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# Land use effects on soil erodibility and hydraulic conductivity in Akure, Nigeria

**Yusuf Habeeb Ajibola[1*], Oguntunde Philip Gbenro[1,2] and Lawal Abosede Khadijah[1]**

[1]Department of Agricultural and Environmental Engineering, Federal University of Technology, Akure, Ondo State, Nigeria.
[2]Institute of Landscape Hydrology, Leibniz Centre for Agricultural Landscape Research, D-15374 Müncheberg, Germany.

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**This research was carried out to investigate the effects of three land use categories (grazed, cropped and forest land) on soil erodibility and hydraulic conductivity. Hydraulic conductivity was determined by a steady-state flow using a mini-disk infiltrometer while soil erodibility was determined following the Wischmeier and Smith equation. A suction rate of 2 cm $s^{-1}$ was chosen for field infiltration measurement and subsequent estimation of soil hydraulic conductivity. The USDA textural classes for the land use types in forest, cropped and grazed lands are clay, sandy clay and sandy clay loam, respectively. The mean values of the hydraulic conductivity for the land uses/land cover are: forest land (0.00162±0.002019 $cms^{-1}$), cropped land (0.002086±0.001299 $cms^{-1}$), and grazed land (0.002244±0.002176 $cms^{-1}$). Highest mean bulk density (1.45 ± 0.23 g $cm^{-3}$) and the lowest mean bulk densities (0.84 ± 0.14 g $cm^{-3}$) were observed in soils of forest and grazed land, respectively. Similarly, mean total porosity values ranged between 0.43 and 0.67 $cm^3$ $cm^{-3}$. Highest organic matter was found out in the grazed soil (4.90%) as a result of the urine and excreta of the cattle. High organic matter was also observed in the forest soil (3.50%) but lower relative to grazed land. The soil erodibility was high in the sampled soils of grazed land with the value of 8.73 × $10^{-2}$ ±0.03, while the least erodibility (6.35 × $10^{-2}$ ± 0.02) was recorded in the forest land. These values indicate the eroding vulnerability of the three land uses.**

**Key words:** Infiltration rate, organic matter, bulk density, total porosity, land cover.

## INTRODUCTION

Land use change is a complex process shaped by human activity and affected by ecological, economic and social drivers capable of influencing a wide range of environmental and economic conditions (Agarwal et al., 2000; MacDonald et al., 2000). Soil is one of the most essential abundant natural resources that sustain biological life. It plays a crucial role in agricultural production. A variety of farming practices often lead to

*Corresponding author. E-mail: hayusuf@futa.edu.ng.

some forms of soil degradation such as soil erosion (Ritter and Eng, 2012). Soil erosion impacts negatively on crop productivity and environmental quality and depresses the socio-economic status of farmers; it is therefore a threat to the landowners’ livelihoods as well as the overall health of an ecosystem (Egbai et al., 2012). Erodibility is the susceptibility of a soil to erosion (Wischmeier and Smith, 1978). Levy et al. (2001) described erodibility as the inherent tendency of soils to erode at different rates due solely to differences in soil properties. Soil erodibility factor is an estimate of the ability of soils to resist erosion based on the physical characteristics of each soil. It is a quantitative description of the susceptibility of soil particles to detachment and transport by rainfall and runoff. Erodibility factor is the rate of erosion per unit erosion index from a standard plot. The factors that influence soil erodibility factor are soil characteristics such as permeability, infiltration, water holding capacity, distribution of particles, aggregate stability, tendency towards dispersion and abrasion, transportability, structure and humus content. Hydraulic conductivity is a property of vascular plants, soils and rocks, which describes the ease with which a fluid (usually water) can move through pore spaces or fractures. It depends on the intrinsic permeability of the material, the degree of saturation, and on the density and viscosity of the fluid. Saturated hydraulic conductivity describes water movement through saturated media. According to Kirkham (2005), hydraulic conductivity is defined as the metres per day of water seeping into the soil under the pull of gravity or under a unit hydraulic gradient. Hydraulic conductivity also shows a temporal variability that depends on different interrelated factors: including soil physical and chemical characteristics affecting aggregate stability, climate, land use, dynamics of plant canopy and roots, tillage operations, activity of soil organisms (Fuentes et al., 2004). Several studies have been conducted over the years on soil erodibility and hydraulic conductivity; for example, Fasinmirin and Olorunfemi (2011) worked on the evaluation and variability of hydraulic conductivity and soil sorptivity to water in the forest vegetative zones of Nigeria and concluded that sorptivity is largely dependent on the total porosity of soil, while increase in soil organic matter content reduces the sorptivity of soil.

