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Topsoil Nutrient Dynamics Across Compound Farms at Slope Gradients in Nsukka, Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Soil management is needed to improve soil fertility and crop productivity in compound farms, particularly in areas with varying slope gradients. Limited information is available related how slope gradients affect soil fertility in compound farms, particularly in tropical Africa. Understanding these

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dynamics can provide insights into improving nutrient management practices in traditional agricultural systems, where the dependence on external inputs is minimal. Soil nutrient dynamics within compound farms were evaluated at the compound farms of the upper slopes (CFUS) and lower slopes (CFLS) in the tropical environment of Nsukka, Nigeria. Soil samples were collected at 0–20 cm depth from both slope positions across 20 compound farms. Different key soil properties, including soil organic carbon, total nitrogen, available phosphorus, exchangeable bases, and cation exchange capacity, were assessed to determine fertility gradients influenced by slope position. Soil fertility status was higher at the upper slopes as opposed to the lower slopes. The results did not follow the typical trend of soil nutrients being transported from the upper to the lower slope, probably due to anthropogenic activities such as buildings and road constructions. The result highlights the role of slope position in soil fertility management, supporting slope-specific soil management strategies in tropical farming systems.

Keywords: Erosion control; nutrient deposition; soil fertility management; sustainable agriculture; tropical soils.

1. INTRODUCTION

Compound farms are traditional agricultural systems in sub-Saharan Africa that integrate crops, livestock, and trees to maximize productivity and sustainability. Households take advantage of available lands surrounding their homes to cultivate crops, using domestic and livestock wastes to fertilized the soil. These lands surrounding homesteads on which crops were grown known as compound farms. Compound farms encompass an agroforestry system involving the management of economic trees and shrubs mixed with crops and small livestock within the compounds of individual houses (Okafor and Fernandes, 1987). Soil fertility is maintained by adding household, farm, and animal wastes into the soil. These systems are vital in tropical regions, ensuring food security and maintaining soil fertility under resource-constrained conditions. The management practices farmers adopt are crucial to the overall soil fertility and productivity status of compound farms.

Soil fertility and physical properties often differ across slope positions (Awdenegest and Nicholas, 2008). Slope gradients influence soil properties through erosion, leaching, and nutrient redistribution. Previous studies have demonstrated that slope position can influence soil pH, organic matter, cation exchange capacity, carbon and nitrogen contents of soils (Mulugeta et al., 2012). Upper slopes are often subjected to nutrient depletion due to runoff, while lower slopes may experience nutrient accumulation. In south-eastern Nigeria, studies have shown that slope gradients affect the distribution of nitrogenous and non-nitrogenous organic compounds, with lower slopes exhibiting higher mean values of humic substances, which are crucial for long-term soil aggregate stabilization (Essien et al., 2024). Similarly, in northwestern Ethiopia, slope gradients, with soil and water conservation practices, significantly impact soil physico-chemical properties including total nitrogen and available phosphorus (Atinafu et al., 2024). But most research has focused on large-scale agricultural systems, neglecting the unique characteristics of compound farms. Farmers must consider the slope positions of their farmlands as a critical approach to managing the fertility of the soils effectively. Nutrient dynamics within compound farms, especially across slope gradients, are poorly researched, despite their potential to influence crop productivity. There is little information on effect of slopes or anthropogenic activities on soil fertility properties in compound farms. The objective of this study was to assess how slope gradients influenced topsoil nutrient dynamics within compound farms in a tropical environment. We hypothesized that slope gradients influence the distribution of key soil nutrients in compound farms. While natural processes typically lead to reduced fertility on upper slopes due to erosion and nutrient accumulation on lower slopes, anthropogenic activities like intensive cultivation, fertilization, irrigation and other management practices in compound farms can alter or even reverse these patterns. Such that upper slopes have higher fertility status through targeted nutrient inputs whereas lower slopes may have reduced nutrient levels through overcultivation and poor management practices. The findings will help compound farmers implement slope-specific soil management strategies, contributing to food security and sustainable farming in resource-limited regions.

