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SOIL PROPERTIES AND GROWTH OF MAIZE AS AFFECTED BY SLOPE POSITION AND FERTILIZER TYPE ON COASTAL PLAIN SANDS

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ABSTRACT

A study was conducted to determine the effects of slope position and fertilizer type on soil properties and growth of maize (*Zea mays*) on Coastal Plain Sands of Akwa Ibom State, Nigeria. Results obtained showed that soils of lower slope (LS) had the highest contents of clay and silt compared with those of upper slope (US) position. Bulk density of the upper slope soil and that of the middle slope (MS) soils were significantly higher (P≤0.05) than that of LS soil and subsequently, total porosity and saturated hydraulic conductivity (Ksat) increased downslope. Bulk density of soils that received poultry manure (PM) and NPK+PM were significantly reduced compared to those of NPK and control while total porosity and Ksat of soils that received PM and NPK+PM were significantly higher (P≤0.05) than those of NPK and control. Soils of LS had highest pH, organic carbon, total nitrogen, available phosphorus, ECEC compared to those of MS and US. The application of poultry manure yielded increase in soil pH, soil organic carbon, total nitrogen, available phosphorus and ECEC when compared to soils of NPK and control. Growth of maize obtained with LS were consistently higher than those of the MS and US soils. Soils of LS that received NPK and NPK+PM had consistently similar maize growth, higher than other combinations of slope position and fertilizer type. The complementary application of poultry manure and NPK 15:15:15 can be the best option for increasing the fertility of soils with varying slope positions on Coastal Plain Sands.

Contribution/Originality: This is one of very few studies that have investigated the combined effect of slope position and fertilizer type on soil properties and crop growth and has demonstrated the possibility of soil improvement and crop growth in across varying slope positions through the complementary organic and inorganic fertilizers application.

1. INTRODUCTION

The pressure exerted on land by the continuous exponential increase in human population demands that the available limited lands be conservatively managed and utilized to support sustainable food production. However, the nature and properties of soils largely influence the extent to which the soil can be effectively put into crop production (Almendro-Candel, Lucas, Navarro-Pedreño, & Zorpas, 2018). Differences in soil properties and soil nutrients have been attributed to changes in topography (Kroetsch, 2004; Seibert, Stendahl, & Sørensen, 2007; Zhang, Zhang, Huffman, Liu, & Yang, 2011), given the fact that topography itself is a factor of soil development, along with climate, soil organisms, parent material and time (Jenny, 1941; Ritter, 2006). The irregularities of the landscape provides the gradient through which the physical movement of the soil by runoff from upslope areas to lower slope positions occurs, thus altering the spatial distribution of soil and soil nutrient across the landscape (Balasundram, Robert, Mulla, & Allan, 2006; Noorbakhsh, Schoenau, Si, Zeleke, & Qian, 2008; Zhang *et al*., 2011), resulting in soils in either the lower slope position (Alemayehu, 2007; Fu, Shi-Liang, Li-Ding, Yi-He, & Jun, 2004; Rhanor, 2013; Soon & Malhi, 2005) or upper slope regions (Li & Lindstrom, 2001; Moges & Holden, 2008; Walle & Sims, 1999) being richer in soil nutrients depending on the prevailing sizes of soil particles that move downslope following detachment by erosive forces. When clay and organic matter predominantly transported downslope, the former is the case whereas, when sand is predominantly moved, the latter case prevails (Moges & Holden, 2008).

The topographic nature of the land can serve as a source of information towards effective soil management (Seibert *et al*., 2007), which will in turn help to reduce the influence of topography on the (Bergstrom, Monreal, & Jacques, 2001), increase soil fertility and address food insecurity (Moges & Holden, 2008). Fertilizer application, be it organic or inorganic is an aspect of soil fertility management aimed at providing the deficient nutrients for the growth and increased yield of crops.

Maize is global staple food crop and also serves the livestock industry as the major energy feed ingredient (Dei, 2017). The growth of maize is highly sensitive to decline in soil nutrient, the ultimate effect of which is low yield. As such, fertilizer management across toposequences must address the peculiarities of each slope position in order to bring about increased yields of the maize crop.

Apart from the direct addition of organic matter to the soil through the application of organic fertilizers, organic matter content of the soil can also be increased through the use of both organic and inorganic fertilizers, which increase vegetative growth (Riley, 2016; Sanginga & Woomer, 2009) and return organic matter to the soil after they complete their life cycle. Organic matter is an important soil property - a measure of soil quality, stability against degradative forces, soil fertility among other things (Jendoubi, Liniger, & Ifejika Speranza, 2019). It provides the needed soil nutrients such as nitrogen, phosphorus calcium, potassium (Bot & Benites, 2005) to boost the fertility of the soil. The combined application of both organic and inorganic fertilizers has been observed to have a far-reaching effect on this regards than individual application of both (Ogundijo, Adetunji, Azeez, & Arowolo, 2014). The effect of organic and inorganic fertilizers on soil and growth of crops have been widely studied (Ayeni & Adetunji, 2010; Mokaya, 2016; Ogundijo *et al*., 2014; Vanlauwe, Wendt, & Diels, 2001), but similar researches have not been widely explored under different topographic positions, especially considering the existence of toposequences across the landscapes of the world. The aim of this work was therefore to examine soil properties and growth of maize as affected by slope position and fertilizer type on the coastal plain sands of Akwa Ibom State, Nigeria. It will provide site specific information needed to improve soil fertility across soils of the different slope position of the study area.

2. MATERIALS AND METHODS

2.1. The Study Area

The study was conducted on the toposequences of the University of Uyo Teaching and Research Farm Use Offot in Akwa Ibom State, southeastern Nigeria, located between latitudes 4°30′ and 5°30′ N and longitudes 7°27′ and 8°27′E. The area is characterized by a uniformly hot wet and humid tropical climate. The climate is characterized by two seasons, the wet and dry seasons. The wet or rain season lasts between the months of April and October, during which the rains are heavy and of high intensity. The pattern of rainfall is bimodal with peaks in July and September. The mean annual rainfall varies from 2500-4000 mm. The dry season lasts from November to March. The average daily temperature ranges from 26°C to 28°C. Solar radiation ranges from 6 to 15 mm/day. Relative humidity ranges from 75% to 95%, while evapotranspiration ranges from 4.11 to 4.95 mm day^{-1}, partly because of the high values of insolation and temperature (Enwezor, Udo, & Sobulo, 1981).

