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Toposequence effect on soil properties and suitability rating for selected crops in Northern Guinea Savanna, Nigeria

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ABSTRACT

A toposequence at Giwa, Kaduna State was studied with the aim of assessing the effect of topography on soil properties and suitability ratings for rainfed rice, cowpea, and tomato. Three slope positions namely, lower slope (LS), middle slope (MS) and upper slope (US) were delineated, and their properties were assessed. Results indicated that soils on all locations were very deep (167 – 192 cm) with occurrence of plinthite at subsurface of MS and US. Slope position of the soils was noted to influence morphological, physical and chemical properties. Content of silt and sand fractions, available water content and moisture retention at field capacity were all significantly influenced by slope. Melanization, braunification, plinthization and argilluviation were some pedogenetic process notable in the soils. Suitability studies revealed that 29.12% of the area was moderately suitable (S2) for rice cultivation with limitations of climate, soil physical property and fertility, while 70.88% of the area were marginally suitable (S3), with an additional limitation in wetness. For cowpea, 68.13% of the soils were S2 with limitations in fertility, while MS was highly suitable (S1). Tomato was rated S2 for the entire area with general limitations in climate and fertility. Suitability for rice increased down the slope from US, while that of cowpea and tomato increased along the slope from LS to US. This effect was attributed to distribution of nutrient and water, as preconditioned by topography. Management practice suggests the use of LS for rice, while MS and US may be rotated for cultivating tomato and cowpea.

Keywords: Northern guinea savanna; soil properties; suitability

INTRODUCTION

Soil properties which differ as a result of interaction among soil forming factors and processes affects soil productivity (Esu, 2010; Lawal *et al.*, 2014; Brady and Weil, 2016). As a soil forming factor, topography plays a major role in the variability of soil properties and nutrient distribution along a heterogeneous agricultural landscape (Lawal *et al.*, 2014; Jimoh *et al.*, 2020; Tijjani and Hassan, 2017). In Africa, most soils are characterized by rolling

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landscape and soil properties differs due to the factor of topography, which play a vital role in bringing about changes in soil properties (Egbuchua, 2014). Relief determines the drainage and depth of a soil profile. For instance, soils on higher elevation are usually well drained, whereas soils on lower slope are usually poorly drained, while soils on a hill or steep slope are usually very shallow and gravelly due to minimal rate of weathering and removal of fine soil particles by erosion, while soil on gentle slope allow ample infiltration of water and develop into deep profile (Esu, 2010; Jimoh *et al.*, 2020). Topography has been found to influence the thickness of ‘A’ horizon, organic matter content, soil color, soil depth, accumulation of salts and calcium carbonate. It also influences both external and internal drainage conditions, differential transport of eroded material, leaching and translocation, which ultimately determines soil characteristics (Buol *et al.*, 1980). Several studies of toposequence soils have revealed variations in morphological, physical, and chemical properties along slopes due to varying pedogenetic processes as conditioned by slope taking place therein (Jimoh *et al.*, 2020).

Topographical landscape affects soil properties, which in turn affects usage and output (Fatihu *et al.*, 2021). Oluwatosin *et al.* (2001) stated that in order to control variability in soil properties and crops yield along toposequence, recommendation for agronomic practices should be made to farmers with due consideration for specific topographic locations that might influence the management options such as choice of crop for cultivation, fertilizer rate and types, tillage operations and herbicides application. Moorman (1981) noted that an understanding of the basic soil properties is essential for developing soil management practices that will maintain the productive potential of a soil. Ogunkunle (1993) worked on variation of some soil properties due to toposequence asserts that for sustainable land use options on variable toposequence, knowledge of the geomorphic position which is related to a systematic variability of soil hydraulic properties among other soil physical properties is necessary. Soil topographic positions are factors considered in establishing local soil characteristics and classification which directs and guides land use and management decisions as well as the processes of soil formation (Ezeaku and Anikwe, 2005; Maniyunda and Gwari, 2014; Jimoh *et al.*, 2020; Fatihu *et al.*, 2021). Therefore, it is important to have insightful study to ascertain the suitability of use to which land is put, and in addition to low yield which could cause loss to farmers, degradation is bound to set in; especially in the less resilient soils of the Savanna (Lal, 1997; Maniyunda and Yau, 2019). The economic impact of soil degradation is extremely severe in densely populated South Asia (Tolba and El-Kholy, 1992; UNEP 1994) and sub-Saharan Africa (Lal, 1995; Maniyunda and Yau, 2021). Its reclamation; where possible, is expensive to the peasant farmers who represent the higher proportion of food producers in Nigeria. Therefore, intensive and scientific investigation is needed in order to curb this threat posed to food security. Rice, cowpea and tomato are important crops in the sub-tropical region of Zaria, where this research is staged with the general objective of determining the effect of topography on the suitability ratings of these crops.

MATERIALS AND METHODS

Location of the Study Area

Field study was conducted along a toposequence at Hayin Gada, Giwa Local Government Area of Kaduna State, located between latitudes 11°11′22.6"N and

11°11′12.3"N, and longitudes 7°34′20.4"E and 7°34′32.5"E with an area of about 15.55 hectares (Figure 1).

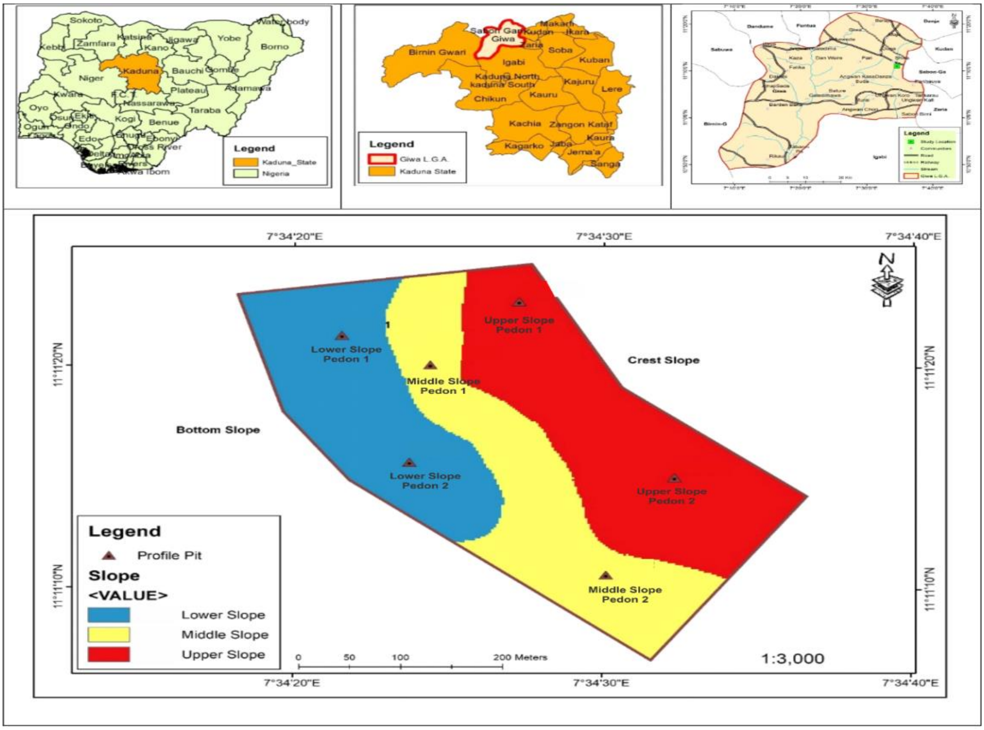


Figure 1: Map of Nigeria showing the toposequence in the study area at Hayin Gada in Giwa LGA, Kaduna State Nigeria