2. MATERIALS AND METHODS

2.1 Location of the Study

The study was carried out at UNN, Southeastern Nigeria whose geographical latitude is 6°54'N and the longitude is 7°24'E with an elevation of 447.26 m above sea level (Oko-Ibom and Asiegbu, 2006). The CFUS and CFLS were at the Ezenwaeze/Ikejiani and Mbanefo areas in the University, respectively, as shown in Fig. 1. The vegetation of Nsukka is secondary, mainly due to anthropogenic activities such as land clearing, bush burning, and land cultivation, and hence best described as derived savannah (Savannamosaic) agroecology (Ezeaku and Iwuanyanwu, 2013). From April to October, it rains heavily in Nsukka, and from November to March is dry season. The wettest months are July and September (1550 mm). The coolest and hottest temperatures are 21°C and 31°C (Asadu, 2002). The humidity level is between 70 and 80% (Oko-Ibom and Asiegbu, 2006). During Harmattan, a short period of three weeks in December and January when the weather is dry and hazy, humidity falls below 60% (Asadu et al., 2001). Historically, the bi-modal rainfall pattern has been good for farming. However, anthropogenic activities had played a major role in transitioning the climate of Nsukka from a humid forest to a Southern Guinea savanna landscape. Temperatures have been rising significantly while the trends of rainfall are changing less consistently which ultimately affects farming methods and nutrient management (Uguru et al., 2011).

2.2 Soils and Geology

According to Ezeaku and Iwuanyanwu (2013), Nsukka soils are a mixture of many types. These soils range from ferrallitic soils known as acid sands or red earth, which are located on the slopes of the cuesta and plateau, to hydromorphic soils, which are found on the floodplains. These soils are well-drained sandy clay loams mostly classified as Ultisols. According to Ezeaku (2000), soil color matrix of the top and middle slopes is a deep red to brownish-red color, and it is formed from sandy layers of false-bedded sandstone. The lower slope soils range in color from reddish-brown to a brownish-black color, and they are classified as alfisols (Soil Survey Staff, 1999). The soils of this region are inherently low in fertility status due to poor nutrient reserves in their parent materials, rapid organic matter decomposition due to high temperatures, and increased nutrient leaching losses due to rainfall of increased amount and intensity (Asadu et al., 2010).

