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SOIL SUITABILITY EVALUATION OF SELECTED ZARIA SOILS FOR CASSAVA PRODUCTION

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ABSTRACT

The utilization of pedometrics to address a variety of soil challenges is increasingly capturing attention in recent times. This research was carried out to assess the capabilities of the newly developed Agricultural Land Use Evaluation System (ALUES) algorithm in predicting soil appropriateness for cultivating cassava in the Zaria region. Samples were taken from soils under different agricultural land management systems. Evaluations of land suitability considered terrain, soil composition, water availability, and temperature conditions. The outcomes yielded by the ALUES algorithm generated suitability scores and classes for the land parcels, employing a fuzzy logic approach. Consequently, the aggregate suitability scores led to the establishment of overall suitability classes of the soils as moderately suitable (S2), marginally suitable (S3), and unsuitable (N). This investigation reaffirms the efficacy of ALUES in gauging the appropriateness of agricultural land for cassava cultivation within tropical settings. Nevertheless, it's important to note that the presence of climate-related variables such as water and temperature, which are not easily adjustable, could impose limitations stemming from the climatic circumstances, potentially restricting the cultivation of cassava in the study areas.

Key words: pedology, pedometrics, qualitative, quantitative, suitability, cassava

INTRODUCTION

Land evaluation involves assessing the potential uses of land based on its properties and limitations (Jimoh *et al*., 2018). This assessment is carried out by a thorough analysis of the land's characteristics, aiming to identify factors that could influence the best practices and optimal use of the land (Babalola, 2017; Peter and Aron, 2019). One specific approach within land evaluation is land suitability evaluation, which categorizes land characteristics into defined classes using qualitative and quantitative assessments in a sustainable manner (Ukaegbu *et al*., 2023). Although this traditional method has been in use for many years (FAO, 1973), recent advancements in Soil Science, particularly in the field of pedometrics, have simplified its application. While pedology has historically focused on descriptive and field-oriented approaches to soil issues (Basher, 1997), pedometrics tackles similar problems using quantitative mathematical and statistical techniques. Unlike traditional methods, pedometrics formulates and solves soil-related problems in a quantitative manner. Various software tools, including Automated Land Evaluation System, ALES (Johnson and Cramb, 1991), Land Evaluation Intelligent Geographical Information System, LEIGIS (Kalogirou, 2002), Mediterranean Land Evaluation Information System, Micro-LEIS (De la Rosa *et al*., 2004), and Agriculture Land Suitability Evaluator, ALSE (Elsheikh *et al*., 2013), have been developed for agricultural land suitability assessment. However, due to certain limitations identified by Elsheikh *et al.* (2013) for ALES, LEIGIS, Micro-LEIS (e.g., lack of flexibility in handling certain soil parameters, limited compatibility with specific data formats, and difficulty in incorporating local knowledge), and by Asaad *et al.* (2022) for ALSE (e.g., issues with model accuracy and scalability), in their comprehensive study on land evaluation, this study opts to utilize ALUES, an *R* statistical package proposed for assessing land suitability for agricultural production.

According to Asaad *et al.* (2022), ALUES is an R programming package specifically designed for evaluating land suitability for various crops. The assessment is based on crop requirements defined by Sys *et al.* (1993), and the classification employs fuzzy logic with membership functions such as triangular, trapezoidal, and Gaussian functions. The input data include characteristics of land units categorized into rainfall, temperature, topography, and soil properties (Asaad *et al*., 2022). Cassava (*Manihot esculenta*) was chosen as the target crop due to its adaptability to a wide range of soils, moderate temperature requirements, and its ability to thrive under varying rainfall conditions. It holds significant importance for many Nigerians' livelihoods and is cultivated extensively in tropical and subtropical regions (Abah and Petja, 2017).

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Previous studies (Gbadegesin and Nwagwu, 1990; Chukwu, 2007; Ande, 2011; Lawal *et al.*, 2012; Ezeaku and Tyav, 2013) on crop suitability manually matched crop requirements with specific conditions and management practices. Despite the ongoing use of this method (Jimoh *et al.*, 2018; Mujiyo *et al.*, 2021) and advancements (Abah and Petja, 2017; Zemba *et al.*, 2017; Akinwumiju *et al.*, 2020) in accurately aligning agricultural practices with spatial information, pedometrics, aided by open-source statistical software like R, is gaining prominence. To enhance accuracy and precision, automating land evaluation is essential. Therefore, this study aimed at assessing the effectiveness of the ALUES model in calculating suitability scores and classes for various land units, under different agricultural land uses, for cassava production.

MATERIALS AND METHODS

Description of the Study Site

The study was conducted in agricultural land-use zones within the Zaria vicinity (Figure 1), situated in the guinea savanna region of northwestern Nigeria. The agricultural land uses encompass cultivated and fallow cutting across Bomo and Shika Wards, respectively for Sabon Gari and Giwa Local Government Areas within the Zaria environs of Kaduna State, Nigeria. These areas are positioned between longitudes 7° 33' and 7° 38' E, and latitudes 11° 09' and 11° 13' N. The study area covers 13280.7 ha.

The entire Zaria region is underlain by the basement complex, as noted by Wright and McCurry (1970), and characterized by seasonal tropical vegetation with a dense ground cover of grasses and notable tree species such as Isoberlina woodland, *Parkia biglobosa*, and *Terminalia* species, as highlighted by Sanford and Isichei (1986). The climate pattern features a singular rainy season, peaking in August, followed by a rapid decline in precipitation levels by October. The period from November to March experiences either minimal rainfall or total monthly precipitation below 25.50 mm, the threshold for effective rainfall. Consequently, the projected annual rainfall for the study sites approximates 996.64 mm (Abaje *et al.*, 2016). The average monthly maximum temperature fluctuates between 28.7 and 35.4 °C, while the minimum range spans from 16.89 to 32.7 °C. Notably, the highest mean air temperature is recorded in April at 38.9 °C, whereas the lowest occur in December (22.9 °C) and January (33.1 °C), as indicated by Abaje *et al.* (2016).

For this study, cassava (*Manihot esculenta*) was chosen as the target crop due to its adaptability to a wide range of soils, a temperature range of 25-27 °C (Mujiyo *et al.*, 2021), and a rainfall range of 500-1500 mm (Keating *et al.*, 1982; Abah and Petja, 2017). Cassava can thrive on various slopes and requires moderate water (Abah and Petja, 2017), making it significant for many Nigerians' livelihoods. This crop, a small perennial shrub, primarily produces starch-filled roots and is cultivated in tropical and subtropical regions (Howeler, 2014; Mujiyo *et al.*, 2021), serving as raw material for the starch-producing food industry (Aristizábal *et al.*, 2017).

