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EFFECT OF SLOPE CHARACTERISTICS ON AGGREGATE-SIZE DISTRIBUTION IN SOILS FORMED ON COASTAL PLAIN SANDS IN AKWA IBOM STATE, NIGERIA

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ABSTRACT

Investigation of slope characteristics influence on aggregate size distribution is necessary in guiding management practices of the soils formed on coastal plain sands, in Akwa Ibom State. Effect of slope characteristics on aggregate size distribution were examined in coastal plain sands in Akwa Ibom State, Nigeria. Five soil samples were collected at 20m interval from each of twelve selected similar slopes / location, based on their form and length. A total of sixty samples were collected and analyzed in the laboratory for physical and chemical properties. Each of the 60 soil samples were separated into four aggregate size fractions; 4-2.0mm, 2.0-0.25mm, 0.25-0.05mm and <0.05mm, using the dry and wet sieving methods. The data generated were analyzed in terms of slope aspect, slope curvature and slope gradient effect on aggregate size distribution. The result shows that the physical and chemical properties of the soils in the study area were affected by slope aspect, curvature and gradient by causing redistribution of soil properties along the slope. Slope aspect significantly (P< 0.05) affected dry aggregate size distribution with the highest mean value of 4.01mm for the < 0.05mm diameter, occurring on the south facing slope was 3.1mm. slope gradient significantly (P< 0.05) affected < 0.05mm dry aggregate size fraction with the highest mean value of 4.35mm occurring on the <10% slope followed by >20% with 3.52mm and 11-20% with 2.80mm/. Understanding the effect of slope characteristics can guide in selecting suitable management practices of the soil.
Keywords: *Slope aspect, slope curvature, slope gradient, aggregate-size distribution, soil physical properties, soil chemical properties, coastal plain sands*

INTRODUCTION

Slope influences aggregate-size distribution by experiencing increasingly greater problems of soil erosion that causes disintegration of macroaggregate that later form microaggregate. Runoff and soil loss are definitely affected by topography. Ogban and Essien (2016) reported that the impact energy of rainfall slakes and physically disintegrates surface soil aggregates resulting in the physiochemical dispersion of clay particles, seal formation and reduced water infiltration (McIntyre, 1958; Tang *et al.,* 2006). The topographical factors that affect water erosion are the degree of slope, length of slope and the velocity of flow increases in proportion to square root of the slope length (Boiling *et al.,* 2008), while (Miller and Baharuddin, 1987) found significant relationship between water-dispersible particle sizes and soil erosion. According to Tisdall and Oades (1982) aggregation is the result of complex interaction among biological, chemical and physical processes in the soil. Aggregation has been conceptualized as a hierarchical system of primary particles forming microaggregates (< 0.25mm), which then become the material for the formation of macroaggregates (> 0.25mm) of varying sizes. Edward and Bremner (1967) proposed that in the hierarchical theory of aggregation, microaggregates join together to form macro aggregates and that the bonds within macro aggregates are stronger than the bonds between micro aggregates. Micro aggregates are formed from organic molecules attached to clay and polyvalent cations to form compound particles (clay particulate organic matter) that later form macroaggregates. Soil aggregates are important for crop establishment infiltration rather than runoff and compaction (Elliot, 1986) and are indicators of soil structural condition as well as erodobility (Haynes and Bears, 1996). Factors affecting aggregate stability can be grouped as abiotoc (clay minerals, sesquioxides, exchangeable cations), biotic (soil organic matter, activities of plant roots, soil fauna and micro-organisms) and environmental factor (soil temperature and moisture) (Chen *et al.,* 1998). Soil aggregates occur in different sizes but are classified as macro aggregate (> 0.25mm) Microaggregates (<0.25mm and mineral fraction (<0.05mm) (Oades and Water, 1991; Oades, 1993). Slope causes differentiation in soil properties, which in turn may affect crop performance and yield. Slope position also influences exchangeable K, organic matter and clay content that aid in soil aggregation (Boiling *et al.,* 2008). Slope land increases soil erosion and constitutes a serious environmental degradation problem that threatens food security and human well – being on the coastal plain sands area in Akwa Ibom State in general. However, defining limits for assessing effect of slope on aggregate size distribution that represent a desired level of aggregate stability and risk of erodibility are not well developed. This study assesses the effect of slope on aggregate-size distribution on coastal plain sands in Akwa Ibom State, Nigeria.

MATERIALSAND METHODS

The study was conducted on the coastal plain sands in Akwa Ibom State, Nigeria. Akwa Ibom Stateis located in latitude 4° 50' N and 5° 50' N, longitudes 7° 30' and 8° 30' E, while the coastal plain sands is located between latitude 4° 40' N and 5° 15' N and longitude 7° 30' E and 8° 15' E. The southern part borders on the Atlantic Ocean with a coastline of 129KM. The state is small in size covering a total land mass of 8412km (Petters *et al.,* 1989). The climate of Akwa Ibom State is the hot humid tropical (Inyang, 1975), and characterized by two season, the wet or rain season, lasts between the months April to October, while the dry season occur between the months of November to March. Rainfall varies from 3,000mm along the coastal to about 2,000mm on the northern fringes. Temperatures are uniformly high averaging 28°c. Relative humidity ranged 95% (Petters *et al.,* 1989), while evapotranspiration ranges from 4.11 to 4.95mm, partly because of the high insolation and temperature (Enwezor *et al.,* 1990). Geological formations in Akwa Ibom State is made up of the Quaternary Benin formation or unconsolidated coastal plain sands, the Tertiary Bende-Ameki (sand stone) formation, and River Alluvium (Ojanuga *et al.,* 1981), the study was conducted on the coastal plain sands in Akwa Ibom State. Apart from the northern corner and the northeastern parts where the land is intensely deserted, the landscape of Akwa Ibom State comprising a generally low – lying plain with no portion exceeding 175m above the sea level. The soils on coastal plain sands vary in texture from sand to loamy sands and mostly brownish in colour. The soils have low water retention capacity and content of organic matter and are susceptible to soil erosion and leaching loses which lead to the depletion of basic cations, rapid can decline in productivity and low yield (Udo and Sobulo, 1981; Lal, 1986). The gentle sloping lowlands are poorly to imperfectly drained clays underlain rately sloping middle and upper slopes are dominated by imperfectly to well drain sandy clay loams over sandy clay or clays. Alluvial stratification seems to be the most common or pronounced profile feature (Udo et al., 2009).The vegetation of Akwa Ibom State is located within the humid zone of Nigeria. The climate favours luxuriant tropical rainforest, which has been almost completely replaced by secondary forest of predominantly raphia / oil palms forest, woody shrubs such as Chromolaena Odorata, Cocoa Plantations, and various grass undergrowth. The predominant land use practices in the area includes forest plantation, tree crop plantation, swamp rice and intensive upland cultivation with a great variety of crops grown such as cassava, yam, maize, cocoa, plantain /banana and assorted vegetables.

FIELD AND LABORATORY METHODS

The study was conducted on twelve (12) selected slopes / sampling locations, based on their forms, curvature (concave and convex), aspect (North and East), and gradient (1-10%, 11-20% and 21-30%). These were selected, based on where the slope forms were found on the coastal plain sands. The study was fitted into a 2×2×3 factorial experiment in randomized Complete block design (RCBD) with slope curvature (convex and concave) as factor A, slope aspect (North and South facing slope) as factor B and slope gradient (< 10%, 11 – 20% and > 20%) as factor C, giving a total of twelve (12) treatment combinations, replicated five times to give a total of sixty (60) Sampling points. The length of the slope was 100m, while distance between the sampling points was 20cm apart. The co-ordinate and elevation was determined with the use of geographical positioning system (GPS). One way to express slope is in terms of percentage which is obtained by dividing the difference between the elevations of the two points by the distance between them and multiplying the quotient by 100. Calculated as follows:

Slope Percentage (Slope %)

Slope % = (rise / run) x 100 ………………… (1)

Slope angle = arctangent (rise / run) ………….. (2)

Five designated slope positions 20m apart were marked out, bulk and core soil samples were collected from 0 - 20m,soil depth. Soil samples were taken to the laboratory for the determination of Soil physical and chemical properties. The bulk samples were collected with a spade, while the core sample was collected with metal cylinders Measuring 7.5cm along and 6.8cm wide. The soil samples were securely held in the cylinder with a piece of Calico cloth wrapped at one end of the cylinder and held in place with rubber band. A total of 60 core and bulk samples, respectively were collected. The core samples were used for the determination of Ksat and Bd, while the bulk samples were bagged, labeled and used for physical (particle size analysis and aggregate size separation) and chemical analyses. The soil samples were air – dried in the laboratory, and sieved through a 4mm sieve and further sieved through a 2mm sieve for particle size analysis done after the destruction of organic matter, using the Bouyoucos hydrometer method as described in Dane and Topp (2002). The clay and silt were obtained by chemical dispersion (Sodium hexametaphosphate solution). Aggregate stability analysis was carried out on the 4mm sieved soil samples. Aggregate – size distribution was determined by physical separation through the dry and wet sieving methods (Nimmo and Perkins, 2002).Aggregate size fractions was isolated using 50g of air –dry 4mm sieve samples and was physically separated into four aggregate – size fractions through wet and dry sieving method with a nest of 4.0 -2.0, 2.0 – 0.25, 0.25 – 0.05 and < 0.05mm sieves.

The sieve sizes represent

(1.) Largemacro aggregates (4.0 - 2.0mm in diameter);(2.)Small macro aggregate (between 0.25 and 2.0);(3.) Micro aggregate (between 0.25 and 0.25mm) and (4.)The mineral fraction (< 0.05mm in diameter).The samples were oven dried and the resistant aggregates that remained on each sieve size recorded. The sand fraction from each aggregate size fraction was determined by stirring and raising the samples with a dispersing agent ($5gl^{-1}$ Na hexametaphosphate).Soil hydraulic conductivity, soil bulk density, total porosity was measured using the methods described in Dane and Topp (2002).The 2mm sieved soil samples were used in the analysis of soil PH electrical conductivity (EC) and exchangeable bases (Ca, Mg, Na, and k) as described in sparks (1996). Effective Caution exchange Capacity (ECEC) was computed as:ECEC = Ca + Mg + K + Na + exchangeable acidity (Ac) (3)

The percentage base saturation was Calculated as (TEB /ECEC) x 100 (4)

Exchangeable sodium percentage (ESP) was computed as: Na /ECEC x 100 (5)

Sodium adsorption ratio (SAR) was calculated from the equation SAR = Na (6)

√ (Ca + Mg)

Organic carbon was determined by the Walkley and Black method (Sparks, 1996), and converted to organic matter.

DATA ANALYSIS

The data generated were fixed into a 2x2x3 factorial arrangement in randomized complete block design. Data were summarized using descriptive statistics. The analysis of variance was used to compare the different components of slope curvature, aspects and gradient. Correlation analysis was used to determine the relationship between Aggregate size distribution with physical and chemical properties of the soil.