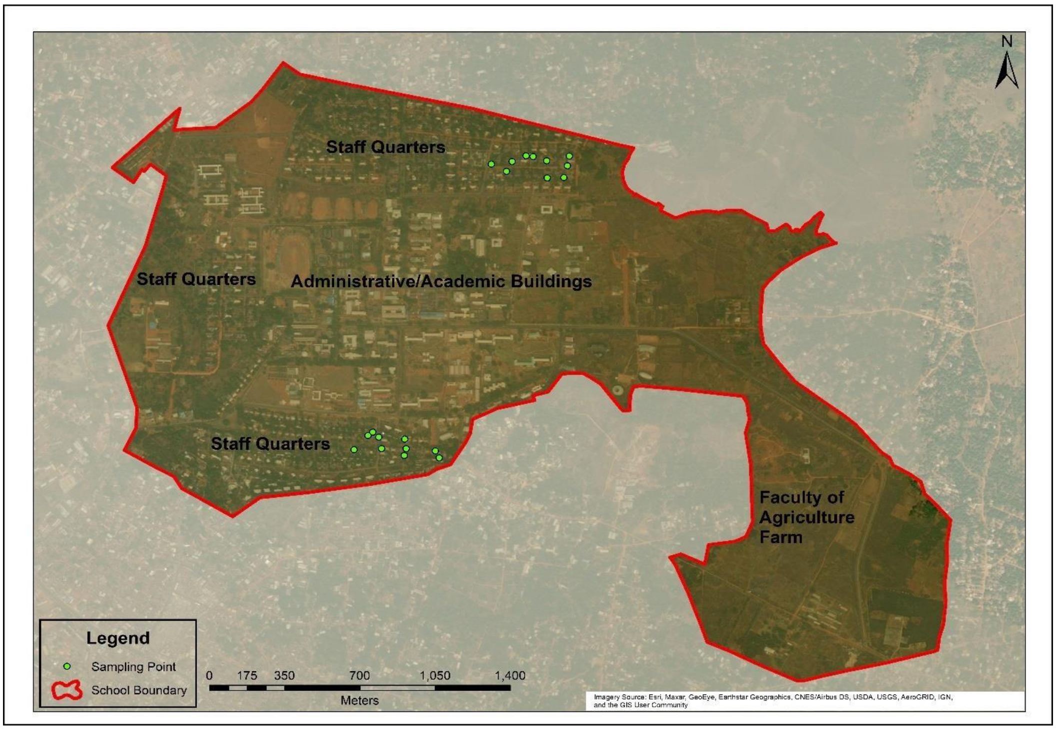

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Fig. 1. Map of the University of Nigeria, Nsukka Campus showing the sampling points in the CFUS and CFLS

2.3 Agriculture

The crops grown by residents range from vegetables and cereals to roots and tubers. Crops grown due to topographic positions and within the streets show no marked difference reflecting prevailing similar climatic conditions within UNN and food preferences by the residents. Rainfall is the primary determinant of agriculture in Nsukka. However, compound farmers irrigate their small farms to supplement rainfall. Subsistence agriculture is practiced in this region. Mainly mixed cropping systems, sole livestock production, and combined crop-livestock agriculture. Ridges and mounds are common seedbeds, often prepared with local hoes after vegetation removal. The primary nutrient inputs for maintaining soil fertility are inorganic or mineral, and organic fertilizers such as manure, household wastes, and some crop residues. The principal crops commonly cultivated in the Nsukka area include cocoyam (*Dioscorea* spp), water yam (*Dioscorea alata*), cassava (*Manihot* spp), maize (*Zea mays*), white yam (*Dioscorea rotundata*), and plantains (*Musa paradisiaca*), potatoes (*Ipomea batatas*) as well as a variety of vegetables such as okra (*Abelmoschus esculentus*), pepper (*Capsicum* sp), fluted pumpkin (*Telfairia occidentalis*), cucumber (*Cucumis sativus*), tomatoes (*Solanum lycopersicum*), garden egg (*Solanum melongena*) and amaranthus (*Amaranthus viridis*).

2.4 Soil Sampling

The altitudes of the entire UNN obtained from the Global Positioning System (A handheld GPS receiver 2.2” monochrome display) were used to delineate the campus area into CFUS and CFLS with elevations in the ranges of 458 to 447 m and 415 to 423 m AMSL. The major road that cuts across UNN’s main gate through St. Peter’s Catholic Church to the Medical Centre, bordering school premises and staff quarters demarcates the upper slopes from the lower slopes. The positions of the compound farms as shown in Fig. 1, were randomly identified and sampled after traversing the compound farms on both slopes. The random sampling method was used to reduce bias during the sample collection. All the compound farms sampled have been cultivated for at least five years or more. A total of twenty soil samples were randomly collected at 0-20 cm depth using a soil auger, ten each at CFUS (Ikejiani Street and Ezenwaeze) and CFLS (Mbanefo) topographical locations (Table 1) (Okorie et al., 2022a).

