TOPOSEQUENCE ANALYSIS OF SOIL PROPERTIES OF AN AGRICULTURAL FIELD IN THE OBUDU MOUNTAIN SLOPES, CROSS RIVER STATE-NIGERIA

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ABSTRACT

We investigated toposequence of soil properties in an agricultural field in the Obudu Mountains using slope gradient and slope positions. Three slope segments along a catena were identified. Soil samples were collected at the median point of each of the contour of the landscape at two depths (0-15 and 15-30 cm), and paced subjectively to capture the full range of the landscape. The soils were analyzed for textural classes, pH, organic matter, available P and exchangeable bases. Descriptive and bivariate statistics analyses were used to analyze the data. The result reveal that variations in soil properties found among the landscape segments were probably because of toposequence characteristics in soils. However, there was no consistent sequence in the distribution of particle size fractions from the upper slope to the foot slope. The soils in the area are dominated with sand fraction. Soil reaction is slightly acidic, with moderate distribution of organic matter. Available phosphorus is low being less than 8 ppm in all the slope gradients. The coefficient of variation indicated that chemical properties were more variable than the physical properties with exchangeable calcium being the most variable (57.1 %) for surface layers and exchangeable sodium (88.9 %) for subsurface layers. The study recommends that a detail soil survey of the area should be carried out to enable farmers employ precision agriculture to enhance food production.

Keywords: Agricultural filed, Obudu Mountains, Nigeria, soil properties, toposequence.

INTRODUCTION

As in other parts of the tropics, rain-fed agriculture featuring different types of crops mainly for subsistence has continued to be plaque with plethora of problems. Prominent among them is soil fertility decline. Brown *et.al* (2004) cited geomorphological factors especially weathering and human activities as leading precursors to soil fertility degradation in the tropics. In addition, the increased peopling of fragile landscapes, with intensive tillage leads to severe soil degradation in tropical environments (Fungo, *et.al*, 2011; Lufafa, *et.al.* 2003).
The rapid rate of soil loss and fertility decline in tropical environments characterized by insidious topography exacerbates the problem of food insecurity in developing countries. Though not all soils are strongly correlated with terrain attributes, much less can be linked to them in a straightforward functional way (Sobieraj, *et.al*, 2002); this is even more complex within an agricultural field where different types of land use types are practiced. The management of an agricultural landscape has a functional relationship with the fertility status of the soil. But in a landscape characterized by intense geomorphological processes of weathering, mudflow, rock fall, and soil erosion the existing relationship may not be clear-cut

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in such a situation. Webster (2000), reports that under such conditions soil variability thus seems to be random.

The randomness of soil fertility in an agricultural field calls for innovative techniques in ensuring environmental sustainability and high food yields. One of such approaches is precision agriculture (ACPA, 2002). Precision agriculture is a concept that is geared toward site specific crop management (SSCM). It is defined as matching resource application and agronomic practices with soil and crop requirements as they vary in space and time within a field (Whelan and McBratney, 2000). An understanding of the fertility status of each land unit (LU) can be linked to the site specific management technique especially in the Obudu Mountain agricultural fields where the combined problems of traditional farming tools and rugged topography challenges food production.

Agriculture in the Obudu mountain slopes is practices on small holdings scattered unevenly across the landscape. The cultivation of crops in any patch of land in the area is determined largely by the configuration of the landscape (Amuyou, 2012). The rugged topography of the Obudu Mountain especially within the shoulder slope (which has a slope gradient of more than 30 percent) does not favour the cultivation of crops. This limitation has forced peasant farmers to concentrate their farm plots within the middle and foot slope of the mountain. The focus of this paper is to analyze the factors of soil variability within an agricultural field and fertility status of the soil. It is hoped that with this information, agricultural management practices can be design that will achieve precision agriculture in the Obudu Mountain slopes.

MATERIALS AND METHODS

Study area

The study area is the Obudu Mountains located in the Obanliku Local Government Area of Cross River State, southeastern Nigeria. It lies between longitude 9^{o} $22^{'}$ $00^{''}$ and 9^{o} $22^{'}$ $45^{''}$ E, and latitude 6^{o} $21^{'}$ $30^{''}$ and 6^{o} 22’ $30^{''}$ N (Figure 1), with an approximate area of $104sqm^2$, and a height of about 1576m above sea level (Ekwueme, 2003). Obudu Plateau is bounded in the north by Benue State, northeast by the Republic of Cameroon, to the southeast by Boki Local Government Area in Cross River State of Nigeria.