RESULTS AND DISCUSSION

Effect of Slope Aspect on Soil Physical Properties

The coarse sand content of NF slope had mean value of 773± 72 gkg^{-1}, CV = 9.4%, while that of SF slope was 729 ± 69gkg^{-1}, CV = 9.4%. Cs content affected by slope aspect had low variations. Also coarse sand being skeletal, combined with the heavy rain which is higher on the SF slope, causes weak inter-particle attractive and cohesive forces and have low aggregation potential, hence aggregates easily slake dispersively and less resistant to the shearing forces of water and therefore vulnerable to erosion, as also reported by Ogban and Essien (2016). Fine sand content revealed that NF slope had low mean of 90± 26.97 gkg^{-1}, CV = 29.9%, while SF slope had high mean of 115 ± 23.14 gkg^{-1}, CV = 20.2 % (Table 4.1). Fine sand had moderate variation. The increase in Fs content of SF is because rainfall is exceedingly heavy during the rainy season, the heavy rainfall increases water flow that weakening the bond between aggregate and causes detachment and transported most the lighter fraction of sand (Fs) to another place (Bennie.*et al.,* 2006). The results of Ts content showed that NF slope had high mean value of 859 ± 67.15gkg^{-1}, CV = 7.8 %, while SF slope recorded low mean of 843± 68.47g kg^{-1}, CV = 8.1 % (Table 4.1). Ts had low variability. The low content of Ts in the SF slope is as a result of heavy rain, especially on the

Coastal plain sands characterized by high detachability potential. Igwe and Obalum (2013) reported that the sandy nature of parent materials of majority of tropical soils militate against aggregate formation and stability. Under slope aspect the result revealed that silt content with NF slope had low mean of 41± 26.07g kg^{-1}, CV = 64.1%, while SF slope had high mean of 52± 25.17 gkg^{-1}, CV = 48.3 % (Table 4.1). Silt content had high Variation. The results of the clay content showed that NF slope had clay content of 93± 46.31 gkg^{-1}, CV = 49.6 %, while SF slope recorded 105 ± 46.05 gkg^{-1}, CV = 44.1 % (Table 4.1). Clay content of slope aspect had high variation. The results indicate that, the soil had non-skeletal clay in the matrix, and the clay fraction being colloidal, highly reactive, cohesive and adhesive (Lal and Shukla, 2004), this may improve formation and stability of aggregate by providing required bonding that will help in binding the aggregate together and will be less susceptible to action of erosion. eported positive correlation between aggregate stability and clay content of soils. Effect of slope aspect revealed that bulk density of NF slope had high mean of 1.54 ± 0.15 Mgm^{-3} CV = 10.4 % while SF slope had 1.49 ± 0.06 Mgm^{-3}, CV = 10.4% (Table 4.1). Bulk density recorded low variation. The high bulk density NF slopes observed were attributed to the high particle fractions in the NF slope. The low bulk density was attributed to the high proportion of erosion activities, along the slope. Total porosity result indicated that NF slope had low mean of 0.42 ± 0.06 m^3m^{-3}, CV = 13, 8% while SF had high mean of 0.44 ± 0.06 m^3m^{-3}, CV = 13. 2 % (Table 4.1). There was a low variability Total porosity affect by slope aspect. The results indicated that SF slope may not experience severe impeded fluid flow; this inturn will reduce the rate of water flow that will also reduce the activities of erosion on aggregate. Saturated hydraulic conductivity results indicated that NF has high mean of 4.82 ± 0.51 $cmhr^{-1}$, CV = 106.8 %, this may be due to irregularity in distribution of soil particles along the slope. While SF slope had low mean of 3.65 ± 0.30 $cmhr^{-1}$, CV = 83.8 % (Table 4.1). The Saturated hydraulic conductivity with slope aspect had high variability. The high saturated hydraulic conductivity in NF may imply that the soils had more open structure and agrees with the inference above that fluid flow may not be impeded.

Table 4.1: Effect of slope aspect on soil physical properties

Sampling Location	Cs	Fs	Ts	Si	Cl	Bd	Tp	Ksat
	←		gkg^{-1}		→	Mgm^{-3}	m^3m^{-3}	$cmhr^{-1}$
			NF slope					
1	773	60	845	48	474	1.51	0.43	1.00
2	784	94	878	47	75	1.53	0.42	0.33
3	676	116	796	56	148	1.60	0.39	0.17
4	820	68	888	26	86	1.62	0.39	0.40
5	786	100	852	28	80	1.51	0.43	0.20
6	798	96	896	40	64	1.47	0.45	0.32
Mean	773	90	859	41	93	1.54	0.42	0.48
sd±	72.79	26.97	67.15	26.07	46.31	0.15	0.06	0.51
CV	9.4	30.0	7.8	64.1	49.6	9.9	13.8	106.8
			SF slope					
1	744	94	838	44	118	1.39	0.48	0.56
2	707	131	838	62	94	1.36	0.49	0.31
3	597	105	842	52	106	1.37	0.48	0.59
4	684	126	810	62	128	1.7	0.36	0.12
5	805	103	908	31	61	1.52	0.43	0.31
6	696	129	824	62	114	1.59	0.40	0.28
Mean	729	115	843	52	105	1.49	0.44	0.36
sd±	68.66	23.14	68.47	25.17	46.05	0.15	0.06	0.30
CV	9.4	20.2	8.1	48.3	44.1	10.4	13.2	83.8

NF = North Facing Slope, SF = South Facing Slope Cs = Coarse sand, Fs = Fine sand, Ts = Total sand, Si = Silt, Cl = Clay, Bd = Bulk density Tp = Total porosity, Ksat = Saturated hydraulic conductivity, NF = North-facing, SF = South-facing, CONC = Concave CONV = Convex

Effect of Slope Curvature on Soil Physical Properties

The data obtained from the coarse sand content revealed that concave slope had the highest mean value of 754± 61.93 gkg^{-1}, CV = 8.2 %, while the lowest mean value of coarse sand content was observed in convex slope with mean value of 748 ±84.66 gkg^{-1}, CV = 11.3% (Table 4.2) coarse sand content had low variability (i.e CV = < 15%), the small variations in coarse sand are responsible for differences in flow pattern. Fine sand content of concave slope recorded low mean value of 97± 27.30 gkg^{-1}, CV = 28.1 %, while concave slope had high mean value of 107± 27.85 gkg^{-1}, CV = 26.0% (Table 4.2). Fine sand had moderate variability (CV = 15 – 35%).The result of Ts content shows that concave slope recorded low mean value of 847±63.91 gkg^{-1}, CV = 7.6 %, while convex slope recorded high mean value of 856 ±72.14 gkg^{-1}, CV = 8.4 %. Total sand had low variability. The highest value observed in the convex slope, is due to physical attribute that are associated with erosion, the different patterns of water flow, which convex slope are dominated by the process of side outflow increases, inturn increases the volume and velocity of runoff, detachment and deposition of Total sand content in line with (Gilsonley *et al.,* 2016). Silt content result revealed that concave slope had low mean value of 43.07 ±27.71 gkg^{-1} with CV = 64.3 %, while convex slope had 50± 24.30 gkg^{-1} with CV = 48.9 % (Table 4.2). Silt content had high variation (CV = > 35%). The highest value of Si content was observed in the convexslope. The result of clay content tended to be higher in concave slope with mean value of 103±41.73 gkg^{-1}, CV = 40.4 %, while concave slope recorded mean value of 94.61 ±50.48 gkg^{-1}, CV = 53.4 % (Table 4.2). Clay content had high variability. It was observed that concave slope had high value of clay. These differences in clay is due to different in pattern of water flow plane water flow increase clay content of the Soil, being more clay will facilitate aggregation, may also be less susceptible to slaking and disruptive forces, due to their associated high cohesion and shear strength (Ogban and Essien, 2016). The result of bulk density indicated that concave slope had low mean value of 1.48 ± 0.15 Mgm^{-3}, CV = 10.1 %, while convex slope had mean value of 1.54 ± 0.16 Mgm^{-3}, CV = 10.2 % (Table 4.2). Bulk density had low variability. The low bulk density in concave slope was therefore due to the higher clay content, compared to the high bulk density in convexslope which is attributed to the high proportion of the skeletal particles, mainly sand.

The total porosity result of concave slope was 0.44 ± 0.06 m^3m-^{3}CV = 12.8 %, while convex slope had 0.42 ± 0.66 m^3m^{-3}, CV = 14.1 % (Table 4.2).Total porosity had low variability. Concaveslope recorded high value than convex slope, indicating that on a volume weighted basis, concaveslope derived more total pore space than convex slope. The observed differences in matrix pore space between the slopes follow a reverse trend to that of bulk density. According to Lal and Shukla (2004) total porosity is affected by particle size distribution. The result reveal that soils in concave may not experience severe impede fluid flow. Saturated hydraulic conductivity, result showed that, concave slope had low mean value of 2.80 ± 0.16cm hr^{-1}, CV = 58.6%, while convex slope had high mean value of 5.60 ± 0.54cm hr^{-1}, CV = 96.9% (Table 4.2).The effect of slope curvature on the hydraulic properties of the layer of soil aggregates is more evident in the concaveslope. This can be explained because the concave landform shows a relatively high percentage of silt, fine sand. The amount of surface soil removed by runoff water depends to a large extent of the resistances of soil aggregates to be disrupted by the energy of raindrop impact (Deyanira, 2003). The ability of a surface soil to accept a continuous heavy rainfall is a critical factor in the prevention of accelerated erosion of soils, and is related to the stability of aggregates to raindrop impact and to the resistance to the shearing force of running water. Moreover, any dispersed clay may effectively lock the pores between the micro-aggregates and give an extremely low infiltration rate. Clay dispersion and swelling result in the elimination of the larger soil pores and reduction in soil hydraulic conductivity.

Table 4.2: Effect of slope curvature on soil physical properties

Sampling Location	Cs	Fs	Ts	Si	Cl	Bd	Tp	Ksat
	←		gkg^{-1}		→	Mgm^{-3}	m^3m^{-3}	$cmhr^{-1}$
				CONC slope				
1	773	66	845	48	414	1.51	0.43	1.00
2	744	94	838	44	118	1.39	0.48	0.60
3	676	116	796	56	148	1.60	0.39	0.70
4	737	461	842	52	106	1.37	0.48	0.59
5	786	100	852	28	80	1.51	0.43	0.20
6	805	103	908	31	61	1.52	0.43	0.31
Mean	754	97	847	43	103	1.48	0.44	0.56
sd±	61.93	27.38	63.91	27.71	41.73	0.15	0.06	0.54
CV	8.2	28.1	7.6	64.3	40.4	10.1	12.8	96.9
				CONV slope				
1	784	94	878	47	75	1.53	0.42	0.30
2	707	131	838	62	94	1.36	0.49	0.31
3	820	68	888	26	86	1.62	0.40	0.40
4	684	126	810	62	128	1.70	0.36	0.12
5	798	96	896	40	64	1.47	0.46	0.32
6	696	129	824	62	114	1.59	0.40	0.28
Mean	748	107	856	50	95	1.54	0.42	0.28
sd±	84.66	27.85	72.14	24.30	50.48	0.16	0.06	0.16
CV	11.3	26.0	8.4	48.9	53.4	10.2	14.1	58.6

Cs: Coarse sand, Fs: Fine sand, Ts: Total sand, Si: Silt, Cl: Clay, Bd: Bulk density, Tp: Total porosity, Ksat: Saturated hydraulic conductivity

Effect of Slope Gradient on Soil Physical Properties

Data for slope gradient revealed that coarse sand content of <10% slope was 752 ±58.72 gkg^{-1}, CV = 7.8%, that of 11-20% slope was 729±90.10 gkg^{-1}, CV = 12.4 %, while that of >20% slope was 771±65.77 g kg^{-1} CV = 8.5%(Table 4.3). The lowest coarse sand content was recording with medium steep slope while the highest was recorded with steep slope. Coarse sand had low variability, coarse sand content increased with increase in slope. This could be adduced to high intensity of erosion and soil loss occurring on the steeper slope.