Geologically, the area is within highly weathered Basement Complex rocks consisting of Gneisses of variable composition and Migmatite which is medium to coarse grained and moderate to weakly foliated (Wright and McCurry, 1970; Obiora and Ukaegbu, 2009). The study area is drained by the tributaries of the Shika River, which in turn is of the tributary of the Galma River. The southward flowing Galma and seasonal Tubo rivers drain the Kaduna plain and empty into River Kaduna, which is a tributary of the Niger River. Giwa lies within a region which has a Tropical Savanna climate type with distinct wet and dry season (Abaje, *et al.*, 2012) also referred to as Northern Guinea Savanna. Characterized by long dry season from November through April, Zaria has a mono-modal wet season fall between May and October with a mean annual rainfall from 1071.7 mm (1988 to 2018). The diurnal temperature fluctuates between an average minimum and maximum ranges of 20°C during cold nights to over 33°C during the hot days, with a mean of 27°C (IAR Meteorological Unit, 2019). The major types of land use in the area include arable crops and livestock farming. Arable farming is characterized by intensive and continuous cultivation of agricultural crops including sorghum, maize, rice, sugarcane, cowpea, onion, cabbage and tomato (Ojanuga, 2006). In order to achieve the objectives of the study, two profile pits were randomly dug on each topographic position. These pits were sampled based on genetic horizons and described according to the procedure described in Soil Survey Manual (Soil Science Division Staff, 2017).

Laboratory Analyses

Disturbed soil samples collected from the surface horizons were air-dried in the laboratory, crushed with porcelain pestle and mortar and sieved to remove material greater than 2 mm (gravel). Soil particles of less than 2 mm fraction were used for the routine physico-chemical analysis. Bulk density determined by oven drying (Blake and Hartge, 1986) and saturated hydraulic conductivity was estimated using the core soil sampled with the aid of constant head permeameter as describe by Young (1976). The hydraulic conductivity was then calculated using the formula:

$$K_s = \frac{V \times L}{A \times T(H_{in} - H_{out})}$$

Where:
K_s= Hydraulic conductivity
V= Volume of water collected over time
L= Length of core sampler
A= Area of core sampler
T= Time taken to collect the volume of water V
H_{in} = Head of water in core sampler
H_{out} = Head of water outside the core sampler.

Soil saturation extract was used to determine soil reaction (pH) and obtain electrical conductivity (Udo *et al.*, 2009). Exchangeable bases (Ca, Mg, K and Na) were determined using ammonium acetate (NH_4OAc) saturation method and exchange acidity was obtained by method described by Thomas (1982). Cation exchange capacity (CEC) was determined by neutral (pH 7.0) NH_4OAc saturation method as described by (Rhoades, 1982). Organic carbon was determined by Walkley-Black dichromate wet oxidation method (Nelson and Sommers, 1982), total nitrogen (TN) was by micro-Kjeldahl technique as described by Bremner and Mulvaney (1982) and available phosphorus (Avail. P) by method described in IITA (1979) laboratory manual. Base saturation percentage was calculated as the proportion of exchangeable bases to CEC, while exchangeable sodium percent was calculated as the proportion of exchangeable Na to CEC.

Land Suitability Evaluation

Square root approach of the parametric method was adopted to assess the suitability of soils across the slope positions for rainfed production of rice, cowpea and tomato. Specific consideration was given to climatic and agronomic factors in the quantitative assessment of soil suitability. The climatic factors considered included rainfall, temperature and atmospheric humidity; while agronomic factors were soil physical characteristics (s) (texture, structure, coarse fragments and depth), erosion hazard (e) (slope), wetness (w) (flooding and drainage), fertility status (f) (CEC, base saturation) and soil toxicity (t) (electrical conductivity and exchangeable sodium percentage) as shown in Table 1. Suitability classification was arrived at by matching the land qualities with the requirements of rice, cowpea and tomato (Sys *et al.*, 1991; FAO, 1993; Naidu *et al.*, 2006) to obtain crop suitability rating for each quality assessed (FAO, 1983). The equation below was used to obtain the overall suitability index from the multiplication approach of the parametric system.

$$\text{IP} = A\left(\sqrt[2]{\frac{B}{100} \times \frac{C}{100} \times \frac{D}{100} \times \frac{E}{100} \times \frac{F}{100}}\right)$$

Where:
IP = Crop Suitability Index (Index of Productivity)
A = Climate (c)
B = Soil Physical Characteristics (s)
C = Erosion hazard (e)
D = Wetness (w)
E = Fertility Status (f)
F = Soil toxicity (t)
A, B, C, D, E and F = lowest characteristic rating for their respective land qualities groups.

Statistical Analyses

The physical and chemical properties of soil samples were statistically analyzed using descriptive statistics in SPSS Statistics 17.0. Analysis of variance (ANOVA) was used to compare the extent of variation between different slope positions. Means of the three different topographic positions were separated using least significant difference (LSD) at 0.05 level of significance (LOS). The types of relationship existing between slope positions and soil suitability evaluation was determined using correlation analysis.

Table 1: Factor Ratings of Land Use Requirements for Rainfed Rice, Cowpea and Tomato

Factor	Land Qualities/ Characteristics	Rice			Cowpea			Tomato		
		S1 (100)	S2 (85)	S3 (60)	S1 (100)	S2 (85)	S3 (60)	S1 (100%)	S2 (85%)	S3 (60%)
A	Climate (c)									
	Annual rainfall (mm)	>1100	900-1100	750-900	>750	600 - 750	500-600	600-750	500-600, 750-1000	450-500, >1000
	Mean Temperature (°C)	29-32	21-29	15 - 20	20 - 35	18–19, 36-40	15– 17, 41- 45	25-28	29-32 20-24	33-36 15-19
	Length of growing season (days)	120-180	90-120	60-120	>75	50 - 75	25 - 50			
B	Soil Physical Characteristics (s)									
	Rooting conditions (Effective soil depth) (cm)	>75	50 - 75	25 - 50				>75	50-75	25-50
	Texture Class	C, CL, SC, SiC	SCL, SiL, L	SL, LS	SL, SCL L, SiL, CL, SC	LS, SiCL, SiC, C	hC, S	SL, L, CL, SCL	SiCL, SiC, SC, C(m/k)	C(ss)
	Percent gravel (%)	<15	15 -35	35 - 50				<15	15-35	>35
C	Erosion hazard (e)									
	Slope (%)	0 - 2	2 - 4	4 – 7	<5	5 - 10	10 - 15	1-3	3-5	5-10
D	Wetness (w)									
	Drainage Class	imperfect, poorly dr.	moderately dr.	well dr.	moderately to well dr.	imperfectly dr.	poorly dr.	Well drained	Moderate	Imperfect
	Depth to water table (cm)	<10	10- 20	20 - 40	<100	50- 100	25 - 49	6.0-7.0	5.0-5.9; 7.1-8.5	<5; >8.5
E	Fertility Status (f)									
	pH	5.5-7.5	5.2-5.5, 7.6 – 8.0	4.5-5.2, 8.0 -8.5	6.0 – 8.5	8.5 – 9.0, 5.5 – 5.9	9.1 – 9.5, 5.0 – 5.4			
	CEC (cmol (+) kg^{-1})	>16	10-16	5 - 10				>15	10-15	<10
	Base Saturation				>50	35 - 50	20 - 35			
F	Soil toxicity (t)									
	Salinity (ECe) (dSm^{-1})	<3	3 - 6	6 - 10	<1.0	1.0 – 2.0	2.0 – 4.0	Non-saline	Slightly saline	Strongly saline
	Soil Sodicity							Non-sodic	Slightly sodic	Strongly sodic

