Research article

Variations in soil physicochemical characteristics in some soil profiles of Okavango Delta's Panhandle region, Botswana

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Abstract: The distribution of organic matter and nutrients in a soil profile provide insights in nutrient inputs, outputs, and the processes involved. A study to assess variations in physicochemical characteristics of soils was conducted at Seronga in the Okavango Delta, Botswana. Soil samples were collected at different soil depths in different land use/cover systems and analysed using standard methods. Soil organic matter (SOM), available P (AP), exchangeable Ca, Mg and K, moisture and texture significantly ($p<0.05$) differed with depth. Exchangeable Na, soil reaction and conductivity did not differ with soil depth. Organic matter varied from 0.19±0.01 at 0-10 cm in *Terminalia sericea* (Burch) ex DC to 1.00±0.6% in *Dichrostachys cinerea* (L.) Wight & Arn woodland at 10-20 cm. Significantly higher concentrations of AP were recorded on the soil surface in the *Cynodon dactylon* (L.) Pers grassland (7.13±0.07 mg/kg) and lowest (1.79±0.04 mg/kg) in *T. sericea* woodland. Exchangeable Ca ranged between 0.10±0.01 in *T. sericea* to 4.59±0.44 cmolc/kg in *Ximenia americana* (L.). Exchangeable Mg increased with depth, with highest concentrations (3.05±0.73 $cmol_c$/kg) recorded at depth 30-40 cm in *D. cinerea*. Exchangeable K was highly concentrated on the soil surface, ranging from 0.031±0.003 in *T. sericea* to 0.445±0.038 $cmol_c$/kg in fallow land. Moisture decreased while electrical conductivity and soil pH increased with depth. Sand fraction decreased with soil depth while clay increased down the profile. Soil organic matter was not correlated with clay content (R^2=0.192) but significantly correlated with moisture, AP and K. The results indicate that Seronga soils are highly sandy (minimum of 96%), with low SOM, AP and exchangeable cations. Vertical variations with depth exist in the physicochemical properties of Seronga soils but there are specific to land use/cover systems.

Keywords: available phosphorus; calcium; cropped land; organic matter; potassium; soil texture; *Terminalia sericea*.

Abbreviations: AP = Available Phosphorus; SOM = Soil organic matter

As variações nas características físico-químicas do solo em alguns tipos de solo da região de Panhandle do delta do Okavango, Botswana

Resumo: A distribuição de materia orgânica e nutrientes em um tipo de solo fornece informações sobre a absorção e vazão de nutrientes e os processos envolvidos. Um estudo para avaliar as variações nas características fisico-químicas do solo foi realizado em Seronga no delta do Okavango, Botswana. Amostras de solo foram coletadas em diferentes profundidades e sistemas de uso/cobertura do solo e analisadas utilizando métodos padrão. A matéria orgânica do solo, o P disponível, o Ca permutável, o Mg e o K, a umidade e a textura ($p<0.05$) diferiram significativamente com a profundidade. O Na permutável, a reação do solo e a condutividade não diferiram com a profundidade. A matéria orgânica variou de 0.19±0.01 em 0-10 cm na *Terminalia sericea* (Burch) ex DC a 1.00±0.61% em 10-20cm na *Dichrostachys cinerea* (L.), floresta Wight & Arn. Concentrações significativamente mais elevadas de P disponível foram registradas na superfície do solo na *Cynodon dactylon* (L.), na campina Pers, (7.13±0.07mg/kg) e mais baixas (1.79±0.04mg/kg) na *T. sericea* dos bosques. O Ca permutável variou entre 0.10±0.01 na *T. sericea* a 4.59±0.44cmolc/kg na *Ximenia americana* (L.). O Mg permutável aumentou com a profundidade, com concentrações mais elevadas (3.05±0.73$cmol_c$/kg) registradas em uma profundidade de 30-40 cm na *D. cinerea*. O K permutável estava altamente concentrado na superfície do solo, variando de 0.031±0.003 na *T. sericea* a 0.445±0.038 $cmol_c$/kg em pousio. A umidade diminuiu enquanto a condutividade elétrica e o pH do solo aumentaram com a profundidade. A fração de areia diminuiu com a profundidade do solo enquanto a argila aumentou. A matéria orgânica era ruim e não significativamente correlacionada com o teor de argila (R^2=0.192), mas significativamente correlacionada com a umidade, o P e o K. Os resultados indicam que os solos de Seronga são altamente arenosos (mínimo de 96%) e com matéria orgânica, P disponível e cátions permutáveis baixos. Variações verticais com a profundidade existem nas propriedades fisico-químicas dos solos de Seronga, mas há variações específicas para os sistemas de uso/cobertura do solo..

