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A Review on the Impacts of Toposequence on Soil Properties

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ABSTRACT

This study demonstrates the significant influence of toposequence position on soil properties and hydrological conditions, affecting crop yield. Variations in toposequence position lead to differences in soil properties; physical and chemical properties may vary minimally or maximally depending on the slope's location. As slope increases, soil moisture and organic carbon rise, while bulk density, pH, and soil temperature decrease. Soils along a toposequence reveal that landscape position, erosion, aspect, and drainage impact soil depth, particle size distribution, and CEC. Understanding topography's influence on soil characteristics is crucial for evaluating soil productivity and devising conservation strategies. This knowledge is essential for assessing soil value and avoiding uneven input distribution in agricultural fields on diverse terrains. This review paper summarizes the impacts of toposequence on soil physical and chemical properties. The study utilized databases such as Google Scholar, African Journals Online (AJOL), Scopus, Web of Science, ScienceDirect, and Directory of Open Access Journals (DOAJ) to identify relevant studies.

INTRODUCTION

African soils exhibit rolling topography, leading to changes in soil properties influenced significantly by slope, which varies from the crest position to the valley bottom (Egbuchua, 2014). Besides parent material and climate, topography plays a vital role in soil mineral distribution (Atofarati *et al*., 2012). It determines soil profile drainage and depth; higher elevations usually have well-drained soil, whereas lower slopes typically feature poorly drained, fine-textured soil (Atofarati *et al*., 2012). The food insecurity challenge in tropical regions with intricate topography arises from rapid soil loss and fertility decline (Sobieraj *et al*., 2002). Topography impacts soil-forming processes through erosion and deposition, leading to specific gradients in soil texture along toposequences (Eshett *et al*., 2000; Yamauchi, 2000). Variations in soil nitrogen (N), phosphorus (P), and potassium (K) content occur between upper and lower fields due to topography-induced differences (Yamauchi, 2000). Topography also affects drainage, soil erosion, texture, and other properties influencing crop growth and productivity (Atofarati *et al*., 2012). Soils on steep slopes are shallow and gravelly due to limited weathering and erosion, whereas gentle slopes foster deep soil profiles with ample water infiltration (Esu, 2010). Topography significantly influences soil physicochemical properties, biomass production, solar radiation, precipitation, and crop yield. Downward slope increments lead to increased soil moisture and organic carbon, with higher elevations having lower bulk density, pH, and soil temperature (Nahusenay and Kibebew, 2016). Topography affects soil morphological, chemical, and physical properties, creating distinct soil types even from the same parent material (Esu *et al*., 2008). This variation results in catenas, a succession of soil types from hilltops to valley bottoms (Aweto and Enaruvbe, 2010). Understanding topography's role in soil properties is crucial for evaluating soil productivity and developing conservation strategies, preventing uneven input distribution in agricultural fields on varying topographies (Oku *et al*., 2010). Soil characteristics, both physical and chemical, play a crucial role in defining and assessing soil types, slopes, and the existing land use or natural cover, considering specific management conditions. Naturally occurring soil variations stem from pedogenic factors and can be observed across various geographic scales, spanning from small fields to extensive agricultural areas. Reviewing the effect of toposequence on soil properties are essential for addressing the proper land use and land management. This study aims to explore the impacts of toposequence on soil properties.

LITERATURE REVIEW

What is Toposequence

A toposequence represents a continuum of interconnected soils, extending from the hilltop to the valley floor. Farmers commonly cultivate the entire toposequence, although some confine their cultivation to specific sections (Oluwatosin *et al*., 2001). Disparities in toposequence positions can result in variations in soil properties and hydrological conditions (Hseu and Chen, 2001; Tsubo *et al*., 2006), thereby affecting crop yield. Despite documented differences in soil properties and crop yield along toposequences, agricultural recommendations are often generalized without considering specific topographic locations that might influence management decisions such as fertilizer types and rates, tillage practices, and herbicide applications (Oluwatosin *et al*., 2001). This oversight leads to significant fluctuations in crop yield. Recognizing fundamental soil properties is crucial for formulating soil management

