



**PHYSICAL PROPERTIES ALONG TOPOSEQUENCE OF TULA HILL SOILS,  
KALTUNGO, NORTHERN GUINEA SAVANNAH, NIGERIA**

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**ABSTRACT**

The study investigated the spatial variability of key soil physical properties along topo-sequences within four distinct wards (Wange, Baule, Bule-Kaltin, and Yiri) of Tula Hill soils, Gombe State, Nigeria. The region is characterized by sandy soils, hilly topography, and underlying sandstone bedrock. Soil samples were collected from 0-30 cm at four landform positions (crest, shoulder, back slope, and foot slope) across each ward and analyzed for pH, organic carbon (OC), texture (sand, silt, clay), bulk density (BD), aggregate stability (AS), and porosity (PS). Results indicated predominantly sandy textural classes across all locations, confirming the influence of sandstone parent material. Soil pH ranged from moderately acidic to neutral. Organic carbon content was generally low (<1%), with some deviations from expected topo-sequence trends, notably higher OC at the crest in Baule and Wange attributed to localized anthropogenic activities (e.g., domestic waste return) and high infiltration due to bedrock. Bulk density remained below critical thresholds (e.g., Baule 1.518–1.573 g/cm<sup>3</sup>), suggesting no impediment to root growth. Aggregate stability varied significantly by landform, with lower slopes often exhibiting greater stability in Baule (e.g., 26.57% vs. 11.67% at crest). Porosity was generally adequate for aeration and water movement, although some variations against typical down slope increases were noted, potentially due to management practices or unique depositional patterns. The consistent sandy texture and adequate porosity, supported by the highly permeable sandstone bedrock and the presence of springs, suggest high infiltration capacity across the Tula Hills, mitigating surface runoff despite the hilly terrain. This study provides crucial insights into the spatial variability of soil physical properties in response to topography and local management, aiding sustainable agricultural practices and land use planning in similar fragile ecosystems.

**Keywords:** Topo-sequence, Tula, Hills, Sandy, Infiltration, Erosion

**INTRODUCTION**

Soil is a living, natural, breathing component composed of solids, liquids, and gases (Gatiboni, 2022). Soil can be said to have five major functions, which are provision of habitat for organisms, recycling of waste products, water filtration, engineering material and a medium for plant growth. Soil provides structural stability for plants retains and relinquishes water and the nutrients necessary for plant growth. Soil has its physical, chemical and biological properties. Physical properties play an important role in determining soil's suitability for agricultural, environmental and engineering uses (Phogat *et al.*, 2015). Soil physico-chemical properties form the backbone of soil functionality, dictating its productivity, structure, water dynamics, and nutrient availability. These properties which include bulk density, porosity, texture, moisture content, pH, organic carbon, cation exchange capacity (CEC), and electrical conductivity are significantly influenced by topography and landscape position (Miller *et al.*, 2020). Topographic variations influence erosion, deposition, moisture retention, and organic matter distribution, which in turn affect soil properties along a slope gradient. Soils on upper slopes (crest and shoulder) are often shallow, less developed, and prone to erosion, resulting in reduced organic carbon content, finer particle loss and lower nutrient reserves (Baker *et al.*, 2020; Smith *et al.*, 2022). In contrast, foot slopes and toe slopes serve as depositional areas, accumulating finer particles, nutrients, and moisture there by creating more fertile and chemically enriched soils (Garcia *et al.*, 2019; Kim *et al.*, 2021)



The physical properties of soils are important components in determining soil potential uses, sustainability and productivity (Thompson *et al.*, 2021). Soil physical properties affect water and chemical movement in the soil and can have a significant impact on crop productivity and the Environment. As soil properties influence productivity, spatial variability of soil properties within fields offers various conditions for the diverse development of crops (Smith *et al.*, 2022). Bulk density, an indicator of soil compaction, tends to be higher in upper slope positions due to erosion-induced removal of surface materials and exposure to weathering (Nuga&Lal, 2015). Lower slopes generally exhibit reduced bulk density and higher porosity because of the accumulation of organic matter and finer soil fractions that promote better soil aggregation (Obalum *et al.*, 2017).

