Scientific Research Publishing

Journal of Environmental Protection, 2024, 15, 475-484
https://www.scirp.org/journal/jep
ISSN Online: 2152-2219
ISSN Print: 2152-2197

Effect of Some Physical Factors on Interrill Erosion of Soils in Gidan-Kwanu Area, Nigeria

Ebierin Akpoebidimiyen Otuaro[1], John Jiya Musa[2], Micheal Abolarin[2]

[1]Department of Civil Engineering, Faculty of Engineering, Maritime University, Okerenkoko, Nigeria
[2]Department of Agriculture and Bioresources Engineering, Federal University of Technology, Minna, Nigeria
Email: e.otuaro@yahoo.com, johnmusa@futminna.edu.ng

How to cite this paper: Otuaro, E.A., Musa, J.J. and Abolarin, M. (2024) Effect of Some Physical Factors on Interrill Erosion of Soils in Gidan-Kwanu Area, Nigeria. *Journal of Environmental Protection*, **15**, 475-484.
https://doi.org/10.4236/jep.2024.154027

Received: March 15, 2024
Accepted: April 22, 2024
Published: April 25, 2024

Abstract

Savanna regions in Nigeria face environmental degradation and barren land, negatively impacting food and agricultural productivity. Inter-rill erosion occurs due to raindrop impact and transport, particularly on hill slopes. A study was conducted using a sprinkler rainfall simulator and plot experiment to study soil erosion processes. Soil samples were collected from four farms in Gidan Kwanu, with varying moisture content. Sand content ranged from 46.0% to 76.20%, silt from 11.30% to 23.50%, and clay from 11.0% to 30.0%. Uncultivated and bare land had a higher average porosity (15.47% and 14.99%), while cultivated land had lower porosity (14.4%). The study found that most people in Gidan-Kwanu primarily practice farming, which is season-dependent and rain-fed. Soil type and texture significantly contribute to inter-rill erosion, with cultivated and uncultivated soil being more resistant to erosion than bare land soil. The study concluded that farming practices in Gidan-Kwanu are primarily season-dependent and rain-fed. Soil type and texture significantly contribute to inter-rill erosion, with cultivated and uncultivated soil being more resistant to erosion than bare land soil.

Keywords

Agriculture, Erosion, Farming, Porosity, Soil

1. Introduction

Soil erosion is a significant issue in the agricultural environment, affecting crop production and environmental degradation [1]. It is a two-phase process consisting of detachment of individual particles and their transport by erosive agents such as flowing water and wind [2]. The rate at which erosion occurs depends on the individual agents responsible for soil erosion [1]. A field analysis was conducted to evaluate the effect of slope steepness, soil strength and texture, and rainfall intensity on inter-rill soil in the Gidan-Kwanu Area of Niger state, Nigeria.

Most savanna regions in Nigeria suffer from environmental degradation and barren land, which has a detrimental impact on food and agricultural productivity and production [3]. As much as 75 billion tons of soil are removed from the land by wind and water erosion, with most coming from agricultural land [4] [5]. The major effect of soil erosion is the loss of arable land suitable for supporting agricultural production. To prevent soil erosion, appropriate soil conservation measures may be required, and understanding the mechanics of erosion and quantifying the current rate of erosion is crucial [6].

Inter-rill erosion occurs in an area where all detachment is due to the forces of raindrop impact and transport, primarily by overland flow, especially on hill slopes [7]. Different factors affect the rate of soil erosion from inter-rill areas, leading to decreased productivity of the upslope area due to the movement of topsoil. The main factors that cause erosion on inter-rill soils include soil slope, soil texture, soil strength, and rainfall intensity.

Farmlands in Gidan-kwanu also experience inter-rill erosion, which has gradually become a problem over time as farmers face soil and nutrient loss on their farmland due to rainfall intensity and the land slope. This study aims to determine and analyze the effect of some physical factors on some inter-rill soils in some farmlands in Gidan-kwanu.

2. Materials and Methodology

2.1. Study Area

The study is conducted in Gidan-kwanu village, the main campus of the Federal University of Technology, Minna, located 10 km from the central part of Minna in Niger state on longitude and latitude of 9.536959, 6.443874; 9.5369208, 6.4463920 and 9.544332, 6.472059 respectively. The soil profile is mainly Alfisols, ranging from sandy loamy to sandy clay with low cation exchange capacity. The geology and parent materials are complex basement, and the topography is nearly level 2%. The study was conducted on farmland areas with crop cover, bare land, and grassland.