Fine sand content of <10% slope had 96±29.60 gkg^{-1}, CV = 30.8 %, that of 11-20% slope had 104 ±28.23 gkg^{-1}, CV = 27.2%, while >20% slope recorded 107±25.88 gkg^{-1}, CV = 24.2% (Table 4.3). Fine sand had moderate variability. Fine sand content decreases with decrease in slope gradient and increases with increase in slope gradient. Similarly, Mohammed *et al.,* (2005) reported that finer soil materials are deposit at the steeper slope. The result of the Total sand content in < 10% was 850±49.67 gkg^{-1}, CV = 5.9 %, that of 11-20 slope was 834±79.70 gkg^{-1}, CV = 9.6%, while that of >20% slope was 870±68.77 gkg^{-1}, CV = 7.9% (Table 4.3). Slope gradient of >20% had higher Total sand content. The higher the slope gradient, the higher the total content. This may be due to high velocity of water flow and high volume of water that causes detachment and deposition of sand in the area. The result of silt content indicated that in gradient of < 10% slope had 50.20 ± 24.23 gkg^{-1}, CV = 48.3 %, that of 11-20% slope was 49 ±30.24 gkg^{-1}, CV = 62.0 %, while that of >20% slope was 40±23.34 gkg^{-1}, CV = 58.1 % (Table 4.3). Slope gradient of <10%, 11-20% and >20% had high silt variability. The lower the slope gradient the higher the silt content. The effect of slope gradient on clay content showed that <10% slope recorded 100±32.47 gkg^{-1}, CV = 32.5 %, that of 11-20% slope had 117±54.35 gkg^{-1}, CV = 46.4 %, while that of >20% slope had 80±43.10 gkg^{-1}, CV = 54.1 % (Table 4.3). Slope gradient of <10% had moderate variation, while 11-20 and >20% had high variation. Slope gradient of 11-20% slope had high mean value, while >20% had low mean value. This is because high slope gradient is affect be erosion and high velocity of water flow. However Ogban *et al.,*(1991), reported that physical and chemical characteristics of soil arerelated to the topography of the soils in the area. Bulk density result revealed that <10% slope recorded 1.45 ± 0.15 Mgm^{-3}, CV = 10.7 %, that of 11 – 20%, which that of >20% slope was 1.52 ± 0.10 Mgm^{-3}, CV = 6.3 % (Table 4.3).The result revealed that, bulk density in the three slope gradients recorded low variability.

The variation of soil bulk density among the slope gradients might be attributed to the variation of soil particle size distribution and disturbance of soil particle with erosion. For instance, the relatively lowest value of bulk density on <10% slope (1.45 Mgm^{-3}) could be due to high clay fraction, total porosity and less disturbance of the soil erosion process. However, the reverse is true for medium steep and steep slopes area (Table 4.3). Total porosity p result of slope gradient indicated that <10% slope had high mean value of 0.45 ± $0.06m^3m^3$ CV = 12.9 %, that of 11 – 20% slope had low mean of 0.41 ± $0.07m^3m^{-3}$, CV = 16.9 %, while that of >20% slope was 0.43 ± $0.04m^3m^{-3}$, CV = 8.5%.The lowest total porosity recorded in medium steep slope area could be attributed to the high bulk density low clay content and low organic matter content (Table 4.3). Hydraulic conductivity result indicated slope gradient of <10% had mean value of 5.3 $\pm$0.41 $cmhr^{-1}$, CV = 76.2 %, that of 11-20% slope was 4.5 $\pm$0.57 $cmhr^{-1}$, CV = 128.7%, this may be due to irregularity in distribution of soil particles along the slope. While that of 20% slope was 2.84 $\pm$ 0.12 $cmhr^{-1}$, CV = 44.2 % (Table 4.3). There was a high variability among the slopes. The effect of slope gradient on the hydraulic properties showed that hydraulic conductivity decreases as slope gradient increases. The decrease in slope gradient >20%, can be explained because the slope gradient (>20%) steep slope shows a relatively high percentage of silt and fine sand, which seal up the pore spaces resulting in low hydraulic conductivity.

EFFECT OF SLOPE CHARACTERISTICS ON SELECTED SOIL CHEMICAL PROPERTIES

Effect of Slope Aspect on Selected Soil Chemical Properties

The results of effect of slope aspect on soil pH (kcl) indicated that NF slope had high mean of 6.20 $\pm$ 0.40, CV = 6.5 %, while SF slope had low mean of 6.11 $\pm$ 0.36, CV= 5.9 %, low variability was recorded on slope aspect affected pH (kcl) (Table 4.5). Slope aspect affected organic matter revealed that, NF slope had organic matter content of 1.46 $\pm$0.74 gkg^{-1}, CV = 50.6 %, while that of SF slope had high mean of 2.20 $\pm$0.96 gkg^{-1}, CV = 43.7 %. Organic matter on slope aspect had high

Table 4.3: Effect of slope gradient on soil physical properties

Sampling Location	Cs	Fs	Ts	Si	Cl	Bd Mgm^{-3}	Tp m^3m^{-3}	Ksat $cmhr^{-1}$
	←		gkg^{-1}		→			
				< 10 % slope				
1	773	66	845	48	107	1.51	0.43	1.00
2	744	94	838	44	118	1.39	0.48	0.56
3	784	94	878	47	75	1.53	0.42	0.26
4	707	131	838	62	100	1.36	0.49	0.31
Mean	752	96	850	50	100	1.45	0.45	0.53
sd±	58.72	29.60	49.67	24.23	32.47	0.15	0.06	0.41
CV	7.8	30.8	5.9	48.3	32.5	10.7	12.9	76.2
				11 - 20 % slope				
1	676	116	796	56	148	1.60	0.39	0.67
2	737	105	842	52	106	1.37	0.48	0.59
3	820	68	888	23	86	1.62	0.39	0.40
4	684	126	810	62	122	1.69	0.36	0.12
Mean	729	104	834	49	117	1.57	0.41	0.45
sd±	90.10	28.23	79.70	30.24	54.35	0.18	0.07	0.57
CV	12.4	27.2	9.6	62.0	46.4	11.6	16.9	128.7
				>20 % slope				
1	786	100	852	28	80	1.51	0.43	0.20
2	805	103	908	31	61	1.52	0.43	0.31
3	798	96	896	40	64	1.47	0.45	032
4	695	129	824	62	114	1.59	0.40	0.28
Mean	771	107	870	40	80	1.52	0.43	0.28
sd±	65.77	25.88	68.77	23.34	43.10	0.10	0.04	0.12
CV	8.5	24.2	7.9	58.1	54.1	6.3	8.5	44.2

Cs: Coarse sand, Fs: Fine sand, Ts: Total sand, Si: Silt, Cl: Clay, Bd: Bulk density, Tp: Total porosity, Ksat: Saturated hydraulic conductivity variation.

The variation in organic matter content between slopes is related to differences in litter decomposition rates. SF slope received sunlight that helps in decomposition of organic materials, while NF is in contrast. The low organic matter render the soils fragile under intense erosion, and is a characteristic of coastal plain sands soils, on account of rapid decomposition rate in soils of the tropic (Jones and Wild, 1975).Ca and Mg were the dominant cations in the soils of the areas. The results of Ca showed that slope aspect affecting Ca content with NF slope recorded Ca content of 5.20 ± 1.03 cmol kg^{-1}, CV = 19.8 %, while that of SF slope recording 4.62 ± 0.85 kg^{-1}, CV = 18.5 % (Table 4.5). Ca had moderate variation. The results of Mg showed that NF slope had Mg content of 1.67 ± 0.31 cmol kg^{-1}, CV = 18.9 %, while that of SF slope had 1.63 ±

0.34 cmol kg^{-1}, CV = 20.7 % (Table 4.5). Mg had moderate variation. Na results revealed that slope aspect affected Na with NF recorded low mean of 0.05 ± 0.01 cmol kg^{-1}, CV = 17.3 %, while SF slope recorded high mean of 0.07 ± 0.02 cmol kg^{-1}, CV = 37.9 % (Table 4.5). NF slope had moderate variation, while SF slope recorded high variation. The results shows that the soils are not sodic because values of Na saturation present are less than 15% in both slopes (Enwezor *et al.,* 1990). Slope aspect affected potassium content of the study soils, with NF slope recorded low mean of 0.13 ± 0.02 cmol kg^{-1}, CV = 17.7 %, while SF slope recorded high mean of 0.14 ± 0.03 cmol kg^{-1}, CV = 21.6 % (Table 4.5). Among the slopes

Table 4.4: Effect of slope aspect on selected chemical properties

Sampling Location	pH(KCl)	OM %	C	Mg	Na Cmol/kg	K	TEB	ECEC	Bsat %	ESP %	SAR	Am.Fe	Cry. Fe mg/kg	Am. Al	Cry.Al
NF Slope															
1	6.2	1.33	4.6	1.7	0.04	0.13	6.47	9.89	65.43	0.51	0.02	413.8	566.6	241.6	319.8
2	6.7	1.9	5.2	1.8	0.06	0.17	7.16	9.01	79.67	0.6	0.07	397.1	520.7	197.9	389.8
3	6.5	1.66	4.4	1.10	0.05	0.11	6.53	8.82	74.6	2.93	0.02	369.10	586.54	288.10	423.7
4	6.54	5.9	5.8	1.6	0.06	0.6	7.53	8.6	88.63	0.70	0.02	350.4	566.6	215.22	422.8
5	5.7	5.6	26.4	1.6	0.05	0.10	7.01	8.3	85.56	0.57	0.01	387.82	626.22	221.8	403.3
6	5.7	1.66	5.92	1.6	0.06	0.13	7.57	10.99	68.79	0.58	0.02	355.8	559.7	156.1	502.42
Mean	6.20	1.46	5.20	1.67	0.05	0.13	7.05	9.26	77.11	0.59	0.02	379.14	571.04	225.26	412.70
sd±	0.40	0.74	1.03	0.31	0.01	0.02	0.95	1.51	10.88	0.13	0.01	76.13	110.17	72.28	98.21
CV	6.5	50.6	19.8	18.9	17.3	17.7	13.5	16.3	14.1	22.4	31.0	20.1	19.3	32.1	23.8
SF Slope															
1	6.4	1.8	4.10	1.8	0.05	0.11	6.92	8.59	8.00	0.58	0.02	395.74	530.6	216.4	368.6
2	6.1	2.36	4.8	1.62	0.06	0.14	6.62	11.09	60.79	0.55	0.02	555.6	534	23872	355.9
3	6.4	1.87	5.0	1.5	0.05	0.11	6.67	8.05	83.22	0.68	0.02	409.6	547.1	212.1	404.3
4	5.6	2.83	4.6	1.8	0.05	0.12	6.53	8.69	76.00	0.58	0.02	367.1	728.2	238.7	403.8
5	6.3	1.72	3.7	1.2	0.06	0.14	5.12	8.12	62.40	0.76	0.03	328.6	434	161.18	247.9
6	5.92	2.60	4.74	1.77	0.12	0.19	6.82	10.19	67.37	0.63	0.09	305.4	631.16	238.78	379.89
Mean	6.11	2.20	4.62	1.63	0.07	0.14	6.45	9.12	71.80	0.63	0.04	377.67	567.51	217.64	360.07
sd±	0.36	0.96	0.85	0.34	0.02	0.03	1.14	1.88	12.01	0.13	0.03	96.93	159.35	74.96	124.54
CV	5.9	43.7	18.5	20.7	37.9	21.6	17.6	20.6	16.7	20.2	78.9	25.7	28.1	34.4	34.6

Ec = Electric conductivity, OM = Organic matter, TN = Total nitrogen, Ca = Calcium, Mg = Magnesium, Na = Sodium, K = Potassium, TEB = Total exchangeable bases, EA = Exchangeable acidity, ECEC = Effective cation exchange capacity, Bsat = Base saturation, ESP = Exchangeable sodium percentage, SAR = Sodium adsorption ratio, Am. Fe = Amorphous of Iron, Cry. Fe = Crystalline of Iron, Am. Al = Amorphous of Aluminum, Cry. Al = Crystalline Aluminnum.