Palavras-chave: cálcio; fósforo disponível, matéria orgânica;, potássio; solo cultivado; *Terminalia sericea*; textura do solo.

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Introduction

Soil activities such as weathering, mineralisation, leaching and aerial deposition can result in intense vertical exchange of materials, which in turn may lead in physical and chemical variations down the soil profile (Buol et al. 1989, Trudgill 1988). The distribution of soil organic matter (SOM) and nutrients in a profile provide insights in nutrient inputs, outputs and the processes involved (Jobbágy & Jackson 2001). Atmospheric deposition and weathering affect the actual depth at which nutrient inputs occur. Leaching causes a downward movement of soil nutrients leading to higher concentration deeper in the soil profile whereas biological cycling and capillary rise of water causes the upward movement of soil nutrients. However, plant cycling has been reported to be the main process driving the vertical distribution of N, P and K in a soil profile (Jobbágy & Jackson 2001). Depending on the type of dominant plants, some plant systems such as grasslands may lead to maximum concentration of nutrients in the surface horizons and these may decrease with depth.

The distribution of organic matter varies with environment, management system and soil depth. Soil organic matter, which plays a major role in nutrient retention, generally decreases with depth and is highly influenced by particle size distribution. As such, many studies have reported strong correlations between soil carbon and clay content (Parton et al. 1993, Schimel et al. 1994, Alverez & Lavado 1998). However, in New Zealand low correlations ($R^2 < 0.05$) with both clay and silt content were reported, suggesting that the importance of clay content vary with region due to other environmental conditions (Percival et al. 2000). Some studies have reported an increase of clay content and decrease of sand content with depth (Salako et al. 2006, Toriyama et al. 2013). In these studies, clay content showed a significant change between 0-50 cm and was relatively stable beyond 50 cm whereas silt content did not vary with soil depth.

Changes in soil profile nutrient distribution have a significant impact on the productivity, ecology and land management systems by altering nutrient availability (Franzluebbers & Hons 1996). The Okavango wetland is susceptible to land use/cover change due to its rich biodiversity and as a source of water in a dry region. Soil nutrients therefore play a vital role in sustaining the productivity of this ecosystem. Studying variations of physicochemical properties in a soil profile will help understand the consequences and shifts in resource use associated with land use/cover change (Jackson et al. 2000). This study aimed at evaluating physicochemical characteristics in a soil profile with intention to generate information vital in sustainable land use management.

Materials and methods

Study area

The research study was conducted in Seronga village and the surrounding areas (Fig. 1), located on the eastern part of the Okavango Delta's Panhandle region (18048'13.37"S and 22º027'25.69"E), 980 m above sea level. Seronga is a focal point for most of the settlements located east of the Okavango Panhandle, hence, susceptible to land use/cover change. The area lies under a semi-arid climate with annual mean precipitation of 250 mm and annual minimum-maximum temperatures of 25ºC and 40ºC. The soils of Okavango Delta floodplains are deep sands and have been classified as arenosols (Simmonds 1998), highly sandy (minimum of 85%), with very low CEC (< 5meq/100g-1 soil) and thus have a low water and nutrient holding capacity (Starring 1978). The seasonal rainfall is therefore likely to leach most of the nutrients down the soil profile.