SiC=silt clay, L=loam, SCL=sandy clay loam, SC=sandy clay, SL=sandy loam, C= clay, LS= loam sand, S=sand. NB. Ratings that do not fall within the S1, S2, and S3 were rated N. Adopted from FAO (1983), Sys *et al.*, (1991) and Naidu *et al.* (2006).

RESULTS AND DISCUSSION

The study covered an area of 15.55 ha which was characterized generally by sandy loam with few horizons of sandy clay loam texture. The characteristics and area extent of the topographic positions studied are presented in Table 2.

Table 2: Topographic Characteristics and Area Extent

Slopes	Designation	Elevation (m)	Slope Gradient (%)	Area (ha)	Percent
Lower Slope	LS	666 - 669	2	4.53	29.12
Middle Slope	MS	670 - 672	3	4.95	31.85
Upper Slope	US	673 - 675	1.4	6.07	39.03
Total				15.55	100.00

Morphology of all the topographic positions were very deep (167 – 192 cm) and not significantly different (Figure 3a), however with plinthite layer occurring in subsoils of MS and US may restrict plant root penetration. Variation in color was due to pedogenic processes occurring in these soils by virtue of topography. Darker coloration on surface horizons were attributed to humification resulting in melanization, grey coloration was attributed to poor drainage (Maniyunda *et al.*, 2015), while brown coloration was attributed to braunification. The subsurface horizons of lower slope soils were characterized by distinct yellowish red (5YR 5/8, wet) mottles which was an indication of very poor drainage (Table 3). Soils in the study area were dominated with fine to coarse sub-angular blocky structure, with few structureless massive material (Maniyunda *et al.*, 2015). The structures were mostly moderate to strongly developed with few weakly developed. The number of genetic subsurface horizons identified, significantly increased along the slope towards the bottom. Horizontal differentiation was mainly attributed to melanization and enrichment with colluvial depositions (Figure 2).

Slope position of the soils was observed to influence both physical and chemical properties. Content of silt and sand fractions (Figure 3b), available water content and moisture retention at field capacity were all significantly influenced by topography (Table 3). The coarseness of materials in surface horizons reduced down the slope and with increasing pedon depth. This was attributed to erosion of fine particles by surface run off down the slope from the upper slope position, and their illuviation into the subsoils respectively. All soils had higher clay content in the subsurface horizons which was attributed to argilluviation process (Maniyunda and Gwari 2014; Jimoh *et al.*, 2020; Fatihu *et al.*, 2021).

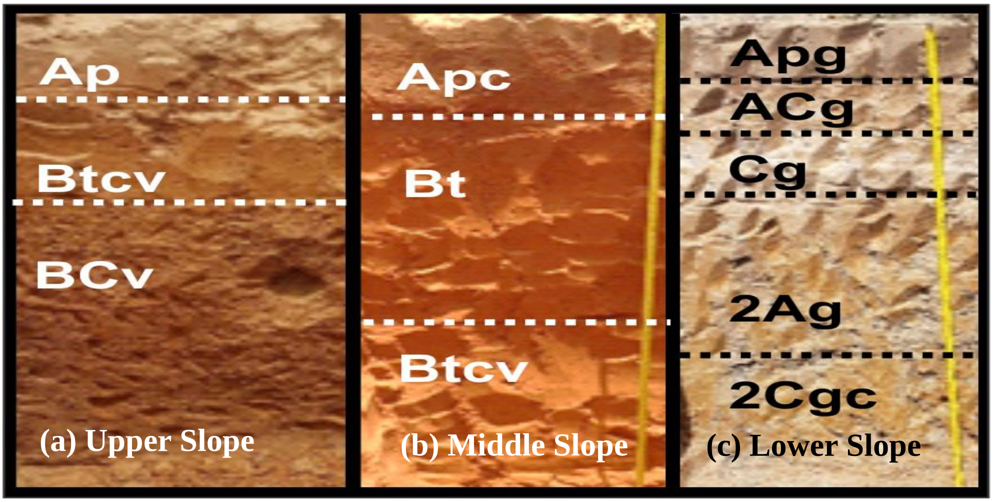


Figure 2: Profile of representative pedons on the different slope positions

The ranking of results of the chemical properties of the soils along the toposequence are presented in Table 4. Chemical properties of the soils indicate very strongly to slightly acid pH (pH value 4.82 – 7.44), medium to low content of Ca (1.80 – 6.20 cmol (+) kg^{-1}), Mg (0.38 – 1.87 cmol (+) kg^{-1}), Na (0.09 – 0.15 cmol (+) kg^{-1}), K (0.07 – 0.11 cmol (+) kg^{-1}), and low to medium CEC (NH_4OAc) (4.29 – 9.02 cmol (+) kg^{-1}, Figure 3c). The base saturation (BS_{CEC}) was also low to medium (41.14 – 66.96 %; Figure 3d). Similarly, organic carbon content was low to medium (3.99 – 11.03 g kg^{-1}), but low in total nitrogen contents (0.81 – 1.06 g kg^{-1}). Only organic carbon significantly varied in an increasing order down the slope (Table 4) and was attributed to alluviation process (Maniyunda and Gwari 2014; Fatihu *et al.*, 2021).

Using USDA Soil Taxonomy, both pedons on LS were classified as Typic Endoaquepts (Soil Survey Staff, 2022), correlating to Gleyic Cambisols on World reference Base Soil Resource 2015 (WRB Soil Resource) (IUSS Working Group WRB, 2022). While both pedons on MS and US were classified as Typic Plinthustalfs correlating to Haplic Alisols of MSP1 and USP2 and Haplic Luvisols for MSP2 and USP1.