Data Collection, Preprocessing and Processing

This study utilized secondary data sourced from Shobayo (2010), comprising a comprehensive set of soil and soil-related parameters from six pedons within two distinct locations of Bomo and Shika wards. These locations encompassed three pedons each. A total of 21 pedogenetic horizons were identified and sampled from the pedons, resulting in 21 observations per sample point. These soil samples, having undergone analysis for more than 22 parameters using standard laboratory protocols, produced the secondary soil data comprising of several constituent tables. These tables were interconnected and refined to generate a new dataset tailored to the requirements of the ALUES algorithm

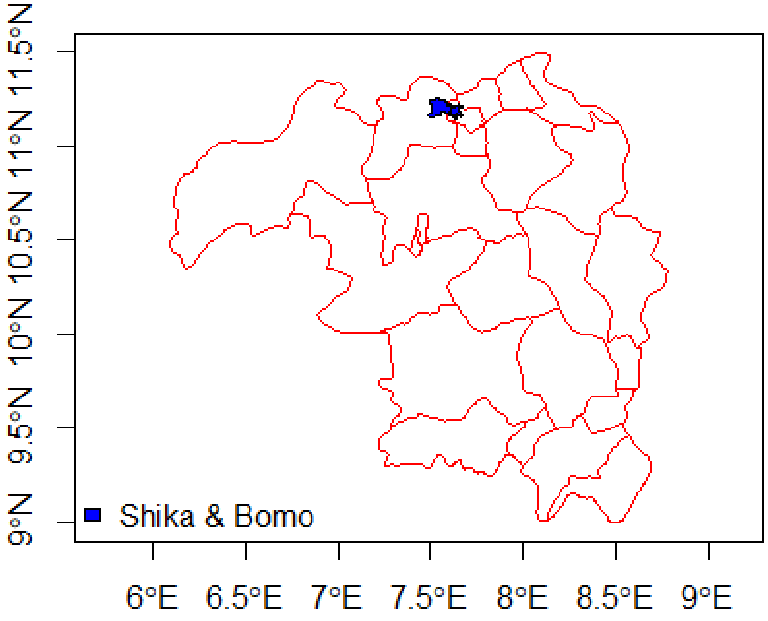

Figure 1: Kaduna State map showing location of study area

(Table 1) encompassing various aspects such as geographical coordinates (latitude, longitude), elevation, soil coarse fragments, soil depth, calcium carbonate, cation exchange capacity, base saturation, sum of base cations, pH levels, organic carbon content, electrical conductivity, soil texture, slope, flood occurrences, drainage conditions, and slope aspect. During the course of this study, the newly formed dataset underwent transformations, leading to the creation of an updated dataset presented in Table 2. The purpose behind these manipulations was to distill the pertinent information (final datasets) required for the study. The final datasets derived from this process were designated as 'soil_property,' 'water_property,' and 'temp_property'. These datasets were subsequently subjected to land evaluation analysis (soil suitability analysis) and interpretation using the ALUES package in the R programming environment. The results were then interpolated by ALUES to cover the entire wards.

The selected soil properties for ALUES algorithm including particle size distribution were determined using the hydrometer method as modified by (Udo *et al*., 2009). Textural class was determined using the textural triangle. Soil pH (water) was determined with glass electrode pH meter in soil: soil and water at ratio 1:1 (McLean, 1982). The organic carbon was determined by the Walkley-Black dichromate wet oxidation method described by Nelson and Sommers (1982). Exchangeable bases (Ca, Mg, K and Na) were determined using NH_4OAc saturation method as described by Thomas (1982). Sum of basic cations was calculated from the formula: sum BCs = Ca + Mg + Na + K. The cation exchange capacity (CEC) was determined by the neutral (pH 7.0) NH_4OAc saturation method (Rhoades, 1982). The CEC of clay fraction was calculated using the method proposed by Sombroek and Zonneveld (1971). Electrical conductivity was determined at a 1: 2.5 soil/water ratio using a Wheatstone bridge at 25 °C (Udo *et al*., 2009). Base saturation was calculated as the percentage ratio of BCs to the CEC.

Table 1: Factors evaluated/desired parameters and terminologies (factors for cassava land evaluation) in the ALUES package for cassava

Soil requirement	
CFragm1	Coarse fragment in surface (Vol.%)
CFragm2	Coarse fragment in depth (Vol.%)
SoilDpt	Soil depth (cm)
$CaCO_3$	$CaCO_3$ (%)
Gyps	Gypsum (%)
CECc	Apparent CEC Clay (cmol (+) kg-clay^{-1})
BS	Base Saturation (%)
SumBCs	Sum of basic cations (cmol (+) kg-clay^{-1})
pHH_2O	pH H_2O
OC	Organic carbon (%)
ECedS	ECe (dS m^{-1})
SoilTe	12 classes of soil texture (Soil Taxonomy)
Temperature requirement	
TyMaxAv	Mean annual maximum temperature (°C)
TmMinXmAb	Absolute min temp. coldest month (°C)
TgAv	Mean temperature of the growing cycle (°C)
Terrain requirement	
Slope1	Slope (%) (1. Irrigated agriculture, basin furrow irrigation)
Slope2	Slope (%) (2. High level of management with full mechanization.)
Slope3	Slope (%) (3. Low level of management animal traction or handwork.)
Flood	Flooding: 1 (No Flood); 2 (Short Time); 3 (Long Time)
Drainage	Drainage: 1 (Good); 2 (Moderate); 3 (Imperfect); 4 (Poor)
SlopeD	Slope (degree, 6 classes): 1 (0-3); 2 (3-8); 3 (8-15); 4 (15-20); 5 (20-25); 6 (> 25)
Water requirement	
WyAv	Annual precipitation (mm)
WmDryLen	Length dry season (months: P < 1/2 PET)
WmnN5	n/N of the 5 driest months

Processes Involved in Soil Evaluation Using the ALUES Model

1. Data Collection and Preprocessing: Relevant datasets including soil properties, climate data, land use, and topography were collected and pre-processed to ensure consistency and compatibility.
2. Layer Integration: Data layers were integrated into a unified spatial framework, incorporating information on soil texture, depth, drainage, pH, and organic matter content, as well as temperature, and precipitation patterns.
3. Weighting and Scoring: Weights were assigned to each data layer based on its importance in determining soil suitability for agriculture. Layers were scored according to their relevance to agricultural productivity and sustainability.
4. Overlay Analysis: The weighted and scored layers were overlaid to generate a composite suitability map, wherein areas with favourable conditions for agriculture received higher suitability scores.
5. Classification: Based on the composite suitability scores, study area was classified into different suitability classes ranging from highly suitable to unsuitable for agriculture, with intermediate classes representing varying degrees of suitability.
6. Output Interpretation: Soil evaluation outcome (suitability map) was generated to facilitate informed decision-making for stakeholders involved in agricultural management and natural resource utilization.

RESULTS

Physico-chemical Properties of the Soils

The study areas featured moderately to very deep soils, with depths ranging from 59 to 180 cm. These soils were positioned on nearly level (2% slope) crestal slopes, revealing excellent drainage without any signs of flooding. The gravel content differed at the surface and subsurface levels: for the Bomo Ward, it spanned from 2-13% on the surface and 4-39% below, while for the Shika Ward, it ranged from 0% to 42% on the surface and from 12.5% to 54.5% below. The pH of the soils under investigation showed variation as well. For the Bomo Ward, pH values ranged from 4.73 to 5.05, while for the Shika Ward, pH spanned from 5.2 to 5.63. These pH ranges indicated that the Bomo Ward's soils were very strongly acidic, while the Shika Ward's soils were moderately acidic.

