INTERNATIONAL JOURNAL OF RESEARCH AND INNOVATION IN APPLIED SCIENCE (IJRIAS)
ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume XI Issue VII July 2026

Topographic Position and Soil Depth Govern Spatial Variability of Soil Physicochemical Properties and Fertility Status along a Humid Tropical Toposequence in University of Uyo Teaching and Research Farm, Akwa Ibom State Nigeria

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DOI: https://doi.org/10.51584/IJRIAS.2026.11070131

Received: 27 July 2026; Accepted: 01 August 2026; Published: 11 August 2026

ABSTRACT

Topographic position and soil depth are among the principal factors governing soil formation, nutrient redistribution, and spatial variability of soil fertility in tropical landscapes. Understanding their influence on soil physicochemical properties is essential for developing site-specific soil fertility management strategies that enhance sustainable agricultural production. This study evaluated the effects of topographic position and soil depth on selected soil physicochemical properties and fertility status along a humid tropical toposequence within the University of Uyo teaching and research farm, Akwa Ibom State, Southern Nigeria. Soil samples were collected from three topographic positions (upper slope, middle slope and valley bottom) at two depths (0–20 and 20–40 cm), resulting in six composite samples. Standard laboratory procedures were employed to determine particle size distribution, soil pH, electrical conductivity (EC), organic carbon (OC), organic matter (OM), total nitrogen (TN), available phosphorus (Av. P), exchangeable acidity (EA), exchangeable bases (Ca, Mg, Na and K), total exchangeable bases (TEB), effective cation exchange capacity (ECEC), cation exchange capacity (CEC), carbon-to-nitrogen (C:N) ratio, and base saturation (BS) following established analytical protocols.

The soils were predominantly sandy, with sand content ranging from 80.60 to 90.40%, reflecting the Coastal Plain Sand parent material characteristic of southeastern Nigeria. Soil pH varied from 5.50 to 6.98, indicating moderately acidic to nearly neutral conditions suitable for many tropical crops. Organic carbon ranged from 0.30 to 3.70%, while total nitrogen ranged from 0.03 to 0.50%, with the highest concentrations occurring at the lower slope surface soil. Available phosphorus varied between 6.20 and 19.25 mg kg^{-1}, whereas effective cation exchange capacity ranged from 3.668 to 6.062 cmol(+) kg^{-1}. Base saturation values ranged from 38.6 to 78.7%, indicating moderate to high nutrient retention across the toposequence. The lower slope (0–20 cm) exhibited the highest organic carbon (3.70%), organic matter (5.00%), total nitrogen (0.50%), available phosphorus (19.25 mg kg^{-1}), magnesium (3.0 cmol(+) kg^{-1}), total exchangeable bases (4.362 cmol(+) kg^{-1}), and effective cation exchange capacity (6.062 cmol(+) kg^{-1}), demonstrating superior soil fertility compared with the upper and centre slope positions.

The study demonstrated that topographic position and soil depth strongly influenced the spatial distribution of soil fertility indicators, with surface soils generally containing greater nutrient concentrations than subsurface soils because of organic matter accumulation and biological cycling. The lower slope functioned as a depositional environment where nutrients and fine materials accumulated, resulting in improved fertility status. These findings highlight the importance of landscape-based soil evaluation for precision nutrient management and sustainable agricultural production in the humid tropics. The adoption of site-specific soil fertility management practices based on topographic variability is therefore recommended to improve nutrient use efficiency, maintain soil health, and enhance crop productivity.

Keywords: Toposequence, topographic position, soil depth, soil fertility, physicochemical properties, humid tropics, sustainable soil management, University of Uyo, Nigeria

INTRODUCTION

Soil is one of the most important natural resources supporting agricultural production, ecosystem functioning, and global food security. The productivity of agricultural soils depends largely on their physicochemical properties, which regulate nutrient availability, water retention, aeration, microbial activity, and root development (Brady & Weil, 2017; Lal, 2021). In tropical regions, particularly in sub-Saharan Africa, rapid population growth, continuous cultivation, inappropriate land management practices, soil erosion, and climate variability have accelerated soil degradation, resulting in declining soil fertility and reduced crop productivity (FAO, 2022; Vanlauwe *et al*., 2023). Consequently, understanding the spatial variability of soil properties has become increasingly important for developing sustainable soil management strategies that optimize agricultural production while conserving soil resources (Bünemann *et al*., 2023).

Soil physicochemical properties exhibit considerable spatial variability due to the combined influence of soil-forming factors, including climate, parent material, topography, organisms, and time (Jenny, 1941). Among these factors, topography plays a particularly significant role because it controls the movement and redistribution of water, sediments, nutrients, and organic materials across landscapes. Variations in slope position influence erosion, runoff, infiltration, drainage, and deposition processes, resulting in distinct differences in soil morphology, texture, organic matter content, nutrient distribution, and overall fertility status (Brady & Weil, 2017; Alves *et al*., 2024). Consequently, soils occupying different positions along a toposequence often exhibit contrasting physical and chemical characteristics despite having developed from the same parent material under similar climatic conditions (Akinbola *et al*., 2024).

A toposequence refers to a sequence of soils occurring along a slope where differences in soil properties arise primarily from changes in topographic position rather than parent material or climate (Jenny, 1941; Alves *et al*., 2024). Upper slope positions are generally characterised by greater erosion, lower organic matter accumulation, reduced moisture retention, and comparatively lower nutrient concentrations because surface runoff continually removes fine particles and dissolved nutrients. In contrast, lower slope positions frequently function as depositional environments where eroded sediments, clay particles, organic residues, and exchangeable nutrients accumulate, resulting in improved soil fertility and greater agricultural productivity (Cornell *et al*., 2020; Gambo *et al*., 2025). Understanding these topography-induced variations is fundamental for precision agriculture, fertiliser recommendation, and sustainable land-use planning.

Soil depth is another critical factor influencing soil fertility because nutrient concentrations, biological activity, and organic matter content generally decrease with increasing depth. Surface soils receive continuous inputs of plant litter, crop residues, root exudates, and microbial biomass, leading to higher concentrations of organic carbon, nitrogen, phosphorus, and exchangeable bases than subsurface horizons (Obalum *et al*., 2022; Lal *et al*., 2024). Subsurface soils, by contrast, often experience reduced biological activity and greater weathering, resulting in comparatively lower nutrient availability. Evaluating soil properties at different depths therefore provides valuable information on nutrient distribution within the soil profile and assists in developing effective nutrient management strategies for different cropping systems (Sanchez, 2019; Vanlauwe *et al*., 2023).