2.2. Experimental Design and Treatment Combinations

The field was laid out based on a 3 x 4 factorial arrangement in randomized complete block design replicated thrice with slope position and fertilizer type as factors. Slope position comprised of three levels, which were upper slope (US), middle slope (MS) and lower slope (LS) while there were four fertilizer types as follows: poultry manure (PM), NPK 15:15:15 Fertilizer (NPK), NPK 15: 15: 15 + poultry manure (NPK+PM) and control. These resulted in twelve (12) treatment combinations) viz: US+PM, US+NPK, US+(PM+NPK), US+control, MS+PM, MS+NPK, MS+(PM+NPK), MS+control, LS+PM, LS+NPK, LS+(PM+NPK) and LS+control,

2.3. Field Experimentation

Twelve subplots measuring 2m x 2m each were marked out with 1m path on the upper slope (US), middle slope (MS) and lower slope (LS) positions, giving a total of thirty-six (36) sub-plots. The subplots were tilled properly to provide good seedbeds. The four fertilizer types were applied to each of the three slope positions on the basis of the designated treatment combination and worked into the soil during tillage. Seeds of maize (*Zea mays*) proven to be viable (100% viability) through a viability test (floatation method) were planted at the spacing of 50 cm x 50 cm, giving a plant population of 25 plants per subplot. The plants recorded 98% germination across all the observation plots. The plots were weeded at 4 weeks after germination.

2.4. Measurement of Growth Parameters

Growth parameters measured at 2, 4, 6 and 8 weeks after germination (WAG) were plant height, leaf area and stem girth. Six plants were randomly selected in each of the subplots for routine measurement. Plant height was measured using a measuring tape stretched from the base of the plant to the tip of the tallest leaf. Leaf area per plant was estimated according to the method of Duncan and Hesketh (1968) for the maize crop thus: LA = L x W x 0.75, where LA is the average total leaf area per plant, L is the average leaf length, W the average greatest leaf width. To measure the stem girth, a rope was wound round the maize stem and the length which went round the stem was placed on a measuring tape to read the stem girth.

2.5. Laboratory Methods

Bulk soil samples were air-dried and sieved through 2-mm mesh for particle-size analysis using the Bouyoucos hydrometer method (Day, 1965). Soil Survey Staff (1999) was used in designating soil texture. Hydraulic conductivity was determined by the constant head permeameter method (Klute, 1986). Bulk density (ℓ_b) was determined by oven-drying the core samples to constant weight at 105ºC, and values of ℓ_b computed as described by Klute (1986). Total porosity (*f*) was calculated from the values of ℓ_b. Chemical analyses were carried out on the fine earth as described by IITA (1979) and Sparks (1996). Soil pH was measured in 1: 2.5 soil:water suspension. Organic carbon was determined by the wet oxidation method of Walkley and Black as modified by Nelson and Sommers (1996) and organic matter was obtained by multiplying the values of organic carbon by a factor of 1.725. Total nitrogen was determined by the modified Kjeldahl digestion procedure. Available phosphorus was estimated by the Bray P-1 method. The phosphorus in the extract was measured by the blue colorimetric method of Murphy and Riley (1962). Exchangeable bases (Ca, Mg, K and Na) were determined by the methods described by Sparks (1996) and exchangeable acidity by the KCl procedure as described by McClean (1965). Effective cation exchange capacity (ECEC) was obtained by summation of exchangeable bases and exchangeable acidity while base saturation (BS) was obtained by dividing the sum of exchangeable bases by ECEC and the result expressed as percentage.

2.6. Statistical Analyses

Analysis of variance (ANOVA) was used to determine the effect of parent material on soil properties of studied soils and significantly different means were separated using the Least Significant Difference (LSD) at 5% level of probability. Simple correlation analysis was used to determine associations between growth of maize and soil properties.

3. RESULTS

3.1. Properties of Soil and Poultry Manure used for the Experiment

Results of the soil study carried out across the three slope positions prior to experimentation is presented in Table 1. The soils were predominantly sandy, with sand content being in the order, upper slope (883 g kg^{-1}) > middle slope (808 g kg^{-1}) > lower slope (710 g kg^{-1}). Sand content decreased down the slope while silt (48, 42 and 96 g kg^{-1} in the upper, middle and lower slope soils, respectively) and clay (69, 150 and 196 g kg^{-1} in the three slope positions, respectively) increased in that direction, resulting in a loamy sand texture in the upper slope (US) position and a sandy loam texture in the middle slope (MS) and lower slope (LS) positions. Based on the classification provided by Chude, Olayiwole, Asho, and Daudu (2012), soil pH of US and MS soils were moderately acidic (between 5.6 and 6.0) while that of LS was slightly acidic (> 6.0); organic carbon was moderate while total nitrogen was low in the three slope positions. Available phosphorus (Bray 2) was low in US and MS and moderate in LS (Udo, Ibia, Ogunwale, Ano, & Esu, 2009). Exchangeable Ca and Mg were high in the soils while exchangeable K was low in US and MS soils and moderate in LS soils (as classified by Amara, Patil, Kamara, and Saidu (2017) and Ibia (2012)). The ECEC was moderate in the soils, but with a relatively high base saturation.

Table-1. Some physicochemical properties of the experimental soil before the experiment.

Soil Property	Unit	Upper Slope	Middle Slope	Lower Slope
Sand	gkg^{-1}	883	808	710
Silt	√	48	42	96
Clay	√	69	150	194
Texture		ls	sl	sl
Soil pH		5.80	5.60	6.20
EC	dSm^{-1}	0.08	0.07	0.10
Organic carbon	gkg^{-1}	11.65	11.17	13.535
To al nitrogen	√	0.50	0.48	0.59
Available phosphorus	$mgkg^{-1}$	13.00	12.80	18.34
Ca	$cmolkg^{-1}$	5.21	5.32	5.73
Mg	√	1.67	1.7	2.1
K	√	0.13	0.14	0.12
Na	√	0.1	0.11	0.12
EA	√	2.83	2.56	2.67
ECEC	√	9.94	9.83	10.74
BS	%	71.53	73.96	75.14

ls – loamy sand, sl – sandy loam, EC – electrical conductivity, EA – exchange acidity,
ECEC – effective cation exchange capacity, BS – base saturation

Table 2 presents the chemical composition of the poultry manure used for the experiment. It shows that the poultry manure was slightly alkaline (pH of 7.5) in reaction and had high contents of organic carbon (309.17 g kg^{-1}), total N (13.36 g kg^{-1}) with a low carbon: nitrogen ratio (less than 24:1). There were high contents of nutrients such as Ca (3290.83 mg kg^{-1}), magnesium (1245.17 mg kg^{-1}), potassium (66.14 mg kg^{-1}) and phosphorus (104.56 mg kg^{-1}). The soil on which the experiment was conducted had varied levels of soil properties that define soil fertility and depicted the nutrient gradient occasioned by differences in slope position (Liu *et al.*, 2020). The high contents of soil nutrients contained in the poultry manure used for this study is further indicative of the fact that poultry manure is a potent means of boosting the fertility inherently poor soils. The low carbon: nitrogen ratio of the poultry manure used in this study implies the propensity of the poultry manure to decompose quickly (McCauley, Jones, & Olson-Rutz, 2017) and return nutrients to the soil during one planting season.