There was a moderate variation observed. The values of exchangeable potassium were low considering the standards of Udo *et al.,* (2009). Total exchangeable bases results indicated that NF slope had total exchangeable bases high mean of 7.05 ± 0.95 cmol kg^{-1}, CV = 13.5 %, while SF slope had low mean of 6.45 ± 1.14 cmol kg^{-1}, CV = 17.6 % (Table 4.4). The NF slope had low variation, while SF slope had moderate variation. The high mean value in the SF slope may be as a result of the soil in the area contains very high Ca which may be related to inherent Ca content of the soil from the parent rock. ECEC content of the NF slope had mean of 9.26 ± 1.51 cmol kg^{-1}, CV = 16.3 %, while that of SF slope was 9.12 ± 1.88 cmol kg^{-1}, CV = 20.6 % (Table 4.4). ECEC had moderate variation in both slopes. The NF slope was relatively higher than the SF slope. This suggests that the ECEC of the NF slope were largely associated with the clay fraction and probably 2:1 clay minerals such as montmorillonite might be present in the clay fraction. The results of Bsat obtained indicates that NF slope had Bsat content higher mean of 77.11 ± 10.88 %, CV = 14.1 % while that of SF slope recorded low mean of 71.80 ± 12.01 cmol kg^{-1}, CV = 16.7 %. North and SF slope had low and moderate variability respectively (Table 4.4). Base saturated obtained revealed that NF slope recorded high mean value. Base saturated is used in classifying the fertility level of soils with values greater or lower than 50% indicating fertile or low fertility soils, respectively (FAO, 1998). However, the high Bsat in the NF slope could best be explained in terms of the proportion of TEB and the ECEC of the respective soils. Exchangeable sodium percentages calculated indicated that NF and SF slopes had mean of 0.59 ± 0.13 %, CV = 22.4 % and 0.6 ± 0.13 %, CV = 20.2 % respectively (Table 4.4). Both slopes had moderate variation. SF slope recorded high mean value. This may be due to high rainfall intensities that brought about erosion devastations and transportation of minerals from one location to the other. Das (1997) reported that any positive value of salt index indicates poor quality. According to various bicarbonate hazard classification systems the value obtained shows that the soils of the area was of good quality.SAR calculated revealed that slope aspect affected SAR with NF slope recorded mean of 0.02 ± 0.01%, CV = 31.0%, while that of SF slope was 0.04 ± 0.03 %, CV = 78.9 % (Table 4.5). The both slopes had high variation. SAR relates the Na content with the dicationic cations Ca and Mg. The SF slope had high values. The SAR values so recorded are for less than the standard safe minimum limits of 10 set by (FAO, 1998). All the salt mean index values were negative indicating, that means waters are of high quality. Slope aspect effect on Am. Fe results indicated that NF slope had mean of

37.94 $\pm$ 76.13 $Mgkg^{-1}$, CV = 20.1 %, while that of SF slope was 37.77 $\pm$ 96.93 $Mgkg^{-1}$, CV = 25.8 %. Both slopes had moderate variation (Table 4.4). There was no difference between north and SF slope. However these amounts dose not high enough to cause a distortion of the physical property such as hardness of the soils but high enough to influence chemical proportion of the soils such as ion adsorption. The result of Cry. Fe fractions were higher compared to values of Am. Fe, in consonance with the report of Ogunkunle and Onanasaya (1992). The values of Cry. Fe indicated that NF slope had mean of 7.10 $\pm$ 11.03 $Mgkg^{-1}$, CV = 19.3 %, while that of SF slope had 56.76 $\pm$ 15.94 $Mgkg^{-1}$, CV = 28.1 % (Table 4.4). North and SF slopes had moderate variation. NF was slightly high than SF slope. These crystalline forms according to Obi *et al.,* (2009) are the more advanced Stage compared to the amorphous form that are mobile in the soil could be associated with organic matter. The high content in NF is approaching the iron content of low grade iron are (Brady and Weil, 1999) which indicate high stability of soil aggregate and high soil porosity. Slope aspect with Am. Al results revealed that NF slope had mean value of 22.53 $\pm$ 7.23 $Mgkg^{-1}$, CV = 32.1 %, while that of SF slope was 21.76 $\pm$ 7.50 $Mgkg^{-1}$, CV = 34.4 % (Table 4.4). Effect of slope aspect on Cry. Al revealed that NF slope recorded higher mean of 41.30 $\pm$ 9.81 $Mgkg^{-1}$, CV = 23.8 %, while SF slope recorded low mean of 36.107 $\pm$ 12.45 $Mgkg^{-1}$, CV = 34.4 %. Both the north and SF slopes had moderate variability. The results revealed that NF slopes had no evidence of migration of clay with amorphous and Cry. Al. The low mean values in the SF slopes indicate that the soils are highly weathered and contained very little weather able minerals.

Effect of Slope Curvature on Selected Soil Chemical Properties

Effect of slope curvature on selected soil chemical properties of the study area revealed that soil pH (kcl) of concave slope had high mean of 6.24 $\pm$ 0.34, CV = 5.5 %, while that of convex slope had low mean of 6.08 $\pm$ 0.41, CV = 6.7 % (Table 4.5). pH (kcl) with slope curvature had low variation. The results of organic matter showed that concave slope had mean of 1.56 $\pm$0.66 gkg^{-1}, CV = 42.6, while convex slope recorded high mean of 2.10 $\pm$1.08 gkg^{-1},CV = 51.4 % (Table 4.5). Slope curvature effect organic matter recorded high variation. Concave slope had low organic matter. This may be as a result that concave slopes had greater variation attributes, organic matter content, superficial flow and slope, indicating that soil attributes have different patterns as a function of slope curvature. Concave slopes have areas with higher erosion rates, in concave environments the processes of sediment loss and accumulation occur simultaneously. Ca results based on slope curvature indicated that, concave slope had mean of 4.6 ± 0.88 $Mgkg^{-1}$, CV = 19.0 %, while convex slope had 5.16 ± 1.03 $Mgkg^{-1}$, CV 19.8 %.Slope curvature effect on Ca showed high variation, (Table 4.5).Mg results of slope curvature effect revealed that concave slope had mean of 1.63 ± 0.37 cmol kg^{-1}, CV = 22.8 %, while that of convex slope was 1.67 ± 0.27 cmol kg^{-1}, CV = 16.4 % (Table 4.5). with a moderate variability among the slopes. The high mean value of Ca and Mg observed in convex slope may be as a result, largely due to the tenacity with which the ions are held on the exchange complex the solubility of Ca and Mg compounds and the condition of limited area of erosion (waterflow). potassium content of concave slope recorded mean value of 0.12 ± 0.02 cmol kg^{-1}, CV = 14.2 %, while that of convex slope recorded mean of 0.14 ± 0.03 cmol kg^{-1}, CV = 19.7 % (Table 4.5). Concave slope had low while convex slope had moderate variation. The variability of potassium content may depend on particle size distribution and soil management practices, Potassium content of the soils are within the medium range, since the critical value of 0.3 cmol kg^{-1} and above are considered to be high (Enwezor *et al.,* 1990). TEB results revealed that concave slope had low mean value of 6.45 ± 1.02 cmol kg^{-1}, CV = 15.7 %, while that of convex slope record high mean value of 7.04 ± 1.08 cmol kg^{-1}, CV = 15.4 %. TEB with slope curvature had moderate variation (Table 4.5). Concave slope with higher area of erosion had low TEB, may be due to intense leading of bases by the high tropical rainfall (FMANR, 1990), this could lead to high acidity of the soils in the area. Effect of slope curvature on ECEC indicated that CONC slope had 8.63 ± 120 cmol kg^{-1}, CV = 13.9 %, while that of CONV slope was 9.76 ± 1.93 cmol kg^{-1}, CV = 19.8 %. CONC slope had moderate variability (Table 4.5). The low ECEC in CONC slope, which by implication low Cation Exchange Capacity (CEC) was a confirmation of the characteristics of the tropical soils having low activity Clays with low contents of negative charges (Gillman, 1985). The CONC slope may have high cation exchange capacity. This further confirmed the limited capacity of soil retention capacity due to the dominance of kalinitic Clays and occupation of the charged sites by aluminum. It also indicates the low buffer capacity of the soils (Gillman, 1985). The results of Bsat obtained indicated that CONC slope had 75.36 ± 11.66 %, CV = 15.5 %, while CONV slope had 73.54 ± 11.81 %, CV = 16.1 % (Table 4.5). There was a moderate variation among the slopes. CONC slope recorded high mean value could be related with the preferable soil pH range and CI content of the study area. This reveals that any factor that could affect Ca, Mg and ECEC of the soil could also affect Bsat in the same manner (Aytenew, 2015). Exchangeable sodium percentage affected by slope curvature showed that CONC slope had 0.62 $\pm$ 0.14 %, CV = 23.2%, while that of CONV slope was 0.61 $\pm$ 0.12 %, CV = 19.5 %. Both the CONC and CONV had moderate variation (Table 4.5). The results shows that CONC have higher content of ESP, with less than 2% exchangeable sodium percentage indicate that the soil may not be susceptible to spontaneous dispersion in water, but this may be more in CONC slope than CONV slope. SAR (SAR) calculation shows effect of slope curvature with CONC slope mean of 0.02 $\pm$ 0.01 %, CV = 32.5 %, while CONV slope had 0.04 $\pm$ 0.03 %, CV = 83.4 %. CONC slope had moderate variation while CONV slope recorded high variation while CONV slope recorded high variation (Table 4.5). The high SAR and high variation in CONV slope, revealed that aggregate in this slope will resist disintegration or breakdown and particle dispersion, also is a good indicators for the stability of soil structure,

Table 4.5: Effect of slope curvature on selected chemical properties

Sampling Location	pH(KCl)	OM %	Ca	Mg	Na	K	TEB	ECEC	Bsat	ESP	SAR	Am.Fe	Cry. Fe	Am. Al	Cry.Al
			←			Cmol kg^{-1}	→		←	% →		←	$mgkg^{-1}$		
								CONC Slope							
1	6.2	1.33	4.7	1.7	0.04	0.13	6.47	9.89	65.43	0.51	0.02	413.8	566.6	241.6	334.9
2	6.4	1.8	4.10	1.8	0.09	0.11	6.9	85.9	81.00	0.58	0.02	395.7	530.6	216.4	368.6
3	6.5	1.66	4.4	1.10	0.05	0.6	6.53	88.3	74.6	0.59	0.02	369.10	586.5	288.10	415.5
4	6.4	1,87	4.10	1.5	0.05	0.19	6.67	8.1	83.22	0.67	0.02	490.6	547.1	212.1	404.3
5	5.7	1.01	5.28	1.6	0.05	0.10	7.01	8.3	85.5	0.7	0.02	387.8	626.3	221.8	403.4
6	6.3	1.7	3.7	1.2	0.06	0.14	5.12	8.12	62.40	0.76	0.03	328.6	414.8	161.2	247.9
Mean	6.24	1.56	4.65	1.63	0.05	0.12	6.45	8.63	75.36	0.62	0.02	397.76	548.51	223.67	363.66
sd±	0.34	0.66	0.88	0.37	0.01	0.02	1.02	1.20	11.66	0.14	0.01	97.25	129.66	77.31	122.16
CV	5.5	42.6	19.0	22.8	19.0	14.9	15.7	13.9	15.5	23.2	32.5	24.5	23.6	34.6	33.6
								CONV Slope							
1	6.6	1.9	85.2	1.7	0.06	0.17	7.16	9.02	79.67	0.61	0.07	397.3	520.7	197.9	389.8
2	6.1	2.37	4.8	1.6	0.06	0.14	6.61	11.09	60.79	0.55	0.02	333.6	5.34	238.7	355.9
3	6.5	1.18	5.8	1.6	0.06	0.12	7.53	8.56	88.63	0.70	0.02	350.4	566.6	215.2	422.8
4	5.6	2.83	4.6	1.8	0.05	0.12	6.53	8.69	75.00	0.58	0.02	367.1	728.2	238.7	403.8
5	5.7	1.66	5.9	1.5	0.06	0.13	7.57	10.99	68.79	0.58	0.02	355.8	559.7	186.1	502.4
6	5.9	2.66	4.8	1.8	0.12	0.19	6.82	10.19	67.37	0.63	0.10	350.4	631.16	238.78	379.89
Mean	6.08	2.10	5.16	1.67	0.07	0.14	7.04	9.76	73.54	0.61	0.04	359.05	590.05	219.23	409.10
sd±	0.41	1.08	1.03	0.27	0.02	0.03	1.08	1.93	11.81	0.12	0.03	70.42	140.83	69.90	102.94
CV	6.7	51.4	19.9	16.4	34.7	19.7	15.4	19.8	16.0	19.5	83.4	19.6	23.9	31.9	25.2