Table 2: Processed data for cassava land evaluation for the ALUES model

Land use	Bomo	Bomo	Bomo	Shika	Shika	Shika
Pedon	1	2	3	4	5	6
Lat.	11.1748	11.1774	11.1799	11.187	11.1867	11.1863
Lon.	7.6202	7.62	7.6198	7.591	7.5915	7.5923
Elev.	726	726	725	711	712	720
CFragm1	2	11	13	42	10	0
CFragm2	4	26	39	12.5	54.5	17.5
SoilDpt	160	100	80	105	59	182
$CaCO_3$	4.31	6.17	8.12	9.87	6.11	5.23
Gyps	NA	NA	NA	NA	NA	NA
CECc	23.07	28.05	32.59	32.72	36.43	33.03
BS	43.33	60.75	69	75.33	72.33	55.75
SumBCs	3.42	4.9	5.6	7.48	4.42	4.33
pHH_2O	4.83	4.73	5.05	5.2	5.63	5.25
OC	0.273	0.265	0.285	0.327	0.273	0.155
ECedS	0.05	0.025	0.028	0.03	0.056	0.018
SoilTe	8	6	6	6	3	6
TyMaxAv	30.38	30.38	30.38	30.38	30.38	30.38
TmMinXmAb	16.89	16.89	16.89	16.89	16.89	16.89
TgAv	32.05	32.05	32.05	32.05	32.05	32.05
Slope1	NA	NA	NA	NA	NA	NA
Slope2	NA	NA	NA	NA	NA	NA
Slope3	2	2	2	2	2	2
Flood	1	1	1	1	1	1
Drainage	1	1	1	1	1	1
SlopeD	1	1	1	1	1	1
WyAv	1011	1011	1011	1011	1011	1011
WmDryLen	5	5	5	5	5	5
WmnN5	0.41	0.41	0.41	0.41	0.41	0.41

Note: Values presented are averages from each pedon. See Table 1 for definition of abbreviations

Soils of the study area were determined to be non-saline, as their electrical conductivity of saturation extract fell within the range of 0.025-0.056 dS m^{-1}. This range was below the threshold of 4.0 dS m^{-1} used to classify soils as saline. Consequently, there is little risk of salinity becoming an issue if the current land use practices are maintained. This assertion was further supported by the highest recorded calcium carbonate ($CaCO_3$) content of 9.87%, which indicated that salinity problems were unlikely to develop.

The exchangeable cations' cumulative values were within a moderate range, varying from 3.42 to 5.20 cmol (+) kg^{-1} soil for the Bomo Ward and reaching a maximum of 7.48 cmol (+) kg^{-1} soil for the Shika Ward, which was still within the moderate range. Soil CECclay for the Bomo Ward ranged from 23.07-32.59 cmol (+) kg^{-1} clay, while for the Shika Ward, they ranged from 32.72 to 36.43 cmol (+) kg^{-1} clay. Base saturation (BS) fluctuated between 43.33% and 69.00% for the Bomo Ward and between 55.75% and 75.33% for the Shika Ward. The Bomo Ward's base saturation was rated as moderate, whereas the Shika Ward's base saturation was rated as high (exceeding 50% - FAO, 2006). This distinction was attributed to the influence of the crop type (cassava) in the case of Bomo Ward and the overall land use practices in the case of Shika Ward on base saturation. The organic carbon (OC) content ranged from 0.27% to 0.29% for the Bomo Ward and from 0.16-0.33% for the Shika Ward. These OC levels were classified as low across the soil profiles for the land use types.

The Bomo and Shika Wards' Temperature and Water Characteristics

The research sites experience a yearly rainfall of 1011 mm and an average maximum annual temperature of 30.38 °C, as indicated in Table 2. Nonetheless, Abah and Petjah (2017) reported that cassava has the capability to thrive in diverse soil types, with temperatures ranging from 25 to 29 °C, and precipitation spanning from 500 to 1500 mm.

Land Suitability Scores and Classes

The ALUES model algorithm generated suitability scores and corresponding classes for the three Pedons (Tables 3, 4 and 5) sited in Bomo Ward and the other three (i.e., Pedons 4, 5 and 6) sited in Shika Ward. The suitability scores were generated through a process involving the evaluation of various factors such as soil, temperature, terrain and water characteristics of the study area (Table 1), using the ALUES model algorithm. Individual suitability scores, representing statistical values for evaluated parameters and factors, were calculated to establish suitability classes (Tables 3a-d) which were ultimately translated into suitability maps (Figures 2a and 2b). Analysis of soil characteristics as a factor, revealed that for pedon 1, the suitability class for coarse fragments was S1/SI for surface and subsurface soils respectively. In sequence, pedons 2, 3, 4, 5, and 6 were classified as S2/S2, S2/S3, N/S1, S2/S3, and S1/S2 (Table 3a), demonstrating the suitability of soil coarse fragments as highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and non-suitable (N) in accordance with FAO's (1976) definition.

Table 3a: Suitability scores and classes for soil characteristics

Soil Characteristics (Suitability Score)

Pedon	CFragm1	CFragm2	SoilD pt	$\mathrm{CaCO_3}$	Gyps	CECc	BS	SumBCs	$\mathrm{pHH_2O}$	OC	ECedS	SoilTe
1	0.9607843	0.9466667	0.000	0.7027586	−1	0	0	0	0.7918033	0.7126316	0.9900	0.6666667
2	0.7843137	0.6533333	0.800	0.5744828	−1	0	0	0	0.7754098	0.7210526	0.9950	0.5000000
3	0.7450980	0.4800000	0.640	0.4400000	−1	0	0	0	0.8278689	0.7000000	0.9944	0.5000000
4	0.1764706	0.8333333	0.840	0.3193103	−1	0	0	0	0.8524590	0.6557895	0.9940	0.5000000
5	0.8039216	0.2733333	0.472	0.5786207	−1	0	0	0	0.9229508	0.7126316	0.9888	0.2500000
6	1.0000000	0.7666667	0.000	0.6393103	−1	0	0	0	0.8606557	0.8368421	0.9964	0.5000000

Soil Characteristics (Suitability Class)

Pedon	CFragm1	CFragm2	SoilDpt	$\mathrm{CaCO_3}$	Gyps	CECc	BS	BS SumBCs	$\mathrm{pHH_2O}$	OC	ECedS	SoilTe
1	S1	S1	N	S2	NA	N	N	N	S2	S1	S1	S2
2	S2	S2	S1	S3	NA	N	N	N	S3	S1	S1	S2
3	S2	S3	S2	S3	NA	N	N	N	S2	S1	S1	S2
4	N	S1	S1	S3	NA	N	N	N	S1	S1	S1	S2
5	S2	S3	S3	S3	NA	N	N	N	S1	S1	S1	S3
6	S1	S2	N	S3	NA	N	N	N	S1	S1	S1	S2