Table-2. Chemical composition of poultry manure used for the study.

Chemical Property	Unit	Concentration/ Level
pH	-	7.5
EC	dSm^{-1}	3.25
Organic carbon	g kg^{-1}	309.17
Total nitrogen	g kg^{-1}	13.36
C/N ratio		23:1
Calcium	mg kg^{-1}	3290.83
Magnesium	mg kg^{-1}	1245.17
Potassium	mg kg^{-1}	66.14
Phosphorus	mg kg^{-1}	104.56

Note: EC – electrical conductivity.

3.2. Effect of Slope Position and Fertilizer Type on Some Soil Physical Properties

Means of soil physical properties as affected by slope position and fertilizer type is presented in Table 3 and are interpreted and discussed in this section.

3.2.1. Particle Size Distribution (Sand, Silt and Clay)

Sand content was significantly affected by the interaction of slope position and fertilizer type. The trend as shown in Figure 1 reveals that the upper slope soils had the highest sand content, irrespective of the fertilizer type applied and was followed by middle slope and lower slope, though exceptions occurred under NPK+PM in which MS and LS had a similar sand content as well as under control in which the sand content of US and MS were equal. Silt content was significantly affected by slope position with the highest content (77 g kg^{-1}) observed in lower slope (LS) soil, followed significantly by 72 g kg^{-1} and 57 g kg^{-1} observed in middle slope (MS) and upper slope (US) soils, respectively. The content of clay in the soil was significantly affected by the interaction of slope position and fertilizer type. Figure 1 (b) shows that Irrespective of the fertilizer type, clay content of LS was significantly higher than those MS and US in that order. The decrease in sand content and a corresponding increase in silt and clay contents downslope observed in this study is attributed to the erosive energy of runoff water, which detaches and carries away fine soil particles in suspension downslope (Harden & Scruggs, 2003; Hillel, 2004). The differences in particle sizes observed can only be attributed more to slope position than fertilizer types despite the significant interactive effects observed in sand and clay for the latter. This is so because particle size is a soil inherent attribute and cannot be affected by soil management (Omenihu & Opara-Nadi, 2015) under human time scale.

Table-3. Effect of slope position and fertilizer type on some soil physical properties.

	Sand	Silt	Clay		BD	TP	Ksat
	←	g kg^{-1}	→	Text	Mg m^{-3}	m^{3}m^{-3}	cm h^{-1}
	Slope Position						
US	821	57	122	sl	1.493	0.436	16.150
MS	793	72	135	sl	1.480	0.442	24.200
LS	729	77	194	sl	1.428	0.461	32.258
LSD $_{(0.05)}$	16	9	19		0.046	0.017	6.447
	Fertilizer						
PM	772	71	157	sl	1.419	0.465	25.656
NPK	774	75	151	sl	1.498	0.435	23.278
NPK+PM	790	68	142	sl	1.410	0.468	30.200
CONTROL	788	61	151	sl	1.541	0.418	17.678
LSD $_{(0.05)}$	ns	Ns	ns		0.053	0.020	7.445
	Slope Position x Fertilizer Interaction						
LSD $_{(0.05)}$	31.08*	Ns	3.806*		ns	ns	ns

Note: ns – not significant. *details of significant interactions are presented in the respective Figure 1.
BD – bulk density, TP – total porosity, Ksat – saturated hydraulic conductivity,

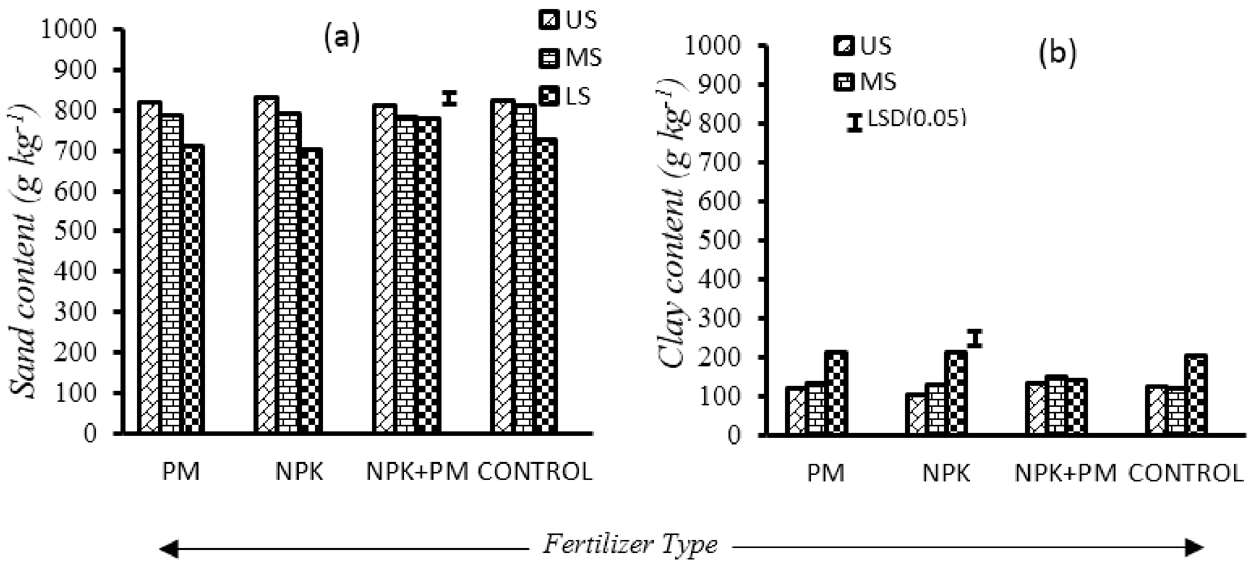

Figure-1. Interactive effect of slope position and fertilizer type on (a) sand content (b) clay content.