OM = Organic matter, Ca = Calcium, Mg = Magnesium, Na = Sodium, K = Potassium, TEB = Total exchangeable bases, ECEC = Effective cation exchange capacity, Bsat = Base saturation, ESP = Exchangeable sodium percentage, SAR = Sodium adsorption ratio, Am. Fe = Amorphous of Iron, Cry. Fe = Crystalline of Iron, Am. Al = Amorphous of Aluminum, Cry. Al = Crystalline Aluminnum.

While CONC slope is in reverse may be due to the pattern of water outflow, that less disturb the formation and stability of aggregate within this area. The result of Am. Fe as affect by slope curvature revealed that CONC slope had mean of 39.76 $\pm$ 97.25 $Mgkg^{-1}$, CV 24.5 %, while CONV slope had 35.91 $\pm$ 70.42 $Mgkg^{-1}$, CV = 19.6 %. Both slopes had moderate variation (Table 4.5). CONC had high mean value could be as a result of high organic matter content, because of the large area of erosion that resulted in transportation and deposition of minerals by water. Cry. Fe results indicated that CONC slope had mean of 54.85 $\pm$ 129.66 $Mgkg^{-1}$, CV =23.6 %, while CONV slope had mean of 59.01 $\pm$ 140.83 $Mgkg^{-1}$, CV = 23.9 %. CONC and CONV slope had moderate variation. CONV slope had high mean value; because of the small area of erosion this reduces the migration of minerals from one location to the other and enhanced aggregate stabilization that help in reduction of impact of erosion within the area. Am. Al indicated that CONC slope recorded mean of 22.37 $\pm$ 77.31 $Mgkg^{-1}$, CV = 34.6 %, while that of CONV slope was 21.92 $\pm$ 69.90 $Mgkg^{-1}$, CV = 31.9 % (Table 4.5). Am. Al had moderate variation in both slopes.Slope curvature effect on Cry. Al showed that CONC slope had 36.37 $\pm$ 122.16 $Mgkg^{-1}$, CV = 33.6 %, while that of CONV slope was 40.91 $\pm$ 102.94 $Mgkg^{-1}$, CV = 25.2 %. CONC and CONV slope had moderate variation (Table 4.5). The high and low mean values could be because of the pattern of water flow which CONC slope had large area of water flow while that of CONV slope had side outflow as a result of these there is variability in the results obtained.

Effect of Slope Gradient on Selected Soil Chemical Properties

Effect of slope gradient on soil pH (kcl) showed that slope (< 10 %) had high means value of 6.33$\pm$0.25, CV =3.9 %, that of medium steep (11 - 20 %) slope had 6.26$\pm$ 0.41, CV = 6.6 %, while that of steep (> 20 %) recorded low mean value of 5.89 $\pm$ 033, CV = 5.7 %. (Table4.6). According Tekalign (1991) cited in Aytenew (2015) rating of soil pH, soils with pH (KCL) >8.0 are characterized as strongly alkaline; 7.4-8.0 as moderately alkaline; 6.7-7.3 as neutral, while soils with pH of 6.0 -66, 5.3-5.9, 4.5 -5.2 and < 4.5 are rated as slightly acid, moderately acid, respectively. In reaction accordingly, the soils in the sloping (<10%) and medium steep (11-20% slope) slopes were slightly acidic while steep slope (>20%) was moderately acidic. The low variation could be contributed by the effect of slope gradient on the soil moisture storage capacity and biomass production. However, in the steep slope there could be high drainage, how moisture storage and less biomass production there by decrease soil pH.Slope gradient affect organic matter, with the high mean value of

1.89±0.86 gkg^{-1} CV =45. 7% been recorded with medium steep slope (11-20%), that of sloping slope (<10%) had 1.84±1.01 gkg^{-1}, CV = 54.8%, while steep slope (> 20%) recorded the lowest mean value of 1.76 ±0.95 gkg^{-1}, CV = 54.1 % (Table 4.6).There was high variation. The variation could be contributed by the effect of slope gradient on the soil moisture storage is better and resulting in better biomass production furthermore, the expected impeded drainage could also show down the organic matter process. The result of gradient affect Ca content revealed that sloping slope (< 10 %) recorded low mean value of 4.90 ±0.70 cmol kg^{-1} that of medium slope (11-20%) recorded high mean value of 4.92 ±0.85 cmol kg^{-1} while that of steep slope (> 20 %) recorded 4.91 ±1.34 cmol kg^{-1}, CV = 27.2 %. Ca result under slop gradient had medium variation among the slopes (Table 4.6). Also there was a small difference among the slope, which generally is negligible. Ca content may be attributed to the combination of hydrous ions and Ca carbonate. The condition enhanced flocculation of soil and improved aggregate stability, which inturns will disrupt effect of aggregate from of water. The result of Mg showed that sloping slope had mean value of 1.71 ±0.23 cmol kg^{-1} , CV=13.5 %, that of medium steep recorded high mean value of 1.73 ±0.38 cmol kg^{-1}CV = 22.2 %, while that of steep slope recorded 1.51 ±0.31 cmol kg^{-1}, CV = 20. 4 %. Mg had medium variation. Slope gradient effected Na content indicate that sloping and medium steep slope recorded same mean value of 0.05 ±0.01 cmol kg^{-1}, CV = 17.3 % and 0.05 ± 0.01 cmol kg^{-1},CV = 14.0 % and medium steep had low variation, while that of steep slope had mean of 0.07 ± 0.03, cmol kg^{-1}, CV = 39.7 % steep slope had high variation (Table 4.6). The difference in variability as a result of the slope gradient. Increase in slope gradient increases the Na content. It may be due to the parent material that shows that the soils are of area.

Table 4.6: Effect of slope gradient on selected chemical properties

Sampling Location	pH(KCl)	OM	Ca	Mg	Na	K	TEB	ECEC	Bsat	ESP	SAR	Am.Fe	Cry. Fe	Am. Al	Cry.Al
		%	←			Cmol kg^{-1}		→	←	% →		←	$mgkg^{-1}$	—	
								< 10 % Slope							
1	6.2	1.33	4.6	1.7	0.05	0.13	6.47	9.89	65.43	0.51	0.02	413.8	566.6	241.64	334.18
2	6.4	1.76	5.0	1.8	0.05	0.11	6.92	8.59	81.00	0.58	0.02	395.7	530.6	216.4	368.6
3	6.6	1.91	5.2	1.7	0.06	0.17	7.16	9.02	79.67	0.61	0.02	397.1	520.7	197.9	389.8
4	6.1	2.36	4.8	1.6	0.06	0.14	6.62	11.09	60.79	0.55	0.02	333.6	534	238.7	355.9
Mean	6.33	1.84	4.90	1.71	0.05	0.14	6.79	9.65	71.72	0.56	0.02	385.06	537.95	223.65	362.12
sd±	0.25	1.01	0.70	0.23	0.01	0.02	0.87	1.75	11.31	0.09	0.01	82.56	152.76	82.32	104.19
CV	3.9	54.8	14.2	13.5	17.3	17.9	12.8	18.1	15.8	15.4	30.5	21.4	28.4	36.8	28.8
								11 - 20 % Slope							
1	6.5	1.66	4.4	2.0	0.05	0.11	6.53	8.83	74.56	0.59	0.02	370.0	586.5	289.0	423.7
2	6.4	1.87	5.0	1.5	0.05	0.12	6.67	8.05	83.22	0.68	0.02	490.6	547.1	212.1	404.3
3	6.5	1.18	5.8	1.6	0.06	0.12	7.53	8.56	88.63	0.70	0.02	350.4	566.6	215.2	422.8
4	5.6	2.83	4.6	1.8	0.05	0.12	6.53	8.69	76.00	0.58	0.04	367.1	648.2	238.7	403.8
Mean	6.26	1.89	4.92	1.73	0.05	0.12	6.82	8.53	80.60	0.64	0.03	394.51	607.11	238.75	413.65
sd±	0.41	0.86	0.85	0.38	0.01	0.01	0.86	1.11	10.49	0.14	0.02	104.73	118.59	63.83	79.46
CV	6.6	45.7	17.3	22.2	14.0	7.9	12.6	13.0	13.0	22.2	65.9	26.6	19.5	26.7	19.2
								>20 % Slope							
1	5.7	1.01	5.3	1.6	0.05	0.10	7.01	8.30	85.56	0.57	0.01	387.8	626.2	221.8	403.3
2	5.7	1.72	3.7	1.2	0.06	0.14	5.12	8.12	62.40	0.76	0.03	328.6	434	161.2	247.94
3	5.7	1.66	5.9	1.5	0.06	0.13	7.57	10.99	68.79	0.58	0.02	355.8	559.7	186.1	502.4
4	5.9	2.66	4.74	1.77	0.12	0.19	6.81	10.19	67.37	0.63	0.10	350.4	631.2	238.9	379.89
Mean	5.89	1.76	4.91	1.51	0.07	0.14	6.63	9.40	71.03	0.64	0.04	355.65	562.77	201.96	383.38
sd±	0.33	0.95	1.34	0.31	0.03	0.03	1.46	1.97	11.20	0.15	0.03	67.37	131.57	70.90	148.33
CV	5.7	54.1	27.2	20.4	39.7	23. 9	22.0	21.0	15.8	23.0	83.8	18.9	23.4	35.1	38.7

OM = Organic matter, Ca = Calcium, Mg = Magnesium, Na = Sodium, K = Potassium, TEB = Total exchangeable bases, ECEC = Effective cation exchange capacity, Bsat = Base saturation, ESP = Exchangeable sodium percentage, SAR = Sodium adsorption ratio, Am. Fe = Amorphous of Iron, Cry. Fe = Crystalline of Iron, Am. Al = Amorphous of Aluminum, Cry. Al = Crystalline Aluminnum.