Table 3b: Suitability scores and classes for water characteristics

Pedon	Score			Class		
	WyAv	WmDryLen	WmnN5	WyAv	WmDryLen	WmnN5
1	0.5947059	0	0.2743363	S1	N	S1
2	0.5947059	0	0.2743363	S1	N	S1
3	0.5947059	0	0.2743363	S1	N	S1
4	0.5947059	0	0.2743363	S1	N	S1
5	0.5947059	0	0.2743363	S1	N	S1
6	0.5947059	0	0.2743363	S1	N	S1

Table 3c: Suitability scores and classes for terrain characteristics

Pedon	Score				Class			
	Slope3	Flood	Drainage	SlopeD	Slope3	Flood	Drainage	SlopeD
1	0.9512195	0.4285714	0.75	0.6	S1	S1	S1	S1
2	0.9512195	0.4285714	0.75	0.6	S1	S1	S1	S1
3	0.9512195	0.4285714	0.75	0.6	S1	S1	S1	S1
4	0.9512195	0.4285714	0.75	0.6	S1	S1	S1	S1
5	0.9512195	0.4285714	0.75	0.6	S1	S1	S1	S1
6	0.9512195	0.4285714	0.75	0.6	S1	S1	S1	S1

Table 3d: Suitability scores and classes for temperature characteristics

Pedon	Score			Class		
	TyMaxAv	TmMinXmAb	TgAv	TyMaxAv	TmMinXmAb	TgAv
1	0	0.925	0	N	S1	N
2	0	0.925	0	N	S1	N
3	0	0.925	0	N	S1	N
4	0	0.925	0	N	S1	N
5	0	0.925	0	N	S1	N
6	0	0.925	0	N	S1	N

Table 4: Overall suitability scores and classes for terrain, soil, temperature and water characteristics

Pedon	Terrain		Soil		Temperature		Water	
	Score	Class	Score	Class	Score	Class	Score	Class
1	0.7106707	S2	0.3988066	S3	0.23125	N	0.295580	S3
2	0.7106707	S2	0.402733	S3	0.23125	N	0.295580	S3
3	0.7106707	S2	0.3628267	S3	0.23125	N	0.295580	S3
4	0.7106707	S2	0.3489183	S3	0.23125	N	0.295580	S3
5	0.7106707	S2	0.3349688	S3	0.23125	N	0.295580	S3
6	0.7106707	S2	0.3842872	S3	0.23125	N	0.295580	S3

Table 5: Combined scores and classes for terrain, soil, temperature and water characteristics

Pedon	Terrain	Soil	Temp	Water	Terrain	Soil	Temp	Water
1	0.7106707	0.3988066	0.23125	0.295580	S2	S3	N	S3
2	0.7106707	0.402733	0.23125	0.295580	S2	S3	N	S3
3	0.7106707	0.3628267	0.23125	0.295580	S2	S3	N	S3
4	0.7106707	0.3489183	0.23125	0.295580	S2	S3	N	S3
5	0.7106707	0.3349688	0.23125	0.295580	S2	S3	N	S3
6	0.7106707	0.3842872	0.23125	0.295580	S2	S3	N	S3

Table 6: Illustration of the enhanced efficiency of the ALUES package (Unit: milliseconds)

min	lq	mean	median	uq	max	neval
12.6192	15.2703	21.75697	17.94885	**25.89575**	46.1785	100

Regarding soil depth suitability scores, the ALUES model assigned a value of 0.000 for pedons 1 and 6. Percent $CaCO_3$ suitability scores ranged from 0.31 to 0.70 across pedons 1 to 6. The algorithm classified all pedons (Table 3a) as marginally suitable (S3), except for pedon 1, which received a classification of moderately suitable (S2). Soil reaction suitability scores varied from 0.78 to 0.92 for pedons 1 to 6. Pedons 1 and 3 were categorized as moderately suitable (S2), pedon 2 as marginally suitable (S3), and pedons 4, 5, and 6 as highly suitable (S1).

DISCUSSION

The slope position of the study areas remains within the critical slope limit of 3%. According to Schwab *et al.* (1981), the slope position is a crucial factor in determining the suitability of land for various uses, including machinery operation and crop cultivation. Steep slopes can pose challenges for machinery operation and increase the risk of soil erosion. Plaster (2013) emphasizes the importance of maintaining slope stability to prevent soil erosion and ensure sustainable crop production.