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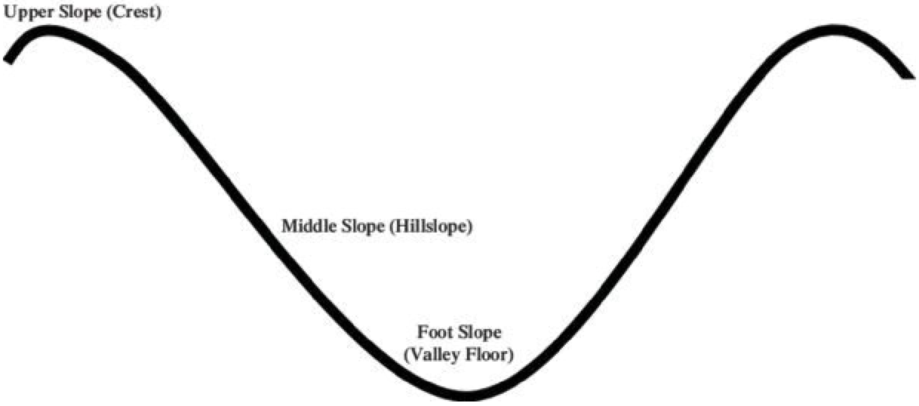

Figure 1: Sketch of Toposequence
Source: Effiom Oke, (2010)

practices that preserve a soil's productive potential. The suitable utilization of land relies on its individual characteristics (Oluwatosin *et al.*, 2001). For example, due to the impact of toposequence position on rice yield, it has been proposed that tailored management suggestions specific to toposequences may be more effective than uniform recommendations, especially in rainfed areas (Banik *et al.*, 2006). Numerous efforts have been made to correlate soil properties with toposequence position across various landscapes (Wysocki *et al.*, 2001). This endeavor partly stems from the acknowledgment of the pivotal role topographic position plays in shaping runoff, soil erosion, and, consequently, soil formation (Babalola *et al.*, 2007).

Topography

Soil topography plays a pivotal role as one of the influencing factors in pedogenesis, shaping the distribution and utilization of soils across the landscape (Esu *et al.*, 2008). Topography is fundamental to the catena concept of soil development (Hook and Burke, 2000), characterized by leaching and the redistribution of elements and soil material along hill slopes. Its impact is particularly pronounced on young and rolling soils in comparison to older and flatter terrains (Fisher and Binkley, 2000). Topography significantly influences both the chemical and physical properties of soil, as well as the spatial arrangement of soil across the landscape (Esu, 2005). Rainfed lowlands often exhibit undulating topography and high spatial variability in environmental conditions (Tuong *et al.*, 2000). Variations in soil nitrogen (N), phosphorus (P), and potassium (K) content have been observed between upper and lower fields. The nutrient status of the soil directly affects crop growth and the formation of yield (Homma *et al.*, 2004). Following heavy rainfall, upper rice fields experience significant runoff, which can be intercepted by lower fields. Consequently, the groundwater table may be deeper and the soil drier in upper fields compared to lower fields. These differences in field hydrology determine water availability for crop growth, directly impacting yield formation. Field water status also affects nutrient availability and influences weed growth, further differentiating crop performance (Pane *et al.*, 2005). According to Mulla and McBratney (2001), small changes in topography can cause variability in soil properties at the series level, affecting the transport and storage of water across and within the soil profile. Ogunkunle (1993), in his study on Alfisols in southwestern Nigeria, noted that soil pH exhibited low variability, regardless of depth. Properties such as organic matter, available phosphorus, total nitrogen, and CEC showed increased variability with depth. Soil pH and porosity were among the least variable properties, whereas those related to water or solute transport were highly variable. Percentage of sand exhibited low to moderate variability, while organic matter and % clay showed moderate to high variability. Available phosphorus and potassium were highly variable (Wollenhaupt *et al.*, 1997).

