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Response of soil water transmission properties to three land-use systems in soils of contrasting origin in Ilorin, Nigeria

Ahamefule, H. E.[1]; Umar Muhammed, B,[1]; Adepoju Adeyemi, S.[1]; Amana Mathew, S.[2]; Wahab Adeshina, A.[3] and Ukelina Chris, U.[4]

[1] *Department of Agronomy, University of Ilorin,P.M.B.1515, Ilorin, Kwara state, Nigeria*
[2] *Department of Agronomy, Nasarawa State University, Lafia, Nigeria*
[3] *Department of Soil Science, Kwara State University Malete,Kwara State, Nigeria*
[4] *Federal College of Education, Obudu, Cross River State, Nigeria*
E-mail*: ahamefule.he@unilorin.edu.ng

Abstract

Ahamefule, H. E., Umar Muhammed, B., Adepoju Adeyemi, S., Amana Mathew, S., Wahab Adeshina, A., Ukelina Chris, U. (2020). Response of soil water transmission properties to three land-use systems in soils of contrasting origin in Ilorin, Nigeria, *Bulgarian Journal of Soil Science Agrochemisty and Ecology, 54*(3), 15-27.

The parent materials and land-use are key factors which determine agricultural productivity and environmental sustainability by their effects on soil properties pertinent for optimal soil function. An inquest was therefore conducted in a Randomized Complete Block Design to determine the effect of soil parent materials and land use types on selected physical properties related to hydraulic characteristics of soils, in Ilorin. The parent materials were sand-stone and basement complex whereas the land use types included forest, grassland and cultivated soils. Results indicated the predominance of sand fraction culminating in a sandy loam soil texture which was not influenced by varying parent materials and land-use. Sand was positively correlated with bulk density irrespective of parent material whereas in soils of basement complex origin, clay was in addition found to be positively correlated with bulk density. Quartz content rather than sand, apparently, was a major determinant of bulk density values in mineral soils. The results also indicated that soil macro-porosity increased by more than a factor of two (2) under the influence of sandstone compared to basement complex parent material. Soil macro-porosity was significantly ($p<0.05$) highest under forest land-use (5.43%) whereas the least was observed in grassland (2.41%). Soils of sand-stone origin and forest soils had the highest infiltration rate and saturated hydraulic conductivity.

Key words: Soil parent material; land-use; soil physical properties; Ilorin

Introduction

There is paucity of information on the relationship between parent materials and soil physical properties in sub-Saharan Africa. Differences in physical, chemical and mineralogical properties of soils are related primarily to parent materials (Washer & Collins, 1988). According to Ritter (2006) the character and chemical composition of parent materials play an important role in determining soil properties; it has strong influence on the composition and texture of the resulting soil. Comparative investigations on the effect of parent materials on soil properties are uncommon; available ones come from soil surveys for the establishment of some agricultural projects by individuals, non-governmental and government agencies. Examination of compiled reports of such surveys may, however, be a useful tool for comparing soils developed on varying parent materials. On the other hand, information abounds regarding changes in soil textural and structural properties induced by land-use changes and its effect on soil hydraulic properties. However, our knowledge in some areas, such as forest soils and mountainous areas is still rather limited as most of the studies and monitoring efforts concern cultivated areas (Pachepsky et al., 2001; Ahamefule & Mbagwu, 2007; Garcia et al., 2012; Molina et al., 2014; Ahamefule & Peter, 2014; Ahamefule, et al., 2015).

Variation in soil properties due to land-use and management and their consequence on soil productive capacity has been the subject of some studies under a range of climatic and edaphic conditions (Aiboni, 2001; Fasina, 2004; Shittu et al., 2006). Variations in soil properties have also been found to influence soil management and crop production (Golchin & Asgari, 2008; Abu, 2013).

According to Trimble (1990) the effects of land abandonment on land quality may be positive or negative depending on the soil and climatic conditions of the area. Soils under favorable climatic conditions that sustain plant cover may improve with time by accumulating organic materials, increasing floral and faunal activity, improving soil structure, increasing infiltration capacity, and therefore, decreasing erosion potential. Martinez-Fernandez et al. (1995) reported a positive effect of land abandonment, the authors reported that soil abandoned over a period of ten years has similar characteristics (organic matter content, water retention capacity, aggregation and structural stability) it had before it was cultivated. Jaiyeoba (1995) and Unger (1997) reported a deterioration of soil fertility under cropping and concluded that the soils under various types of agricultural land uses contained less organic matter, total nitrogen, exchangeable bases and cation exchange capacity (CEC) than similar soils under natural vegetation. Onijigin et al. (2016) showed that under forest fallow, soil organic matter content, soil pH and nutrients increased. Senjobi & Ogunkunle (2011) and Aminu & Jaiyeoba (2015) reported serious impact of land degradation on soil physio-chemical properties.