Minna is a sub-humid climate with a mean annual rainfall of 1209.7 mm and a distinct dry season lasting 5 months from November to March [8]. The area features gently undulating high plains on complex rocks, with bedrock being the major parent material. The annual rainfall is 36.192 inches, with the driest periods occurring from March to November. The highest amount of rain is received in August and September, with 16 days of precipitation in each month. Gidan-Kwanu is home to the Southern Guinea Savanna Vegetation, characterized by grassland, shrubs, and trees, with Guinea grass being the major grass species [9]. The land use in the area is mainly agriculture and habitat.

2.2. Rainfall Intensity

The study used a sprinkler rainfall simulator to simulate rainfall on soil [9]. The initial 1-hour application was around 64 mm/h, followed by a second 1-hour wet run 24 hours later. The rainfall characteristics were similar to natural rainfall, with a mean intensity of 49.1 mm/h. Tap water was used for the simulations, and although lower erosion rates were observed for some soils using tap water instead of deionized water, the effects were assumed to be negligible for the soil due to its clay mineralogy and low sodium content. The study was conducted during a period of low precipitation in the study area.

2.3. Soil Erodibility and Runoff

A plot experiment was conducted to study soil erosion processes and assess it at a site. The soil erosion mass was measured under different rainfall and soil conditions using a rain simulator and sprinkler [9]. The runoff was sampled every 2 - 5 minutes for 80 minutes, with sediments splashed off the tray's front. Net downslope splash erosion was measured, not total splash erosion, which is lost in all directions. Downslope splash erosion rates were slightly underestimated. Splash and runoff samples were oven-dried at 105˚C to obtain soil loss in gm/min. The experiment aimed to show the effect of rainfall intensity and derive the USLE.

2.4. Rainfall and Runoff

The study utilized a 1.24 m long, and 1.2 m wide catchment area made of wood, a rain simulator to initiate rainfall, a rain gauge to measure intensity, and a specific volume container to collect runoff, following the work of Musa *et al.*, [10]. The depth of runoff was calculated using:

$$\text{Depth of runoff} = \frac{\text{Volume}\left(\text{m}^3\right)}{\text{Area}\left(\text{m}^2\right)} \quad (1)$$

2.5. Soil Sampling

Soil samples were collected from four farms in Gidan Kwanu, labelled A, B, and C. Three samples were randomly collected on each farmland, while three were collected from areas with severe erosion. The samples were collected at depths of 15 – 25 cm due to the major crops being deep-rooted. The soil was collected using a soil auger, gently driven 15 – 25 cm into the ground in each location. The samples were carefully removed and emptied into containers with lids to prevent moisture escape. About 6 containers weighing 1.5 kg were collected from each location, labelled with paper tape following the method stated by Musa *et al.* [11] [12]. The samples were taken to the laboratory for analysis, with four core rings used in each location for soil sample collection.

2.6. Data Collection

The Mechanical soil analysis and Fractionalization method was used to determine the particle size of soil samples, which helps estimate the sand, silt, and clay particle content [13]. The samples were sieved using a 2 mm sieve and collected into containers. A 5 % sodium hexametaphosphate solution was prepared by dissolving 50 g of sodium hexametaphosphate in 1 litre of distilled water. The solution was added to each sample in the containers, and the soil suspensions were stirred with a mechanical stirrer for 15 minutes. The soil suspensions were then transferred to a 1-litre capacity measuring cylinder, and distilled water was added to each cylinder. The cylinders were stirred for 2 minutes to ensure all particles were in suspension. A hydrometer was inserted into each soil suspension, and readings were recorded at 40 seconds. The thermometer readings were also taken immediately after the hydrometer readings. The cylinders were left undisturbed for 2 hours, and the hydrometer and thermometer readings were measured and recorded. The Soil textural class was determined from the result of particle size analysis. The various percentages of sand silt and clay were determined and aligned on the soil textural triangle.

2.7. Bulk Density

The coring method was employed to determine the bulk density of soil samples. Core rings were gently driven into the ground and removed without disturbing the samples. Samples were stored in polyethene bags and oven-dried at 120˚C for 24 hours. Precautions were taken to avoid compaction within the core cylinder. Dry Bulk Densities were calculated by dividing the weight of dried soil per unit volume. The bulk density is normally expressed as g/cm^3.

$$\text{Bulk density} = \frac{\text{weight of dried soil} - \text{Weight of container}}{\text{volume of core ring}} \tag{2}$$

2.8. Total Porosity

The total porosity was calculated using the values obtained from the determined bulk densities of the soil samples.

$$\text{Total porosity}(\%) = \left(\frac{1-\rho b}{\rho p}\right) \times 100 \tag{3}$$

Where ρb = dry Bulk density (Mg/m^3) and ρp= particle density (Mg/m^3).

