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Full Length Research Paper

Differences in physical and chemical properties of soils on Yelwa-Dobora toposequence in Ganye local government area, Adamawa State, Nigeria

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This study was carried out to assess the differences of some soil properties at lower, middle and upper slope positions (0 - 2%, 2 - 3% and 3 - 5%) on Yelwa-Dobora toposequence in Ganye, Adamawa State, Nigeria. Mapping units were delineated using the Geographic Information System (GIS) ArcGIS 9.1 software, where the study area was categorized into 3 different slope positions (SP1, SP2 and SP3) and each slope position was recognized as a mapping unit. Three (3) profile pits were dug on each mapping unit. Data obtained from some physical and chemical properties were subjected to analysis of variance (ANOVA) using R Statistical package 3.1.3 and the means were separated using Duncan's Multiple Range Test. Test for variance was carried out on physical properties of %sand, %silt, %clay, bulk density (g/cm^3), particle density (g/cm^3), %porosity, %water holding capacity (WHC) and %water retention (WR) and chemical properties on pH, electrical conductivity (ds/m), organic carbon (%), total nitrogen (%), available phosphorus (ppm), calcium, magnesium, sodium and potassium (cmol/kg), total exchangeable bases (TEB), total exchangeable acidity (TEA), effective cation exchange capacity (cmol/kg) and %base saturation (BS). The results revealed soil properties such as %sand decreased with increase in slope, while the %clay increased with decrease in slope and water content was highest at the lower slope. pH of the soils ranged between slightly acidic to neutral (6.1-6.5 to 6.6-7.3) and the soils were low in soil OC (<1%) and TN (0-0.15%). The ECEC, Mg^{2+}, OC, TEB and TN indicated significant difference for soil chemical properties. The study confirmed that detrimental effects of soil erosion are higher at upper slopes as compared to middle and lower slopes thereby changing the mineral nutrient concentration in the root zone. Control of damaging effects of erosion would require soil conservation strategies such as afforestation, terracing and inclusion of restorative crops in cropping systems on the lands.

Key words: Soil, slope position, physical and chemical properties, and mapping unit.

INTRODUCTION

Soil is an important natural resource for growing plants. The suitability of soil for crop production is based on the quality of the soil's physical, chemical and biological properties. One of the naturally occurring processes that affect soil properties and subsequent crop production is the pattern of water movement along the slope. The geometry of slope such as slope angle, length and curvature influence runoff, drainage, and soil erosion causing a significant difference in soil physico-chemical properties (Brubaker et al., 1993).

Farmers are beginning to crop on marginal lands including farming on slopes in many tropical countries. It is important to know that different soils occur at different positions on the landscape (Nuga et al., 2006). This various positions can have effect on yield of crops. Depending on the location on a slope physical and chemical properties of the soil will also vary either minimally or maximally. Soil physical and chemical properties are necessary to define and evaluate soil types, slopes, existing land use or natural cover under given condition of management.

Slope gradient is the angle of inclination of the soil

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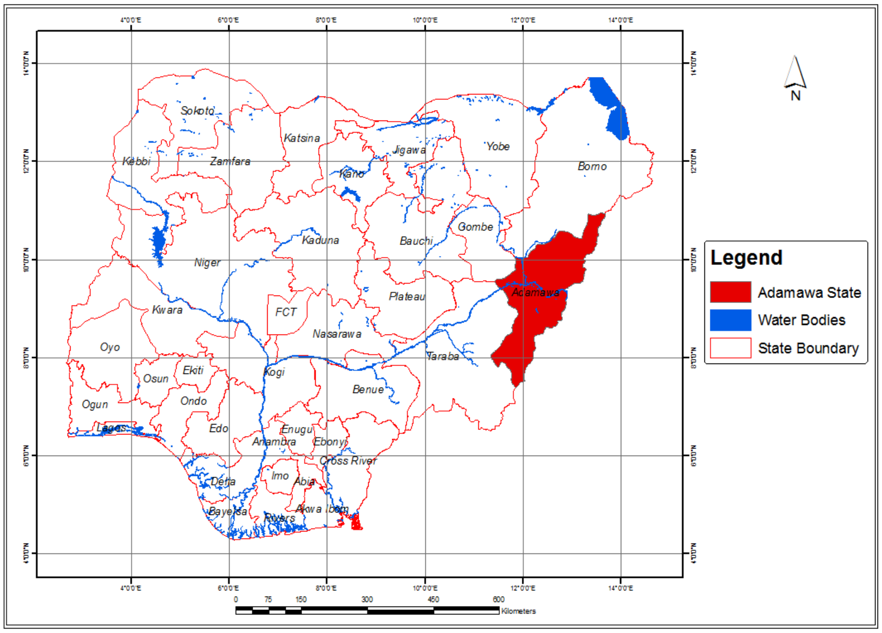