In order to promote sustainable land utilization, long-term land use must be accompanied by conservation measures (Uzoho, 2005; Senjobi & Ogunkunle, 2011). These measures will include credible land use approach, detailed soil survey and land use planning through assessment and monitoring of soil resources (Idoga & Azagaku, 2005; Senjobi & Ogunkunle, 2011). Soil degradation processes must reduce in other to preserve soil fertility and soil health which is largely dependent on soil moisture. Hillel (1998) reported that soil moisture regime is determined by soil hydraulic properties which may vary with parent material. Therefore, the main objective of this study was to determine the effect of land use as influenced by parent materials on soil hydraulic properties.

Materials and Methods

Description of the study site

The experimental sites were University of Ilorin (Unilorin) and Oke-oyi all in Kwara State, Nigeria (Plate 1). Table 1 shows the geographical coordinates of the experimental sites. The soil of Unilorin was developed over basement complex (Okusanmi et al., 1985). The soil of Oke-oyi was developed over sandstone (LNRBRDA, 1994;

Ogunwale et al., 1975). Both study sites where located in Ilorin, capital of Kwara state.

Ilorin is geographically located by latitude 8°30`N to 8°50`N and longitudes 4°20`E to 4° 35`E of the equator. Ilorin city occupies an area of about 468 sqkm and it is situated in the transitional zone within the forest and the guinea savannah region of Nigeria. Ilorin experiences two climatic seasons, the dry season and the rainy season. The rainy season is between March and November. Its mean annual rainfall varies from 1000 mm – 1500 mm. The mean monthly temperature is generally high: January (25º C), May (27.5º C), and September (22.5º C).

Experimental design

The design used was Randomized Complete Block Design (RCBD). The soil parent materials: sandstone and basement complex was used as the block, and three land-use types: forest land (predominated by Parkia biglobosa, Acacia and neem), grassland (predominated by Panicum maximum, Setaria barbata, Agerantum conyzoides, Andropogon tectorum), and cultivated land (under maize) were the treatments. Each treatment was replicated thrice. The grasslands and cultivated lands chosen had similar history and management. Tillage in the cultivated lands was achieved by traditional hoe.

Layout of the experiment

Two soil parent materials namely; sandstone derived and basement complex were selected for this experiment. Three land-use types namely: forest land, grass land, and cultivated land were selected and replicated thrice under soils of sandstone and basement parent material origin. A total of eighteen (18) plots were sampled. Using a hand held Global Positioning System (GPS) receiver, the basement complex forest land was located on latitude 08°29′04.6″N and longitude 004°40′54.4″E at an elevation of 345 m above sea level, the grass-land use on latitude 08°29′07.1″N and longitude 004°40′39.4″E at an elevation of 365 m, whereas the cultivated land was located on latitude 08°27′45.0″N and longitude 004°39′41.6″E at an elevation of 329 m.

On the sandstone derived soil, forest land was located by latitude 08°34′03.0″N and longitude 004°42′27.2″E at an elevation of 329 m above sea level, the grassland was located by latitude 08°34′13.0″N and longitude 004°42′20.4″E at an elevation of 332 m, whereas the cultivated land was located by latitude 08°34′04.5″N and longitude 004°42′12.7″E at an elevation of 333 m.

Soil sampling and preparation

Point sampling method was used with 10 m interval between the replicates. Soil samples were collected from each land-use type using metal core sampler (internal diameter = 5.5 cm and length = 6.5 cm) for the determination of saturated hydraulic conductivity (Ksat), macro porosity, and bulk density. Soil samples for particle size determination were collected from each plot at a depth of 0-15 cm using soil auger, air-dried and sieved with 2 mm mesh sieve.

Laboratory determination

The soil bulk density was determined according to Blake & Hartge (1986) whereas soil particle size distribution was determined using the Bouyoucos hydrometer method. The soil Ksat was determined according to Klute & Dirken (1986) using the constant head method in which the volume of water discharged was measured with the aid of a measuring cylinder

Ksat calculation:

Using Darcy's law:

$$Ksat = \frac{QL}{Aht} \text{ (cm/s)}$$

Where, Ksat = saturated hydraulic conductivity (cm/s)

Q= quantity of water measured (cm^3)

L= length of the metal core sampler (cm)

A= cross sectional area of the metal core sampler (cm^2)

t= time required for the quantity of water to be discharged (s)

h= hydraulic head (cm)