3. Results and Discussion

3.1. Soil Textural Classification

The study found that the soil aggregate in various locations was predominantly sandy, with the highest amount found on bare land. This aligns with previous research by Musa *et al.* [11], indicating that sandy soil is a significant soil in the area. Table 1 displays the soil textural class of soil samples collected at different farmlands, illustrating the particle size distribution of the soil.

3.2. Moisture Content

Table 2 shows the moisture content of soil on cultivated farmland, collected at 0 – 10 cm depth and 15 - 25 cm depth to avoid affecting plant roots. The average moisture content was determined from samples in each study area, with the

Table 1. Soil textural classification on cultivated land, uncultivated land, and bare land.

Land Condition	Samples	%Sand	%Silt	%Clay	Textural class
	1	68.91	16.72	14.37	Sandy Loam
Cultivated	2	64.25	20.71	15.05	Sandy clay loam
	1	56.00	23.50	20.50	Sandy clay loam
Uncultivated	2	46.00	24.00	30.00	Loam
	1	76.20	12.80	11.00	Sandy Loam
Bare-land	2	68.80	11.30	19.90	Sandy Loam

Table 2. Moisture content for the various land conditions.

Land Condition	Sample	Soil depth (cm)	Weight of container (g)	Weight + sample	Weight of oven-dried sample	Moisture content (%)	Average Moisture content (%)
Cultivated	1	0 - 10	20	145.048	129.40	14.30	7.88
	2	10 - 20	20	145.268	139.438	4.89	
	3	20 - 25	20	153.317	147.641	4.45	
Uncultivated	1	0 - 10	20	148.20	142.52	4.65	8.83
	2	10 - 20	20	139.45	133.62	5.14	
	3	20 - 25	20	129.54	113.89	16.69	
Bare	1	0 - 10	20	142.72	137.51	4.44	2.2
	2	10 - 20	20	139.20	138.96	0.20	
	3	20 - 25	20	127.39	125.32	1.97	

highest moisture content percentage at the surface level and least at the depth where the soil was collected. The average moisture content for the uncultivated land showed the lowest moisture content at the soil surface level and highest at the soil collected, and the percentage moisture content increases gradually with soil depth while the soil moisture content for the bare land showed that it was least at farmland depth and highest at surface level and decreases as soil depth increases. This indicates a correlation between soil moisture content and soil quality.

3.3. Bulk Density and Porosity

The soil sample underwent laboratory analysis to determine its bulk density and porosity, revealing the percentage of micro-pore spaces available for water and air movement. The study used the same core ring across all areas, resulting in an average bulk density of 1.12 - 1.21 g/cm^3 and porosity of 14.44% - 15.47% as presented in **Table 3**. This is similar to the findings of Musa *et al.* [14].

The study reveals that rainfall intensity varies across farmland types, with bare land having the least rainfall intensity application rate and highest sediment yield (**Figure 1**). Cultivated farmland has the most negligible sediment yield at high rainfall intensity, possibly due to reduced runoff velocity due to vegetation cover.

Table 3. Bulk density, Particle density and porosity.

Land Condition	Sample	Bulk Density (g/cm³)	Particle Density (g/cm³)	Porosity (%)	Average BD (g/cm³)	Average PD (g/cm³)	Average Porosity (%)
Cultivated	1	1.11	1.32	15.91	1.21	1.41	14.44
	2	1.22	1.42	14.08			
	3	1.3	1.45	13.33			
Uncultivated	1	1.24	1.36	14.48	1.12	1.32	15.47
	2	1.16	1.36	14.7			
	3	0.96	1.16	17.24			
Bare-land	1	1.19	1.4	15	1.16	1.36	14.99
	2	1.21	1.4	13.57			
	3	1.07	1.28	16.4			

