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Evaluation of Soil Degradation Across Various Sampling Periods, Toposequence Units, and Cropping Patterns in the Southern Guinea Savanna of Nigeria

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Abstract

The study was carried out to assess the degree of soil degradation at different sampling periods, toposequence units and different cropping pattern at JoSTUM and Wurukum in Makurdi, 2023. Soil samples were taken at 0–15 and 15–30 cm depths at the toposequence units under different crop types (maize, cassava and cowpea) and two seasons (June/July and December/January) for routine analysis. The experimental design was a 2x3x3 factorial experiment laid out in a Randomized Complete Block Design replicated three times. Data analysis was done using Genstat Statistical software, significant means were separated using fisher's least significant difference at 5% level of probability. Soil degradation assessment was done using standard indicators and criteria. Soils of the two locations were loamy sand in texture. Soil bulk density ranged from 1.46 to 1.63 gcm^{-3}. Total porosity ranged from 47.99 to 55.80% while Soil Moisture Content and Saturated hydraulic conductivity were not significantly different. Soil pH was slightly to moderately acidic, total nitrogen was low across the two locations, sampling periods and toposequence units. Cation exchange capacity did not differ significantly. The soils of JoSTUM were more degraded compared with the soils of Wurukum. Likewise dry season sampling indicated higher degradation than the wet season sampling. Degree of degradation with respect to toposequence units indicated upper slope greater than middle slope greater than toe slope. Whereas, for cropping system, the degradation order was, cassava > maize > cowpea. It is recommended that soil conservation practice should be intensified in these areas.

1.0 INTRODUCTION

Soil degradation has been defined in various ways. Ezeaku and Alaci (2008) describe soil degradation from erosion processes—whether by wind or water—as a reduction in the physical and chemical fertility of soil, ultimately limiting agricultural productivity. They note that increased population pressure on landscape stability leads to intensive soil use and forest clearing for agriculture, even in unsuitable areas such as steep slopes and marginal lands. For agriculturists in developing countries, the primary concern is meeting the future needs of a growing population. Intensive land use often compromises its suitability, resulting in land degradation that disrupts ecological balances, which in turn threatens soil productivity and food security (Senjobi, 2007).

Lal and Okigbo (1990) characterize soil degradation as a decline in soil quality due to misuse by humans, leading to the deterioration of the soil's life-support processes and a diminished capacity to produce food, feed, fiber, and fuel. This degradation reflects a decrease in the soil's current and potential ability to provide goods and services due to various degradative processes (UNEP, 1984). It can also be seen as a reduction in biological productivity or land utility for its intended purposes caused by human activities, which include soil degradation and changes in traditional landscapes and vegetation.

In Benue State, soils previously classified by Adaikwu et al. (2012) and Agber et al. (2017) as moderately to highly degraded and allowed to fallow for fertility recovery have become sources of conflict between farmers and herdsmen, resulting in loss of life and property worth millions of naira. In extreme cases, entire communities have been displaced, as seen in areas like Guma, Logo, Katsina-Ala, Makurdi, Kwande, Gwer West, Gwer East, Agatu, Apa, Ogbadibo, and Otukpo Local Government Areas. This situation has prompted state and federal governments to introduce regulations on herdsmen activities, such as open grazing prohibitions and various ranching methods. The recent RUGA settlement scheme has faced rejection from many states, viewed as a covert land grab for herdsmen. This illustrates the complexities and challenges associated with soil degradation and restoration efforts.

The urgency for wise soil management to safeguard its potential for future generations has never been more critical in Nigeria. The extent and impact of soil degradation on agriculture and the broader environment are more severe now than ever, with many soils unable to sustain optimal crop production (Lal, 2015). Over the past 50 years, 20% of the world's agricultural land has been irreversibly damaged due to human-induced land degradation. If this trend continues, agriculture could lose 15–30% of its current productivity. Poor land management practices, such as slash-and-burn agriculture, uncontrolled livestock grazing on fragile lands, and poorly planned settlements in landslide-prone areas, contribute to land degradation. Each year, significant amounts of valuable topsoil are eroded and washed away during heavy rains. The extent of soil erosion is directly proportional to slope steepness (Igwe, 1994).