Soil macro porosity was estimated using the formulae below:

$$\text{Macro porosity} = \frac{\text{volume of water discharged at 60 cm tension X 100 (\%)}}{\text{Volume of bulk soil}}$$

Table 1. Geographical coordinates of the experimental site

Experimental location	Geographic coordinates
University of Ilorin	latitudes 8°05`N – 10°05`N; longitudes 2°50`E – 6°05`E of the equator
Oke-oyi	latitudes 7°45`N – 9°30`N; longitudes 2°30`E – 6°25`E of the equator

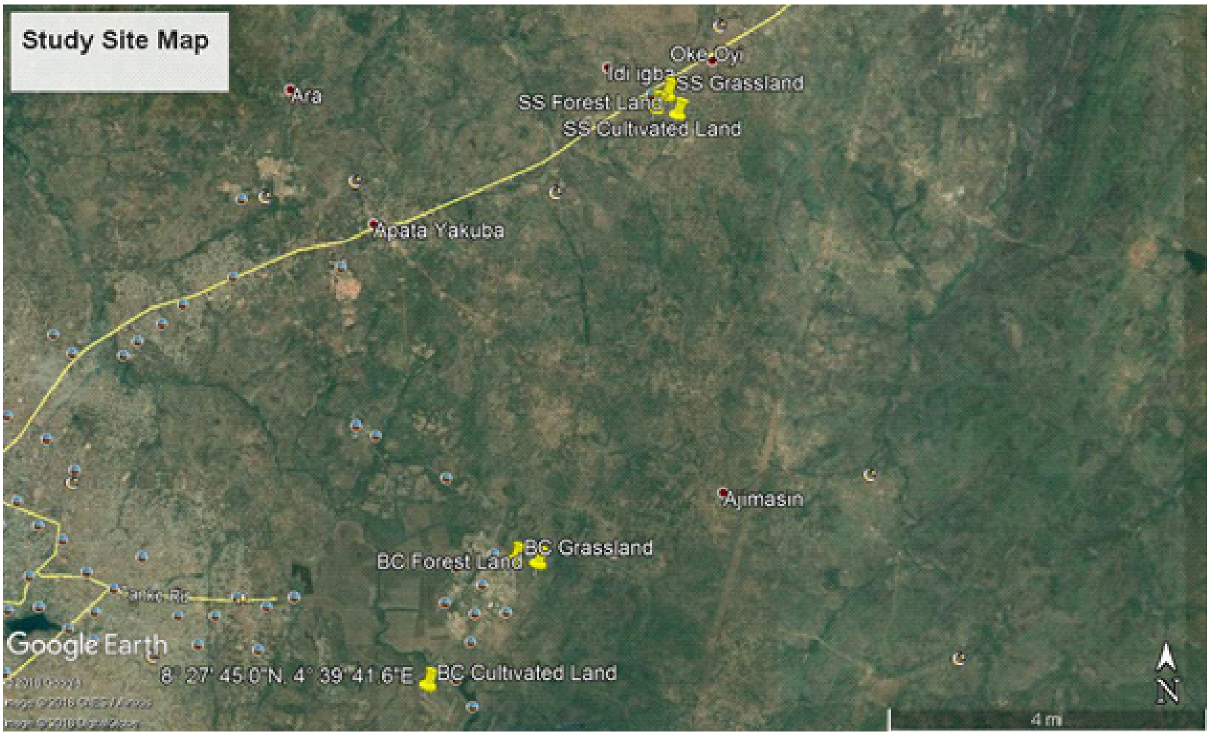

Plate 1. Google earth map showing the study locations

Field determination

The soil infiltration rate was determined using double ring infiltrometer according to ASTM (2003). The operational technique used with the double ring infiltrometer to measure the infiltration rate is constant head method.

Data analysis

The data obtained were subjected to Analysis of Variance (ANOVA) using GenStat 17th Edition. The means were separated using Least Significant Difference (LSD) at 95% probability level.

Results

The result indicates predominance of sand fraction culminating in a sandy loam soil texture which was not influenced by varying parent materials and land-use (Table 2).

The response of the bulk density of the soils to the various land-use types interestingly did not show significant difference even with varying parent material (Table 3). The bulk density values were observed to be generally high.

