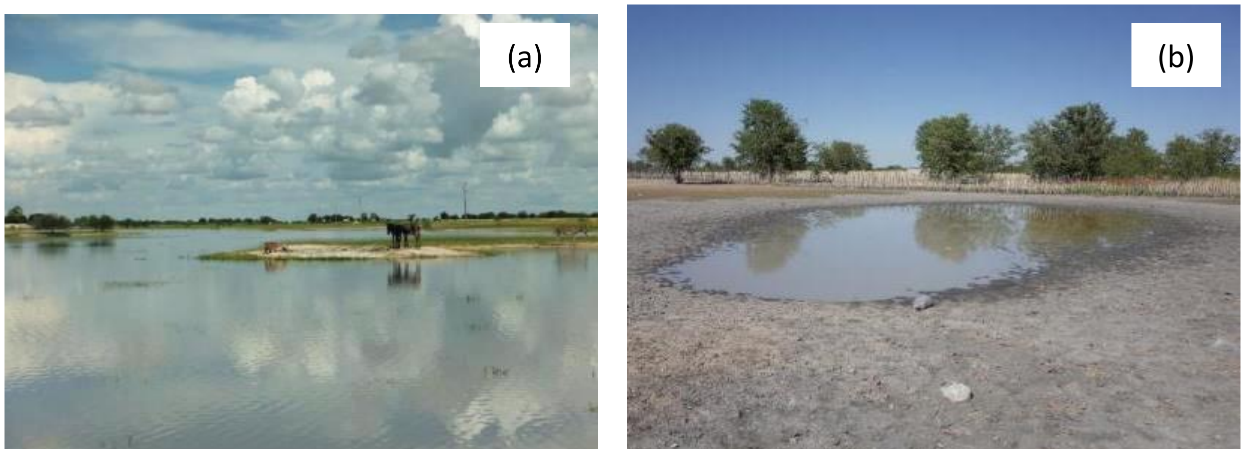

Figure 1. Picture of *oshana* (a) and *ondombe* (b).