Among the physicochemical properties commonly used to assess soil fertility, soil texture, pH, electrical conductivity, organic carbon, total nitrogen, available phosphorus, exchangeable bases, effective cation exchange capacity, cation exchange capacity, and base saturation are considered fundamental indicators of soil quality and agricultural productivity (Hazelton & Murphy, 2016; Brady & Weil, 2017). Soil texture influences water movement, aeration, and nutrient retention, whereas soil pH regulates nutrient solubility and microbial activity. Organic carbon serves as the principal reservoir of nutrients and contributes significantly to soil aggregation, moisture retention, and cation exchange capacity. Similarly, nitrogen and phosphorus are essential macronutrients required for plant growth, while calcium, magnesium, potassium, and sodium contribute to nutrient balance and physiological functions. Effective cation exchange capacity and base saturation provide integrated measures of the soil's ability to retain and supply essential nutrient cations to growing plants (Bünemann *et al*., 2023; Lal *et al*., 2024).

The soils of southeastern Nigeria are predominantly derived from the Coastal Plain Sands (Benin Formation), which are generally coarse-textured, highly weathered, acidic, and inherently low in nutrient reserves (Esu, 2018).

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume XI Issue VII July 2026

Although these soils support extensive agricultural production, their fertility is often constrained by rapid nutrient leaching, low organic matter content, and limited cation exchange capacity, particularly under continuous cultivation (Udo *et al*., 2009; FAO, 2022). However, variations in topography can modify these characteristics through differential erosion and sediment deposition, producing considerable spatial variability in soil fertility even within relatively small landscapes (Akinbola *et al*., 2024; Gambo *et al*., 2025). Understanding these variations is therefore essential for improving fertiliser-use efficiency and promoting sustainable crop production.

Despite increasing research on tropical soil fertility, relatively few studies have comprehensively evaluated the combined effects of topographic position and soil depth on soil physicochemical properties within the humid rainforest zone of southern Nigeria. Most previous investigations have focused on individual soil properties or broader landscape assessments without integrating the major fertility indicators required for site-specific nutrient management (Adekiya *et al*., 2023; Ojetade *et al*., 2024). Furthermore, information on soil variability within the University of Uyo landscape remains limited despite its importance for agricultural research, teaching, and land management.

Therefore, this study was undertaken to evaluate the influence of topographic position and soil depth on the physicochemical properties and fertility status of soils along a humid tropical toposequence within the University of Uyo Permanent Site, Akwa Ibom State, Nigeria. Specifically, the study aimed to (i) determine the spatial variation in selected soil physical and chemical properties across upper, centre and lower slope positions, (ii) assess the influence of soil depth on nutrient distribution and fertility indicators, and (iii) identify the topographic position with the greatest agricultural potential for sustainable crop production. The findings are expected to provide baseline information for landscape-based soil fertility management, precision agriculture, and sustainable land-use planning in the humid tropics of southern Nigeria.

MATERIALS AND METHODS

Study Area

The study was conducted at the University of Uyo teaching and research farm, Uyo, Akwa Ibom State, Nigeria. The study area is geographically located between Latitude 5°02′23″ N and Longitude 7°58′42″ E and lies within the humid tropical rainforest zone of southern Nigeria. The region experiences a bimodal rainfall pattern with an annual precipitation ranging between 2,000 and 3,500 mm, while the mean annual temperature ranges from 26 to 28°C with relative humidity generally exceeding 75% throughout most of the year (NIMET, 2024). The dominant parent material is the Coastal Plain Sands (Benin Formation), which gives rise to predominantly sandy soils characterised by rapid drainage, low nutrient-retention capacity, and susceptibility to leaching (Esu, 2018; Brady & Weil, 2017).

The natural vegetation consists mainly of secondary rainforest interspersed with cultivated fields and perennial tree species. Owing to prolonged weathering under high rainfall conditions, soils within the area are generally classified as highly weathered tropical soils with variable fertility status depending on landscape position and land-use history (Soil Survey Staff, 2022; FAO, 2022).

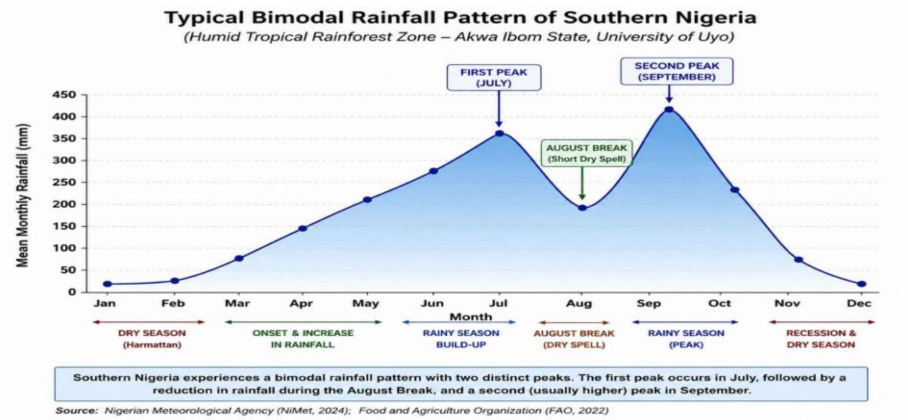


Figure 1. Typical bimodal rainfall pattern of southern Nigeria showing the first rainfall peak in July, followed by the August Break, and a second peak in September. This bimodal rainfall regime is characteristic of the humid rainforest zone, including Akwa Ibom State, and significantly influences soil moisture availability, nutrient cycling, weathering processes, and agricultural productivity.

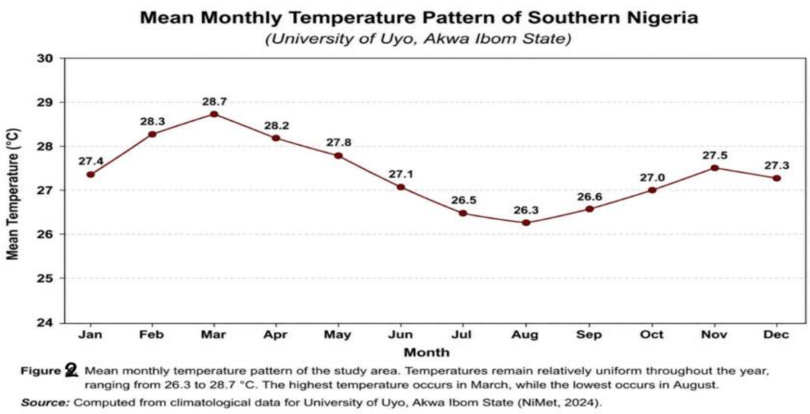


Figure 2. Mean monthly temperature pattern of the study area (University of Uyo, Akwa Ibom State, Southern Nigeria). The figure shows that mean monthly air temperature has remained relatively uniform throughout the year, ranging from 26.3 °C in August to 28.7 °C in March. Temperatures were highest during the late dry season (February–March) and gradually declined with the onset of the rainy season, reaching their lowest values during the peak rainy months (July–August), before increasing slightly towards the end of the year (October–December). This relatively stable temperature regime is characteristic of the humid tropical rainforest zone of southern Nigeria and promotes continuous soil weathering, organic matter decomposition, nutrient mineralisation, and year-round crop growth.

