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Original Research Article

Relationship Between Soil Physicochemical Properties and Weed Abundance Along Topographic Gradients in Niger State, Nigeria

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Abstract: The relationship between soil properties and weed distribution across two geological formations were evaluated on morphological, physical, and chemical properties, and their influence on weed distribution along two toposequences in different geological formations, Minna (Basement Complex) and Bida (sedimentary formation) in Niger State.. Six soil profile pits were excavated across the two toposequence three from each toposequence at upper, middle, and lower slope positions, and samples were collected from identified genetic horizons for laboratory analyses using standard procedures. Weed assessment was conducted using 1 m² quadrants, and species were identified using standard taxonomic guides. The results showed that soils across the two toposequences were predominantly loamy sand, with sand content ranging from 800–840 g kg^{-1}, indicating coarse texture. The soil structure varied from weak granular in surface horizons to moderate subangular blocky in subsoils. The soil pH ranged from slightly acidic to near neutral (6.00–6.91) in the two toposequence, while organic carbon and total nitrogen decreased with depth, indicating surface accumulation of organic matter. Exchangeable bases were moderate, suggesting a moderate fertility status. Lower slope positions exhibited relatively higher organic matter and nutrient accumulation due to erosion–deposition processes. Weed distribution varied markedly across slope positions, with drought-tolerant species dominating the upper slopes and moisture-loving species prevalent on the lower slopes, particularly under Basement Complex soils. The study demonstrates that topography and parent material jointly influence soil variability and weed distribution. These findings highlight the importance of site-specific soil and weed management strategies for improved and sustainable agricultural productivity.

Keywords: *Toposequence, soil properties, weed distribution, Basement Complex, sedimentary formation.*

1.0 INTRODUCTION

Soil is a dynamic natural resource composed of minerals, organic matter, water, and air, formed through the interaction of climate, organisms, relief, parent material, and time (Soil Survey Staff, 2014). It plays a central role in agricultural productivity, food security, and environmental sustainability (Brady and Weil, 2017). Variations in soil properties arising from these factors significantly influence plant growth and crop performance.

Topography is a key soil-forming factor that drives spatial variability in soil properties across landscapes. Differences in slope position create distinct soil conditions along a toposequence, forming a sequence of soils known as a catena (Aweto and Enaruvbe, 2010). Soils on upper slopes are typically shallow and erosion-prone, while those in lower positions are deeper and more fertile due to deposition and moisture accumulation (Moeslund *et al*., 2013). These variations influence soil morphology, nutrient distribution, and productivity (Jimoh *et al*., 2020).

Given research information on productive potential and technical know-how available for sustainable management of land resources of this zone, it is technically feasible to manage land resources intensively for sustained agricultural production without jeopardizing their future potential (Lal, 2004).

Weeds are unwanted plants that compete with crops for nutrients, water, and sunlight, thereby reducing yield and quality (Ngadiani and Restia, 2020). They also serve as hosts for pests and diseases and account for significant

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crop losses globally (Gharde *et al*., 2018). Weed distribution varies across environments and is influenced by species, composition, density, and seasonal conditions (Korav *et al*., 2018).

Soil properties such as texture, structure, pH, organic matter, and moisture content influence weed occurrence and distribution. However, the interaction between soil variability along toposequences and weed dynamics remains insufficiently understood, particularly in heterogeneous landscapes.

In Niger State, soils are derived from Basement Complex rocks and sedimentary formations, resulting in diverse soil characteristics (Amadi *et al*., 2012). The Basement Complex, dominated by granites, gneisses, and migmatites, produces predominantly coarse-textured soils, while sedimentary formations often support finer and more fertile soils (Jones and Faheem, 2020). These variations, combined with topographic differences, create complex soil patterns that may influence weed distribution.

Despite this variability, there is limited information on how soil properties interact with weed occurrence across toposequences in different geological formations in Niger State. This knowledge gap restricts the development of effective, site-specific weed management strategies. Therefore, this study investigates the relationship between soil characteristics and weed distribution along two contrasting geological formations to support sustainable land management and improved agricultural productivity.

The objectives of this paper are to characterize and classify soils along the two toposequences, and to identify weed species and assess their distribution along the toposequences of different geological formations.

