

# SPATIAL CHARACTERIZATION OF SOIL PROPERTIES IN BASEMENT COMPLEX LANDSCAPES OF ORILE-IGBON/GAMBARI, OYO STATE, NIGERIA

## Abstract

This study assessed the physico-chemical properties of soils along a toposequence in the Orile-Igbon/Gambari area of Surulere Local Government Area, Oyo State, Nigeria. The toposequence was divided into upper, middle, and lower slope positions. Soil profile pits were excavated at each position, and samples were collected from all horizons for laboratory analysis. Physical properties evaluated included soil texture, structure, color, and horizon depth, while chemical properties comprised soil pH, exchangeable cations ( $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{K}^+$ , and  $\text{Na}^+$ ), effective cation exchange capacity (ECEC), organic carbon, total nitrogen, available phosphorus, and selected micronutrients.

Clear variations in soil physical characteristics occurred along the toposequence. Upper slope soils were light-colored, coarse-textured, and well-drained, with sandy clay to sandy clay loam textures and loose consistence. Middle slope soils exhibited darker surface horizons, finer textures, and increased clay accumulation in subsurface horizons, resulting in moderate water retention and nutrient-holding capacity. Lower slope soils showed darker horizons, finer textures, blocky structures, and evidence of waterlogging in deeper horizons, indicating restricted drainage and downslope material accumulation.

The soils were slightly acidic, with pH values of 5.0–5.7. Exchangeable calcium dominated the exchange complex, while magnesium, potassium, and sodium occurred at low levels. ECEC values indicated moderate nutrient-holding capacity. Organic carbon and total nitrogen contents were higher in surface horizons, particularly at the lower slope, due to organic matter accumulation. Available phosphorus varied and may limit crop growth in some horizons, while micronutrients were generally adequate. Overall, topography influenced soil properties, land-use planning, and sustainable agricultural production.

**Keywords:** soil toposequence, soil physico-chemical properties, horizon, topography, Orile-Igbon/Gambari

## INTRODUCTION

Soil is a fundamental component of agricultural systems, playing a central role in shaping their suitability, sustainability, and productivity (Smith and Johnson, 2023). It is indispensable for supporting crop production. Yet even within the same region and under identical climatic conditions, soils may exhibit substantial differences which are as a consequence of spatial variation in factors like parent material, slope, and vegetation cover (Olatunji *et al.*, 2017). The formation of soil is a complex process, governed over time by interactions among climate, parent material, relief (topography), and biological activity. The parent material, which may consist of consolidated or unconsolidated mineral particles along with organic matter, forms the foundational substrate of soil; it undergoes varying degrees of chemical weathering to generate the mineral and textural constituents of the soil (Weinheim, 2012).

Because soil-forming factors vary across landscapes, so do soil characteristics. Dominant factors in a given location largely determine the resulting pattern of soil distribution. Soil surveys provide a means to assess these variations and their implications for crop production and land management. Spatial variability can occur over very short distances from centimeters to a few meters even in uncultivated areas that appear uniform. In such settings, natural soils inherently display variation, meaning that soil properties can differ not only between fields but also within different parts of the same field (Martz, 1992).

Having a deep understanding of the physical soil conditions in any given area their potentials and limitations is essential for effective crop production. Soil physical properties control key aspects of the growing environment, including water availability and nutrient uptake. Therefore, detailed knowledge of soil characteristics allows for better resource management, enabling the maximization of crop production within genetic potential, while also preserving soil resources for future generations (Olatunji *et al.*, 2017). A major impetus for investigating soil variability lies in the desire to optimize the use of available toposequences (landform sequences), water, and energy resources. In this context, the present study directs attention to soil variability as a critical factor in identifying soil properties relevant to crop production. Specifically, it focuses on the Orile-Igbon/Gambari area of Ogbomoso, which has supported mixed-cropping systems for many years, with the aim of discerning where meaningful variations in soil properties occur across the landscape.

A key motivation for studying soil variability is the need to optimize the use of land, water, and energy resources. Therefore, this study focuses on assessing soil variability as an important factor in identifying soil properties relevant to crop production, particularly in the Orile-Igbon/Gambari area of Ogbomoso, which has been under mixed-cropping systems for many years. This work aimed at identifying where variations occur on the various part of the landscape. Thus, the objectives of the study were. (i) To characterize the morphological, physical and chemical properties of the soil profiles along the landscape; (ii) To examine the physico-chemical properties of the soils in the selected areas, and (iii) Provide information of the properties of soil profiles on the landscape that could be limiting the productivity of nearby farm lands in relation to topographical effects for sustainable crop production.