Field Sampling and Experimental Design

A reconnaissance survey was carried out to identify representative landscape positions along a toposequence within the study area. Based on differences in elevation, three topographic positions were delineated, namely the upper slope, middle slope and valley bottom.

At each topographic position, soil samples were collected from two depths:

0–20 cm (surface soil)

20–40 cm (subsurface soil)

This resulted in a total of six sampling units, namely:

Upper slope (0–20 cm)

Upper slope (20–40 cm)

Middle slope (0–20 cm)

Middle slope (20–40 cm)

Valley bottom (0–20 cm)

Valley bottom (20–40 cm)

The sampling depths were selected because they represent the active root zone of most arable crops and permit assessment of vertical nutrient distribution within the soil profile (Landon, 2014; Sanchez, 2019).

Approximately 1 kg of soil was collected from each sampling point using a stainless-steel soil auger after carefully removing surface litter. Samples were placed in clean polyethylene bags, properly labelled, transported to the Soil Science Laboratory, Department of Soil Science, University of Uyo, for analysis.

Sample Preparation

The collected soil samples were air-dried under laboratory conditions at room temperature (approximately 25 ± 2°C) until a constant weight was attained. Visible roots, stones, and plant residues were removed manually before the samples were gently crushed using a porcelain mortar and pestle. The processed samples were then passed through a 2-mm stainless steel sieve to obtain the fine earth fraction used for physicochemical analyses. Samples designated for organic carbon and total nitrogen determinations were carefully handled to minimise contamination and preserve their chemical integrity (IITA, 1982; Udo *et al*., 2009).

Laboratory Analyses

Particle Size Distribution

Particle size distribution was determined using the Bouyoucos hydrometer method after dispersion with sodium hexametaphosphate. (Bouyoucos, 1962; Soil Survey Staff, 2022).

Soil pH

Soil pH was determined potentiometrically using a calibrated digital pH meter in a 1:2.5 soil-to-distilled water suspension after equilibration with intermittent stirring. Soil reaction was expressed as pH (H_2O) (Thomas, 1996; Udo *et al*., 2009).

Electrical Conductivity (EC)

Electrical conductivity was measured in the same soil-water suspension using a digital conductivity meter. Results were expressed in dS m^{-1} and used as an indicator of soluble salt concentration within the soil (Rhoades, 1996).

Organic Carbon (OC)

Organic carbon was determined by the Walkley and Black wet oxidation method. The results were expressed as percentage organic carbon (Walkley & Black, 1934; Nelson & Sommers, 1996).

Organic Matter (OM)

Organic matter values were obtained from laboratory determinations and expressed as percentages. (Brady and Weil, 2017; Bünemann et al., 2023).

Total Nitrogen (TN)

Total nitrogen was determined using the macro-Kjeldahl digestion, distillation, and titration procedure. Total nitrogen was expressed as a percentage of nitrogen in the soil (Bremner, 1996; Udo et al., 2009).

Available Phosphorus (Av. P)

Available phosphorus was determined using the Bray-1 extraction method, suitable for acidic tropical soils. Results were expressed as mg kg^{-1} (Bray & Kurtz, 1945; Murphy & Riley, 1962).

Exchangeable Calcium (Ca), Magnesium (Mg), Potassium (K) and Sodium (Na)

Exchangeable bases were extracted using 1 N ammonium acetate (NH_4OAc) buffered at pH 7.0. Calcium and magnesium concentrations were determined using an Atomic Absorption Spectrophotometer (AAS), whereas

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume XI Issue VII July 2026

potassium and sodium were determined using a flame photometer. The results were expressed in cmol(+) kg^{-1} (Page *et al*., 1982; Udo *et al*., 2009).

Exchangeable Acidity (EA)

Exchangeable acidity was extracted using 1 N potassium chloride (KCl) solution. The extract was titrated with a standardised sodium hydroxide solution to determine the combined concentration of exchangeable hydrogen (H^+) and aluminium (Al^{3+}), expressed in cmol(+) kg^{-1} (McLean, 1982).

Total Exchangeable Bases (TEB)

Total exchangeable bases were calculated as the sum of exchangeable calcium, magnesium, potassium and sodium:

where all components are expressed in cmol(+) kg^{-1} (Hazelton & Murphy, 2016).

Effective Cation Exchange Capacity (ECEC)

Effective cation exchange capacity was computed as:

where ECEC is expressed in cmol(+) kg^{-1} (Soil Survey Staff, 2022).

Carbon-to-Nitrogen Ratio (C: N Ratio)

The carbon-to-nitrogen ratio was calculated by dividing organic carbon by total nitrogen:

The C:N ratio provides information on organic matter quality, nitrogen mineralisation potential, and decomposition dynamics within the soil (Brady & Weil, 2017).

Base Saturation (BS)

Base saturation was calculated as:

This parameter was used to assess the proportion of the soil exchange complex occupied by basic cations (Ca^{2+}, Mg^{2+}, K^+ and Na^+), serving as an important indicator of soil fertility and nutrient availability (Hazelton & Murphy, 2016; Brady & Weil, 2017).

Data Analysis

The analytical data were summarised using descriptive statistics. The effects of topographic position and soil depth on the measured soil physicochemical properties were evaluated through comparative analysis. Tables and bar charts were prepared to illustrate variations in soil properties among the six sampling units. Soil fertility was interpreted using internationally accepted critical limits for tropical soils (Landon, 2014; Hazelton & Murphy, 2016).

RESULTS AND DISCUSSION

Variation in Soil Physicochemical Properties Along the Toposequence

Table 1. Physicochemical properties of soils at different topographic positions and soil depths within the University of Uyo Permanent Site.

Sample	Topographic Position	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Textural Class	pH	EC (dS m^{-1})	OC (%)	OM (%)	TN (%)	Available P (mg kg^{-1})
S1	Upper slope	0–20	80.80	8.60	10.60	Sand	6.95	0.030	2.69	3.00	0.15	14.83

S2	Upper slope	20–40	80.60	9.40	10.00	Sand	6.98	0.036	0.61	1.50	0.03	10.40
S3	Middle slope	0–20	86.80	3.60	9.60	Sand	5.50	0.130	1.60	2.00	0.125	7.90
S4	Middle slope	20–40	88.80	1.60	9.61	Sand	5.74	0.036	0.30	1.00	0.19	6.20
S5	Valley bottom	0–20	86.80	5.60	7.60	Sand	5.93	0.023	3.70	5.00	0.50	19.25
S6	Valley bottom	20–40	90.40	1.00	8.60	Sand	5.96	0.027	2.54	3.00	0.20	15.30

Particle Size Distribution

Particle size analysis showed that all soils were predominantly sandy, with sand content ranging from 80.60 to 90.40%, silt from 1.00 to 9.40%, and clay from 7.60 to 10.60% (Table 1). According to the USDA textural classification, all six sampling units were classified as sand.