In order to reduce soil erodibility effects on soil resources, adequate conservation practices such as maintaining permanent soil cover, avoiding the use of slash and burn methods and promoting minimal mechanical disturbance of soil through zero tillage systems to enhance soil and water conservation and control soil erosion and other practices that minimize soil disturbance must be employed (Fasinmirin and Olorunfemi, 2013).

High sand content and the high dispersion ratios in soils make it highly detachable. However, with remarkably good properties exhibited by majority of soils in Nigeria, particularly high infiltration rate, organic matter and adequate vegetative cover, erosion faces high resistance Ezeabasili et al. (2011).

Therefore, this research aimed to determine the effects of different land uses on hydraulic conductivity and erodibility of soils in Akure, southwestern part of Nigeria.

## METHODOLOGY

### Study area

This research was carried out on different land uses in Akure, the capital city of Ondo State, Nigeria. The land use types include grazed, forest and cropped land. The grazed land is located on latitude and longitude 7° 17’ 00” N and 5° 13’ 07” E, respectively. The forest land is located on latitude and longitude 7° 17’ 01” N and 5° 08’ 04” E, respectively. The cropped land is an area under continuous cultivation of arable crops such as maize, yam, cassava and vegetables. It is located on latitude and longitude 7° 17’ 02” N and 5° 13’ 09” E, respectively.

### Sampling collection and analysis

This research adopted a random sampling method for the field measurement. Six sampling locations were chosen for the collection of different soil samples for bulk density, porosity, moisture content, organic matter content, particle size analysis and infiltration rate of each land use/land cover.

### Infiltration rate

The process involved using mini disk infiltrometer to determine the hydraulic conductivity of each land use. The bubble chamber was filled up to three-quarter of its volume by running water down the suction control tube or removing the upper stopper. Immediately after the upper chamber was full, the suction control tube was slided and the infiltrometer was inverted to remove the bottom elastomer and the porous disk, and the water reservoir was then filled. The position of the end of the tube with respect to the porous disk was carefully set to ensure a zero suction offset while the tube bubbles. After filling the water reservoir, the bottom elastomer was replaced making sure the porous disk is firmly in place. No water leaked out when the infiltrometer was held vertically. Suction rate of 2 $cms^{-1}$ was chosen on the field for the soil infiltration measurement for the different land uses soil. After the adjustment of the suction rate, the starting water volume was record at time zero, the infiltrometer was then placed on a smooth spot (scraped to remove any vegetation and ensure a level surface) on the soil surface. Instantaneously, water began to leave the lower chamber and infiltrate into the soil at a rate determined by the hydraulic properties of the soil. The infiltration measurements were recorded every 30 s for the duration of the experiment in all the land use. The infiltrometer was run for not less than 5 min on each of the land use/land cover for the accurate calculation of hydraulic conductivity. The water reservoir was refilled after the experiment. The data collected in each of the points were used to determine the water infiltration rates of the soil, then to calculate hydraulic conductivity. The hydraulic conductivity of soil in the entire plot was then calculated using the method of Zhang (1997). The method requires measuring cumulative infiltration vs. time and fitting the results with the function

A number of methods are available for calculating soil hydraulic conductivity from these data. The method proposed by Zhang

**Table 1.** Soil structure codes.

| Soil structure | Very fine granular | Fine granular | Medium, coarse granular | Blocky, platy, massive |
|---|---|---|---|---|
| Code | 1 | 2 | 3 | 4 |

Source: http://www.soils.wisc.edu.