3.2.2. Bulk Density and Total Porosity

Bulk density (BD) and total porosity (TP) were all significantly affected independently by slope position and fertilizer type. Upper slope (US) had the highest bulk density of 1.49 Mg m^{-3}, which was equal with that of MS (1.49 Mg m^{-3}) but significantly higher than that of LS (1.43 Mg m^{-3}). Total porosity followed an opposite trend with the value observed in LS (0.46 m^{3} m^{-3}) being significantly higher than the 0.44 m^{3} m^{-3} observed in both US and MS. The implication of this result is that bulk density reduced while total porosity increased downslope. This can be attributed to the fact that increasing organic carbon content was also observed in the downslope direction in this study. Organic carbon is a major indicator of the increase in soil organic matter and enhanced soil health, thus, increase in soil organic carbon had been noted to be associated with reduction in bulk density and increase in total porosity (Bot & Benites, 2005; Sanginga & Woomer, 2009; USDA, 2014) among other benefits. For Fertilizer type, the highest significant bulk density of 1.54 Mg m^{-3} was observed in control soil, which was statistically similar with that of soils to which NPK was applied, but significantly higher than those of PM (1.42 Mg m^{-3}) and NPK+PM (1.41 Mg m^{-3}). The highest total porosity of 0.47 m^{3} m^{-3} was observed in PM and NPK+PM and was significantly higher than those of NPK (0.44 m^{3} m^{-3}) and control (0.42 m^{3} m^{-3}). The addition of poultry manure, which led to an increase in soil organic carbon in soils of PM and NPK+PM may have been responsible for the reduced bulk density and higher total porosity in these soils over those of NPK and control). In the same vein, Agbede, Ojeniyi, and Adeyemo (2008) had in an experiment conducted in southwestern Nigeria reported a reduction in soil bulk density and increase in total porosity following the application of poultry manure. Soil that received NPK alone had equally low bulk density and total porosity as the control soils because they did not receive direct addition of organic matter. Inorganic fertilizers normally aid in the vegetative bloom, which returns organic matter to the soil at the expiration of the life cycles of plants. The combination of external organic input with NPK will therefore go a long way to improving soil ecological functions better than inorganic fertilizers alone.

3.2.3. Saturated Hydraulic Conductivity

Saturated hydraulic conductivity (Ksat) was significantly affected ($P \leq 0.05$) by slope position and fertilizer type. The highest significant Ksat of 16.15 cm h^{-1} was observed in US soil, followed significantly by soils of MS (24.20 cm h^{-1}) and then LS (32.26 cm h^{-1}). The reduced bulk density and increased total porosity downslope also resulted in downslope increase in saturated hydraulic conductivity. It has been established that soil pore volume determines the ease with which water flows through the soil (Hillel, 2004; Nimmo, 2004). Other studies also found Ksat to be positively associated with total porosity (Ogban & Utin, 2015; Pagliai, Vignozzi, & Pellegrini, 2004).

Regarding fertilizer type, the highest Ksat of 30.20 cm h^{-1} was recorded in soils of NPK+PM, which was equal with the 25.66 cm h^{-1} observed in PM but was significantly higher (P≤0.05) than those of NPK (23.28 cm h^{-1}) and control (17.45 cm h^{-1}). The higher Ksat observed in soils of PM and PM+NPK over those of NPK and control is probably caused by the higher organic carbon, lower bulk density and higher total porosity observed in those soils, resulting from the incorporation of poultry manure.

3.3. Effect of Slope Position and Fertilizer Type on Some Soil Chemical Properties

Means of soil chemical properties as affected by slope position and fertilizer type is presented in Table 4 and interpreted in this section as follows.

3.3.1. Soil pH

The interaction of slope position and fertilizer type significantly affected (P≤0.05) soil pH Table 4. Figure 2 shows that the control soils had the lowest soil pH across the three slope positions. The application of PM and NPK + PM to soils of LS caused significant increases in the soil pH over the control. The application of NPK alone to soils of the three land use types did not result in a significant increase in the soil pH over those of the control Figure 2. The significant increases in the pH of LS soils that received PM and NPK+PM over the control soils were probably due to an increased cation input from poultry manure (Bakayoko *et al.*, 2009) in addition to the fraction which may have been moved with soil particles by erosion from the US and MS position to increase the already elevated cation concentrations of the lower slope position (Hillel, 2004; Ritter., 2012; Xiaojun, Jianhui, & Zhengan, 2013). These cations may have neutralized soil acidity (Bot & Benites, 2005), thus resulting in an increase in soil pH observed in soils to which PM and NPK+PM were applied when compared with those of the pre-experimental soil as well as the NPK-treated and control soils. Duruigbo, Obiefuna, and Onweremadu (2007) similarly reported that increase in soil pH in soils that received poultry manure was a result of cation inputs from the poultry manure. Several other studies have reported increase in soil pH owing to the application of poultry manure (Duruigbo *et al.*, 2007; Moore & Edwards, 2005; Vadas, Meisinger, Sikora, McMurtry, & Sefton, 2004; Whalen, Chang, Clayton, & Carefoot, 2000). The ability of organic manures to bind soil nutrient in order to prevent leaching (Ciarkowska & Miechówka, 2019) may have also boosted the effect of PM and NPK+PM on soil pH increase that was observed. The application of NPK alone to soils of the three land use types did not result in a significant increase in the soil pH over those of the control since they did not receive poultry manure input.

3.3.2. Electrical Conductivity

Slope position and fertilizer type independently had significant effects on the electrical conductivity (EC) of the soils. The EC recorded for LS (0.20 dSm^{-1}) was significantly higher (P≤0.05) than those of MS (0.15 dSm^{-1}) and US (0.12 dSm^{-1}) while those of US and MS were themselves not significantly different. The significant increase in electrical conductivity in LS than MS and US soils suggests the washing of soluble salts (ions) down the slope. Beshir, Lemeneh, and Kissi (2015) similarly reported an increase in electrical conductivity downslope. Regarding fertilizer type, the EC of NPK+PM (0.20 dSm^{-1}) and PM (0.17 dSm^{-1}) were equal and while the value recorded for NPK+PM was significantly higher (P≤0.05) than that of NPK (0.15 dSm^{-1}) and control (0.11 dSm^{-1}), that of PM was equal with the value recorded under NPK application but significantly higher (P≤0.05) than that of control. NPK also had significantly higher (P≤0.05) EC than the control. Soils that received PM and NPK+PM had higher electrical conductivity (soluble ion concentrations) than those of NPK and control possibly due increase in soil nutrients (Carmo, Lima, & Silva, 2016) observed with poultry manure application. Increased electrical conductivity resulting from application of poultry manure had already been reported by other authors including Watanabe, Hoshino, and Adachi (2017) and Dikinya and Mufwanzala (2010).