The dominance of sand indicates that the soils originated from the Coastal Plain Sands (Benin Formation), which are widespread across southeastern Nigeria and are characterized by coarse-textured materials with inherently low nutrient-retention capacity. Such soils generally possess high infiltration rates, rapid internal drainage, and relatively low water-holding capacity, making them prone to nutrient leaching, especially under the high rainfall conditions of the humid tropics (Esu, 2018; Brady & Weil, 2017).

A slight increase in clay content was observed in the upper and middle slope positions compared with the lower slope. However, the differences were relatively small, suggesting that parent material exerts a stronger influence on soil texture than topographic redistribution within the study area.

Soil reaction (pH)

Soil pH ranged from 5.50 in the middle slope surface soil to 6.98 in the upper slope subsurface soil (Table 1), indicating that the soils were moderately acidic to nearly neutral.

The comparatively lower pH values recorded at the middle slope and valley bottom positions may be associated with prolonged leaching of exchangeable bases, decomposition of organic residues, and the accumulation of hydrogen and aluminium ions under humid tropical conditions. Conversely, the relatively higher pH recorded in the upper slope may reflect reduced organic acid accumulation and localized differences in base distribution.

Overall, the measured pH range falls within levels considered suitable for the cultivation of many tropical food crops because most essential nutrients remain reasonably available within this range (Brady & Weil, 2017; Hazelton & Murphy, 2016).

Electrical Conductivity (EC)

Electrical conductivity values were uniformly low, ranging from 0.023 to 0.130 dS m^{-1} (Table 1). The highest EC was recorded in the middle slope surface soil (0.130 dS m^{-1}), whereas the lowest occurred at the valley bottom surface soil (0.023 dS m^{-1}).

These values are far below the threshold commonly associated with saline soils (4 dS m^{-1}), indicating that soluble salt accumulation is negligible within the study area. Consequently, soil salinity is unlikely to limit plant growth or nutrient uptake. The generally low EC values reflect intense rainfall, efficient drainage, and continuous leaching of soluble salts typical of humid tropical environments.

Organic Carbon and Organic Matter

Organic carbon exhibited substantial variability across the toposequence, ranging from 0.30 to 3.70%, while organic matter ranged from 1.00 to 5.00% (Table 1).

The highest concentrations of both organic carbon (3.70%) and organic matter (5.00%) were recorded at the valley bottom surface soil (0–20 cm). In contrast, the middle slope subsurface soil contained the lowest values (0.30% OC and 1.00% OM).

The enrichment of organic carbon at the valley bottom is consistent with the role of lower landscape positions as depositional zones where eroded sediments, plant residues, and dissolved organic materials accumulate. Surface soils also contained greater organic matter than their corresponding subsurface layers because of continuous litter deposition, root turnover, and intense microbial activity in the upper horizon.

Higher organic carbon concentrations generally improve aggregate stability, increase water-holding capacity, enhance nutrient retention, and promote microbial activity, thereby contributing significantly to improved soil fertility.

Total Nitrogen

Total nitrogen ranged from 0.03 to 0.50% across the study area (Table 1). The highest nitrogen concentration (0.50%) occurred in the valley bottom surface soil, whereas the lowest (0.03%) was recorded in the upper slope subsurface soil.

The elevated nitrogen concentration observed in the valley bottom is closely associated with its higher organic carbon and organic matter contents, since soil organic matter serves as the principal reservoir of nitrogen in most agricultural soils. The accumulation of organic residues at depositional landscape positions therefore contributes to improved nitrogen availability.

Nitrogen concentrations generally declined with increasing soil depth, reflecting reduced biological activity and lower organic residue inputs within subsurface horizons.

Available Phosphorus

Available phosphorus ranged from 6.20 to 19.25 mg kg^{-1}, with the highest value recorded in the lower slope surface soil and the lowest in the middle slope subsurface soil.

The greater phosphorus concentration in the valley bottom may be attributed to sediment deposition and the accumulation of phosphorus-rich organic materials transported from upper landscape positions. Conversely, lower phosphorus levels in the centre slope may reflect continuous crop uptake, phosphorus fixation, and erosion losses.

Overall, the results indicate that phosphorus availability varies considerably along the landscape, emphasising the need for site-specific phosphorus management to improve fertiliser-use efficiency and crop productivity.

Exchangeable Bases and Soil Fertility Indices

Table 2. Exchangeable bases and fertility indices of soils under different topographic positions and soil depths.

Sample	Topographic Position	Depth (cm)	Ca	Mg	Na	K	TEB	EA	ECEC	CEC	Base Saturation (%)	C:N Ratio
S1	Upper slope	0–20	0.60	2.90	0.099	0.097	3.698	1.00	4.698	4.698	78.71	17.93
S2	Upper slope	20–40	0.60	2.30	0.097	0.074	3.071	1.10	4.171	4.171	73.63	20.33
S3	Middle slope	0–20	0.80	2.50	0.095	0.054	3.449	0.50	3.949	3.949	87.34	12.80 *
S4	Middle slope	20–40	0.80	2.50	0.095	0.073	3.468	0.20	3.668	3.668	94.55	1.58¹

S5	Valley bottom	0–20	0.90	3.00	0.121	0.341	4.362	1.70	6.062	6.062	71.95	7.40
S6	Valley bottom	20–40	0.80	2.60	0.097	0.271	3.768	0.80	4.568	4.568	82.49	12.70

Exchangeable Calcium (Ca)

Exchangeable calcium ranged from 0.60 to 0.90 cmol(+) kg^{-1} (Table 2). The highest calcium concentration was observed at the valley bottom surface soil (S5), whereas the lowest concentrations occurred in both upper slope samples.

The relatively greater calcium content at the valley bottom suggests downward translocation and accumulation of basic cations through runoff and sediment deposition. This observation agrees with the concept that lower landscape positions function as nutrient sinks where leached materials from upper slopes accumulate (Brady & Weil, 2017; Vanlauwe *et al*., 2023). Despite this enrichment, calcium concentrations remain relatively low, reflecting the highly weathered nature of the Coastal Plain Sand soils.

Exchangeable Magnesium (Mg)

Exchangeable magnesium was the dominant exchangeable cation across all sampling locations, varying from 2.30 to 3.00 cmol(+) kg^{-1}.

The highest magnesium concentration occurred at the valley bottom surface soil, while the lowest was recorded at the upper slope subsurface soil.