Soil texture remains a relatively stable inherent property but its surface expression can be altered by topographic redistribution. Upper slope soils may be sandier due to erosion of fine particles, while lower slopes tend to accumulate clay and silt, leading to better moisture retention (Baker *et al.*, 2020; Thompson *et al.*, 2021), this enhances microbial activity and nutrient cycling. This increased moisture availability supports a more active soil biota, leading to improved soil health and fertility (Zhang *et al.*, 2022; Smith *et al.*, 2022). Organic carbon content is a key indicator of soil fertility. Lower slope positions, characterized by favorable moisture conditions and reduced erosion, typically exhibit higher organic carbon levels compared to upper slopes. This accumulation of organic carbon enhances soil health and productivity (Lal, 2016). Agricultural activities on hillsides have a unique set of challenges and opportunities. The topography significantly influences soil properties, water movement, and the suitability of different farming practices, topography to a large extent determine the rate and acceleration of soil degradation i.e. erosion, nutrient lost, stability and productivity of the soil, it contribute to the special variability of the soil in terms of drainage, mineral sustainability, hydrology, crop yield, is also a significant factor for soil differentiation (Jendoubi& Hani, 2024).

Tula hills located in Kaltungo local government area of Gombe State Nigeria is a unique and ecologically significant area characterized by hilly terrain thereby making farming on marginal lands the order of the day. However, stone terracing is widely practiced. Tula hills fall under the geological interface between the Cretaceous Bima Sandstone Formation and the underlying Basement Complex rocks (Carter *et al.*, 1963). Tula is characterized by a semi-arid climate which means relatively low and variable rainfall with distinct dry and wet seasons. The vegetation in Tula hills region typically falls within the Sudan Savannah zone which is associated with grassy plains interspersed with scattered trees and vegetation adapted to seasonal drought. Been a hilly terrain it's prone to be faced with erosion risk, water runoff, soil heterogeneity and accessibility (access fields and transporting agricultural inputs and outputs). Water scarcity is a major challenge in Tula as only small springs from the rocks serve as water source in the communities which are affected by seasonal variation as to its flow and availability as well. Tula also contains areas with rocky outcrops which further add to the variability of the terrain.

Globally, population is on the increase, thereby putting more pressure on limited land resources, hence, putting more land area under arable crop production by clearing forests is has become common practice. However, negative impacts of loss of forest lands on the climatic have been reported (Maja&Ayano, 2022). Tula being mountainous area, has limited scope of arable land for farming activities due to exposed bedrocks and surrounding hills. Cultivation is mostly on hillslopes and is prone to soil degradation due to an increased risk of soil erosion and degradation.

Soil physical properties controls to a large extent the productivity of soil, ensuring maximum crop production output and sustainability of soil fertility. Thus, different soil classes require different management so that the inherent productivity of the soil, as such making this study will enable farmers to make right land use and crop selection choices with changing landforms, knowing the soil physical will help in taking adequate measures and management strategies for sustainable agricultural production with maximum yield as it is widely acknowledged that surface runoff loss can directly aggravate soil erosion, thus decreasing surface runoff is the key to preventing and controlling soil erosion (Dai *et al.*, 2018; Shi *et al.*, 2021), thus this study will help in knowing the effect of the hilly terrain on these properties studied so as to profound solutions to improve and maintain the soil in Tula hill soil which can be applied on other places of similar features.



## MATERIAL AND METHODS

Gombe State, located in northeastern Nigeria, is bordered by Borno and Yobe to the north and northeast, Taraba to the south, Adamawa to the southeast, and Bauchi to the west. Kaltungo is a local government area in Gombe State, Nigeria, known for its unique characteristics. The study area is located in Tula, within the Kaltungo local government area of Gombe State. It is situated 11.390 to 11.565 along the longitude and 9.700 to 10.000 along the latitude. Tula comprises four different communities (ward): Wange, Baule, Bule-Kaltin, and Yiri.