The result (Fig. 1) also shows that sand content across all the land-use types on sandstone derived soils was strongly correlated with bulk density, contributing about 40.3% (R^2=0.4032) to the determination of bulk density values whereas silt and clay contents (Fig. 2, Fig. 3) negatively correlated with bulk density, this is supported by

Table 2. Soil texture of the study sites

Parent Material	Land-use	Sand (%)	Silt (%)	Clay (%)	Soil Texture
Sandstone	Forest Land	78	12	10	Sandy Loam
Sandstone	Grass Land	80	10	10	Sandy Loam
Sandstone	Cultivated Land	80	8	12	Sandy Loam
Basement Complex	Forest Land	78	10	12	Sandy Loam
Basement Complex	Grass Land	78	10	12	Sandy Loam
Basement Complex	Cultivated Land	80	10	10	Sandy Loam

Table 3. Effect of Land-use as influenced by parent material on soil bulk density (g/cm^3)

	Parent Material			
Land Use	Sandstone	Basement Complex	Mean	Standard Deviation
Forest land	1.71	1.64	1.68	±0.35
Grass land	1.88	1.71	1.79	±0.09
Cultivated land	1.75	1.75	1.75	¬¬¬¬¬¬¬¬¬¬¬¬¬ -
Mean	1.78	1.70		
LSD (0.05); L = ns; P = ns; L×P = ns				

ns = nonsignificant

the finding of Chaudhari et al., (2013). On soils of basement complex origin, sand content (Fig. 4) was positively correlated and contributing about 11% (R^2=0.1098) to the determination of bulk density values whereas silt content (Fig. 5) was negatively correlated; however, clay content indicated a positive correlation to bulk density (Fig. 6) which is contrary to the report of Chaudhari et al., (2013) that soil bulk density is negatively correlated with clay and silt content of the soil. This positive correlation however, contributed about 3.5% (R^2=0.0354) to the determination of bulk density values in soils formed on basement complex, using the best fit regression model.

Soil macro-porosity was significantly ($p<0.05$) highest under forest land-use whereas the least was observed in grassland (Table 4). The results also indicated that soil macro-porosity increased by more than a factor of two (2) under the influence of sandstone compared to basement complex parent material.

The highest macro-porosity value of 7.55% was observed in forest soils under sandstone parent material whereas the least value of 2.41% was in grassland soils of basement complex origin.

Table 5 shows that though land-use significantly ($p<0.05$) affected infiltration rate, the parent material from which the soils were formed did not play significant role in the determination of their infiltration rate. The highest infiltration rate of 200.5 cm/h was observed under forest soils, followed by 119.5 cm/h under cultivated soils while the least value of 70 cm/h was obtained in grasslands.

Table 4. Effect of Land use as influenced by parent material on soil macro porosity (%)

	Parent Material			
Land Use	Sandstone	Basement Complex	Mean	Standard Deviation
Forest land	1.71	1.64	1.68	±0.35
Grass land	1.88	1.71	1.79	±0.09
Cultivated land	1.75	1.75	1.75	-
Mean	1.78	1.70		
LSD (0.05); L = ns; P = ns; L×P = ns				

Table 5. Effect of Land use as influenced by Parent material on soil infiltration rate (cm/h)

	Parent Material (P)			
Land Use (L)	Sandstone	Basement Complex	Mean	Standard Deviation
Forest land	178	223	200.5	±22.5
Grass land	78	62	70	±8.0
Cultivated land	145	94	119.5	±25.5
Mean	133.7	126.3		
LSD (0.05); L = 8.67; P = ns; L × P = 12.26				

ns = non-significant

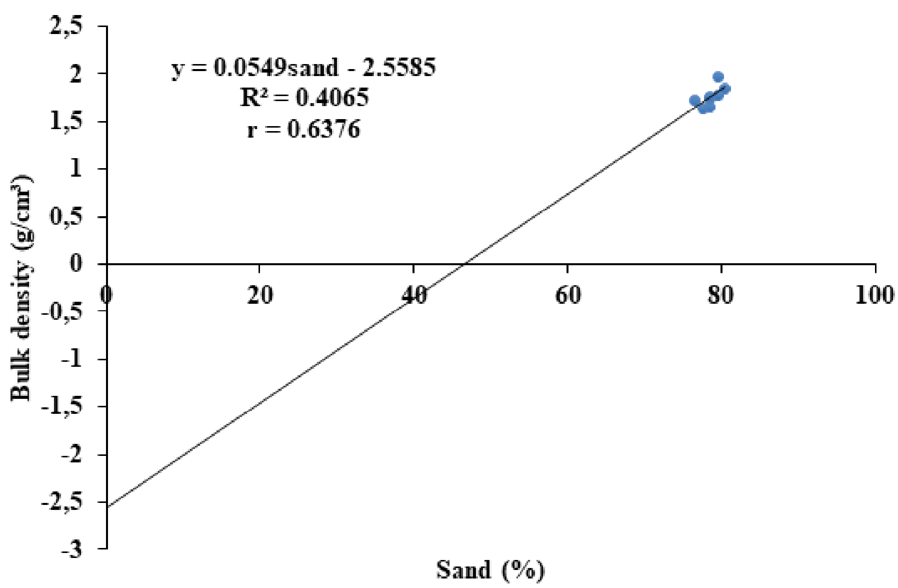

Fig. 1. Correlation between sand and bulk density of soils across land-use types under sandstone parent material in Ilorin