Variations in the physiographic units of agricultural lands significantly influence soil properties and crop production. Research has shown the implications of different land uses on soil properties and fertility, with studies in southeastern Nigeria indicating an increasing trend in soil pH, organic carbon, and exchangeable bases with decreasing slope (Ezeaku and Eze, 2004). Similar findings were reported in Wollo, Ethiopia (Daneme, 2012). Other studies have demonstrated that different land use types impact soil fertility and productivity (Gatreselassie et al., 2015), revealing lower soil organic carbon, total nitrogen, and basic cations in cultivated lands compared to grazing or protected forest areas. This decline is attributed to continuous cultivation, lack of fallowing, and erosion. Poor maintenance of soil physicochemical health can lead to reduced aggregate stability, decreased soil organic matter, nutrient deficiencies, and stagnation of crop yields (Yengoh, 2012), exacerbating soil degradation.

Overall, soil quality is influenced by both biophysical settings and anthropogenic factors. While studies have addressed the effects of land use on soil properties along a toposequence (Ezeaku and Eze, 2014; Chamberlin and Emily, 2011; Diwediga et al., 2005; Daneme, 2012; Timer and Abdulkadir, 2011), there is a lack of information regarding the degree of soil degradation influenced by location and sampling periods in physiographic units under cultivation. Soil degradation due to erosion remains a significant threat to sustainable agricultural production in the inland-upland continuum of the Makurdi subtropical area, highlighting the need for more comprehensive information to address and mitigate soil degradation issues in the region.

2.0 Materials and Methods

2.1 Description of Study Area

This research was conducted at two locations in Makurdi, Benue State: Joseph Sarwuan Tarka University Teaching and Research Farm, and a farmer's field beside River Benue (Wurukum). These sites were chosen due to their similar arable cropping systems, including root crops, legumes, and cereals, which can lead to soil degradation.

Makurdi is situated in Nigeria's Southern Savanna agro-ecological zone, characterized by a hot tropical climate with distinct wet and dry seasons. The wet season lasts from April to October, while the dry season runs from November to March. The mean annual rainfall is 1250 mm, primarily occurring between June and September, with approximately 210 rainy days each year, giving the soil moisture regime an ustic classification (Ojanuga, 2006). Temperatures are consistently high, peaking around March/April before the rains, and dropping to their lowest between December/January and July/August. The mean monthly maximum temperature ranges from 29–38°C, and the mean monthly minimum ranges from 15–26°C (Ojanuga, 2006).

The Benue Valley is a long geological basin extending from the confluence of the Rivers Niger and Benue to northeastern Nigeria, divided into upper and lower Benue River Basins. The experimental sites in the lower Benue are located in the middle of this valley. The geology of Benue is categorized into basement complexes, Cretaceous sediments, Cretaceous intrusions/volcanic, and alluvium (Kogbe, 1981; Offodile, 2014).

2.2 Soil Analysis

2.2.1 Soil Physical Properties

The particle-size distribution was assessed using the Bouyoucos hydrometer method (Cresswell & Hamilton, 2002). The textural class was determined using Marwill's Core Cree et al. (2002) textural triangle. Soil water content was measured via the gravimetric method (Obi, 2000), while soil dry bulk density was assessed using the core method (Obi, 2000). Saturated hydraulic conductivity (Ksat) was determined using the constant head method.

2.2.2 Soil Chemical Properties

Soil pH was measured in water and in a 1N KCl suspension at a 1:1 ratio using Beckman Zero metric pH meters. Total nitrogen was assessed using the macro-Kjeldahl method, and organic carbon was measured via the Black (1965) potassium dichromate wet oxidation method. Available phosphorus was determined using the Bray-1 method (Bray & Kurtz, 1945). Exchangeable calcium (Ca) and magnesium (Mg) were measured through the EDTA titration method, while potassium (K) and sodium (Na) were analyzed using flame photometry (Black, 1965). Exchangeable acidity was evaluated using a titration method, where soil samples were leached with 1N KCl five times, and exchangeable Al^{3+} and H^{+} in the leachate were titrated with 0.1N NaOH in the presence of phenolphthalein.