The area is situated within the tropics but it has a climate that is likened to temperate region with mean daily temperatures range between 15^{0}C and 22^{0}C. It has a mean annual rainfall of about 4300mm with highest rainfall sof about 76.2cm usually recorded in August while the lowest of 0.76cm is usually recorded in December (Mabugunje, 1983). The Obudu Plateau is part of the Precambrian Basement Complex of Nigeria (Ekwueme, 2003). It is a giant spur forming the western prolongation of the Cameroon Mountains into the Cross River plains of southeastern Nigeria.

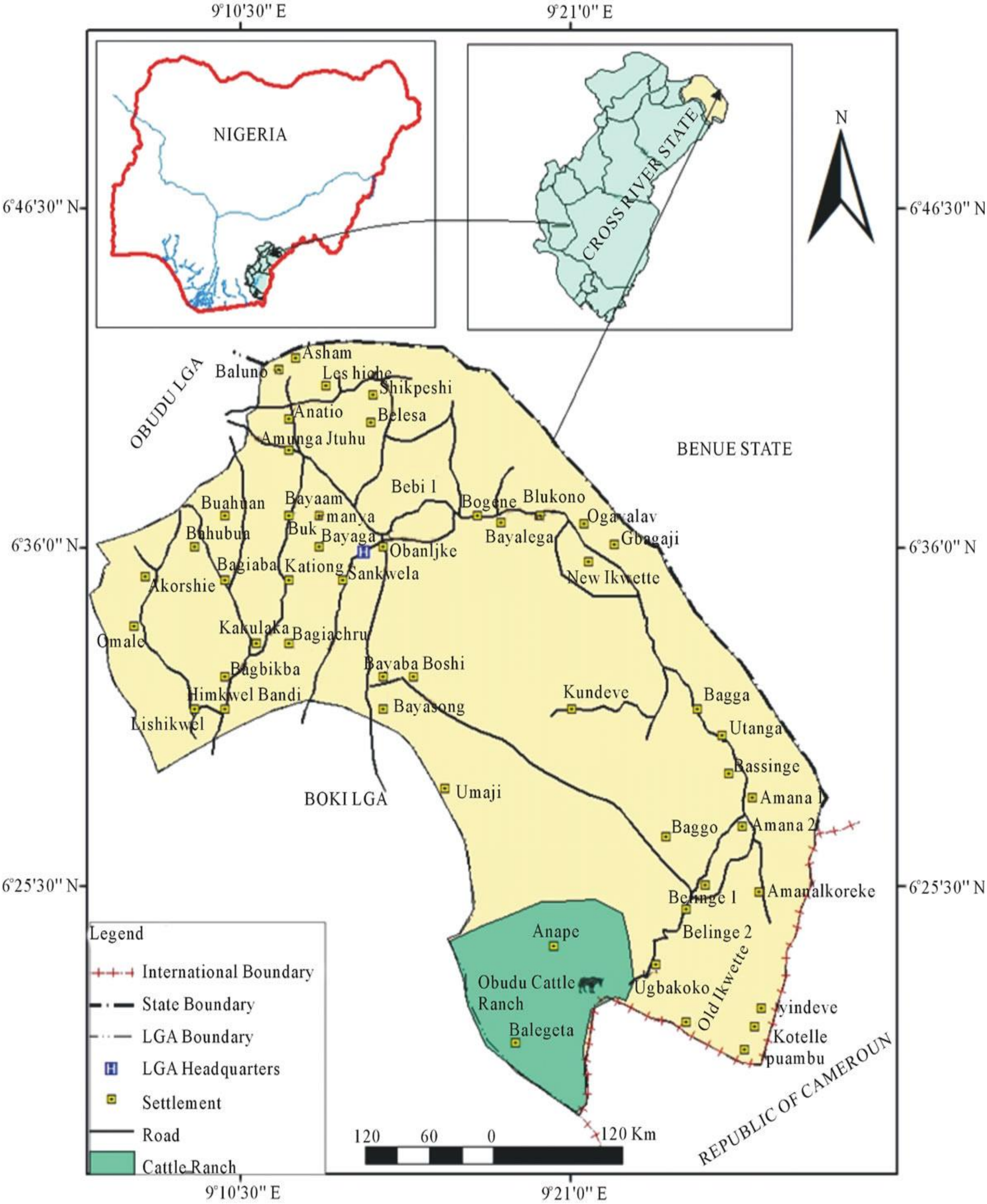

Figure 1: Map of Cross River State showing the Study area. Source: Akpan-idiok & Ofem (2014)

The natives of the study area are farmers. They cultivate arable crops mostly. On the mountain summit, temperate vegetables are cultivated while staple food crops are predominantly cultivated on the mountains slopes cattle's rearing is practice by the Fulani herdsmen and the government of the Cross River State.

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The population density coupled with the weather conditions of the area poses a constraint on the length of fallow period being allowed. The fallow period in the area is between 1 and 3 years for most farmers in the area while for some, it is over 3 years. There are improvised irrigation facilities in the area used by very few farmers between December and March when the weather condition is relatively harsh. However, a greater number of them practices rain fed agriculture.

The soil management system in the area is the application of organic fertilizer. The ingenuity of rural cultivators in the hilly area reduces the rate of soil wash. Ridging is practice on steep slopes. Mounds are common in undulating terrain. Both distance and compound farms exist amongst the communities. The morphology of the land to a large extent determines the type and duration of farming in the area. On the summit, shallow rooted crops are cultivated mostly and are carried out all year round. Deep-rooted crops are often cultivated along the slopes due to the weak shear strength of the soil while in the valleys both shallow and deep-rooted crops are planted.

Field procedures

The Obudu mountain was stratified into the traditional three slope segments; the shoulder slope (Shs), middle slope (Ms), and the foot slope (Lts) using topographic map of the area. An abney level was employed to confirm the various topographic gradients along the soil catena from the shoulder to the foot slope.