(1997) is quite simple and works well for measurements of infiltration into dry soil. The method requires measuring cumulative infiltration versus time and fitting the results with the function:

$$I = C_1 t + C_2 \sqrt{t} \quad (1)$$

Where $C_1$ (m s$^{-1}$) and $C_2$ (m s$^{-1/2}$) are parameters. $C_1$ is related to hydraulic conductivity, and $C_2$ is related to soilsorptivity. The hydraulic conductivity of the soil (k) is then computed from

$$k = \frac{C_1}{A} \quad (2)$$

Where, $C_1$is the slope of the curve of the cumulative infiltration vs. the square root of time, and A is a value relating the van Genuchten parameters for a given soil type to the suction rate and radius of the infiltrometer disk. A is computed from:

$$A = \frac{11.65(n^{0.1}-1)\exp(2.92(n-1.9)\alpha h_0)}{(\alpha r_0)^{0.91}} \quad n \geq 1.9 \quad (3)$$

$$A = \frac{11.65(n^{0.1}-1)\exp(7.5(n-1.9)\alpha h_0)}{(\alpha r_0)^{0.91}} \quad n \leq 1.9 \quad (4)$$

Where, ‘n’ and ‘α’ are the van Genuchten parameters for the soil, $r_0$ is the disk radius, and $h_0$ is the suction at the disk surface.

The van Genuchten parameters for the 12 texture classes of soil were obtained from Carsel and Parrish (1998) as quoted by Decagon (2008). The mini disk has a radius of 1.25 cm and a suction of 2.0.

### Bulk density and porosity

The bulk density (BD) was obtained by the gravimetric soil core method described by Blake and Hartage (1986) and the particle density (PD) was assumed to be 2.65 g cm$^{-3}$ (Osunbitan et al., 2005). The total porosity (PT) was obtained from BD and PD using the equation and relationship developed by Danielson and Sutherland (1986):

$$PT = 1 - \frac{BD}{PD} \quad (5)$$

Where, BD = Bulk density and PD = particle density (= 2.65 Mg/m$^3$). The default value of 2.65 g/cm$^3$ is used as a ‘rule of thumb’ based on the average bulk density of rock with no pore space (Fasinmirin and Olorunfemi, 2013).

### Soil moisture

The moisture content was calculated using gravimetric method from the values recorded during the measurement of soil bulk density as:

$$\text{Moisture content wet basis} = \frac{((W_2-W_1)-(W_3-W_1))}{W_2-W_1} \times 100\% \quad (6)$$

$$\text{Moisture content dry basis} = \frac{((W_2-W_1)-(W_3-W_1))}{W_3-W_1} \times 100\% \quad (7)$$

### Erodibility

The regression equation by Wischmeier and Smith (1971) (Equation 11) was used to calculate the erodibility factor.

$$100K = 2.1 \times 10^{-4} \times (silt\,\% \times (100 - \%clay)) \times ((12 - OM) + (3.25 \times (St - 2)) + (2.5 \times (Pt - 3))) \quad (8)$$

Where, OM is organic matter content %, St is soil structure code and Pt is permeability class

The soil structure is determined by physically looking at a column of undisturbed soil. The columns of soil, which were gotten using core samplers, were carefully examined physically using the eyes. Cracks were checked, the relative sizes of the particles, aggregation, ped form, and the entire structure in terms of grade, form and the entire structure and size were observed. The observations were graded according to the following codes in Table 1.

The permeability class test was done to determine the permeability of soils of the three land use. Soil samples from the three land use were put in separate measuring cylinders and 100 ml of water was added to each of the cylinders containing soil. Observation was then made on the time taken for the measured quantity of water to reach a particular level in the cylinder as it infiltrates down through the soil sample. The time was recorded and this was used for soil permeability classification according to the following codes: fast– 1, moderate to fast– 2, moderate– 3, slow to moderate– 4, slow– 5, and very slow– 6 as described by Wischmeier and Smith (1971).

### Soil texture

The soil texture was determined using samples of soil collected from the site. The soil was air dried to reduce the moisture content after which it was taken to the laboratory where the soil texture was measured using the method described by Schlichting et al. (1995). Soil texture classes were defined according to FAO/USDA soil classification system.