2.5 Laboratory Analysis

All soil samples were bagged in clean polythene bags for analyses in the laboratory after air drying and sieving using a 2 mm sieve. Samples were analyzed for physico-chemical properties as reported by Okorie et al. (2022a). Particle size distributions, soil pH, organic carbon, total nitrogen, available phosphorus, exchangeable acidity, and exchangeable calcium, magnesium, potassium, and sodium were analyzed. Bouycuous hydrometer was used to determine soil particle size distribution according to Gee and Orr (2002). Soil organic carbon was determined using the Walkley and Black wet digestion method (Nelson and Sommers, 1982), pH of the soil was tested in water and KCl at a ratio of 1:2.5 between the soil and the liquid. The micro Kjeldahl digestion procedure was used to determine soil total nitrogen content (Bremner and Mulvaney, 1982). Bray II method was used to quantify the amount of soil available phosphorus (Olsen and Sommers, 1982). ETDA titration method was used to quantify the amount of exchangeable calcium and magnesium, whereas flame photometry was used to determine the amount of exchangeable potassium and sodium (Jackson, 1962). Exchangeable acidity was determined using titration method (Mclean, 1982). Effective Cation Exchange Capacity (ECEC) was calculated by summing the concentrations of the exchangeable cations (Ca^{2+}, Mg^{2+}, K^+, Na^+, Al^{3+}, and H^+) as shown in Equation 1. Base saturation was calculated as a percentage of the value of the summation of exchangeable bases over cation exchange capacity in Equation 2.

$$\text{ECEC} = [Ca^{2+}] + [Mg^{2+}] + [K^+] + [Na^+] + [Al^{3+}] + [H^+] \quad \dots \quad 1$$

$$\text{PBS} = \frac{\sum \boldsymbol{EB}}{CEC} * 100 \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad 2$$

where; ∑EB = summation of the exchangeable bases.

2.6 Statistical Analysis

The data generated from the laboratory analysis were subjected to a simple factor t-test using GenStat Discovery Edition 2. To compare the means, Fisher's least significant difference (LSD) was employed at a significant level of $p \le 0.05$. The critical limits of interpreting fertility levels of soil analytical parameters, developed by Enwenzor et al. (1989), were used to rate the fertility status. The critical limit is the concentration below which deficiency occurs, thus distinguishing deficiency from sufficiency.

Table 1. Sampling locations and site characteristics

CFUS	**Altitude (m amsl)**	**Latitude (N)**	**Longitude (E)**	**Crops Grown**	**CFLS**	**Altitude (m amsl)**	**Latitude (N)**	**Longitude (E)**	**Crops Grown**
4 Ezenwaeze	451	N6°51.493′	E7°24.472′	Maize, cassava, fluted pumpkin	4 Mbanefo	415	N6°52.236′	E7°24.748′	Maize, cassava, vegetables, tomato
7 Ezenwaeze	453	N6°51.493′	E7°24.534′	Maize, cassava, fluted pumpkin	7 Mbanefo	417	N6°52.217′	E7°24.786′	Maize, cassava, fluted pumpkin
11 Ezenwaeze	453	N6°51.475′	E7°24.529′	Maize, cassava, fluted pumpkin, pepper	8 Mbanefo	418	N6°52.243′	E7°24.800′	Cassava, cocoyam
236 Ikejiani	449	N6°51.490′	E7°24.403′	Maize, cassava, fluted pumpkin, cocoyam, potatoes, okra	10 Mbanefo	417	N6°52.258′	E7°24.835′	Maize, water yam, vegetables
238 Ikejiani	447	N6°51.523′	E7°24.465′	Maize, cassava, vegetables, potatoes	12 Mbanefo	419	N6°52.256′	E7°24.853′	Maize, cassava, yam, fluted pumpkin
239 Ikejiani	447	N6°51.527′	E7°24.438′	Maize, cassava, okra, curry	15 Mbanefo	420	N6°52.200′	E7°24.888′	Maize, cassava, yam, fluted pumpkin
241 Ikejiani	447	N6°51.536′	E7°24.450′	Maize, potato	16 Mbanefo	419	N6°52.245′	E7°24.887′	Cocoyam, cassava, fluted pumpkin, plantain
243 Ikejiani	449	N6°51.518′	E7°24.530′	Maize, vegetables, fluted pumpkin, amaranthus	17 Mbanefo	423	N6°52.201′	E7°24.930′	Yam ,plantain
248 Ikejiani	455	N6°51.487′	E7°24.607′	Maize	19 Mbanefo	421	N6°52.232′	E7°24.939′	Maize, cassava, plantain, banana
250 Ikejiani	458	N6°51.469′	E7°24.617′	Maize, cassava, cocoyam, potatoes	20 Mbanefo	423	N6°52.257′	E7°24.944′	Maize, cassava, groundnut, okra

