SEBELAS MARET UNIVERSITY

SAINS TANAH – Journal of Soil Science and Agroclimatology

Journal homepage: http://jurnal.uns.ac.id/tanah

GIS-based approach in land suitability evaluation for maize (*Zea mays*) and cassava (*Manihot esculenta*) production in Nsukka local government area of Enugu State

Chigozie Pascal Umeugokwe[1]*, Nancy Ekene Ebido[1], Ihuoma Eileen Uroawuchi[1], Chukwuebuka Edwin Awaogu[1,2], Obiageli Umeugochukwu[3], Chika Mike Jidere[1], Ifeyinwa Monica Uzoh[1], Charles Livinus Anija Asadu[1]

[1] Department of Soil Science, University of Nigeria, Enugu State, Nsukka, 410001, Nigeria
[2] Department of Crop Science, Faculty of Natural and Agricultural Sciences, North West University, Mafikeng Campus, Private Bag X2046, Mmabatho 2735, South Africa
[3] Carl von Ossietzky Universitat Oldenburg, Germany

ARTICLE INFO

Keywords:
Agro-ecological zone
Arable crops
Crop specific management
Nutrient variability
Soil fertility indicators

Article history
Submitted: 2025-04-27
Revised: 2025-08-06
Accepted: 2025-10-03
Available online: 2025-11-26
Published regularly: December 2025

* *Corresponding Author*
Email address:
pascal.umeugokwe@unn.edu.ng

ABSTRACT

Agriculture remains a cornerstone of economic development, food security, and the livelihoods of rural communities in sub-Saharan Africa. This study employed a parametric evaluation approach to assess the suitability of soils in the Nsukka Local Government Area (LGA) of Enugu State, Southeastern Nigeria, for cultivating maize (*Zea mays*) and Cassava (*Manihot esculenta*) using the Geographical Information System (GIS). The study applied the FAO land evaluation framework using systematic soil sampling, laboratory analyses, and GIS mapping. A total of thirty geo-referenced soil samples from the surface (0-20 cm) were gathered in triplicate across Nsukka LGA. Climatic and topographic data were integrated with soil parameters to assess suitability. Thematic maps were developed and overlaid to generate suitability classes for maize and cassava using the ArcGIS software. The climate characteristics were highly suitable for crop production. Topography (slope) and soil characteristics (texture, organic carbon, and base saturation) were the most limiting factors for both crops. The maps showed that 6.18% of the study region was highly suitable, while 93.82% was moderately suitable for maize production. The study region was entirely suitable for cassava cultivation. These results support the recommendation for crop-specific land-use planning and targeted soil management practices to improve maize productivity and leverage cassava's resilience in marginal soils.

How to Cite: Umeugokwe, C. P., Ebido, N. E., Uroawuchi, I. E., Awaogu, C. E., Umeugochukwu, O., Jidere, C. M., . . . Asadu, C. L. A. (2025). GIS-based approach in land suitability evaluation for maize (*Zea mays*) and cassava (Manihot esculenta) production in Nsukka local government area of Enugu state. Sains Tanah Journal of Soil Science and Agroclimatology, 22(2), 410-419. https://doi.org/10.20961/stjssa.v22i2.101534

1. INTRODUCTION

Agriculture in Nigeria makes a substantial contribution to both the gross domestic product (GDP) and employment, with staple crops such as cassava (*Manihot esculenta*) and maize (*Zea mays*) serving as key drivers of food security and income generation (National Bureau of Statistics, 2023). However, the sector faces multifaceted challenges, including poor land use practices (Umeobi et al., 2021), soil degradation (Obalum et al., 2017), and limited knowledge of the land's suitability for specific crops (Umeugokwe et al., 2022).

The continuous use of land throughout history, regardless of its suitability, has led to consequences that often outweigh the benefits gained (FAO, 2006). Therefore, comprehensive land evaluation is essential to addressing this global challenge, as it promotes a deeper understanding of how land can be used more effectively for the collective good of humanity.

Land suitability evaluation (LSE) as a concept refers to the assessment of the land in a particular area in a bid to determine how appropriate the land is for a particular land use type (Singha & Swain, 2016). It refers to the evaluation of land performance over time in relation to a designated land use type (Mazahreh et al., 2019) Land suitability evaluation is an important step in the determination of the environmental limit in sustainable land use planning, dealing with land performance assessment for the land use type that is peculiar to the location being evaluated (Mugiyo et al., 2021).

The LSE is one of the key processes of land use planning (Dedeoğlu & Dengiz, 2019). According to Taghizadeh-Mehrjardi et al. (2020), LSE is a crucial step in the land use planning process when resources are limited. It serves as a fundamental requirement for the optimal use of available

STJSSA, p-ISSN 1412-3606 e-ISSN 2356-1424
http://dx.doi.org/10.20961/stjssa.v22i2.103549

land resources (Mugiyo et al., 2021). It, therefore, serves to check that the requirements for the particular land use are met adequately by the properties of the land. The LSE, also supports effective land use planning by promoting optimal resource management that meets present needs while preserving them for future generations.

Among the various applications of land use planning, this study focuses on its role in agriculture. The purpose of LSE in agriculture is prediction. i.e., to assess the land's capabilities and constraints for crop cultivation (Pan et al., 2022). Agricultural LSE identifies key limiting factors that affect crop productivity based on the specific soil requirements of crops within a given agroecological zone.

A variety of crops can be found growing and thriving in the Nsukka Local Government Area, located in Enugu State, Nigeria. This research, however, concentrates on two principal crops: maize (*Zea mays*) and cassava (*Manihot esculenta*). These crops were selected because they are the most widely cultivated and consumed staple foods in the region. Moreover, their contrasting soil and climatic requirements make them ideal indicators for evaluating land suitability across a range of environmental conditions.

Maize (*Zea mays*) is a cereal crop, possibly the most commonly found in the study area. It is part of the list of staple foods that is found among the people of Nsukka. As a tropical crop, maize grows well under a wide range of temperatures but not above 35°C. Its optimum growth performance occurs at a temperature of 20°C and 400–900 mm of rainfall (Waqas et al., 2021). Cassava (*Manihot esculenta*) is the most widely eaten tuber crop in the Nsukka agroecological zone and probably in the entire southeastern region of Nigeria. As a lowland tropical crop, cassava thrives well with a good amount of rainfall. It favours humid climates, performing optimally under a temperature range of about 25°C to 27°C and 1200-1500 mm of rainfall (Akinola et al., 2020).