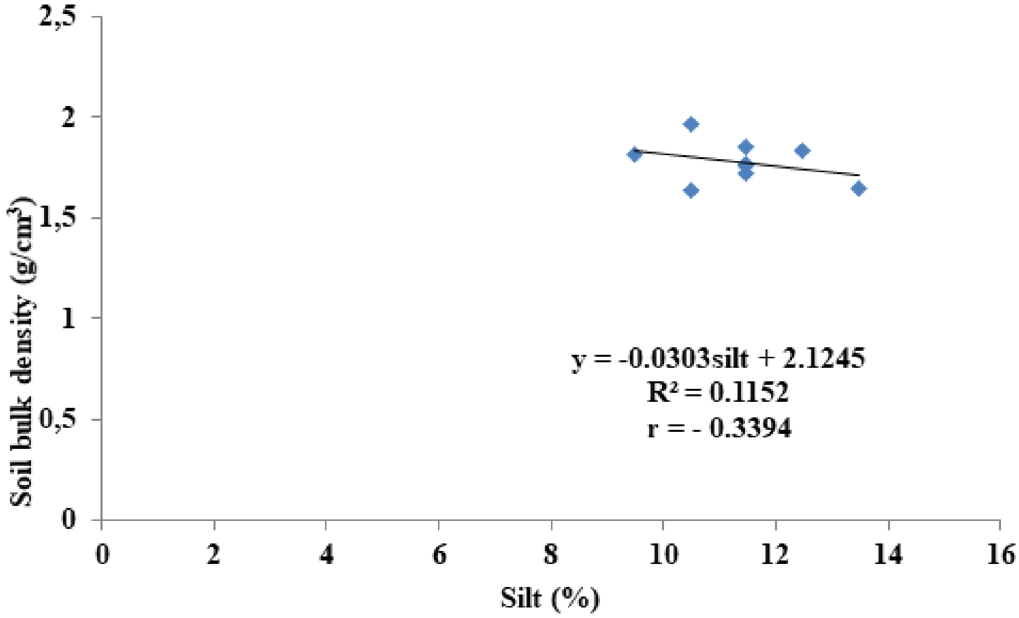

Fig. 2. The relationship between silt and bulk density of soils across land-use types under sandstone parent material in Ilorin

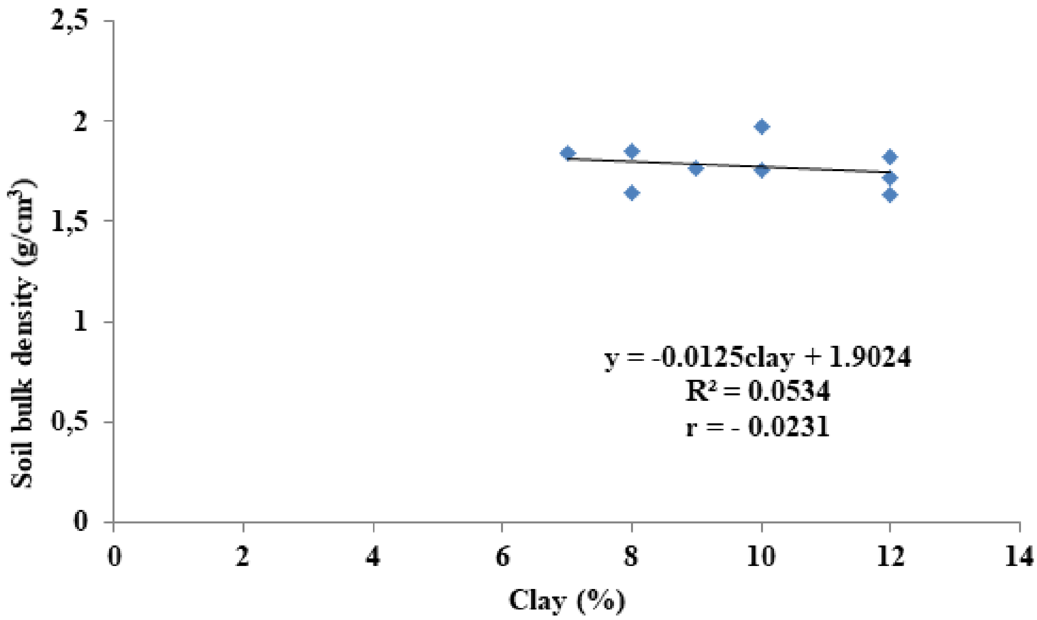

Fig. 3. The relationship between clay and bulk density of soils across land-use types under sandstone parent material in Ilorin