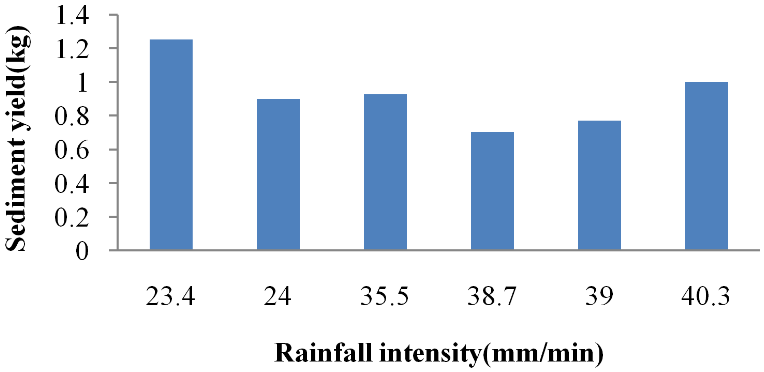

Figure 1. Rate of sediment yield at different rainfall intensities.

3.4. Soil Erodibility and Runoff

Table 4 presents the rate of sediment accumulation as raindrops hit the soil surface. Rain intensity was measured using a rain gauge, and sediments were collected from runoff using a barrel and oven-dried to calculate soil loss on each farmland after 10 minutes of rain.

4. Discussion of Results

Gidan-Kwanu's indigenous people primarily engage in farming during the rainy season, preparing for rainfall to control various crops in the locality. The study revealed that farming is predominantly conducted by males and females, with many relying on rainfall and some using irrigation, and the types of crops planted are annual and biennial. Most farmlands involve manual planting and cultivation, with 60% of farmers using inorganic and organic fertilizers, as well as chemical pesticides, herbicides, and pesticides.

The soil samples from the study areas had high sand and loam content, with average clay content. The soil belongs to a textural class of sandy loam, except for uncultivated farmland with loamy soil. Sand content ranged from 46.0% to 76.20%, silt from 11.30% to 23.50%, and clay from 11.0% to 30.0%. These values

Table 4. Soil runoff in the selected study area.

Land Condition	Sample	Time (min)	Rainfall intensity (mm/min)	Sediment yield (kg)	Weight of dry runoff (kg)	Volume of barrel (m)	Soil loss (kg/m)	Soil loss (kg/ha)
Cultivated	1	0 - 10	35.50	0.928	0.678	36.70	0.018	2.89
	2	10 - 20	38.70	0.702	0.452		0.012	1.93
Uncultivated	1	0 - 10	40.30	1.000	0.750	36.70	0.020	3.21
	2	10 - 20	39.00	0.770	0.500		0.014	2.25
Bare	1	0 - 10	23.40	1.254	1.074	36.70	0.029	4.66
	2	10 - 20	24.00	0.720	0.720		0.020	3.21

align with previous research by Abdulkadir [14] [15]. Uncultivated farmland had higher clay and silt content compared to cultivated and bare land.

The moisture content of soil samples for the bare land shows a low content compared to cultivated and uncultivated farmland. The average moisture content values range from 0.20% to 16.69%, similar to previous studies by Musa *et al.*, [11] in the same location. They also noted that the difference in moisture content between cultivated and uncultivated farmland can be attributed to soil types/texture.

The study analysed soil strength and compaction using bulk density and porosity values. The results showed that cultivated farmlands had higher average bulk densities than uncultivated and bare farmland. However, these values were lower in previous studies in Gidan-Kwanu. Bulk density values ranged from 1.458 g/cm^3 to 1.606 g/cm^3, with differences attributed to the volume of the core ring and the depth of the soil sample. The results align with Enokela and Egharevba's [16] bulk density values of 1.04 g/cm^3 to 1.80 g/cm^3. The porosity of the soil sample showed that uncultivated and bare land had higher average porosity (15.47% and 14.99%), while cultivated land had lower porosity (14.4%). This difference is consistent with Musa *et al.*'s [11] work, which ranges from 7.05% - 57%. Soil disturbances were found to be a contributing factor to the lower porosity of cultivated farmland.

The initial rainfall gave room for more sediment from runoff than other applications, even with higher rainfall intensity. This could be due to the soil's natural cohesive force. The sediments were oven-dried to determine soil loss on each farmland at a mean intensity of 33.48 mm/min, with a range of 23 - 40 mm/min rainfall intensity. Runoff sediments on bare land have more runoff than cultivated and uncultivated farmland which is similar to the works of Abua *et al.*, [17].

The cultivated and uncultivated soils had higher moisture content than bare land, indicating low water-holding capacity. The slope steepness of the lands is less than 3%, indicating flat topography, which is in accordance with Kuti and Ewemoje's [18] work.

