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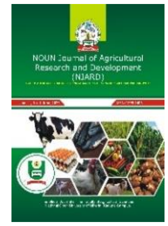

Original Article

Assessment of Soil Degradation under Different Toposequence Units and Cropping Systems 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 seasons, toposequence units and different cropping systems 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, and 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 between locations. Soil pH was slightly to moderately acidic, total nitrogen was low across the two locations, sampling seasons 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 wet-season sampling. Degradation decreased progressively with slope position, being most severe at the upper slope, followed by middle slope, and least at the toe slope. The study revealed that degradation was more pronounced in upper slope positions, during the dry season, and under cassava cultivation, indicating the need for improved soil conservation and nutrient restoration practices.

Keywords: Soil degradation, toposequence, soil quality, cropping systems, Southern Guinea Savanna

1. 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 have continued to deteriorate due to intensified land use, leading to reduced soil fertility and declining crop productivity. Continuous cultivation without adequate nutrient replenishment has accelerated soil degradation in many farming communities across the state, underscoring the urgency of evidence-based soil management interventions.

This underscores the urgent need for sustainable soil management practices 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 significantly to land degradation. Each year, substantial amounts of valuable topsoil are eroded and washed away during heavy rains, and 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, 2014). 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., 2015; Daneme, 2012), most of these investigations focused on single land use types or did not concurrently evaluate the combined effects of sampling season, slope position, and cropping system on the degree of soil degradation. Specifically, there is limited information on how the interaction of location, sampling season, and cropping system influences quantitative degradation indices within physiographic units under cultivation in the Makurdi area. This study therefore aimed to assess the degree of soil degradation at different sampling seasons, toposequence units, and under different cropping systems, with a view to providing data-driven recommendations for soil conservation in the Southern Guinea Savanna of Nigeria.

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

The experimental design was a 2×3×3 factorial arranged in a Randomized Complete Block Design (RCBD) replicated three times. Factor A comprised two locations (JoSTUM and Wurukum); Factor B comprised three toposequence units (summit/upper slope, middle slope, and toe slope); and Factor C comprised three cropping systems (maize, cassava, and cowpea). Soil samples were collected at two depths (0–15 cm and 15–30 cm) across the three toposequence units at each location during two sampling seasons: the wet season (June/July) and the dry season (December/January). At each sampling point, five sub-samples per plot were collected and bulked to form a composite sample, yielding three composite samples per treatment combination per season. Each plot measured approximately 5 m × 5 m. Samples were air-dried, ground, and sieved (2 mm) prior to laboratory 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 a 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 Zeromatic 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 Seasons, Toposequence Unit and Cropping Systems 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 are classified as loamy sand (LS), with JoSTUM showing higher sand (871.31 g kg^{-1}) and silt (68.70 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 showed a significantly higher SBD than the wet season, as well as the maize cropping system (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).

3.2 Interaction Effects of Location and Sampling Depth, and Location and Cropping Systems, 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.

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

Locations and sampling seasons showed no significant effects on particle size distribution (PSD) across study areas; all soils classified as loamy sand (LS) regardless of location or cropping system (Table 5). Similarly, the interaction of sampling seasons 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 3: Main Effects of Location, Sampling Seasons, Toposequence Unit and Cropping Systems on Soil Properties in the Study Areas

	Sand	PSD Silt (gkg^{1})	Clay	Text. Class	BD ($g\ cm^{-3}$)	Poro. (%)	Ksat. (Cms^{-})	Moist. Cont. (%)	pH	OC	OM (%)	Total N.	Ap (mgkg-)	K	Na ($Cmolkg^{-1}$)	CEC
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**

Table 4: Interaction Effects of Location and Sampling Depths, as well as Location and Cropping Systems 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
		← (g kg^{-1}) →			(gcm^{-3})	(gcm^{-3})	(%)	(Cms^{-1})	(%)	← (%) →				($mgkg^{-1}$)	← (Cmol kg-^{1}) →		
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	0.22	8.05
	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	0.23	8.03
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	0.22	7.73
	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	0.22	7.97
	LSD	**NS**	**NS**	**NS**		**NS**	**3.11**	**NS**	**NS**	**0.09**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
	Cropping System																
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	0.23	7.93
	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	0.21	7.40
	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	0.23	8.32
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	0.21	7.9
	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	0.23	8.09
	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	0.23	7.98
	LSD	**NS**	**NS**	**NS**		**0.08**	**NS**	**0.01**	**1.97**	**0.10**	**NS**	**0.28**	**NS**	**0.43**	**0.03**	**NS**	**0.35**