The result shows that the soils are not sodic because values of Na present are less than 15% in all the slops (Enwezor *et al.,*1989) potassium was affected by slop gradient the result obtained indicate that sloping and steep slopes recorded same means value of 0.14 ±0.02 cmol kg^{-1}, CV= 17.9 % and 0.14 ±0.03 cmol kg^{-1}, CV = 23.9 %, while medium steep slope recorded how means of 0.12 ±0.01 cmol kg^{-1}, CV=7.9 %(Table 4.6). Sloping slopes and steep slope had moderate, medium steep had low. TEB result revealed that sloping shape recorded means value of 6.79 ±0.87 cmol kg^{-1}CV = 12.8 %, that of 6.79 ± 0.87 cmol kg^{-1}, CV = 12. 7 %, that of medium step had mean of 6.82 ±0.86 cmol kg^{-1} CV = 12.7 %, while that of steep shope had 6.63 ± 1.46 cmol kg^{-1}, CV = 22.0 % (Table 4.6). Sloping and medium had how variation, while steep shop had medium variation. Ca and Mg are the dominant TEB, in line with Folorunsho and Kargbo (1986) gave reasons for the predominance of Ca and Mg in soils as largely due to the tenancity with which the ions are held on the exchange complex, the solubility of Ca and mg compounds and the condition of limited soil moisture content in soils of the slope. There was no consistence in the values of TEB between the slope gradient. ECEC was affected by slope gradient. The result indicate that sloping slope had high mean of 9.65 ± 1.75 cmol kg^{-1}, CV = 18.1 %, that of medium steep had low mean of 8.53 ± 1.11 cmol kg^{-1}, CV = 13.0 %, while the steep slope recorded 9.40 ± 1.97 cmol kg^{-1}, CV = 21.0 % (Table 4.6). < 10 % and > 20 % slope had moderate variation, while 11 - 20 % slope had low variation. ECEC did not follow a specific trend as a result of differences in soil properties other than slope which also affected the ECEC. The low values of ECEC (Udo *et al.,* 2009). This could be as a result of the high erodibility occurring most on a sloping land. Base saturation result revealed that sloping slope had mean of 71.72 ± 11.31 %, CV = 15.8 %, that of medium steep had high mean of 80.60 ± 10.49 %, CV = 13.0 %, while that of steep slope had 71.03 ± 11.20%, CV = 15.8% (Table 4.6). Medium steep had low variation while sloping and steep had medium variation. Bsat did not follow a specific trend, due to irregularity deposition of materials caused by erosion. Exchangeable sodium percentage result obtained, indicated that sloping slope had low mean of 0.56 ± 0.09%, CV = 15.4 %, while that of medium steep and steep slope recorded same mean of 0.64 ± 0.14 %, CV = 22.2 % and 0.64 ± 0.15, CV = 23.0 % (Table 4.6). Exchangeable sodium percentage values affected by slope gradient had medium variability.

SAR calculation was affected by slope gradient. The result showed that SAR in sloping slope recorded low mean of 0.02 ± 0.01, CV = 30.5 %, that of medium steep had 0.03 ±

0.02, CV = 65.9 %, while steep slope had high mean of 0.04 ± 0.03, CV = 83.8 %, sloping slope had moderate variation while medium steep and steep slope had high variation (Table 4.6). Increased in slope gradient increases SAR content. The SAR which relates the Na content with the dicationic cations Ca and Mg were less than the standard safe minimum limits of 10, set by FAO (FAO, 1984). This could not cause easily dispensability of the aggregate. The results of amorphous Fe revealed that sloping slope had mean of 38.51 ± 82.56 $Mgkg^{-1}$, CV = 21.4 %, that of medium steep had high of 39.45 ± 104.73 $Mgkg^{-1}$, CV = 26.6 %, while that of steep slope had low mean of 35.57 ± 67.37, $Mgkg^{-1}$, CV = 18.9 %. Amorphous Fe content affected by slope gradient had moderate variation. (Table 4.6). According to Stone house and Arnaud (1971), Soils with Fe ratios of less than 0.35 were classified as being poorly drained, whereas well drained soils had values greater than 0.35. The dominance of Fe amorphous (mobile) in slope soils is further buttressed by the Fe (mobile) ratio which displaced irregularly within the slopes, medium steep is well-drained soils, this reduces the rate or volume of water flow, that decreases the effect of erosion on aggregate. The results of Cry. Fe (immobile Fe) indicated that, Cry. Fe fractions were higher compared to values of Am. Fe. Crystalline Fe content of sloping slope had low mean of 53.80 ± 152.76 $Mgkg^{-1}$ CV = 28.4 %, that of medium steep had high mean of 60.71 ± 118.59 $Mgkg^{-1}$, CV = 19.5 %, while that of steep slope had 56.28 ± 131.57 $Mgkg^{-1}$, CV = 23.4 %. There was a moderate variability among the slopes (Table 4.6). Medium steep slope recorded high mean value. It could be as a result of deposition of the Cry. Fe that has been washed down along with eroded water (Tahir *et al.,* 2006). Effect of slope gradient on Am. Al showed that sloping slope had mean of 22.37 ± 82.32 $Mgkg^{-1}$, CV = 36.8 % of medium steep slope had high mean of 23.88 ± 63.83 $Mgkg^{-1}$ CV = 26.7 %, while that of steep slope recorded 20.20 ± 70.90 $Mgkg^{-1}$, CV = 35.1 %(Table 4.6). Medium steep had moderate, while sloping and steep slopes had high variation. Cry. Al (Immobile Al) result indicated that sloping slope had h=low mean of 36.21 ± 104.19 $mgkg^{-1}$, CV = 28. 7 %, that of medium steep had high mean of 41.37 ± 79.46 $Mgkg^{-1}$, CV = 19.2 %, while that of 38.34 ± 148.33 $Mgkg^{-1}$. CV = 38.7 % (Table 4.6). The sloping and medium steep slopes had moderate variation. The low men values may be as a result that those slope were highly weathered soils and the high mean may be due to high content of organic matter.

Effect of Slope Characteristics on Aggregate-size Distributions

Wet aggregate stability suggests how well a soil can resist raindrop impact Aggregate size fraction was obtained in the 4.0-2.0mm (Large macro aggregate), 2.0-0.25mm (Small micro aggregate), 0.25mm- 0.05mm (Micro aggregate) and < 0.05mm (mineral fraction) aggregate class rang.

Effect of Slope Aspect on Dry Aggregate Size Distribution

Dry aggregate size distribution of 4.0 – 2.0 mm (Large macro aggregate size fraction result revealed that NF slope recorded high mean value of 23.0 ± 8.42mm, CV = 36.6 %, while SF slope had mean lower of 20.1 ± 9.57 mm, CV = 47.5 % (Table 4.7)Dry aggregate size distribution of 2.0 – 0.25 mm (Small macro aggregate) fraction result revealed that NF slope had aggregate size fraction of 23.0 ± 7.60 mm, CV = 33.1 % (Table4.7) while SF slope recorded 25.1 ± 8.46 mm, CV = 33.7 %. The result of aggregate-size fraction of 0.25 – 0.05 mm (micro aggregate), revealed that NF slope recorded mean of 0.87 ± 0.43 mm, CV = 50.1, while SF slope had high mean of 0.83 ± 0.44, CV = 53.6 %. This may be due to the fact that in NF slope dry aggregate are much affected by wind in dry brases while in SF slope under dry condition are not affected by wind.In aggregate-size fraction < 0.05 mm (mineral fraction), the result shows that NF had mean value 3.10 ± 1.45 mm, CV = 46.7 % while SF slope had 4.01 ± 1.82 mm, CV = 45.4 %.

Table 4.13: Effect of slope aspect on dry aggregate size distribution

	Dry Aggregate Size Distribution			
	4 -2	2 – 0.25	0.25 – 0.05	< 0.05
	←	mm		→
		NF		
1	24.6	21.0	1	3.8
2	18.4	24.2	0.8	2.5
3	26.4	21.3	0.9	2.0
4	26.6	19.3	0.9	2.2
5	22.6	22.0	0.8	4.0
6	16.6	30.2	0.9	3.4
Mean	23.0	23.0	0.9	3.1
Sd+	8.42	7.60	0.43	1.45
CV	36.6	33.1	50.1	46.7
		SF		
1	16.7	29	0.8	3
2	14.3	30.2	0.8	6.6
3	21.3	18.2	1.0	3.4
4	22.6	24.6	0.6	2.2
5	32.8	17.6	1.0	1.8
6	11.7	30.76	0.8	7.1
Mean	20.1	25.1	0.8	4.0
Sd+	9.57	8.46	0.44	1.82
CV	47.5	33.7	53.6	45.4

Effect of Slope aspect on wet aggregate-size distribution

Wet aggregate size distribution of 4.0-2.0mm (Large macro aggregate) size fraction result showed that north- facing slope had mean higher value of 6.03± 4.99mm, CV = 82.8 % while south- facing slope had mean lower of 5.21± 5.60mm CV= 107.5% (Table4.8), There was high variation among the slope aspect, and aggregate size fraction of 4.0-2.0mm in the north facing shows that, north facing slope receive less rain, which implies low disruption of soil aggregates by the energy of raindrop impact.Wet aggregate size distribution of 2.0- 0.25mm (small macro aggregate) fraction result indicated that north- facing slope had aggregate size fraction of 38.9 ± 4.71 mm, CV = 12.1 %, while SF slope had 39.89± 5..10mm, CV= 12.8% (Table 4.8). Slope aspect of aggregate size 2.0- 0.25mm had low variation. Aggregate-size fraction of 2.0- 0.25mm was little high in the south facing than north facing slope. This is due to the fact that south facing slope receive much rainfall, that causes disinter fraction of large macro aggregate (4.0 – 2.0 mm) fraction into small macro aggregate (2.0- 0.25mm) size fraction, which size produces artificial redistribution that later are accounted for the smaller fractions (Marquez, 2004). The result of aggregate-size fraction of 0.25-0.05mm (micro aggregate), Showed that north facing slope of aggregate size fraction had high mean of 0.97± 0.67mm, CV= 69.2 %, while SF slope had low mean of 0.94 ± 0.65mm, CV= 69.4 % (Table 4.8). Slope aspect of aggregate-size of 0.25-0.05mm had high variation. South facing slope receives much sunlight that, which comes in rain form, generated a lot of raindrop impact on the slope facing south ward. The amount of water surface soil received, cause weakening of bond of aggregate, during wetting and to the resistance to the shearing force of running water that causes redistributed of the 0.25- 0.05mm on south facing slope. Aggregate-size fraction of <0.05 mm (mineral constituent) indicated that north-facing slope recoded. Mean value of 4.7± 2.30mm, CV = 56.6%, while that of SF slope had 3.40 ±2.44mm, CV = 61. 0% (Table 4.8). The mineral constituent had high variation as affected by slope to accept a continuous heavily rainfall, causes dispersion and redistributed of the mineral fraction.