Figure 1. Map of Nigeria showing Adamawa state.

surface from the horizontal. It is expressed in percent, which is the number of feet rise or fall in 100 feet of horizontal distance. Erosion would normally be expected to increase with increase in slope length and slope steepness, as a result of respective increase in velocity and volume of surface runoff. The spatial variation of soil properties is significantly influenced by some environmental factors such as climate, landscape features, including landscape position, topography, slope gradient and evolution, parent material, and vegetation (Ollinger et al., 2002). It is common knowledge that topography influences local microclimates by changing the pattern of precipitation, temperature and relative humidity (Yimer et al., 2006) and significantly affects some soil parameters.

Differences in soil properties due to slope position differ due to degree of detachment, transportation and deposition of soil materials. Understanding soil properties and their variation is important for their sustainable utilization and proper management. The concept of slope position, which involves processes that cause properties differentiation along hillslopes and among soil horizons have improved evaluating the interaction of pedogenic and geomorphic processes (Gessler et al., 2000; Esu et al., 1987; Ovalles and Collins, 1986; Daniel et al., 1971).

The physical and chemical properties of soils are influenced by slope position from the upper slope, middle slope and lower slope and are characterised by variations in the horizons within each of the slope position and profile. Each of the slope position is affected at different levels as parent materials are eroded from the upper slope downwards, nutrient elements, water and gradients also moves downward and accumulates at the lower slope. This action is continues and bring about variations in the soils over a period of time.

Effective land use management for crop production on a landscape therefore requires knowledge of both the physical and chemical properties of the soil at different slope positions. Despite the potentials to produce some cash crops and food crops in the study area, farmers are facing problems of declining productivity and nutrient loss through the action of erosion. Therefore, the objective of this paper is to assess the variability in some physical and chemical properties of soil on a slope positions and classify the soils of the study area using the USDA taxonomic classification system in the study area, with the view of providing information to the farmers on the best management practices that should be adopted.

MATERIALS AND METHODS

Location and extent

The study was carried out in Yelwa-Dabora toposequence in Ganye Local Government Area, Southern Part of Adamawa State, Nigeria (Figures 1, 2 and 3. The study area is located between Longitude 11^0 58'0"E and Latitude 8^0 26' 0"N to Longitude 12^0 40' 0"E and Latitude 8^0 30' 8"N, covering a total area of 7, 452.58 hectares. The study area is within the northern guinea savannah zone which is characterized by tall grasses