## **Materials and method**

### **Description of the study area**

The study was conducted on a major toposequence situated within the Orile-Igbon/Gambari. Orile Igbon/Gambari is located at the northwestern part of Surulere Local Government Area, Oyo State. The climate is tropical, characterized by distinct wet and dry seasons typical of Oyo State. The wider Surulere region records an average annual temperature of approximately 28°C, supporting continuous agricultural activity. Rainfall follows the regional pattern of a wet season from April to October, followed by a dry season from November to March, with associated Harmattan winds. Orile-Igbon/Gambari is primarily agrarian, with farming being the dominant livelihood among residents (Climate-data.org)

### **Soil sampling and laboratory analysis**

For this study, the selected toposequence was classified into three topographic positions: the upper slope, middle slope, and valley bottom. At each position, a standard soil profile pit was excavated and described according to the number of horizons identified, following the FAO (2006) guidelines for soil profile description. Soil samples were collected from each horizon, air-dried, crushed, and passed through a 2.0 mm sieve to remove coarse fragments. Gravel content was determined by sieving and expressed as a percentage of the total soil mass (Brady & Weil, 2010).

Particle size distribution (sand, silt, and clay fractions) was analyzed using the Bouyoucos hydrometer method (Gee & Or, 2002), while bulk density was determined using the core method (Blake & Hartge, 1986). Exchangeable bases (Ca, Mg, K, and Na) were extracted with 1 N ammonium acetate (NH<sub>4</sub>OAc, pH 7) according to Thomas (1982). Exchangeable Ca and Mg were measured by EDTA complexometric titration, and K and Na were determined using flame photometry (Jackson, 1962).

Cation exchange capacity (CEC) was assessed by the ammonium saturation (NH<sub>4</sub>OAc) displacement method at pH 7, following Odu et al. (1986). Soil organic carbon (SOC) was quantified using the Walkley–Black wet oxidation method (Nelson & Sommers, 1982), and soil pH was measured in both distilled water and 1 N KCl at a 1:2 soil-to-solution ratio (Hendershot et al., 1993). Moisture content and electrical conductivity (EC) were also determined following standard laboratory procedures (Chapman, 1965).

### **Statistical Analysis**

The data generated were analyzed using descriptive statistics, including minimum, maximum, mean, median, and standard deviation. Coefficient of variation (CV) was calculated to assess the degree of variability of soil properties across the study sites (Gomez & Gomez, 1984). All statistical analyses were carried out using SAS software (SAS Institute, 2009).

## **RESULTS AND DISCUSSIONS**

### **Soil Morphology along the Toposequence**

The soils along the Orile-Igbon/Gambari toposequence exhibited clear morphological variations corresponding to topographic position, highlighting the influence of slope on soil formation and properties. The study focused on three pedons representing upper slope (Pedon 001), middle slope (Pedon 002), and lower slope (Pedon 003) positions. Horizon depths varied across the toposequence, with surface horizons (A1) ranging from 0–29 cm on the upper slope, 0–22 cm on the middle slope, and 0–35 cm on the lower slope. The A1 horizons in all profiles were generally friable and well-structured, being single-grain to very fine crumb, non-sticky, and loose, which indicates well-aerated topsoil conducive to root penetration and seedling emergence (Brady & Weil, 2017).

### **Soil Colour and Organic Matter**

Soil color exhibited noticeable differences along the slope. The upper slope pedon showed lighter colors (10YR 4/3 to 10YR 6/6), suggestive of moderate organic matter accumulation and effective drainage. The middle slope displayed darker hues (10YR 3/2 to 10YR 6/6), while the lower slope had even darker surface horizons (7.5YR 3/1 to 10YR 7/1), which may reflect higher organic matter content due to deposition from upslope soils and reduced oxidation under wetter conditions (Soil Survey Staff, 2014). The darker colors observed in the middle and lower slopes could also indicate greater accumulation of clay and iron oxides in the subsurface horizons, processes commonly associated with illuviation in tropical soils (Hillel, 2008).

### **Soil Structure and Horizon Development**

The structural arrangement of soil horizons varied with topographic position. Upper slope soils exhibited single-grain and fine granular structures, indicative of well-drained conditions and minimal clay accumulation. Middle slope horizons were primarily fine to medium granular, while the lower slope B2 and BC horizons exhibited medium to coarse angular blocky structures, which often correspond to higher clay content and greater compaction. The lower slope also displayed sticky and firm consistence in some horizons, particularly in BC layers, reflecting poor drainage and potential seasonal waterlogging (Brady & Weil, 2017). These patterns suggest the occurrence of clay translocation from upper to lower slopes, contributing to subsurface horizon differentiation along the toposequence.