2.0 MATERIALS AND METHODS

2.1 Location:

Two toposequence were selected for this study within the sedimentary and basement complex (Minna and Bida geological formations) in Niger state. Both locations lie within latitudes 9°32′–9°42′N and longitudes 6°30′–6°40′E and latitudes 9°00′–9°09′N and longitudes 5°56′–6°04′E, and the altitude range from 196-203m above sea level (ASL). The first toposequence in the basement complex was located within the experimental farm site of the Federal University of Technology, Minna, while the second toposequence was located along Kataeragi-Bida road.

Minna lies within the northwestern Nigerian Basement Complex, dominated by crystalline rocks such as gneisses, migmatites, and schists (Mohammed et al., 2008). Bida is located within the Cretaceous Mid-Niger (Bida/Nupe) Basin (Daramola et al., 2019).

Niger State has a sub-humid climate with a distinct wet season occurring between March and October. In Minna, temperatures typically vary throughout the year between about 15°C and 34°C (Weather Spark, 2022). Mean annual rainfall in Minna is about 1200 mm (Adeboye et al., 2011). Bida experiences a tropical continental climate influenced by the ITCZ, with annual rainfall of 1100–1500 mm and temperatures ranging from 12°C to 40°C (Daramola, 2013).

2.2 FIELD AND LABORATORY STUDIES

Six profiles were excavated in the two locations, three from each. TP1, TP2 and TP3 were sited in Basement complex soils, while TP4, TP5 and TP6 were sited in Sedimentary formations. Soil of the pedogenic horizons of each profile was studied morphologically on the field. The soil samples were collected from these horizons, air-dried and passed through a 2mm sieve.

Soil Taxonomic Classification

The soils were classified up to Subgroup level using the guidelines of USDA Soil Taxonomy (Soil Survey Staff, 2022) and correlated with World Reference Base for Soil Resources (WRB) in accordance with the IUSS Working group (2022).

Determination of soil properties

The particle size distribution was determined by the hygrometer method (Boycous 1962) after the removal of organic with hydrogen peroxide and dispersion with sodium hexametamophosphate (IITA 1979). The pH was determined with a glass electrode, pH meter in soil; water and soil; KCL media, each at ratio 1:1. Exchangeable cations (Ca, Mg, K and Na) were extracted with neutral normal sodium acetate(NH_4OAc at pH 7.0), Ca and Mg in the ammonium acetate extract were determined by atomic absorption spectrophotometry, while K and Na were determined by flame photometry. The effective cation exchange capacity (ECEC) was determined by the summation of the exchangeable bases (K, Mg Na and K) and exchangeable acidity. The organic carbon content of the soil was determined by the modified wet oxidation method (Shamsudeen *et al.,* 1995). Available P was extracted with Bray-1 solution and P concentration in the extract was determined colorimetrically by the method of Murphy and Riley (1962).

Assessment of weeds

Weeds were assessed in an undisturbed, uncropped field using three randomly placed 1 × 1 m quadrats per toposequence (one each at the upper, middle and lower slopes), giving six quadrats across both locations. Weed species were identified in the field using Akobundu and Agyakwa (1987), with no unidentified species recorded. Sampling was conducted during peak weed

establishment to ensure representative weed occurrence across slope positions.

3.0 RESULTS AND DISCUSSION

3.1 Taxonomic Classification of the Soils

None of the pedons revealed a fully developed argillic horizon because of their irregular clay distribution and inability to satisfy minimum variation of 1.2-times higher clay content in the immediate horizons next to the Ap. Thus, the soils were qualified as having cambic horizons, hence, placed under the USDA Soil Order, Inceptisols in accordance to the criteria outlined in Soil Survey Staff (2022). All the soils were developed under the ustic moisture regime characteristics with the ecosystems hence were classified as Ustepts at Sub-order level. At Great group level, the soils were placed under Haplustepts because they lacked diagnostics properties that will qualify them to fit into any class at this taxon (level). At Subgroup, levels, pedons at lower slope positions were classified as Oxyaquic Haplustepts due to water saturation in one or more layers within 100 cm of the mineral soil surface for 20 or more consecutive days in normal years. Pedons at the upper and middle slope positions were classified as Typic Haplustepts due to lack of diagnostic feature that qualify them to fit into any of the classes at subgroup taxon.