Table 4.8: Effect of slope aspect on wet aggregate size distribution

Sampling Location	Wet Aggregate Distribution 4 - 2	2 - 0.25	0.25 - 0.05	< 0.05
	←	mm	→	
		NF Slope		
1	3	41	1	5
2	7	36	2	5
3	3	43	1	3
4	3	41	1	5
5	10	36	1	4
6	10	36	1	3
Mean	6.0	38.9	1.0	4.1
sd±	4.99	4.71	0.67	2.30
CV	82.8	12.1	69.2	56.6
		SF Slope		
1	3	42	1	4
2	2	42	1	5
3	3	42	1	3
4	4	39	1	5
5	15	33	0	2
6	4	41	1	5
Mean	5.2	39.9	0.9	4.0
sd±	5.60	5.10	0.65	2.44
CV	107.5	12.8	69.4	61.0

Effect of Slope Curvature on Dry Aggregate Size Distribution

The result of dry aggregate size distribution of 4.0 – 2.0 mm (large macroaggregate) size fraction revealed that CONC slope had low mean value of 21.00 ± 8.59 mm, CV = 40.9 % while CONV slope recorded high mean value of 22.18 ± 9.61 mm, CV = 43.3 %. (Table 4.9)The result of dry aggregate size distribution of 2.0 – 0.25mm (small macro aggregate) indicated that CONC slope had mean value of 24.30 ± 7.95 mm, CV = 32.7 % while CONV slope had high mean of 23.76 ± 8. 26 mm, CV = 34.8 %. There was a low variation. The small variation in the slope curvature may be due to the difference in the pattern of water flow. Dry aggregate size (micro aggregate) showed that CONC slope recorded mean of 0.97 ± 0.14 mm, CV = 42.8 %, while

CONV slope recorded mean of 0.73 ± 43 mm, CV = 59.1%.The result of, < 0.05 mm (mineral) dry aggregate distribution shows that CONC slope recorded mean of 3.73 ± 1.31 mm CV = 35.1 %, which CONV slope had mean of 3.38 ± 2.01 mm, CV = 59.6 %. There was high variability in mineral fraction. (Table 4:9)

Effect of Slope Curvature on Wet Aggregate Size Distribution

The result of wet aggregate-size distribution of 4.0 – 2.0 mm (large macro aggregate) size fraction showed that CONC slope recorded high mean value of 6.10± 5.94mm CV = 97.5%, while CONV slope recorded low mean value of 5.14±4.57mm, CV= 88.8 % (Table 4.10). Wet aggregate size of 4.0-2.0mm had high variation. The high mean recorded in CONC slope is that CONCslopes have areas with higher erosion rates in the highest slopes positions and higher sediment loss and accumulation rates occur in the lowest slopes positions, in contrast, sediment loss is the dominant process.

Table 4.10: Effect of some physical properties of studied soils based on slope curvature

	Dry Aggregate Size Distribution			
	4 – 2	2 - 0.25	0.25 – 0.05	<0.05
	← mm →			
	CONC			
1	21.6	23.2	1	4
2	18.4	26.8	1	3.8
3	23	22.8	0.9	3.4
4	29.4	16.2	1	3.4
5	20.6	24.2	0.9	4.2
6	13	32.6	0.9	3.6
Mean	21.0	24.3	1.0	3.7
Sd±	8.59	7.95	0.41	1.31
CV	40.9	32.7	42.8	35.1
	CONV			
1	16.8	29	0.8	3
2	14.4	28.2	0.8	6.6
3	23.4	23.6	0.5	2.2
4	25.6	21.6	0.6	22
5	32.8	14.6	0.7	1.8
6	20.1	25.6	1	4.5
Mean	22.2	23.8	0.7	3.4
Sd±	9.61	8.26	0.43	2.01
CV	43.3	34.8	59.1	59.6

Wet aggregate-size distribution of 2.0-0.25mm (small macro aggregate) fraction revealed that CONC slope had mean value of 39.53± 5.70mm, CV= 14.4%, while that of CONV slope had 39.29± 4.02mm, CV= 10.2% (Table 4.10). The differences in the wet aggregate size fraction of 2.0-0.25mm was negligible and there was a low variation. The small variation in the slope curvature are responsible for differences in the water flow patterns. The result of 0.25- 0.05mm (micro aggregate) showed that CONC slope recorded 0.08± 0.62mm,CV =83.0%, while that of CONV slope had 1.11± 0.62mm, CV = 55.9 % (Table 4.10). High variation was recorded in micro aggregate affected by slope curvature.

The high mean in CONV slope, may be due to the fact that CONVslopes are dominated by the process of side outflow and carrying effect of micro aggregate fractions (Gil Sonlcy *et' al.,* 2015). Mineral constituent (<0.05mm), aggregate-size fraction revealed that CONC slope was 3.57± 2.43mm, CV = 68.2 %, while that of CONV slope was 4.49± 2.21mm, CV=49.3 % (Table 4.10).Slope curvature with mineral fraction of aggregate size fraction. The pattern of CONV flow (side outflow) increases the volume and velocity of accelerated erosion and causes high distribution of mineral fraction.

Table 4.10: Effect of slope curvature on wet aggregate size distribution

Sampling Location	Wet Aggregate Distribution 4 - 2	2 - 0.25	0.25 - 0.05	< 0.05
	→	mm	←	
		CONC Slope		
1	3	41	1	5
2	3	42	1	4
3	3	43	1	3
4	3	42	1	3
5	9	36	1	3
6	15	33	0	2
Mean	6.10	39.53	0.80	3.57
sd±	5.94	5.70	0.66	2.43
CV	97. 5	14.4	83.1	68.2
		CONV Slope		
1	7	36	2	5
2	2	42	1	5
3	3	41	1	5
4	4	39	1	5
5	10	36	1	3
6	4	41	1	5
Mean	5.14	39.29	1.11	4.49
sd±	4.57	4.02	0.62	2.21
CV	88.8	10.2	55.9	49.3

Effect of Slope Gradient on Dry Aggregate Size Distribution

The result of slope gradient influence dry aggregate size distribution, indicated that aggregate size fraction of 4.0 – 2.0 mm (macro aggregate) of < 10 % slope had mean value of 17.8 ± 7.67 mm, CV = 43.1%, that of 11 – 20 % slope had 25.4 ± 9.96 mm, CV = 35.0 %, while that of > 20 % slope recorded mean value of 21.6 ± 9.34 mm, CV = 43.2 %. Dry aggregate size fraction of 4.0 – 2.0 mm showed that < 10 % and > 20 % were same, but varied from 11 – 20 % slope. (Table 4.11)The effect of slope gradient on dry aggregate size fraction of 2.0 – 0.25 mm (small macro aggregate) revealed that, < 10 % slope had mean value of 26.9 ± 6.71 mm, CV = 25.0 %, that of 11 – 20 % slope recorded mean value of 21.1 ± 8.11 mm, CV = 38.6 %, while that of > 20 % slope had mean value of 24.2 ± 8.49 mm, CV = 35.1 %. There was little variation among the slope gradient. The effect of slope gradient of dry aggregate size distribution of 0.25 – 0.05mm aggregate size distribution of 0.25 – 0.05 mm aggregate size fraction revealed that slope gradient < 10 % slope recorded mean value of 1.0 ± 0.32 mm, CV = 32.4 %, that of 11 – 20 % slope had mean value of 0.8 ± 0.52 mm, CV = 65.4 %, while that of > 20 % slope had mean value of 0.7 ± 0.41 mm, CV = 55.8 %. There was high variability among the slope gradient. The result of slope gradient on dry aggregate size fraction with < 0.05 mm (mineral fraction) indicated that < 10 % slope had mean value of 4.4 ± 2.06 mm, CV = 47.3%, that of 11 – 20 % slope had 2.8 ± 1.28 mm, CV = 45.8 % while that of > 20 % slope recorded 3.5 ± 1.33 mm, CV = 37.8 %. There was little variation among the slope gradient. (Table 4.11)

Table 4.11: Effect of some physical properties of studied soils based on slope gradient

	Dry Aggregate Size Distribution			
	4 – 2	**2 - 0.25**	**0.25 – 0.05**	**<0.05**
	←	mm		→
		< 10 % Slope		
1	21.6	23.2	1	4
2	18.4	26.8	0.9	3.8
3	16.8	29	0.9	3
4	14.4	28.2	1	6.6
Mean	17.8	26.9	1.0	4.4
Sd±	7.67	6.71	0.32	2.06
CV	43.1	25.0	32.4	47.3
		11 – 20 % Slope		
1	23	22.8	0.8	3.4

2	29.4	16.2	1	3.4
3	23.4	23.6	0.6	2.2
4	25.6	21.6	0.6	2.2
Mean	25.4	21.1	0.8	2.8
Sd±	8.9	8.1	0.5	1.3
CV	35.0	38.6	65.4	45.8
		> 20% Slope		
1	20.6	24.2	0.6	4.2
2	13	32.6	0.8	3.6
3	32.8	14.6	0.2	1.8
4	18.08	25.4	1.4	4.5
Mean	21.6	24.2	0.7	3.5
Sd±	9.34	8.49	0.41	1.33
CV	43.2	35.1	55.8	37.8

Effect of Slope Gradient on Wet Aggregate Size Distribution

The result of slope gradient effect on wet aggregate size distribution revealed that, aggregate size fraction of 4.0-2.0mm (Macro aggregate) of < 10% slope had mean value of 4.05 ± 3.52mm, CV = 86.8%, that of 11 – 20% slope had 3.35 ± 1.81mm, CV = 54.2 %, while that of >20% slope was 9.47 ± 6.87mm, CV = 72.6% (Table 4.12).Wet aggregate size fraction of 4.0 – 2.0mm, affected by slope gradient had high variation. There was irregular distribution of 4.0 – 2.0mm aggregate along the slope, as >20% slope had high mean, which 11-20% slope had low mean value, may be due to high deposition of 4.0 – 2.0mm aggregate on the steep slope.The effect of slope gradient on wet aggregate size fraction of 2.0 – 0.25mm (Small macro aggregate indicated that slope gradient of <10% slope had mean value of 40.35 ± 3.66mm, CV = 9.1, that of 11-20% slope had 41.60 ± 2.44mm, CV = 5.9 %, while that of >20% slope was 36.29 ± 6.22mm, CV = 17.2 % (Table 4.12). <10% and 11 – 20% slope had low variation which >20% slope had medium variation. Changer and Lal (1997) reported that soil properties are affected by soil erosion process through the redistribution of soil particles in the topography. The effect of slope gradient on wet aggregate-size distribution of 0.25 – 0.05mm aggregate size fraction revealed that slope gradient of <10% recorded mean value of 1.10 ± 0.72mm, CV = 65.3 %, that of 11-20 % slope had 0.95 ± 0.69mm, CV = 72.3 %, while that of >20% slope was 0.82 ± 0.55mm, CV = 68.0 % (Table 4.12). Generally slope gradient of wet aggregate – size fraction of 0.25 – 0.05mm had high variability (i.e. CV > 35%). The result of 0.25 – 0.05 mm aggregate size indicated that, increase in slope gradient, decrease 0.25 – 0.05mm aggregate size fraction. Wet aggregate-size fraction of < 0.05mm (Mineral fraction) of <10% slope had 4.50 ± 2.16 mm, CV = 48.1 %, that of 11 – 20% slope was 4.10 ± 2.55mm, CV = 62.3 %, while that of > 20% slope had 3.49 ± 2.33mm, CV = 66 -8 % (Table 4.12).The mineral fraction had high variability.

Table 4.12: Effect of slope gradient on wet aggregate size distribution

Sampling Location	Wet Aggregate Distribution 4 - 2	2 - 0.25	0.25 - 0.05	< 0.05
	→	mm	←	
		<10 % Slope		
1	3	41	2	5
2	3	42	1	4
3	7	36	2	5
4	2	42	1	5
Mean	4.05	40.35	1.10	4.50
sd±	3.52	3.66	0.72	2.16
CV	86.8	9.1	65.3	48.1
		11 - 20 % Slope		
1	3	43	1	3
2	3	42	1	3
3	3	41	1	5
4	4	39	1	5
Mean	3.35	41.60	0.95	4.10
sd±	1.81	2.44	0.69	2.55
CV	54.2	5.9	72.3	62.3
		>20 % Slope		
1	10	36	1	4
2	15	33	1	2
3	10	36	1	3
4	4	41	1	5
Mean	9.47	36.29	0.82	3.49
sd±	6.87	6.23	0.55	2.33
CV	72.6	17.2	68.0	66.8

The results indicated that decrease in slope gradient increases mineral fraction, the result of micro aggregate and mineral fraction revealed that. Slope gradient is one of the important slope factors that influence the process of drainage; runoff and soil erosion thereby affects aggregate size distribution of the soil. In line with Farmanullah (2013) reported that soil loss would normally be expected to increase with increase in slope gradient, because of respective increase in velocity of surface runoff and decrease in infiltration rate.