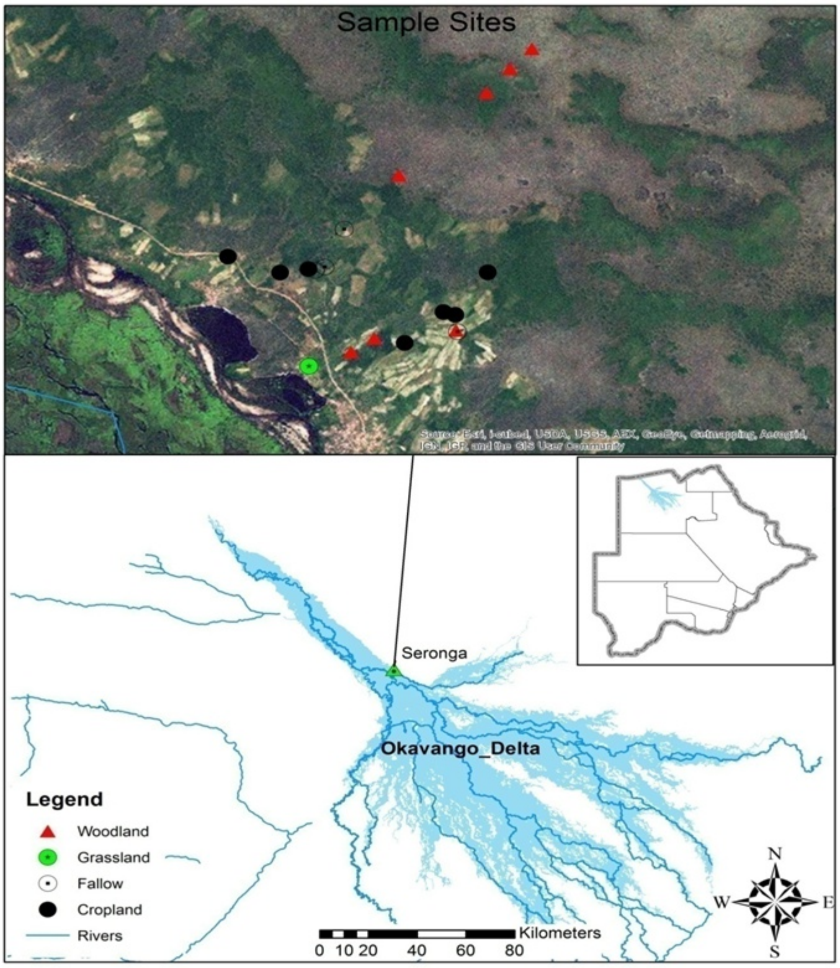

Fig. 1: Map of the Okavango Delta, Botswana showing the sampling points at Seronga, the study site.

Soil sampling and processing

Soil samples were collected in May 2012, during the dry season when the temperatures range from 10 ºC to 28 ºC (http://en.climate-data.org/location/29847), from a 20 by 5km sampling area, (18.8136S 22.3442E; 18.8423S 22.3816E; 18.6755S 22.4675E and 18.7047S 22.5038E) in Seronga region. The area consists of cropped and fallow land, and different vegetation types consisting of grasslands closet to the channel, followed by *Dichrostachys spp, Terminalia, Ximenia americana* and eventually *Colosphernum mopane* woodlands furthest from the water channel. Thus the sampled area cuts across a wide range of land cover i.e., grassland, cropped, fallow and woodland. The vegetation types are defined based on the dominant plant species on that particular land use/cover system.

Soil sampling was done every 0.5-1.0 km based on land use/cover systems and accessibility. For each land cover three soil profiles chosen were located at least 10 m apart. Each profile sampled consisted of 4 sub-samples of approximately 1 m apart. The samples were taken from different soil depths (0-10, 10-20, 20-30 & 30-40 cm) using a depth marked undisturbed soil auger and probe.

Representative samples of approximately 500 g each were then packed into polyethylene bags with

Ziploc closure and kept in cooler boxes. In all a total of 228 samples were collected, (12 sampling points x 19 land use/cover systems: 1 *C. dactylon*; 1 *D. cinerea*; 1 *X. americana*; 2 *T. sericea*; 2 *C. mopane* (short); 1 *C. mopane* (tall); 4 fallow land and 7 cropped land). After 2 days the samples were transported to the Okavango Research Institute (ORI) laboratory. Once at the laboratory soil moisture content was determined gravimetrically by drying at 105ºC and then expressed on dry weight basis (Anderson and Ingram 1993). The rest of the samples were air dried at room temperature, sieved through a 2 mm sieve and then stored in airtight vials prior analysis.