The dominance of magnesium contributed substantially to the overall exchangeable base status of the soils and suggests moderate nutrient reserves despite the sandy texture. Similar observations have been reported for humid tropical soils where magnesium often remains relatively abundant because of continuous mineral weathering and organic matter mineralisation (Obalum *et al*., 2022).

Exchangeable Potassium (K)

Exchangeable potassium varied considerably across the toposequence, ranging from 0.054 to 0.341 cmol(+) kg^{-1}.

The highest potassium concentration was recorded at the valley bottom surface soil, whereas the lowest occurred in the middle slope surface soil.

Potassium is one of the most mobile nutrient cations within tropical soils. Consequently, its accumulation at the valley bottom likely reflects continual transport through surface runoff and subsurface flow from higher elevations. Elevated potassium concentrations at depositional landscape positions are advantageous because potassium plays essential roles in enzyme activation, osmotic regulation, and photosynthesis.

Exchangeable Sodium (Na)

Exchangeable sodium values ranged from 0.095 to 0.121 cmol(+) kg^{-1}, indicating relatively little variation among the sampling positions.

These concentrations are sufficiently low to eliminate concerns regarding soil sodicity. The absence of excessive sodium confirms that the soils possess favourable chemical conditions for crop growth and root development.

Total Exchangeable Bases (TEB)

Total exchangeable bases ranged from 3.071 to 4.362 cmol(+) kg^{-1}.

The highest TEB occurred at the lower slope surface soil, while the lowest was recorded at the upper slope subsurface soil.

The relatively high TEB at the lower slope reflects cumulative enrichment of calcium, magnesium, potassium, and sodium due to sediment deposition and nutrient redistribution along the landscape. This confirms that lower topographic positions possess greater nutrient reserves than upslope locations.

Exchangeable Acidity (EA)

Exchangeable acidity ranged from 0.20 to 1.70 cmol(+) kg^{-1}.

The highest acidity was recorded at the valley bottom surface soil, whereas the lowest occurred at the middle slope subsurface soil.

Although exchangeable acidity was relatively variable, the measured values remained within acceptable limits for most tropical agricultural soils. Moderate acidity is characteristic of highly weathered humid tropical soils and results primarily from prolonged rainfall and leaching of base-forming cations.

Effective Cation Exchange Capacity (ECEC)

Effective cation exchange capacity varied between 3.668 and 6.062 cmol(+) kg^{-1}.

The highest ECEC occurred at the valley bottom surface soil, while the lowest was observed at the centre middle subsurface soil.

Higher ECEC indicates greater nutrient-retention capacity and reduced susceptibility to nutrient loss through leaching. The elevated ECEC at the lower slope is closely associated with higher organic carbon and exchangeable base concentrations recorded in this landscape position.

Base Saturation

Base saturation ranged from 71.95 to 94.55% across the toposequence.

Interestingly, the middle slope subsurface soil exhibited the highest base saturation (94.55%), whereas the valley bottom surface soil recorded the lowest value (71.95%).

Although the valley bottom possessed greater nutrient reserves, its comparatively higher exchangeable acidity resulted in a lower percentage of base saturation. Nevertheless, all soils exhibited relatively high base saturation values, indicating that a large proportion of exchange sites were occupied by nutrient cations rather than acidic ions.

According to internationally accepted soil fertility ratings, base saturation values above 50% generally indicate moderate to high inherent fertility and favourable conditions for nutrient availability (Hazelton & Murphy, 2016; Brady & Weil, 2017).

Carbon-to-nitrogen (C:N) Ratio

The lowest C:N ratio occurred at the lower slope surface soil, indicating rapid decomposition and active nitrogen mineralisation. In contrast, the upper slope subsurface soil exhibited the highest ratio, suggesting slower organic matter decomposition and reduced nitrogen release.

Overall, the relatively low to moderate C:N ratios observed across most samples indicate favourable conditions for microbial decomposition and nutrient cycling within the study area.

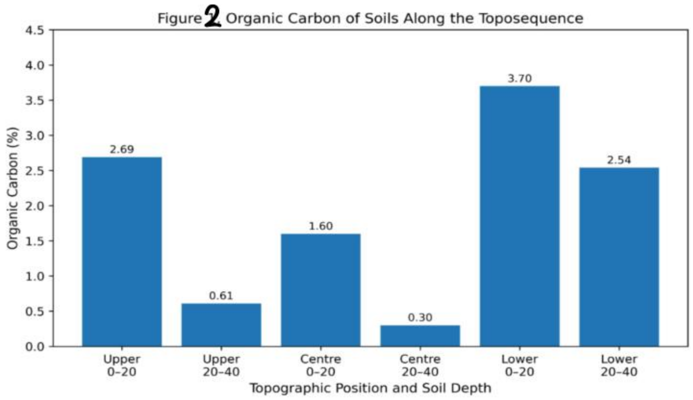
General Interpretation

The exchangeable cation data clearly demonstrate that topographic position exerts a strong influence on soil fertility. The lower slope consistently accumulated greater concentrations of organic carbon, total nitrogen, exchangeable bases, total exchangeable bases, and effective cation exchange capacity, confirming its role as a

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume XI Issue VII July 2026

depositional landscape position. Conversely, the upper and centre slope positions exhibited comparatively lower nutrient reserves because of erosion, runoff, and nutrient redistribution. These findings emphasise the importance of incorporating topographic information into soil fertility assessment and fertiliser recommendation programmes to enhance sustainable crop production in humid tropical environments.

Figure 2. Variation in Soil Organic Carbon Along the Toposequence

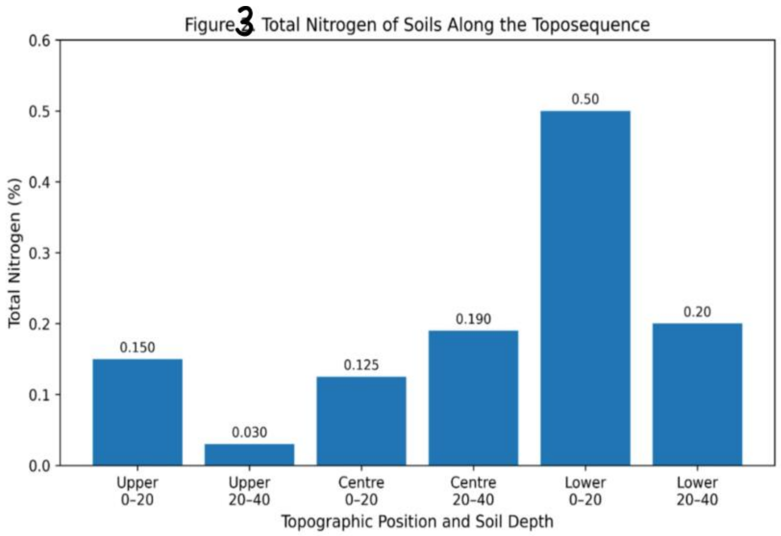


Interpretation

Figure 2 shows substantial variation in soil organic carbon across the six sampling locations. Organic carbon was consistently higher in the surface soils than in the corresponding subsurface layers, reflecting continuous inputs of plant litter, fine roots and microbial residues into the upper soil horizon. The valley bottom surface soil (S5) recorded the highest organic carbon content (3.70%), whereas the centre slope subsurface soil (S4) recorded the lowest (0.30%).