3. RESULTS AND DISCUSSION

3.1 Soil Particle Size Distributions across Slope Gradients

The result of particle size distributions (PSD) of all the compound farms sampled at the University of Nigeria, Nsukka Campus is given in Table 2. The particle size distribution results revealed that the trend across the slopes is sand>clay>silt. The sand, silt, and clay particles for both slopes ranged from 818.00 – 902.00 g kg^{-1}; 40.00 – 72.00 g kg$^{-1,}$ and 62.00 – 110.00 g kg^{-1} respectively, and they were all significantly ($p \leq 0.05$) different across CFUS and CFLS. The sand fraction was significantly greater on the lower slope than on the upper slope ($p \leq 0.05$). The high sand values can be attributed to the quartz-rich parent material, and low silt values to high rainfall, which promote the washing away and leaching of silt-sized and clay-sized fractions (Mbagwu, 1995). Ritter (2006) opined that soil developed on sandstone parent material is prone to leaching due to its coarse texture.

Slope affects soil properties by enhancing the eluviation of materials from upper to lower slopes. However, these results did not follow this typical trend, probably due to anthropogenic activities such as buildings and road constructions between the upper and lower slopes of the campus. This explains why the silt and clay contents were higher at CFUS whereas sand fractions were higher at the CFLS. In addition, soil texture is mostly determined by the origin of the soil, which is comprised of a variety of rocks, minerals, and other geologic materials. Soil texture is equally influenced by the types of plants and other vegetation that grow on the soil (Asadu et al., 1997). Ogban (2021) reported non-significant differences in particle size fractions across different slope positions contradicting the results of this study. The soil textural classes of the compound farms ranged from sand, sandy loam, and loamy sand such that soils of the upper slopes are made up of loamy sand and sandy loam, majorly with sand texture only in one farm, compared to the lower slopes made up of sandy soils, majorly with sandy loam texture only in one farm.

3.2 Soil Nutrient Dynamics across Slope Gradients

The results revealed that significant variations in soil fertility parameters between the upper and lower slopes of compound farms in the tropical environment of Nsukka, Nigeria (Tables 3 and 4). We expected significant differences in nutrient levels between the upper and lower slopes. This is because of the recognized fact that through the processes of sediment transportation, nutrients are washed down from the higher to lower slopes leading to higher soil health indicators in the lower slopes. Runoff and sediment from higher slopes increase the amount of nutrients in lower slope areas (Wu et al., 2022). Soil properties and hydraulic factors affect sediment transport mechanisms, making it easier for fine particles high in nutrients to end up in lower slope areas (Liu et al., 2024). However, our results show that that might not be the case in compound farms across slope gradients. Soil nutrient contents such as soil organic matter (OM), total nitrogen (TN), pH and exchangeable bases (calcium, magnesium, and potassium) were consistently higher at the upper slopes compared to the lower slopes (Fig. 2).