The porosity of farmlands, ranging from 15% - 20%, indicates small pore spaces, with water moving more quickly through these spaces than in cultivated and uncultivated farmlands. This is due to the sandy soil texture on bare land, which makes water storage difficult. Cultivated farmland has the highest bulk density, indicating soil strength, possibly due to plant root growth and external forces. This is consistent with the work of Akinola *et al.* [19] work.

The slope of the study area which generally affects rainfall impact, detachment process, and runoff velocity, was observed to be flat, which may not significantly affect soil interrill erosion. Previous studies have shown that slopes less than 3 % do not affect soil erodibility. The soil samples for the cultivated and uncultivated farmland had soil characteristics that hold water and have good cohesive force for resisting erodibility, increasing their erodibility to some extent. Bareland has the least clay composition, with a high surface area-to-volume ratio, making it more resistant to interrill. Uncultivated land is more porous and has less bulk density, possibly due to less agricultural activities and soil disturbance. This makes the farmland less erodable. Rainfall intensity is powerful on exposed or without vegetation cover, resulting in more soil loss than cultivated farmland. The average soil loss calculated by the weight of dried sediments to the volume of barrels used to collect sediments from cultivated and uncultivated farmland is lower than that from bare land, with an average soil loss of 3.935 kg/ha. This is because the soil texture results from cultivated and uncultivated farmland show that the soil can hold more water than bare land soils, making it more dispersible by erosion agents. This is following the work of Musa *et al.* [11].

5. Conclusion

The study found that most people in Gidan-Kwanu primarily practice farming, which is mainly season-dependent and rain-fed. Soil type and texture significantly contribute to inter-rill erosion, with cultivated and uncultivated soil being more resistant to erosion than bare land soil. The entire range of soil slope has little to no contribution to soil detachment, as the initial application of rainfall decreases inter-rill soil loss. Rainfall intensity accounted for the total erosion of all farmlands, as it increases the transport capacity of runoff. The study concluded that bare land farms are mostly affected by soil type and rainfall intensity as physical factors in Gidan-Kwanu. Soil exposed to raindrop impact is easily detached, suggesting the use of crop cover and crop residue to reduce the effect of raindrops. Soil type and vegetation also help minimize the impact of rainfall intensity, as the least rainfall intensity results in more sediment yield.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Issaka, S. and Ashraf, M.A. (2017) Impact of Soil Erosion and Degradation on Water Quality: A Review. *Geology, Ecology, and Landscapes*, **1**, 1-11.

https://doi.org/10.1080/24749508.2017.1301053

[2] Das, S., Sarkar, R. and Bora, P.K. (2018) Comparative Study of Estimation of Soil Erodibility Factor for the Lower Transact of Ranikhola Watershed of East Sikkim. *Journal of Plant Development Sciences*, **10**, 317-322.

[3] Adenle, A.A., Eckert, S., Adedeji, O.I., Ellison, D. and Speranza, C.I. (2020) Human-Induced Land Degradation Dominance in the Nigerian Guinea Savannah between 2003-2018. *Remote Sensing Applications: Society and Environment*, **19**, 100360. https://doi.org/10.1016/j.rsase.2020.100360

[4] Bhat, S.A., Dar, M.U.D. and Meena, R.S. (2019) Soil Erosion and Management Strategies. *Sustainable Management of Soil and Environment*, 73-122. https://doi.org/10.1007/978-981-13-8832-3_3

[5] Nasir, M.J., Alam, S., Ahmad, W., Bateni, S.M., Iqbal, J., Almazroui, M. and Ahmad, B. (2023) Geospatial Soil Loss Risk Assessment Using RUSLE Model: A Study of Panjkora River Basin, Khyber Pakhtunkhwa, Pakistan. *Arabian Journal of Geosciences*, **16**, 440. https://doi.org/10.1007/s12517-023-11555-2

[6] Molla, T. and Sisheber, B. (2017) Estimating Soil Erosion Risk and Evaluating Erosion Control Measures for Soil Conservation Planning at Koga Watershed in the Highlands of Ethiopia. *Solid Earth*, **8**, 13-25. https://doi.org/10.5194/se-8-13-2017

[7] Shen, H.O., Wen, L.L., He, Y.F., Hu, W., Li, H.L., Che, X.C. and Li, X. (2018) Rainfall and Inflow Effects on Soil Erosion for Hillslopes Dominated by Sheet Erosion or Rill Erosion in the Chinese Mollisol Region. *Journal of Mountain Science*, **15**, 2182-2191. https://doi.org/10.1007/s11629-018-5056-5

[8] Musa, J.J., Otuaro, E.A., Dada, P.O.O., Adewumni, J.K. and Okafor, C.A. (2021) Evaluation of Different Irrigation Methods in Chanchaga Irrigation Scheme, North-Central Nigeria. *Journal of Research in Forestry, Wildlife and Environment*, **13**, 27-36.