Soil analysis

Active soil acidity was determined in 1:2 soil:water solution while potential acidity was determined in 1:2 soil:0.01M $CaCl_2$ using an HB-LB-152H corning pH meter with a glass electrode (Anderson & Ingram 1993). Electrical conductivity of the soil was determined in a 1:2 soil:water solution using an EC meter. Particle size distribution was determined using sedimentation method and sodium hexametaphosphate as a dispersing agent (Kettler et al. 2001). Soil organic matter was determined using the loss on ignition (LOI) procedure (Ben-Dor & Banin 1989). The samples were oven dried at 105ºC and then put in a furnace at 375ºC for 2 hours. Available P was determined according to Bray & Kurtz (1954) using Bray P1 extractant (0.03*N* NH_4F and 0.025*N* HCl). Exchangeable Ca and Mg were measured with atomic absorption spectrophotometry while Na and K were determined using flame photometer after extracting with 1*N* NH_4OAc at pH 7.0 (Thomas 1982).

Statistical Analysis

Soil profile variations of physicochemical properties with depth were determined for each land use/cover system. Assumptions of normality and homogeneity of data were checked using Kolmogorov-Smirnov and Levene's test in SPSS (SPSS Inc. 1993). All data violated the assumptions of ANOVA therefore the Kruskal-Wallis test was used to determine variations of soil physicochemical properties in a soil profile. Mean separation was based on soil depth in different land use/cover systems. The relationship among soil properties was investigated using Pearson product-moment correlation coefficient in SPSS.

Results

Effect of soil depth on moisture content, texture, soil activity and electrical conductivity

In general, there was no significant difference in the sand content with depth amongst all the land use/cover systems, except for except in *X. americana* woodland (Table 1). Silt content varied significantly with soil depth except for cropped land and *T. sericea* ranging from 2.4±0.1% in cropped land to 0% in woodland *T. sericea*, *Colosphernum mopane*, and *D. cinerea*. Clay content showed an increase with depth (Table 1). Overall, very low silt and clay content is contained in Seronga soils. Regardless of the minor variations observed on particle size, soil texture was similar in all the land use/cover systems i.e. sandy.

For each land use/cover, moisture content and soil texture differed significantly ($p<0.05$) with depth (Table 1). For all soil samples, moisture decreased from a maximum on cropped land of 4.11±0.10% at 0-10 cm to a minimum of 1.24±0.17% in *T. sericea* woodland.

Soil pH increased with soil depth but the variation was not significant. Soil pH ($CaCl_2$) varied from 3.70±0.02 in *T. sericea* at 0-10 cm to 6.7±0.2 in grassland at 30-40 cm whereas pH(H_2O) varied from 7.06±0.27 at 30-40 cm in grassland to 4.41±0.01 at 0-20 cm in *T. sericea*. (Table 2). Electrical conductivity increased with depth but the increase was not significant (Table 2).

Variations of soil organic matter and macronutrients with depth

Soil organic matter, Ca, Mg and K differed significantly ($p<0.05$) with depth in only few land use/cover systems (Table 3). Overall, very low organic matter contents were recorded and there was little differences between different soil depths. Soil organic matter ranged from 1.00±0.61% in *D. cinerea* woodland at depth 10-20 cm to 0.19±0.01% in *T. sericea* at depth 0-10 cm (Table 3). Similarly, P decreased significantly with soil depth from 7.13±0.07 mg/kg (0-10 cm) in grassland to 1.79±0.04 mg/kg at depth 30-40 cm in *T. sericea*. Variation of P within the soil profile was also limited to woodland *X. americana*, fallow and cropped land. Differences were observed between depth 0-10 cm and 30-40 cm.

Calcium concentration ranged from 4.59±0.44 cmolc/kg in *X. americana* at 20-30 cm to 0.10±0.01 cmolc/kg in *T. sericea* (Table 3). Exchangeable Ca differed significantly ($p<0.05$) with soil depth. Exchangeable magnesium ranged from 3.05±0.73 $cmol_c$/kg in *D. cinerea* to 0.049±0.003 $cmol_c$/kg in *T. sericea* (Table 3). Exchangeable Mg varied with depth in *X. americana* and in Mopane woodland between depth 0-10, 20-30 and 30-40 cm. Table 3 shows that K ranged from 0.445±0.038 $cmol_c$/kg in fallow land to 0.031±0.003 $cmol_c$/kg at depth 20-30 cm in *T. sericea*. There was no significant difference in Na concentration with depth at different land use/cover systems.