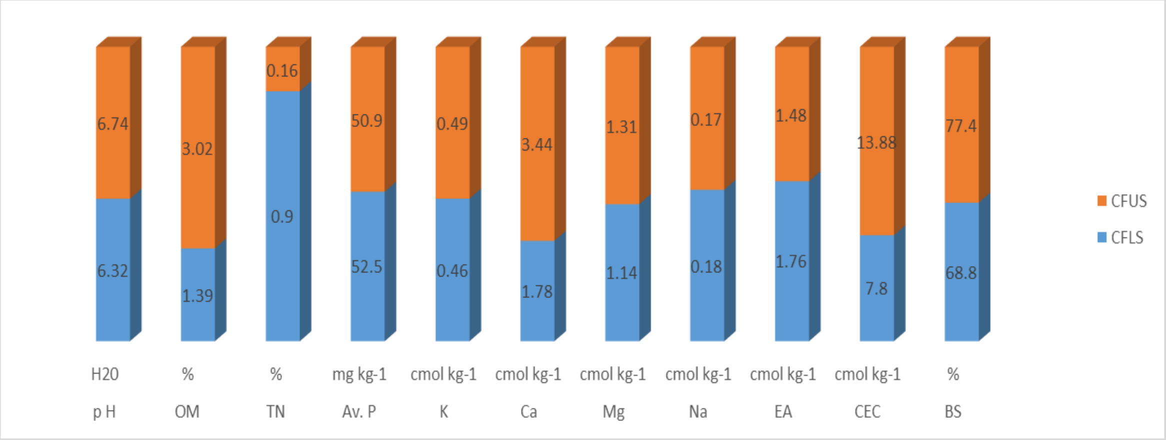

Fig. 2. Soil fertility properties at CFLS and CFUS

Table 2. Soil particle size distribution at CFLS and CFUS

Compound farms	Sand %	Silt %	Clay %
CFLS	90.20	4.00	6.20
CFUS	81.80	7.20	11.00
P-Value	**0.001**	**0.014**	**0.001**
T-value	-3.838	2.709	4.00

Table 3. Selected soil fertility properties at CFLS and CFUS.

CF	pH (H_20)	OM (%)	TN (%)	Ca (cmol kg^{-1})	Mg (cmol kg^{-1})	K (cmol kg^{-1})	Na (cmol kg^{-1})	EA (cmol kg^{-1})	Av. P (mg kg^{-1})	CEC (cmol kg^{-1})	ECEC (cmol kg^{-1})	BS (%)
CFLS	6.32	1.39	0.9	1.78	1.14	0.46	0.18	1.76	52.5	7.8	5.34	68.8
CFUS	6.74	3.02	0.16	3.44	1.31	0.49	0.17	1.48	50.9	13.88	6.88	77.4
P-Value	NS	0.00	0.004	0.001	NS	NS	NS	NS	NS	0.00	0.001	0.005
T-value	1.73	6.28	3.28	3.89	1.52	0.72	-0.87	-1.78	-0.11	6.97	3.74	3.17

CF - compound farms, CFLS - compound farms in the upper slopes, CFUS - compound farms in the lower slopes, OM - Organic Matter, TN -Total Nitrogen, Ca^{2+} - Calcium, Mg^{2+} - Magnesium, K^{+} - Potassium, Na^{+} -Sodium, CEC - Cation Exchange Capacity, ECEC - Effective Cation Exchange Capacity, BS - Base Saturation, Av. P - Available Phosphorus, EA -Exchangeable Acidity

Table 4. Rating of Nutrient Dynamics of CFLS and CFUS using Enwezor et al. (1989) critical limits

S/N	Fertility Parameters	Upper Slope	Lower Slope
1	pH	Neutral	Slightly Acid
2	Organic Matter	High	Low
3	Total Nitrogen	High	Very High
4	Calcium	Moderate	Low
5	Magnesium	High	High
6	Potassium	High	High
7	Sodium	Moderate	Moderate
8	Cation Exchange Capacity	Moderate	Low
9	Effective Cation Exchange Capacity	Moderate	Low
10	Base Saturation	High	High
11	Available Phosphorus	High	High
12	Exchangeable Acidity	Low	Low

The pH values in H_2O ranged from 6.74 to 6.32 in the upper and lower slopes and were rated neutral to slightly acidic respectively, by Enwenzor et al. (1989). The higher pH value of the upper slope (6.74 for pH in H_2O) can be attributed to the reduced mineralization of organic material at the upper slope, hence the accumulation of more organic matter content which increased the soil pH. Amuyou and Kotingo (2015) also reported a relatively high soil pH value in the upper slope segment compared to other segments of the catena which was attributed to grasses covering the upper slope. Ogunwale et al. (2002) and Babalola et al. (2007) also reported a decreased pH going downward the hill. Contrariwise, Hendershot et al. (1992) reported a slightly higher pH at the downslope positions. Landon (1991) explained the production of complexes of iron, manganese, and aluminum compounds by phosphates in the presence of pH values lower than 5.5 results in the inaccessibility of these compounds to plants. This is one of the impacts of low and high pH on the availability of nutrients to plants. Furthermore, high pH values decrease microbial activity thus retarding the decomposition of organic matter. However, our results show that the differences in pH (H_2O) values were not significant across the slopes.