### Statistical analysis

Field data obtained were subjected to statistical analysis such as mean, standard deviation and correlation coefficients.

## RESULTS AND DISCUSSION

### Particle size composition of collected samples

Table 2 shows the result of variations in the particle size composition of the collected soil samples for different land use. There were variations in the percentage of sand, silt and clay among different land use soil samples. According to the USDA classification system, each land

**Table 2.** Textural classifications of soil of the experimental land use at 15 cm depth.

| Land use/cover | Sand | Clay | Silt | USDA textural class |
|---|---|---|---|---|
| Forest | 41.47 | 42.87 | 15.67 | Clay |
| Cropping | 46.80 | 35.20 | 18.00 | Sandy clay |
| Grazing | 66.80 | 22.50 | 10.73 | Sandy clay loam |

**Table 3.** Bulk density and porosity of different land use soil samples.

| Land use | Bulk density ($gcm^{-3}$) | Porosity (cm $cm^{-3}$) |
|---|---|---|
| Forest | 1.45±0.23 | 0.43±0.088 |
| Cropped | 1.35±0.34 | 0.47±0.133 |
| Grazed | 0.84±0.14 | 0.67±0.053 |

**Table 4.** Moisture content (dry basis) of different land use soil samples.

| Land Use | Moisture content dry (%) |
|---|---|
| Forest | 27.4843±10.7501 |
| Cropped | 26.3252±13.2979 |
| Grazed | 38.5786±22.4413 |

**Table 5.** Organic matter content and organic carbon of the soils sampled.

| Land use/cover | Organic matter content (%) | Organic carbon (%) |
|---|---|---|
| Forest | 3.548±1.092 | 2.058±0.633 |
| Cropped | 2.833±1.316 | 1.643±0.764 |
| Grazed | 4.888±1.241 | 2.835±0.721 |

use soil sample has different types of soil, that is, the soil samples collected at the forest zone is predominantly clay while those at the cropped and grazed zone are sandy clay and sandy clay loam, respectively. Grazed zone has a slightly higher sand content (66.80%) than the others, as well as the lowest silt (10.73%) content and also with the lowest clay (22.50%) content. The high sand content could be attributed to the selective removal of clay particles by erosion leaving the sand particles in the freely grazed land. Forest zone has the highest clay (42.87%) content and the lowest sand (41.47%) content, respectively. Cropped zone has the highest silt (18.00%) content.

## Bulk density and porosity

Table 3 presents the experimental result for both porosity and bulk density for forest, cropping and grazing zones. Of the three land uses, forest land had the highest bulk density (1.45 $gcm^{-3}$) but lowest porosity (0.43 cm $cm^{-3}$) while grazed land at 0.8 $gcm^{-3}$ had the lowest bulk density but highest porosity 0.67 cm $cm^{-3}$. This observation agrees with the works of Vogelmann et al. (2010), Kay and Angers (2002), Gantzer and Anderson (2002) and Ringrose-Voase (1996).

## Volumetric moisture content

Table 4 presents the moisture content of soil samples for each land use. High moisture content (38.58±22.44%) was found in the grazed zone. At 26.33±13.30% moisture content, the cropped land had the lowest moisture content. This was a result of the soil type (sandy clay loam) and the presence of crops which continuously tap moisture from the soil.

## Organic matter and organic carbon

Table 5 shows the organic matter content (OMC) and organic carbon of different land use. From the results, it was observed that high organic matter was found in the