Relationships among organic matter, nutrients, moisture, texture, acidity and electrical conductivity

Table 4 shows the correlation coefficients between organic matter, nutrients and other selected soil parameters. Organic matter showed significant and positive correlation with P ($p<0.05$), K, moisture and electrical conductivity ($p<0.01$). There was a positive but non-significant correlation ($R^2=0.19$) between organic matter and clay content. Exchangeable Ca and Mg showed a strong and significant relationship (R2=0.778) at $p<0.01$. Basic cations (Ca and Mg) negatively and significantly correlated with sand but positively correlated with clay. A highly significant ($p<0.01$) correlation was observed between Ca and K with EC.

Discussion

Vertical distribution of soil physical and chemical properties with depth along soil profiles

The results (Table 1 and Table 3) show that there is a significant effect of soil depth on the distribution and availability of both physical and chemical characteristics of Seronga soils. Soil moisture, texture, organic matter, P, Ca, Mg and K differed significantly ($p<0.05$) with soil depth, even though variations were limited to specific land use/cover systems.

Table 1: Profile distribution of soil texture in different land use/cover systems (± standard error). Means followed by the same letter in the same column are not significantly different from each other at 5% (p<0.05).

Parameter (%)	Depth (cm)	Grassland	*Ximenia americana*	*Dicrostachys cinerea*	*Terminalia sericea*	Mopane (short)	Mopane (tall)	Fallow land	Cropped land
Sand	0-10	98.4±0.6	97.2±0.1ab	97.6±1.2	99.6±0.2	97.6±0.6	97.6±2.0	97.6±0.6	98.0±1.0
	10-20	97.6±0.1	97.6±0.1b	97.2±1.0	99.2±0.1	97.6±0.1	99.6±0.2	97.6±1.1	97.2±0.1
	20-30	98.0±0.6	96.0±0.3a	97.2±0.6	99.6±0.2	96.4±1.7	98.0±0.6	97.6±1.8	97.2±0.6
	30-40	98.0±0.6	96.8±0.6ab	97.2±1.5	99.6±0.1	96.8±1.2	98.4±0.8	96.0±0.3	96.8±0.6
p-value		0.791	0.045	0.978	0.281	0.871	0.362	0.478	0.644
Silt	0-10	0.8±0.1ac	1.6±0.1a	1.2±0.2ab	0	2.0±0.3ac	2.0±0.1a	2.0±0.3ac	1.6±0.03
	10-20	1.6±0.1b	0.4±0.1b	1.2±0.1b	0	0.4±0.1b	0b	2.0±0.1bc	2.4±0.1
	20-30	0.4±0.1a	1.2±0.1ab	0.8±0.1abc	0	1.6±0.1c	0.8±0.1ab	1.6±0.1c	2.0±0.3
	30-40	1.2±0.1bc	1.2±0.1ab	0c	0	1.2±0.1bc	0b	3.2±0.1ab	2.4±0.1
p-value		0.016	0.033	0.022	1	0.022	0.014	0.043	0.097
Clay	0-10	0.8±0.1	1.2±0.1a	1.2±0.1a	0.4±0.1	0.4±0.1	0.4±0.1a	0.4±0.1a	0.4±0.1
	10-20	0.8±0.2	1.6±0.1ab	1.6±0.1ab	0.8±0.2	2.0±0.5	0.4±0.1a	0.4±0.1a	0.4±0.1
	20-30	1.6±0.1	2.8±0.2bc	2.0±0.2ac	0.4±0.1	2.0±0.5	1.2±0.1ab	0.8±0.02b	0.8±0.1
	30-40	0.8±0.1	2.0±0.2ac	2.8±0.1bc	0.4±0.1	2.0±0.1	1.6±0.4b	0.8±0.1b	0.8±0.1
p-value		0.087	0.019	0.02	0.154	0.095	0.035	0.038	0.055

Soil moisture decreased with depth (Table 1), a result of water uptake by roots. Seronga soils are highly sandy leading to poor water holding capacity (Starring 1978; Foth 1990). This is also supported by the negative correlation (Table 4) between moisture content and sand.