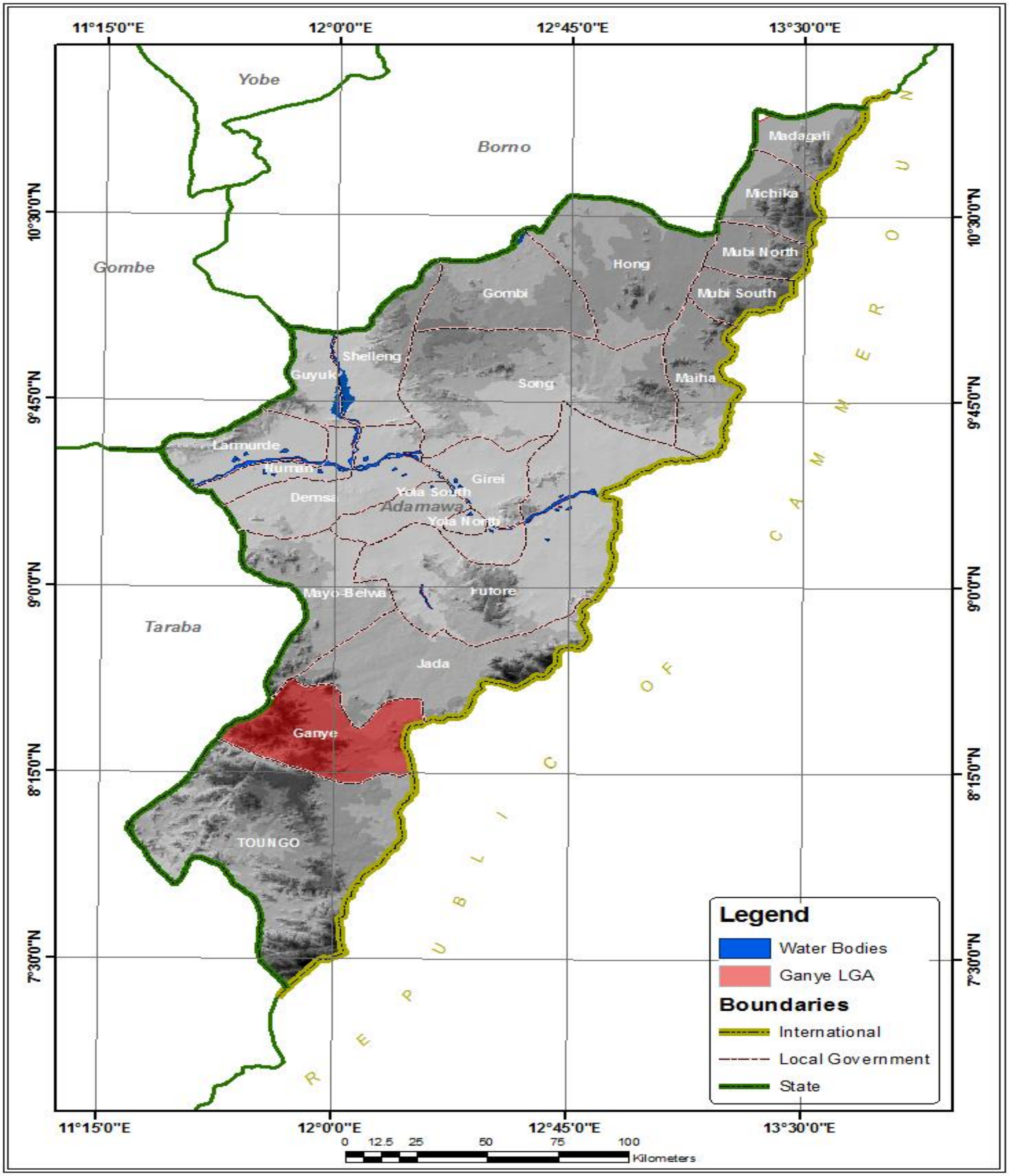

Figure 2. Map of Adamawa state showing Ganye Local Government.