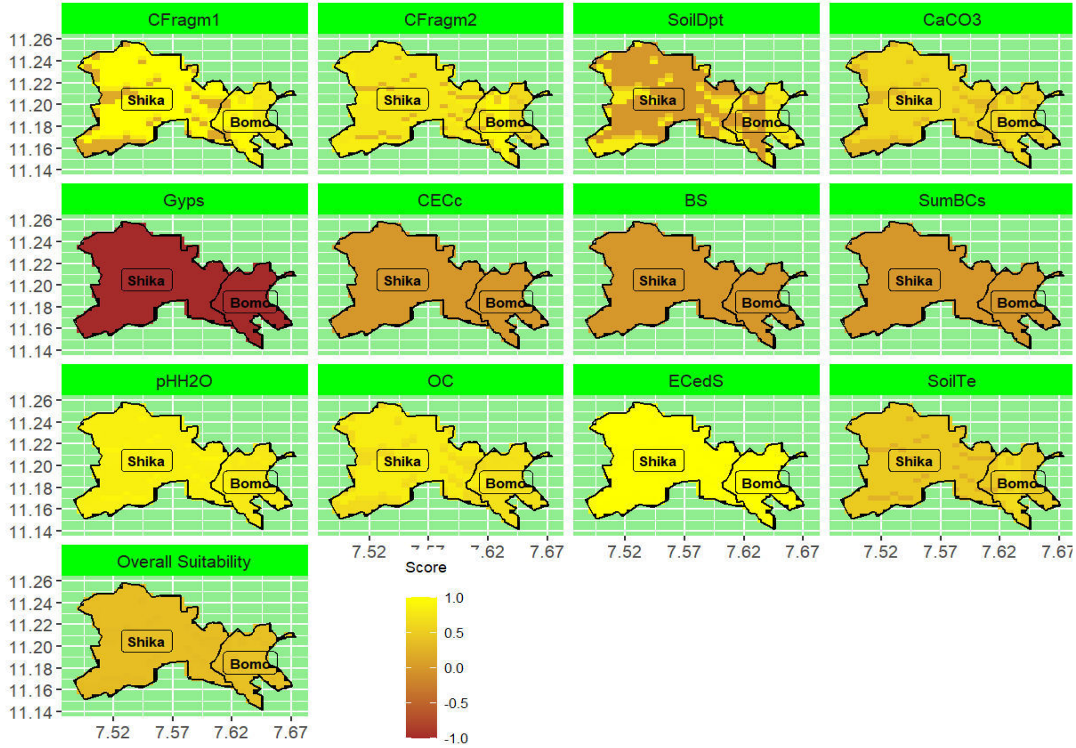

Figure 2a: Suitability map (showing suitability scores) of the study locations

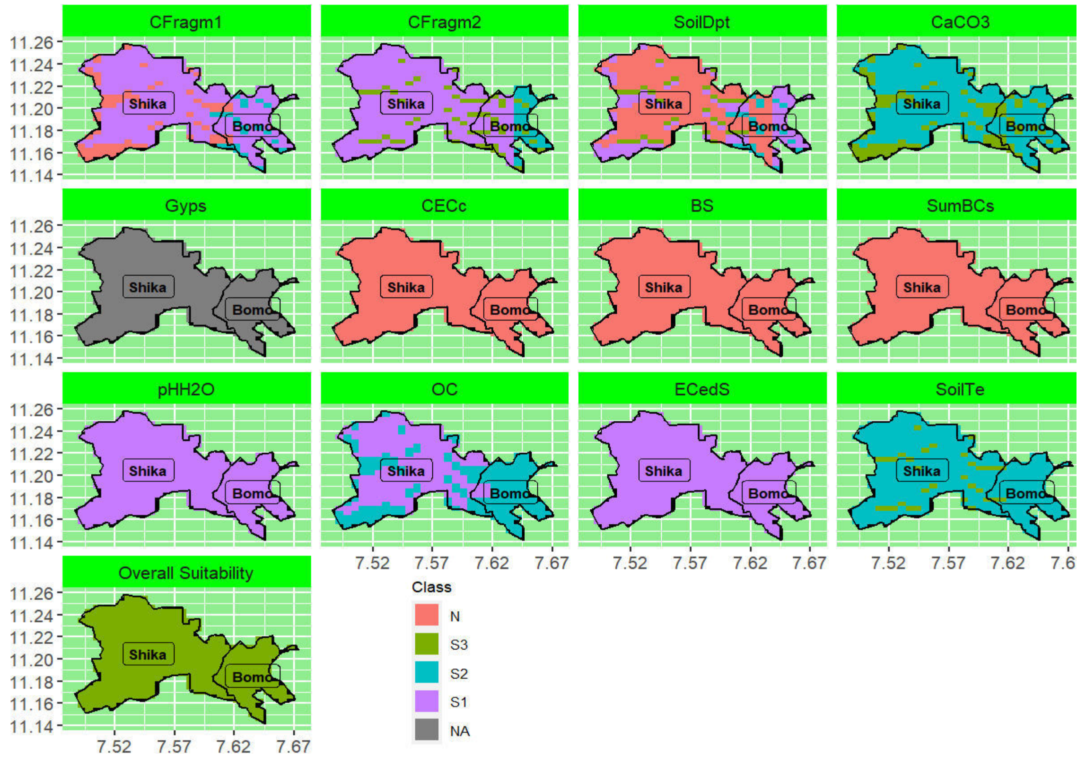

Figure 2b: Suitability map (showing suitability classes) of the study locations

The soils under study were deep. Hodge (2004) explored the plasticity of root systems in response to heterogeneous nutrient supplies and found that roots can selectively elongate and branch in nutrient-rich patches. This indicates that the effective soil depth can be significantly influenced by the spatial distribution of nutrients, as deeper soils with uneven nutrient distribution allow roots to exploit available resources more efficiently. Bengough *et al.* (2011) reviewed the limiting stresses and beneficial root tip traits related to root elongation. They highlighted the role of mechanical impedance, such as compacted soil, in limiting root growth. They also discussed the importance of root tip traits, such as root hairs and exudation of mucilage, in overcoming mechanical impedance and facilitating root penetration. The soils exhibit varying textures, ranging from sandy clay loam to clay loam and sandy loam to clay loam for the cultivated and fallow areas, respectively. Brady and Weil (2016) submitted that loamy texture promotes efficient mechanical soil manipulation with minimal damage to its structure and reduces leaching of fertilizer nutrients.

The prevalence of gravel in the subsurface soils reflects their parent material's origin (basement complex). These gravelly soils can hinder the growth of crops sensitive to acidic conditions by limiting root penetration and reducing soil moisture retention, which negatively impacts root development and nutrient uptake. Several studies have examined the influence of parent material on soil properties and crop growth. Smith and Johnson (2010) found that parent material, such as granitic origin, can significantly affect soil properties through various processes, including mineral weathering, which alters pH levels and nutrient availability, as well as influences on soil texture and structure, ultimately impacting water-holding capacity. These effects can vary depending on the stage of soil development and the specific geochemical characteristics of the parent material. These soil properties, in turn, can have a direct impact on crop growth and development.

Brown and Jones (2015) focused specifically on the effects of gravel in subsurface soils on crop growth and root development. They found that high gravel content can lead to poor soil drainage, which can hinder root development and limit nutrient uptake by crops. Additionally, the presence of gravel can increase soil acidity, which can negatively affect the growth of crops sensitive to acidic conditions. Smith and Johnson (2010) investigated the impact of granitic parent material on soil acidity and its effects on crop production. They found that soils derived from granitic parent material tend to have higher acidity levels, which can be detrimental to the growth of crops that prefer neutral or slightly acidic conditions. The researchers also noted that the presence of gravel in these soils can exacerbate the acidity issue, further hindering crop growth.

Soils with an ECe value of 0.056 dS m^{-1} pose minimal adverse effects on crop growth and microbial populations, making them suitable for saline-sensitive crops (Shrivastava and Kumar, 2015), possibly influenced by the local rainfall pattern that supports leaching and capillary movement of essential nutrients. The moderate basic cation level benefits both soil and crop health, optimizing nutrient availability and pH levels. Blanco-Canqui *et al.* (2015) posited the optimal basic cation level in soil improves both soil and crop health. It enhances pH levels and nutrient availability, and hence soil productivity and crop yields (Sainju and Liptzin, 2022). Basic cations such as calcium (Ca), magnesium (Mg), potassium (K), and sodium (Na) are essential for plant growth and are more accessible to crops at higher pH levels (Sainju and Liptzin, 2022). These cations play a crucial role in nutrient uptake and utilization by plants (Kollie and Semu, 2022).

Parent material might have contributed to the observed low CECclay values due to its granitic origin; low CEC values observed in soils with a granitic origin has been attributed to the characteristics of the parent material (Ishihara and Qin, 2015). Low organic carbon content in cultivated areas can be attributed to land use practices and high temperatures in the region. Land-use change, particularly conversion of native vegetation to cropland, has been found to cause a significant loss of soil organic carbon (Houghton *et al*., 2012). Continuous cultivation aggravates organic carbon oxidation, leading to lower organic carbon levels in continuously cultivated land (Obalum *et al*., 2012; Onwuka and Adesemuyi, 2019). Agricultural fields in certain areas have been observed to have low organic carbon content (Welemariam *et al*., 2021). Additionally, rapid mineralization and loss of carbon from the soil can contribute to low organic matter content in cultivated land use systems (Chauhan *et al*., 2014).

The presence of coarse fragments in the surface soil of pedon 4 makes it unsuitable for use, highlighting a challenging constraint (Howeler, 2001). The actual soil depths of 160 and 182 cm (Table 2) exceed the 125 cm limit recommended for cassava, classifying the soils as unsuitable depth-wise (Merumba *et al*., 2020). The algorithm applies the "not suitable" classification when values surpass the upper limit of S3 or fall below the lower limit of S1 (Asaad *et al*., 2022). These depths could be suitable based on previous studies, but the algorithm categorizes them as unsuitable (Asaad *et al*., 2022).