Table 3: Morphological and Physical Properties of Pedons in the Study Area

Horizon	Depth (cm)	Color Dry	Color Moist	Mottle color	Texture	Structure	PSD ($g\ kg^{-1}$) Sand	Silt	Clay	ρd (Mgm^{-3})	f_a (%)	F.C. (%)	K_s ($cm\ h^{-1}$)
Lower Slope (LS)													
LSP1: (N 11º11'12.9'' E 7º34'28.9'')													
Ap	0-13	10YR 5/4	10YR 4/2	-	SL	2fsbk	675.2	170	154.8	1.32	40.67	20.93	0.47
ACt	13-37	10YR 4/6	10YR 3/3	5YR 5/8	SCL	2msbk	605.2	160	234.8	1.45	35.93	20.84	1.27
C	37-97	10YR 6/4	10YR 5/4	5YR 5/8	SL	2-3fsbk	645.2	170	184.8	1.36	41.31	23.06	1.16
2A	97-141	10 YR 6/3	10YR 5/3	5YR 5/8	SL	3mms	685.2	150	164.8	1.67	29.51	17.82	1.16
2C	141-187	10YR 6/2	10YR 6/1	5YR 5/8	SL	3fms	645.2	170	184.8	1.76	27.55	15.91	4.02
LSP2: (N 11º11'17.7'' E 7º34'22.5'')													
Apg	0-16	10YR 4/2	10YR 3/2	-	SL	1fsbk	705.2	200	94.8	1.57	31.31	17.95	4.02
ACg	16-31	10YR 6/3	10YR 4/3	-	SL	3csbk	685.2	200	114.8	1.51	31.70	14.01	4.02
Cg	31-53	10YR 7/1	10YR 5/1	-	SL	3csbk	685.2	190	124.8	1.49	35.30	11.35	4.77
2Ag	53-110	10YR 6/2	10YR 5/2	10YR 5/6	SL	3ms	705.2	100	194.8	1.45	41.88	15.67	1.91
2Cgc	110-192	10YR 6/2	10YR 6/1	10YR 5/8	SCL	3ms	675.2	120	204.8	1.62	27.72	21.79	1.34
Middle Slope (MS)													
MSP1: (N 11º11'14.9'' E 7º34'28.2'')													
Apc	0-25	10YR 7/3	10YR 5/4	-	SL	1fsbk	745.2	160	94.8	1.57	32.56	10.74	4.02
Bt	25-60	7.5YR 5/8	7.5YR 5/6	-	SCL	3mabk	645.2	140	214.8	1.58	30.78	17.46	4.24
Btcv	60-167	7.5YR 6/8	7.5YR 5/6	-	SL	3fsbk	685.2	130	184.8	1.59	30.46	16.22	4.49
MSP2: (N 11º11'17.4'' E 7º34'24.3'')													
Apc	0-30	10YR 6/8	10YR 4/6	-	SCL	1csbk	775.2	120	104.8	1.61	32.00	8.77	4.77
Btc1	30-60	5YR 6/8	5YR 5/8	-	SL	3fsbk	655.2	150	194.8	1.67	35.06	17.13	4.02
Btc2	60-105	5YR 5/8	5YR 5/6	-	SCL	3msbk	695.2	100	204.8	1.72	28.85	18.24	2.01
Btcv	105-170	5YR 5/8	5YR 4/6	7.5YR 8/6	SL	3msbk	695.2	110	194.8	1.32	26.59	17.54	1.91
Upper Slope (US)													
USP1: (N 11º11'16.6'' E 7º34'28.9'')													
Ap	0-26	5YR 5/8	5YR 4/6	-	SL	2fsbk	705.2	130	164.8	1.54	31.58	15.18	0.87
Bt1	26-90	5YR 6/8	5YR 5/8	-	SL	2mabk	685.2	130	184.8	1.40	41.98	17.11	2.01
Bt2	90-170	5YR 6/8	5YR 5/8	-	SL	3msbk	695.2	130	174.8	1.50	36.02	17.18	4.02
USP2: (N 11º11'19.0'' E 7º34'25.8'')													
Ap	0-13	7.5YR 6/8	10YR 6/8	-	SL	1fsbk	785.2	130	84.8	1.37	40.77	15.18	4.24
Btcv	13-106	5YR 5/8	5YR 5/8	-	SL	2m sbk	705.2	100	194.8	1.36	41.07	17.86	4.24
BCv	106-168	5YR 5/8	5YR 4/6	-	SL	2msbk	695.2	130	174.8	1.53	35.75	17.45	1.21

Structure: 0 = Structureless, 1 = weak, 2 = moderate, 3 = strong; f = fine, m = medium, c = coarse; ms = massive, abk = angular blocky, sbk = subangular blocky. PSD: Particle Size Distribution.

Table 4: Ranking of Means of Physical and Chemical Properties of Slope Positions

Parameter	Unit	Lower Slope	Middle Slope	Upper Slope	SE±	LOS
Depth	cm	190.00a	168.50b	169.00b	16.76	*
Clay	g kg^{-1}	165.80	170.51	163.13	15.64	NS
Silt	g kg^{-1}	163.00a	130.00b	125.00b	12.87	*
Sand	g kg^{-1}	671.20b	699.48ab	711.86a	14.03	*
Gravel	g kg^{-1}	1.31	2.05	1.14	1.98	NS
B.D.	M gm^{-3}	1.52	1.61	1.45	0.05	NS
P.D.	M gm^{-3}	2.31	2.32	2.33	0.03	NS
Tot. Porosity	%	34.29	30.89	37.86	2.34	NS
F. C.	%	17.93a	15.15b	15.36b	1.49	*
P.W.P	%	14.69	13.38	13.53	1.59	NS
A.W.C	%	3.23a	1.77b	1.83b	0.45	**
K_s	cm h^{-1}	2.41	3.64	2.77	0.77	NS
pH_{H2O}	-	5.39	5.18	5.23	0.22	NS
OC	g kg^{-1}	4.45a	3.85a	2.07b	0.58	***
N	g kg^{-1}	0.62	0.74	0.68	0.08	NS
P	mg kg^{-1}	4.15	3.28	9.63	3.59	NS
Ca	cmol (+) kg^{-1}	4.42	4.54	4.20	0.64	NS
Mg	cmol (+) kg^{-1}	1.23	1.25	1.15	0.18	NS
K	cmol (+) kg^{-1}	0.11	0.11	0.17	0.03	NS
Na	cmol (+) kg^{-1}	0.10	0.09	0.10	0.01	NS
EA	cmol (+) kg^{-1}	2.30	2.09	1.60	0.34	NS
CEC	cmol (+) kg^{-1}	10.06	9.96	9.49	0.72	NS
TEB	cmol (+) kg^{-1}	5.86	6.00	5.62	0.52	NS
BS_{NH4AOc}	%	58.18	58.53	57.89	3.07	NS

Note: Means followed by different alphabets in the rows are statistically different.
SE = Standard Error, LOS = Level of Significance, NS = Not significant, * = Significant ($P \leq 0.05$), ** = Highly Significant ($P \leq 0.01$), *** = Very Highly Significant ($P \leq 0.001$)**

