DOI: 10.29050/harranziraat.1299165
Harran Tarım ve Gıda Bilimleri Derg. 2023, 27(4): 624-642

Research Article/Araştırma Makalesi

Characterization and suitability assessment of soils in rain forest zone southwest Nigeria for cassava, maize and rice production using parametric method

Nijerya'nın güneybatısındaki yağmur ormanı bölgesindeki toprakların manyok, mısır ve çeltik üretimi için parametrik yöntem kullanılarak karakterizasyonu ve uygunluğunun değerlendirilmesi

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To cite this article:
Fawole, Olakunle A, Ojetade, Julius O. & Muda, Sikiru A. (2023). Characterization and suitability assessment of soils in rain forest zone southwest Nigeria for cassava, maize and rice production using parametric method. Harran Tarım ve Gıda Bilimleri Dergisi, 27(4): 624-642
DOI: 10.29050/harranziraat.1299165

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Received Date:
18.05.2023
Accepted Date:
07.12.2023

ABSTRACT

The study assessed the properties of soils derived from medium-grained granite gneiss, developed their taxonomic classification, established soil suitability groups for the selected arable crops production, and proposed sustainable land management practices to improve soil sustainability. Four soil profile pits were established along each of the two topo-sequences identified at the site in compliance with FAO/UNESCO standards. From the identified genetic horizons, soil samples were collected and subjected to routine physical and chemical analyses in the laboratory for characterization and suitability assessment. Data generated from the analyses were subjected to descriptive and inferential statistics. Employing a parametric approach, land attributes observed in the field were merged with those established in the laboratory and crop requirements to produce soil suitability classes. The soils encountered were classed according to the USDA classification system as Typic Isohyperthermic Paleustult, Plinthic Isohyperthermic Paleustult, and aquic Psamment. They were further classified as Lixisol, Plinthic Lixisol, and Fluvisol (WRB), in that order. The actual suitability revealed that all the soil series were presently unsuitable for crop production. Potentially Typic Isohyperthermic Paleustult soil was rated moderately suitable while Plinthic Isohyperthermic Paleustult and Ustipsamment soils were rated marginally suitable for cassava and maize production. All the soils, however, are both actual and potentially unsuitable for rice production. Slope, soil nutrient availability and nutrient retention together with physical characteristics were the key agronomic constraints of the soils encountered in the studied area. Although the soils have a complex relationship, the investigation indicated that they are not homogeneous and vary in potentiality with different physiographic units; as a result, different management techniques at different physiographic positions are required to ensure the sustainable use of soil resources.

Key Words: Soil suitability, Arable crops, Granite gneiss, Taxonomic classification, isohyperthermic and Paleustult.

Çalışmada, orta taneli granit gnaysı üzerinde oluşmuş toprakların özellikleri değerlendirilmiş, bunların taksonomik sınıflandırması yapılmış, mısır, maniok ve pirinç üretimi için toprak uygunluk sınıfları belirlenmiş ve toprak sürdürülebilirliğini artırmak için bir arazi yönetimi stratejisi önerilmiştir. İki topografik kesitte, FAO/UNESCO standartlarına uygun olarak her bir topografik kesit boyunca dört toprak profili açılmıştır. Tanımlanan genetik horizonlardan toprak örnekleri toplanmış ve karakterizasyon ve uygunluk değerlendirmesi için fiziksel ve kimyasal parametreler açısından analiz edilmiştir.

Analizlerden elde edilen veriler tanımlayıcı ve çıkarımsal istatistiklere tabi tutulmuştur. Parametrik ve CBS tekniklerinin kullanılmasıyla, saha gözlemlerinde gözlemlenen arazi özellikleri, laboratuvarda belirlenenler ve bitki gereksinimleri ile birleştirilerek toprak uygunluk sınıfları oluşturulmuştur. Çalışma bölgesinde haritalanan topraklar, USDA'ye göre Typic isohyperthermic Paleustults, Plinthic isohyperthermic Paleustults ve Aquic Psamments olarak sınıflandırıldı. Bu topraklar WRB'ye göre sırasıyla Lixisol, Plinthic Lixisol ve Fluvisol olarak sınıflandırıldı. Gerçek uygunluk, tüm toprak serilerinin şu anda bitki üretimi için uygun olmadığını ortaya koymuştur. Potansiyel olarak Typic isohyperthermic Paleustults topraklar, orta derecede uygun olarak değerlendirilirken, Plinthic isohyperthermic Paleustults ve Aquic Psamments topraklar, maniyok ve mısır üretimi için marjinal olarak uygun olarak değerlendirilmiştir. Ancak, tüm topraklar hem gerçekte hem de potansiyel olarak pirinç üretimi için uygun değildir. Çalışma alanındaki toprakların başlıca tarımsal kısıtlamaları, toprak fiziksel özellikleri, besin maddelerinin bulunabilirliği, besin maddelerinin tutulması ve eğim idi. Çalışma, topraklar yakın ilişkili olmalarına rağmen, homojen olmadıklarını ve farklı fizyografik birimlerde farklı potansiyellere sahip olduklarını ortaya koymuştur; bu nedenle, toprak kaynaklarının sürdürülebilir kullanımını sağlamak için farklı fizyografik konumlarda farklı yönetim tekniklerine ihtiyaç duyulmaktadır.

Anahtar Kelimeler: Orta taneli granit gnays, Taksonomik sınıflandırma, Tipik İzohipertermik Paleustults, Plintik İzohipertermik Paleustults ve Aquic Psamments

Introduction

Soil is a valuable nonrenewable resource that can be found all over the planet. Different types of soil behave differently, provide critical support in terms of food security to human existence and play a critical role in a wide range of human activities and society (FAO, 2015). The resource is vital to the health of the Earth's biosphere. It is essential to maintain healthy soil, its functions, and its qualities to sustain agricultural output and food security (Blum, 1993; De Groot et al., 2002; European Commission, 2006). As a result, every effort to wisely use land must begin with an understanding of the nature, type, and spatial distribution of soils in a region as established by land resource surveys (Thapinta and Hudak, 2003). It has been identified that in any location, a lack of information on soil resources contributes to the problem of soil degradation and global food crises, among other things, because of improper land resource use and management (Esu, 2004). Research has indicated that soils currently in their native state are found on a few landscapes across the globe, based on its characteristics and possibilities, each piece of land is best suited for a specific land use (Opeyemi, 2008).

Due to the anthropogenic activities, the earth's surface is being drastically altered, and man's presence on the planet together with the use of land has had a significant impact on the natural ecosystem (Wilkie and Finn, 1996; Briney, 2008). This problem is aggravated by a lack of knowledge about land's potential, which leads to land management techniques that are unrelated to its acceptable potential and at large socioeconomic situations (FAO, 2015). Nigeria is currently implementing a program of increasing cultivated area and increased crop output that involves a continuous cropping system of some arable crops including Maize (*Zea mays*), rice (*Oryza sativa*), and cassava (*Manihot esculenta*) because of their global relevance in response to the current global food crisis (Nwite *et al.,* 2012).