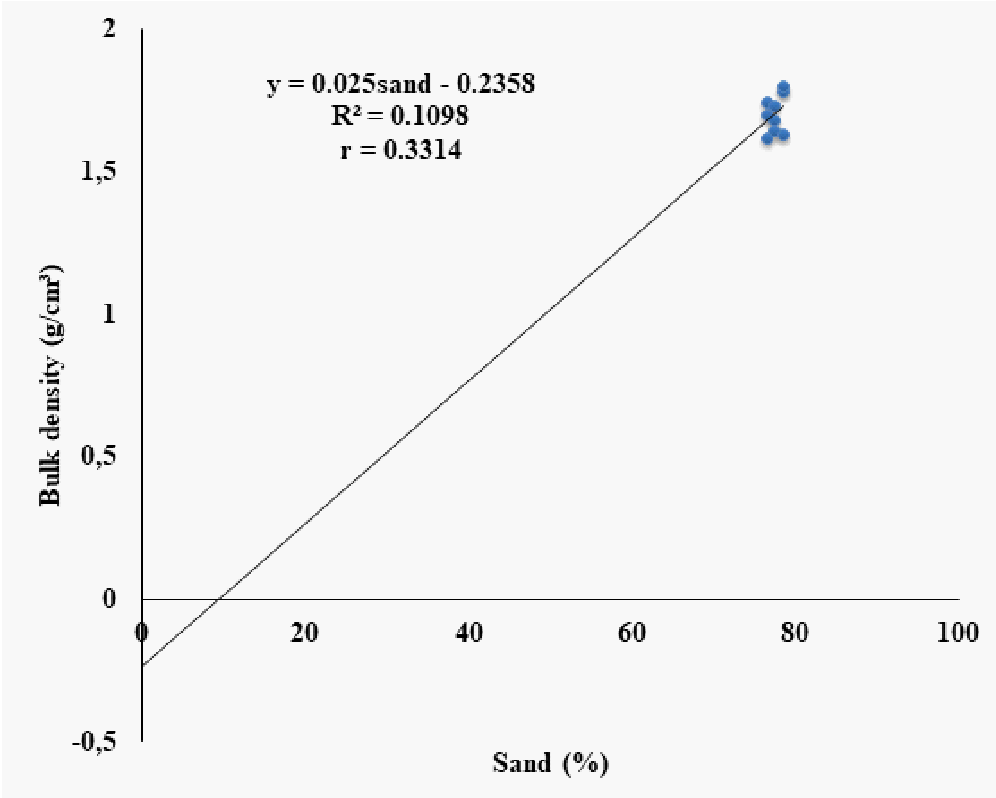

Fig. 4. The relationship between sand and bulk density of soils across land-use types under basement complex parent material in Ilorin

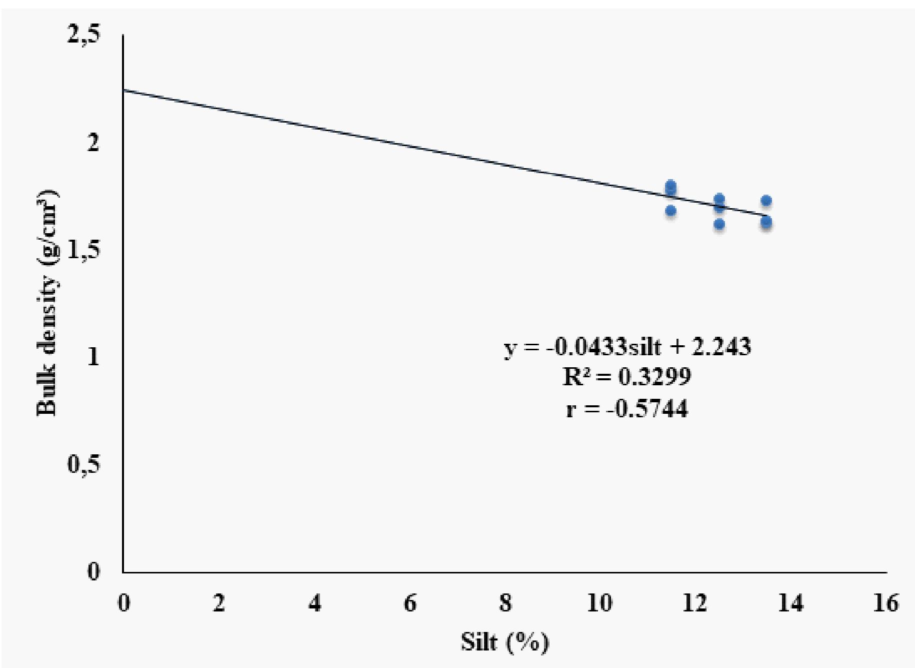

Fig. 5. The relationship between silt and bulk density of soils across land-use types under basement complex parent material in Ilorin