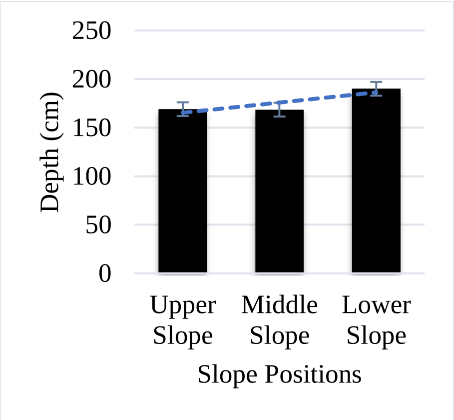


Figure 3(a): Soil Depth across Toposequence

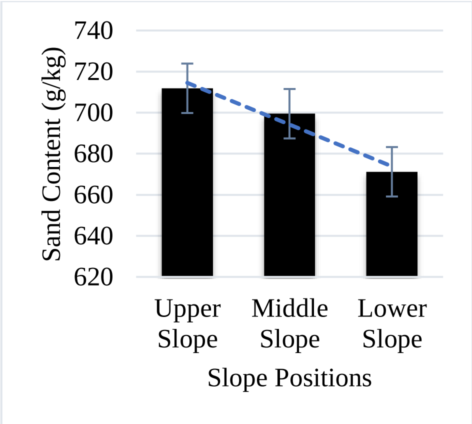


Figure 3(b): Sand Content across Toposequence

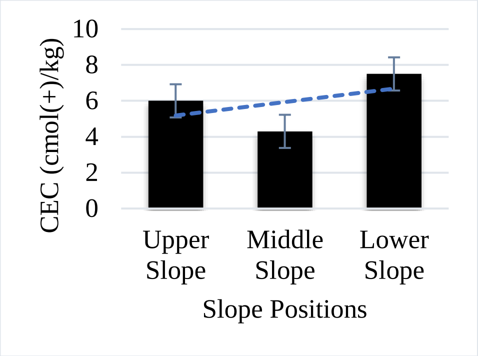


Figure 3(c): CEC Level across Toposequence

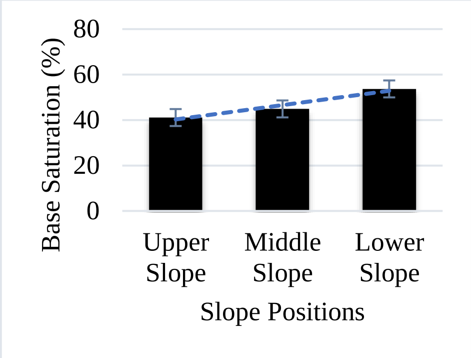


Figure 3(d): BS Percentage across Toposequence

Soil Suitability Classification

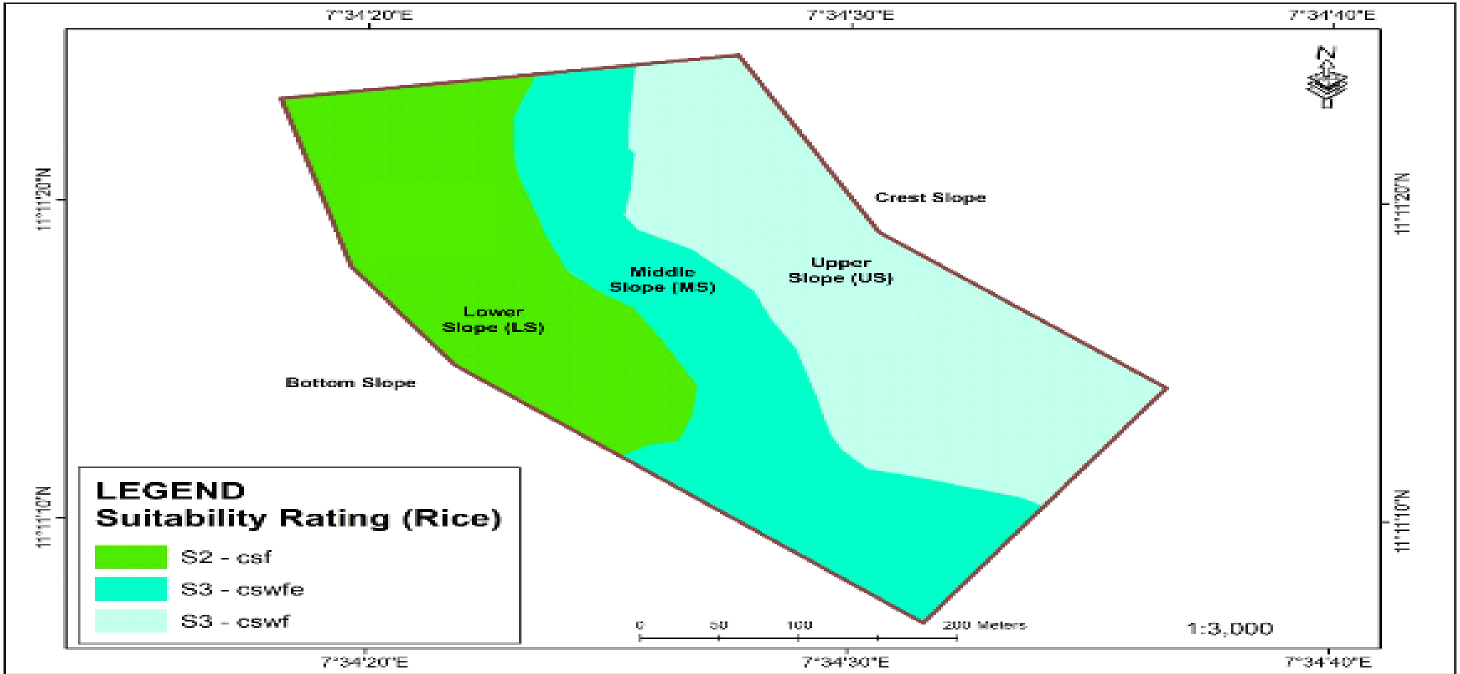
Land qualities for various slope positions are presented in Table 5. The suitability rating obtained from the matching of land qualities/soil properties (Table 5) with the soil criteria (Table 1) produced the various suitability classes for the slope positions as presented in Table 6. Land characteristics that were rated highly suitable for rice production in the entire area were rainfall, rooting depth and salinity hazard (Table 6).