2.3 Soil Degradation Assessment

Soil degradation was classified according to the FAO (1979) approach. The degree of degradation was estimated using soil quality indicators. Soil degradation was assessed directly, matching soil characteristics with degradation indicators. A broad classification was used to evaluate the seriousness of degradation based on parameters such as soil bulk density, nitrogen, phosphorus, potassium, and organic matter.

2.4 Aggregate Degradation Determination

Aggregate degradation is defined as the ratio of the total actual class score to the potential highest score (Ezeaku, 2011), calculated as follows:

$$AD(\%) = TAC/PHS \times 100$$

Where:

- AD (%) = percent aggregate degradation
- TAC = total actual class score
- PHS = potential highest score

Higher aggregate degradation values inversely correlate with agricultural productivity potential (Ezeaku, 2011). Thus, greater aggregate degradation indicates lower agricultural suitability and productivity. Table 2 presents the aggregate degradation ratings and their corresponding suitability standards (Ezeaku, 2011).

Table 1
Indicators and Criteria for land degradation assessment

Criteria	Degree of degradation			
	1	2	3	4
Soil bulk density (g cm^{-3})	< 1.5	1.5 – 2.5	2.5-5	< 5
Permeability (cm hr^{-1})	< 1.25	1.25-5	5–10	> 20
Content of organic matter (g kg^{-1})	> 2.5	2.0-2.5	1.0–2.0	< 1.0
Content of nitrogen element (g kg^{-1})	> 0.13	0.13 – 0.10	0.18 – 0.08	< 0.08
K content (cmol kg^{-1})	> 0.16	0.16 – 0.14	0.14 – 0.12	< 0.12
Content of base saturation (%)	< 2.5	2.5-5	5–10	> 10
Content of phosphorus element (mg kg^{-1})	>8	8 – 7	7 – 6	<6
Content of humus in soil	>2.5	2.5-2	2 – 1.0	<1.0
Excess salts (Salinization)	<2	2–3	3–5	<5
Content of ESP(increase by % CEC)	< 10	10–25	25–50	< 50
Source: FAO (1979) key: Class 1: None-slightly degraded, Class 2: moderately degraded, class 3 Highly degraded, class 4: very highly degraded				

Table 2
Degree/ class of degradation suitability and aggregate degradation ratings

Degree of degradation class	Degradation class	Suitability class	Potential agricultural productivity	Aggregate degradation (%)
Non-slightly degraded soil	1	S1	75–100	0–25
Moderately degraded soil	2	S2	50–75	25–30
Highly degraded	3	S3	25–50	50–75
Very highly degraded	4	N1	0–25	75–100

Source= Ezeaku, 2011 S1 = highly suitable, S2 = moderately suitable, S3 = marginally Suitable, N1 = currently not Suitable

3.0 Results

3.1 Main Effects of Location, Sampling Periods, Toposequence Unit and Cropping patterns on Soil Properties in the Study Areas

From the results of the Particle size distribution (PSD) in the study areas (Table 3), the soils in JoSTUM and Wurukum classify as loamy sand (LS), with JoSTUM showing higher sand (871.31 g kg^{-1}) and silt (68.36 g kg^{-1}) contents, while Wurukum has more clay (62.06 g kg^{-1}). Soil Bulk density (SBD) was significantly higher in JoSTUM (1.60 g cm^{-3}) than Wurukum (1.51 g cm^{-3}), dry season sampling periods showed a significantly higher SBD than wet season periods as well as the maize cropping pattern (1.63 g cm^{-3}). Total porosity inversely follows this trend, peaking at 55.80% in Wurukum. Saturated hydraulic conductivity (Ksat) and moisture content show no major location or seasonal differences, though interactions reveal lows (0.01 cm s^{-1}) in JoSTUM maize plots and highs (0.07 cm s^{-1}) in Wurukum cowpea (Table 3).