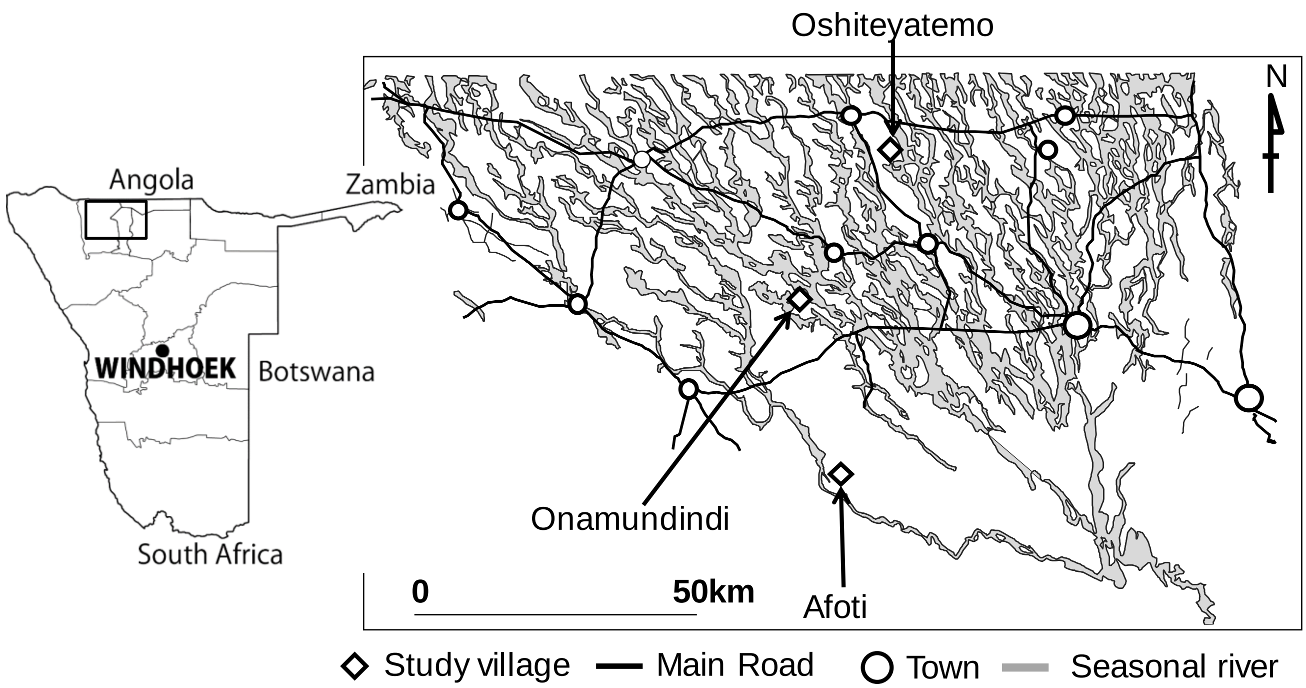

Figure 2. Location of the study sites in north-central Namibia.

determine soil pH in water (soil: H_2O, 1:2.5), and hereafter 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) spectrophotometer (Spectrophotometer; UV mini 1240, Shimadzu Corporation, Kyoto, Japan). Exchangeable calcium (Ca), magnesium (Mg), and potassium (K) and sodium (Na) 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 saturated, the electrical conductivity of the saturation extract (ECe) and the concentrations of soil Ca, K, Mg and Na were determined in the extract from saturated paste of the soil samples and were subsequently determined using a pH-mV and conductivity meter (MultiLab 540; WTW Wissenschaftlich- Technische Werkstätten GmbH Weilheim i. OB, Germany), and an Inductively Coupled Plasma-Optical Emission Spectrometer (ICP-OES; Optima 7000 DV, Perkin Elmer Inc., U.S.A.). Soil salinity is expressed by the soil electrical conductivity of saturated paste extract (ECe). The adsorption of sodium by the soil is 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 follows:

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

Table 1. Physicochemical properties, salinity and sodicity in *oshana*, cropland and *ondombe* soils.

Variables	pH (H_2O)	Organic carbon	Total N	C/N ratio	Av. P	Ex. Ca	Ex. Mg	Ex. K	Ex. Na
	($g\ kg^{-1}$)				($mg\ P\ kg^{-1}$)	($cmolc\ kg^{-1}$)			
Oshana	7.61^{a}	1.95^{a}	0.27^{a}	7.61^{a}	3.49^{a}	1.49^{a}	0.41^{a}	0.45^{a}	4.88^{a}
Cropland	7.57^{a}	2.62^{a}	0.32^{ab}	8.00^{a}	9.55^{b}	3.58^{b}	0.76^{a}	0.25^{ab}	0.12^{b}
Ondombe	6.30^{b}	6.28^{b}	0.41^{b}	17.80^{b}	4.81^{a}	2.31^{b}	1.44^{b}	0.21^{b}	0.61^{b}

Variables	Sand	Silt	Clay	pH saturated	ECe	Ca2+	Mg2+	K+	Na+	SAR
	($g\ kg^{-1}$)				($dS\ m^{-1}$)	($mmolc\ L^{-1}$)				
Oshana	852^{a}	45	103^{a}	6.55^{a}	5.47^{a}	1.92^{a}	2.08^{a}	1.29^{a}	54.06^{a}	39.84^{a}
Cropland	932^{b}	37	31^{b}	7.32^{b}	0.42^{b}	1.57^{ab}	0.75^{ab}	1.11^{ab}	1.73^{b}	2.08^{b}
Ondombe	864^{a}	53	83^{a}	6.54^{a}	0.62^{b}	0.55^{b}	0.61^{b}	0.66^{b}	4.94^{b}	7.32^{b}

Different letters indicate significant differences between treatments at 5 % significance level using Tukey-Kramer test.