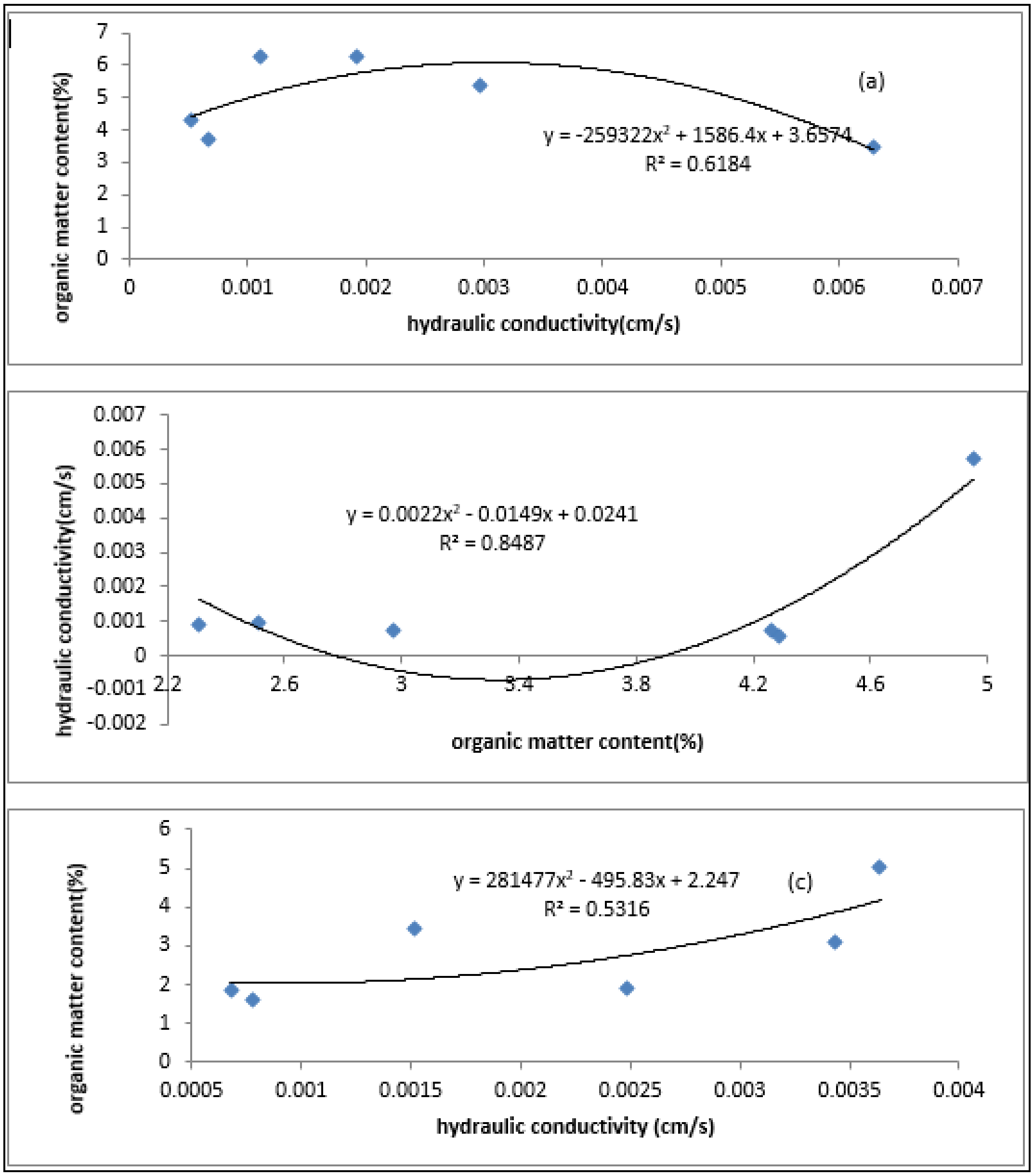


**Figure 1.** Relationship between hydraulic conductivity and organic matter of soils under land use/cover type, (a) grazed, (b) forest and (c) cropped.

grazed soil due to the urine and excreta of the cattle. High organic matter content was also observed in the forest soil, however at a lower quantity to grazed soil. High organic matter is attributed partly to the continuous accumulation of undecayed and partially decomposed plant and animal residues in the surface soil. The presence of high nutrient in the forest land can help to support farming. The cropped soil had the least organic matter content as a result of continuous depletion from crop use and also as a result of burning of plant residues before cropping and after harvesting. The reduction was also caused by continuous tilling of the soil for cultivation.

## Hydraulic conductivity

Figures 1 and 2 present the relationship between hydraulic conductivity (HC), organic matter content (OMC) and bulk density (BD) of the different land use (grazing, forest and cropping). Observed trends between HC and OMC, BD and TP of different land use are presented in Table 7. The forest zone indicated positive correlation between HC and OMC, TP and BD. There was a perfectly negative correlation between HC and TP in the grazing and cropping zone.