Table 5: Interaction Effects of Location and Sampling Seasons, as well as Location and Toposequence 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	CEC
		← (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	7.87
	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	7.90
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	8.09
	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	7.91
	LSD	**NS**	**NS**	**NS**		**0.07**	**3.11**	**NS**	**NS**	**NS**	**NS**	**NS**	**0.01**	**NS**	**NS**	**NS**	**0.02**
	Toposequence																
JoSTUM	Summit	874.20	56.10	69.70	LS	1.62	46.20	0.028	10.10	5.82	0.52	0.89	0.04	6.95	0.24	0.21	7.62
	Middle	871.30	59.80	68.90	LS	1.59	48.10	0.030	10.55	5.98	0.61	0.96	0.05	7.26	0.25	0.22	7.88
	Toe	867.50	63.20	69.30	LS	1.55	50.50	0.032	11.20	6.15	0.69	1.04	0.06	7.68	0.27	0.24	8.15
Wurukum	Summit	874.50	55.80	69.70	LS	1.54	52.10	0.032	10.80	5.75	0.49	0.85	0.04	7.10	0.24	0.23	7.85
	Middle	872.10	59.20	68.70	LS	1.51	54.40	0.035	11.15	5.89	0.56	0.94	0.05	7.34	0.25	0.24	8.09
	Toe	868.40	62.70	68.90	LS	1.48	56.80	0.038	11.70	6.04	0.64	1.02	0.06	7.65	0.27	0.25	8.38
	LSD	**NS**	**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 Location	**JoSTUM**			**Wurukum**		
Soil properties	**US**	**MS**	**TS**	**US**	**MS**	**TS**
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 slope

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

December/January Location	JoSTUM			WURUKUM		
Soil properties	US	MS	TS	US	MS	TS
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 sand and silt contents during the June/July sampling season, consistent with loamy sand profiles typical of the Southern Guinea Savanna zone. 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; Hillel, 2004). High sand content promotes coarse texture, reducing water-holding capacity and nutrient retention, while silt enhances retention and clay improves structure but risks compaction under intensive cultivation (Brady & Weil, 2017; Hillel, 2004).

These textural and structural patterns are consistent with observations in West African toposequences, where clay content at lower slope positions contributes to improved aggregate stability and soil porosity (Bossa et al., 2022; Brady & Weil, 2017).

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 content aligns with typical sandy soil norms and influences plant water uptake efficiency (Hillel, 2004).

Organic matter (OM) levels indicate moderate fertility, crucial for water retention, CEC, and nutrient cycling (Hillel, 2004; 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 degraded variably across toposequence units, with degradation scores ranging from 1 (non-slightly degraded) to 4 (very highly degraded). Organic matter and total nitrogen exhibited the highest degradation scores (classes 3 and 4), limiting optimal crop performance due to their essential role in nutrient supply and biological activity (Brady & Weil, 2017; Gatreselassie et al., 2015). Upper slope positions showed the most severe degradation, a pattern mechanistically attributable to the greater kinetic energy of runoff water on steeper gradients, which preferentially removes fine particles and organic-matter-enriched topsoil from higher elevation positions (Thiemann et al., 2015; Diwediga et al., 2015). This erosion-driven loss of organic matter from upper slopes directly depletes nitrogen reserves and reduces cation exchange capacity, thereby diminishing the soil's ability to retain and supply nutrients to crops. The progressive improvement in soil quality from upper slope to toe slope is further explained by the translocation and deposition of eroded materials at lower positions, enriching toe slope soils in organic matter, fine particles, and nutrients (Ezeaku and Eze, 2014). Soil pH increased downslope, likely due to rainfall-driven leaching of acidic cations from upper positions and their accumulation at lower slope units, as documented in tropical contexts (Ezeaku and Eze, 2014). This pH gradient influences nutrient availability and microbial activity along the slope (Fageria & Baligar, 2008). The greater degradation observed under cassava cultivation is explained by cassava's deep and extensive rooting system, which physically disturbs soil aggregates, and by the large biomass harvest associated with tuber extraction, which removes significant quantities of nutrients without equivalent organic matter return. In contrast, cowpea's nitrogen-fixing symbiosis, combined with its lower biomass removal and residue incorporation, promotes soil fertility and reduces degradation (Brady & Weil, 2017; Gatreselassie et al., 2015).