Various studies (Asadu et al., 2017; Okebalama et al., 2024; Ugadu & Asadu, 2019; Umeugokwe et al., 2022) regarding LSE, has been carried out in the research area. However, these studies primarily relied on conventional LSE methods, which are often limited to specific sampled locations. The GIS-based approach allows for greater accuracy and efficiency in extrapolating and mapping suitability across unsampled regions (Sappe et al., 2022). This represents a critical gap in the literature, particularly given the region's agricultural significance and the central role these crops play in local diets and food security (Agou et al., 2024). This study, unlike earlier research, employs GIS tools to offer a detailed, crop-specific analysis of land suitability and a localized evaluation of the agro-ecological conditions of the region for maize and cassava, which are key staple crops in the region. Accordingly, this study aimed to assess the land suitability of Nsukka Local Government Area for maize and cassava cultivation using GIS-based tools and to provide specific soil management recommendations for improving crop productivity.

2. MATERIALS AND METHODS

2.1 Location of study

The research site was Nsukka Local Government Area, situated within Enugu State, Nigeria. The location lies between latitudes 6° 42' 30" and 7° 0' 50" N and longitudes 7° 11' 0" and 7° 33' 0" E with an elevation ranging from 130 to 580 m (Fig. 1). Nsukka Local Government Area comprises a total of 30 towns, within which there are many other composite villages.

2.2 Climate

The region studied is marked by a humid tropical climate, marked by clearly defined wet and dry seasons that differ somewhat in duration and location. The area has an average temperature that exceeds 20°C in all months and precipitation of over 1,300.00 mm per year. The annual rainfall amounts ranged from 1537.28 to 1757.61 mm for 10 years of climatic data (Fig. 2) of the study area. The annual minimum temperature varied between 18.2°C and 23.4°C, whereas the maximum ranged from 27.4 °C to 32.94 °C (Fig. 2).

2.3 Geology and soils

Geologically, the study region comprises formations from the Upper and Lower Coal Measures, Nkporo Shale, and False Bedded Sandstone (Nigerian Geological Survey Agency, 2006). The terrain is generally undulating with moderately drained soils, predominantly classified as Ultisols, Alfisols, and Oxisols (Umeugokwe et al., 2022).

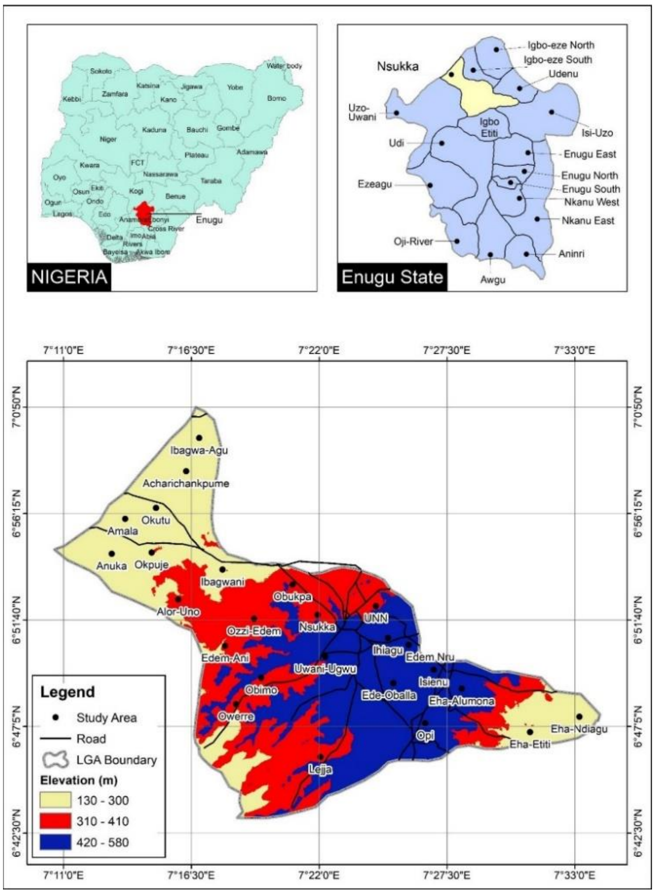
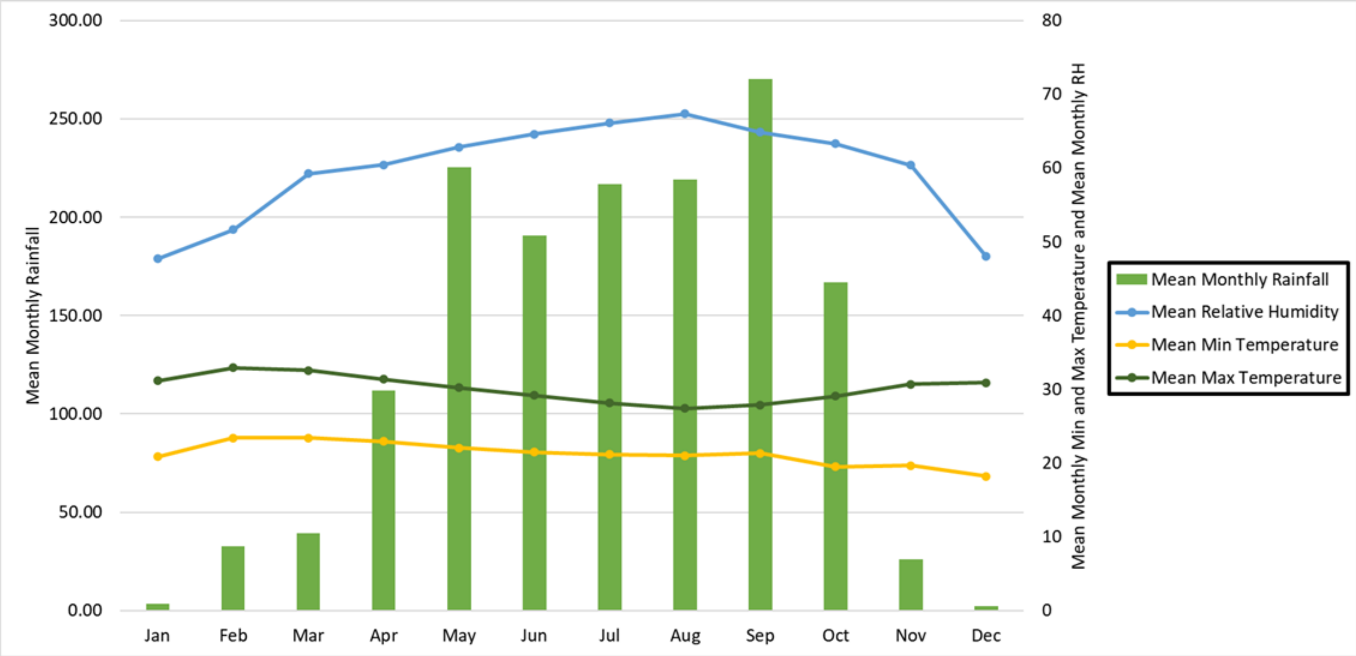


Figure 1. Map of Nsukka Local Government Area showing the towns



Remark: RH = relative humidity
Source: The Meteorological Station of the University of Nigeria, Teaching and Research Farm, located at Nsukka Campus of the University

Figure 2. Graph showing the climatic distribution of Nsukka Local Government Area over the past decade (2013-2024).