Table 6 presents the average hydraulic conductivity of

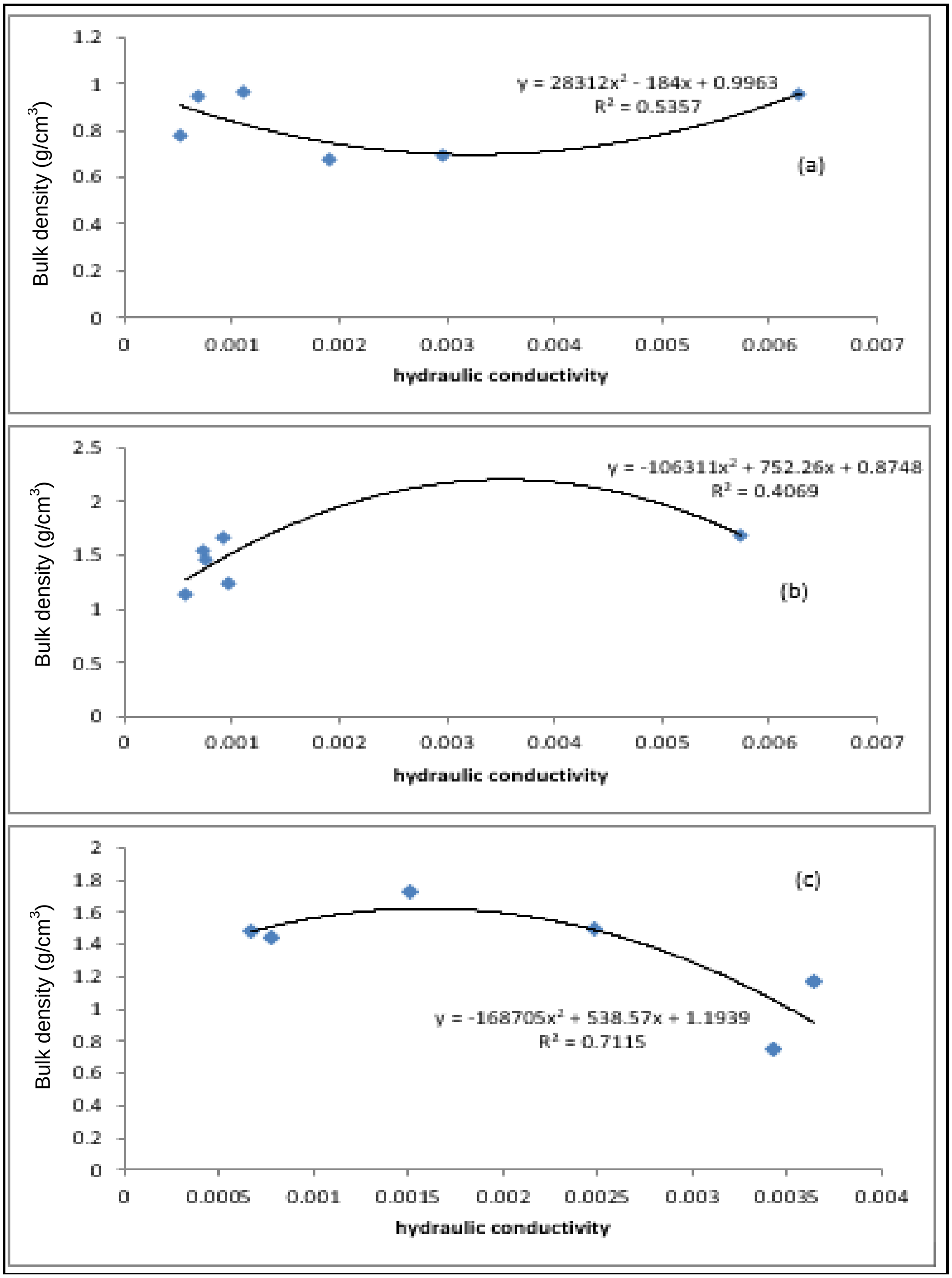


**Figure 2.** Relationship between hydraulic conductivity and bulk density of soils under land use/cover type, (a) grazed, (b) forest and (c) cropped.