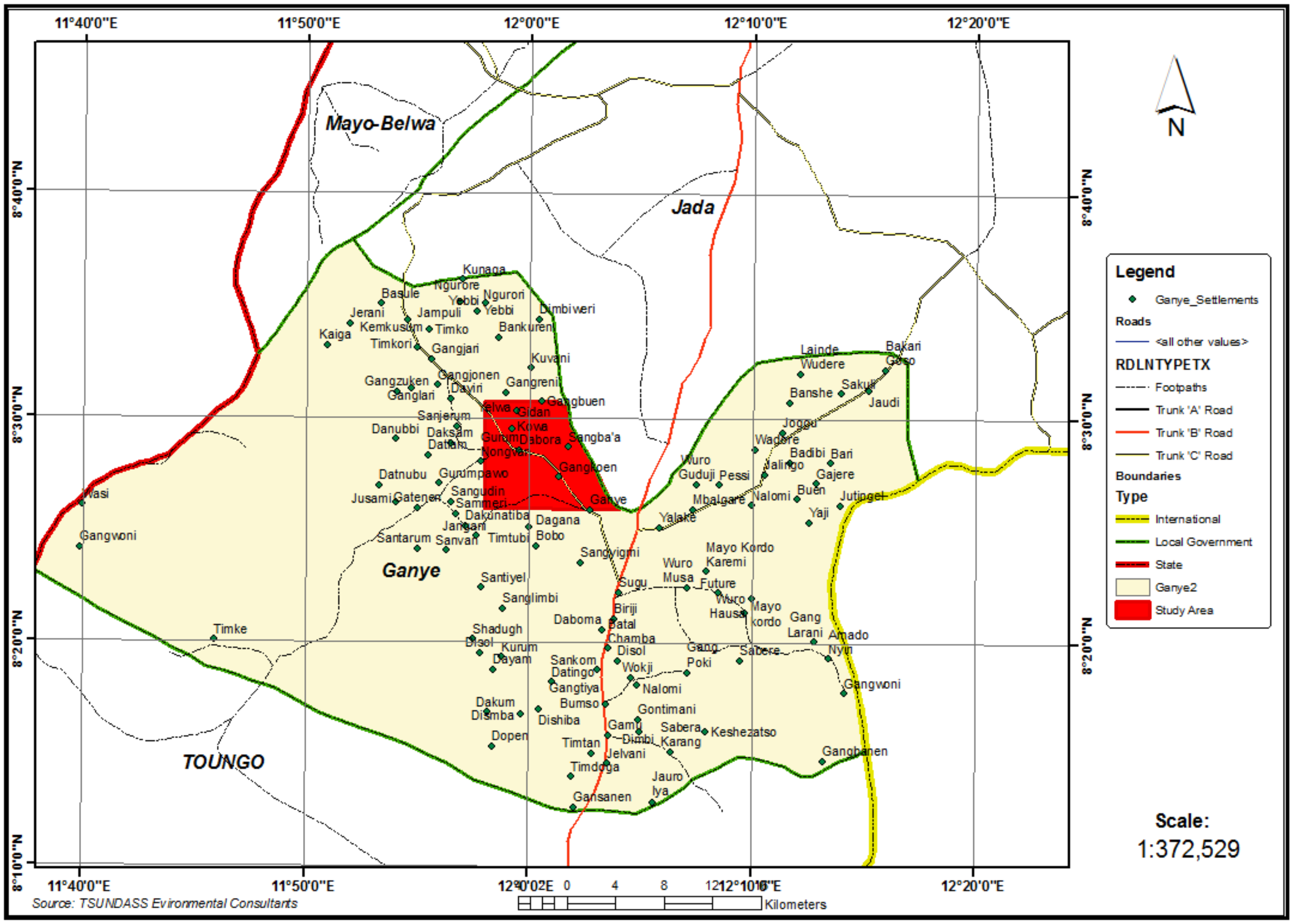

Figure 3. Map of Ganye Local Government Area showing the study area.

with few trees and many shrubs. Temperature in this region is high throughout the year because of the high radiation influx which is relatively evenly distributed throughout the year. Seasonal change in temperature occurs in this region, there is a gradual increase in temperature from February to May, the maximum usually occur in April/May and drops at onset of rains due to cloudiness. Maximum temperature in the state can reach 40^0C with the mean monthly range of 26.70°C in the north eastern part (Adebayo, 1997).

Rainfall is the most variable element of the tropical climate; most of its characteristics such as amount, frequency and intensity vary widely in time and space. The movement of the inter-tropical discontinuity (ITD) and it associated zones of rainfall during the course of the year is the major factor controlling rain fall in the state (Adebayo, 1997). There is hardly any rainfall received between November and February in the area. Rainfall amounts ranges between 700 – 1000 mm annually which falls between May – October. The peak periods of the rains are between July – September

Field work and sample collection

Mapping units were delineated using the Geographic Information System (GIS) where the study area is categorized into 3 different slope positions (SP1, SP2 and SP3) and each slope position is recognized as a mapping unit (SP1 = Mappig unit 1, SP2= Mapping unit 2 and SP3 = Mapping unit 3). Three (3) profile pits were dug in each mapping unit making nine (9) in all located at Yelwa (SP3), Sangba'a (SP2) and Dabora (SP1). Soil samples were collected in each of the soil horizon of the pits identified, placed in polythene bags and well labeled as described by the Soil Survey Field and Laboratory Methods Manual (Burt, 2014).