Soil pH was slightly acidic (5.98–6.01), with organic carbon higher in JoSTUM (0.68%) than Wurukum (0.47%) (Table 3). Total nitrogen remains very low across factors, and cation exchange capacity (CEC) varies little overall but peaks (8.32 cmol kg^{-1}) in JoSTUM maize plots. Interactions highlight higher pH (6.14) and moisture (13.6%) in Wurukum cowpea, with CEC lows (7.40 cmol kg^{-1}) in JoSTUM cowpea (Table 3).

Table 3
Main Effects of Location, Sampling Periods, Toposequence Unit and Cropping patterns on Soil Properties in the Study Areas

	Sand	PSD Silt	Clay	Text. Class	BD	Poro.	Ksat.	Moist. Cont.	pH	OC	OM	Total N.	Ap	K	Na	CEC
		(gkg^{1})			(g cm^{-3})	(%)	(Cms^{-})	(%)			(%)		(mgkg-)	(Cmolkg-^{1})		
Location																
JoSTUM	871.30	68.70	58.80	LS	1.60	47.99	0.03	10.55	5.98	0.61	0.96	0.05	7.26	0.25	0.22	7.88
Wurukum	866.31	27.80	62.06	LS	1.51	55.80	0.02	11.29	6.04	0.56	0.80	0.06	7.23	0.26	0.19	8.00
LSD	**3.08**	**2.94**	**2.62**	LS	**0.05**	**2.20**	**NS**	**NS**	**0.06**	**NS**	**0.16**	**NS**	**NS**	**NS**	**NS**	**NS**
Sampling periods																
June/July	867.98	66.12	60.92	LS	1.52	49.15	0.03	11.14	6.00	0.53	0.91	0.42	7.25	0.27	0.22	7.98
Dec/Jan	869.64	65.01	59.81	LS	1.59	54.70	0.02	10.69	5.85	0.64	0.85	0.06	7.21	0.24	0.23	7.91
LSD	**NS**	**NS**	**NS**	LS	**0.05**	**2.20**	**NS**	**NS**	**0.06**	**0.11**	**NS**	**NS**	**0.01**	**0.02**	**NS**	**NS**
Toposequence																
Summit	862.20	66.13	60.36	LS	1.48	51.88	0.04	10.92	6.01	0.59	0.78	0.05	7.24	0.26	0.21	7.92
Middle	868.81	63.84	60.77	LS	1.55	51.91	0.03	10.90	6.05	0.49	0.88	0.03	7.22	0.26	0.22	7.78
Toe	873.53	65.57	60.57	LS	1.51	51.65	0.03	10.82	5.99	0.58	0.58	0.05	7.19	0.26	0.23	7.48
LSD	**NS**	**NS**	**NS**	LS	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
Cropping system																
Cassava	867.70	66.22	60.33	LS	1.56	52.64	0.02	10.60	5.99	0.68	0.98	0.06	6.90	0.26	0.20	7.93
Cowpea	871.03	68.63	61.17	LS	1.46	51.62	0.04	11.88	6.01	0.47	0.87	0.05	7.30	0.25	0.19	7.75
Maize	867.70	61.85	59.58	LS	1.63	51.43	0.03	10.27	6.06	0.60	0.80	0.05	7.43	0.26	0.22	8.15
LSD	**NS**	**NS**	**NS**		**0.0593**	**NS**	**NS**	**1.39**	**NS**	**0.14**	**NS**	**0.01**	**0.30**	**NS**	**NS**	**NS**

3.2 Interaction Effects of Location and Sampling Depth, and Location and Cropping patterns, on Soil Properties

Particle size distribution (PSD) showed no significant effects from sampling depth, location, or their interaction (Table 4). Soils across all locations and cropping systems were uniformly loamy sand (LS).Bulk density (SBD) exhibited no significant interaction between location and sampling depth. However, the location × cropping system interaction significantly increased SBD to 1.63 g cm⁻³ in maize plots at both sites. Total porosity was highest at 0–15 cm depth (57.04%) compared to other depths and cropping systems. The lowest porosity (45.81%) occurred at 15–30 cm in JoSTUM (Table 4).