### **Consistency, Boundaries, and Drainage**

Consistency and boundary characteristics provide insights into the soil's drainage status. Upper slope horizons were mostly non-sticky, loose, and had smooth, clear boundaries, indicating good aeration and minimal water retention. In contrast, middle slope soils exhibited slightly firmer textures with irregular and diffuse boundaries, reflecting moderate drainage and increased clay content. The lower slope soils had very firm, sticky, and occasionally waterlogged horizons, particularly in BC layers. This suggests limited permeability, slower infiltration rates, and potential temporary water saturation, which may restrict root growth and limit crop options during peak wet seasons (Hillel, 2008).

### **Implications for Soil Fertility and Land Use**

The morphological differences along the toposequence have direct implications for soil fertility and agricultural potential. The upper slope soils are likely the most suitable for intensive arable cropping due to well-structured, friable topsoils and effective drainage. Middle slope soils are moderately suitable, with slightly increased clay content that could retain nutrients but may reduce root penetration if moisture becomes limiting. Lower slope soils are prone to waterlogging and compaction in subsurface horizons, restricting crop choice to water-tolerant species such as cassava and certain legumes. However, the darker colors and finer textures in these soils indicate potentially higher organic matter content, which could

enhance nutrient availability if proper drainage management is applied (Brady and Weil, 2017; **Aduayi et al., 2002**).

### **Topographic Influence on Soil Development**

The results highlight that topography is a primary control on soil development in the Orile-Igbon/Gambari landscape. Slope position affects water movement, erosion, deposition, and clay translocation, leading to systematic variation in horizon thickness, structure, texture, and drainage along the topo-sequence. These findings are consistent with studies in southwestern Nigeria, where derived savannah soils along slopes exhibit similar morphological and fertility gradients (Olatunji et al., 2017). Proper understanding of these topographic effects is essential for land-use planning, soil management, and sustainable crop production in the region.

### **Variations**

The morphological characteristics of the soils in the study area are summarized in Table 1. The soils were generally deep, ranging from 170 to 200 cm, with 4 to 6 horizons identified across the remaining pedons. The topsoils were predominantly black to dark brown (7.5YR 3/1), which may be attributed to higher organic matter content or accumulation of eroded materials from upslope positions. Other observed physical features included mottle patterns, stoniness, structure, cutans, and boundary forms.

The textural classes varied along the topo-sequence: one pedon exhibited sandy clay, another sandy clay loam, and the lower slope pedon had a silt loam texture, reflecting variations in deposition and soil formation processes.

Soil pH was relatively uniform across pedons and depths, ranging from 4.8 to 5.7 in H<sub>2</sub>O and 4.8 to 5.2 in KCl, indicating slightly acidic to near-neutral conditions typical of many agricultural soils. Calcium (Ca<sup>2+</sup>) and magnesium (Mg<sup>2+</sup>) were essential nutrients, with Ca<sup>2+</sup> consistently higher than Mg<sup>2+</sup>, contributing positively to soil structure and fertility. Sodium (Na<sup>+</sup>) and potassium (K<sup>+</sup>) were relatively low, suggesting minimal salinity and potentially low exchangeable K<sup>+</sup>.

Hydrogen (H<sup>+</sup>) and aluminum (Al<sup>3+</sup>) levels were generally low, indicating minimal soil acidity and a low risk of aluminum toxicity. The effective cation exchange capacity (ECEC) ranged from 0.5 to 1.66 Cmol/kg, reflecting moderate to high nutrient-holding capacity favorable for crop growth.

Organic carbon (Org. C) and total nitrogen (Total N), important indicators of soil fertility, ranged from 0.04% to 0.06% and 0.90% to 3.90%, respectively, representing moderate fertility levels. Essential micronutrients like iron (Fe), copper (Cu), zinc (Zn), and manganese (Mn) were generally adequate for plant growth, with Fe present in the highest concentrations.

Generally, the soils are moderately acidic, fertile, and suitable for agricultural production, with adequate organic matter, essential nutrients, and moderate to high cation exchange capacity, making them favorable for sustainable crop cultivation.