Preparation of Soil Samples

Soil samples were air-dried, crushed and passed through a 2 mm sieve after a carful removal of plant parts and other unwanted materials for some soil physical and chemical analysis in the laboratory as described by the Soil Survey Field and Laboratory Methods Manual (Burt,

Table 1. Results of Mean ± SEM for some soil physical properties in the study area.

Location	%Sand	%Clay	Bulk Density (g/cm^3)	Water Retention (%)
Yelwa (SP3)	75.40 ± 2.04^{a}	9.00 ± 2.45^{a}	1.56 ± 0.04^{ab}	9.37 ± 0.01^{a}
Sangba'a (SP2)	65.00 ± 1.79^{ab}	14.60 ± 1.72^{ab}	1.51 ± 0.02^{ab}	11.18 ± 0.03^{ab}
Dabora (SP1)	56.60 ± 2.86^{b}	23.00 ± 5.66^{b}	1.43 ± 0.03^{a}	17.60 ± 0.16^{b}

Values are expressed as mean ± S.E.M. Values with different superscript down the column are significantly ($p<0.05$) different, same superscript are similar.

2014).

Laboratory analysis

Particle size distribution was determined in the Laboratory by Bouyoucos hydrometer method as described by Day (1965). Soil Textural Class was determined using USDA textural triangle (NSSC, 1995), Bulk density was determined using the cylindrical metal core sampler method according to the Soil Survey Staff (2014), Particle density was determined by the use of graduated cylinder method as described by International Center for Agricultural Research in the Dry Areas (Ryan, et al., 2013), soil sample clods were collected in the field and water retention was determined as described by the Soil Survey Laboratory Information Manual (Burt, 2011). The result of particle size distribution was used to determine soil textural class by subjecting the results of the particle size distribution to Marshall's Textural Triangle as described by the Soil Survey Laboratory Information Manual (Burt, 2011) and Soil moisture content was determined by the gravimetric method as described by the laboratory testing procedure for soil and water sample analysis (Pawar et al., 2009).

Chemical test was carried out for soil pH, determined by the use of Electrode method, Electrical conductivity (EC) was determined as described by the Soil Survey Field and Laboratory Methods Manual (Burt, 2014), Titration method was used to determine Extractable acidity, Total Nitrogen was determined using Sulfuric Acid (H_2SO_4), concentrated (98%, sp. gr. 1.84) and Potassium permanganate solution ($KMnO_4$) as described by International Center for Agricultural Research in the Dry Areas (Ryan et al., 2013). Available Phosphorus was determined by extraction method using Spectrophotometer, Base saturation was determined by Sum of NH_4OAc Extractable Bases + 1N KCl Extractable method as described by the Soil Survey Laboratory Information Manual (Burt, 2011).

Data analysis

The result from the laboratory analysis of some soil physical and chemical test was subjected to descriptive statistical analyses and one way analysis of variance (ANOVA). The means were separated using Duncan's new multiple range test in R Statistics version 3.1.3 (R Development Core Team, 2015) with the Agricolae (de Mendiburu, 2015). The results were reported as mean ± sem to show the confidence interval of lower and upper limit of the population mean. Test was carried out on %sand, %silt, %clay, bulk density (BD), particle density (PD), %porosity, %water holding capacity (WHC) and %water retention (WR) for soil physical properties and pH, electrical conductivity (EC), %organic carbon (OC), %total nitrogen (TN), available phosphorus (AV-P), calssium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{2+}) and potassium (K^{+}), total exchangeable bases (TEB), total exchangeable acidity (TEA), effective cation exchange capacity (ECEC) and %bases saturation (BS) for soil chemical properties.