These arable crops are among the most important staple food crops that play great roles in the rural economy of Southwestern (SW) Nigeria, and by extension, their use is vital for both humans and livestock. Because of their enormous relevance to human survival and contribution to food security, there is a need to boost production (Ezedinma *et al.,* 2006). Domestic production for each of these crops has yet to satisfy demand due to less viable agricultural inputs, the cropping system, and, most importantly, a lack of information on the crops' land adaptability potential. Increased crop production and sustaining it can only be achieved if there is a better understanding of the soil's suitability potential in the area.

Nigerian agriculture and indeed African agriculture have not succeeded in meeting the continuously changing needs of the citizenry (Chukwu *et al.,* 2013). Persistent food insecurity and failure to supply adequate quantities of raw materials to industries are stark realities. These are attributed to many factors, among which soil resource illiteracy is that hinders agricultural development in some parts of Nigeria (Chukwu *et al.,* 2013). This is not a surprise as similar observations had been made in most parts of Africa (Ololade *et al.,* 2010). Some of the reasons for this situation are related to lack of soil survey reports of most rural communities and Local Government Areas (LGAs). However, agricultural activities had been taking place in the study area from time immemorial, nevertheless, up till date, no documented studies have been carried out to determine the suitability of the area for the specific crop production. Detailed information on the soils is still very limited, yet, there is the need to generate soil data to improve agricultural production and for detailed knowledge of the potential and agronomic limitations of the soils for their sustainable management and use.

Evaluating soil genesis characteristics and suitability potential is crucial in the land use planning process because it guides decisions on land utilization in such a way that the soil's resources are optimally exploited, and a sustainable land management strategy is accomplished. Therefore, this study is aimed at documenting the soils properties such as morphological, physical, and chemical properties in the study region to classify them, evaluate their suitability for rice, cassava, and maize production, and recommend land management strategies for long-term crop production at an optimal level.

Materials and Methods

Study area

An integrated farm settlement located at Alaye village, near Ikire in Irewole Local Government Area of Osun State in southwest Nigeria was selected as the study location owing to its immense contribution to agricultural output within the southwestern Nigeria. The region which is situated within the rainforest zone, and is characterized by underlying Precambrian Basement complex rocks in Southwestern Nigeria (Rahaman, 1988), lies within 7°21′40″N and 4°11′00″E with a land expanse of about 271 square kilometers and a population of 143,599 people (NPC, 2007). The location like other parts of Nigeria has an equatorial climatic system with wet (April - October) and dry (November - March) seasons marked by occasionally high humidity. FMANR, (1990) reports that the average daily atmospheric temperature all year-round ranges between 25 °C and 35 °C, which is moderately high, and has a narrow range between the monthly mean minimum (25.0 / 27.9°C) and maximum temperatures (33.8/ 35.0°C). The point at which the temperature is mostly felt (high temperature regime) which falls within February and March coincides with the start of rains, while the lowest temperature regime which falls within July and August marks the peak period of rainfall. The selected arable crops together with other crops such as yam, cacao, watermelon, and a variety of peppers are among the most important crops in the area.

Fieldwork

On the field, the free method of soil survey was employed, taking into consideration geological and geomorphological properties, with the use of a base map developed to identify soil units. The observations were based on Smyth and Montgomery's (1962) soil-landscape relationship. Random sampling was carried out across the study area within each of the physiographic units which in turn guided in citing of profile pits. Following that, standard profile pits which are eight (8) in number were established by the various soil units along various physiographic positions observed throughout the area. Cluster sampling at 0-15cm and 15-30cm depth was also carried out across the study area both within and outside each of the physiographic unit to assess the fertility status of the top and sub soils and examine the soil morphology. Soil morphological descriptions according to the identified genetic horizons from each soil profile pit established were performed and soil samples were collected following the FAO/UNESCO (2006) recommendations. The soil samples were transferred to the laboratory for the analysis. A soil core sampler was also used to collect undisturbed soil samples to determine soil bulk density (Blake and Hartge, 1986).

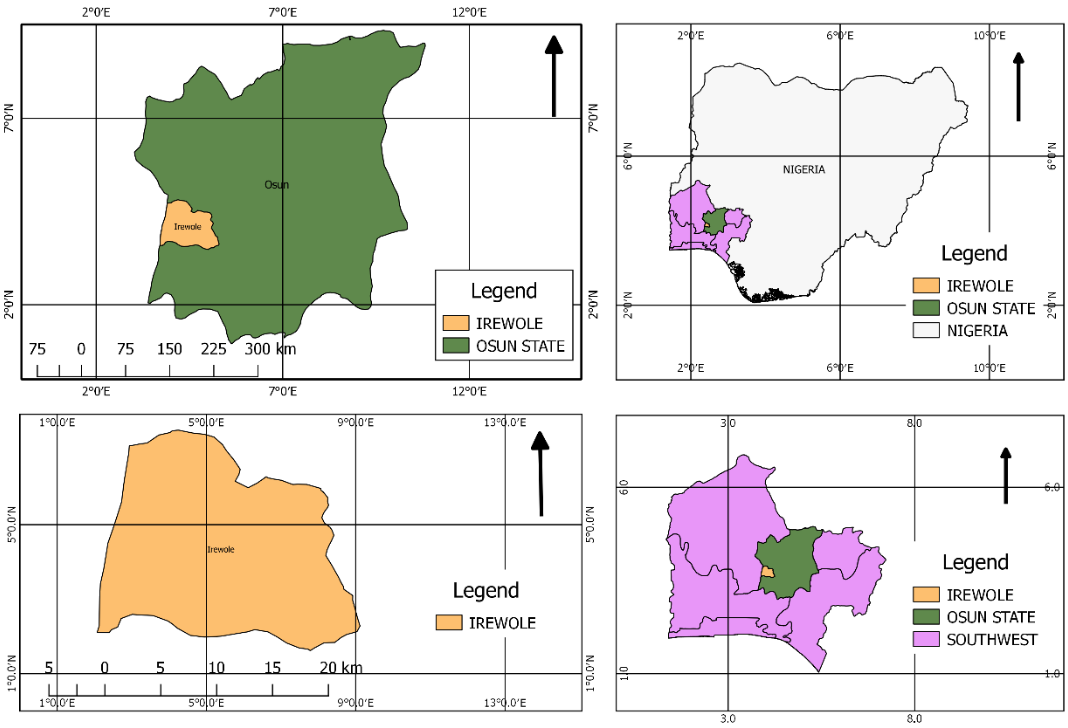

Figure 1. Map of the area under investigation

Laboratory analyses

Soil samples collected from different horizons together with the cluster soil sample across the area were air-dried, gently crushed, and passed through a 2 mm sieve size to separate gravel content from other soil components. The portions of the soil that are less than 2 mm were retained for physical and chemical procedures.