Table 1. Climate and Land Characteristics for Maize Production.

	S1	S2	S3	NS
Climatic characteristics				
Precipitation of growing cycle (mm)	750-1200	1200-1600	>1600	-
	750-500	500-400	400-300	< 300
Mean temperature (ºC)	24-18	18-16	16-14	< 14
Mean minimum temperature (ºC)	17-24	24-28	28-30	> 30
Relative humidity maturation stage (%)	40-75	75-90	> 90	-
Topography (t)				
Slope (%)	0-2	2-4	4-6	> 6
Physical soil characteristics (s)				
Texture/structure	C<60, SiC, SiCL, Si, SiL, CL, SC, C>60s, L, SCL	C<60, SL, LfS, LS	fS, S, LcS	cS
Coarse fragment (vol%)	0-15	15-35	-	> 55
Soil depth	>75	75-50	35-55 50-20	< 20
Soil fertility indices (f)				
Effective CEC (cmol kg^{-1})	>16	< 16 (-)	< 16 (+)	-
Base saturation (%)	>50	50-35	35-20	< 20
Organic carbon (%)	>1.2	1.2-0.8	< 0.8	-

Notes: C = coarse fragment, SiCL = silty clay loam, cS = coarse sand, SiC = silty clay, Si = silty, CL = clay loam, SiL = silty loam, SC = sandy clay, SCL = sandy clay loam, L = loam, SL = sandy loam, LS = loamy sand, fS = fine sand, S = sand, LcS = loamy coarse sand, CEC = cation exchang capacity, S3 = Marginally Suitable, NS = Not Suitable, S2 = Moderately Suitable S1 = Highly Suitable.
Source: Sys et al. (1993).

2.4 Vegetation

The vegetation of the study area has been characterised by Asadu et al. (2010) as a derived or man-made savanna. Commonly cultivated crops in the study area include Nsukka yellow pepper (*Capsicum chinese nsukkadrilus*), yam (*Dioscorea rotundata*), cassava (*Manihot esculenta*), maize (*Zea mays*), cocoyam (*Colocasia esculenta*), and sweet potato (*Ipomoea batatas*).

Table 2. Climate and land characteristics for cassava production.

	S1	S2	S3	NS
Climatic characteristics				
Annual precipitation (mm)	1400-1000 1600-1400	1000-600	600-500	< 500
Mean annual temperature (ºC)	20-18 23-20	18-16	16-12	< 12
Mean minimum temperature (ºC)	18-24 17-18	> 24	-	-
Topography (t)				
Slope (%)	1-2 0-1	2-4	4-6	> 6
Physical soil indices (s)				
Texture/structure	L, SCL, SL, SiC, Co, CL, SiCL, SC	LfS, LcS, LS Fs	S, cS	Cm, SiCm
Coarse fragment (vol%)	1-3 0-1	3-15	15-35	> 35
Soil depth	>100	100-75	75-50	< 50
Soil fertility indices (f)				
Effective CEC (cmol kg^{-1})	> 16 Any	-	-	-
Base saturation (%)	>20	< 20		
Organic carbon (%)	>0.8	< 0.8	-	-

Notes: C = coarse fragment, SiCL = silty clay loam, cS = coarse sand, SiC = silty clay, Si = silty, CL = clay loam, SiL = silty loam, SC = sandy clay, SCL = sandy clay loam, L = loam, SL = sandy loam, LS = loamy sand, fS = fine sand, S = sand, LcS = loamy coarse sand, CEC = cation exchang capacity, Cm = massive clay, SiCm = massive silt clay, Co = clay, oxisol structure, S3 = Marginally Suitable, NS = Not Suitable, S2 = Moderately Suitable S1 = Highly Suitable.

Source: Sys et al. (1993).

2.5 Field work

Soil samples were gathered from 30 communities within Nsukka LGA. Surface soil samples (0-20 cm) were gathered utilizing a grid sampling technique at geo-referenced points to ensure spatial coverage. At each location, three replicate samples were taken and composited. In total, 90 composite soil samples were obtained for laboratory analysis. The geographic coordinates for each sampling site were captured with a portable GPS device. Prior to analysis, the samples were air-dried, ground, and sieved through a 2-mm mesh.

2.6 Land suitability evaluation

Tables 1 and 2 provided reference data on climate and land features, which guided the land evaluation process for maize and cassava production, respectively, in the research area. Land suitability evaluation was conducted in accordance with the principles of the limiting factor method. In this method, the most limiting characteristics (whether climatic, soil fertility, or physical property) dictate overall suitability for each soil. Each sampling location was evaluated against the standard crop requirements, where the parameters were compared with the threshold for each suitability class. If a single parameter failed to meet the minimum requirement for a higher class, it constrained the land to a lower class. The classification of land in the study area into four suitability categories for maize and cassava was determined by the number and degree of limiting factors: highly suitable (S1) refers to land with no or minor limitations, requiring little to no input for optimal yields. Moderately suitable (S2) includes land with some constraints that can be addressed with moderate management interventions. Marginally suitable (S3) describes land with significant limitations that restrict productivity, even with inputs. Not suitable (N) refers to land with severe limitations, making it unsuitable for cultivation under current conditions.

2.6.1 Climate and land characteristics sources

The climatic (minimum temperature, mean temperature, precipitation, and relative humidity) data were obtained from the Faculty of Agriculture Meteorological Station, which is managed by the Department of Crop Science (Fig. 2). The slope position of each town was derived from a Digital Elevation Model (DEM) from the Shuttle Radar Topography Mission 1 (SRTM) provided by the United States Geological Survey. The soil depth was measured up to 100 cm using a soil auger to determine if the depth met the minimum requirements for root development of the selected crops.

The particle size distribution of the soil samples was analyzed using the Bouyoucos hydrometer method, employing 0.1N NaOH as the dispersing agent. The coarse fragment content of the soil samples was determined using the formula by Eash et al. (2015) in Equation 1.

Volume percentage of coarse fragments =

$$\frac{\text{Volume of coarse fragments}}{\text{Total volume of sample}} \times \frac{100}{1} \quad \text{......................................[1]}$$

The organic carbon content was assessed through the modified Walkley and Black wet digestion and oxidation technique (Nelson & Sommers, 1996). The exchangeable bases (Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+}) were determined by the complexometric titration method. Potassium and sodium were extracted using 1N ammonium acetate (NH_4OAc) solution and were determined using flame photometry (Chapman, 1965), and exchangeable acidity was determined using a titration method after extraction with 1N KCl. The Effective Cation Exchange Capacity (ECEC) and percentage (%) base saturation were calculated thus (Equations 2 & 3, respectively).