Soil samples collection

Soil samples were collected from the median point of each of the landform. For instance, at the shoulder slope which ranges from 20 to 30 %, soil samples were collected at the median gradient point of 25 %, middle slope 15% and foot slope 5 %. No soil sample was collected at the summit slope because it is inhabited by people. Transect placement and sampling intervals along transects were determined subjectively to capture the full range of soil variability within landforms as described by Young *et al*, (1992). Soil samples were taken with a soil auger at 0-15 and 15-30 cm depths of the soil. These layers are considered the most productive soil layers that exert the greatest effect on crop yield and geomorphologic processes are enacted within such layers (Aweto and Enaruvbe, 2010). All samples were assumed to be independent of one another.

LABORATORY METHODS

The soil samples were air-dried, crushed and passed through a 2mm-sized sieved. Particle size analysis was carried out by Bouyoucos (1962) hydrometer method. Soil pH was determined in 1:2 soil/water ratios by use of glass electrode pH meter. The Walkley and Black method as outlined by Juo (1979) was used to determined organic carbon, available phosphorus by Bray No. I method (Bray and Kutz 1945). Exchangeable cations were extracted with NH_4OAC (pH 7); potassium and sodium were determined by the flame photometry while calcium and magnesium contents were measured by EDTA titration method.

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RESULTS AND DISCUSSION

Descriptive statistics

Table 1 is the descriptive statistics of soil properties analyzed. Using Aweto (1982) soil coefficient of variability classification, (little variation ≤ 20%, moderate variability 20 to 50 % and highly variable ≥ 50 %), soil physical properties in the sampled areas were less variable than chemical properties in both layers (0-15 and 15-30 cm).

Sand particle fractions exhibited moderate to little variation from topsoil to subsoil as revealed by the coefficient of variation of 25 and 53 %. Silt was more variable (40.3 %) at the surface layer than at the subsurface (27.9 %) while clay fraction exhibited very high coefficient of variation at both layers (0-15 and 15-30cm).