Soil bulk density was carried out with the use of the core method as reported by (Blake and Hartge, 1986), while Bouyoucos hydrometer method (Bouyoucos, 1965) as reported by (Gee and Or, 2002) was used to evaluate the particle size distribution of the soil samples employing the use of 0.2 M sodium hydroxide as the dispersing agent. Soil pH was determined in both water and 1.0 M KCl solution using a 1:1 soil/solution mixture (Thomas, 1996). Total exchangeable acidity and Al of the soil samples were evaluated by titration using 1.0 M KCl solution for extraction (Sims, 1996) and titrated with 0.05N NaOH solution (Bertsch and Bloom, 1996 and Sims, 1996). Exchangeable cations were determined by extracting with 1.0 N ammonium acetate (NH_4OAc) solution (Thomas, 1982). Concentrations of Ca, Na and K in the extract were determined using a flame photometer while that of Mg was determined using an atomic absorption spectrophotometer (AAS). The effective CEC (ECEC) was estimated by the summation of exchangeable cations (bases) and exchangeable Al (Sumner and Miller, 1996). The soil organic carbon was evaluated by the Walkley-Black method (Nelson and Sommers, 1996), total nitrogen in the soil samples was determined by the Kjeldahl method (Bremmer, 1996) and available phosphorus was determined by the Bray-1 method (Kuo, 1996). Selected extractable micronutrients (Cu, Zn, Mn, Fe and Co) contents of the soil samples were determined by extracting the soils with 0.5 sodium-ethylenediaminetetraacetic acids (Na-EDTA) solution and the concentrations of the elements in the filtrate were then determined with the use of atomic absorption spectrophotometer (AAS). However, the soil's electrical conductivity (EC) was determined in deionized water.

All the data generated were subjected to inferential and descriptive statistics that include the coefficient of variation and correlation to determine the relationship between the soil, its geographical location and its productive potential as related to their physical and chemical properties.

Soil development and classification

A modified version of Bilzi and Ciolkosz's (1977) and Meixner and Singer's (1981) field morphology rating systems were utilized to assess pedological development by quantitatively evaluating the relative distinctiveness of horizons and determining the relative development of the soils. All of this, together with the laboratory results of the physical and chemical properties of the soils, was used for soil classification into different taxonomic groups.

Land suitability parametric approach

Land characteristics observed in the field were combined with those identified in the laboratory to provide the necessary land qualities needed to determine crop suitability. The suitability classes were obtained from the matching, according to the rating guidelines specified by Sys (1985). The land indices were then determined before being converted to suitability classes using Storie's (1976) equation. The suitability index (Si) was then transformed into the suitability class using the conversion table developed by Sys *et al.* (1991).

The land characteristics that were selected for the rating were those that have been found to contribute to the growth and yield of maize, rice and cassava to avoid repetition of characteristics that may depress the final land index. Therefore, all the land qualities expressed by one characteristic were rated together. As such, a single rating of the soil texture was made regarding the capacity to retain nutrients, water availability, permeability, and drainage.

Land qualities/ characteristics

The following land qualities/characteristics were employed as the basis for assessment in the parametric approach for rice, maize, and cassava suitability.

(i) Climate: annual rainfall, mean temperature (c)
(ii) Soil physical characteristics: soil depth, texture, clay content (s)
(iii) Wetness: drainage (w)
(iv) Topography: slope percent (t)
(v) Nutrient availability (f): pH, N, P, K, Mn, Fe, Cu, Zn
(vi) Nutrient retention capacity (n): organic matter, base status, and effective cation exchange capacity (ECEC).

Application of the ratings

The land characteristics (LC) for each soil type were matched with the land use requirements for rice, maize, and cassava. Suitability classes were then derived from the matching. Land indices were calculated before converting them to suitability classes using the equation as developed by Storie (1976):

$$S_i = A \times \frac{B}{100} \times \frac{C}{100} \ldots \frac{n}{100}$$

Where, S_i is the suitability index, A is index of the most limiting characteristic, B is the index of topography, C is the index of moisture availability, n is the index of nth characteristic. The index of suitability (S_i) was then converted to the suitability class using Sys (1978) conversion table.

Results and Discussion

Relationship between landforms and soil morphology in the research area

Medium-grained granite and gneisses were reported as the parent materials of the soils along the top sequences under investigation are derived from. Smyth and Montgomery (1962) classified similar soils formed on similar rock types as Ondo association (Local classification). The sequence of soils along the topography was Balogun, Ondo, Oba and Jago series which are located at the different physiographical positions of the top sequence (upper, middle, lower slope, and valley bottom) respectively. Changes in slope position and drainage conditions influence the color and texture of the soils in the area down to the Jago series at the valley bottom. Well drained, with sandy loam topsoil overlying sandy clay loam to sandy clay subsurface were the characteristics observed among the soils that occupied the higher elevation position, a characteristic observed in practically all the pedons under study. Conditions favourable for iron segregation, most likely in the form of plinthites might have played out at a time with the presence of iron stone gravels in-situ in residual upland soils as observed in some of the profiles. A sufficient supply of iron, alternating wet and dry seasons, and typically flat land surfaces with seasonally wet soils, such as those found in the research area, are requirements for this process Ogunwale *et al.* (1975).

Physical properties of the soils

Table 1a and b display the soils' bulk density and particle size distribution information. Across the top sequences, sand to sandy loam is the observable characteristics of the soil texture for surface horizons. Clay loam texture, except a few pedons that were more clayey was the composition of the B and BC horizons as noted in the area. The soils' sand percentage varied from 57 to 92%, however, it followed an irregular pattern down the profiles, except for pedon 6, where the maximum sand content occurred at the surface and declined with profile depth. This observation was applicable to all the topographical segments on the two top sequences. Amusan (1991) reported that the translocation of colloidal clay particles deep into the profile with percolating water as well as selective erosion and transportation of fine particles to the lower slope position during heavy rains was responsible for the higher content of sand in the surface horizon.