Soil attributes related to nutritional requirements, such as apparent CECclay, base saturation, and sum of basic cations, are scored at the maximum limit, implying excess nutrient levels for cassava production as defined in the ALUES. However, this high nutrient state might limit cassava production, as indicated by the algorithm's classification. According to Howeler (1991), long-term cassava cultivation can have an impact on soil productivity. This suggests that the high nutrient state indicated by the ALUES scoring system may not necessarily translate into optimal cassava production. Also, Costa *et al*. (2021) found that the diversity of management practices in cassava production areas leads to high variability in soil chemical attributes. This variability further emphasizes the need to consider soil management strategies that go beyond nutrient levels alone.

Cassava, a globally important food security crop, requires specific soil conditions for optimal growth and yield. The pH range of 4.5-7.0 is considered optimal for cassava (Souza *et al*., 2016). The recorded pH values of 4.73-5.63 fall within this range, indicating favourable conditions for cassava growth (Souza *et al*., 2016). Additionally, all pedons (soil profiles) were deemed highly suitable (S1) for cassava due to sufficient organic carbon content. This suggests that the soils provide the necessary nutrients for cassava growth. The electrical conductivity scores of the soils were high, classifying them as highly suitable (S1) for cassava growth (Souza *et al*., 2016). This indicates that the soils have good nutrient availability and water-holding capacity, which are important for cassava growth and development. However, the soil texture scores were mostly moderate, with one pedon being marginally suitable. Soil texture affects water infiltration and root penetration (Souza *et al*., 2016), so the moderate texture scores may slightly limit cassava growth in some areas.

Water and temperature characteristics, including annual precipitation, dry season length, and temperature metrics, were evaluated for suitability. The similarity in scores and classes (Table 4, Figures 2a and 2b) for both fallow and cultivated soils highlight the shared climatic conditions. This suggests that the suitability of the soil is not significantly affected by the type of land use. Terrain characteristics, such as slope, flooding, and drainage, did not impose limitations on the overall soil suitability. This implies that the terrain factors did not significantly affect the water and temperature characteristics that were evaluated for suitability. Overall, the soil suitability for terrain factors was moderately suitable. This suggests that the terrain factors did not pose significant limitations on the suitability of the soil. However, it is important to consider other factors, such as nutrient content and soil composition, in addition to water and temperature characteristics when evaluating soil suitability for specific purposes (Chen *et al*., 2017).

The study found that the soil characteristics in the study areas were marginally suitable for cassava production across all pedons (Table 5). This indicates that there are limitations in the soil that need to be addressed, particularly in terms of nutrient availability. Nutrient limitations can negatively impact cassava cultivation and reduce crop productivity (Awoyale *et al*., 2020). In addition to soil characteristics, water availability is another important factor for cassava production. The study indicates that water characteristics in the study areas were also marginally suitable for cassava production (Table 5). Water availability is essential for the growth and development of cassava plants, and inadequate water supply can lead to reduced yields and poor crop performance (Parmar *et al*., 2017). Therefore, addressing water limitations is crucial for successful cassava cultivation. Furthermore, temperature characteristics were identified as a major constraint (not suitable - Table 5) for cassava cultivation in the study areas. Cassava is a tropical crop that requires warm temperatures for optimal growth and development. Unsuitable temperature conditions, such as extreme heat or cold, can negatively affect cassava plants and limit their productivity (Burns *et al*., 2010). Climate constraints, including temperature variations, can pose significant challenges to cassava cultivation.

The timing efficiency of the pedometric application - Agricultural Land Use Evaluation System (ALUES) algorithm, was evident in the evaluation of the study data frame consisting of the six pedons for cassava suitability, which took an average of 26.0 milliseconds (Table 6). Pedometrics, a field within soil science, has utilized statistical models to understand and learn with speed from data how soil is distributed in space and time (Padarian *et al*., 2020).

CONCLUSION

The ALUES model within the field of pedometrics was applied to assess the suitability of cassava production. Through an algorithmic process, the model generated suitability scores and classes. The terrain in the study areas was categorized as moderately suitable overall, soil and water characteristics as marginally suitable, and temperature conditions as unsuitable. This algorithmic approach not only facilitated efficiency testing but also demonstrated the execution of the program within approximately 26.0 milliseconds. The versatility of the ALUES package, which covers more than 50 essential crops and offers the necessary secondary data for the crop of interest, enables rapid suitability studies for various crops within a matter of minutes.

REFERENCES

Abah R.C. and Petja B.M. (2017). Crop suitability mapping for rice, cassava, and yam in North Central Nigeria. *J Agric. Sci.,* **9 (1),** 916-9760

Abaje I.B., Abdullahi N. and Jeje O.G. (2016). Climate change and infectious diseases in Funtua Local Government Area of Katsina State, Nigeria. *Int. J. Sci. Technol.,* **5 (1),** 47-58

Abua M.A. (2015). Suitability assessment of soil for cassava production in the coastal and hinterland areas of Southern Cross River State - Nigeria. *Academic Journals*, **6 (5),** 108-115

Akinwumiju, A.S., Adelodun, A.A. and Orimoogunje, O.I. (2020). Agro-climato-edaphic zonation of Nigeria for a cassava cultivar using GIS-Based analysis of data from 1961 to 2017. *Sci. Rep.*, **10,** 1259

Ande O.T. (2011). Soil suitability evaluation and management for cassava production in the derived savanna area of southwestern Nigeria. *Int. J. Soil Sci.*, **6,** 142-149. http://dx.doi.org/10.3923/ijss.2011.142.149

Aristizábal J., García J.A. and Ospina B. (2017). Refined cassava flour in bread making: A review. *Ing. e Investig.,* **37 (1),** 25-33. https://doi.org/10.15446/ing.investig.v37n1.57306

Asaad A.B., Salvacion A.R. and Yen B.T. (2022). ALUES: R package for Agricultural Land Use Evaluation System. *J. Open-Source Softw.*, **7 (73),** 4228. https://doi.org/10.21105/joss.04228

Awoyale W., Asiedu R., Kawalawu W.K.C., *et al.*, (2020). Assessment of the suitability of different cassava varieties for gari and fufu flour production in Liberia. *Asian Food Science Journal*, 36-52. https://doi.org/10.9734/afsj/2020/v14i230128

Babalola T.S. (2017). *Pedogenesis of Soils Derived from Different Parent Materials in Two Agroecological Zones of Nigeria*. PhD Thesis Submitted to the Department of Soil & Environmental Resources, Ekiti State University, 289 pp.