Most of the fertility properties of the soils were moderately variable except Calcium which had a high coefficient of variation (57.1 %) for subsoil. Organic matter, calcium potassium and sodium on the other hand showed high coefficient variation at the subsoil layers (50.0; 78.6; 50.0 and 88.9 %). The variation of organic matter and other nutrient parameters at both depths may not be unconnected to the agricultural and geomorphological processes in the area. These processes go to explain the poor crop yields in the area. The critical limit for available phosphorus is 8ppm (Udo and Ogunwale, 1986; Enweozor *et.al*. 1989) for tropical soils. By this standard, available phosphorus is deficient in the agricultural fields of the Obudu Mountains. Essoka (2007) attributed the low available P in the area to Kaolinitic minerals that dominate the area.

Table 1: Descriptive statistics of selected soil parameters in an agricultural field of Obudu Mountain.

Topsoil

	Sand (%)	**Silt (%)**	**Clay (%)**	**pH**	**OM (%)**	**Avail P ppm**	**Ca cmol/kg^{-1}**	**Mg cmol/kg^{-1}**	**K cmol/kg^{-1}**	**Na cmol/kg^{-1}**
Mean	6.3	1.8	1.9	5.2	0.7	4.4	4.8	1.8	0.3	0.5
Standard Error	6.7	3.2	4.1	0.7	0.1	0.3	1.0	0.2	0.0	0.1
Minimum	30.4	11.7	7.0	4.0	3.0	3.3	3.4	1.0	0.1	0.4
Maximum	75.6	32.6	37.2	5.8	0.9	5.4	10.1	2.9	0.4	0.7
Range	45.2	20.9	30.2	1.8	0.6	2.0	6.7	1.9	0.3	0.4
CV	45.2	20.9	30.2	11.3	30.8	20.5	57.1	33.3	33.3	33.0
Skewness	1.1	1.8	-2.2	-1.9	-1.7	-0.5	2.3	0.9	-0.1	-0.3

Subsoil

	Sand	**Silt**	**Clay**	**pH**	**OM**	**Avail P**	**Ca**	**Mg**	**K**	**Na**

	(%)	(%)	(%)		(%)	ppm	cmol/kg-1	cmol/kg-1	cmol/kg-1	cmol/kg-1
Mean	6.6	1.4	1.8	4.7	1.1	3.6	5.6	1.7	0.3	0.9
Standard Error	4.1	1.7	5.2	0.3	0.2	0.5	1.8	0.2	0.1	0.3
Minimum	52.1	10.6	3.3	3.5	0.2	2.2	2.1	0.9	0.2	0.3
Maximum	76.3	20.7	35.2	5.4	1.7	5.1	14.0	2.2	0.6	2.4
Range	24.1	10.1	31.9	1.8	1.5	2.8	11.9	1.3	0.4	2.1
CV	15.3	27.9	67.9	18.8	50.0	34.3	78.6	29.4	50.0	88.9
Skewness	-0.5	0.5	-0.1	-0.9	-0.7	0.0	1.9	-0.6	0.7	2.0

-- OM= Organic matter; Avail. P= Available phosphorus; Ca= calcium; K=potassium; Na=sodium.
Source: Authors analysis (2014)

Correlation between soil properties

Table 2 is a summary of the correlation coefficients of the relationships between determined soil properties in agricultural fields of Obudu Mountain slopes. The correlation matrix revealed that sand have the highest negative correlation coefficients in both layers of soil with nutrients such as Ca, Mg, and Na in the surface and subsurface layers. This is obviously because sand particle fractions are chemically inert and are incapable of absorbing nutrient elements. Surprisingly, sand had a positive relationship with organic matter in both layers; implying that high sand content is associated with increased organic matter. This can possibly be linked to the fact that the area is an agricultural field. And possible that organic residue left after harvesting might have influence the result. Silt also correlated negatively with fertility parameters in both layers which again are contrary to expectation. Clay in the other hand had a positive relationship with nutrient elements. This is to be expected since clay particles are capable of absorbing soil cations on sites on their surfaces that carry unsatisfied negative charges (Aweto, 1982). pH and Ca had the highest positive correction in topsoil and subsoil. But pH was significantly correlated with organic matter (0.9*), and Ca correlated with Na (0.9**) a two tail significant level in the topsoil samples. pH also had a positive and significant relationship with organic matter (0.8*), organic matter correlated with available phosphorus (0.8*).