The soils silt concentrations as observed on the field ranged from 3% to 19%. The soils generally have low silt contents, which is a characteristic of most Nigerian soils (Ojanuga, 1975), most especially the soils from the basement complex in southwest Nigeria according to reports from Mbagwu *et al.* (1983) and Okusami and Oyediran (1985) which is consistent with the study. The clay content ranged from 02 to 35%, it increased generally with depth to a maximum, perhaps caused by the interaction of illuviation and eluviation and then decreased in the BC horizon. Ojanuga (1978) observed a similar pattern in the Ife and Ondo soils in southwestern Nigeria. This could be a result of sorting of soil material by biological and agricultural activities, clay migration, surface erosion by run-off or a combination of these factors. In general, clay content was higher in the intermediate and lower slope positions compared to the valley bottom position. The soil bulk density measured ranged between 1.09 g cm^{-3} in the Ap horizon and 1.65 g cm^{-3} in the subsurface. Root penetration becomes an issue when bulk density surpasses 1.6 g cm^{-3}, but high total porosity in soils is typically linked with low bulk density (Payne, 1988). Except for the valley bottom, where the trend varies, the bulk density value often increased with depth to reach a maximum. However, as shown by the deep roots of plants into deeper depth in some cases, the higher values at depth in the profiles seem to have not produced any barriers to plant root penetration.

Table 1 (a). Soils physical characteristics along Transect 1

Horizon	Depth in (cm)	Total sand	Silt	Clay	Silt/Clay Ratio	Bulk density (g/cm^3)	Textural class

			(%)				
Profile 01 (Upper slope) (Balogun series)							
Ap	0-15	75	19	06	3.17	1.10	Sandy Loam
AB	15-65	80	12	08	1.50	1.28	Loamy Sand
Bt1	65-140	80	08	12	0.67	1.55	Sandy Loam
Bt2	140-175	57	08	35	0.23	1.58	Sandy Clay
Profile 02 (Mid- slope) (Ondo series)							
Ap	0-15	83	11	06	1.83	1.15	Lomay Sand
AB	15-55	89	07	04	1.75	1.57	Sand
Bt1	55-115	75	07	18	0.39	1.61	Sandy Loam
Bt2	115-160	64	12	24	0.50	1.64	Sandy Clay Loam
Profile 03 (Lower slope) (Oba series)							
Ap	0-10	69	19	12	1.58	1.23	Sandy Loam
AB	10-40	77	15	08	1.88	1.36	Sandy Loam
Bt1	40-85	77	11	12	0.92	1.42	Sandy Loam
Bt2	85-140	83	05	12	0.42	1.55	Loamy Ssand
Profile 04 (Valley bottom) (Jago series)							
Ap	0 -12	70	18	12	1.5	1.23	Sandy Loam
AB	12 – 45	84	10	06	1.67	1.48	Loamy Sand
Bg	45 – 70	75	15	10	1.5	1.41	Sandy Loam

Table 1 (b). Soils physical characteristics along Transect 2

Horizon	Depth in (cm)	Total Sand	Silt	Clay	Silt/Clay Ratio	Bulk density (g/cm^3)	Textural class
			(%)				
Profile 05 (Upper slope) (Balogun series)							
Ap	0-15	88	08	04	2.00	1.22	Sand
AB	15-55	86	08	06	1.33	1.43	Loamy Sand
Bt1	55-100	84	06	10	0.60	1.52	Loamy Sand
Bt2	100-150	90	03	07	0.43	1.60	Sand
BC	150-195	73	07	20	0.35	1.65	Sandy Clay Loam
Profile 06 (Mid-slope) (Ondo series)							
Ap	0-20	90	06	04	1.50	1.09	Sand
AB	20-60	76	04	20	0.20	1.38	Sandy Clay Loam
Bt1	60-95	67	06	27	0.22	1.44	Sandy Clay Loam
Bt2	95-160	61	14	25	0.56	1.65	Sandy Clay Loam
Profile 07 (Lower slope) (Oba series)							
Ap	0-25	90	08	02	4.00	1.34	Sand
B1	25-65	86	10	04	2.50	1.43	Loamy Sand
B2	65-145	90	04	06	0.67	1.45	Sand
BC	145-180	73	03	24	0.13	1.65	Sandy Clay Loam
Profile 08 (Valley bottom) (Jago series)							
Ap	0-11	75	19	06	3.17	1.54	Sandy Loam
AB	11-35	80	14	06	2.33	1.48	Loamy Sand
Bg	35-60	92	06	02	3.00	1.26	Sand

Chemical properties of the soils

The chemical characteristics of the pedons under investigation are shown in Tables 2a and 2b. (Orimoloye *et. al.,* 2019) justified the classification of soils investigated as slightly acidic to neutral as observed from the pH (H_2O) values that ranged from 5.2 to 6.8 and pH (1M KCl) values ranging from 4.1 to 6.1. In general, pH decreased with increasing soil depth and followed no definite pattern. Sharu *et al*. (2013) observed and reported similar trends in some of the soils of southwest Nigeria. The surface soil horizons were medium to neutral acid class (pH 6.1 – 6.9), while the subsurface soils, B and C-horizon were slightly acid to medium acid having pH values that ranged from 5.2 – 6.7. The pH range across the profiles in 1M KCl was lower than the pH in water (H_2O), thus the difference in soil pH values between the pH in KCl and H_20 (as expressed by ΔpH = pH (KCl) – pH (H_2O)) were all negative ranging from -0.1 to -2.2. This implies that the silicate clay minerals predominate over oxides (Van Raij *et al.*, 1972).

Landon (1991) revealed that a pH range of 5.5-7.0 is the ideal range for most crops. Heavy rainfall, the acidity of the parent rock, crop removal around the study region, and other factors have been proposed as potential contributors to the amount of acidity in the soils in the study area. The research areas receive between 1200 and 1400 mm of rain annually, with the majority of that falling between five to seven months in the year, this pattern of rainfall is assumed to be responsible for leaching and colloidal translocation which is a common occurrence in the humid tropics (Amusan, 1991). The higher pH values observed at the soil surface could potentially be attributed to nutrients bio cycling and the liming the effects of bush burning which is a common practice in the area.

The total exchangeable bases decreased with soil depth, except for some cases where this was due to nutrient biocycling. Other possible explanations include differential weathering that had taken place, plant uptake, and leaching losses. In general, there was a higher accumulation of bases in the surface horizon of the soils (3.24–9.22 cmol(+) kg^{-1}). Exchangeable calcium and sodium, as earlier discovered in most tropical soils dominated the exchangeable sites of the soils under investigation. Calcium and magnesium concentrations vary at random as the soil depth increases and changes in slope position. Exchangeable potassium (K^+) and sodium (Na^+) concentrations in soil ranged from 0.08 to 0.53 cmol(+)kg-1 and 0.22 to 1.32 cmol(+) kg^{-1}, respectively. Due to their mobility within the soil, these low values suggested that the soils under consideration originated from low K^+ and Na^+ content sources or had been depleted by plant uptake or leaching. Higher values observed at the pedons' surface horizon may be due to a higher level of organic materials. However, the readings varied erratically down the soil profile.