Table-4. Effect of slope position and fertilizer type on some soil chemical properties.

	pH	EC	OC	TN	AvP	Ca	Mg	Na	K	EA	ECEC	BS
		dSm-1	← g kg-1 →		mg kg-1	←			cmol kg-1		→	%
Slope Position												
US	5.79	0.12	13.46	0.58	18.26	5.83	2.51	0.14	0.12	2.58	11.19	76.96
MS	6.01	0.15	12.83	0.55	23.21	6.03	2.46	0.15	0.14	2.87	11.64	75.43
LS	6.11	0.20	16.15	0.70	31.34	6.41	2.65	0.14	0.17	2.76	12.14	77.26
LSD (0.05)	0.19	0.04	1.42	0.06	4.10	0.24	0.14	ns	0.02	ns	0.43	ns
Fertilizer												
PM	6.27	0.17	15.37	0.66	25.73	6.21	2.58	0.17	0.15	2.65	11.76	77.47
NPK	5.80	0.15	14.46	0.63	26.39	6.15	2.55	0.12	0.14	2.96	11.92	75.17
NPK+PM	6.42	0.20	16.47	0.71	26.19	6.22	2.67	0.15	0.15	2.59	11.78	78.01
Control	5.38	0.11	10.28	0.44	18.78	5.77	2.37	0.13	0.12	2.75	11.14	75.31
LSD (0.05)	0.22	0.04	1.64	0.07	4.73	0.27	0.17	0.02	0.02	ns	0.50	ns
Slope Position x Fertilizer Type Interaction												
LSD (0.05)	0.37	ns	ns	ns	ns	ns	ns	ns	ns	ns	Ns	ns

Note: ns – not significant. *details of significant interactions are presented in Figure 2
OC – organic carbon, TN – total nitrogen, Av.P – available phosphorus, ECEC – effective cation exchange capacity, BS – base saturation.

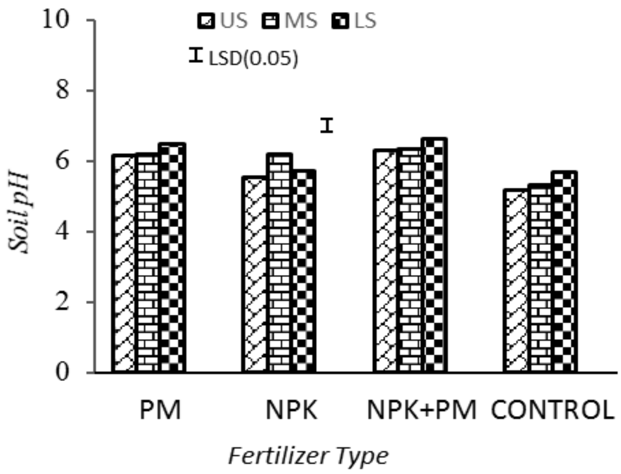

Figure-2. Interactive effect of slope position and fertilizer type on soil pH.

3.3.3. Organic Carbon, Total Nitrogen and Available Phosphorus

Soil organic carbon (in index of organic matter content), total nitrogen and available phosphorus concentrations were significantly affected (P≤0.05) by slope position and fertilizer type while interactive effects of the two factors on organic carbon and total nitrogen were not significant. The highest significant organic carbon content of 16.15 g kg-1 was observed with LS soil, which was significantly higher (P≤0.05) than those of MS (12.83 g kg-1) and US (13.46 g kg-1). The highest significant total nitrogen content of 0.70 g kg-1 was recorded in LS soil and was significantly higher (P≤0.05) those of MS (0.55 g kg-1) and US (0.58 g kg-1). The highest significant available P concentration of 31.34 mg kg-1 was obtained in the LS soil, followed by MS (23.21 mg kg-1) and lastly, US (18.26 mg kg-1) soils. There was a wide difference between the available P of the LS position and those of US and MS. The significant differences in organic carbon, total N and available P observed in the lower slope positions could be attributed to the processes of erosion, deposition and leaching (Mohammed, Takele, & Kibret, 2020). Also, organic carbon, nitrogen and phosphorus are among the constituents of organic matter (Bakayoko *et al.*, 2009; Bot & Benites, 2005) thus the movement of organic matter towards the downslope regions was the reasons for the higher organic carbon, total N and available P in soils of LS than those of US and MS. Several studies have reported the increase in organic carbon downslope (Balasundram *et al.*, 2006; Noorbakhsh *et al.*, 2008; Rhanor, 2013; Soon & Malhi, 2005). Effect of fertilizer type on organic carbon content showed NPK+PM and PM having statistically similar organic carbon contents of 16.47 and 15.37 g kg-1, respectively, followed by NPK (14.46 g kg-1) and control (10.28 g kg-1). Regarding total N, NPK+PM gave the highest significant total nitrogen concentration of 0.71 g kg^{-1}, which was equal with the 0.66 g kg^{-1} obtained in soil that received PM application, but was significantly higher ($P \leq 0.05$) than that of NPK (0.63 g kg^{-1}) while that of control (0.44 g kg^{-1}) was the least significant. The effect of fertilizer type on available P showed similarity between the concentration obtained for NPK (26.39 mg kg^{-1}), NPK+PM (26.19 mg kg^{-1}) and PM (25.73 mg kg^{-1}) while that of control (18.78 mg kg^{-1}) was the lowest significant. The significant increase in organic carbon, total N and available P in soils of PM and NPK+PM can be attributed to the application of poultry manure, being a notable nutrient source (Ogundijo *et al.*, 2014). These nutrients (organic carbon, nitrogen and available P) could probably also be recycled from the applied poultry manure (Bot & Benites, 2005; Murphy., 2015) to improve the soil fertility. Phosphorus is less soluble, thus largely unavailable (Hue, 1995). The wide difference between the available P of the LS position and those of US and MS can be attributed to the fact that phosphorus availability is highly pH-dependent and easily get fixed (Brady & Weil, 2000). The unavailable phosphorus compounds concentrated in the surface soil are readily removed and washed down the slope by erosion where any favourable pH downslope may have solubilized and increased their availability. That Soil pH values between 6 and 7.5 are best for P-availability, outside this range, P is fixed by aluminum, iron, or calcium, and therefore becomes unavailable for use by plants (Alori, Glick, & Babalola, 2017).