Data analysis

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

RESULTS

General soil fertility conditions

Data of mean soil physicochemical properties of the *ondombe* soils are shown in Table 1. Soil pH (H_2O) from extracted soil solution in *ondombe* ranged from 4.6 to 8.8 with a mean soil pH of 6.3. Most *ondombe* soils were neutral, but some were acidic and alkaline. The soil organic C and total N in *ondombe*s ranged from 6.18 to 54.27 and 0.11 to 3.31 g kg^{-1} with a mean 6.28 and 0.41 g kg^{-1}, respectively. Available P ranged from 0.24 to 91.04 mg P kg^{-1} with a mean of 4.81 mg P kg^{-1}. The means of exchangeable Ca, Mg, K, and Na in *ondombe* were 2.31, 1.44, 0.21, and 0.61 $cmol_c$ kg^{-1}, respectively. Calcium is the cation which occupies the greater part of the exchange sites. The means of sand, silt, and clay in *ondombe* were 864, 53 and 83 g kg^{-1}, respectively. These results show that *ondombe* soils are sandy with little clay contents.

The mean values for soil salinity and sodicity of the *ondombe* soils are shown in Table 1. Based on determinations from saturated extract solution, the pH saturated of *ondombe*s ranged from 4.6 (acidic) to 8.7 (alkaline) with a mean soil pH saturated of 6.5. The ECe and SAR in *ondombe* soils ranged from 0.03 to 9.38 ds m^{-1} and 0.80 to 110.60 with a mean of 0.62 ds m^{-1} and 7.32, 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, 2008). The results show that most of *ondombe* soils do not have saline and sodic problems. In a few instances, high ECe and SAR values have been observed. The mean values for Ca, Mg, K, and Na determined from saturated extract solution were 0.55, 0.61, 0.66, and 4.94 $mmol_c$ l^{-1}. Sodium was greater than the other extracted elements.

The result of soil physicochemical properties of the *ondombe* soils from upper, middle and lower positions are shown in Figure 3. The lower positions at *ondombe* happen to have a relatively higher amount of nutrients, compared to upper and middle positions. Organic C, total N, available P, exchangeable Ca, Mg, K Silt, and Clay for the lower positons of the *ondombe* soils were significantly higher than that of the upper and middle positions. The results of soil salinity and sodicity of *ondombe* soils at different slope positions are shown in Figure 4. Soil pH saturated at upper position was significantly higher than that of middle and lower positions. Other salinity and sodicity properties were not significantly different along slope positons.

Comparison of soil physicochemical properties of *ondombe* with cropland and *oshana*

The result of mean soil physicochemical properties of the *oshana,* cropland*,* and *ondombe* soils are shown in Table 1. Soil pH (H_2O) at the *ondombe* soils was significantly lower than the croplands. The C/N ratio at all positions of the *ondombe* soils was significantly higher than that of the croplands. Organic C, exchangeable Mg, and clay at the *ondombe* soils were significantly higher than those at the croplands. Soil available P and sand at the *ondombe*s were significantly lower than that of the cropland soils. ECe and SAR, salinity and sodicity indicators, for *ondombe*s were not different from the croplands.

Soil pH (H_2O) at the *ondombe* soils was significantly lower than the *oshana*s (Table 1). Soil organic C, total N,