Baker I., Prihodko L., Denning S., Goulden M., Miller S.D. and Rocha H.R.D. (2008). Seasonal drought stress in the amazon: reconciling models and observations. *J. Geophys. Res-Biogeo.,* 113(G1), n/a-n/a. https://doi.org/10.1029/2007jg000644

Basher L.R. (1997). Is pedology dead and buried? *Aust. J. Soil Res.,* **35,** 979-994

Bengough A.G., McKenzie B.M., Hallett P.D. and Valentine T.A. (2011). Root elongation,water stress, and mechanical impedance: a review of limiting stresses and beneficial root tip traits. *J. Exp. Bot.,* **62,** 59-68

Blanco-Canqui H., Shaver T.M., Lindquist J.L., *et al.* (2015). Cover crops and ecosystem services: insights from studies in temperate soils. *Agronomy*, **107 (6),** 2449-2474. https://doi.org/10.2134/agronj15.0086

Brady N.C. and Weil R.R. (2016). *The Nature and Properties of Soils*. Pearson Education

Brown R. and Jones S. (2015). Effects of gravel in subsurface soils on crop growth and root development. *Soil Sci. Soc. Am. J.*, **79 (3),** 234-245

Burns A.E., Gleadow R.M., Cliff J., Zacarias A. and Cavagnaro T.R. (2010). Cassava: the drought, war and famine crop in a changing world. *Sustainability,* **2 (11),** 3572-3607. https://doi.org/10.3390/su2113572

Chauhan R.P., Pande K.R. and Thakur S. (2014). Soil properties affected by land use systems in Western Chitwan, Nepal. *Int.l J. Appl. Sci. Biotechnol.*, **2 (3),** 265-269. https://doi.org/10.3126/ijasbt.v2i3.10660

Chen J., Xiao G., Kuzyakov Y., *et al.* (2017). Soil nitrogen transformation responses to seasonal precipitation changes are regulated by changes in functional microbial abundance in a subtropical forest. *Biogeosci,* **14 (9),** 2513-2525. https://doi.org/10.5194/bg-14-2513-2017

Chukwu G.O. (2007). Land suitability classification of Southeastern Nigeria wetlands for azolla. *Sci. Res. Essays*, **2 (12),** 512-515

Costa A.G., Souza L.D.S., Xavier F.A.D.S., Cova A.M.W., Silva E.F.d. and Bonfim M.R. (2021). Characterization of soils cultivated with cassava under different managements. *Revista Brasileira De Engenharia Agrícola E Ambiental*, **25 (11),** 764-771. https://doi.org/10.1590/1807-1929/agriambi.v25n11p764-771

De la Rosa D., Mayol F., Diaz-Pereira E., Fernandez M. and De la Rosa D. (2004). A land evaluation decision support system (MicroLEIS DSS) for agricultural soil protection. *Environ. Model. Softw.,* **19,** 929942. https://doi.org/10.1016/j.envsoft/2003.10.006

Elsheikh R., Mohammed Hariff A.R.B., Amiri F., Ahmad N.B., Balasundram S.K., and Soom M.A.M. (2013). Agriculture Land Suitability Evaluator (ALSE): A decision and planning support tool for tropical and subtropical crops. *Comput. Electron. Agric.,* **93,** 98110. https://doi.org/10.1016/j.compag.2013.02.003

Ezeaku P.I. and Tyav C. (2013). Fuzzy and parametric methods for land evaluation along Katsina-Ala flood plains in central region of Nigeria: Application to rice production. *Elixir Agriculture*, **61,** 17033-17039

FAO (1973). A framework for land evaluation. Draft Edition. AGL/MISC/73/14. FAO Rome, 65

FAO (1976). A framework for land evaluation. FAO, Rome. https://www.fao.org/3/x5310e/x5310e03.htm#2.7%20land%20suitability%20and%20land%0capability

FAO (2006). Guidelines for soil description, 4th edn. Food and Agriculture Organization (FAO) of the United Nations, Rome

Gbadegesin A.S. and Nwagwu U. (1990). Suitability assessment of the forest and savanna ecological zones of south western Nigeria for maize production. *Agric. Ecosys. Environ.*, 31 (2), 99-114

Hernández T.D.B., Slater B.K. and Shaffer J.M. (2019). Characterizing minimally disturbed soils in a highly disturbed urban environment. *Agrosyst., Geosci Amp. Environ.,* **2 (1),** 1-13. https://doi.org/10.2134/age2019.07.0053

Hodge A. (2004). The plastic plant: root responses to heterogeneous supplies of nutrients. *New Phytol.*, **162,** 9-24

Houghton R.A., House J.I., Pongratz J., *et al.* (2012). Carbon emissions from land use and land-cover change. *Biogeosci.*, **9 (12),** 5125-5142. https://doi.org/10.5194/bg-9-5125-2012

Howeler R.H. (1991). Long-term effect of cassava cultivation on soil productivity. *Field Crops Res.,* **26 (1),** 1-18. https://doi.org/10.1016/0378-4290(91)90053-x

Howeler R.H. (2001). Cassava mineral nutrition and fertilization. *Cassava: Biology, Production and Utilization,* 115-147. https://doi.org/10.1079/9780851995243.0115

Howeler R.H. (2014). Sustainable soil and crop management of cassava in Asia: A reference manual. Cali: Centro Internacional de Agricultura Tropical. https://core.ac.uk/download/pdf/132662687.pdf

Ishihara S. and Qin K. (2015). Composition of Cape Ashizuri granitoids. *Resource Geol*., **65**, 47-51. https://doi.org/10.1111/rge.12054

Jimoh A.I., Malgwi W.B., Aliyu J. and Shobayo A.B. (2016). Characterization, classification and agricultural potentials of soils of Gabari District, Zaria, Northern Guinea Savanna Zone, Nigeria. *Biol. Environ. Sci. J. Tropics (BEST),* **13 (2),** 102-113

Jimoh A.I., Aliyu J., Sabo A.T. and Yusuf O.Y. (2018). Land suitability evaluation of Kubanni floodplain for rice production in Zaria, Kaduna State, Nigeria. *Nign. J. Basic Appl. Sci.,* **26 (1),** 46-54. http://dx.doi.org/10.4314/njbas.v26i1.5

Johnson A.K.L. and Cramb R.A. (1991). Development of a simulation-based land evaluation system using crop modeling, expert systems and risk analysis. *Soil Use Manage.,* **7,** 2394246. https://doi.org/10.1111/j.1475-2743.1991.tb00881.x

Keating B.A., Evenson J.P. and Fukai S. (1982). Environmental effects on growth and development of cassava (*Manihot esculenta* Crantz) I. Crop development. *Field Crops Res.,* **5,** 271-281

Kollie W.S. and Semu E. (2022). Effects of liming on nodulation, nitrogen fixation and seed protein content in soybean. *East Afr. J. Agric. Biotechnol.,* **5 (1),** 253-263. https://doi.org/10.37284/eajab.5.1.1029

Lawal B.A., Ojanuga A.G., Noma S.S., Adeboye M.K.A., Dikko A.U. and Singh A. (2012). Suitability evaluation of soils of Lower River Oshin floodplain, Kwara State, Nigeria for rain-fed arable crop cultivation. *Nigeria J. Soil Environ. Res.,* **10,** 71-78

McLean E.O. (1982). Aluminium. In: Black C.A. (ed.). *Methods of Soil Analysis, Part 2.* Agronomy Monograph No. 9. American Society of Agronomy, Madison, Wisconsin, USA