Degradation assessments classify SBD as moderately degraded (MD), organic matter and total nitrogen as very highly degraded (VHD), and exchangeable K as non-slightly degraded. Aggregate scores indicate moderate degradation overall, worsening toward upper slope positions. This reflects the progressive nutrient depletion typical of cultivated toposequences in sub-Saharan Africa, where erosion removes organic-matter-enriched topsoil from elevated positions while deposition occurs at lower slopes (Gatreselassie et al., 2015; Diwediga et al., 2015). The very high degradation of organic matter and nitrogen observed across all toposequence units is consistent with findings from similar Guinea Savanna soils where low organic matter inputs combined with continuous cultivation lead to rapid depletion of soil nitrogen reserves (Lal, 2015; Brady & Weil, 2017). Available phosphorus showed moderate to high degradation, a pattern common in West African ferralsols where phosphorus fixation by sesquioxides limits availability in acidic, sandy soils (Fageria & Baligar, 2008).

No significant location-depth or location-season effects were observed on particle size distribution (PSD) or SBD, maintaining loamy sand (LS) texture throughout. Location-cropping system interactions boosted SBD and CEC in maize plots but improved porosity, pH, and Ksat in cowpea plots. Location-toposequence effects showed stable porosity but variable CEC and pH, with no significant Ksat differences. These results underscore the dominant role of cropping system over topographic position or seasonal variation in driving short-term soil property changes. The improvement in soil physical properties under cowpea is likely attributable to the nitrogen-fixing capacity of legumes and greater root biomass turnover, which enhances macroporosity and organic matter inputs (Brady & Weil, 2017; Gatreselassie et al., 2015). Conversely, the higher SBD under maize reflects the compacting effect of tillage operations and lower organic matter return under sole cereal cropping (Arshad et al., 1996).

4.1 Study Limitations

This study has several limitations that should be noted. First, the assessment was conducted at only two locations within a single agro-ecological zone, which limits the spatial generalizability of findings. Second, microbial biomass carbon and soil enzyme activity, which would provide mechanistic insight into biological degradation processes, were not measured due to analytical resource constraints. Third, long-term temporal replication across multiple growing seasons was beyond the scope of this study; accordingly, the seasonal comparisons presented here reflect a single year of data and may not fully capture inter-annual variability. Future studies should incorporate repeated measures across multiple years, broader spatial coverage, and biological soil quality indicators to provide a more comprehensive assessment of soil degradation dynamics in the Southern Guinea Savanna.

5.0 Conclusion

This study evaluated the degree of soil degradation at different sampling seasons, toposequence units, and cropping systems at two locations in the Southern Guinea Savanna of Nigeria. Both sites exhibited loamy sand (LS) textures, with soil pH ranging from slightly to moderately acidic regardless of location, season, or cropping system. The key degradation indicators were organic matter and total nitrogen, which were classified as very highly degraded (VHD) across most treatment combinations, posing the greatest threat to long-term soil productivity. Exchangeable potassium was non- to slightly degraded, while available phosphorus showed moderate to high degradation. Soils at JoSTUM showed greater aggregate degradation than those at Wurukum, reflecting the influence of more intensive land use history. Dry-season sampling indicated higher degradation than wet-season sampling, likely due to reduced organic matter inputs and greater mineralisation of nitrogen under drier conditions. Degradation decreased progressively downslope, with summit positions most severely degraded due to erosion-driven removal of organic-matter-enriched topsoil. Among cropping systems, cassava caused the most degradation, followed by maize and cowpea, with cowpea's nitrogen-fixing capacity and residue contribution contributing to superior soil quality maintenance. These findings highlight the critical importance of organic matter replenishment, slope-specific conservation practices, and legume integration as priority interventions for sustainable soil management in this agro-ecological zone.

6.0 **Recommendations for Soil Management**

- To minimize erosion and mitigate degradation at upper slope positions, conservation tillage and contour planting should be prioritized. Incorporation of organic amendments (compost or well-decomposed farmyard manure) is recommended to improve soil porosity and reduce bulk density, particularly at JoSTUM.
- Cowpea-maize rotations should be favoured over sole maize cultivation to enhance Ksat, moisture retention, and CEC, and to improve overall soil structure through legume nitrogen fixation and residue contribution.
- 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.

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