3.3.4. Exchangeable Cations (Ca, Mg, Na and K), and Effective Cation Exchange Capacity

Exchangeable calcium, magnesium, potassium and Na increased significantly with changes in slope position. The highest concentrations of exchangeable Ca (6.41 cmol kg^{-1}), Mg (2.65 cmol kg^{-1}) and K (0.17 cmol kg^{-1}) were observed in the LS soils while the lowest values of Ca (5.83) and K (0.12 cmol kg^{-1}) were observed in the upper slope and the lowest for Mg (2.46 cmol kg^{-1}) was observed in the middle slope soil. Effective cation exchange capacity (ECEC) was significantly affected ($P \leq 0.05$) by both slope position and fertilizer type. The ECEC obtained in the soil of LS (12.14 cmol kg^{-1}) was the highest significant, followed by that of MS soil (11.64 cmol kg^{-1}) and lastly US soil (11.19 cmol kg^{-1}). The washing down of organic matter and clay and their deposition downslope was probably responsible for the significant increase in basic cations (Ca, Mg, K and Na) in the lower slope position, which also culminated in the significant increase in ECEC in the LS position. This occurs because clay and organic matter possess large surface area onto which cations are adsorbed, thus their typically higher cation exchange capacity (McCauley *et al.*, 2017).

Exchangeable Ca obtained in soils of PM, NPK, PM+NPK and control were 6.21, 6.15, 6.22 and 5.77 cmol kg^{-1}, respectively. For exchangeable Mg, the respective values were 2.58, 2.55, 2.67 and 2.37 cmol kg^{-1}; for exchangeable Na, values of 0.17, 0.12, 0.15 and 0.13 cmol kg^{-1}, respectively were obtained while for exchangeable K, the respective values were 0.15, 0.14, 0.15 and 0.12 cmol kg^{-1}. Soils that received PM, NPK and NPK+PM had statistically similar concentrations of Ca, Mg and K while that of control was the significantly lower ($P \leq 0.05$). Higher concentrations of exchangeable Na were recorded in soils that received PM and NPK+PM over those of NPK and control. The effect of fertilizer type shows that ECEC of 11.76, 11.92 and 11.78 cmol kg^{-1} recorded in soils to which PM, NPK and NPK+PM, respectively were applied were statistically similar but were higher than that of control (11.14 cmol kg^{-1}). The significant increase in basic cations and ECEC in soils that received PM and NPK+PM over that of control could be linked to the poultry manure, which increased organic matter content, which serves as exchange complex for basic cations (Wilding, Nobles, Wilcox, Woodruff Jr, & Lin, 2012), thereby acting as a major contributor to total cation exchange capacity (Ciarkowska & Miechówka, 2019; Ramos *et al.*, 2018) and has been reported to outperform clay (Blaser, Walthert, Zimmermann, Graf Pannatier, & Luster, 2008; James, Littke, Bonassi, & Harrison, 2016), which serves a similar function. Significant increase in exchangeable cations had equally been reported following the application of organic and inorganic fertilizers (Bakayoko *et al.*, 2009; Ogundijo *et al.*, 2014).

3.4.5. Exchangeable Acidity

Exchangeable acidity was 2.58 cmol kg^{-1} in US soil, 2.87 cmol kg^{-1} in MS soil and 2.76 cmol kg^{-1} in LS soil. The increase in exchangeable acidity down the slope observed in this study is perhaps as a result of the increase in exchange sites (clay and organic matter) observed in the downslope position as well as possible favourable pH which may have caused the acid-forming cations (H^+ and Al^{3+}) to displace the basic cations (McCauley *et al.*, 2017). On the basis of fertilizer type, soil to which PM was applied had exchangeable acidity of 2.65 cmol kg^{-1}, those of NPK, NPK+PM and control had exchangeable acidity of 2.96, 2.59 and 2.79 cmol kg^{-1}, respectively. There were no significant effects of slope position, fertilizer type and their interaction on exchangeable acidity. The apparent decrease in exchangeable acidity in soils where poultry manure was added shows the efficacy of poultry manure in replacing some of the exchangeable H^+ and Al^{3+} with basic cations in the exchange sites, thus neutralizing soil acidity (Ogundijo *et al.*, 2014).

3.5.6. Percent Base Saturation

Percent Base saturation observed in soils of US, MS and LS were 76.96, 75.43 and 77.26 %, respectively. For fertilizer type, PM, NPK, NPK+PM and control had base saturation of 77.47, 75.17, 78.01 and 75.31 %, respectively. There were no significant effects of slope position, fertilizer type and their interaction on base saturation, but the values of base saturation were generally high based on classification by Udo et al. (2009).

3.6. Effect of Slope Position and Fertilizer Type on the Growth of Maize (Zea Mays)

3.6.1. Maize Plant Height

At 2, 4 and 6 weeks after germination (WAG), there were significant effects of the interaction of slope position and fertilizer type on maize plant height Table 5. Figure 3 shows that at all the studied stages of growth, significantly higher ($P \leq 0.05$) plant heights were observed in LS soils irrespective of the fertilizer type applied. Control soils had the lowest plant height across the three slope positions. On the whole, NPK and NPK+PM gave the highest plant heights across all the slope positions, followed by PM and lastly Control.

At 8 WAG, there was no significant interactive effect of slope position and fertilizer type on the plant height of maize Table 5. Slope position and fertilizer type independently had significant effect on plant height at this stage of growth. The highest plant height of maize (146.88 cm) was obtained in LS soil, followed in that order by MS and US soils with plant heights of 135.17 and 116.47 cm, respectively. In terms of fertilizer type, the highest plant height of maize (149.80 cm) was obtained in soils that received NPK, followed by soils that received NPK+PM (139.12 cm). Maize plant height obtained in soils that received NPK+PM was not significantly different from that of PM (132.96 cm) but was significantly higher ($P \leq 0.05$) than that of control (109.48 cm).

Table-5. Effect of slope position on maize plant height (cm).

	2WAG	4WAG	6WAG	8WAG
Slope Position				
US	11.3	42.64	73.43	116.47
MS	12.81	43.6	79.32	135.17
LS	15.93	54.32	90.32	146.88
LSD	0.39	2.13	3.45	6.1
Fertilizer Type				
PM	12.73	45.17	81.19	132.96
NPK	15.19	52.26	89.81	149.8
NPK+PM	13.92	48.48	86.08	139.12
CONTROL	11.54	41.51	67.02	109.48
LSD	0.46	2.46	3.98	7.04
Slope Position x Fertilizer Type Interaction				
LSD	0.79*	4.27*	6.9*	ns

Note: WAG – weeks after germination, ns – not significant. *details of significant interactions are presented in Figure 3.