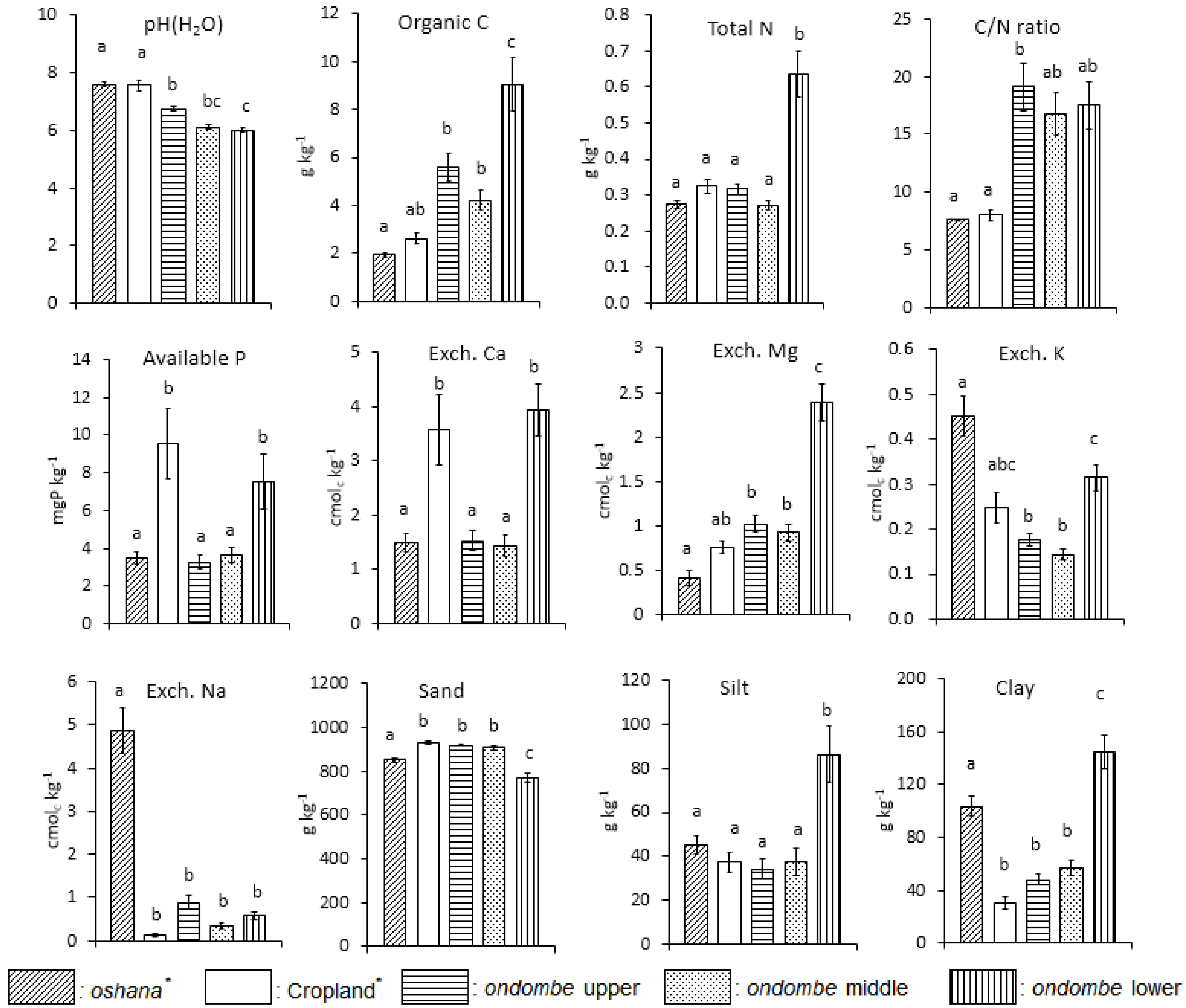

Figure 3. Soil physicochemical properties for *ondombe* soils at different slope positions, croplands, and other wetland soils. Error bars represent the standard error of mean. Different letters indicate significant differences between treatments at 5% significance level using Tukey-Kramer test. *Watanabe et al., 2016. Reference methodology (Watanabe et al., 2016) is same as the method of this paper.

C/N ratio, and exchangeable Ca and Mg at the *ondombe*s were significantly higher than the *oshana* soils. Exchangeable K and Na at the *ondombe*s were significantly lower than the *oshana* soils. ECe, Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}, and SAR for *oshana* soils were much higher than that of *ondombe*s.

Correlation between soil physicochemical properties in *ondombe*

Table 2 shows the correlation matrix of the physicochemical and saline-sodic parameters in different slope positions. The organic C was positively correlated with available P in upper and middle positions. It was correlated with exchangeable Ca, Mg and K in lower positions. The clay content was positively correlated with total N, and exchangeable cations at all slope positions, and it was correlated with ECe and SAR in upper position. Although available P was correlated with organic C, C/N ratio and exchangeable Mg in upper and middle positions, it was only correlated with C/N ratio in lower position. Among exchangeable cations, exchangeable Ca, Mg and K were positively correlated with each other.