The accumulation of organic carbon at the valley bottom demonstrates the influence of topography on organic matter redistribution. During rainfall events, eroded sediments and decomposed organic materials are transported downslope and deposited at lower landscape positions, thereby enriching these soils with carbon and nutrients. This accumulation improves soil structure, enhances microbial activity, increases water-holding capacity, and contributes to greater nutrient retention.

Figure 3. Variation in Total Nitrogen Along the Toposequence



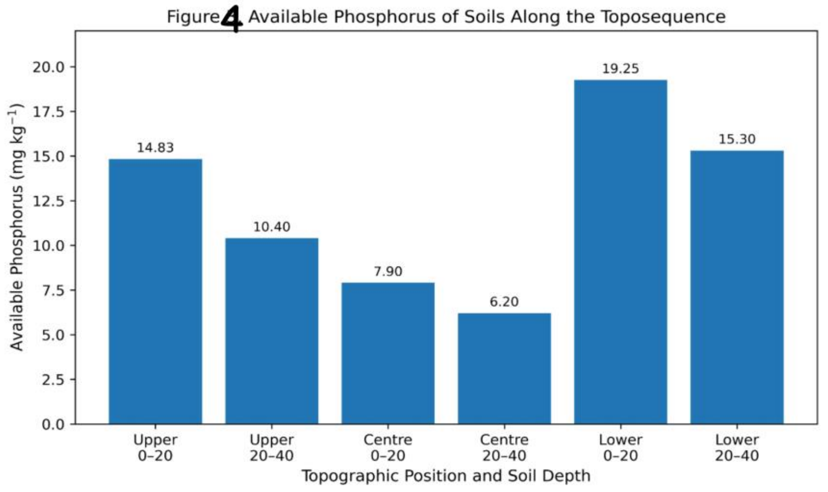
Interpretation

Figure 3 illustrates the distribution of total nitrogen among the six sampling units. Nitrogen concentrations followed a pattern similar to that of organic carbon, with the highest value recorded in the valley bottom surface soil (0.50%) and the lowest in the upper slope subsurface soil (0.03%).

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume XI Issue VII July 2026

The close relationship between organic carbon and nitrogen reflects the fact that soil organic matter is the principal reservoir of nitrogen in tropical soils. Consequently, landscape positions with greater organic matter accumulation also possess higher nitrogen reserves. Surface soils generally contained higher nitrogen concentrations than subsurface soils because of greater biological activity, root turnover, and continuous litter deposition.

Figure 4. Variation in Available Phosphorus Along the Toposequence

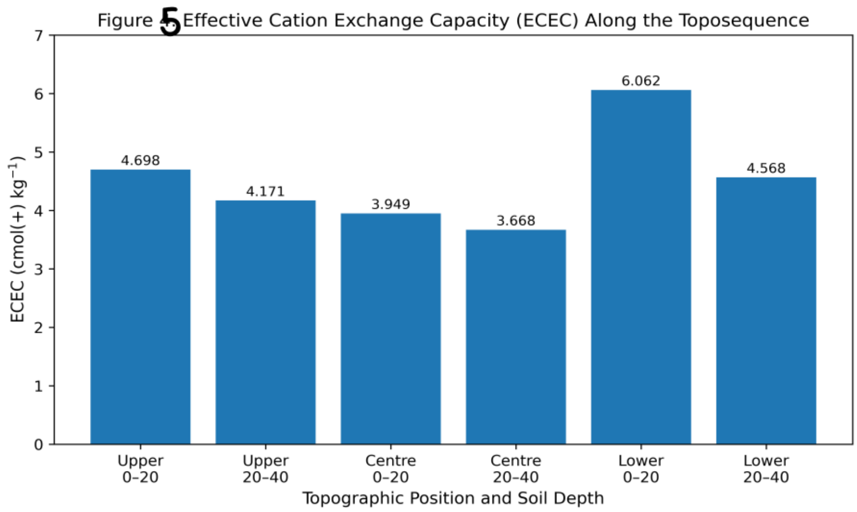


Interpretation

Available phosphorus varied considerably among the sampling locations (Figure 3). The valley bottom surface soil recorded the highest phosphorus concentration (19.25 mg kg^{-1}), whereas the middle slope subsurface soil recorded the lowest (6.20 mg kg^{-1}).

The observed distribution indicates that phosphorus, although relatively immobile compared with nitrogen, can accumulate in lower landscape positions through sediment deposition and organic matter enrichment. The greater phosphorus availability at the lower slope suggests improved nutrient status and greater potential for supporting crop growth.

Figure 5. Variation in Effective Cation Exchange Capacity (ECEC)

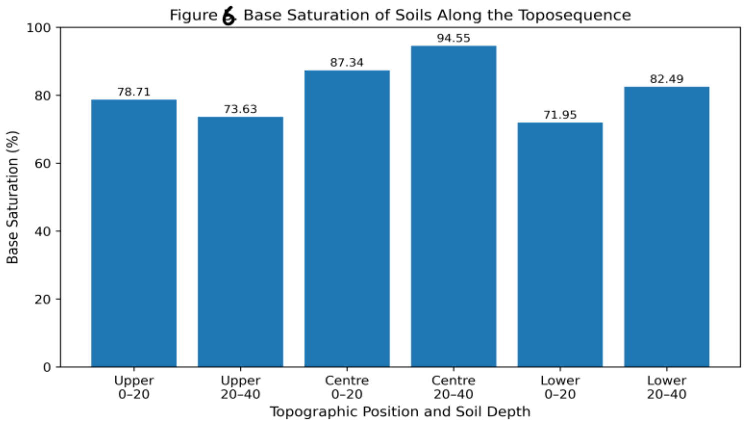


Interpretation

Effective cation exchange capacity exhibited noticeable variation across the toposequence. The highest ECEC (6.062 cmol(+) kg^{-1}) occurred in the valley bottom surface soil, whereas the lowest (3.668 cmol(+) kg^{-1}) was observed in the middle slope subsurface soil.

Higher ECEC indicates a greater capacity of the soil to retain and exchange essential nutrient cations, thereby reducing nutrient losses through leaching. The elevated ECEC observed at the valley bottom is attributable to its higher organic matter content and greater accumulation of exchangeable bases.