RESULTS AND DISCUSSION

Table 1 presents the results for Mean ± Sem of some soil physical properties as in the study area. The %sand in Yelwa (75.40 ± 2.04) recorded the highest %sand at the upper slope varied with the %sand in Sangba'a (65.00 ± 1.79) and the soils of Dabora (56.60 ± 2.86). These variations might be due to the distribution of sand in the study area as a result of the effect of erosion and decomposition were clay particles are eroded down slope leaving causer materials of sand at the upper slope (Table 3). Similar findings were recorded by Ogeh and Ukodo (2012) where they showed sand fraction generally dominated the soils along the toposequence. These results are also in agreement with the findings of Voncir et al. (2008). The highest %clay mean±sem was recorded in Dabora (23.00 ± 5.66) when compared with the mean ± sem of Yelwa (9.00 ± 2.45) and Sangba'a (14.60 ± 1.72) at the upper and midslopes respectively. This might be due to downward movement of clay particles as a result of the action of erosion, transportation and deposition downslope. Noma et al. (2011) also reported similar results. This is also in agreement with the findings of Udoh et al. (2010).

Brady and Weil (2007) also recorded their findings and stated that the trend may be due to down-ward accumulation of clay at bottom slope. All slopes showed significant difference for water retention with the highest at the lower slope in Dabora (17.60 ± 0.16) when compared with the middle and upper slopes in Sangba'a

Table 2. Results of Mean±SEM for some soil chemical properties of the study area.

Location	ECEC (Cmol/kg)	Mg (Cmol/kg)	OC (Cmol/kg)	TEB (Cmol/kg)	TN (%)
Yelwa (SP3)	8.52 ± 0.46[ab]	2.40 ± 0.51[a]	0.53 ± 0.02[a]	6.60 ± 0.49[a]	0.05 ± 0.003[a]
Sangba'a (SP2)	8.74 ± 0.84[ab]	2.80 ± 0.25[a]	0.72 ± 0.03[b]	6.42 ± 0.54[a]	0.07 ± 0.003[b]
Dabora (SP1)	9.98 ± 0.77[a]	3.80 ± 0.54[ab]	0.63 ± 0.03[ab]	7.58 ± 0.77[ab]	0.06 ± 0.004[ab]

Values are expressed as mean ± S.E.M. Values with different superscript down the column are significantly ($p<0.05$) different, same superscript are similar.

Table 3. Some physical properties of the soils of the study area.

Pedon	HD	Depth (cm)	% Sand	% Silt	% Clay	Txs Cls	B.D (g/cm^3)	P.D (g/cm^3)	Porosity (%)	WHC (%)	WR (%)
SP3	Ap	0-11	79	18	3	LS	1.58	2.56	38.28	0.22	9.40
SP3	E	11-34	75	20	5	LS	1.68	2.65	36.60	0.20	9.38
SP3	Bs	34- 55	71	20	9	SL	1.48	2.47	40.08	0.06	9.35
SP3	Bt	55 -68	81	8	11	LS	1.57	2.60	39.62	0.20	9.33
SP3	C	68-110	71	12	17	SL	1.49	2.30	35.22	0.26	9.34
		Mean	75.40	15.60	9.00		1.56	2.52	37.96	0.19	9.36
SP2	Ap	0-10	71	14	15	SL	1.51	2.61	42.15	0.19	11.27
SP2	E	10-28	67	24	9	SL	1.58	2.19	27.85	0.21	11.16
SP2	B	28-40	63	24	13	SL	1.51	2.23	32.29	0.21	11.14
SP2	Bt	40-60	61	22	17	SL	1.47	2.43	39.51	0.21	11.13
SP2	C	60-120	63	18	19	SL	1.46	2.39	38.91	0.16	11.12
		Mean	65.00	20.40	14.60		1.51	2.37	36.14	0.20	11.16
SP1	Ap	0-23	61	26	13	SL	1.51	2.65	43.02	0.29	17.92
SP1	E	23-34	53	28	19	SL	1.44	2.41	40.25	0.33	17.10
SP1	B	34-61	55	24	21	SCL	1.43	2.35	39.15	0.26	17.51
SP1	Bt	61-88	65	18	17	SL	1.48	2.63	43.73	0.21	17.55
SP1	Bw	88-121	49	6	45	SC	1.31	2.49	47.39	0.36	17.94
		Mean	56.60	20.40	23.00		1.43	2.51	42.71	0.29	17.60

Key: HD = Horizon Designation, Txs Cls = Textural Class, BD = Bulk Density, PD = Particle Density, WHC = Water Holding Capacity, WR = Water Retention.