Soil organic matter (SOM) values ranged from 0.18 to 4.81% and decreased with increasing soil depth. SOM concentrations were higher on the soil surface than in the subsoil, likely because the topsoil contained more decomposable plant components. Akinbola *et al.* (2006), reported that surface horizons are the site where organic materials disintegrate and humified, hence the reason for the higher organic matter contents encountered. The subsurface horizons' SOM ranged from 0.18 to 2.87%. Adepetu (1986) rated SOM percentage into three categories: >2.5% rated high; between 1.5-2.5% are rated medium, and low values ranged between 0-1.5%. The overall organic matter content of the soils studied was often less than 2%, with a few exceptions yielding higher values. These higher values were most likely caused by the transfer of organic materials from one part of the topography to another, resulting in erosional deposition at the valley bottom. The effect of high temperature and relative humidity on organic matter mineralization, or rather the degradative effect of agriculture and other land use and management activities, such as the regular burning of farm wastes, which destroys most of the organic compounds that could have been provided to the soil could be attributed as the reasons for the low organic matter encountered in the area. Exchangeable soil acidity (Al^{3+} and H^+) levels varied from 0.1 to 1.4 cmol (+) kg^{-1}. The exchangeable acidity of all the examined pedons exhibited little variation, and the values were essentially constant with soil depth. Exchangeable Al^{3+} was observed to account for a higher proportion of overall acidity in the soils studied, subsequent increases in Al^{3+} will result in aluminium toxicity, reducing plant nutrient availability if the soil is not adequately managed.

Effective cations exchange capacity (ECEC) values in the soils under investigation ranged from 3.38 to 9.42 cmol (+) kg^{-1} soil and are adjudged generally from low to medium going by Esu (1987) ratings that put the values as 6 = low, 6-12 medium, and >12 = high. The values were higher in most of the surface horizons of all the soils studied than in the subsoil, most likely due to the impacts of organic carbon on the soil exchange sites. Research has revealed that low ECEC values were compatible with low soil organic carbon content, particularly in the B-horizons, which is not unconnected most likely to the kaolinitic nature of the soil clay (Yakubu and Ojanuga, 2009). In most of the horizons investigated, as the soil depth increased, the ECEC values decreased. This is an indication that the soil's ability to hold plant nutrients is limited, underlining the significance of effective soil management. Total nitrogen concentrations in the soil are severely low, having values that are less than 1 g/kg across the pedons. Surface soils had total nitrogen contents ranging from 0.07 to 0.13% and subsurface soils had total nitrogen contents ranging from 0.02 to 0.11%. Total nitrogen percentages were classed as low (0.10%), medium (0.10 - 0.20%), and high (>0.20%) (Sobulo and Adepetu, 1987). Low nitrogen values in soils are most likely caused by a rapid rate of soil organic matter decomposition, a high rate of leaching, and loss because of soil erosion (Solarin and Ayolagha, 2006). Total nitrogen values fluctuated irregularly with depth in the area, which could be attributed to the influence of continuous cultivation, a common practice on most Nigerian soils that are accompanied by constant crop residue removal. Values of the soils' Extractable Micronutrients concentration revealed that Fe ranged from 80.0 to 520.0 mg/kg, Zn from 0.25 to 1.52 mg/kg, Co from 0.12 to 13.46 mg/kg, and Mn from 0.90 to 13.0 mg/kg with an irregular distribution down the soil profiles. Fe concentration was higher in all the pedons studied, probably because of the mineral composition of the underlying rock or transported materials, uptake of essential nutrients by plants, leaching of cations due to heavy rainfall or erosion, or a combination of these factors. The higher values recorded may lead to the occlusion of some plant nutrients, such as phosphorus and so unavailable for plant uptake, as well as the lower exchangeable cations found in the soils under study. This can be handled with a good soil management system.

The range of the soils' electrical conductivity (EC) was 0.01 to 1.32 dS/m. All the soils' EC values were typically less than 2 dS/m. Brady and Weil (1999) stated that soils with EC values less than 2 dS/m were neither saline nor sodic. Many plants typically experience salt stress when the soil EC surpasses 2.0 dS/m salt index (Hanlon *et al.,* 1993).

The correlation studies of soil physical and chemical parameters along the top sequences (Table 3) revealed the levels of interaction and importance among the soil properties. Positive and significant relationships thus suggested that the more components in the soils, the more available they were, and vice versa for every negative and significant association.

The genesis of the soil

In general, all the pedons studied have comparable morphological, physical, and chemical properties, which are highly correlated with landforms and landscapes. The results suggest that pedogenic processes operating in the study area that might have led to soil formation are decomposition and humification of organic materials as evidenced by the dark color of the topsoils, illuviation/ eluviation/ colloidal transformation, and leaching. This could be beneficial for predicting the spatial distribution of soil characteristics that are directly related to local land use and management in the area.

Soil classification (Local system)

The report of Smyth and Montgomery's (1962) soil survey work in central western Nigeria served as a reference for the local classification of the soils. The characteristics of the parent material, bedrock type, physiographic position, drainage, and soil morphology were all taken into consideration. The parent rock of the Ondo Association soils encountered in the area is medium-grained granite and gneisses (Smyth and Montgomery, 1962). The soils at the upper slope position from the two transects under investigation were therefore classified as Balogun series, Mid slope position as Ondo series, lower slope position as Oba series, and the soils that occupied valley bottom position in the top sequences as Jago series, a member of Jago association.

Higher category classification (Taxonomic)

All the pedons studied exhibited subsoil clay bulge that is distinctive with low activity clay, ECEC at 125 cm below the top boundary of the kandic horizon is reported low with a slightly acidic subsoil horizon (USDA, 2010). All these classified the pedons examined as Ultisol. The soils encountered in the area are mineral soils with high color values and chromas but low SOM concentration. The soils are dried for a period that was above 90 days but less than 180 days. Periaswamy and Ashaye, (1982) and Okusami and Oyediran (1985) reported a moisture regime of soils encountered in southwestern Nigeria as ustic, placing the soils in the Ustult suborder. Amusan and Ashaye (1991) have reported an isohyperthermic soil temperature regime in southwestern Nigeria, although the landscape is old and geologically stable with ochric epipedon, making the profiles pale. The soils at the upper and mid slope position are thus classified as Typic isohyperthermic Paleustult in the USDA Soil Taxonomy, while soils at the lower slope position that displayed a plinthic material within its 100 below soil surface are classified as Plinthic isohyperthermic Paleustult, soils of Jago series at the valley bottom position were classified as Ustipsamment (Soil Survey Staff, 2006). However, employing the FAO/UNESCO system of classification, Upper and mid slope soils were classified as Chromic Lixisol owing to the displayed presence of argillic B horizon that is reported to be low in CEC, base saturation with high chroma. Lower slope soils with plinthitic material are Plinthic Lixisol and the soils at the valley bottom as Fluvisol respectively.