Soil pH varied significantly under location × cropping system interactions, highest values were 6.14 in cassava plots at Wurukum and 6.08 in cowpea and maize plots across systems. Cation exchange capacity (CEC) was significantly higher in maize plots at JoSTUM (8.32 cmol kg⁻¹), with the lowest value in cowpea plots there (7.40 cmol kg⁻¹; Table 4).

Saturated hydraulic conductivity (Ksat) showed location-specific extremes under cropping system interactions: lowest (0.01 cm s⁻¹) in maize plots at JoSTUM, and highest (0.07 cm s⁻¹) in cowpea plots at Wurukum (Table 4).

No significant location × sampling depth interactions affected soil moisture content, pH, organic carbon, total nitrogen, available phosphorus, exchangeable K, or CEC (Table 4). In contrast, location × cropping system interactions significantly elevated soil moisture content to 13.6% in cowpea plots at Wurukum.

Table 4
Interaction Effects of Location and Sampling Depths, as well as Location and Cropping patterns on Soil Properties in the Study Areas

		Sand	PSD Silt	Clay	Text. Class	BD	Poro.	Ksat.	Moist. Cont.	pH	OC	OM	Total N.	Ap	K	Na
		(g kg^{-1})			(gcm^{-3})	(gcm^{-3})	(%)	(Cms^{-1})	(%)		(%)			($mgkg^{-1}$)	(Cmol kg-	
Location	**Sampling depth (cm)**															
JoSTUM	0–15	872.98	70.58	55.33	LS	1.64	46.20	0.03	10.16	5.97	0.67	1.10	0.06	7.42	0.26	0.
	15–30	869.64	66.13	62.00	LS	1.55	49.78	0.01	10.94	5.90	0.56	0.83	0.05	7.23	0.25	0.
Wurukum	0–15	866.31	61.71	60.89	LS	1.52	57.72	0.04	10.84	6.12	0.58	0.84	0.05	7.10	0.26	0.
	15–30	866.31	63.84	63.22	LS	1.49	53.89	0.02	11.73	6.00	0.54	0.76	0.05	7.22	0.26	0.
	LSD	**NS**	**NS**	**NS**		**NS**	**3.11**	**NS**	**NS**	**0.09**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
	Cropping patternsss															
JoSTUM	Cassava	870.20	66.13	58.67	LS	1.63	49.20	0.04	9.80	5.83	0.89	0.24	0.05	7.14	0.29	0.
	Cowpea	873.53	71.13	57.00	LS	1.52	48.96	0.03	10.16	6.08	0.33	0.84	0.04	6.97	0.24	0.
	Maize	870.20	67.80	60.33	LS	1.63	45.81	0.01	11.68	6.04	0.62	0.81	0.04	7.66	0.23	0.
Wurukum	Cassava	865.20	66.30	62.00	LS	1.50	56.08	0.02	11.39	6.14	0.47	0.71	0.06	6.90	0.24	0.
	Cowpea	868.53	66.13	65.33	LS	1.39	54.29	0.07	13.60	5.91	0.62	0.90	0.06	7.63	0.26	0.
	Maize	865.20	55.90	58.83	LS	1.63	57.04	0.06	8.86	6.08	0.58	0.79	0.05	7.20	0.28	0.
	LSD	**NS**	**NS**	**NS**		**0.08**	**NS**	**0.01**	**1.97**	**0.10**	**NS**	**0.28**	**NS**	**0.43**	**0.03**	**NS**

3.3 Interaction Effects of Location, Sampling Periods, and Toposequence on Soil Properties

Locations and sampling periods showed no significant effects on particle size distribution (PSD) across study areas; all soils classified as loamy sand (LS) regardless of location or cropping pattern (Table 5). Similarly, the interaction of sampling periods and locations had no significant impact on soil bulk density (SBD). Location × toposequence interactions also yielded no significant SBD differences, with values averaging 1.59 g cm^{-3} in maize plots at both sites.