(11.18 ± 0.03) and Yelaw (9.37 ± 0.01) which recorded the lowest water retention respectively. This trend suggests the downward movement of water downslope due to the action of aspect and the effect of erosion in the area. Osuaku et al. (2014) showed similar work when they reported that the moisture content was higher in the bottom slope with depth than in other topographic units in the study area.

Table 2 shows results for mean ± sem of some soil chemical properties of the study area. The soils of Dabora (SP1) 9.98±0.77 showed significant difference with both the soils of Sangba'a (SP2) 8.74 ± 0.84 and Yelwa (SP3) 8.52 ± 0.46 respectively but did not show significant difference between the two for ECEC. Dabora (SP1) 3.80 ± 0.54 indicated difference in the soils of the area for Mg^{2+} with Sangba'a (SP2) 2.80 ± 0.25 and Yelwa (SP3) 2.40 ± 0.51 but the two did not show significant difference. Similar result was reported by Bahilu et al. (2014) that when comparing three slope position Mg^{2+} and K^{+} in the upper slope position showed difference compared with middle and lower slopes. OC of the soils indicated significant difference in all the three slope positions of the soils of Dabora (SP1) 0.63±0.03, Sangba'a (SP2) 0.72 ± 0.03 and Yelwa (SP3) 0.53 ± 0.02 respectively. This might be due to cultural practices by the farmers and effect of erosion in the study area. A loss due to soil erosion and deposition effects by slope position of OC was recorded by Gregorich et al., 1998.

In Dobora (SP1) 7.58 ± 0.77, the soils showed significant difference with the soils in Sangba'a (SP2) 6.42 ± 0.54 and Yelwa (SP3) 6.60 ± 0.49 but the two did not show significant difference for TEB. All the slope positions indicated significant difference in Dabora (SP1) 0.06 ± 0.004, Sangba'a (SP2) 0.07 ± 0.003 and Yelwa (SP3) 0.05±0.003 for soil TN. This might be due to the reduction of soil organic matter content and residue removal of crops in the area. The action of soil erosion from the upper slope is also a factor (Table 4). This

Table 4. Some chemical properties of the soils of the study area.