ECEC = Exchangeable Bases + Exchangeable Acidity .... [2]

Percentage Base Saturation =

$$\frac{\text{Total exchangeable bases}}{\text{Effective Cation Exchange Capacity}} \times \frac{100}{1} \quad \text{[3]}$$

2.6.2 Development of spatial data maps

The spatial data maps utilized in this research encompass climate maps (showing temperature, rainfall, and relative humidity), soil maps (depicting physical properties and fertility characteristics of the soil), and topographic maps (indicating slope). The thematic maps were developed, modified, combined, and visualized through suitability analysis utilizing ArcGIS 10.8 software. The use of GIS for overlaying thematic layers in the development of a land suitability database required converting all layer maps to a standard coordinate system (UTM WGS84 Zone 32N) for the study area. This process entailed the systematic arrangement and organization of the collected data to ensure analytical consistency. Subsequently, all maps were reclassified into four suitability classes based on the growth requirements for maize and cassava (Tables 1 & 2). Each thematic map was reclassified to generate individual suitability maps for specific parameters, which were later integrated to produce the final land suitability maps for maize and cassava.

RESULTS

3.1 Land suitability evaluation for maize cultivation in the research area

This section outlines the findings of the evaluation of land suitability for maize cultivation in the research area. It highlights how various land parameters, including climatic conditions, soil quality, and topographical features, are related to the crop's needs. These parameters were used to generate individual suitability maps, which were integrated to produce the overall land suitability map for maize.

3.1.1 Climatic characteristics of the research area for maize production

Table 3 shows the findings from the climatic maps of the research area. The climatic parameters, including temperature, humidity, and rainfall, indicated favorable conditions for maize cultivation. The suitability assessment revealed that the entire study area, or 100%, was classified as highly suitable (S1) for all three climatic variables, highlighting the region's significant agro-climatic capability for maize production.

3.1.2 Physical and fertility properties of the soils in the research area

Despite favourable climatic conditions, soil physical and fertility characteristics posed significant limitations to maize productivity. As shown in Figure 3, merely 19.56% of the soils displayed a highly suitable texture for maize cultivation, whereas 52.19% were classified as moderately suitable, and 28.24% were deemed marginally suitable.

Soils with loam to sandy clay loam textures were classified as highly suitable; sandy loam or loamy sand as moderately suitable; and clayey or excessively sandy soils as marginally suitable. The distribution suggests textural variability across the area, which may impact root penetration and water retention. In terms of cation exchange capacity, 100% of the study area was moderately suitable, indicating that the soils possess a fair capacity to retain and supply essential nutrients to crops (Table 3). Regarding percentage-based saturation, a key fertility indicator, the results in Figure 4 revealed 61.54% of the area was highly suitable, 23.44% moderately, and 14.69% marginally suitable, respectively. The organic carbon content posed on additional constraints. Only 15.27% of the area showed high suitability, whereas 52.98% and 31.73% were moderately and marginally suitable, respectively (Fig. 5). This highlights the need for organic matter enhancement strategies in over 80% of the soils to support sustainable maize yields.

3.1.3. Topographic characteristics of the study area

Slope emerged as the most significant constraint affecting maize production. Figure 6 reveals that only 7.17% of the region was highly suitable based on slope, while 14.31%, 17.21%, and 61.29% of the soils were considered moderately, marginally, and not suitable for growing maize due to steep gradients that increase erosion risks. Soils with 0–2% slope were considered highly suitable (S1), 2-4% as moderately suitable (S2),4-6% as marginally suitable (S3), and slopes exceeding 6% were classified as not suitable (N) due to severe erosion potential and reduced ease of cultivation.

3.1.4. Final suitability rating of the study area for maize production

Combining all criteria, the final suitability map (Fig. 7) revealed that only 6.18% of the study region was highly suitable (S1) for maize production, while the remaining 93.82% was moderately suitable (S2).

Table 3. Suitability rating of land characteristics parameter for maize and cassava production

Land characteristics	Maize	Cassava
Precipitation	Moderately Suitable	Highly Suitable
Mean Temperature	Highly Suitable	Highly Suitable
Mean Minimum Temperature	Highly Suitable	Moderately Suitable
Humidity	Highly Suitable	Highly Suitable
Effective CEC	Moderately Suitable	Highly Suitable
Base Saturation	**	Highly Suitable