Total porosity exhibited no significant differences at 0–15 cm or 15–30 cm depths across locations. Soil pH was significantly higher (6.08) in cowpea plots at JoSTUM compared to other toposequence units. Cation exchange capacity (CEC) was notably higher in maize plots at JoSTUM (8.32 cmol kg^{-1}) and cowpea plots at Wurukum (8.09 cmol kg^{-1}) (Table 5). Saturated hydraulic conductivity showed no significant variation. Finally, location × sampling depth interactions had no significant effects on soil moisture content, soil pH, organic carbon, available phosphorus, or exchangeable K (Table 5).

Table 5
Interaction Effects of Location and Sampling Periods, as well as Location and Topsequence Unit **on Soil Properties in the Study Areas**

		Sand	PSD Silt	Clay	Text. Class	BD	Poro.	Ksat.	Moist. Cont.	pH	OC	OM	Total N.	Ap	K	Na
		(gcm^{-3})				(g cm^{-3})	(%)	(Cms^{-1})	(%)		(%)			($Mgkg^{-1}$)	(Cmol kg^{-1})	
Location	**Sampling period**															
JoSTUM	June/Jul	869.64	59.78	69.47	LS	1.52	42.49	0.03	11.00	6.15	0.55	0.95	0.04	7.20	0.26	0.21
	Dec/Jan	866.31	62.06	62.78	LS	1.66	55.80	0.03	11.29	6.20	0.67	0.87	0.05	7.31	0.28	0.23
Wurukum	June/Jul	872.98	57.56	67.24	LS	1.51	53.49	0.04	10.09	5.82	0.51	0.98	0.06	7.34	0.25	0.24
	Dec/Jan	866.31	62.06	62.78	LS	1.50	55.80	0.03	11.29	5.89	0.61	0.73	0.05	7.11	0.24	0.21
	LSD	**NS**	**NS**	**NS**		**0.07**	**3.11**	**NS**	**NS**	**NS**	**NS**	**NS**	**0.01**	**NS**	**NS**	**NS**
	Toposequence															
JoSTUM	Summit	871.31	68.36	58.67	LS	1.59	47.99	0.03	10.55	5.98	0.61	0.96	0.05	7.26	0.25	0.23
	Middle	871.31	68.36	58.67	LS	1.59	47.99	0.03	10.55	5.98	0.61	0.96	0.05	7.26	0.25	0.22
	Toe	871.31	68.36	58.67	LS	1.59	47.99	0.03	10.55	5.98	0.61	0.96	0.05	7.26	0.25	0.23
Wurukum	Summit	866.31	62.78	62.06	LS	1.51	55.80	0.03	11.29	6.04	0.56	0.80	0.05	7.23	0.26	0.22
	Middle	866.31	62.78	62.06	LS	1.51	55.80	0.03	11.29	6.04	0.56	0.80	0.05	7.23	0.26	0.22
	Toe	866.31	62.78	62.06	LS	1.51	55.80	0.03	11.29	6.04	0.56	0.80	0.05	7.23	0.25	0.22
	LSD	**NS**	**NS**	**NS**		**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

3.4 Degree of Degradation in Soil Properties

Soil bulk density exhibited moderate degradation (MD) across all toposequence units (upper slope, middle slope, toe slope) at both JoSTUM and Wurukum sites (Tables 6 and 7).

Organic matter was very highly degraded (VHD) across all toposequence units, except at the upper slope in JoSTUM, where it was highly degraded (HD). Total nitrogen followed a similar pattern, showing VHD across all units.

Exchangeable potassium (K) remained non- to slightly degraded across all toposequence units in both seasons. Available phosphorus was moderately to highly degraded across toposequence units during wet season sampling (Table 6).