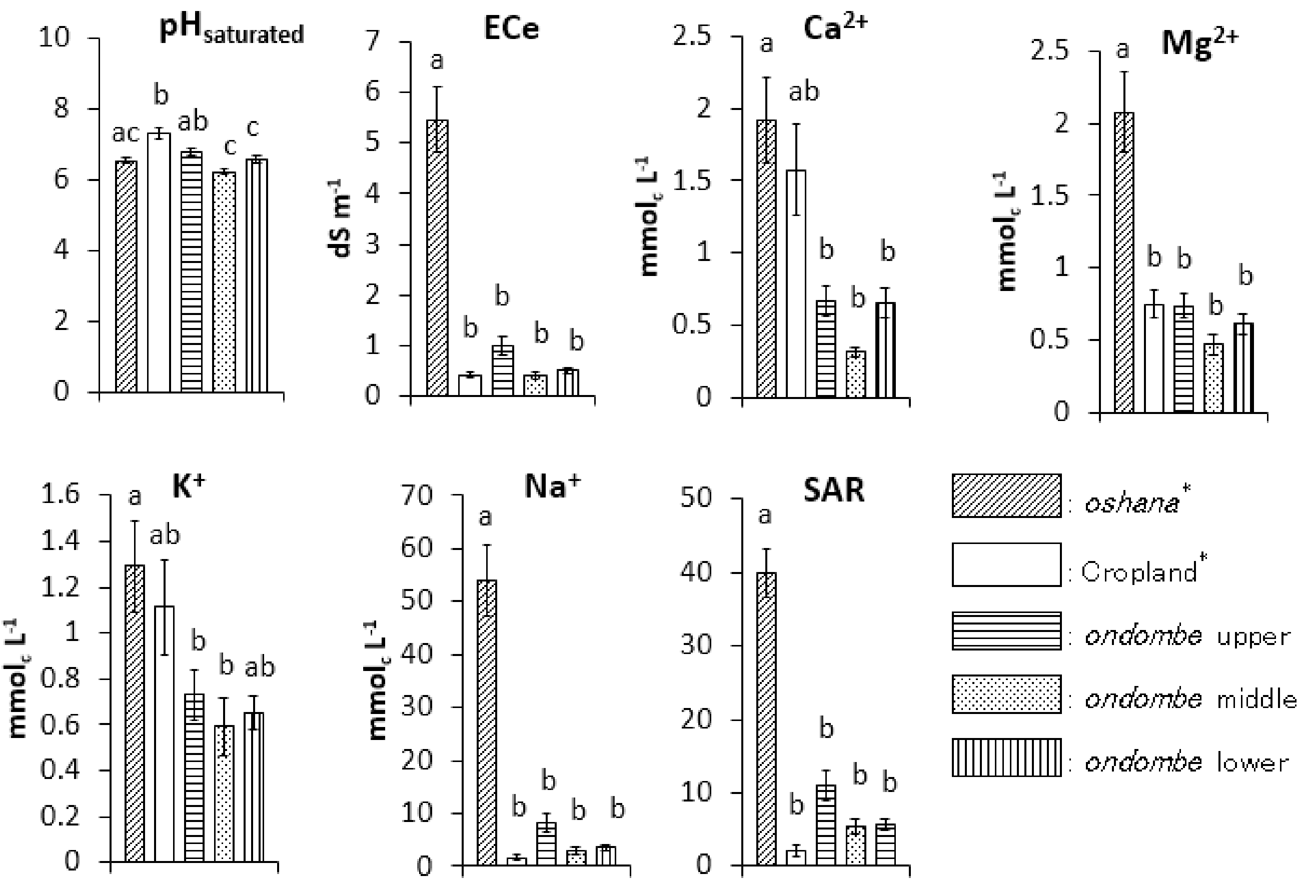

Figure 4. Soil salinity and sodicity of *ondombe* soils at different slope positions, croplands, and other wetland soils. Error bears represent the standard error of mean. Different letters indicate significant differences between treatments at 5% significance level using Tukey-Kramer test. *Watanabe et al., 2016. Reference methodology (Watanabe et al., 2016) is same as the method of this paper.