Generally, most of the properties have very high positive relationship in both layers (≥ ± 0.3). Soil processes controlling variability of the characteristics may be different at different scale (Castrignano *et.al*. 2000b). This probably account for the seemingly significant relationship shown by some soil properties. The implication of the low organic matter observe in both layers in the study area is that the area is porous and aerated which increases the rate of infiltration. The low water retaining capacity of the soil is a constraint to food production. The steepness of the slopes also increases the rate of nutrient wash by rain.

Table 2: Correlation matrix for soil variables

Topsoil

	Sand (%)	Silt (%)	Clay (%)	pH	OM (%)	Avail P ppm	Ca cmol/kg-1	Mg cmol/kg-1	K cmol/kg-1	Na cmol/kg-1
Sand	1.00	0.67	-0.99**	0.11	0.25	0.29	-0.73	-0.40	0.42	-0.73
Silt		1.00	-0.83	-0.14	0.15	0.36	-0.44	-0.10	-0.04	-0.44
Clay			1.00	0.01	-0.20	-0.31	0.66	0.34	0.31	0.66
Ph				1.00	0.90*	0.57	-0.54	0.27	-0.18	-0.57
Org. M					1.00	0.85	-0.53	0.43	-0.01	-0.56
Avail. P						1.00	-0.22	0.67	0.31	-0.26
Ca							1.00	0.50	0.75	0.99**
Mg								1.00	0.84**	0.46
K									1.00	0.73
Na										1.00

Subsoil

	Sand (%)	Silt (%)	Clay (%)	pH	OM (%)	Avail P ppm	Ca cmol/kg-1	Mg cmol/kg-1	K cmol/kg-1	Na cmol/kg-1
Sand	1.00	0.67	-0.97**	0.22	0.23	0.17	-0.70	-0.32	0.52	-0.70
Silt		1.00	-0.83	-0.14	0.15	0.33	-0.48	-0.10	-0.03	0.44
Clay			1.00	-0.06	-0.18	-0.21	0.65	0.27	0.17	0.64
pH				1.00	0.89*	0.62	-0.58	0.16	-0.35	-0.62
Org. M					1.00	0.88*	-0.55	0.33	-0.19	-0.57
Avail. P						1.00	-0.27	0.67	0.20	-0.28
Ca							1.00	0.67	0.20	-0.28
Mg								1.00	0.79	0.49
K									1.00	0.75
Na										1.00

OM= Organic matter (%); Avail. P= Available phosphorus (ppm); Ca= Calcium (cmol/kg^{-1}); K=Potassium (cmol/kg^{-1}); Na=Sodium (cmol/kg^{-1})
Values with * ** were significant correlation at 0.05 and 0.01 alpha level, respectively.
Source: Authors analysis (2014)

Influence of slope position on soil properties

Cultivation and slope gradients have marked influence in soil properties as expressed in the distribution in soils along slope positions in the Obudu Mountains. However, the variation in soil properties in the area was not remarkable. Sand fractions were relatively uniform across the upper, middle and foot slope positions of the catena (table 3). But silt and clay were observed to record high values (22.14 %) and (28.75 %) in the lower segment of the slope within top layers while they exhibited irregular distribution at 15-30 cm of soil depth. In any case, sand particle fraction was the dominant inorganic fragment across the different slope complex. Ekwueme (2003) earlier described the geology of the Obudu Mountains as a basement complex principally constituted by schiests, granites and gneiss, which explains the preponderance of sand fractions in the texture of the soil.

The distribution of soil pH across the upper, middle and foot slope positions was moderately acidic. But soil pH value was relatively high in the upper slope segment compared to other segments of the catena. The pH value at the upper slope position could probably be attributed to the site being covered with grasses. Since there is limited change in the vegetation and turning of the soil as compared to cultivated fields; this mean the pH is likely remain unaffected (Fungo, et.al, 2011). On the contrary, the frequency of cultivation may result in a more repaid decomposition of organic matter and weakening of soil structure which later results in lowering of soil pH.