Table 5: Land Qualities for the Various Slope Positions

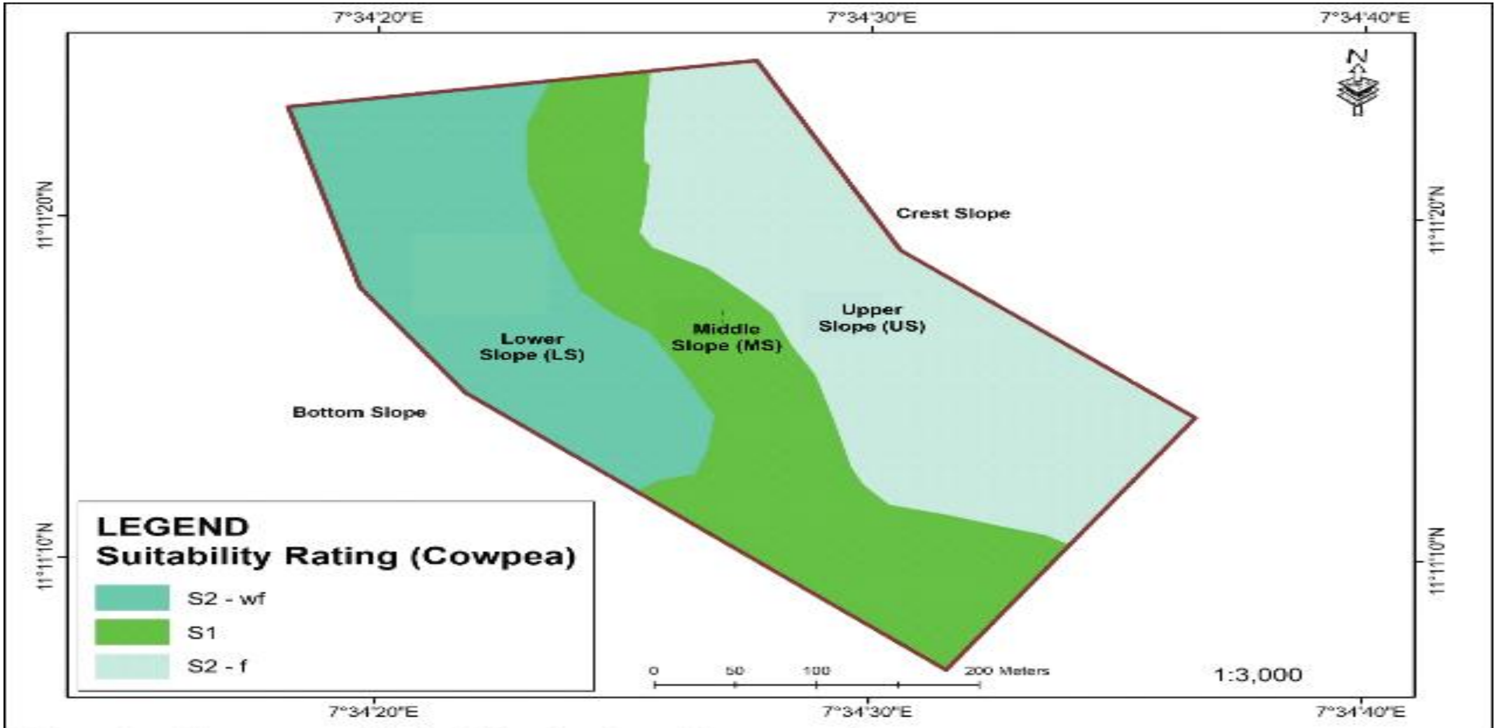
Factor	Land Qualities/Characteristics	Unit	Toposequence Positions		
			Lower Slope	Middle Slope	Upper Slope
A	Climate (c)				
	Annual rainfall	mm yr^{-1}	1171.7	1171.7	1171.7
	Length of rainy season	Months	6	6	6
	Mean annual temp.	°C	27	27	27
	Relative humidity	%	67	67	67
B	Soil physical properties (s)				
	Texture	Class	SL	SL/SCL	SL
	Soil structure	Class	1-2fsbk	Fsbk/csbk	1-2fsbk
	Coarse fragment	%	1.31	2.05	1.14
	Depth	cm	190	169	168
C	Erosion hazard (e)				
	Slope	%	1-2	2-4	1-2
D	Wetness (w)				
	Flooding	Class	F2	F0	F0
	Drainage	Class	Very poor	Good	Good
E	Fertility status (f)				
	CEC	cmol (+) kg^{-1}	7.5	4.3	6
	Base saturation	%	53.7	44.9	41.1
	pH	-	5.5	5.6	4.8
	Avail. P (mg kg^{-1})	mg kg^{-1}	13.6	5.8	3.9
F	Soil toxicity (t)				
	Salinity (EC)	dSm^{-1}	0.01	0.07	0.07
	Sodicity (ESP)	%	2.26	1.86	1.17

Table 6: Suitability Index of Matching Land Qualities and Land use Requirements for Rice