[9] Musa, J.J., Otuaro, E.A., Dada, P.O.O., Adewumni, J.K., Kuti, I.A. and Adams-Suberu, J. (2021) Validation of Universal Soil Loss Equation for Selected Soil Locations in Northcentral Nigeria Using a Rainfall Simulator. *Agricultural Engineering International: CIGR Journal*, **23**, 21-30.

[10] Musa, J.J., Adewumi, J.K. and Ohu, J. (2013) Comparing Developed Runoff Coefficients for Some Selected Soils of Gidan Kwano with Exiting Values. *International Journal of Basic and Applied Science*, **1**, 469-473. https://doi.org/10.17142/ijbas-2012.1.3.2

[11] Musa, J.J., Anijofor, S.C., Obasa, P. and Avwevuruvwe, J.J. (2017) Effects of Soil Physical Properties on Erodibility and Infiltration Parameters of Selected Areas in Gidan Kwano. *Nigerian Journal of Technological Research*, **12**, 46-54. https://doi.org/10.4314/njtr.v12i1.8

[12] Musa, J.J., Dada, P.O.O., Adewumi, J.K., Akpoebidimiyen, O.E., Musa, E.T., Otache, M.Y. and Yusuf, S. (2020). Fishpond Effluent Effect on Physico-Chemical Properties of Soils in Southern Guinea Savanna, Nigeria. *Open Access Library Journal*, **7**, 1-16. https://doi.org/10.4236/oalib.1105990

[13] Yudina, A.V., Fomin, D.S., Kotelnikova, A.D. and Milanovskii, E.Y. (2018) From the Notion of Elementary Soil Particle to the Particle-Size and Microaggregate-Size Distribution Analyses: A Review. *Eurasian Soil Science*, **51**, 1326-1347. https://doi.org/10.1134/S1064229318110091

[14] Musa, J.J., Adewumi, J.K. and Ohu, J. (2012) Development of an Empirical Hydrologic Model to Determine Manning and Runoff Coefficient for Some Selected Soils of the Permanent Site of Federal University of Technology, Minna, Nigeria. *Journal of Science, Technology, Mathematics and Education* (*JOSTMED*), 165-171.

[15] Abdulkadir, A. (2018) Erosion Effect on Soil Physical Properties in Selected Farmlands in Gidan-Kwano, Niger State. *Journal of Horticulture and Plant Research*, **2**, 10-22. https://doi.org/10.18052/www.scipress.com/JHPR.2.10

[16] Enokela, E. and Egharevba, N. (2012) Measurement of the Productivity of Soils under Various Environmental Conditions. *Journal of Agronomy*, **42**, 282-292. https://doi.org/10.2134/agronj1950.00021962004200060004x

[17] Abua, M.A., Igelle, E.I., Eneyo, V.B., Abali, T.P., Akpan, N.A., Archibong, E.P., Abdelrahman, K., Fnais, M.S., Andráš, P. and Eldosouky, A.M. (2023) Predicting Sediment Yield on Different Landuse Surfaces in Calabar River Catchment, Nigeria. *Heliyon*, **9**, E19071. https://doi.org/10.1016/j.heliyon.2023.e19071

[18] Ewemoje, T.A. and Kuti, I.A. (2021) Effect of Tillage Direction on Phosphorus Loss from Sediment Yield and Surface Runoff. *FUOYE Journal of Engineering and Technology* (*FUOYEJET*), **6**, 1-6. https://doi.org/10.46792/fuoyejet.v6i1.592

[19] Akinola, F.F., Fasinmirin, J.T., Olanrewaju, O.O., Ewulo, B.S. and Olorunfemi, I.E. (2023) Changes in Soil Physical and Mechanical Properties under Different Tillage and Cropping Systems in Alfisol Soil of Southwestern Nigeria. *Farming System*, **1**, 100050. https://doi.org/10.1016/j.farsys.2023.100050