Notes: ** refer to Figure 4

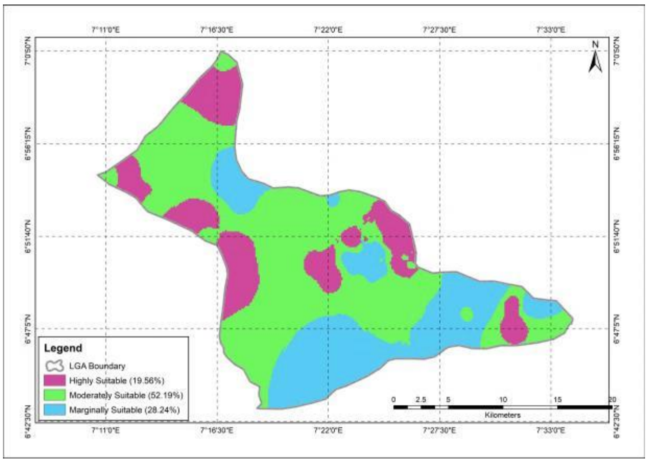


Figure 3. Map of texture

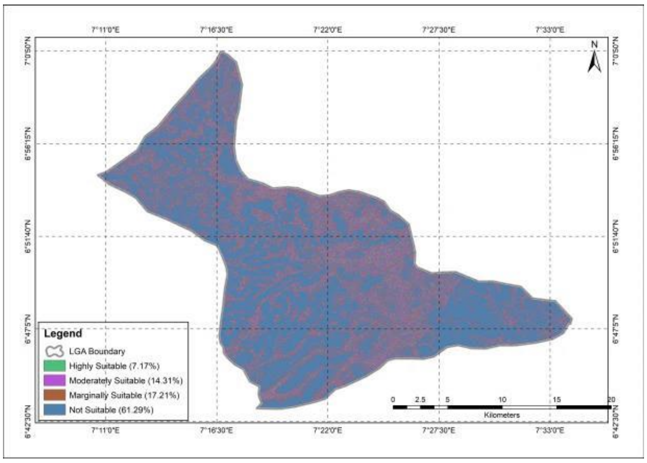


Figure 6. Map of slope

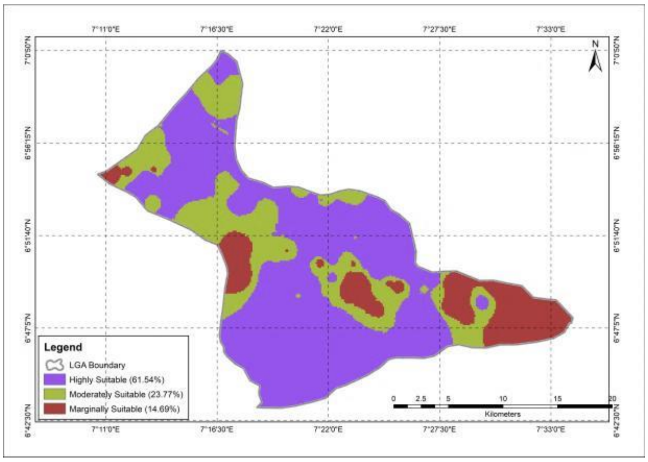


Figure 4. Map of percentage base saturation

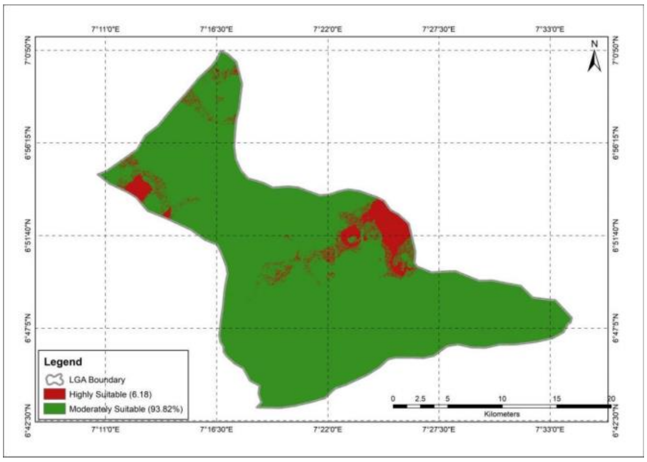


Figure 7. Final suitability map (overlay) of the climatic, physical and fertility, and topographic properties of soils for maize

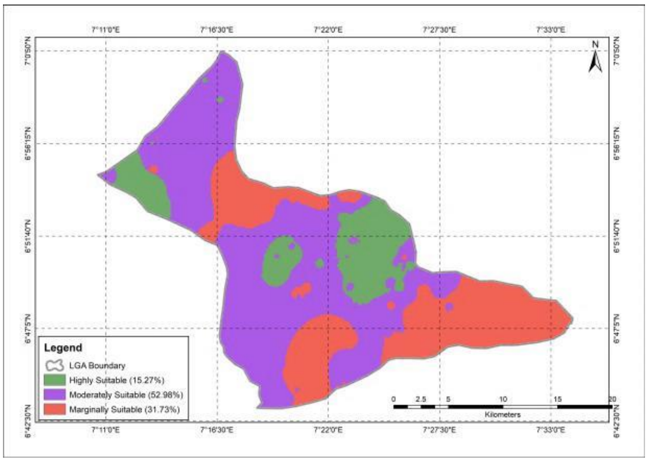


Figure 5. Map of organic carbon

The overall land suitability assessment showed no areas classified as marginally or not suitable. This indicates that the entire study area has at least moderate capacity for crop production, although topography and soil fertility remain the primary limiting factors.

3.2 Suitability evaluation for cassava production in the study area

The following parameters were used for the production of the final suitability map for cassava production: precipitation, temperature, humidity, slope, texture, depth, organic carbon content, PBS, and effective cation exchange capacity.

3.2.1. Climatic characteristics of the study area

As seen in Table 3, temperature, humidity, and rainfall across the entire study area met the optimal thresholds for cassava production. The suitability ratings were uniformly 100% highly suitable, confirming the crop's strong adaptability to Nsukka's humid tropical climate.

3.2.2. Physical and fertility properties of the soils in the research area

Cassava demonstrated a higher tolerance to differences in soil texture than maize. As shown in Figure 8, 24.38% of the soils had a highly suitable texture for cassava, 45.48% were moderately suitable, and 30.14% were marginally suitable. While the pattern is similar to that of maize, the slightly higher proportion of highly suitable soils suggests that cassava is better adapted to variations in soil texture.

Base saturation and ECEC recorded 100% high suitability across the study area (Table 3), indicating that essential exchangeable cations are adequately available for cassava uptake. This outcome aligns with expectations, given cassava's relatively moderate nutrient requirements.