Figure 6. Variation in Base Saturation



Interpretation

Base saturation values ranged from 71.95 to 94.55% (Figure 5). Although all sampling locations exhibited relatively high base saturation, the middle slope subsurface soil recorded the highest percentage because of its comparatively low exchangeable acidity relative to total exchangeable bases.

The consistently high base saturation values indicate that most exchange sites were occupied by nutrient cations rather than acidic ions, suggesting generally favourable chemical conditions for crop production despite the sandy nature of the soils.

Overall Interpretation of Figures 2–4

The graphical results clearly demonstrate that topographic position and soil depth strongly influenced soil fertility. Surface soils consistently contained greater concentrations of organic carbon, nitrogen, phosphorus, and exchangeable nutrients than subsurface soils, reflecting the accumulation of organic residues and enhanced biological activity near the soil surface. Furthermore, the lower slope functioned as a nutrient accumulation zone, recording the highest values for most fertility indicators, including organic carbon, total nitrogen, available phosphorus, total exchangeable bases, and effective cation exchange capacity. These findings emphasise the importance of considering landscape position when developing fertiliser recommendations and soil management strategies for sustainable agricultural production in humid tropical environments.

CONCLUSION

This study demonstrated that topographic position and soil depth are major determinants of the spatial variability of soil physicochemical properties and fertility status within the humid tropical landscape of the University of Uyo teaching and research farm, Akwa Ibom State, Nigeria. Although all soils were derived from the same Coastal Plain Sand parent material and were predominantly sandy in texture, considerable differences were observed in their chemical properties and nutrient status across the toposequence.

The valley bottom soils consistently exhibited superior fertility characteristics, including higher organic carbon, organic matter, total nitrogen, available phosphorus, exchangeable bases, total exchangeable bases, and effective cation exchange capacity. These findings indicate that the valley bottom functions as a depositional environment where nutrients and organic materials transported from upper landscape positions accumulate through erosion and runoff processes. In contrast, the upper and middle slope positions generally contained lower nutrient concentrations because of continuous nutrient redistribution and leaching associated with humid tropical conditions.

The moderately acidic soil reaction observed throughout the study area provides favourable conditions for the cultivation of many tropical crops, while the generally high base saturation values indicate appreciable nutrient availability despite the relatively low cation exchange capacity associated with sandy soils. The close relationship observed between soil organic carbon, total nitrogen, and effective cation exchange capacity further emphasizes the central role of soil organic matter in sustaining soil fertility and improving nutrient retention in highly weathered tropical soils.

Overall, the findings confirm that topographic position is an important predictor of soil fertility status and should be considered during soil evaluation, fertiliser recommendation, and land-use planning. The study provides valuable baseline information for precision soil fertility management and contributes to the understanding of landscape-induced variability in tropical agricultural soils. Adoption of landscape-based nutrient management strategies will improve fertiliser-use efficiency, enhance crop productivity, and promote sustainable agricultural production within the humid rainforest agroecological zone of southern Nigeria.

RECOMMENDATIONS

Based on the findings of this study, the following recommendations are proposed:

1. Fertiliser recommendations should be developed according to topographic position rather than applying uniform fertiliser rates across the entire landscape.

2. The comparatively low organic carbon and nutrient status of the upper and centre slope soils should be improved through regular incorporation of organic amendments such as compost, poultry manure, green manure, and crop residues to enhance soil organic matter and nutrient retention.

3. Conservation practices including contour farming, mulching, cover cropping, minimum tillage, and vegetative barriers should be adopted to reduce erosion and minimise nutrient losses from upper landscape positions.

4. Soil testing should be conducted before fertiliser application to ensure site-specific nutrient management, improve fertiliser-use efficiency, and reduce unnecessary production costs.

5. Future studies should investigate the influence of seasonal variation, land-use practices, biological soil properties, and micronutrient dynamics along toposequences to provide a more comprehensive assessment of soil quality and agricultural productivity in humid tropical environments.

6. Long-term monitoring of soil physicochemical properties should be encouraged to evaluate changes in soil fertility under different management systems and to guide sustainable land-use planning in south-eastern Nigeria.

REFERENCES

1. AbdelRahman, M. A. E., Natarajan, A., & Hegde, R. (2023). Assessment of soil quality and fertility status using integrated soil physicochemical indicators. *Geoderma Regional*, 34, e00678.
2. Adekiya, A. O., Agbede, T. M., Olayanju, A., Ejue, W. S., Aremu, C. O., & Adenusi, T. T. (2021). Organic amendments improve soil fertility, nutrient uptake and crop productivity in tropical agroecosystems. *Archives of Agronomy and Soil Science*, 67(15), 2094–2110.
3. Adekiya, A. O., Agbede, T. M., Ejue, W. S., & Aremu, C. O. (2023). Sustainable nutrient management through organic soil amendments in tropical agriculture. *Archives of Agronomy and Soil Science*, 69(8), 1123–1140.
4. Agbede, T. M. (2024). Understanding soil and plant nutrition (3rd ed.). Salman Press.
5. Agbede, T. M., Adekiya, A. O., & Eifediyi, E. K. (2022). Organic residue management and soil fertility restoration in humid tropical soils. *Nigerian Journal of Soil Science*, 32(1), 15–29.
6. Akpan, G. U., Ibia, T. O., & Udo, E. J. (2022). Soil fertility management strategies for sustainable crop production in southeastern Nigeria. *Nigerian Journal of Soil Science*, 32(2), 118–132.