The clay content of these soils was generally low (0.4-2.8%) (Table 1) when compared to other Delta regions in Africa (Benka & Ekundayo 1995). However, in all the samples, the clay content was always lowest on the soil surface and increased with soil depth, supporting findings by Salako et al. (2006) and Toriyama et al. (2013). In most cases, maximum clay content was observed in the 30-40 cm depth. This may indicate leaching of clays and lower migration of clays in sandy soils (Foth 1990). Ringrose et al. (2005) documented evidence of clay migration having occurred 10-40 Ka years ago in these soils. Although several studies have indicated a significant and strong relationship between organic matter and clay content (Parton et al. 1993; Schimel et al. 1994), in this study the organic matter concentrated close to the surface while the clay was mostly at depth. Therefore the low (R^2=0.19) and non-significant correlation between organic matter and clay obtained in this study (Table 4). This could also be that clay is more significant in controlling the distribution of organic matter in deeper layers as reported in other studies (e.g. Jobbágy & Jackson 2000). In their study that included data from other regions in Africa and emphasized on tropical soils, 0.07, 0.10 and 0.61 were recorded as R2 values between organic carbon and clay content at depths 0-20, 20-40 and 200-300 cm respectively showing that the importance of clay might increase with depth.

There was no significant difference in pH values with depth (Table 2). However, pH correlated positively and significantly with EC and organic matter (Table 4). This could be due to soluble salts increasing soil buffering capacity leading to an increase in pH (Gao et al. 2010) and high organic matter content on the soil surface producing acids during decomposition contributing to low pH on the soil surface.

Soil organic matter varied significantly ($p<0.05$) with soil depth (Table 3). The variation was observed between depth 0-

Table 2: Soil moisture, pH, organic matter (SOM), and available P along soil profiles in different land use/cover systems (± standard error). Means followed by the same letter in the same column are not significantly different from each other at 5% (p<0.05).

Parameter	Depth (cm)	Grassland	*Ximenia americana*	*Dicrostachys cinerea*	*Terminalia sericea*	Short mopane	Tall mopane	Fallow	Cropped
% Moisture	0-10	2.74±0.07	3.74±0.14a	3.41±0.14a	2.27±0.85	3.23±0.35a	2.44±0.07a	3.30±0.17a	4.11±0.10a
	10-20	2.71±0.13	3.66±0.06ab	2.92±0.20ab	2.02±0.84	2.74±0.05a	2.37±0.02a	3.08±0.09a	4.07±0.13a
	20-30	2.67±0.03	3.06±0.13bc	2.86±0.18ab	1.73±0.40	2.46±0.03ab	2.09±0.08ab	2.79±0.10ab	3.73±0.12ab
	30-40	1.54±0.10	2.29±0.54c	1.54±0.02b	1.24±0.17	1.57±0.17b	1.75±0.18b	1.81±0.10b	1.98±0.05b
p-value	0.082	0.034	0.038	0.679	0.022	0.028	0.022	0.041	
pH(H_2O)	0-10	6.65±0.15	6.40±0.16	5.94±0.26	4.41±0.01	5.93±0.14	5.64±0.17	6.07±0.06	6.50±0.06
	10-20	6.82±0.24	6.44±0.15	6.13±0.17	4.41±0.04	5.98±0.01	5.66±0.16	6.09±0.05	6.52±0.02
	20-30	6.80±0.27	6.54±0.15	6.24±0.07	4.54±0.13	6.01±0.05	5.74±0.10	6.16±0.16	6.63±0.05
	30-40	7.06±0.27	6.67±0.36	6.35±0.03	4.65±0.11	6.29±0.27	5.76±0.09	6.58±0.12	6.69±0.02
p-value		0.553	0.933	0.238	0.254	0.639	0.979	0.084	0.079
% SOM	0-10	0.67(±0.07)	0.74(±0.18)	0.53(±0.13)	0.19(±0.01)a	0.60(±0.20)	0.40(±0.20)	0.67(±0.09	0.53(±0.03)
	10-20	0.60(±011	0.80(±0.12)	1.00(±0.61)	0.46(±0.13)b	0.67(±0.18)	0.27(±0.07)	0.57(±0.02)	0.68(±0.36)
	20-30	0.60(±0.20)	0.67(±0.29)	0.40(±0.12)	0.40(±0.06)b	0.57(±0.09)	0.27(±0.07)	0.53(±0.04)	0.49(±0.03)
	30-40	0.62(±0.05)	020(±0.0004)	0.27(±0.07)	0.25(±0.05)ab	0.40(±0.10)	0.33(±0.13)	0.48(±0.04)	0.37(±0.03)
p-value		0.781	0.113	0.74	0.041	0.568	0.516	0.204	0.228
Available P (ppm)	0-10	7.13(±0.07)	3.48(±0.07)a	3.30(±0.40)	2.10(±0.14)	4.56(±1.62)	3.06(±0.38)	2.64(±0.05)a	5.70(±0.45)a
	10-20	6.960(±1.36)	3.32(±0.35)a	244(±0.02)	1.88(±0.07)	2.70(±0.21)	2.41(±0.03)	2.04(±0.01)ab	3.28(±0.14)a
	20-30	5.57(±1.21)	2.47(±0.08)ab	2.33(±0.05)	2.16(±0.31)	2.13(±0.22)	2.41(±0.08)	1.91(±0.06)b	2.52(±0.07)b
	30-40	3.44(±0.71)	2.12(±0.05)b	2.44(±0.23)	1.79(±0.04)	2.30(±0.12)	2.27(±0.13)	1.85(±0.06)b	2.38(±0.02)b
p-value		0.108	0.024	0.103	0.176	0.408	0.121	0.022	0.019