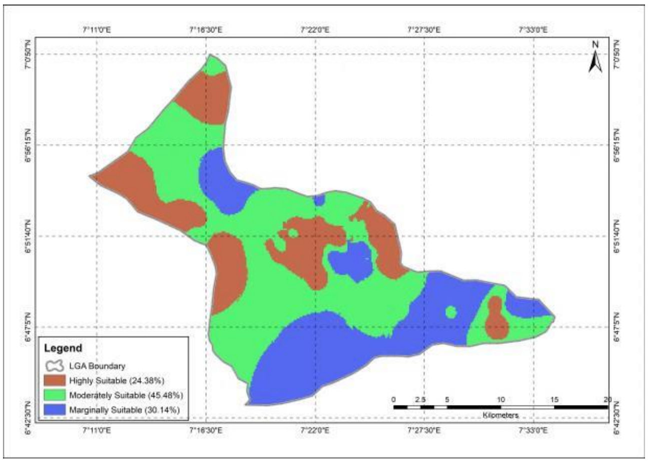


Figure 8. Map of texture

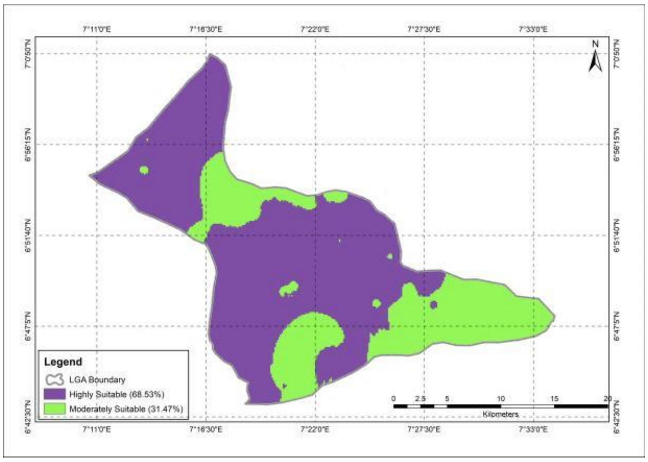


Figure 9. Map of organic carbon

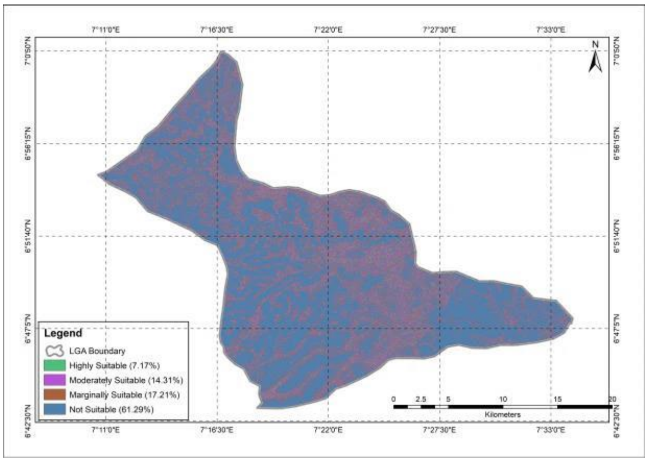


Figure 10. Map of slope

The organic carbon content was considerably more adequate for cassava than maize, with 68.53% of the area rated highly suitable, as seen in Figure 9, while 31.47% of the soils were moderately suitable.

3.2.3. Topographic characteristics of the research area

Similar to maize, slope remained a limiting factor for cassava, although the impact appears less severe. Figure 10 shows only 7.17% of the land as highly suitable, while 14.31%, 17.21%, and 61.29% were moderately, marginally, and not suitable, respectively. This suggests that while cassava can

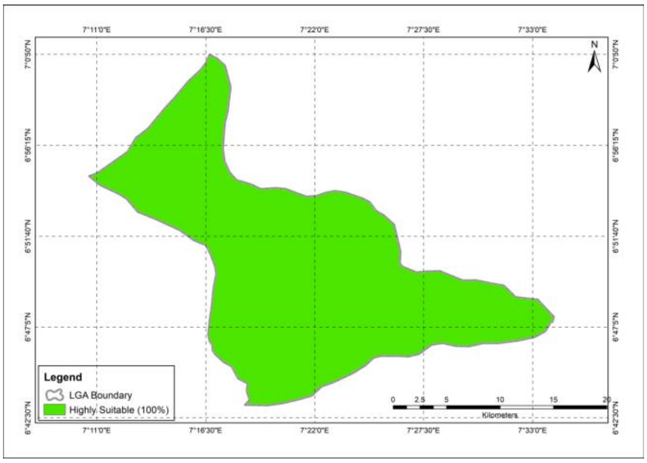


Figure 11. Final suitability map (overlay) of the climatic, physical and fertility, and topographic properties of soils for cassava

tolerate moderate slopes without significant yield reduction, flat to gently sloping lands are still the best for achieving optimal production.

3.2.4. Final suitability rating of the study area for cassava production

The final suitability map for cassava production (Fig. 11) reveals that 100% of the study area was classified as highly suitable (S1). Although 61.29% of the area had slope conditions that would typically be considered limiting, cassava's tolerance to a broader range of physical conditions, including slope, allowed for a uniformly high suitability rating in the integrated assessment.

4. DISCUSSION

Land suitability for maize and cassava production in Nsukka LGA of Enugu State, Nigeria, was assessed using a combination of climatic, soil fertility, and topographic parameters (Tables 1 & 2, respectively). The climatic parameters, which include precipitation, temperature, and humidity, were found to be highly suitable for maize and cassava production across the study area. Each of these parameters recorded a 100% suitability rating, as shown in Table 3. These findings are consistent with the previous climatic conditions of the study area, where annual rainfall exceeds 1,200 mm and temperatures range between 20°C and 32°C, which is suitable for both crops (Asadu et al., 2010). This implies that climatic variability is not a limiting factor for crop performance in the study area.

Although the climatic conditions (temperature: 25-30 °C; annual rainfall: 1000-1500 mm) are favourable for both maize and cassava, variations in soil properties and topography affect the overall land suitability ratings for each crop. Maize, a high-demand cereal crop, requires well-structured soils with good drainage, moderate organic matter, and moderately acidic to slightly alkaline soil with a pH range of 5.5-7.5 for optimal yield (Awoonor et al., 2023). The ECEC was found to be 100% highly suitable across the study area for both maize and cassava, indicating good nutrient-holding capacity (Table 3). Despite this, maize suitability was more limited by soil texture and organic carbon content. Only 19.56% of the area had a highly suitable texture (Fig. 5), and just 15.27% exhibited high organic carbon levels (Fig. 9), suggesting nutrient limitations for maize in certain areas.

The percentage base saturation (PBS), a key indicator of soil fertility and nutrient availability, exhibited a high suitability level (61.54%) for maize, with moderate and marginal suitability levels at 23.44% and 14.69%, respectively (Fig. 4). This distribution indicates that although a majority of the soils possess adequate reserves of essential base cations, such as calcium, magnesium, potassium, and sodium, approximately 38% of the area falls below optimal thresholds for maize cultivation. These thresholds were determined based on standard agronomic literature by Sys et al. (1993), where PBS > 50% is considered highly suitable, 50–35% moderately suitable, 35–20% marginally suitable, and values below 20% are regarded as not suitable. This supports the findings of Okorie et al. (2020), who noted that maize cultivation in southeastern Nigeria is closely linked to soil chemical properties such as base saturation and organic matter content, which influence nutrient retention and uptake in land suitability assessments.

In contrast, PBS for cassava, was 100% highly suitable across the study area (Table 3), suggesting a broader tolerance of cassava to a wider range of base saturation values or possibly reflecting the generally less demanding nutrient requirements of cassava compared to maize (Howeler, 2017). This finding is important for fertility management strategies and highlights cassava's resilience in nutrient-variable soils. This distinction underscores the importance of crop-specific fertility management. While cassava can thrive without extensive nutrient amendments, maize may require targeted soil interventions to correct deficiencies and achieve optimal productivity. According to Havlin and Heiniger (2020), effective nutrient management involves determining both the nutrient needs of crops and the soil's ability to provide those nutrients through soil analysis.

Only 19.56% of the area had a highly suitable texture, specifically loam and sandy clay loam textures for maize (Fig. 3), and just 15.27% exhibited high levels (>1.2 g kg^{-1}) of organic carbon (Fig. 5). In contrast, cassava, a more resilient root crop, showed better adaptation, with 24.38% of the soils having a highly suitable texture (Fig. 8) and a significantly higher 68.53% classified as highly suitable in terms of organic carbon content (Fig. 9). The moderate to marginal suitability observed in soil texture can be linked to differences in parent material and the degree of weathering processes, which are particularly evident in the region (Umeugokwe et al., 2022). The observed low levels of organic carbon can be attributed to the high temperatures and relative humidity, which create conditions conducive to rapid decomposition and mineralisation of organic matter (Ebido et al., 2021). These findings underscore cassava's greater adaptability to a broader range of soil conditions compared to maize, rendering it a resilient crop, confirming existing agronomic knowledge (Pushpalatha & Gangadharan, 2024).