Topographic Attributes and Vegetation as Factors in Soil Properties Variations

The spatial variation in soil properties is influenced by biotic and abiotic factors such as topography-induced microclimate differences, altitude, landscape position, parent material and vegetation community (Ollinger *et al.*, 2002). Topography influences local and regional climate by changing the pattern of precipitation and temperature solar radiation and relative humidity (Smith and Smith, 2000). Microclimate variations with altitude dramatically influence the type and composition of vegetation species, weathering rates and leaching intensity, resulting in feedback on soil properties such as amount and quality of organic matter, clay and mineralogy, cation exchange capacity and base saturation (Dahlgren *et al.*, 1997). Topographic aspect is a potentially significant factor in generating differences in ecosystem characteristics (Sardinero, 2000). For example, the hydrological and solar energy regimes of mountainous topography differ according to aspect, leading to divergence in the composition and distribution of vegetation, soil formation and organic matter decomposition (Ganuza and Almendros, 2003). Aspect also induces local variations in temperature and precipitation, which along with chemical and physical composition of the substrate are the main regulators of decomposition rates of soil organic matter (Mendoza-Vega, 2002).

Topography and Soil Variation

Topography plays a vital role in biogeochemical processes which performs key environmental, economic and social functions (Griffiths *et al.*, 2009). Any spatial patterns depend on soil forming processes, our understanding of which is still limited, especially in regards to topographic effects. As the landscape is undulating, soil characteristics at different topographic positions differ. Soils vary in their characteristics primarily because of topography (Amhakhian and Achimugu, 2011) which modifies soil water relationships and large extent influences on rainfall, drainage, soil erosion, textural composition and other soil properties that affect plant growth within a field (Atofarati *et al.*, 2012). Topographic variability associated with crop production is an integrated reflection on soil properties and factors affecting agricultural productivity (Dinaburga *et al.*, 2010). The numbers of studies have publicized (Griffiths *et al.*, 2009) a clear association between land uses and topographical parameters (slope, soil surface curvature and elevation). Topography of agricultural fields can influence soil physicochemical properties (soil depth, texture, and mineral contents), biomass production, incoming solar radiation, precipitation and affect crop production (Reuter *et al.*, 2005). As increase in topography/elevation occur, it significantly increased soil moisture, precipitation, soil organic matter and labile carbon, whereas bulk density, pH and soil temperature were significantly lower at the higher elevations (Si and Farrell, 2004).

METHODOLOGY

A literature review was carried out to identify the relevant articles published. The earliest research publication concerning the review was found in 1981. Google Scholar, African Journals Online (AJOL), Books, Scopus, Web of Science, Science Direct and Directory of Open Access Journals (DOAJ) databases were explored to identify studies on the impacts of toposequence on soil properties using the following keywords in English; 'toposequence effects on soil variation', 'topography and soil properties', 'toposequence impacts on soil physical and chemical properties.' A total of 300 articles were identified in the initial review but 24 articles were selected to be a good match for the review study based on the objective of the study. Figure 2 below shows the system search method.