Correlation Matrix of Aggregate-size Distribution of Soil Physical Properties

Correlation analysis was carried out between the soil physical properties (Table 4.13), the results revealed that coarse sand correlation positively with dry aggregate 2.0 – 0.25 mm (r = 0.303*). Total sand correlated positively with dry aggregate 2.0 – 0.25 mm (r = 0.322*) and negatively with dry aggregate 4.0 – 2.0 mm (r = - 0.273*). This can be explained that under dry condition more coarse sand and total sand of aggregate size 2.0 – 0.25 mm are enhanced. (Table 4.13)Silt had negative correlation with dry aggregate 2.0 – 0.25 mm. Clay correlated positively with dry aggregate 4.0 – 2.0 mm (r = 0.316*) and negatively with dry aggregate 2.0 – 0.25 mm (r = -0.360**). The positive result obtained in the present work was in consonance with the findings of Parfitt *et al.* (1997) reported positive correlation between aggregate and clay and silt content, may be due to the clay fraction being colloidal, high reactive, cohesive and adhesive, providing bonding that will help in binding the aggregate together and less susceptible to action of erosion. Saturated hydraulic conductivity correlated positively with dry aggregate 0.25 – 0.5 mm and wet aggregate 2.0 – 0.25 mm (r = 0.289* and r = 0.346**), respectively and negatively with wet aggregate 4.0 – 2.0 mm (r = -0.284*). There was increase in saturated hydraulic conductivity under dry condition of aggregate size 0.25 – 0.05 mm and wet aggregate size 2.0 – 0.25 mm, the negative correlation under wet condition with aggregate size 4.0 – 2.0 mm may be as a result that wet condition (4.0 – 2.0 mm) may produce artificial mineral fraction that will seal up the pore space and increases the rate of erosion that causes disaggregation. Bulk density correlation positively with dry aggregate 4.0 – 2.0 mm (r = 0.274*) and negatively with dry aggregate < 0.05 mm and wet aggregate 2.0 – 0.25 mm (r = -0.273* and r = -0.302*), respectively. (Table 4.13)Total porosity correlated positively with dry aggregate 0.25 – 0.5 mm (r = 0.260*) and dry aggregate < 0.05 mm (r = 0.280*), and negatively with dry aggregate 4.0 – 2.0 mm (r = -0.270*) and wet aggregate <0.05 mm (r = -0.298*). Positive correlation show increase in infiltration under dry condition, there was no impeded fluid flow, but at wet condition with aggregate size < 0.05 mm, there was decrease in infiltration rate, which encouraged soil erosion though runoff.

Correlation Matrix of Aggregate-size Distribution and Soil Chemical Properties

The result in Table 4.14 Shows that pH correlated negatively with wet aggregate 2.0 – 0.25mm (r = -0.257*). This may be likely due to high rate of eading, which appreciable amounts of TEB may be leaded from one point to the other under wet condition. Organic matter correlated positively with fine sand and silt ($r = 0.431^{**}$ and $r = 0.384^{**}$) and negatively with dry aggregate 0.25 – 0.05mm Cs and Ts ($r = -0.288^{*}$, $r = -0.246^{**}$ and $r = 0.264^{*}$) respectively. Organic matter correlated positively and significantly with fine sand and silt, Shows that organic matter contains humin and humic substances, which increases fine sand and silt content stability and also the increment may be due to their associated high cohesion and shearing strength. TEB correlated negatively with dry aggregate < 0.05 mm ($r = -0.280^{*}$). As the Base saturation is increasing, under dry condition aggregate size < 0.053 mm decreases Base saturation had negative correlation with silt ($r = -0.301^{*}$). Exchangeable sodium percentage correlated negatively with saturated hydraulic conductivity ($r = -0.283^{*}$). Exchangeable sodium percentage is a good indicator of the stability of soil aggregate to breakdown and particle dispersion. The results, with exchangeable sodium percentage being less than 2%, indicate that the soils may be susceptible to spontaneous dispersion in water, but that this may impede infiltrate of erosion through particle that filled up the pore space which increases Am. Fe positively correlated with dry 4.0 – 2.0 mm ($r = 0.264^{*}$) and negatively with dry aggregate 2.0 – 0.25 mm ($r = -0.285^{*}$). (Table 4.14)

Table 4.13 Correlation matrix of aggregate size distribution and soil physical properties

	Dry Agg 40.-2.0	Dry Agg. 2.0-0.25	Dry Agg. 0.25-0.05	Dry Agg. < 0.05	Wet Agg. 4.0-2.0	Wet Agg .0-0.25	Wet Agg- 0.25-0.05	Wet Agg <0.05	Cs	Fs	Ts	Si	Cl	Ksat	Bd	Tp
Dry Agg< 2	1.000															
Dry Agg.-0.25	-0.983**	1.000														
Dry Agg.-0.053	-0.408**	0.346**	1.000													
Dry Agg.< 0.053	-0.575**	0.423**	0.280*	1.000												
Wet Agg.< 2	0.066	-0.035	-0.198	-0.137	1.000											
Wet Agg-0.25	-0.169	0.138	0.219	0.196	-0.881**	1.000										
Wet Agg-0.053	0.251	-0.268*	-0.148	-0.028	-0.197	0.025	1.000									
Wet Agg< 0.053	0.133	-0.132	0.029	-0.086	-0.359**	-0.107	0.114	1.000								
Cs	-0.242	0.303*	0.228	-0.211	0.085	-0.016	0.047	-0.176	1.000							
Fs	-0.065	0.035	-0.135	0.225	0.005	0.038	0.032	-0.091	-0.374**	1.000						
Ts	-0.273*	0.322*	0.181	-0.120	0.081	0.021	0.033	-0.238	0.904**	-0.128	1.000					
Si	0.200	-0.263*	-0.180	0.230	-0.056	-0.023	0.007	0.177	-0.847**	0.100	-0.813**	1.000				
Cl	0.316*	-0.360**	-0.189	0.070	-0.121	0.019	-0.057	0.250	-0.882**	-0.021	-0.892**	0.715**	1.000			
Ksat	-0.005	0.004	0.289*	-0.064	-0.284*	0.346**	-0.061	-0.066	0.217	-0.138	0.212	-0.272*	-0.111	1.000		
Bd	0.274*	-0.242	-0.163	-0.273*	0.196	-0.302*	0.033	0.181	-0.150	0.012	-0.213	0.036	0.218	-0.268*	1.000	
Tp	-0.270*	0.229	0.260*	0.280*	-0.084	0.232	-0.003	-0.298*	0.242	0.007	0.275*	-0.109	-0.325*	0.295*	-0.808**	1.000

Cs: Coarse sand, Fs: Fine sand, Ts: Total sand, Si: Sil, Cl: Clay, Ksat: Saturated hydraulic conductivity, Bd: Bulk density, Tp: Total porosity

Table 4.14: Correlation matrix of aggregate-size distribution of soil chemical properties

	pH(KCl)	OM	Ca	Mg	TEB	ECEC	Bsat	ESP	Am. Fe	Cry. Fe	Am. Al	Cry. Al
pH(KCl)	1.000											
OM	-0.085	1.000										
Ca	0.016	0.014	1.000									
Mg	-0.100	-0.109	0.112	1.000								
TEB	-0.050	0.058	0.906**	0.308*	1.000							
ECEC	-0.220	0.206	0.538**	0.205	0.611**	1.000						
Bsat	0.159	-0.247	0.359**	0.133	0.335**	-0.500**	1.000					
ESP	0.162	-0.007	-0.100	-0.016	-0.134	-0.322*	0.235	1.000				
Am. Fe	-0.034	-0.121	-0.128	0.000	-0.067	-0.164	0.103	0.124	1.000			
Cry. Fe	-0.220	0.315*	0.025	0.198	0.060	0.219	-0.173	0.008	0.348**	1.000		
Am. Al	-0.156	0.065	-0.117	0.293*	-0.061	0.112	-0.157	0.165	0.445**	0.633**	1.000	
Cry. Al	-0.006	0.079	0.211	0.128	0.218	0.139	0.075	0.084	0.158	0.421**	0.481**	1.000

pH(KCl): pH in potassium chroride
OM: Organic matter
Ca: Calcium
Mg: Magnessium
TEB: Total exchangeable bases
ECEC: Effective cation exchange capacity
Bsat: Base saturation
ESP: Excahngeable sodium percentage
Am. Fe: Amorphous of iron
Cry. Fe: Crystalline of iron
Am. Al: Amorphous of alumunium
Cry. Al: Crystalline of alumunium

Crystalline Iron correlated positively with dry aggregate 4.0 – 2.0 mm (r = 0.386**), wet aggregate < 0.05 mm (r = 0.318*), silt (r = 0.420**), clay (r = 0.366**) and bulk density (r = 0.323*) and negatively with dry aggregate 2.0 – 0.25 mm (r = -0.393**), dry aggregate 0.25 – 0.05 mm (r = -0.258*), silt (r = -0.403**), total sand (r = -0.449**), and total porosity (r = -0.444**). The positive correlation can be more explained that the nature of the clay fraction presence, may be effective in bringing about strong inter-particle forces and stability in the tropical soils (Igwe *et al.,* 2009), and also tropical soils appear to possess stable micro aggregates because they contain active Al and Fe in the clay fraction which act as a strong binding and flocculation agent (Gallez *et al.,* 1977).Am. Al correlated positively with silt (r = 0.330*) and clay (r = 0.326*) and negatively with coarse sand (r = -0.366**) and total porosity (r = -0.363**), The negative relationship of coarse sand and total sand may be because they are more skeletal comprised more than 85% non-reactive sand, not electrically charged, characterized by weak inter-particle attractive and weak cohesive forces, low plasticity and aggregation potential, easily slake dispersively or less resistant to the shearing forces of water, and therefore Vulnerable to erosion as also reported by (Ogban and Essien, 2016). Cry. Al correlated positively with dry aggregate 4.0 – 2.0 mm (r = 0.368*) and clay (r = 0.293*) and negatively with dry aggregate 2.0 – 0.25 mm (r = - 0.366*), total sand (r = - 0.325*) and total porosity (r = - 0.296*).The positive relations of amorphous and crystalline Al with silt and clay shows that Al polymers may play a significant role in cementing silt and clay particles HSU (1977). Also Acra and Weed (1986) reported that there is a strong positive relationship of clay content in aggregation because of the electronegatively charged surfaces that normally attract positively charged cations from the solution (Brady and Weil, 1999).

CONCLUSION

Effect of Slope characteristics on aggregate size distributes was examined in coastal plain sands soils in Akwa Ibom State. Slope characteristics to some extend led to long or short term stabilization, and the amount and distribution of stable and unstable aggregates in the soil can be used to know the stabilized and destabilization of soil aggregates. In aggregate size distributes, wet aggregate stability suggest how well a soil can resist rain drop impact and water erosion and was affected by slop aspect, curvature and gradient. This implies that low disruption of soil aggregates by the energy of raindrop impact, while south facing slope receives much rain, associated with high erosion rates that cause detachment of individual parties, splash, transported and accumulation of sediment in the valley bittern. Slope curvature effects shows that convex slope are dominated by the process of side outflow and the carrying effect of soil particles, while concave slope have area with higher erosion rates in the highest landscape positions and higher sediment accumulation rate in the lowest landscape positions, this likely explains why concave slope generally show more heterogeneous distribution of soil attributes, while slope gradient effects indicated that the steeper the slopes the more effect on water erosion, because of the high velocity and high volume of water runoff.

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