7. Akinbola, G. E., Olatunji, O. O., & Adesodun, J. K. (2024). Influence of topographic position on selected soil physicochemical properties in a humid tropical environment. *Catena*, 235, 107624.
8. Alves, M. C., Souza, Z. M., & Marques, J. J. (2024). Topographic controls on nutrient redistribution across tropical landscapes. *Geoderma*, 447, 116763.
9. Ashworth, A. J., Allen, F. L., Saxton, A. M., Tyler, D. D., & Taylor, A. M. (2025). Organic residue decomposition and nutrient release dynamics under tropical environments. *Soil Use and Management*, 41(1), 45–60.
10. Blake, G. R., & Hartge, K. H. (1986). Bulk density. In A. Klute (Ed.), *Methods of Soil Analysis*. Part 1. Physical and Mineralogical Methods (2nd ed., pp. 363–375). American Society of Agronomy.
11. Bouyoucos, G. J. (1962). Hydrometer method improved for making particle size analyses of soils. Agronomy Journal, 54, 464–465.
12. Brady, N. C., & Weil, R. R. (2017). *The nature and properties of soils* (15th ed.). Pearson Education.
13. Bray, R. H., & Kurtz, L. T. (1945). Determination of total, organic and available forms of phosphorus in soils. *Soil Science*, 59, 39–45.
14. Bremner, J. M. (1996). Nitrogen-total. In D. L. Sparks (Ed.), *Methods of Soil Analysis*. Part 3: Chemical Methods (pp. 1085–1121). Soil Science Society of America.
15. Bünemann, E. K., Bongiorno, G., Bai, Z., Creamer, R. E., De Deyn, G., de Goede, R., Fleskens, L., Geissen, V., Kuyper, T. W., Mäder, P., Pulleman, M., Sukkel, W., van Groenigen, J. W., & Brussaard, L. (2023). Soil quality—A critical review. *Soil Biology and Biochemistry*, 120, 105–125.
16. Cao, Y., Zhang, X., Wang, L., & Chen, H. (2024). Soil nutrient dynamics and fertility evaluation across agricultural landscapes. *Science of the Total Environment*, 918, 170526.
17. Cornell, R. M., Schwertmann, U., & Theng, B. K. G. (2020). Landscape position and nutrient redistribution in tropical soils. *Geoderma*, 367, 114254.
18. Esu, I. E. (2018). *Soils of Nigeria*. Sterling-Horden Publishers.
19. Food and Agriculture Organization (FAO). (2022). World Reference Base for Soil Resources 2022: International Soil Classification System for Naming Soils and Creating Legends for Soil Maps. FAO.
20. Gambo, B. A., Mohammed, I., & Yakubu, M. T. (2025). Influence of topographic variability on soil physicochemical properties and fertility status in tropical agricultural landscapes. *Catena*, 238, 108002.
21. Gil-Martínez, M., Zornoza, R., García-Orenes, F., & Bastida, F. (2025). Soil fertility restoration through sustainable nutrient management in degraded agricultural ecosystems. *Agriculture, Ecosystems & Environment*, 374, 109114.
22. Hazelton, P., & Murphy, B. (2016). *Interpreting soil test results: What do all the numbers mean?* (3rd ed.). CSIRO Publishing.
23. International Institute of Tropical Agriculture (IITA). (1982). *Selected methods for soil and plant analysis*. International Institute of Tropical Agriculture, Ibadan, Nigeria.
24. Jackson, M. L. (1973). *Soil chemical analysis*. Prentice-Hall of India.
25. Jenny, H. (1941). Factors of soil formation: A system of quantitative pedology. McGraw-Hill.
26. Klute, A. (Ed.). (1986). *Methods of soil analysis*. Part 1: Physical and mineralogical methods (2nd ed.). American Society of Agronomy.
27. Lal, R. (2020). Soil organic matter and global food security. *Soil and Tillage Research*, 203, 104684.
28. Lal, R. (2021). Soil organic matter and its role in sustainable agriculture. *Journal of Soil and Water Conservation*, 76(5), 123A–130A.
29. Lal, R., Smith, P., Stewart, B. A., & Powlson, D. S. (2024). Soil health and sustainable intensification of agriculture under changing climates. *Advances in Agronomy*, 176, 1–48.
30. Landon, J. R. (Ed.). (2014). *Booker tropical soil manual: A handbook for soil survey and agricultural land evaluation in the tropics and subtropics*. Routledge.
31. Laub, M., Schröder, J., & Wiesmeier, M. (2025). Soil nutrient dynamics and sustainable nutrient cycling in agricultural systems. *Soil Systems*, 9(1), 17.
32. Lindsay, W. L., & Norvell, W. A. (1978). Development of a DTPA soil test for zinc, iron, manganese and copper. *Soil Science Society of America Journal*, 42(3), 421–428.
33. Matisic, I., Fernández-Ugalde, O., Zaller, J. G., & Huber, S. (2024). Organic amendments enhance soil fertility and ecosystem functioning under sustainable agricultural management. *Applied Soil Ecology*, 198, 105391.

34. McLean, E. O. (1982). Soil pH and lime requirement. In A. L. Page (Ed.), *Methods of soil analysis*. Part 2: Chemical and microbiological properties (2nd ed., pp. 199–224). American Society of Agronomy.
35. Murphy, J., & Riley, J. P. (1962). A modified single-solution method for the determination of phosphate in natural waters. *Analytica Chimica Acta*, 27, 31–36.
36. Matisic, I., Fernández-Ugalde, O., Huber, S., & Zaller, J. G. (2024). Soil quality improvement through organic amendments and sustainable management practices. *Applied Soil Ecology*, 198, 105391.
37. Nelson, D. W., & Sommers, L. E. (1996). Total carbon, organic carbon, and organic matter. In D. L. Sparks (Ed.), *Methods of Soil Analysis*. Part 3: Chemical Methods (pp. 961–1010). Soil Science Society of America.
38. Nigerian Meteorological Agency (NiMet). (2024). Annual climate review and seasonal rainfall prediction for Nigeria. Nigerian Meteorological Agency, Abuja, Nigeria.
39. Obalum, S. E., Chibuike, G. U., Peth, S., & Ouyang, Y. (2022). Soil degradation, restoration and sustainable management in southeastern Nigeria. *Soil Use and Management*, 38(2), 709–725.
40. Ojetade, B. M., Adeboye, M. K. A., & Adebayo, A. G. (2024). Landscape variability and fertility assessment of cultivated soils in southwestern Nigeria. *Nigerian Journal of Soil Science*, 34(1), 55–70.
41. Okon, M. A., Udo, E. J., & Ibia, T. O. (2021). Soil fertility evaluation of coastal plain sand soils under different land-use systems in Akwa Ibom State, Nigeria. *Nigerian Journal of Soil Science*, 31(2), 88–101.
42. Olsen, S. R., Cole, C. V., Watanabe, F. S., & Dean, L. A. (1954). Estimation of available phosphorus in soils by extraction with sodium bicarbonate (USDA Circular No. 939). United States Department of Agriculture.
43. Page, A. L. (Ed.). (1982). *Methods of Soil Analysis*. Part 2: Chemical and microbiological properties (2nd ed.). American Society of Agronomy.
44. Page, A. L., Miller, R. H., & Keeney, D. R. (Eds.). (1982). *Methods of Soil Analysis*. Part 2: Chemical and microbiological properties (2nd ed.). American Society of Agronomy and Soil Science Society of America.
45. Paradelo, R., Barral, M. T., & Virto, I. (2024). Organic amendments and nutrient cycling for sustainable soil management. *Soil and Tillage Research*, 238, 106019.
46. Rhoades, J. D. (1996). Salinity: Electrical conductivity and total dissolved solids. In D. L. Sparks (Ed.), Methods of Soil Analysis. Part 3: Chemical Methods (pp. 417–435). Soil Science Society of America.
47. Ross, S. M. (1993). Organic matter in tropical soils: current conditions, concerns and prospects for conservation. Progress in Physical Geography, 17(3), 265–305.