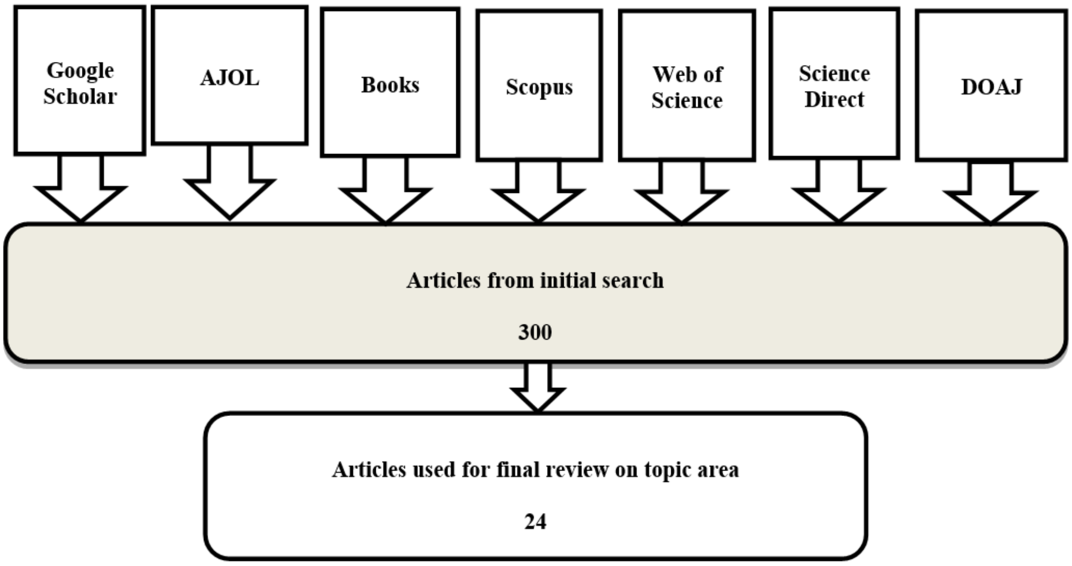

Figure 2: Flow chart showing methodology of review of discussion

DISCUSSION

Impacts of Toposequence on Soil Physical Properties

Bulk Density

Bulk density is a measure of the mass of soil per unit volume. When soil particles are pushed close together, increasing the mass per unit volume, the soil is compacted. However, soil compaction is an increase in bulk density due to external load leading to the degradation of physical soil properties such as root penetration, hydraulic conductivity and aeration (Mitiku *et al.*, 2006). The bulk specific gravity of sandy soils with a relatively low volume of pores may be as high as 1.6, whereas that of aggregated loams and clay soils may be below 1.2. The low bulk density and gravel content at foot slope position indicates low level of soil compactness and associated improvement in root penetration (Ogban and Babalola, 2003), and hence favourable root activity (Ogban and Babalola, 2009). In addition, changes in gravel content may explain why there were changes in soil physical properties (Fasina *et al.*, 2007).

Soil Texture

Soil texture refers to the relative proportion of stone, gravel, sand, silt and clay in a specified quantity of soil. Sand particles are 2.00-0.05 mm in diameter, silt 0.050-0.002 mm and clay <0.002 mm. Soil texture determines soil workability, water-holding capacity, soil structure and nutrient retention. Compared to sandy soils, clay soils hold more water and retain nutrients. Clay particles are lighter than sand particles, and once detached by erosion they are easily transported. Therefore, unchecked erosion leads to a loss of soil productivity (Gachene and Kimaru, 2003). According to Buol *et al.* (2003), the particle size distribution of the soils varied along the toposequence. Soils situated at the middle slope position had relatively higher clay content (25 - 85%), throughout the profile, followed by soils located at upper (15 - 60%), toe (35 - 55%) and lower slope (25 - 30%) positions. The sand contents also varied among the soils, with values ranging from 20 - 50%, 30 - 40%, 20 to 40% and 10 - 35% at upper, lower, toe and middle slope positions, respectively. Soils at the upper and middle slope positions have discernable increase in clay content with soil depth compared to those found at lower and toe slopes, which have slight clay increase. It could also be due partly to deposition by runoff from the adjacent upland and partly to low erosion status of the soil at the present level of cultivation (Ogban and Babalola 2003, 2009). This observation did not conform to expectation that clay content are commonly higher at foot slopes due washing away of clay-rich materials from upper slopes as explained by Babalola *et al.* (2007). According to Ovales and Collins (1986), sand particles due to their size are normally deposited at the upper slopes. In general, properties, such as percentage sand, clay were affected by topographic position.