Table 3: Soil nutrient cations and electrical conductivity (EC) along the profiles in the different land use/cover systems (± standard error). Means followed by the same letter in the same column are not significantly different from each other at 5% (p<0.05).

Parameter ($cmol_c/kg$)	Depth (cm)	Grassland	*Ximenia americana*	*Dicrostachys cinerea*	*Terminalia sericea*	Short mopane	Tall mopane	Fallow	Cropped
Ca	0-10	1.89(±0.09)	2.58(±0.42)	1.75(±0.24)a	0.30(±0.06)	1.77(±0.17)	1.77(±0.10)	2.71(±0.27)	2.24(±0.17)
	10-20	2.57(±0.33)	3.46(±0.24)	2.83(±0.45)ab	0.17(±0.03)	2.14(±0.04)	1.51(±0.15)	2.60(±0.37)	3.18(±0.07)
	20-30	2.52(±0.31)	4.59(±0.44)	3.75(±0.19)b	0.10(±0.01)	2.12(±0.12)	1.34(±0.18)	2.76(±0.30)	2.69(±0.15)
	30-40	2.62(±0.14)	4.19(±0.40)	3.82(±0.32)b	0.16(±0.04)	2.27(±0.25)	1.10(±0.18)	3.25(±0.11)	2.79(±0.18)
p-value		0.192	0.057	0.041	0.079	0.192	0.123	0.361	0.055
Mg	0-10	0.72(±0.12)	0.89(±0.11)a	1.36(±0.44)	0.08(±0.01)	0.76(±0.07)	0.65(±0.06)a	0.96(±0.05)	0.75(±0.04)
	10-20	1.18(±0.29)	1.16(±0.16)ab	1.69(±0.78)	0.07(±0.02)	1.10(±0.05)	0.84(±0.11)ab	0.99(±0.04)	0.94(±0.0
	20-30	1.06(±0.17)	1.72(±0.13)bc	2.15(±0.38)	0.05(±0.00)	1.07(±0.06)	1.17(±0.04)b	1.12(±0.11)	0.96(±0.01)
	30-40	1.08(±0.18)	1.58(±0.12)ac	3.05±0.73)	0.06(±0.01)	1.04(±0.04)	1.21(±0.10)b	1.37(±0.08)	0.99(±0.02)
p-value		0.546	0.04	0.361	0.306	0.086	0.034	0.103	0.063
K	0-10	0.27(±0.05)	0.35(±0.10)	0.22(±0.02)	0.04(±0.00)	0.30(±0.06)	0.27(±0.03)a	0.45(±0.04)	0.24(±0.02)
	10-20	0.19(±0.02)	0.31(±0.09)	0.20(±0.02)	0.03(±0.00)	0.28(±0.04)	0.25(±0.00)a	0.28(±0.03)	0.28(±0.00)
	20-30	0.17(±0.02	0.24(±0.08)	0.15(±0.02)	0.03(±0.00)	0.24(±0.01)	0.21(±0.00)ab	0.29(±0.02)	0.24(±0.02)
	30-40	0.16(±0.01)	0.22(±0.02)	0.15 (±0.04)	0.03(±0.00)	0.19(±0.04)	0.18(±0.02)b	0.27(±0.01)	0.23 (±0.01)
p-value		0.361	0.863	0.259	0.218	0.361	0.03	0.082	0.132
EC (µS/cm)	0-10	112±13	232±93	58.4±15	36±4	77±9	65±4	88±17	76±8
	10-20	116±24	137±9	76.7±12	34±6	80±2	79±5	95±6	82±9
	20-30	149±25	138±7	78.7±19	38±1	86±4	86±7	105±6	84±6
	30-40	139±15	155±25	130.6±47	38±0	100±10	90±13	129±5	78±7
p-value		0.44	0.91	0.39	0.91	0.13	0.2	0.08	0.62