**Table 6.** Soil hydraulic conductivity of different land use soil samples.

| Land use | USDA textural class | Calculated hydraulic conductivity ($cms^{-1}$) |
|---|---|---|
| Forest | Clay | 0.00162±0.002019 |
| Cropped | Sandy clay | 0.002086±0.001299 |
| Grazed | Sandy clay loam | 0.002244±0.002176 |

**Table 7.** Spearman's rho correlation coefficient (r) among different land uses.

| Land use | | BD | HC | E | MC | TP | OMC |
|---|---|---|---|---|---|---|---|
| | BD | - | 0.600 | -0.314 | -0.257 | -0.314 | 0.086 |
| | HC | - | - | -0.029 | 0.143 | 0.029 | 0.086 |
| FOREST | E | - | - | - | -0.200 | -1.00** | -0.771 |
| | MC | - | - | - | - | 0.200 | 0.429 |
| | TP | - | - | - | - | - | 0.771 |
| | BD | - | -0.029 | -0.314 | -0.314 | 0.029 | -0.029 |
| | HC | - | - | 0.029 | 0.029 | -1.00** | -0.116 |
| GRAZED | E | - | - | - | 1.000** | -0.029 | 0.203 |
| | MC | - | - | - | - | -0.029 | 0.203 |
| | TP | - | - | - | - | - | 0.116 |
| CROPPED | BD | - | -0.486 | -0.486 | -0.486 | 0.486 | -0.086 |
| | HC | - | - | 0.257 | 0.257 | -1.000** | -0.771 |
| | E | - | - | - | 1.000** | -0.257 | 0.486 |
| | MC | - | - | - | - | -0.257 | 0.486 |
| | TP | - | - | - | - | - | -0.771 |

**Correlation is significant at the 0.01 level.

different land use soil samples. HC of sampled soils ranged from 0.00162 $cms^{-1}$ in the forest zone to 0.00224 $cms^{-1}$ in the grazing zone. Low hydraulic conductivity in the forest zone was as a result of low exposure of soil to sunlight and low rate of infiltration of water in the soil which was due to the effects of weight of the overlying soil. High hydraulic conductivity was caused by high soil total porosity, an indication of the infiltration rate of water into soil.

**Table 8.** Erodibility of different land use soil samples.

| Land use | Erodibility |
|---|---|
| Forest | 0.063451±0.020874 |
| Cropped | 0.076486±0.021189 |
| Grazed | 0.087351±0.032167 |

## Erodibility

The result of soil erodibility of the land uses is presented in Table 8. Soil erodibility of sampled soils ranged from $6.35 \times 10^{-2}$ in the forest zone to $8.73 \times 10^{-2}$ in the grazing zone. These high values indicate vulnerability of soils on each land use to erosion. This is due to high percent of silts in each land use. The least erodibility was observed in the forest zone as it had the least clay content among the three land uses. This is in relation to the work of O'Geen et al. (2006) who concluded that erodibility is low for clay-rich soils with a low shrink-swell capacity, because clay particles come together to form large aggregates that resist detachment and transport processes. It was found that average soil loss is negatively correlated with clay content but positively correlated with very fine sand and silt plus very fine sand contents. High erodibility value of the grazed zone was due to grazing intensity of cattle which increases soil compaction thereby increasing soil density and the reduction of soil aggregate stability. Figure 3 presents the relationship between erodibility and organic matter content of the different land use (grazed, forest and cropped). Organic matter content contributes about 55% to the factors causing erodibility in the grazed zone and 77% to the forest and cropped zones.

## Conclusion

This study reveals the significant differences in the soil physical properties of three land uses in Akure, southwestern Nigeria. The hydraulic conductivity is strongly correlated to bulk density and total porosity. The soil in forest zone had significantly high bulk density as compared to the low bulk density in grazed zone. However, organic matter content, moisture content and hydraulic conductivity were significantly high in the grazed zone. Erodibility values are derived solely from soil properties and factors such as slope, rainfall, surface cover, or management practices were not considered. Soil properties used for this interpretation include surface soil texture, permeability and organic matter.