Infiltration

Infiltration is the downward entry of water from the surface into the soil profile (Lal, 2004). It is the key to soil and water conservation because it determines the amount of runoff over the soil surface during rainstorms. The relation between the rate of water supply to the soil and the rate of infiltration through it determine the distribution of such water between runoff and storage in the root zone (Pla, 2007). Thus, the ability of the soil surface to accept continuous heavy rainfall or irrigation depends on the infiltration behaviour or characteristics of the soil. According to Ogban *et al.* (2000), low values of the infiltration characteristics indicate a potentially high runoff (erosion) on such toposequence or slopes. These will invariably affect the water economy of the rooting zone of plants. Such soil will have difficulty in meeting the water needs for crop production where water is a major limiting factor (Wuddivira and Abdulkadir, 2000).

Hydraulic Conductivity

The term hydraulic conductivity, which has been defined as the meters per day of water seeping into the soil under the pull of gravity or under a unit hydraulic gradient Tsegaye *et al.* (2006). The values of soil moisture content were highest at the foot slopes (FS) under all land use. This is very much expected and is an indication of seepage and the concentration of runoff from upper slopes as was found by Tsegaye *et al.* (2006). This also indicates that soil moisture content is highly influenced by slope position.

Total Porosity

Porosity is an index of the relative pore space in a soil. Its value generally ranges from 0.3 to 0.6 (30–60%). Coarse textured soils tend to be less porous than fine-textured soils, though the mean size of individual pores is greater in the former. In clay soils, the porosity is highly variable because the soil alternately swells, shrinks, aggregates, disperses, compacts, and cracks. Total porosity (TP) values ranged from 45.10 to 59.65%. Except for plantain land use, total porosity values were highest at the foot slopes (FS) along toposequence (USDA, 2001). The total porosity (TP) of the soils varied between 53% and 61% (volume percentage), while macro pores (pores at field capacity) ranged from 12% to 28% (volume percentage). According to Brady and Weil (2002), the ideal total pore space values suitable for crop production typically hover around 50%. Consequently, the soils in this study fall within an acceptable range of total porosity values conducive to crop production.

Impacts of Toposequence on Soil Chemical Properties

Cation Exchange Capacity

According to Brady and Weil (2002), CEC depends on the nature and number of colloidal particles. Landon (1991) noted that, the cation exchange capacity of the soils was low both within and between profiles along the toposequence. The distribution trend within the profiles is similar to that of clay content. The CEC values within the toposequence position also follow the pattern of clay distribution with the upper slope position having the highest value of clay contains and the lower slope position having the lowest value clay contains. Furthermore, the upper and middle pedons have relatively higher CEC than the lower and toe slope pedons. CEC values are rated < 5 as very low, 5 - 15 as low; 15 - 25 as medium, 25 - 40 as high and > 40 as very high. (Landon, 1991).

Soil pH

Soil pH depends on a variety of factors including the season of the year, cropping practices, the soil horizon sampled, the water content at the sampling time and the way the pH is determined (Troeh and Thompson, 1993). The toposequence affect the soil ph thus, least values at the upper slope positions indicate that acidity decreases down the slope. It must be stated that the prevalence of acidity at the upper slopes is an indication of strong chemical weathering and leaching of plants nutrients as reported by Babalola *et al.* (2007). Onweremadu (2007) reports that increased pH at foot slopes account for high total nitrogen, cation exchange capacity and organic matter.

Soil Organic Carbon

Soil organic carbon (SOC) is an important soil component that plays key roles in the functions of both natural ecosystems (greatly influencing soil structure, fertility, and water-holding capacity) and agricultural systems, in which it also affects food production and quality (Lal, 2004). Topography and toposequence affects soil C through erosion and redistribution of fine soil particles and organic matter across landscape, and through water redistribution leading to varying leaching, infiltration, and runoff potentials (Creed *et al.*, 2002). Topography is one of the key factors of soil formation and its effects on soil C have been well documented; many researchers reported a strong relationship between terrain attributes and soil C at a field scale (Ziadat, 2005; Papiernik *et al.*, 2007). General topographical influences on soil C are likely to differ in magnitude under agricultural systems with different tillage. Tillage controls soil organic matter dynamics by three major actions, such as periodic disruption of soil structure, incorporating plant residues within soil horizon, and altering soil microclimate (Balesdent *et al.*, 2000).