The Oxyaquic Haplustepts at lower slope positions correlated with WRB system as Gleyic Cambisols (Loamic). Also, the Typic Haplustepts correlated as Dystric Cambisols (Loamic) under the WRB (IUSS Working Group WRB, 2022).

3.2 Morphological and Physical Properties of the Soils

The soils of both the Basement Complex and Sedimentary formations exhibited similar morphological characteristics as shown in Table 1. Surface horizons were dark brown to dark grayish brown due to organic matter accumulation, while subsurface horizons changed to reddish or gray colours, indicating pedogenic development. All soils were loamy sand (80–84% sand), with weak crumb or granular structures at the surface grading into subangular blocky subsoils. Soil consistence became firmer with depth, whereas organic matter decreased and coarse fragments increased, particularly in the Basement Complex. These trends suggest that parent material and topographic position influenced soil profile development and agree with previous studies on tropical toposequences in Nigeria (Ibrahim *et al.,* 2020).

Table 1. Summary of morphological and physical properties of soils along the toposequences under Basement Complex and Sedimentary formations

Geological Formation	Slope Position	Colour (Matrix)	Texture	Soil Structure	Soil Consistence (Wet/Moist/Dry)	Inclusions
Basement Complex	Upper	10YR 3/4(DYB)–5YR 4/3 (RB)	LS	2-vfcr to 3-vcsbk	ss–ns / Firm–Friable / Loose–Very hard	Few to many angular gravels, cobbles and stones
	Middle	10YR 3/2(VDGB)–5YR 4/4 (RB)	LS	1-vfcr to 3-msbk	ns–ss / Friable–Firm / Soft–Hard	Common gravels and cobbles
	Lower	10YR 3/2(VDGB)–10YR 4/1 (DG)	LS	1-fcr to 3-vcsbk	ss–ns / Firm–Very firm / Soft–Hard	Common angular gravels
Sedimentary Formation	Upper	10YR 4/4(DYB)–5YR 4/4(RB)	LS	1-fcr to 2-msbk	ns–ss / Friable–Very firm / Loose–Slightly hard	Few rounded gravels

Middle	10YR 4/4(DYB)–5YR 4/4(RB)	LS	1-vfcr to 2-msbk	ns–ss / Loose–Firm / Loose–Slightly hard	Few rounded gravels
Lower	10YR 4/2(DGB)–10YR 6/3(LG)	LS	1-vfgr to 2-msbk	ns–ss / Loose–Very firm / Loose–Slightly hard	Common rounded gravels

Note: LS = loamy sand; vfcr = very fine crumb; fcr = fine crumb; vfgr = very fine granular; msbk = medium subangular blocky; vcsbk = very coarse subangular blocky; ss = slightly sticky; ns = non-sticky; sp = slightly plastic; np = non-plastic. Colour nomenclature: DYB = dark yellowish brown; VDGB = very dark grayish brown; DGB = dark grayish brown; RB = reddish brown; DG = dark gray; LG = light gray.

3.3 Chemical Properties of the Soils

The chemical properties of the soils are presented in Table 2. Results interpretation was based on fertility classifications of Esu (1991) and Chude *et al*. (2011). Soil pH ranged from 6.0 to 6.9, indicating slightly acidic to nearly neutral conditions that favour nutrient availability and crop growth. Ibrahim *et al*. (2020) similarly reported that topographic position influences nutrient distribution and soil reaction across tropical landscapes. Organic carbon and total nitrogen were generally low but showed relatively higher values at the lower slope positions, reflecting the downslope movement and accumulation of organic materials. Likewise, Mahmud *et al.* (2019) observed greater nutrient accumulation in lower landscape positions due to erosion and depositional processes. Calcium and magnesium were the dominant exchangeable bases, whereas potassium, sodium and exchangeable acidity remained low. Despite the favourable pH, the coarse-textured soils and low organic carbon indicate limited nutrient and moisture retention, suggesting the need for appropriate soil fertility management.