Land characteristics and qualities

The climatic condition of the area in terms of the amount of rainfall, rainfall distribution and temperature were favorable for the cultivation of the three crops. All the pedons regardless of their position on the top sequence were deep (140 cm to 195 cm) while groundwater table was encountered at a depth of 75 cm and 60 cm in Profiles 4 and 8 respectively. All the mapping units were well drained except for the two pedons that occupied the valley bottom, and this was due to their location on the top sequences. The fertility of the soils was low, and the slope of the area is moderate to slightly steep of about 2 to 6% and the sand content was high.

Table 2a. Selected chemical properties of soils along transect 1 in the studied area

Horizon	Depth (cm)	pH (H_20)	pH KCl	ΔpH	EC (dS/m)	Exchangeable Bases Ca^{2+}	Mg^{2+}	K^+	Na^+	OM (%)	Exch. Acidity Al^{3+}	H^+	Sum of Bases	ECEC	Base sat. (%)	Al. Sat. (%)	Total N (%)	Avail. P	Mn	Co	Fe	Cu	Zn
						(cmol/kg)					(cmol/kg)							(mg/kg)					
Profile 01 (Upper slope) Balogun series																							
Ap	0-15	6.3	5.3	-1.0	0.59	3.09	0.79	0.53	0.47	3.56	0.4	0.2	4.88	5.28	92	8	0.10	47.66	2.70	8.58	88.00	3.60	0.72
AB	15-65	6.1	5.1	-1.0	0.70	2.61	0.41	0.19	0.32	1.34	0.2	0.3	3.53	3.73	95	5	0.06	17.28	1.10	9.32	80.00	3.40	0.59
Bt1	65-140	5.7	5.6	-0.1	0.95	4.51	0.52	0.31	0.36	0.74	0.3	0.3	5.70	6.00	95	5	0.08	29.07	1.30	9.50	166.00	2.20	0.85
Bt2	140-175	5.2	4.8	-0.4	0.90	3.80	0.98	0.27	0.65	0.41	0.7	0.3	5.70	6.40	89	11	0.02	33.12	4.30	9.60	96.00	2.20	1.49
Profile 02 (Mid- slope) Ondo series																							
Ap	0-15	6.8	5.9	-0.9	0.71	3.32	0.66	0.51	0.65	2.68	0.4	0.2	5.14	5.54	93	7	0.12	75.21	0.90	9.51	118.00	4.10	1.50
AB	15-55	6.6	6.2	-0.4	0.31	3.09	0.46	0.29	0.57	1.68	0.4	0.3	4.41	4.81	92	8	0.07	34.14	1.10	10.47	122.00	2.90	0.62
Bt1	55-115	6.5	6.1	-0.4	0.75	3.09	0.39	0.27	0.57	0.74	0.1	0.4	4.32	4.42	98	2	0.04	18.08	1.10	10.84	80.00	2.10	0.78
Bt2	115-160	6.5	5.4	-1.1	0.52	4.28	0.69	0.29	0.65	0.67	0.4	0.3	5.91	6.31	94	6	0.06	11.49	1.30	10.87	520.00	2.00	1.52
Profile 03 (Lower slope) Oba series																							
Ap	0-10	6.9	5.2	-1.7	0.49	2.61	1.07	0.27	1.32	3.05	0.4	0.3	5.27	5.67	97	7	0.13	12.34	4.60	11.43	510.00	7.70	1.38
AB	10-40	6.7	5.9	-0.8	0.61	2.85	0.98	0.13	0.72	1.27	0.3	0.3	4.68	4.98	93	6	0.08	6.42	1.50	10.63	486.00	5.60	0.83
Bt1	40-85	6.5	6.1	-0.4	1.12	2.85	1.05	0.13	0.65	1.07	0.2	0.2	4.68	4.88	94	4	0.08	6.08	1.00	5.66	120.00	6.40	1.07
Bt2	85-140	6.1	5.7	-0.4	1.32	3.09	1.03	0.17	0.75	0.4	0.2	0.3	5.04	5.24	96	4	0.05	69.12	1.90	11.67	106.00	1.90	1.50
Profile 04 (Valley bottom) Jago series																							
Ap	0-14	6.1	4.5	-1.6	0.52	3.7	2.05	0.23	0.24	4.81	0.6	0.4	6.22	6.42	97	3	0.13	32.12	13.00	5.44	386.00	3.10	0.48
AB	14-50	5.7	4.3	-1.4	0.56	2.9	1.67	0.12	0.22	2.87	0.5	0.3	4.91	5.11	96	4	0.11	28.14	7.10	7.32	356.00	2,44	0.25
Bg	50-75	5.7	4.1	-1.6	1.11	2.2	1.67	0.08	0.24	2.01	0.7	0.4	4.19	4.39	95	5	0.07	14.44	8.12	9.10	368.00	2.28	0.51

Table 2b. Selected chemical properties of soils along transect 2 in the studied area