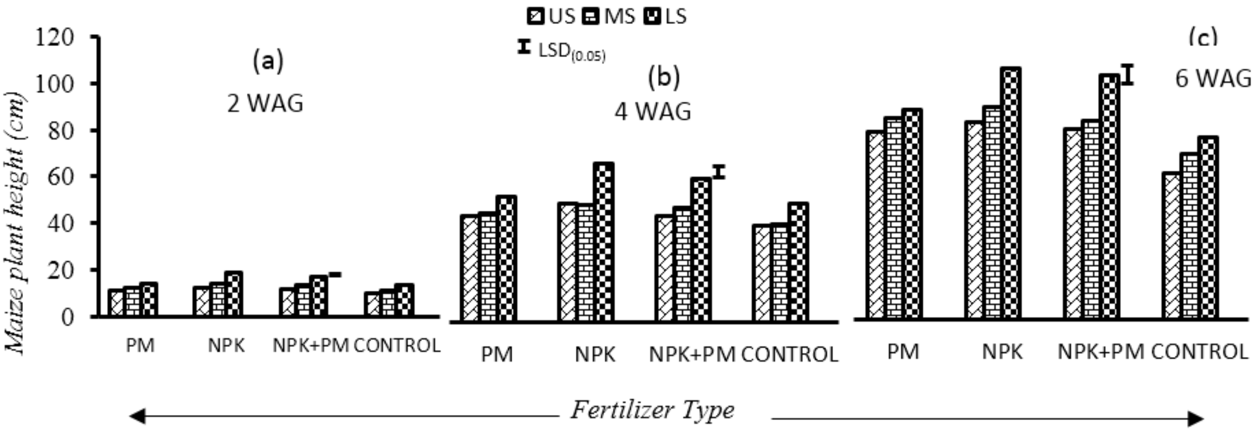

Figure-3. Interactive effect of slope position and fertilizer type on maize plant height at (a) 2 weeks after germination (WAG) (b) 4 WAG (c) 6 WAG.

3.6.2. Maize Leaf Area

Leaf area was significantly affected (P≤0.05) by the interaction of slope position and fertilizer type at 2, 4, 6 and 8 WAGs Table 6. Figure 4 shows that at all the staged of growth studied, LS consistently had the highest leaf area across all fertilizer types with exceptionally higher figures obtained with NPK and NPK+PM over PM and control in that order.

Table-6. Effect of slope position on maize leaf area (cm^2).

	2WAG	4WAG	6WAG	8WAG
Slope Position				
US	12.24	54.33	165.00	258.73
MS	14.32	70.94	201.84	347.83
LS	19.56	109.66	285.74	410.36
LSD	0.63	7.84	22.35	30.34
Fertilizer Type				
PM	14.23	70.50	212.02	333.59
NPK	18.42	99.81	279.36	425.51
NPK+PM	16.23	86.03	251.90	369.72
CONTROL	12.62	56.91	126.82	227.07
LSD	0.72	9.06	25.8	35.03
Slope Position x Fertilizer Type Interaction				
LSD	1.25	15.69	44.69	60.67

Note: WAG – weeks after germination, ns – not significant. *details of significant interactions are presented in Figure 4

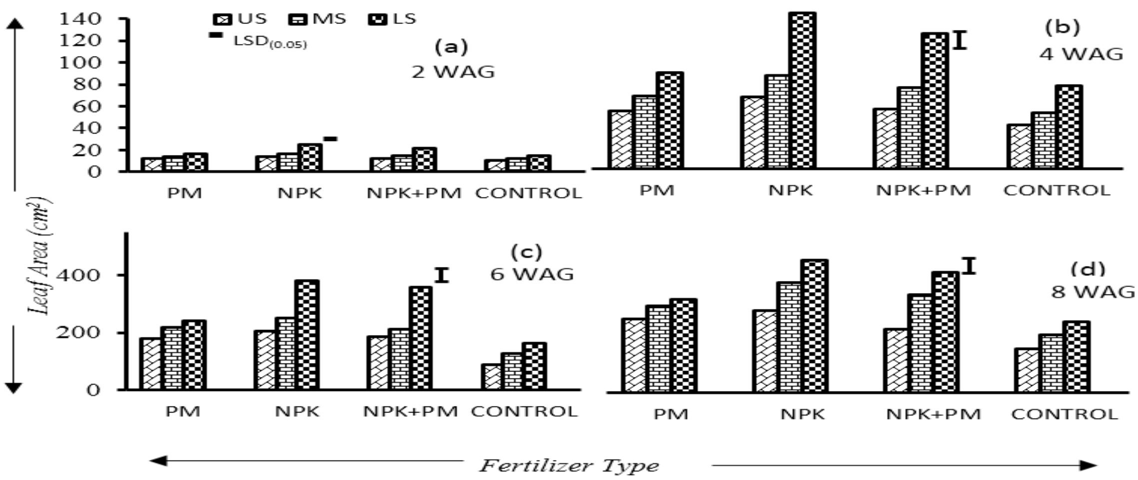

Figure-4. Interactive effect of slope position and fertilizer type on maize leaf area at (a) 2 WAG (b) 4 WAG (c) 6 WAG (d) 8 WAG.

3.6.3. Maize Stem Girth

Maize stem girth was significantly and separately affected by slope position and fertilizer type at 2, 6 and 8 WAG while their interactions showed no significant effect on maize stem girth Table 7. At 2 WAG, maize stem girth of 2.60 cm recorded in soil of LS was significantly higher (P≤0.05) than the 2.11 cm and 2.08 cm recorded in soils of US and MS, respectively. At 4 and 8 WAGs, maize planted in soils of MS and LS showed statistically equal stem girth while the lowest significantly stem girth was observed in maize planted in US soil.

At 2 WAG, the application of PM, NPK and NPK+PM gave statistically equal stem girths of 2.41, 2.23 and 2.44 cm, respectively, which were significantly higher (P≤0.05) than the 1.96 cm observed in control soil. At 6 and 8 WAGs, the highest maize stem girth (7.67 cm) was obtained with the application of NPK, this was equal with the 7.31 cm recorded with the application of NPK+PM, but significantly higher (P≤0.05) than those of PM (4.77 cm) and control (3.40 cm).

In the case of 4 WAG, in which stem girth was significantly affected (P≤0.05) by the interaction of slope position and fertilizer type. Figure 5 shows that across all fertilizer type, LS gave the highest maize stem girth, with those of NPK and NPK+PM being exceptionally higher than those of PM and control.

Table-7. Effect of slope position on maize stem girth (cm).

	2WAG	4WAG	6WAG	8WAG
Slope Position				
US	2.11	2.56	4.13	5.59
MS	2.08	3.01	4.99	6.96
LS	2.6	4.43	5.31	7.2
LSD	0.2	0.17	0.49	0.53
Fertilizer Type				
PM	2.41	3.16	4.77	6.8
NPK	2.23	4.01	5.5	7.67
NPK+PM	2.44	3.61	5.56	7.31
CONTROL	1.96	2.56	3.4	4.54
LSD	0.23	0.2	0.56	0.61
Slope Position x Fertilizer Type Interaction				
Stem Girth	ns	0.34*	ns	ns

Note: ns – not significant. *details of significant interactions are presented in Figure 5
WAG – weeks after germination.