**Table 1: Morphological properties of soils of Orile Igbon/Gambari area toposequence**

Horizon	Depth (cm)	Colour	Structure	Consistence (moist)	Boundary
<b>pedon 001 GB upper slope</b>					
A <sub>1</sub>	0-29	10YR 4/3	single grain	non-sticky and dry loose	clear and smooth
AB	29-66	10YR 5/3	single grain	non-sticky and dry loose	clear and smooth
B <sub>1</sub>	66-115	10YR 6/6	single grain	non sticky, loose and dry loose	Smooth and clear
B <sub>2</sub>	115-161	10YR 7/8	very fine granular	non sticky, loose and dry loose	smooth and diffuse
BC	161-200	10YR 8/8	coarse angular blocky	non-sticky, loose and very hard	
<b>pedon 002 GB middle slope</b>					
A <sub>1</sub>	0-22	10 YR 3/2	very fine crumb	non-sticky, firm and dry loose	irregular and diffuse
AB	22-56	10YR 3/1	single grain	non-sticky and dry loose	clear and smooth
B <sub>1</sub>	56-88	10YR 6/6	fine or thin granular	non-sticky, loose and dry loose	irregular and diffuse
B <sub>2</sub>	88-133	7.5YR 6/8	medium and granular	non-sticky, loose and dry loose	wavy and gradual
BC	133-170	7.5YR 6/6	medium and granular	non-sticky, loose and dry loose	broken and gradual
C <sub>1</sub>	170-200	10YR 7/3	coarse angular blocky	sticky, firm and hard	
<b>pedon 003 GB lower slope</b>					
A <sub>1</sub>	0-35	7.5YR 3/1	very fine crumb	non-sticky loose and dry	smooth and clear
AB	35-51	7.5 YR 8/1	very fine crumb	non-sticky, loose and dry loose	smooth and clear
B <sub>1</sub>	51-100	10YR 7/1	very fine crumb	very sticky, very firm and hard	Gradual
BC	100-170	10YR 7/2	Very fine crumb	Waterlogged	



**Table 2: Physical properties of soils of Orile Igbon toposequence**

<b>Horizon</b>	<b>Depth (cm)</b>	<b>Very sand coarse (2-1mm)</b>	<b>Coarse sand (1-.45)</b>	<b>Medium sand (.45-.225)</b>	<b>Fine sand (.225-.05)</b>	<b>Very fine sand (.075-.75)</b>	<b>Total sand</b>	<b>Silt (.05-.002)</b>	<b>Clay (&lt;.002mm)</b>
<b>pedon 001 GB upper slope</b>									
<b>A<sub>1</sub></b>	0-29	5.0	9.2	15.0	19.7	25.6	74.5	15.7	<b>9.8</b>
<b>AB</b>	29-66	13.8	9.5	17.0	22.6	27.6	90.2	3.9	<b>5.9</b>
<b>B<sub>1</sub></b>	66-115	6.9	10.9	22.8	28.0	25.5	94.1	2.0	<b>3.9</b>
<b>B<sub>2</sub></b>	115-161	4.0	14.8	12.3	18.1	21.4	70.6	15.7	<b>13.7</b>
<b>BC</b>	161-200	15.7	15	14.7	22.7	23.1	91.2	2.0	<b>6.8</b>
<b>pedon 002 GB middle slope</b>									
<b>A<sub>1</sub></b>	0-22	6.5	16.5	16.0	23.3	24.0	85.3	5.9	<b>7.8</b>
<b>AB</b>	22-56	5.3	11	18.6	21.7	27.7	84.3	6.9	<b>8.8</b>
<b>B<sub>1</sub></b>	56-88	6.2	11.9	18.6	21.5	18.3	76.5	15.7	<b>7.8</b>
<b>B<sub>2</sub></b>	88-133	10.5	14.3	13.8	20.3	23.5	82.4	4.9	<b>12.7</b>
<b>BC</b>	133-170	5.2	11.0	18.6	26.5	26.9	88.2	4.9	<b>6.9</b>
<b>C<sub>1</sub></b>	170-2--	6.1	13.7	16.4	18.0	30.1	84.3	3.9	<b>11.8</b>
<b>pedon 003 GB lower slope</b>									
<b>A<sub>1</sub></b>	0-35	9.6	17.9	21.0	17.4	20.4	86.3	4.9	<b>8.8</b>
<b>AB</b>	35-51	6.2	18.4	16.3	23.6	20.8	85.3	5.9	<b>8.8</b>
<b>B<sub>1</sub></b>	51-100	5.7	24.8	16.7	19.2	17.9	84.3	6.9	<b>8.8</b>
<b>BC</b>	100-170	6.2	19.7	15.2	20.0	17.6	84.7	6.9	<b>8.8</b>