Horizon	Depth cm	pH H_2O	pH KCl	ΔpH	EC (dS/m)	Exchangeable Bases Ca^{2+}	Mg^{2+} (cmol/kg)	K^+	Na^+	Total N (%)	OM (%)	Exchangeable Acidity Al^{3+}	H^+ (cmol/kg)	Sum of Bases	ECEC	Base sat. (%)	Al. Sat. (%)	Avail. P	Mn	Co	Fe (mg/kg)	Cu	Zn
Profile 05 (Upper slope) Balogun series																							
Ap	0-15	6.5	5.2	-1.3	0.32	2.61	0.66	0.49	0.57	0.07	3.02	0.4	0.2	4.33	4.73	91	8	10.82	4.60	11.50	192.00	1.50	0.39
AB	15-55	6.5	5.2	-1.3	0.40	2.85	0.56	0.15	0.54	0.03	1.07	0.2	0.3	4.10	4.30	95	5	10.14	7.10	12.89	112.00	1.70	0.38
Bt1	55-100	6.3	5.0	-1.3	0.51	3.56	0.54	0.21	0.54	0.05	0.54	0.3	0.3	4.85	5.15	94	6	22.14	1.20	12.60	170.00	1.30	0.40
Bt2	100-150	5.9	5.8	-0.1	0.46	3.56	0.64	0.42	0.72	0.02	0.4	0.7	0.3	5.34	6.04	88	12	14.87	1.00	11.97	152.00	0.60	0.42
BC	150-195	5.7	5.5	-0.2	0.52	2.61	0.95	0.33	0.79	0.02	0.67	1.1	0.4	4.68	5.80	81	19	19.44	1.30	11.54	80.00	0.70	1.24
Profile 06 (Mid- slope) Ondo series																							
Ap	0-20	6.6	5.2	-1.4	0.14	2.38	0.61	0.42	0.61	0.13	1.68	0.4	0.2	4.02	4.42	91	9	10.82	1.30	12.82	120.00	0.10	0.41
AB	20-60	6.1	5.7	-0.4	0.04	2.85	0.46	0.23	0.29	0.09	0.87	0.4	0.3	3.83	4.23	91	9	14.70	1.10	12.27	94.00	0.90	0.40
Bt1	60-95	5.7	4.8	-0.9	0.03	2.38	0.74	0.25	0.40	0.09	1.14	0.1	0.4	3.77	3.87	97	3	12,84	1.40	13.46	112.00	2.50	0.57
Bt2	95-160	5.4	5.1	-0.3	0.06	2.38	0.90	0.40	0.43	0.05	0.54	0.4	0.3	4.11	4.51	91	9	10.82	1.20	12.73	138.00	0.20	0.41
Profile 07 (Lower slope) Oba series																							
Ap	0-25	6.5	5.4	-1.1	0.02	2.14	0.49	0.29	0.32	0.12	1.07	0.4	0.3	3.24	3.64	89	11	15.72	1.10	12.25	194.00	0.50	0.39
B1	25-65	6.0	5.5	-0.5	0.02	2.14	0.38	0.27	0.29	0.08	0.81	0.3	0.3	3.08	3.38	94	9	13.01	1.40	0.12	198.00	0.20	0.36
B2	65-145	5.8	5.5	-0.3	0.09	3.56	0.62	0.19	0.40	0.03	0.81	0.2	0.2	4.77	4.97	96	4	24.34	2.20	0.53	146.00	1.60	0.67
BC	145-180	5.2	5.0	-0.2	0.02	2.76	1.05	0.15	0.75	0.04	0.87	0.3	0.2	4.71	4.91	96	4	14.11	2,44	1,12	244.00	1.12	0.42
Profile 08 (Valley bottom) Jago series																							
Ap	0-11	6.7	4.5	-2.2	0.03	4.7	4.05	0.23	0.24	0.13	1.45	0.4	0.2	9.22	9.42	98	2	32,22	7.10	6.43	520.00	5.11	0.31
AB	11-35	6.2	4.3	-1.9	0.01	3.2	5.67	0.12	0.22	0.05	0.86	0.4	0.3	9.21	9.41	98	2	23.66	4.22	8.22	296.00	5.42	1.50
Bg	35-60	5.9	4.1	-1.8	0.17	2.2	5.67	0.08	0.24	0.03	0.18	0.6	0.3	8.19	8.39	98	2	15.55	6.23	13.46	354.00	6.86	1.52

Suitability evaluation using parametric approach

The suitability of the soils for the selected crops (maize, rice, and cassava) was evaluated using the physical and chemical parameters of the pedons across the study area, as suggested by Sys (1985). The parametric approach thus, assigns a numerical rating to each limitation, with no limitation (highly suitable) being 100%, low limitation (highly suitable) being 95%, moderate limitations (moderately suitable) being 85%, severe limitations (marginally suitable) being 60%, and very severe limitations (not suitable) being 40%. Suitability classes were established based on the nature and severity of the constraints. They were often tied to the specific land index value. Soils were classified based on their suitability for the cultivation of a given crop. The rating scores were determined by combining land characteristics/land qualities and crop requirements to develop suitability classes (Tables 4 a, b, and c) for the various mapping units in the study region. Soils were placed in classes according to their suitability to produce specific crop.

Actual suitability defines the soil's suitability for crop production in its current state when correctable limits (in this case, nutrient availability - N. P., K, Mn, Cu, Fe, Zn) are not modified. Potential suitability (p) evaluates crop performance when fertilizers are given to rectify fertility deficiencies during cropping. This presentation is required since the distinction between actual and potential suitability is merely a management factor.

The actual (a) suitability examination revealed that the soils are not presently (N1) suitable for commercial cultivation of maize, rainfed rice, and cassava in their current state. The soils, on the other hand, were graded as moderately suitable (S2) at the upper, middle, and lower slope position but marginally suitable (S3) at the valley bottom for maize production. Potential suitability for cassava production at the upper and lower slope position were rated moderately suitable (S2), while those at the mid slope and valley bottom were rated marginally suitable (S3). However, all the soils in the area are potentially not suitable (N1) for upland rice.

Physical factors are the primary agronomic restrictions of these soils such as texture, structure and coarse fragments, nutrient availability, and nutrient retention such as nitrogen and organic matter contents of the soils and perhaps their position on the topography (slope) in the order of severity.

Suitability assessment of the soils using GIS based approach

The following steps were followed in the GIS environment: Database was created for the soil properties collected on the field using Microsoft Excel. The soil map of the areas were produced in GIS environment using digital elevation model guided by the field data; Land quality maps were produced using Boolean operations; Diagnostic queries on the spatial and attribute data was carried out to compare soil characteristics/qualities with crop requirements for maize, rice and cassava; and thereafter, overlay and intersection functions performed on the land quality maps generated to produce the soil suitability maps.

The suitability map of the studied area using GIS for maize production was mapped as permanently not suitable, not suitable, marginally suitable, and moderately suitable. About 15% of the area was mapped as permanently not suitable, 50% not suitable, 25% marginally suitable and the remaining 10% was mapped as moderately suitable for maize production. The area mapped as not presently suitable was occupied by soils of Balogun and Jago series, Figure 2. The suitability map of the area for rice production showed a different result from that maize. About 80% of the study area was mapped as marginally suitable and the remaining 20% was not presently suitable for rice production, figure 2.

The suitability map of the area for cassava production showed that about 50% of the study area was presently not suitable (N1) and 40% marginally suitable (S3) while 10% are moderately suitable (S2) for cassava production. The area mapped as not presently suitable was occupied by the soils of Balogun and Jago series, figure 3.