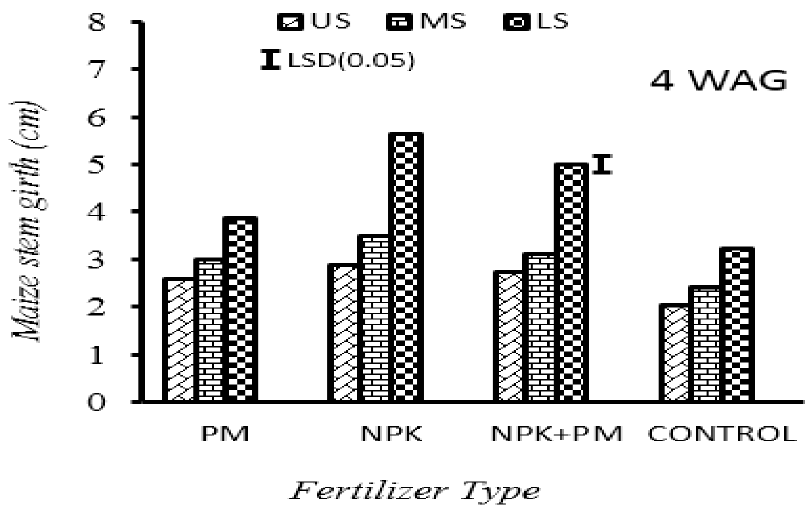

Figure-5. Interactive effect of slope position and fertilizer type on maize stem girth at 4 WAG.

Plant height, leaf area and stem girth of maize were affected in a similar way by slope position, fertilizer type and their interactions. The significant increase these growth parameters in soils of LS and less so in soils of MS over that of US can be attributed to the increased concentrations of plant nutrients such as organic carbon, total nitrogen, available phosphorus, basic cations observed in this study, which arises from the erosion of these nutrients from the upper and middle slope positions towards the lower slope position (Alemayehu, 2007; Fu *et al*., 2004; Mohammed *et al*., 2020; Rhanor, 2013; Soon & Malhi, 2005; Wolde *et al*., 2007) . These nutrients have been noted to be crucial to the growth of plants (Wubie & Assen, 2020). The consistently similar growth of maize observed for NPK and NPK+PM soils is indicative of the fact that complementary application of the poultry manure and NPK is as good as inorganic fertilizer alone in increasing the yield of maize. Therefore, considering the harmful effects of excessive application of inorganic fertilizers to the environment and human health, the adoption of complementary doses of both poultry manure and inorganic fertilizers becomes necessary. It would also reduce the total cost and increase the efficiency of fertilization given the fact that organic when fused with inorganic fertilizers reduces the rapid leaching and volatilization (Yang, Liu, Shuting, Zhang, & Zhao, 2020) of active elements (ingredients) and releases them gradually to the soil (Khan, Mobin, Abbas, & Alamri, 2018). Lower slope that received NPK and NPK+PM gave the highest growth in terms of plant height, leaf area and stem girth because of the combined benefit of nutrient deposition (at the lower slope) and higher soil nutrient input (from NPK and NPK+PM).

3.6.4. Correlations of Maize Growth with Soil Properties

The correlation of maize growth parameters with soil properties are presented in Table 8. Maize plant height, leaf area and stem girth correlated significantly and positively with silt, clay total porosity, Ksat, soil pH, organic carbon, total nitrogen, available phosphorus, calcium, potassium and ECEC while correlations with sand and bulk density were negative. The significant positive correlations of maize growth parameters with clay (plant height and leaf area) and organic carbon (plant height, leaf area and stem girth) are indicative of the dependence of the growth of maize on abundance of soil particles that increase the cation exchange capacity of the soil. The growth of maize depends on soil nutrients (Wubie & Assen, 2020), thus the positively significant correlation of maize growth parameters with total nitrogen, available phosphorus, calcium, potassium and ECEC seen in the study.

The significantly negative association of bulk density, significantly positive association of total porosity and saturated hydraulic conductivity with the growth of maize expresses the role of soil pore spaces in soil water movement, air circulation in the soil as well as ease of root movement as they relate to the growth of plants (Hillel, 2004).

Table-8. Correlation of maize growth parameters and soil properties.

	PH	LA	SG
Sand	-0.534**	-0.537**	-0.378*
Silt	0.657**	0.651**	0.561**
Clay	0.380*	0.386*	0.237
BD	-0.452**	-0.433**	-0.520**
TP	0.452**	0.433**	0.520**
Ksat	0.611**	0.612**	0.467**
pH	0.482**	0.457**	0.601**
OC	0.704**	0.687**	0.679**
TN	0.704**	0.687**	0.679**
Av.P	0.627**	0.625**	0.571**
Ca	0.607**	0.620**	0.531**
Mg	0.323	0.326	0.254
Na	0.052	0.068	-0.023
K	0.554**	0.545**	0.547**
EA	0.146	0.113	0.233
ECEC	.641**	0.627**	0.627**
BS	0.146	0.178	0.050

Note: *P≤0.05, ** P≤0.01.
PH – plant height, LA – leaf area, SG – stem girth, BD – bulk density, TP – total porosity,
Ksat – saturated hydraulic conductivity, OC – organic carbon, TN – total nitrogen, Av.P – available phosphorus, ECEC – effective cation exchange capacity, EA – exchange acidity, BS – base saturation.

4. CONCLUSION

Slope position and fertilizer type significantly affected soil properties and the growth of maize grown on coastal plain sands of Akwa Ibom State, Nigeria. Lower slope position and less so, the middle slope position had higher contents of clay and silt than the upper slope positions. There were reductions in bulk density which led to an increase in total porosity and hydraulic conductivity in the lower slope position when compared with the upper and middle slope positions. Soils of the lower slope position had highest organic carbon, total N, available P, basic cations and ECEC compared to those of middle and upper slopes. The application of poultry manure led to an increase in soil organic carbon in soils of PM and NPK+PM and also significantly reduced bulk density, increased total porosity and saturated hydraulic conductivity over those of NPK and control. Soils of PM and NPK+PM also recorded higher total N, available P, basic cations and ECEC compared to those of NPK alone and the control. Growth of maize obtained with NPK and NPK+PM were consistently similar and higher than those of PM and control. The combined application of poultry manure and NPK can be the best option in a bid to increase the fertility of soils across toposequences. More researches are advocated to unravel how higher application rates of organic and inorganic fertilizer combination can help to counterbalance the excessive loss of soil and nutrients at the upper and middle slope positions towards the lower slope positions.

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