Exchangeable Na was strongly correlated with ECe and SAR. ECe was strongly correlated with SAR in all positions. SAR was positively correlated with pH (H_2O).

DISCUSSION

General soil fertility conditions of *ondombe*s

Soil pH (H_2O) of *ondombe*s was significantly lower than soil pH (H_2O) of the croplands and *oshana*s (Table 1). Organic C in *ondombe* soils is higher than the cropland and the *oshana*s soil (Table 1). High organic matter in *ondombe* soils can increase soil productivity and mitigate soil alkalinity by influencing soil pH (H_2O). Organic matter can associate H^+ irons, and can dissociate in high pH conditions, thereby modifying soil pH (Brady and Weil, 2014).

The organic carbon contents in *ondombe* soils are quite high (Table 1). The clay contents in lower positions of *ondombe* soils are also high, signifying the potential of high nutrient retention (Figure 3). *Ondombe*s are usually used for livestock grazing. Livestock come to drink water and drop their dung. A lot of studies reported that livestock manure affected and increased soil organic carbon and nitrogen (Jokela, 1992; Wani et al., 1993; Agele et al., 2005). The high plant biomass at some spots in the *ondombe*s is likely due to the high soil organic matter contents of *ondombe* soils and the dung added by animals. Under this study, organic C, total N, silt, and clay contents at the lower position of *ondombe* soils were significantly higher than that of the cropland soils (Figure 3). Soil organic C and total N of *ondombe* soils were significantly higher than the *oshana* soils (Table 1). Organic matter tends to accumulate in lower positons of *ondombe* soils. Other studies also confirm that wetlands have long-term soil organic carbon stabilization mechanisms (Cui et al., 2014). Soil organic matter and clay are well known to influence soil physicochemical properties, which as a matter of fact is suitable for agriculture. Soil organic matter reduces the plasticity and cohesion of soils, and increases water holding capacity while soil organic matter and clay hold nutrient cations (Brady and Weil, 2014). Clay content is an important

Table 2. Correlation matrix of selected physiological parameters in upper (a), middle (b), and lower (c) ondombe slope positions.

(a) Upper slope Position

	pH (H2O)	OC	Total N	C/N	Av. P	Ex. Ca	Ex. Mg	Ex. K	Ex. Na	Sand	Silt	Clay	Ece	SAR
pH	1.00													
OC	-	1.00												
Total N	0.08	0.02	1.00											
C/N	-	0.93 **	-0.24 *	1.00										
Av. P	0.07	0.56 **	0.00	0.50 **	1.00									
Ex. Ca	0.04	0.16	0.58 **	-0.06	0.15	1.00								
Ex. Mg	0.28 *	0.06	0.21	-0.08	0.27 *	0.42 **	1.00							
Ex. K	0.37 **	0.13	0.43 **	-0.03	0.42 **	0.29 *	0.55 **	1.00						
Ex. Na	0.59 **	-0.27 *	0.06	-0.29 *	-0.04	-0.13	0.34 **	0.45 **	1.0					
Sand	- **	-0.02	-0.39 **	0.15	-0.13	-0.59 **	-0.82 **	-0.55 **	- **	1.00				
Silt	-	0.22	0.30 *	0.09	0.03	0.37 **	0.34 **	0.23	0.0	-0.48 **	1.00			
Clay	0.44 **	-0.07	0.31 *	-0.21	0.13	0.50 **	0.77 **	0.52 **	0.5 **	-0.92 **	0.09	1.00		
Ece	0.34 **	-0.24 *	0.08	-0.27 *	-0.03	-0.09	0.17	0.36 **	0.8 **	-0.32 **	0.09	0.32 **	1.00	
SAR	0.43 **	-0.25 *	-0.02	-0.24 *	-0.07	-0.21	0.10	0.33 **	0.8 **	-0.28 *	0.03	0.30 *	0.86 **	1.00