Tula has deep valley with temperate weather; it's a dissected plateau with steep valley and formations of hard igneous and sedimentary rocks. The plateau is 700 meters above sea level. Terrace farming is practiced along the steep hill sides. It is seasonally wet and dry, having an average annual rainfall regime ranging from 850 to 1200 mm over a period of three decades (Yusuf and Yahaya 2017; Jimoh *et al.* 2022), having 5 to 6 months of rain of 173 days effective length of wet season. Tula experiences its highest mean monthly rainfall in September (7.91 inch) followed by 7.28 inch in August. The terrain is marked by prominent sandstone scarps and hills, and the dominant soils are raw mineral and ferruginous tropical soils developed on sandstone parent material. Sorghum, cocoyam are the most dominantly cultivated crops in Tula along maize, groundnut and millet.

A reconnaissance survey of the study area was carried out; coordinates were taken to help strategize the sampling. Using the coordinates, a Digital elevation model was made to enable landscape sampling. Four landscape positions were cited on each hill (Crest, Shoulder, Back slope and Foot slope landscape positions). At each of the landscape position four auger points were sampled by systematic random sampling. Soil samples were collected at 0–30 cm, representing the topsoil. On each hill, 16 samples were collected, 4 per each landscape position, amounting to a total of 64 samples were collected from the four hills. Soil samples collected were transferred into polythene bags for further analysis. Where Organic carbon, pH, particle size density, Porosity, Aggregate stability and Bulk density were analyzed in the laboratory using a standard procedure described by IOAC.

## RESULT AND DISCUSSION

### Soil Properties of the Study Area

Table 1 to 4 are the post hoc analysis for top soil results from the laboratory. From the post hoc analysis, in Baule (Table 1), soil pH varied significantly across landform segments, with lower pH observed at the foot slope ( $5.998 \pm 0.304$ ) and higher values at the crest ( $6.723 \pm 0.191$ ) confirming the influence of topography on soil acidity. This supports findings of Jimoh *et al.* (2020) who noted the leaching of acid cations toward lower slope positions as a major contributor to decreased pH levels and higher values at the upper positions.

Organic carbon (OC) followed a similar trend but did not differ significantly, possibly due to the widespread use of stone terracing in Baule, which reduces erosion and organic matter wash-off across slopes. This aligns partially with Chilundo *al.* (2016) who observed higher soil organic carbon values at elevated landscape positions. However, the lack of significant differences here deviates from Salem and Hamani (2022) who reported notable soil organic carbon redistribution along topographic sequences.

Bulk density remained relatively consistent across slope positions, with no statistically significant variation. This observation echoes (Mikha & Rice, 2016; Fenton *et al.* 2020; Siddiqui *et al.* 2023) emphasizing that land use and management practices often have more influence on bulk density than topographic variation alone.

Aggregate stability showed significant differences between the upper (crest and shoulder) and lower (back and foot) slopes, with the lower segments exhibiting greater stability. These positions are transitional zones where erosion and deposition processes interact as stated by Ibrahim *et al.* (2015).

Porosity showed no significant variation across slope positions, indicating that soil management (e.g., tillage, cropping system) may be a stronger determinant than topography (Mikha & Rice, 2016; Fenton *et al.* 2020; Siddiqui *et al.* 2023). All landscape segments in Baule shared a sandy loam textural class, which deviates from Dungait *et al.* (2019) and Wang *et al.* (2022) as a shift in particle size

distribution along slopes is expected. The uniformity here likely reflects the impact of long-standing stone terracing, which minimizes downslope sediment transport

**Table 1: Physicochemical Properties of Topsoil (0-30cm) at Baule**

Landform	pH	OC (%)	Sand (%)	Silt (%)	Clay (%)	BD (g/cm <sup>3</sup> )	AS (%)	PS (%)
Crest	6.723 <sup>a</sup> ±0.191	0.873 <sup>a</sup> ±0.257	76.493 <sup>a</sup> ±5.126	11.873 <sup>a</sup> ±5.915	11.633 <sup>a</sup> ±1.642	1.573 <sup>a</sup> ±0.041	11.670 <sup>b</sup> ±6.679	0.413 <sup>a</sup> ±0.025
Shoulder	6.443 <sup>ab</sup> ±0.108	0.638 <sup>a</sup> ±0.326	82.318 <sup>a</sup> ±4.735	4.548 <sup>a</sup> ±3.238	13.130 <sup>a</sup> ±2.076	1.518 <sup>a</sup> ±0.029	7.978 <sup>b</sup> ±2.023	0.428 <sup>a</sup> ±0.005
Back Slope	6.350 <sup>ab</sup> ±0.519	0.563 <sup>a</sup> ±0.075	82.418 <sup>a</sup> ±2.404	4.228 <sup>a</sup> ±0.586	13.355 <sup>a</sup> ±2.136	1.553 <sup>a</sup> ±0.038	26.568 <sup>a</sup> ±6 .428	0.438 <sup>a</sup> ±0.015
Foot Slope	5.998 <sup>b</sup> ±0.304	0.415 <sup>a</sup> ±0.093	81.040 <sup>a</sup> ±11.080	5.293 <sup>a</sup> ±3.969	13.670 <sup>a</sup> ±8.386	1.555 <sup>a</sup> ±0.162	26.555 <sup>a</sup> ±14.536	0.395 <sup>a</sup> ±0.084