Pedon	HD	Depth (cm)	pH	EC (dS/m)	O.C (%)	TN (%)	AV-P (ppm)	Ca^{2+}	Mg^{2+}	Na^{2+}	K^{+} cmol/kg	TEB	TEA	ECEC	BS (%)
SP3	Ap	0-11	6.10	0.05	0.52	0.05	14.48	0.80	4.00	0.10	0.20	5.10	3.60	8.70	58.79
SP3	E	11-34	6.94	0.09	0.56	0.06	13.76	4.00	1.60	0.20	0.80	6.60	1.20	7.80	84.65
SP3	Bs	34- 55	6.10	0.10	0.61	0.06	11.85	4.10	1.60	0.50	0.30	6.50	1.20	7.70	84.39
SP3	Bt	55 -68	6.19	0.06	0.50	0.05	14.24	4.60	1.60	0.10	0.20	6.60	1.60	8.20	80.40
SP3	C	68-110	6.21	0.07	0.47	0.05	11.37	3.20	3.20	0.20	1.60	8.20	2.00	10.20	80.42
		Mean	6.31	0.07	0.53	0.05	13.14	3.34	2.40	0.22	0.62	6.60	1.92	8.52	77.73
SP2	Ap	0-10	6.65	0.05	0.68	0.07	13.28	1.60	2.40	0.30	0.30	4.60	1.60	6.20	74.17
SP2	E	10-28	6.33	0.06	0.64	0.06	12.33	2.40	3.20	0.10	0.60	6.30	2.00	8.30	75.89
SP2	B	28-40	6.73	0.11	0.83	0.08	12.09	2.40	3.20	0.30	0.80	6.70	1.60	8.30	80.62
SP2	Bz	40-60	6.52	0.06	0.68	0.07	10.65	4.80	2.00	0.50	0.70	8.00	1.60	9.60	83.37
SP2	Ck	60-120	6.96	0.14	0.75	0.07	7.79	2.40	3.20	0.10	0.80	6.50	4.80	11.30	57.62
		Mean	6.64	0.08	0.72	0.07	11.23	2.72	2.80	0.26	0.64	6.42	2.32	8.74	74.33
SP1	Ap	0-23	6.65	0.06	0.71	0.07	12.57	4.80	4.00	0.30	0.30	9.40	3.20	12.60	74.59
SP1	E	23-34	6.00	0.12	0.62	0.06	10.89	1.84	5.60	0.10	0.30	7.90	2.40	10.30	76.65
SP1	B	34-61	6.18	0.09	0.65	0.06	11.61	3.20	2.40	0.20	0.30	6.10	3.60	9.70	62.82
SP1	Bt	61-88	6.35	0.08	0.66	0.07	12.33	0.80	4.00	0.30	0.50	5.50	2.40	7.90	69.80
SP1	Bw	88-121	6.30	0.13	0.51	0.05	12.33	4.60	3.00	0.40	1.00	9.00	0.40	9.40	95.75
		Mean	6.30	0.096	0.63	0.06	11.95	3.05	3.80	0.26	0.48	7.58	2.40	9.98	75.92

Key: HD= Horizon Designation, EC= Electrical Conductivity, O.C= Organic Carbon, TN= Total Nitrogen, AV-P= Available Phosphorus, Ca= Calcium, Mg= Magnesium, Na= Sodium, K= Potassium, TEB= Total Exchangeable Bases, TEA= Total Exchangeable Acidity, ECEC= Effective Cation Exchange Capacity, BS= Base Saturation.

agrees with the findings by Hawando (1997).

Conclusion and recommendations

Variations in soil properties due to slope position differ due to degree of detachment, transportation and deposition of soil materials. Understanding soil properties and their variation is important for their sustainable utilization and proper management. This study has shown the relationship between soil properties and slope position on a toposequence and how slope position can affect the physical and chemical properties of soil across a landscape. The study confirmed that detrimental effects of soil erosion are higher at upper slopes as compared to mid and lower slopes thereby changing the mineral nutrient concentration in the root zone thus affecting soil productivity.

Soil properties such as %sand decreased with increase in slope from upper to lower slopes, while the %clay content of the soils increased with decrease in slope with the lower slope having the highest value of clay content and the water content was highest at the lower slope. pH of the soils ranged between slightly acidic to neutral (6.1-6.5 to 6.6 - 7.3) and the soils were low in soil OC (<1%) and TN (0-0.15%). Analysis of variance indicated that values were significantly different at $p < 0.05$ for %sand, %clay, bulk density (g/cm^3) and %water retention between slope positions in the study area and ECEC, Mg^{2+}, OC, TEB and TN indicated significant difference for soil chemical properties.

Recommendations

In order to attain sustainable food security and enhance agricultural productivity and quality of life in the study area, it is suggested that close attention should be given to upper slope positions to control the damaging effects of erosion and for soil fertility restoration across the landscape. Therefore, the following recommendation will help ameliorate the identified soil problems;

i.) The Ap horizon on all the profiles have high sand content (>67%) with low clay content and weak structure. Therefore, mechanical land clearing should be avoided because of the fragile and sandy, loose nature of the soils.

ii.) Farmers should adopt effective crop residue management with increase in the use of leguminous plants as well as judicious use of organic fertilizers to improve soil fertility in the area.

iii.) The control of some of the damaging effects of erosion would require soil conservation strategies such as proper land levelling, afforestation, terracing and inclusion of restorative crops in cropping systems on these lands.

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