The value of organic matter was higher at the upper slope (30.2 g kg^{-1}) against (13.9 g kg$^{-1)}$ at the lower slope. Generally, the OM content was rated moderate to high, according to Enwenzor et al. (1989). The higher value of organic matter on the upper slope (30.2 g kg^{-1}) relative to the lower slope (13.9 g kg^{-1}) could be due to the increment of economic trees leading to a higher accumulation of organic materials in the upper slope compound farms. Contrarily, Khan et al. (2013) reported that organic matter was higher at the lower slope than at the upper slope.

Total nitrogen was 0.9 g kg^{-1} at the lower slope and 1.6 g kg^{-1} at the upper slope and was rated low and very high, respectively, according to Enwenzor et al. (1989). Nitrogen influences the decomposition of organic matter in the soil, leading to enhanced fertility (Essiet, 1990). Because organic nitrogen accounts for most of the total nitrogen in tropical soils, Noma et al. (2005) noted that total nitrogen followed a pattern comparable to soil organic matter. This was because organic nitrogen is the primary source of nitrogen in tropical soils. On the other hand, our conflicting result may be the result of increasing fertilization levels with nitrogen fertilizers on CFUS relative to the CFLS. For example, Ezeaku and Iwuanyanwu (2013) stated that the process of soil cultivation leads the organic matter in the soil to be subjected to a higher rate of decay and oxidation, which ultimately results in a lower level of total nitrogen content. The available phosphorus content in the soil was 50.9 mg kg^{-1} in the CFUS, but in CFLS, it was higher (52.5 mg kg^{-1}). These values fall into the high rating category (Enwenzor et al., 1989) and can be attributed to organic matter mineralization making more phosphorus available in the soil. Moreover, with the intensification of the cropping system, phosphorus and other nutrient reserves are slowly but steadily mined whereas organic matter and N in the soils are readily depleted (Tanimu et al., 2013). However, slightly lower P at the upper slopes can be attributed to higher clay content and pH values in CFUS. This outcome is in harmony with Khan et al. (2013) who reported that phosphorus was higher on lower slope relative to upper slope.

The exchangeable K varied from 0.49 cmol kg^{-1} in the upper slope to 0.46 cmol kg^{-1} in the lower slope with no significant difference between the means. Nonetheless, these values of K were rated high by Enwenzor et al. (1989). Zhang et al. (2016) and Zhang et al. (2015) reported higher available phosphorus (AP) and potassium (AK) at the top relative to the lower slope. Whereas Khan et al. (2013) reported higher values of K at lower slopes relative to top slopes. The higher values of exchangeable K on the upper slopes as to the lower slopes could result from combined fertilization with organic and inorganic fertilizers.

The result for EA was 1.76 cmol kg^{-1} in the lower slope and 1.48 cmol kg^{-1} in the upper slope with no significant difference between the means at $p \leq 0.05$. The soil has mainly hydrogen ions and their EA values were rated low based on the rating standard of Enwenzor et al. (1989). This can be attributed to the pH values, that were neutral to slightly acidic. Moreover, Aguilera et al. (2013) discussed that continuous cultivation could lead to acidification of soils.