Table 4: **Correlation coefficients of the relationship between selected soil physical and chemical properties. *p< 0.05 **p<0.01, N=32.**

	SOM	AP	Ca	Mg	Na	K	moisture	%sand	%silt	%clay	pH ($CaCl_2$)	EC
SOM	-	0.36*	0.33	0.09	0.29	0.49**	0.60**	-0.33	0.4	0.19	0.39*	0.57**
AP		-	0.06	-0.05	-0.09	0.15	0.36*	0.05	0.34	-0.17	0.47**	0.31
Ca			-	0.78**	0.44*	0.53**	0.35	-0.80**	0.36	0.76**	0.72**	0.60**
Mg				-	0.25	0.25	0.03	-0.63**	0.13	0.80**	0.39*	0.31
Na					-	0.67**	0.40*	-0.61**	0.42*	0.63**	0.47**	0.1
K						-	0.61**	-0.54	0.60**	0.34	0.66**	0.59**
Moisture							-	-0.24	0.46	0.17	0.44*	0.40*
%sand								-	-0.65**	-0.79**	-0.58**	-0.45**
%silt									-	0.13	0.47*	0.48*
%clay										-	0.39	0.3
pH ($CaCl_2$)											-	0.66**
EC												-

10 to 20-30 and 30-40 cm and was limited to specific land use/cover systems. Variation in organic matter with soil depth could be influenced by vegetation type. According to Jobbágy & Jackson (2000), the relative distribution of organic carbon have a strong correlation with vegetation as compared to climate and clay content. This has been attributed to differences in root distributions, above-and belowground patterns, as root distributions affect the vertical placement of organic matter in the soil (Jackson et al. 2000).

Variations in mean nutrient concentration among soil depth were low (Table 3), probably because the soils are sandy and most of the nutrients were leached. Available P and exchangeable K were concentrated on the soil surface and decreased with depth (Table 3). A study by Jobbágy & Jackson (2001) also recorded a high concentration of extractable P and exchangeable K in the top soil.

The decrease in P and K with depth could be due to low organic matter content at deeper depths. Organic matter showed a significant and positive correlation with P ($p<0.05$) and K ($p<0.01$) showing the importance of organic matter as a source of P and K pools (Table 4). The low AP content of the subsurface soils may also be explained by low leaching of AP to lower depth as phosphorus compounds generally have low mobility in soils. These results also indicate the importance of plant and biological cycling in controlling the distribution of P and K in the soil profile (Jobbágy & Jackson 2001). Capillary rise of soil moisture also transports nutrients upwards that may remain in the surface horizon after moisture evaporation. Trees may also contribute to upbringing of nutrients from deeper horizons to be recycled on the soil surface through litter-fall and through-fall (Trudgill 1988).

Conclusions

The results show that there is a significant effect of soil depth on soil nutrient availability and distribution. Seronga soils are highly sandy, with low levels of organic matter, available P, Ca, Mg, and K. The soils are acidic to neutral with low soluble salts and moisture content. Organic matter, P and K are highly concentrated on the soil surface and variation of soil physical and chemical characteristics in the soil profile is low. The different concentrations of nutrients and organic carbon in different land use/cover can help understand the consequences and shifts of land use/cover on changes in soil nutrient distribution with soil depth hence lead to sustainable land use management.

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