Means with the same letter are not significantly different

In Bule (Table 2), sand percentage differed significantly across landform segments, except between the crest and foot slopes. A corresponding variation was observed in clay content with the shoulder position having the highest clay content (12.49 ± 3.65%) and the foot slope the lowest (5.43 ± 1.49%). These findings align with Miller and Haff (2018) and Johnson *et al.* (2021) who described the gravitational sorting of suspended materials downslope. However, the dominance of sand (up to 92%) in the foot slope suggests that coarse particle accumulation is more prominent than expected. The sandy texture at the crest and foot slope positions contrasts with the loamy sand at the shoulder and back slope, which supports Anderson *et al.* (2016) and Nguyen *et al.* (2019) who reported coarse materials depositing earlier as runoff velocity reduces.

Bulk density, aggregate stability, and porosity did not show significant differences among slope positions, consistent with the findings of (Mikha & Rice, 2016; Fenton *et al.* 2020; Siddiqui *et al.* 2023), who emphasized that land use and cropping history often override topographic effects in shaping these properties.

**Table 2: Physicochemical Properties of Topsoil (0-30cm) at Bule**

Landforms	pH	OC (%)	Sand (%)	Silt (%)	Clay (%)	BD (g/cm <sup>3</sup> )	AS (%)	PS (%)
Crest	6.000 <sup>a</sup> ±0.447	0.150 <sup>a</sup> ±0.136	92.293 <sup>a</sup> ±3.818	1.630 <sup>a</sup> ±1.489	6.083 <sup>b</sup> ±2.583	1.785 <sup>a</sup> ±0.142	37.405 <sup>a</sup> ±9.963	0.353 <sup>a</sup> ±0.051
Shoulder	6.115 <sup>a</sup> ±0.079	0.330 <sup>a</sup> ±0.029	84.675 <sup>b</sup> ±1.596	2.835 <sup>a</sup> ±2.615	12.490 <sup>a</sup> ±3.652	1.575 <sup>a</sup> ±0.126	37.725 <sup>a</sup> ±7.410	0.390 <sup>a</sup> ±0.029
Back Slope	6.010 <sup>a</sup> ±0.143	0.328 <sup>a</sup> ±0.265	88.283 <sup>ab</sup> ±1.833	1.998 <sup>a</sup> ±1.558	9.720 <sup>ab</sup> ±3.259	1.678 <sup>a</sup> ±0.093	40.223 <sup>a</sup> ±1.388	0.360 <sup>a</sup> ±0.029
Foot Slope	5.753 <sup>a</sup> ±0.067	0.770 <sup>a</sup> ±0.742	92.260 <sup>a</sup> ±2.599	2.308 <sup>a</sup> ±1.195	5.435 <sup>b</sup> ±1.487	1.650 <sup>a</sup> ±0.076	27.853 <sup>a</sup> ±14.817	0.368 <sup>a</sup> ±0.015

Means with the same letter are not significantly different

Wange (Table 3) exhibited a significant pH differences across slope segments, with the lowest pH at the back slope (5.618 ± 0.120) and the highest at the crest (6.728 ± 0.206), reflecting minimal leaching of base cations at higher elevations (Bork *et al.* 2018). Organic carbon showed a clear gradient, highest at the crest (1.200 ± 0.455%) and decreasing downslope, contrary to the typical pattern described by Isola *et al.* (2020). This anomaly may result from concentrated organic inputs such as animal manure and household waste applied near residential areas predominantly situated at upper slopes, and stabilized by terracing practices.