Soil Organic Matter (SOM)

Soil organic matter reduces compaction by promoting soil aggregation and increasing porosity (Teklu, 2005). Highest concentration of SOM and total nitrogen occurred at the foot slope position whiles least concentrations occurred at upper slope position. The high concentrations of these nutrients at foot slopes suggest that overland flow and surface runoff may have transported these soil nutrients to the foot slope. This observation is consistent with findings made by Babalola *et al.* (2007) and Onweremadu (2007).

Nitrogen

Topography influence soil nitrogen and carbon through erosion and redistribution of soil materials through leaching, infiltration and runoff potentials (Creed *et al.*, 2002, Senthilkumar *et al.*, 2009). However, the effects of topography on soil carbon are likely to vary in magnitude under agricultural systems with different management practices and soil depth. Soil depth controls soil nitrogen and carbon dynamics by bioturbation, placement of plant and animal residues on the surface of the soil and/or incorporation of organic materials within the epipedon and endopedon of soil (Senthilkumar *et al.*, 2009). Nitrogen, a vital nutrient for plant nutrition, exists in soils primarily in two forms: organic and inorganic. Approximately 95-99% of the total nitrogen in soils is in the organic form, with the remaining 1-5% present as ammonium and nitrates (Buruah and Barthakur, 1997). Total nitrogen serves as an indicator of the soil's potential for this element; however, it does not directly measure its availability to plants. Assessing nitrogen content in soils is crucial for evaluating the C:N ratios, providing insights into the processes of transforming organic nitrogen into available forms such as ammonium nitrite (Buruah and Barthakur, 1997).

Phosphorus

Phosphorus (P) stands as a vital nutrient element, classified as a macro-nutrient due to its significant quantity essential for plant growth. It plays crucial roles in various plant processes such as energy metabolism, nucleic acid and membrane synthesis, photosynthesis, respiration, nitrogen fixation, and enzyme regulation. In the soil, phosphorus exists in diverse organic and inorganic forms. The inorganic P in soil includes iron-bound phosphate, aluminum-bound phosphate, and calcium phosphate (Jianbo *et al.*, 2011). Particularly in tropical soils, phosphorus is identified as one of the most limiting nutrient elements (Ahn, 1993). The low availability of phosphorus in tropical soils can be attributed to the specific nature and forms of soil phosphorus, as well as the high levels of iron and aluminum oxides associated with phosphate fixation (Osodeke and Osondu, 2006). Juo and Moorma (1981) define a toposequence as a sequence of sites from the crest to the valley bottom, encompassing a variety of soil profiles representative of the landscape and soil. The distribution of individual soil series within a toposequence, as well as the spatial arrangement of the toposequence itself, significantly influences soil properties and land use patterns (Ogban *et al.*, 1999). Therefore, Oluwatosin *et al.* (2001) recommended the adoption of agronomic practices after careful consideration of specific topographic locations, as these locations can influence mineral availability and fertilizer recommendations.

CONCLUSION

Research finding has indicated that the difference in slope level, and landscape position has an influence on soil physical and chemical properties. The properties of soils along a toposequence showed that landscape position, erosion, aspect, and drainage significantly influenced variation in soil depth, particle size distribution, CEC and others. Particle size distribution of the soils varied along the toposequence. Soils at the upper and middle slope positions have discernable increase in clay content with soil depth compared to those found at lower and toe slopes, which have slight clay increase. The low bulk density and gravel content at foot slope position indicates low level of soil compactness. Corresponding to the position with the highest amount of organic carbon and the lowest value were at the lower slope position. This revealed that soil properties such as water content, total porosity, sand content, clay content, bulk density, soil pH, organic matter and carbon are influenced by topographic position. In general, toposequence has a great influence on soil physical and chemical properties.

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