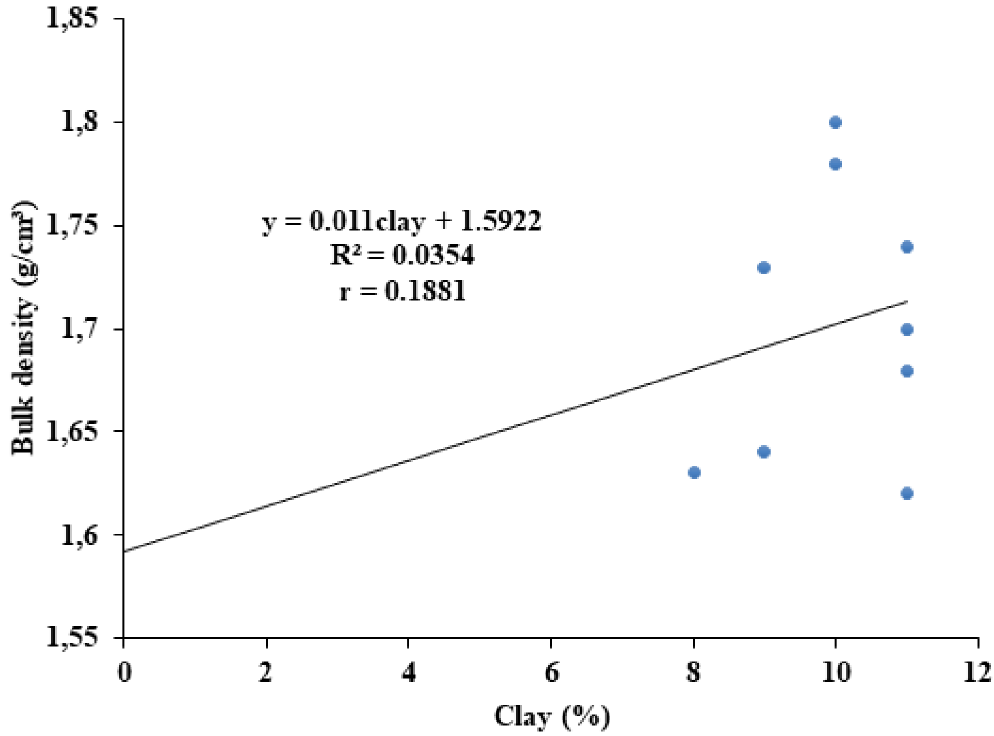

Fig. 6. The relationship between clay and bulk density of soils across land-use types under basement complex parent material in Ilorin

The result indicated that land-use significantly affected ($p<0.05$) saturated hydraulic conductivity (Ksat) of the soil (Table 6). The saturated hydraulic conductivity (Ksat) of forest land (84.6 cm/h) was significantly different from that of grass land (27.6 cm/h) and cultivated land (27.8 cm/h), while Ksat on grass land and cultivated land did not vary. The Ksat of soils developed over sandstone parent material was found to be significantly ($p<0.05$) higher than those on basement complex. The Ksat values were significantly influenced by the interaction of land-use and parent material. The highest Ksat was observed in forest soil under sandstone (108.0 cm/h) while the lowest Ksat was in cultivated soil under basement complex (20.2 cm/h). This indicates very high Ksat values for forest soils and high for the grassland and cultivated land (Soil survey staff, 1993).

Discussion

The uniform textural class (Sandy loam) observed across the study sites suggest homogeneity of soil forming processes for both parent materials. Obi (1999) reported that land-use does not affect soil texture, since soil texture is largely determined by the soil parent material. On the other hand, Dada et al., (2015) reported sandy loam texture as the most common soil type formed from basement complex parent material.