Table 2. Summary of selected chemical properties of soils under Basement Complex and Sedimentary formations

Soil Property	Basement Complex	Sedimentary Formation	Interpretation
pH (H_2O)	6.00–6.91	6.47–6.78	Slightly acidic to near neutral
Organic Carbon (g kg^{-1})	2.0–3.5	2.4–3.2	Low; higher at lower slopes
Total Nitrogen (g kg^{-1})	0.38–1.41	0.79–1.23	Low to moderate
Available P (mg kg^{-1})	9.5–11.7	9.9–11.5	Moderate
Ca (cmol kg^{-1})	2.4–3.3	2.6–3.0	Dominant exchangeable base
Mg (cmol kg^{-1})	1.4–2.6	1.4–2.1	Moderate
K (cmol kg^{-1})	0.03–0.18	0.03–0.09	Low
Na (cmol kg^{-1})	0.10–0.19	0.11–0.17	Low
Exchangeable Acidity (cmol kg^{-1})	0.09–0.15	0.07–0.13	Low

3.4 Weed Occurrence and Distribution

The dominant weed species varied with geological formation and slope position (Table 3). In the Basement Complex, *Dyssodia papposa* dominated the upper and middle slopes, whereas *Schoenoplectus senegalensis* and *Paspalum scrobiculatum* were predominant on the lower slope. In contrast, the Sedimentary formation was characterized by the dominance of *Dactyloctenium aegyptium* and *Gomphrena celosioides* on the upper slope, *Mitracarpus villosus* and *Tridax procumbens* on the middle slope, and *Tridax procumbens* together with *Boerhavia erecta* on the lower slope. Ugen and Wortmann (2001) similarly reported that weed composition is strongly influenced by soil properties and landscape position, while Koné et al. (2013) showed that soil characteristics along toposequences significantly affect weed occurrence. The greater variability observed in the Basement Complex therefore suggests stronger soil–topography interactions than in the Sedimentary formation, highlighting the need for site-specific weed management.

Table 3. Dominant weed species and relative abundance (%) along the toposequences under Basement Complex and Sedimentary formations

Geological Formation	Upper Slope	Middle Slope	Lower Slope
Basement Complex	*Dyssodia papposa* (88.4%), *Corchorus olitorius* (2.9%), *Hyptis suaveolens* (2.9%)	*Dyssodia papposa* (37.5%), *Hyptis suaveolens* (31.8%), *Trixis californica* (10.2%)	*Schoenoplectus senegalensis* (46.2%), *Paspalum scrobiculatum* (23.1%)
Sedimentary Formation	*Dactyloctenium aegyptium* (53.9%), *Gomphrena celosioides* (26.9%), *Tridax procumbens* (11.5%)	*Mitracarpus villosus* (35.5%), *Tridax procumbens* (32.3%), *Setaria barbata* (12.9%)	*Tridax procumbens* (52.2%), *Boerhavia erecta* (23.9%), *Hyptis suaveolens* (13.0%)

3.5 Correlation Analysis between Abundance of Dominant Weed Species and Selected Soil Properties

Tables 4 and 5 present the Pearson correlation coefficients between selected soil properties and the abundance of dominant weed species along the Basement Complex and Sedimentary Formation toposequences, respectively. Overall, most correlations were not statistically significant, indicating that no single soil property consistently controlled the distribution of the dominant weed species across the different slope positions. This suggests that weed abundance is influenced by the combined effects of soil physical and chemical properties together with topographic conditions, rather than by individual soil variables alone (Walter *et al*., 2002).

Under the Basement Complex, a significant negative correlation was observed between clay content and *Corchorus olitorius* abundance at the upper slope ($r = -0.940$, $P \leq 0.05$), indicating that the species was more abundant in coarser-textured soils with lower clay content. Similar preferences of some weed species for lighter-textured soils have been attributed to improved aeration, rapid drainage and favourable seedling establishment (Storkey *et al*., 20). At the lower slope, no significant relationship was observed between the dominant weed species and the selected soil properties, suggesting that local environmental conditions such as moisture accumulation and depositional processes may have exerted greater influence on weed distribution than individual soil characteristics (Adeux *et al*., 2019).