Topography posed a significant challenge for both crops. As slope increases, soil properties tend to decline due to reduced deposition and lower accumulation of organic carbon and soil moisture - conditions that are more favorable in lowland or floodplain areas (Nahusenay & Kibebew, 2015). Steep slopes covering over 61% of the study region were determined to be unsuitable for maize (Fig. 6) and only marginally suitable for cassava (Fig. 10). Slope not only influences the spatial variability of soil properties but also significantly impacts the suitability of land for different crop types (Chadwick & Asner, 2016). The identification of slope as a critical limiting factor in land suitability evaluation corresponds with the findings of Ogbu et al. (2023), who emphasized that topography significantly affects soil variability and the agricultural potential of lands in Southeast Nigeria.

The final suitability maps revealed a stark contrast: only 6.18% of the study region was highly suitable for maize cultivation (Fig. 7), while 100% of the area was highly suitable (Fig. 11) for cassava. This disparity highlights cassava's ecological robustness and suitability for cultivation in the study area with minimal soil amendment. It also suggests that while maize can be cultivated selectively, especially in plain and better-structured soils, cassava offers broader cultivation potential with fewer environmental constraints.

From a practical standpoint, the observed differences in land suitability between cassava and maize have substantial implications for agricultural policy, sustainable land use, and food security in the area. Promoting cassava as a strategic crop based on its higher land suitability could support the study's objective of improving land use decisions. It may enhance overall productivity, reduce input costs, and provide greater resilience to both climatic and soil-related challenges in the region. Meanwhile, maize cultivation should be supported with targeted soil management interventions such as organic matter enrichment, texture improvement through cover cropping or compost application, and erosion control measures on sloped lands (Wahab et al., 2024).

While this study employed geospatial techniques and relevant agro-climatic data, certain limitations remain, including static soil datasets and the lack of socio-economic factors like land tenure and access to farm inputs. These aspects can affect land use and crop performance. The 100% suitability for cassava may reflect these limitations, particularly the reliance on static soil data that doesn't account for local variability. Future studies should incorporate dynamic environmental variables, conduct field-based validation (ground-truthing), and explore machine learning integration for more robust, multi-criteria land suitability modelling.

5. CONCLUSION

The findings reveal that while the climatic conditions of the region are optimal for maize and cassava, edaphic and topographic factors significantly constrain maize cultivation. Only 6.18% of the study region was deemed highly suitable for maize farming, compared to 100% suitability for cassava. Key soil fertility indicators, particularly percentage base saturation, organic carbon content, and texture, emerged as limiting factors for maize but were generally favourable for cassava. Additionally, extensive areas of steep slopes reduced land suitability for maize. To enhance maize cultivation, soil management practices such as minimum tillage, composting, crop rotation, manure application, mulching, liming, terracing, contour cropping, and fertiliser use are recommended. These measures will help mitigate the identified constraints and improve maize productivity in the region. The findings of this study will enable better sustainability of land resources, as well as aid better land use planning and efficiency, especially for agricultural purposes in the study area. They will also serve as a basis for educating farmers via extension agents, thereby improving the overall well-being of the farmers and improving the economy at large.

Declaration of Competing Interest

The authors declare that no competing financial or personal interests may appear to influence the work reported in this paper.

References

Agou, D. G., Onwubuya, A. E., Agwu, E. A., Chah, M. J., Olatunji, M. O., Chibuzo, U. I., . . . Inynag, P. (2024). The Food Safety Practices of Maize Farmers in Taraba State, Nigeria: Food Safety Practices of Maize Farmers. *Journal of Agricultural Extension*, *28*(2), 98-107. https://journal.aesonnigeria.org/index.php/jae/article/view/3900.

Akinola, R., Pereira, L. M., Mabhaudhi, T., de Bruin, F.-M., & Rusch, L. (2020). A Review of Indigenous Food Crops in Africa and the Implications for more Sustainable and Healthy Food Systems. *Sustainability*, *12*(8), 3493. https://doi.org/10.3390/su12083493.

Asadu, C. L. A., Dixon, A. G. O., Ajogu, G. M., Ugadu, M., & Edeh, I. (2017). Comparison of the Suitability of Contiguous Fallow-forest Lands for Cassava, Yam, Cocoyam and Sweet Potato Production in Nsukka, Southeastern Nigeria. *Path of Science: International Electronic Scientific Journal*, *3*(1). https://doi.org/10.22178/pos.18-1.

Asadu, C. L. A., Obasi, S. C., & Dixon, A. G. O. (2010). Variations in Soil Physical Properties in a Cleared Forestland Continuously Cultivated for Seven Years in Eastern Nsukka, Nigeria. *Communications in Soil Science and Plant Analysis*, *41*(2), 123-132. https://doi.org/10.1080/00103620903426931.

Awoonor, J. K., Dogbey, B. F., & Quansah, G. W. (2023). Soil suitability assessment for sustainable intensification of maize production in the humid Savannah of Ghana [Original Research]. *Frontiers in Sustainable Food Systems*, *Volume 7 - 2023*. https://doi.org/10.3389/fsufs.2023.1094290.

Chadwick, K. D., & Asner, G. P. (2016). Tropical soil nutrient distributions determined by biotic and hillslope processes. *Biogeochemistry*, *127*(2), 273-289. https://doi.org/10.1007/s10533-015-0179-z.

Chapman, H. D. (1965). Cation-Exchange Capacity. In *Methods of Soil Analysis* (pp. 891-901). https://doi.org/10.2134/agronmonogr9.2.c6

Dedeoğlu, M., & Dengiz, O. (2019). Generating of land suitability index for wheat with hybrid system aproach using AHP and GIS. *Computers and Electronics in Agriculture*, *167*, 105062. https://doi.org/10.1016/j.compag.2019.105062.

Eash, N. S., Sauer, T. J., O'Dell, D., & Odoi, E. (2015). *Soil science simplified*. John Wiley & Sons. https://www.wiley.com/en-us/Soil+Science+Simplified%2C+6th+Edition-p-9781118540633

Ebido, N. E., Edeh, I. G., Unagwu, B. O., Nnadi, A. L., Ozongwu, O. V., Obalum, S. E., & Igwe, C. A. (2021). Rice-husk biochar effects on organic carbon, aggregate stability and nitrogen-fertility of coarse-textured Ultisols evaluated using Celosia argentea growth. *Sains Tanah Journal of Soil Science and Agroclimatology*, *18*(2), 11. https://doi.org/10.20961/stjssa.v18i2.56330.