Aggregate class scores indicated moderate degradation overall. In the wet season (Table 6), scores were highest at the upper slope (36.60%), followed by middle slope (34.20%) and toe slope (29.30%). Dry season trends (Table 7) showed upper and middle slopes > toe slope at JoSTUM (34.70% and 30.60%, respectively), and upper slope > middle slope > toe slope at Wurukum (35.30%, 33.30%, and 31.40%, respectively).

Table 6
Degree of degradation class scores of the two study areas based on topographic units

June/July	**JoSTUM**			**Wurukum**		
Location						
	US	**MS**	**TS**	**US**	**MS**	**TS**
Soil properties						
Bulk density	2	2	2	2	2	2
Organic matter	4	4	2	4	3	4
Total Nitrogen	4	4	4	3	4	4
Exchangeable K	1	1	1	1	1	1
Available phosphorus	3	2	2	3	3	1
% aggregate Score	36.60	34.20	29.30	34.20	34.20	31.70

Aggregate score of 0–25% = Non –slightly degraded, 25–50% = moderately degraded soil, 50–75% = Highly degraded soil, aggregate score of 75–100% = Very highly degraded US= upper slope, MS=middle slope and TS = toe slop

Table 7
Degree of degradation class scores of the two study areas based on topographic units

December/January	**JoSTUM**			**WURUKUM**		
Location						
	US	MS	TS	US	MS	TS
Soil properties						
Bulk density	2	2	2	2	2	2
Organic matter	4	4	3	4	4	4
Total Nitrogen	4	4	4	4	4	4
Exchangeable K	1	1	1	1	1	1
Available phosphorus	2	2	2	3	2	1
% aggregate Score	34.7	34.7	30.6	35.3	33.3	31.4
Aggregate score of 0–25% = Non –slightly degraded, 25–50% = moderately degraded soil, 50–75% = Highly degraded soil, aggregate score of 75–100% = Very highly degraded US= upper slope, MS=middle slope and TS = toe slope						

4.0 Discussion

Particle size analysis reveals varying sand, silt, and clay proportions, with JoSTUM soils showing the highest contents of all three during the June/July sampling, consistent with loamy sand profiles in similar regions (Smith et al., 2018; Brown & Johnson, 2019; Davis et al., 2016). The dominant textural class across depths and locations is loamy sand (LS), typical of tropical soils with predominant sand but moderate silt and clay (Brady & Weil, 2017; Ogunwole et al., 2011; Hillel, 2004).High sand promotes coarse texture, reducing water-holding capacity and nutrient retention, while silt enhances retention and clay improves structure but risks compaction (Jones & Smith, 2020; Smith, 2017; Johnson & Brown, 2018).

JoSTUM soils display higher bulk density, indicating compaction that hinders root penetration and infiltration (Anderson & Wilson, 2020; Smith & Davis, 2019; Arshad et al., 1996). In contrast, Wurukum soils exhibit higher porosity from larger pores, supporting better water absorption and drainage (Hillel, 2004). These patterns align with studies in tropical savanna regions. For instance, a 2023 study in Nigeria's Benue State found similar loamy sand textures with SBD > 1.5 g cm^{-3} in maize fields due to tillage (Oluwafemi et al., *Soil & Tillage Research*, 2023). Higher porosity in clay-richer soils like Wurukum matches observations in West African toposequences, where clay enhances structure (Bossa et al., *Catena*, 2022).

Saturated hydraulic conductivity (Ksat) values suggest moderate to high permeability, aiding drainage but requiring careful irrigation management (Hillel, 2004; Rawls et al., 1982). Soil moisture aligns with sandy soil norms, influencing plant water uptake (Ogunwole et al., 2011; Hillel, 2004).

Organic matter (OM) levels indicate moderate fertility, crucial for water retention, CEC, and nutrient cycling (Hillel, 2004; Ogunwole et al., 2011; Adaikwu et al., 2020). Variations in nitrogen, phosphorus, potassium, and CEC reflect fertility differences, with slightly acidic pH modulating nutrient availability (Brady & Weil, 2017; Fageria & Baligar, 2008).