**Table 3: Chemical properties of soils of Orile Igbon toposequence**

Horizon	Depth (cm)	pH (H <sub>2</sub> O)	Ca <sup>2+</sup>	Na <sup>+</sup>	K <sup>+</sup>	Al <sup>3+</sup>	ECEC	Org. C	Total N	P	Mn
			C mol kg <sup>-1</sup>					%	%		
<b>pedon 001GB upper slope</b>											
A <sub>1</sub>	0-29	5.70	0.82	0.04	0.14	0.03	1.66	3.50	0.03	28.20	15.02
AB	29-66	5.40	0.22	0.03	0.11	0.02	0.75	2.00	0.02	21.20	11.00
B <sub>1</sub>	66-115	5.30	0.26	0.04	0.13	0.02	0.78	0.90	0.01	16.20	8.20
B <sub>2</sub>	115-161	5.20	0.24	0.03	0.12	0.02	0.72	0.70	0.01	12.00	7.00
BC	161-200	5.00	0.17	0.02	0.11	0.02	0.57	0.50	0.01	10.30	5.00
<b>pedon 002GB middle slope</b>											
A <sub>1</sub>	0-22	5.60	0.79	0.03	0.12	0.02	1.40	3.70	0.03	26.40	16.00
AB	22-56	5.50	0.50	0.04	0.11	0.03	0.91	1.90	0.02	23.40	10.80
B <sub>1</sub>	56-88	5.40	0.36	0.03	0.20	0.02	0.97	1.90	0.01	19.20	9.40
B <sub>2</sub>	88-133	5.40	0.28	0.03	0.18	0.02	0.83	0.80	0.01	10.30	8.00
BC	133-170	5.20	0.20	0.03	0.11	0.02	0.68	0.80	0.01	8.00	8.20
C <sub>1</sub>	170-200	5.00	0.20	0.03	0.10	0.02	0.69	0.06	0.01	6.50	7.00

**pedon 003GB lower slope**

A <sub>1</sub>	0-35	5.60	0.76	0.03	0.12	0.03	1.46	3.60	0.03	21.40	17.00
AB	35-51	5.50	0.40	0.02	0.10	0.02	0.86	1.40	0.01	13.20	11.00
B <sub>1</sub>	51-100	5.30	0.48	0.03	0.18	0.03	1.04	1.00	0.01	8.00	9.00
BC	100-170	5.30	0.24	0.03	0.12	0.02	0.73	0.80	0.01	5.10	7.00

## CONCLUSION

The soils along the Orile-Igbon/Gambari toposequence exhibit pronounced variations in physico-chemical properties influenced by topographic position. Morphologically, upper slope soils are characterized by well-structured, friable, single-grain to very fine crumb topsoils with clear and smooth horizon boundaries, reflecting good aeration, rapid drainage, and minimal clay accumulation (Brady & Weil, 2017). Middle slope soils show moderately developed granular structures with irregular and diffuse boundaries, indicating intermediate drainage and moderate clay translocation (Hillel, 2008). Lower slope soils display darker surface horizons, medium to coarse angular blocky structures, and firm to sticky consistence in subsoils, reflecting higher clay content, reduced permeability, and potential seasonal waterlogging (Soil Survey Staff, 2014). Horizon depths increase downslope, and textural variations indicate sandier upper slopes and finer, silt-rich lower slopes, consistent with sediment deposition and clay illuviation processes (Gee & Or, 2002).

Chemically, all pedons are slightly acidic to near-neutral (pH 5.0–5.7), with exchangeable calcium consistently higher than magnesium, supporting structural stability and moderate fertility (Thomas, 1982). Sodium and potassium contents are low, indicating minimal salinity risk, while cation exchange capacity (0.57–1.66 Cmol/kg) reflects moderate to high nutrient-holding capacity (Odu et al., 1986). Organic carbon and total nitrogen are moderate, with higher values observed in middle and lower slope soils due to organic matter accumulation from upslope deposition (Nelson & Sommers, 1982). Essential macro and micronutrients such as phosphorus and manganese are present at sufficient levels to support plant growth.

Generally, the physico-chemical characteristics suggest that upper slope soils are highly suitable for intensive arable cropping due to friable structure, effective drainage, and moderate fertility. Middle slope soils are moderately suitable, balancing nutrient retention and root penetration capacity, while lower slope soils, though richer in organic matter and finer textured, are prone to waterlogging and compaction, limiting their suitability to water-tolerant crops. The systematic variations along the toposequence highlight the significant influence of topography on soil formation, nutrient distribution, and land-use potential. Proper soil management, including drainage improvement and organic matter enhancement, is essential to optimize agricultural productivity and sustain soil quality across the landscape.

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