(b) Middle slope Position

	pH (H2O)	OC	Total N	C/N	Av. P	Ex. Ca	Ex. Mg	Ex. K	Ex. Na	Sand	Silt	Clay	Ece	SAR
pH	1.00													
OC	0.07	1.00												
Total N	-	0.14	1.00											
C/N	0.29 *	0.62 **	-0.24 *	1.00										
Av. P	0.17	0.63 **	0.25 *	0.36 **	1.00									
Ex. Ca	0.06	0.11	0.60 **	-0.20	0.31 **	1.00								
Ex. Mg	0.12	0.08	0.68 **	-0.29 *	0.27 *	0.82 **	1.00							
Ex. K	-	0.16	0.67 **	-0.21	0.17	0.46 **	0.52 **	1.00						
Ex. Na	0.67 **	0.06	0.12	-0.12	0.18	0.11	0.32 **	0.17	1.0					
Sand	-	-0.12	-0.80 **	0.30 *	-0.25 *	-0.84 **	-0.91 **	-0.58 **	-	1.00				
Silt	0.05	0.18	0.77 **	-0.28 *	0.18	0.62 **	0.71 **	0.48 **	0.0	-0.87 **	1.00			
Clay	0.10	0.08	0.73 **	-0.28 *	0.26 *	0.88 **	0.93 **	0.57 **	0.3 *	-0.96 **	0.71 **	1.00		
Ece	0.54 **	0.07	-0.05	-0.21	0.15	-0.08	0.02	0.05	0.8 **	0.01	-0.11	0.05	1.00	
SAR	0.59 **	0.02	-0.08	0.13	0.10	-0.17	-0.04	0.06	0.8 **	0.05	-0.10	-0.02	0.93 **	1.00

(c) Lower slope Position

	pH (H2O)	OC	Total N	C/N	Av. P	Ex. Ca	Ex. Mg	Ex. K	Ex. Na	Sand	Silt	Clay	Ece	SAR
pH	1.00													
OC	0.04	1.00												
Total N	- **	0.42 **	1.00											
C/N	0.29 *	0.62 **	-0.24 *	1.00										
Av. P	0.15	0.20	0.00	0.36 **	1.00									
Ex. Ca	-	0.27 *	0.61 **	-0.20	0.00	1.00								
Ex. Mg	-	0.29 *	0.62 **	-0.29 *	-0.01	0.75 **	1.00							
Ex. K	-	0.29 *	0.66 **	-0.21	0.02	0.55 **	0.72 **	1.00						
Ex. Na	0.39 **	0.00	0.01	-0.12	0.00	-0.01	0.38 **	0.30 *	1.0					
Sand	0.08	-0.14	-0.53 **	0.30 *	0.05	-0.69 **	-0.85 **	-0.72 **	-	1.00				

Table 2. Contd.

Silt	0.07	0.07	**0.39** **	**-0.28** *	-0.07	**0.52** **	**0.74** **	**0.59** **	0.2	**-0.87** **	1.00			
Clay	-	0.17	**0.55** **	**-0.28** *	-0.03	**0.71** **	**0.83** **	**0.72** **	0.1	**-0.97** **	**0.72** **	1.00		
Ece	**0.31** *	-0.10	0.00	-0.21	-0.01	0.02	0.19	0.09	**0.7** **	-0.09	-0.01	0.14	1.00	
SAR	**0.30** *	-0.01	-0.23	0.13	0.11	**-0.36** **	-0.19	-0.05	**0.5** **	**0.25** *	**-0.29** *	-0.21	**0.62** **	1.00

*, ** = significant at 0.05 and 0.01 probability levels, respectively; OC = organic carbon; Av. P = Available P (Olsen method); Ex. Ca, Ex. Mg, Ex. K., Ex. Na = exchangeable cations, respectively; ECe = Electrical conductivity of the saturation extract; SAR = Sodium Adsorption Ratio of the saturated paste extract.

factor for land productivity and drought tolerance (He et al., 2014). At our study site, organic C and clay contents were correlated with many soil fertility parameters (Table 2a to c). These results suggest that *ondombe* soils, especially at lower positions, have appropriate condition for agriculture.