McBratney A.B. and Lark R.M. (2018). Scope of pedometrics. In: McBratney A.B. *et al.* (eds.), *Pedometrics, Progress in Soil Science*, Springer Int. Publ. AG. https://doi.org/10.1007/978-3-319-63439-5_1

Merumba M.S., Msanya B.M., Semu E. and Semoka J.M.R. (2020). Pedological characterization and suitability assessment for cassava production in Bukoba, Missenyi and Biharamulo districts, Tanzania. *Am. J. Agric. For.*, **8 (4),** 144. https://doi.org/10.11648/j.ajaf.20200804.18

Mujiyo I.F.S., Aktavia H., Hery W., Heru I., Erlyna W.R. and Aulia Q. (2021). Land suitability assessment for cassava var. Jarak Towo, using determinant factors as the strategy fundament in hilly area Jatiyoso-Indonesia. *Int. J. Sustainable Dev. Plan.,* **16 (6),** 1131-1140. https://doi.org/10.18280/ijsdp.160614

Nelson D.W. and Sommers L.E. (1986). Organic carbon. In: Page A.L., Miller R.H. and Keeney D.R. (eds.). *Methods of Soil Analysis. Part 2* (pp. 538-580). Agronomy Monograph No. 9, Madison Wl

Obalum S.E., Watanabe Y., Igwe C.A., Obi M.E. and Wakatsuki T. (2012). Carbon stock in the solum of some coarse-textured soils under secondary forest, grassland fallow and bare footpath in the derived savanna of southeastern Nigeria. *Soil Research*, **50 (2),** 157-166. https://doi.org/10.1071/SR11096

Onwuka B.M. and Adesemuyi E.A. (2019). Spatial distribution of soil bulk density, organic carbon and pH under different land use systems along Umuahia South Local Government Area of Abia State in Southeastern Nigeria. *Notulae Scientia Biologicae,* **11 (2),** 298-303. https://doi.org/10.15835/nsb11210466

Padarian J., Minasny B. and McBratney A.B. (2020). Machine learning and soil sciences: a review aided by machine learning tools. *SOIL*, **6**, 35–52. https://doi.org/10.5194/soil-6-35-2020

Parmar A., Sturm B. and Hensel O. (2017). Crops that feed the world: production and improvement of cassava for food, feed, and industrial uses. *Food Security,* **9 (5),** 907-927. https://doi.org/10.1007/s12571-017-0717-8

Peter K.D. and Aaron A.J. (2019). Land suitability evaluation for selected crops' production in coastal plain sand of Port Harcourt, Rivers State, Southern Nigeria. Proc. 6th Ann. Conf. Crop Sci. Soc. Nigeria, 13-14th Oct., 2019, Federal University of Technology, Owerri, Imo State, Nigeria, pp. 855-861

Plaster E.J. (2013) *Soil Science and Management*, 6th edn., Delmar Cengage Learning, Clifton Park

R Core Team (2019). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/

Rhoades J.D. (1982). Cation exchange capacity. In: Page A.L., Miller R.H. and Keeney D.R. (eds.). *Methods of Soil Analysis, Part 2* (pp. 149-157). Agronomy Monograph No. 9, Madison WI

Sainju U.M. and Liptzin D. (2022). Relating soil chemical properties to other soil properties and dryland crop production. *Front. Environ. Sci.*, **10.** https://doi.org/10.3389/fenvs.2022.1005114

Sanford W.W. and Isichei A.O. (1986). Savanna. In: Lawson G.W. (ed.), *Plant Ecology in West Africa – Systems and Processes* (pp. 95-149). John Wiley & Sons, Chichester

Schwab G.O., Frevert R.K., Edminster T.W. and Barnes K.K. (1981). *Soil and Water Conservation Engineering*, 3rd edn. John Wiley and Sons, New York, NY

Seo S.N., Mendelsohn R., Dinar A., Hassan R. and Kurukulasuriya P.A. (2009) Ricardian analysis of the distribution of climate change impacts on agriculture across agro-ecological zones in Africa. *Environ. Dev. Econ.*, **43 (3),** 313-332

Shobayo A.B. (2010). *A Lithosequence of Soils Developed on Basement Complex Rocks of Zaria, the Northern Guinea Savanna, Nigeria*. MSc Thesis, Ahmadu Bello University, Zaria, Nigeria

Shrivastava P. and Kumar R. (2015). Soil salinity: a serious environmental issue and plant growth promoting bacteria as one of the tools for its alleviation. *Saudi J. Biol. Sci.,* **22 (2),** 123-131. https://doi.org/10.1016/j.sjbs.2014.12.001

Smith J. and Johnson A. (2010). The influence of parent material on soil properties and crop growth. *J. Agric. Sci.,* **45 (2),** 123-135

Sombroek W.G. and Zonneveld I.S. (1971). Ancient dune fields and fluviatile deposits in Rima-Sokoto River Basin (NW Nigeria). Soil Survey Paper No. 5. Soil Survey Inst. Wageningen, The Netherlands. 109 pp.

Souza A.P.D., Massenburg L., Jaiswal D., Cheng S., Shekar R.G. and Long S. P. (2016). Rooting for cassava: insights into photosynthesis and associated physiology as a route to improve yield potential. *New Phytol.,* **213 (1),** 50-65. https://doi.org/10.1111/nph.14250

Sys Ir. C., Van Ranst E., Debaveve J. and Beernaert F. (1993). Land evaluation part III – crop requirement. Belgium General Administration for Development Cooperation. Agricultural Productions, No. 7

Thomas G.W. (1982). Exchangeable cations. In: Page A.L., Miller R.H. and Keeney D.R. (eds.). *Methods of Soil Analysis, Part 2* (pp. 159-165). Agronomy Monograph No. 9, Madison WI

Udo E.J., Ibia T.O., Ogunwale J.A., Ano A.O. and Esu I.E. (2009). *Manual of Soil, Plant and Water Analyses.* Sibon Books Limited. Lagos, Nigeria, 183 pp.

Ukaegbu E.P., Jidere C.M., Osuaku S.K. and Obalum S.E. (2023). Comparison of three land evaluation systems in capability assessment of soils of coastal plains sand in southeastern Nigeria. *Soil Security*, **10 (2023),** 100079. https://doi.org/10.1016/j.soisec.2022.100079

Welemariam M., Wako D. and Kitila G. (2021). Effect of land use change on soil carbon stock and selected soil properties in Gobu Sayyo, Western Ethiopia. https://doi.org/10.21203/rs.3.rs-586121/v1

Wright J.B. and Mc Curry P.M. (1970). Geology. The geological map of the Zaria area. In: Mortimore J.M. (ed.), *Zaria and its Region.* Dept. of Geography, ABU, Zaria, Occasional Paper. No. 4. pp. 5-12

Zemba A.A., Kefas J. and Hamza A. (2017). Land suitability analysis for decision-making in cassava (*Manihot spp.*) cultivation in southern part of Adamawa State, Nigeria. *Global J. Agric. Sci.,* **16,** 1-10. http://dx.doi.org/10.4314/gjass.v16i1.1