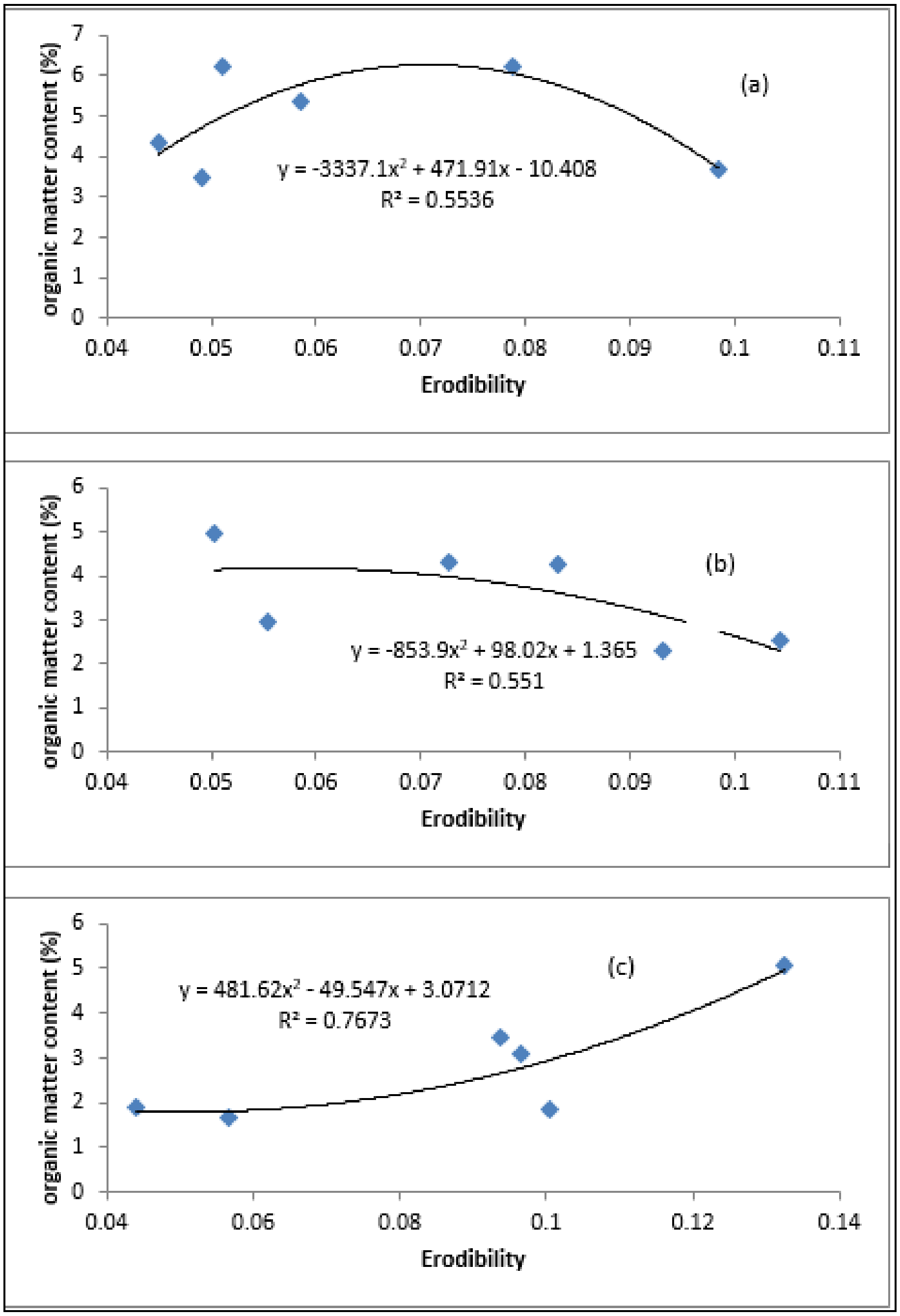


**Figure 3.** Relationship between erodibility and organic matter content of soils under land use/cover type, (a) grazed (b) forest and (c) cropped.

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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