No significant differences were found in sand, silt, or clay content across slope segments, suggesting minimal material translocation due to effective soil conservation strategies (e.g. stone

terracing). Likewise, bulk density and porosity were stable across the slope positions. However aggregate stability differed significantly between the crest and lower positions. The crest had the lowest value ( $1.463 \pm 0.070\%$ ) increasing steadily downslope to the back slope ( $12.903 \pm 3.321\%$ ). This trend aligns with Jimoh *et al.* (2020) and Isola *et al.* (2020), who attributed similar patterns to erosion and surface runoff redistributing stable aggregates to lower slopes. Texturally, Wange's soils ranged from sandy clay loam at the crest to loamy sand at the back slope, again supporting the findings of (Obalum *et al.* 2017; Miller &Haff, 2018; Johnson *et al.* 2021) on the movement of fine materials from upper to lower positions under steep topography.

**Table 3: Physicochemical Properties of Topsoil (0-30cm) at Wange**

Landforms	pH	OC (%)	Sand (%)	Silt (%)	Clay (%)	BD (g/cm <sup>3</sup> )	AS (%)	PS (%)
Crest	6.728 <sup>a</sup> ±0.206	1.200 <sup>a</sup> ±0.455	69.670 <sup>a</sup> ±9.674	10.333 <sup>a</sup> ±6.468	20.003 <sup>a</sup> ±5.525	1.513 <sup>a</sup> ±0.056	1.463 <sup>b</sup> ±0.070	0.453 <sup>a</sup> ±0.019
Shoulder	6.373 <sup>b</sup> ±0.362	0.543 <sup>b</sup> ±0.255	79.880 <sup>a</sup> ±8.438	7.863 <sup>a</sup> ±5.737	12.258 <sup>a</sup> ±2.893	1.550 <sup>a</sup> ±0.091	11.985 <sup>a</sup> ±2.086	0.428 <sup>a</sup> ±0.061
Back Slope	5.618 <sup>c</sup> ±0.120	0.463 <sup>b</sup> ±0.152	82.445 <sup>a</sup> ±10.147	5.888 <sup>a</sup> ±6.245	11.668 <sup>a</sup> ±4.798	1.580 <sup>a</sup> ±0.053	12.903 <sup>a</sup> ±3.321	0.395 <sup>a</sup> ±0.019
Foot Slope	6.315 <sup>b</sup> ±0.100	0.668 <sup>b</sup> ±0.413	80.005 <sup>a</sup> ±7.850	6.555 <sup>a</sup> ±3.185	13.440 <sup>a</sup> ±5.054	1.560 <sup>a</sup> ±0.094	10.385 <sup>a</sup> ±8.137	0.428 <sup>a</sup> ±0.019

*Means with the same letter are not significantly different*

Yiri (Table 4) presented a markedly different scenario. None of the measured soil properties pH, OC, texture, bulk density, aggregate stability or porosity showed significant differences across landform segments. While organic carbon values were generally lower than in other locations, bulk density remained consistently moderate and the sandy loam to loamy sand textural classes were uniformly distributed. The relatively uniform soil properties across Yiri's landscape segments can be attributed to its gentle topography which limits erosion, runoff, and translocation of soil materials. This supports the conclusions of Zhang *et al.*, 2021 and Liu *et al.*, 2023 who observed more consistent soil development under gentle slope gradients with improved water retention and reduced heterogeneity.