Exchangeable calcium varied significantly at $p \leq 0.05$ with the upper slope having 3.44 cmol kg^{-1} compared to the lower slope which was 1.78 cmol kg^{-1} signifying moderate and low status respectively. Low values of Ca^{2+} could be attributed to leaching losses by the high tropical rainfall and its low content in the parent rock from which the soils were formed. Higher Ca^{2+} levels in the upper slopes could be due to the denser vegetation that hinders the impact of raindrops on the soil surface, thus decelerating runoff and leaching of nutrient elements down the slope. The lower clay, silt, and organic matter content of the lower slope farms and unfavorable management practices might be responsible for the low values of Ca^{2+}. These values of Ca^{2+} were rated low to moderate by Enwenzor et al. (1989). According to Essiet (2001), soil fertility is determined by two compounds, clay and organic matter. Although exchangeable magnesium was numerically higher in the upper slope (1.31 cmol kg^{-1}) than in the lower slope (1.14 cmol kg^{-1}) with no significant difference between the means. The exchangeable Na result failed to show any significant difference between the two slopes. Similarly, Garcia et al. (1990) reported the highest Na^{+} concentration at the bottom slope in eroded sites relative to top locations.

The BS (%) values were significantly different across CFUS and CFLS and were rated high based on the rating standard of Enwenzor et al. (1989). CFUS recorded the highest percentage (77.4%) relative to the CFLS (68.8%). Eshetu and Wogi (2024) reported that the lower slope sites in the Danka watershed had more exchangeable bases and micronutrients, which means that nutrients were better retained and available. In the current study, nutrients could be said to be well retained in both slopes given the high base saturation, but the CFUS outperformed the CFLS.

The CEC varied from 7.80 cmol kg^{-1} on the lower slope to 13.88 cmol kg-1 on the upper slope. This value of CEC was rated low to moderate by Enwenzor et al. (1989). According to Landon (1991), the higher the CEC, the more soil fertility. Cation exchange capacity (CEC) is an overall assessment of the potential fertility of the soil, and the values depend critically on soil pH (Kodiya, 1988). The low values of CEC recorded may be attributed to low clay and humus contents and low pH values (Asadu et al., 1997). It has been reported that the low to medium CEC value of tropical soils is due to the dominance of kaolinitic clays in the fine-earth fractions (Ojanuga and Awojuola, 1981). Most researchers have observed that the CEC of tropical soils is related to their organic matter content (Noma et al., 2005). Ludwig et al. (2001) noted that soils with low CEC might have been subjected to leaching nutrients like nitrogen, potassium, and magnesium and hence lower yield potentials than those with higher CECs (Asadu et al., 1997). Soil CEC across CFUS and CFLS were significantly different. The low CEC values at the lower slope could be due to low organic matter contents and the influence of soil texture and the type of clay minerals. Clayey soils were reported to have higher CEC than sandy soils mainly due to charges resulting from isomorphous substitution (Rhoades, 1982). Similarly, ECEC was significantly higher at the upper slope (6.88 cmol kg^{-1}) relative to the lower slope (5.34 cmol kg^{-1}) and was rated lower to moderate respectively by Enwenzor et al. (1989). Therefore, sustainable fertility management based on slope gradients will help reduce nutrient loss, optimize crop productivity and contribute to broader goals of soil conservation, reduced environmental degradation, and improved food security (Montgomery et al., 2022).

4. CONCLUSIONS

The results did not follow the typical trends of soil nutrients being washed from upper to lower slopes, probably due to anthropogenic activities such as buildings and road constructions between the upper and lower slopes of the campus. The CFUS had higher soil pH, organic matter content, total nitrogen, exchangeable calcium, cation exchange capacity, and effective cation exchange capacity than the lower slope. Because of these differences, the findings of this study emphasize the need for tailored soil management practices that account for slope-induced nutrient variability. Addressing slope-specific nutrient dynamics is critical for achieving sustainable agricultural systems in tropical environments. Further research is needed to explore long-term changes in nutrient distribution under slope-specific interventions to sustained soil health, enhance productivity, and promote resilience in tropical agricultural landscapes.

CONFERENCE DISCLAIMER

Some part of this manuscript was previously presented and published in the conference: Eurasian Journal of Soil Science- The Digital Experience dated from 18th to 19 December, 2021 in Samsun, Turkey, Web Link of the proceeding:
https://www.fesss.org/uploadfile/1640866658.pdf

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Authors hereby declare that NO generative AI technologies such as Large Language Models

(ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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