The non-significant effect of the various land-use types on the bulk density of soils under basement complex and sandstone parent material is thought to be related to the high percentage of the sand fraction observed across all the study locations. Chaudhari et al., (2013) reported strong positive correlation between sand content and bulk density in soils. The authors reported that the effect of sand content on soil bulk density was higher than other soil properties. This phenomenon is hinged on the coarse nature and mineralogy (quartz content) of the sand fraction. Similar studies by Gebeyaw (2006) and Moges et al., (2013) also reported that land-use types did not affect soil bulk density. However, some studies (Lemenih et al., 2005; Moges & Holden, 2008) found that bulk density significantly varied with land-use types due to differences in land management and land-use histories. The generally high bulk density values were indicative of compaction due to the pressure of human related exploitation.

The non-conformity of the relationship between bulk density and clay content to the report of Chaudhari et al., (2013) is suggestive of a clay mineralogy predominated by tectosilicates in the soil of basement complex origin. According to Allen and Fanning (1983) tectosilicates among other silicate forming clays is partly composed of quartz. Quartz is the dominant component of mineral soils like sandy soils with specific density of 2.65 gcm-3 (Mahilum, 2004). The foregoing strongly suggests that quartz content of soil fractions rather than sand may be the major determinant of positive correlations of soil fractions with bulk density.

Rich supply of organic matter and consequent high biological (earth worm) activity and soil loosening by tillage implements on forest and cultivated lands respectively is responsible for their higher macro-porosity compared to grassland. Grasslands in this area are most exposed to frequent trampling by the uncontrolled grazing of herds of cattle and sheep reared by Fulani herdsmen in Nigeria with attendant soil compaction leading to reduction in macro-porosity. Lower vegetation cover in grasslands and cultivated lands compared to forested lands likewise predisposes the soil to compaction resulting from impacting raindrops. According to FAO, (2008) lands with natural vegetation such as forestland have highly diversified vegetation with high quality and quantity leaf litter and good root production, which create a particular soil environment that favours the development of diverse and abundant soil macro fauna, which cumulatively improves macro-porosity. Furthermore, it reported that when vegetation is cleared and land is cultivated for cropping, the soil macro fauna are highly depleted as a consequence of the reduction in the quality and quantity of organic matter and the physical disturbance induced from tillage operations and the effects of fertilizer (decreasing soil pH) and non-targeted pesticides. Moreover, soils under pasture are more favorable for earthworm development with less physical disturbance and improvement in leaf litter quality, resulting to high quantity of manure adding to the soil unless seriously overgrazed (FAO, 2008). The higher (by more than a factor of two) macro-porosity values of soils under sandstone compared to those of basement complex parent material may be related to differences in clay content.

The response of the soil infiltration rate to land-use reflected more of effects related to human exploitation than the influence of parent material. Plaster (2014) reported high soil infiltration rate in forest soils and low in agricultural soils whereas Gol and Yilmaz (2017) reported higher soil infiltration rate in agricultural soils compared to grassland soils. Thurow et al., (1988) submitted that grazing intensity significantly impacted on soil infiltration rate. They further stated that the hooves of grazing animals compress the land and the resultant compaction therefore reduced soil infiltration rate. The non-significant difference in infiltration rate across the two parent materials under study may be due to overlay by soils of similar texture (sandy loam).

The highest value of Ksat observed in forest land may be attributed to litter accumulation and undisturbed soil structure of the forest soil. This result corresponds to that of Gol & Yilmaz (2017) who reported that land-use significantly affected Ksat. They further stated that the Ksat of forest land was significantly different from Ksat of grass land and cultivated land; the authors reported same Ksat values for grass land and cultivated land. Tillage operations in cultivated lands result in a change of number, shape, continuity and size distribution of the pore network, which controls the ability of soil to store and transmit air, water and agricultural chemicals (Rashidi & Keshavarzpour, 2007). The

Table 6. Effect of Land use as influenced by Parent material on soil saturated hydraulic conductivity (cm/h)

	Parent Material (P)			
Land Use (L)	Sandstone	Basement Complex	Mean	Standard Deviation
Forest land	108.0	61.2	84.6	±23.4
Grass land	30.6	24.5	27.6	±3.05
Cultivated land	35.3	20.2	27.8	±7.55
Mean	58.0	35.3		
LSD (0.05) ; L = 1.84; P = 2.27; L × P = 3.2				

result obtained implies that deforestation of land for agricultural and other purposes will reduce the Ksat of the soil which may enhance runoff and consequent soil erosion. Higher Ksat values observed in soils of sandstone compared to those of basement complex origin may be attributed to relatively higher macro-porosity observed in soils of sandstone parent material.

Conclusion

It can be concluded from this study that: 1. land use significantly affects soil macro porosity and ksat under the influence of sandstone and basement complex parent materials even when there are no differences in soil texture, 2. Forest land-use imparted superior water transmission properties on soils as against lowest values in grasslands irrespective of whether such soils are of sandstone or basement complex origin.

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