FAO. (2006). *Guidelines for soil description* (4th ed.). Food and Agriculture Organization of the United Nations. https://www.fao.org/4/a0541e/a0541e.pdf

Havlin, J., & Heiniger, R. (2020). Soil Fertility Management for Better Crop Production. *Agronomy*, *10*(9), 1349. https://doi.org/10.3390/agronomy10091349.

Howeler, R. (2017). Cassava cultivation and soil productivity. In H. Clair (Ed.), *Achieving sustainable cultivation of cassava Volume 1* (pp. 303-310). Burleigh Dodds Science Publishing. https://hdl.handle.net/10568/90631

Mazahreh, S., Bsoul, M., & Hamoor, D. A. (2019). GIS approach for assessment of land suitability for different land use alternatives in semi arid environment in Jordan: Case study (Al Gadeer Alabyad-Mafraq). *Information Processing in Agriculture*, *6*(1), 91-108. https://doi.org/10.1016/j.inpa.2018.08.004.

Mugiyo, H., Chimonyo, V. G. P., Sibanda, M., Kunz, R., Masemola, C. R., Modi, A. T., & Mabhaudhi, T. (2021). Evaluation of Land Suitability Methods with Reference to Neglected and Underutilised Crop Species: A Scoping Review. *Land*, *10*(2), 125. https://doi.org/10.3390/land10020125.

Nahusenay, A., & Kibebew, K. (2015). Land suitability evaluation in Wadla Delanta Massif of north central highlands of Ethiopia for rainfed crop production. *African Journal of Agricultural Research*, *10*(13), 1595-1611. https://doi.org/10.5897/AJAR2014.9248.

National Bureau of Statistics. (2023). *Nigerian Gross Domestic Product Report: Q3 2023*. National Bureau of Statistics. https://www.nigerianstat.gov.ng/pdfuploads/Q3_2023_GDP_Report.pdf

Nelson, D. W., & Sommers, L. E. (1996). Total Carbon, Organic Carbon, and Organic Matter. In *Methods of Soil Analysis* (pp. 961-1010). https://doi.org/10.2136/sssabookser5.3.c34

Nigerian Geological Survey Agency. (2006). *Geological and Mineral Resources Map of Enugu State*. Nigeria, Nigerian Geological Survey Agency.

Obalum, S. E., Chibuike, G. U., Peth, S., & Ouyang, Y. (2017). Soil organic matter as sole indicator of soil degradation. *Environmental Monitoring and Assessment*, *189*(4), 176. https://doi.org/10.1007/s10661-017-5881-y.

Ogbu, P. O., Shaibu, I., & Okwe, P. O. (2023). Effects of Topography on Soil Properties and Their Implications for Agricultural Land Use in Ipinu-Oju, Benue, Nigeria. *Agriculture, Forestry and Fisheries*, *12*(6), 172-179. https://doi.org/10.11648/j.aff.20231206.11.

Okebalama, C. B., Anih, F. C., & Awaogu, C. E. (2024). Morphology and fertility evaluation of soils from different geological materials for agricultural production in Southeastern Nigeria. *Technology in Agronomy*, *4*(1). https://doi.org/10.48130/tia-0024-0017.

Okorie, F. C., Chinyere, C.-N., Ifeanyi, J. O., & Lazarus, C. (2020). Geospatial analysis of soil properties and their effects on maize and cassava production in Ohaji/Egbema Imo State, Nigeria. *Open Access Library Journal*, *7*(4), 1-16. https://www.scirp.org/journal/paperabs?paperid=99742.

Pan, Z., Tang, D., Kong, H., & He, J. (2022). An Analysis of Agricultural Production Efficiency of Yangtze River Economic Belt Based on a Three-Stage DEA Malmquist Model. *International Journal of Environmental Research and Public Health*, *19*(2), 958. https://doi.org/10.3390/ijerph19020958.

Pushpalatha, R., & Gangadharan, B. (2024). Climate resilience, yield and geographical suitability of sweet potato under the changing climate: A review. *Natural Resources Forum*, *48*(1), 106-119. https://doi.org/10.1111/1477-8947.12309.

Sappe, N. J., Baja, S., Neswati, R., & Rukmana, D. (2022). Land suitability assessment for agricultural crops in Enrekang, Indonesia: combination of principal component analysis and fuzzy methods. *Sains Tanah Journal of Soil Science and Agroclimatology*, *19*(2), 15. https://doi.org/10.20961/stjssa.v19i2.61973.

Singha, C., & Swain, K. C. (2016). Land suitability evaluation criteria for agricultural crop selection: A review. *Agricultural reviews*, *37*(2), 125-132. https://doi.org/10.18805/ar.v37i2.10737.

Sys, C., Van Ranst, E., & Debaveye, J. (1993). *Land Evaluation Part III: Crop requirements*. General Administration for Development Cooperation, Agric. Publications N.7, Brussels, Belgium.

Taghizadeh-Mehrjardi, R., Nabiollahi, K., Rasoli, L., Kerry, R., & Scholten, T. (2020). Land Suitability Assessment and Agricultural Production Sustainability Using Machine Learning Models. *Agronomy*, *10*(4), 573. https://doi.org/10.3390/agronomy10040573.

Ugadu, M., & Asadu, C. (2019). Physicochemical Properties of an Alfisol under Fallow and Adjacent Forest Lands and their suitability for Cocoyam, Pi-geon pea and Sweet potato Production in Nsukka, Southeastern Nigeria. *Nigerian Journal of Soil Science*, *29*(1), 102–110. https://soilsjournalnigeria.com/article.php?id=243.

Umeobi, E., Ezeaku, P., Umeugokwe, C. P., & Ezeaku, V. (2021). Influence of Land Use on Soil Physiochemical Properties in Semi-Humid Nsukka Area of Southeast-ern Nigeria. *Nigerian Journal of Soil Science*, *31*(3), 6-17. https://soilsjournalnigeria.com/article.php?id=339.

Umeugokwe, C. P., Ajoagu, G. M., & Asadu, C. L. A. (2022). Characterization, classification and suitability evaluation of soils on three geological formations in Nsukka Area of Enugu State for pepper production. *Nigerian Journal of Soil Science*, *32*(2), 95-104. https://soilsjournalnigeria.com/article.php?id=379.

Wahab, A. A., Yusuf, O. J., Nofiu, T. T., Olowoake, A. A., & Yaman, I. U. (2024). Spatial soil variability and precision management strategies for optimizing maize productivity in Kwara State, Nigeria. *Agriculture, Food, and Natural Resources Journal*, *3*(2), 368-377. https://doi.org/10.5281/zenodo.14498003.

Waqas, M. A., Wang, X., Zafar, S. A., Noor, M. A., Hussain, H. A., Azher Nawaz, M., & Farooq, M. (2021). Thermal Stresses in Maize: Effects and Management Strategies. *Plants*, *10*(2), 293. https://doi.org/10.3390/plants10020293.