In the Sedimentary Formation, *Mitracarpus villosus* showed a significant negative correlation with clay content ($r = -0.999$, $P \leq 0.05$) and a corresponding significant positive correlation with total nitrogen ($r = 0.999$, $P \leq 0.05$) at the middle slope, indicating that this species was favoured by relatively sandy, nitrogen-rich soils. The positive association with total nitrogen may reflect the tendency of *M. villosus* to proliferate under relatively fertile conditions where nutrient availability promotes rapid vegetative growth, while the negative relationship with clay further suggests preference for well-drained soils (Cordeau *et al*., 2016). These findings support previous reports that soil texture and fertility jointly act as major environmental filters influencing weed community composition and abundance in agricultural landscapes (Storkey *et al*., 2021).

Table 4. Pearson correlation coefficients between selected soil properties and abundance of dominant weed species along the Basement Complex toposequence

Soil Property	Upper (*Dyssodia papposa*)	Upper (*Corchorus olitorius*)	Middle (*Dyssodia papposa*)	Middle (*Hyptis suaveolens*)	Lower (*Schoenoplectus senegalensis*)	Lower (*Paspalum scrobiculatum*)
Sand	-0.466	0.608	0.896	-0.573	-0.155	0.649
Clay	0.695	-0.940*	-0.895	-0.232	-0.520	-0.918
pH (H_2O)	-0.273	0.111	0.812	-0.687	-0.865	-0.655
Organic Carbon	-0.713	0.387	-0.809	-0.129	0.082	0.236
Total Nitrogen	-0.640	0.325	-0.807	0.655	-0.562	0.195
Available P	-0.118	0.422	-0.933	-0.167	0.508	0.681

Note: Values are Pearson correlation coefficients between selected soil properties and abundance of dominant weed species. * indicates significance at **$P \leq 0.05$**.

Table 5. Pearson correlation coefficients between selected soil properties and abundance of dominant weed species along the Sedimentary Formation toposequence

Soil Property	Upper (*Dactyloctenium aegyptium*)	Upper (*Gomphrena celosioides*)	Middle (*Mitracarpus villosus*)	Middle (*Tridax procumbens*)	Lower (*Tridax procumbens*)	Lower (*Boerhavia erecta*)
Sand	0.924	-0.471	0.849	-0.001	-0.774	0.143
Clay	-0.924	0.316	-0.999*	0.500	0.579	0.266
pH (H_2O)	-0.546	-0.737	-0.221	0.945	-0.004	-0.792
Organic Carbon	-0.220	-0.801	0.982	-0.360	0.603	-0.774
Total Nitrogen	-0.375	0.882	0.999*	-0.564	0.928	-0.445
Available P	0.495	0.079	0.777	-0.945	0.232	-0.501

Note: Values are Pearson correlation coefficients between selected soil properties and abundance of dominant weed species. * indicates significance at **$P \leq 0.05$**.

5. Conclusion

The investigations on soils and weeds distribution and diversity on toposequencies under two contrasting geological formations in Niger State had established low fertility status of the soils, particularly organic carbon and major soil nutrients: total nitrogen, available phosphorus and exchangeable potassium. The study also revealed the catena effects on distribution of exchangeable bases and percent base saturation. Drainage pattern was also affected by the topography leading to evolution of Typic Haplustepts at the upper and middle slope positions and Oxyaquic Haplustepts in the lower slope positions in both toposequences.

Density and diversity of some weeds were soil/slope position specific. Under the Sedimentary formation, only *Tridax procumbens* thrived across the physiographic positions and soil type. *Hyptis suaveolens* thrived only in middle and lower slopes. All other weed specie were either soil type or slope position specific. Under the Basement complex formation, *Paspalum scrobiculatum* and *Hyptis suaveolens* preferred middle and lower slopes while *Tridax procumbens* and *Hyptis suaveolens* preferred upper and middle slopes. The rest were either soil type or slope position specific.

Recommendations

Based on the findings of this study with respect to catena effects on soil properties, weed diversity and density, the following suggestions are made efficient land use and management.

1. Choice of crops should be physiographic (slope) position specific. Water loving crops should be cultivated on the lower slope position.
2. Fertiliser application should take cognisance of fertility gradients for precision management.
3. Topographic positions should also be considered in weed management

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