The amount of available P at the lower positons in the *ondombe* soils, which is significantly higher than that of the upper and middle positions (Figure 3), can improve the amount and quality of crop production. Balkcom et al. (2005) reported that landscape position affected soil P concentration. It was considered that phosphorus accumulated by erosion and deposition during flooding from higher to lower positions in *ondombe*s. The available P at cropland was significantly higher than that of soils along *oshana*s and *ondombe*s. Generally, high P fertility on the floodplain would only be expected to arise if long-term floodplain P deposition was the dominant process affecting P fertility (Ogden et al., 2007). Phosphorus deficiency is a major constraint to crop production in sub-Sahara Africa due to inherently low P in the parent material and no use of fertilizer (Nziguheba et al., 2016). These soils have high iron and aluminum oxides and hydroxides, and resultantly also have high P sorption (Bekunda et al., 2010). These compounds are the least soluble and the least available sources of phosphorous. However, phosphorus is released and made available under wet conditions. Therefore, soil in lower *ondombe* position has higher available phosphorus content, due to solubility by water, and that position is a very important spot in semi-arid Africa. Available soil P, exchangeable Ca and Mg, silt and clay at the upper and middle positions of *ondombe*s were lower than that of lower position of *ondombe*s. The soil fertility of inland valley bottom in West Africa is similarly enriched by soil deposition of organic C, available P, exchangeable Ca and Mg, silt and clay (Ogban and Bebalola, 2003). Exchangeable Ca and Mg increased downslope positions (Brubaker et al., 1993). Our results suggest that available P, exchangeable Ca and Mg, silt and clay materials tend to be removed by erosion from upper parts of *ondombe*s and accumulate in bottom land positions.

Soil salinity and sodicity conditions of *ondombe*s

The average ECe and SAR in the *ondombe* soils were 0.62 ds m^{-1} and 7.36, respectively (Table 1). These values were less than the threshold of saline and sodic soils which was defined by Soil Science Society of America (2008). Although most *oshana* soils are saline-sodic soils (Watanabe et al., 2016), problems of salinity and sodicity do not so much appear to be in *ondombe* soils. In fact, ECe, and SAR values at all positions of the *ondombe* soils were significantly lower than the *oshana*s (Figure 4). In understanding, semi-arid landscapes, sodic soils begin to appear from the footslope position (Dye and Walker, 1980). Clays and salts are transported downslope from uplands by runoff and accumulate at the footslope (Sumner, 1993). Hence, the *oshana* soils are likely to accumulate salts. Humphries et al. (2011) reported that soil salinity and sodicity are related with salt contents in groundwater. It was considered that soil formation processes are different around *oshana*s compared to *ondombe* soils. Therefore, only *ondombe* soils generally have low saline and sodic levels. According to the mean values of saturated extract solution, the Na^+ (sodium) content is much higher than the Ca^{2+}, Mg^{2+}, and K^+, contents in other solutions (Table 1). The sodium extracted from saturated extract solution signifies that Na is main factor for soil sodicity. These results indicated that the *ondombe* soils are likely prone to sodicity in the long run. It is evident that sodic soils tend to be worse than saline-sodic soil; in terms of detrimental factors such as poorer physical soil conditions which include low permeability to air and water than saline-sodic soil (Brady and Weil, 2008). Therefore, it is important to monitor soil management from such adverse soil conditions.

Conclusion

*Oshana*s and *onbombe*s are both seasonal wetlands in north-central Namibia, although the surrounding soils are significantly different in their physicochemical properties. Most of *ondombe* soils did not exhibit salinity and sodicity problems. They contained reasonable amount of essential nutrients and favorable pH. *Ondombe* soils also have higher organic C and clay due to erosion from higher to lower positions. *Ondombe*s consist of a good amount of water for a period of about 5 to 6 months through the year. From this study, it can be concluded that *ondombe* soils have far better favorable conditions for crop production than *oshana* soils.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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