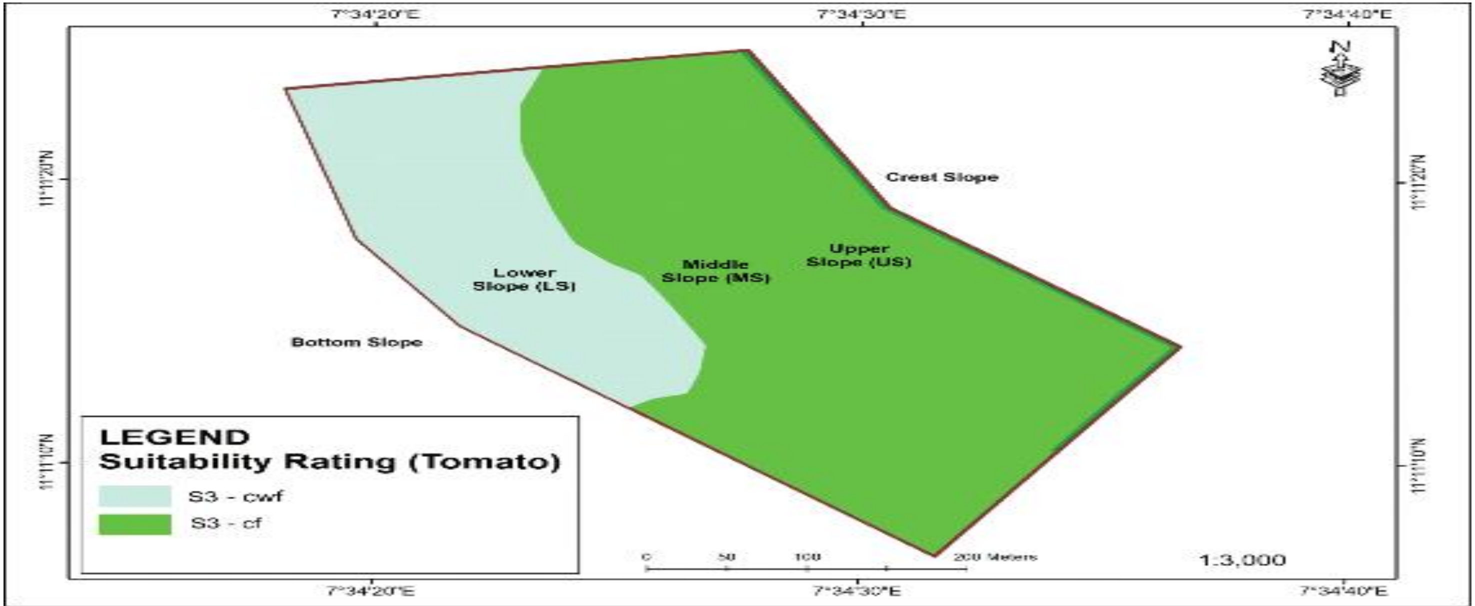
Factor	Land Qualities/ Characteristics	Rice Lower Slope	Rice Middle Slope	Rice Upper Slope	Cowpea S1 (100)	Cowpea S2 (85)	Cowpea S3 (60)	Tomato S1 (100%)	Tomato S2 (85%)	Tomato S3 (60%)
A	Climate (c)									
	Annual rainfall (mm)	S1 (100%)	S1 (100%)	S1 (100%)	S1 (100%)	S1 (100%)	S1 (100%)	S1 (100%)	S1 (100%)	S1 (100%)
	Mean Temperature (ºC)	S2 (85%)	S2 (85%)	S2 (85%)	S1 (100%)	S1 (100%)	S1 (100%)	S3 (60%)	S3 (60%)	S3 (60%)
	Length of growing season (days)	S1 (100%)	S1 (100%)	S1 (100%)						
B	Soil Physical Characteristics (s)									
	Rooting conditions (Effective soil depth) (cm)	S1 (100%)	S1 (100%)	S1 (100%)	S1 (100%)	S1 (100%)	S1 (100%)	S1 (100%)	S1 (100%)	S1 (100%)
	Texture Class	S3 (60%)	S3 (60%)	S3 (60%)	S1 (100%)	S1 (100%)	S1 (100%)	S1 (100%)	S1 (100%)	S1 (100%)
	Percent gravel (%)	S1 (100%)	S1 (100%)	S1 (100%)						
C	Erosion hazard (e)									
	Slope (%)	S1 (100%)	S2 (85%)	S1 (100%)	S1 (100%)	S1 (100%)	S1 (100%)	S1 (100%)	S1 (100%)	S1 (100%)
D	Wetness (w)									
	Drainage Class	S1 (100%)	S3 (60%)	S3 (60%)	N1 (40%)	S1 (100%)	S1 (100%)	N1 (40%)	S1 (100%)	S1 (100%)
	Depth to water table (cm)	S1 (100%)	S1 (100%)	S1 (100%)	S1 (100%)	S1 (100%)	S1 (100%)	S3 (60%)	S3 (60%)	S3 (60%)
E	Fertility Status (f)									
	pH	S1 (100%)	S1 (100%)	S3 (60%)				S2 (85%)	S2 (85%)	S2 (85%)
	CEC (cmol (+) kg^{-1})	S3 (60%)	N1 (40%)	S3 (60%)	S2 (85%)	S2 (85%)	N1 (40%)	S3 (60%)	S3 (60%)	S3 (60%)
	Base Saturation	S1 (100%)	S1 (100%)	S1 (100%)	S1 (100%)	S1 (100%)	S1 (100%)	S1 (100%)	S1 (100%)	S1 (100%)
F	Soil toxicity (t)									
	Salinity (ECe) (dSm^{-1})	S1 (100%)	S1 (100%)	S1 (100%)	S1 (100%)	S1 (100%)	S1 (100%)	S1 (100%)	S1 (100%)	S1 (100%)
	Soil Sodicity							S1 (100%)	S1 (100%)	S1 (100%)
Actual Suitability (Index of Productivity)		S2-csf (51.00%)	S3-cswfe (29.74%)	S3-cswf (39.50%)	S2-wf (58.31%)	S1 (92.20%)	S2-f (63.25%)	S3-cwf (29.39%)	S3-cf (46.48%)	S3-cf (46.48%)
Potential Suitability (Index of Productivity)		S2-cs (65.84%)	S3-cswe (47.02%)	S2-csw (51.00%)	S2-w (63.24%)	S1 (100%)	S1 (100%)	S3-cw (37.95%)	S2-c (60.00%)	S2-c (60.00%)



Slope Position	Suitability Rating	Interpretation
LS (Lower Slope)	S2 – csf	The soil was moderately suitable for rice cultivation with limitations due to climate, soil texture and fertility factors. Judicious nutrient management and climate-smart agriculture may improve suitability rating.
MS (Middle Slope)	S3 - cswfe	The soil was marginally suitable for rice cultivation with limitations due to climate, soil texture, wetness, fertility and erosion factor due to slope angle. With sprinkler irrigation scheme and nutrient management, suitability rating for rice may be improved.
US (Upper Slope)	S3 - cswf	The soil was marginally suitable for rice cultivation with limitations due to climate, soil texture, wetness, and fertility factor.



Slope Position	Suitability Rating	Interpretation
LS (Lower Slope)	S2 – wf	The soil was moderately suitable for cowpea cultivation with limitations due to soil wetness and fertility factors. Additional nutrient inclusions and building drainage channels may improve suitability rating.
MS (Middle Slope)	S1	The soil was highly suitable for cowpea cultivation.
US (Upper Slope)	S2 - f	The soil was moderately suitable for rice cultivation with limitations due to soil fertility factor. This can be improved by addition of fertilizer.



Slope Position	Suitability Rating	Interpretation
LS (Lower Slope)	S3 – cwf	The soil was marginally suitable for the cultivation of tomato with limitations due to climate, soil wetness and fertility factors. Additional nutrient inclusions, building drainage channels and additional nutrient application may improve the suitability rating.
MS (Middle Slope)	S3 - cf	The soil was marginally suitable for tomato cultivation with limitations due to climate and fertility. Irrigation and fertilizer application may improve tomato suitability in the area.
US (Upper Slope)	S3 - cf	The soil was marginally suitable for tomato cultivation with limitations due to climate and fertility. Irrigation and fertilizer application may improve tomato suitability in the area.

Figure 4 (a-c): Actual Suitability Map for Rice, Cowpea and Tomato Cultivation in the Study Area

Land qualities that critically limited the suitability of the study area for rainfed rice cultivation included mean temperature and length of growing days, which were both rated moderately suitable (S2). Textural class and CEC were rated marginally suitable (S3) for LS and US and not suitable (N1) for MS. Erosion hazard (e) was rated moderately suitable (S2) for MS, and highly suitable for both LS and US. Wetness (w) limited the suitability of rice production in MS and US respectively and constituted 70.88% of the entire study area. Drainage class was rated moderately suitable (S2) for MS and marginally suitable (S3) for US, while depth to water table was rated S3 for both slope positions. The overall actual suitability rating for rice showed that LS, which covers 4.53 ha (29.12%) of the study area was considered moderately suitable (S2-csf), while MS which covers 4.95 ha (31.85%) and US which covers 6.07 ha (39.03%) were rated marginally suitable (S3-cswfe and S3-cswf respectively) for rainfed rice production (Figure 4a). These limitations were similar to those reported by Olaleye *et al.*, (2002) who assessed the suitability of selected wetland soils in Nigeria for rainfed rice cultivation.