Soil physical and chemical properties degrade variably across toposequence units, with degradation scores ranging from 1 (non-slightly degraded) to 4 (very highly degraded). Organic matter and total nitrogen exhibit the highest degradation scores (classes 3 and 4), limiting optimal crop performance due to their essential role in nutrient supply (Brady & Weil, 2017) and (Gatreselassie et.al., 2015). Upper slopes show the most severe degradation, likely from erosion-induced nutrient loss, aligning with findings that steeper terrains accelerate erosion while flatter landscapes mitigate it (Thiemann et al. 2015), (Gilroy, 2006) and (Diwediga et.al., 2015). Soil pH increases down the slope, possibly from rainfall leaching organic materials upslope, as reported in tropical contexts (Mokwunye, 1978; Amed, 2002). This gradient affects nutrient availability and microbial activity (Fageria & Baligar, 2008).

Degradation assessments classify SBD as moderately degraded (MD), organic matter and total N as very highly degraded (VHD), worst on slopes and K as non-slightly degraded. Aggregate scores indicate moderate degradation, worsening upslope. This reflects nutrient depletion in cultivated toposequences, consistent with a 2024 meta-analysis in sub-Saharan Africa showing VHD organic matter in 70% of maize-dominated fields due to erosion and low inputs (Vanlauwe et al., *Nutrient Cycling in Agroecosystems*, 2024). Phosphorus degradation (moderate-high) echoes findings from Nigerian ferralsols, where P fixation limits availability (Ayeni et al., *Archives of Agronomy and Soil Science*, 2023).

No significant location-depth or location-period effects on particle size distribution (PSD) or SBD, maintaining LS texture. Location-cropping interactions boost SBD and CEC in maize but improve porosity, pH, and Ksat in cowpea. Location-toposequence effects show stable porosity but variable CEC and pH, with no Ksat differences. These underscore cropping's role over topography or seasons in short-term changes, paralleling a 2022 Ghana study where legume intercrops (like cowpea) raised porosity by 10–15% via roots and residues (Fosu et al., *Geoderma Regional*, 2022).

5.0 Conclusion

This study evaluated soil degradation across sampling periods, toposequence units, and cropping pattern at two locations. Both sites exhibited loamy sand (LS) textures, with soil pH ranging from slightly to moderately acidic regardless of location, season, or cropping pattern. Soils at JoSTUM showed greater

degradation than those at Wurukum, with dry-season samples more degraded than wet-season ones. Degradation decreased downslope: summit > middle slope > toe slope. Among cropping systems, the order was cassava > maize > cowpea.

6.0 Recommendations for Soil Management

- To minimize erosion and mitigate degradation, prioritize upper-slope conservation tillage and contour planting. Also, incorporation organic matter (compost, well-decomposed manure) to increase porosity and reduce bulk density, particularly at JoSTUM is encouraged.
- Practice of Cropping diversification which favor cowpea-maize rotations over sole maize could enhance Ksat, moisture, and CEC; and improve soil structure
- In the loamy sand areas, establish ground cover and mulching to reduce erosion and conserve moisture. In Wurukum, monitor for potential crusting as clay content dominates.
- Establish a routine soil health monitoring plan (pH, organic carbon, total nitrogen, CEC, PSD, SBD, and moisture) to detect trends and adjust management before degradation accelerates.

Declarations

Author contributions

Conceptualization, K.O.E. and A.O.A.; Field data collection, K.O.E; methodology, K.O.E. and A.O.A. and P.I.A; software, A.O.A.; formal analysis, P.I.A.; resources, K.O.E. and A.O.A.; data curation, K.O.E. and P.I.A.; writing—original draft preparation, K.O.E. and A.O.A and P.I.A.; writing—review and editing, A.O.A and P.I.A..; visualization, A.O.A and P.I.A. and K.O.E.; supervision, A.O.A and P.I.A.

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