**Table 4: Physicochemical Properties of Top Soil (0-30cm) at Yiri**

Landforms	pH	OC (%)	Sand (%)	Silt (%)	Clay (%)	BD (g/cm <sup>3</sup> )	AS (%)	PS (%)
Crest	6.550 <sup>a</sup> ±0.216	0.095 <sup>a</sup> ±0.017	80.530 <sup>a</sup> ±7.268	8.455 <sup>a</sup> ±5.052	11.018 <sup>a</sup> ±5.092	1.548 <sup>a</sup> ±0.083	38.735 <sup>a</sup> ±5.861	0.430 <sup>a</sup> ±0.008
Shoulder	6.595 <sup>a</sup> ±0.104	0.123 <sup>a</sup> ±0.051	81.330 <sup>a</sup> ±4.934	8.195 <sup>a</sup> ±6.000	10.473 <sup>a</sup> ±1.197	1.573 <sup>a</sup> ±0.019	27.860 <sup>a</sup> ±10.362	0.408 <sup>a</sup> ±0.005
Back Slope	6.708 <sup>a</sup> ±0.460	0.093 <sup>a</sup> ±0.039	84.420 <sup>a</sup> ±3.844	6.795 <sup>a</sup> ±4.212	8.788 <sup>a</sup> ±1.514	1.613 <sup>a</sup> ±0.057	40.185 <sup>a</sup> ±14.796	0.388 <sup>a</sup> ±0.028
Foot Slope	6.575 <sup>a</sup> ±0.388	0.083 <sup>a</sup> ±0.010	75.855 <sup>a</sup> ±6.253	10.803 <sup>a</sup> ±3.183	13.340 <sup>a</sup> ±7.233	1.610 <sup>a</sup> ±0.080	36.118 <sup>a</sup> ±16.879	0.413 <sup>a</sup> ±0.037

*Means with the same letter are not significantly different*

## CONCLUSION AND RECOMMENDATION

This study comprehensively characterized the physical properties of Tula Hill soils along topo sequences in four distinct wards, revealing significant spatial variability influenced by the interaction of topography, parent material (Bima Sandstone Formation), and localized management practices. The soils are predominantly sandy, reflecting their geological origin, and generally exhibit pH values ranging from moderately acidic to neutral, suitable for arable crops. Despite the hilly terrain, the consistently low bulk density and generally adequate porosity across most positions suggest favorable conditions for root proliferation and water and air movement.

A key finding is the deviation from some conventional topo sequence trends; for instance, organic carbon distribution in Baule and Wange suggests localized enrichment at upper slopes, likely



due to domestic activities and the influence of highly permeable underlying bedrock. This bedrock, coupled with the inherent sandy texture, appears to facilitate high infiltration rates, effectively mitigating surface runoff and erosion risk despite the steep slopes. Aggregate stability, while variable, showed promising improvements in lower slopes in some areas, indicating depositional advantages. Overall, the physical properties of Tula Hill soils highlight their unique characteristics shaped by complex geo-morphological processes and human interventions. This detailed understanding of soil variability is essential for optimizing agricultural management and land use planning in this ecologically sensitive semi-arid and hilly region.

Based on the findings of this study, the following recommendations are put forth for sustainable agricultural management and future research in Tula Hill soils and similar hilly, sandy-textured regions:

1. Tailored Nutrient Management. Given the g
2. Generally low organic carbon content and the observed pH variations, site-specific nutrient management plans are recommended. This includes promoting practices that increase organic matter return, such as composting, cover cropping, and judicious application of organic fertilizers, to enhance soil fertility and water retention.
3. Strategic Water Conservation Measures. While the soils exhibit high infiltration capacity tendencies due to their sandy nature and the underlying fractured sandstone, localized water conservation strategies are still beneficial. The widely practiced stone terracing should be continually encouraged and potentially expanded, alongside other artificial water retention strategies like contour bunds or infiltration trenches, especially in areas where rapid surface runoff might still reduce water availability for crops, even with high infiltration rates or as the case may be.
4. Optimize Management for Toposequence Positions. Recognizing the spatial variability in soil properties along the toposequence, differential land use and crop selection choices should be adopted. Upper slopes might benefit from practices that build organic matter and enhance aggregate stability to counteract potential erosion, while lower slopes may be optimized for crops requiring higher moisture and nutrient availability due to depositional effects.
5. Long-term Monitoring of Soil Health: Establish long-term monitoring sites across different toposequence positions to track changes in soil physical and chemical properties in response to climate variability and evolving agricultural practices. This will provide valuable data for adaptive management strategies.
6. Education and Capacity Building: Local farmers should be educated on the significance of maintaining soil health, particularly through sustainable land management practices that enhance organic matter and minimize soil disturbance, considering the unique challenges and opportunities presented by Tula Hill's terrain.

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