For cowpea, annual rainfall, temperature, effective depth, texture, erosion hazard, depth to water table and salinity did not limit suitability rating in the study area. Land characteristics that lowered the suitability ratings across all slope positions in the study area included soil pH which was rated as S2 for LS and MS and N1 for US, soil drainage, was rated as N1 for LS, and base saturation was rated S2 for MS and US. The parametric evaluation of actual suitability for cowpea cultivation in the study area showed that 68.15% of the area (LS and US) was classified as moderately suitable (S2-wf and S2-f respectively), while 31.85% of the total area (MS) was rated as highly suitable for cowpea production (Figure 4b). Cowpea has wide range of adaptation across Nigerian savanna agro-ecological zones, although, it is sensitive to water logging, but tolerant to drought stress than most cereal and other legume (Igomu and Idoga, 2017). Soil wetness was important in lowering suitability classification of cowpea in the study areas. Ogunwale *et al.* (2009), Sharu *et al.* (2013) and Igomu and Idoga, (2017) reported poor drainage as a major limitation to cowpea suitability on lowland soils.

Tomato was rated moderately suitable for the entire area with general limitations in rainfall and fertility. Poor drainage lowered suitability of tomato in 29.12% of soils in the study area (LS). Land qualities and characteristics that critically limited the suitability of the study area for tomato production included total rainfall which was rated as marginally suitable, soil drainage class, which was rated as N1 for LS, soil pH and CEC were rated as S2 and S3 respectively for all slope positions (Figure 4c). These limitations were similar to those reported by Aliyu (2016), who assessed suitability of soils of Dakace, Galma Basin, North Western Nigeria, for irrigated tomato production. Simons and Sobulo (1974) have reported that tomato can grow on a variety of soils except worst soils such as gravelly soils and water-logged soils.

Effect of Topography on Soil Suitability Rating

The effect of topography on suitability of soils was determined by examining the trajectory of major suitability limitations on different slope positions. Figure 5 shows linear suitability trendline for the crops in the studied soils. Table 6 shows a correlation analysis between suitability of the selected crops and the various slope positions studied. From the Figure, the highest potential suitability for rice was noted in lower slope, while cowpea and tomato were higher upper slope. The suitability of rice increased down the slope, while that of cowpea and tomato were found to reduce down the slope from the upper slope to lower slope (Figure 5). This reflects how varying soil properties as conditioned by differences in slope positions may affect suitability of crops based on their distinct requirements. The correlation studies reveals that rice negatively correlated significantly (r = -0.540*) (Table 6) with topography. This meant that actual Index of Productivity of rice tend to increase down the slope from the upper slope position. This was attributed to increase in impeding drainage condition which favors rice cultivation.

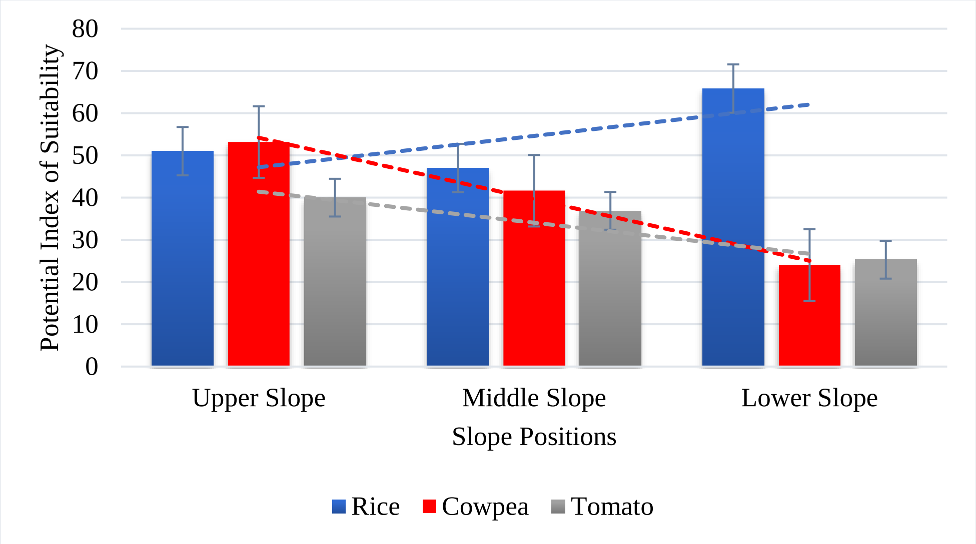


Figure 5: Effect of Slope Position on Suitability Ratings for the Selected Crops

Table 7: Correlation between Slope Positions and Crop Suitability in the Studied Area

	Topography	Rice	Cowpea
Rice	-0.540*		
Cowpea	0.135	-0.907***	
Tomato	0.866**	-0.889**	0.612*

Correlation significance: *≤0.05, **≤0.01, ***0.001

Cowpea and tomato had positive correlation with slope positions (r = 0.135 and r = 0.866** respectively), meaning that their suitability increased with increasing slope positions from bottom slope. This was attributed to better drainage condition. Drainage is a severe factor which may significantly affect soil suitability (Maniyunda and Gwari, 2014) and it is pre-conditioned by the effect of topography (Lawal *et al.*, 2013; Maniyunda *et al.*, 2014; Jimoh *et al.*, 2017a).

Soils on MS and US may also be used for rice cultivation but in conjunction with climate-smart agriculture technologies such as the use of sprinkler or drip irrigation to supplement for moisture, as well as employment of early maturing or drought resistant rice varieties on the soils. Based on the findings of the suitability studies amongst the selected crops, soils on MS and US are more appropriate for annual or biannual rotation of tomato and cowpea; both crops having higher ratings on US compared to MS (Figure 5).

CONCLUSION

The study focused on assessing the impact of slope on soil properties and suitability ratings for selected crops in Giwa Local Government Area of Nigerian Northern Guinea Savanna region. Parametric approach of the Index of Productivity (IP) was employed in arriving at the final suitability rating. The results revealed that slope position significantly influenced morphological, physical and chemical properties of the soils. Silt and sand fractions, available water content, and moisture retention at field capacity were all significantly ($P \leq 0.05$) influenced by topographic position. Pedogenetic processes such as melanization, braunification, and argilluviation were observed in all the slope positions, however, plinthization was noted on the subsurface layers of US and MS, while mottling was noticed on the subsurface layers of LS as a result of the poor drainage status. The suitability evaluation showed that 29.12 % of the land area was moderately suitable (S2) for rice cultivation, while the 70.88 % were marginally suitable (S3) due to limitations in wetness. For cowpea, 68.15 % of the soils were rated S2 with limitation to soil fertility, while the remaining 31.15 % was rated highly suitable (S1) with no notable limitation. Tomato was rated S2 for the entire area, with limitation to soil fertility status (Figure 4 a-c). The Index of Productivity (IP) for rice had a negative correlation with slope increase (-0.540*), while that of cowpea and tomato positively correlated to increase in slope (0.135 and 0.866 respectively). This indicated that the suitability of rainfed rice cultivation increased down the slope from US, while the suitability for cowpea and tomato increased up the slope from LS to US. Based on this finding, it was recommended to use LS for rice cultivation, while MS and US can be rotated annually or biannually for cultivating tomato and cowpea. Additionally, the implementation of practices such as sprinkler irrigation to supplement moisture, efficient fertility management practices such as application in split doses and the use of early maturing or drought-resistant crop varieties may be employed to further enhance crop production, especially on the MS and US.

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