Organic matter decreased with increased slope gradients. High values of organic matter (2.57 and 1.71 %) were recorded in the foot slope in the topsoil and subsoil layers. The relocation of topsoil materials from the upper to lower slope positions is probably due to the effect of cultivation and geomorphological processes that involves the mechanical movement of soil materials. This observation corroborate earlier studies by Brunner *et.al* (2004), Mulumba (2004), Essoka and Jaieyeoba (2008) where it was recorded that down slope transportation and deposition of organic residues is common in Mountainous areas. The trend of available phosphorus is irregular in both surfaces and slope positions. While the general pattern of distribution of exchangeable calcium, magnesium, potassium, and sodium across the slope segments of the catena was also irregular. However, exchangeable magnesium increased with decreased slope gradient (upper slope position 1.43, middle 1.81 and foot 2.26 cmol/kg^{-1}) in the topsoil. In the subsoil layer exchangeable calcium increased with decreased in slope gradient.

The study has generally shown that mechanical erosion dominates the hill slope tops. Particles are detached and then carried downward. Consequently, a gradual clay enrichment of the surface horizon is observed along the slope, at the hill slope scale (Fungo, *et al*., 2011). However, toposequence variation in other soil properties was not remarkable. There were no distinct patterns in soil properties across the different slope positions. The reason for this could be due to land use types (Agriculture) where samples were collected. This is quite common in African soils (Fungo, et.al, 2011).

Table 3: Soil properties across slope position in the Obudu Mountain slopes
Topsoil

Slope Positions	Sand (%)	Silt (%)	Clay (%)	pH	OM (%)	Avail P ppm	Ca cmol/kg^{-1}	Mg cmol/kg^{-1}	K cmol/kg^{-1}	Na cmol/kg^{-1}
Shoulder Position	71.9	18.55	10.1	4.97	1.35	4.0	1.27	1.43	0.70	0.37
Mid Position	68.9	12.7	18.3	5.47	1.44	4.95	3.95	1.81	0.46	0.30
Foot Position	49.2	22.14	28.75	5.47	2.57	4.38	3.59	2.26	0.48	0.33

Subsoil

Slope Positions	Sand (%)	Silt (%)	Clay (%)	pH	OM (%)	Avail P ppm	Ca cmol/kg^{-1}	Mg cmol/kg^{-1}	K cmol/kg^{-1}	Na cmol/kg^{-1}
Shoulder Position	73.25	14.65	12.1	5.22	0.45	3.75	4.27	1.69	1.58	0.40
Mid Position	61.3	13.9	24.8	5.29	1.35	4.56	4.55	1.86	0.70	0.30
Foot Position	64.08	15.67	19.25	3.76	1.71	2.47	8.05	1.44	1.38	0.40

Source: Authors analysis (2014).

CONCLUSION AND RECOMMENDATIONS

The proportion of sand fractions in these soils exhibit little to moderate variability within the study area. This is presumably because all the soils are derived from basement complex parent materials across the slope segments of the catena. In contrast, silt fraction tend to be more variable in the surface layer than the subsurface layers while clay was highly variably in both soil layers. The possible reason for this could be due to differences in slope gradients and agricultural practices in the area that involves mechanical maneuvering of the soil. This will affect the rate of fine soil materials removal from the upper slope segment of the catena. The dominance of sandy soils makes the presence of high clay values in the soils very relevant to soil fertility since it influences soil nutrient and water holding capacities. Since the inorganic soil particles such as sand, silt, and clay cannot be altered or changed by man, there is need for a detail soil survey at the farm level before any form of agricultural activity can be carried out in the Obudu Mountain slopes.

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The content of available phosphorus was low across the different slope positions. And the distribution of most the fertility parameters were irregular across the various slope catena. These mean that topography had minimal influence on the distribution of soils within the study area. The survey and classification of the soils in the Obudu Mountain slopes will help to reduce the poor agricultural output trend given the adoption of precision agriculture which encourages the cultivation of specific crops in an agricultural field according to it requirement. We recommend further that since the soil is predominantly sand fractions, the use of crop residues after harvest should be encourage. This again will increase soil water holding capacity and boost food production.

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