Table 4 a. Aggregate Suitability evaluation scores of the soils from the study area for maize production using parametric approach

Soil Profiles	Soil series name	Topography slope (t)	Drainage (w)	Moisture Avail (m)	Physical soil properties (s)			Nutrient availability (f)						Nutrient retention (n)			Suitability	
					Texture	Gravel	Soil Depth	N	P	K	Mn	Zn	Cu	ECEC	Base Sat	Organic Matter	Index	Class
1	Balogun	85	100	100	95	95	100	95	100	100	40	40	60	60	100	95	4	NS a
		85	100	100	95	95	100	-	-	-	-	-	-	-	100	-	77	S2 p
2	Ondo	95	100	100	85	95	100	95	100	100	40	40	60	85	100	95	6	NS a
		95	100	100	85	95	100	-	-	-	-	-	-	-	100	-	77	S2 p
3	Oba	95	100	100	85	95	100	95	100	95	40	40	60	85	100	95	5	NS a
		95	100	100	85	95	100	-	-	-	-	-	-	-	100	-	77	S2 p
4	Jago	100	85	100	60	100	95	95	100	95	60	40	60	60	100	95	4	NS a
		100	85	100	60	100	95	-	-	-	-	-	-	60	100	95	48	S3 p

a = actual suitability when characteristic (f) is not corrected. p = potential suitability after the correction of characteristic (f).

Table 4 b. Aggregate suitability evaluation scores of the soils from the study area for cassava production using parametric approach

Soil Profiles	Soil series name	Topography slope (t)	Drainage (w)	Moisture Avail (m)	Physical soil properties (s)			Nutrient availability (f)							Nutrient retention (n)			Suitability	
					Texture	Gravel	Soil Depth	N	P	K	Fe	Mn	Zn	Cu	ECEC	Base Sat	Organic Matter	Index	Class
1	Balogun	85	95	100	95	85	100	95	100	100	100	40	85	95	60	100	85	6	NS a
		85	95	100	95	85	100	-	-	-	-	-	-	-	-	100	-	65	S2 p
2	Ondo	85	95	100	85	60	100	95	100	100	100	40	60	95	85	100	85	4	NS a
		85	95	100	85	60	100	-	-	-	-	-	-	-	-	100	-	41	S3 p
3	Oba	95	95	100	95	85	100	95	100	100	100	40	60	95	85	100	85	4	NS a
		95	95	100	95	85	100	-	-	-	-	-	-	-	-	100	-	73	S2 p
4	Jago	95	60	100	95	95	85	95	100	100	100	60	60	95	60	100	60	5	NS a
		95	60	100	95	95	85	--	-	-	-	-	-	-	-	100	-	44	S3 p

a = actual suitability when characteristic (f) is not corrected. p = potential suitability after the correction of characteristic (f).

Table 4 c. Aggregate suitability evaluation scores of the soils from the study area for rain fed rice production using parametric approach

Soil Profiles	Soil series name	Topography slope (t)	Drainage (w)	Rainfall	Temp.	Physical soil properties (s)				Nutrient availability (f)							Nutrient retention (n)			Suitability	
						Texture	Structure	Coarse Frag	Soil Depth	pH	N	P	K	Fe	Zn	Mn	ECEC	Base Sat	Organic Matter	Index	Class
1	Balogun	85	100	100	100	95	85	40	100	100	40	95	100	100	85	100	40	100	100	4	NS a
		85	100	100	100	95	85	40	100	-	-	-	-	-	-	-	-	100	100	27	NS p
2	Ondo	95	100	100	100	85	85	40	100	100	40	100	100	100	85	95	60	100	100	5	NS a
		95	100	100	100	85	85	40	100	-	-	-	-	-	-	-	-	100	100	27	NS p
3	Oba	95	100	100	100	95	85	40	100	100	40	100	95	100	60	100	60	100	100	5	NS a
		95	100	100	100	95	85	40	100	-	-	-	-	-	-	-	-	100	100	31	NS p
4	Jago	100	60	100	100	95	85	60	95	100	40	100	95	100	60	100	40	100	95	2	NS a
		100	60	100	100	95	85	60	95	-	-	-	-	-	-	-	-	100	-	28	NS p

a = actual suitability when characteristic (f) is not corrected. p = potential suitability after the correction of characteristic (f)

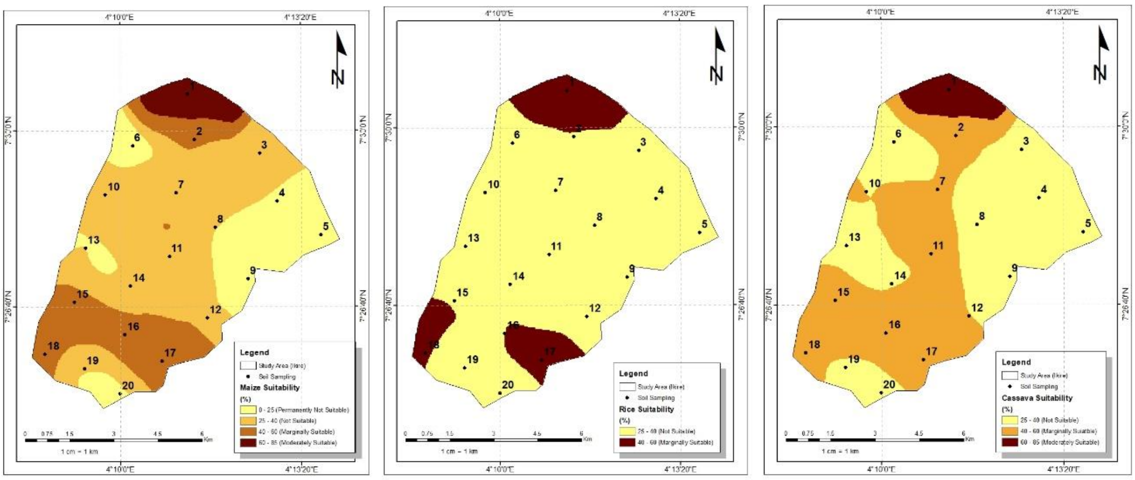

Figure 2 A. Map showing the suitability order of the study site for Maize production, B: Map showing the suitability order of the study site for Rice production, **C:** Map showing the suitability order of the study site for Cassava production

Conclusion and Recommendation

The purpose of the study was to characterize and classify the soils in the study region, as well as to evaluate their suitability for maize, cassava, and rice production using a parametric method, to suggest land management strategies for sustainable crop production. The soils in the area differ in their suitability for the selected crops based on their agronomic constraints ranging from texture, nutritional makeup, position on the topography and the ecological region.

The study thus revealed that although the soils are not homogeneous, they are closely related. Different soil types are present on the landscape because of pedogenesis, which was influenced by physiography in the studied area. Hydrolytic weathering and leaching of bases are the main pedogenetic processes that appear to have evolved the soils, together with lessivation, mobilization and immobilization of iron, and cyclic climatic change. As a result, this study demonstrated the need to adopt different management practices such as prevention and control of soil erosion through practicing of cross slope farming at the upper slope position, deep ploughing to break up the plinthic material at the subsoils and promote tuberization in cassava, practicing of crop rotation to sustain fertility status of the soils over a long time, avoidance of soils at the low level for root and tuber crops. In the same vein, considering the economy of liming in an area with low pH to meet the agronomic requirements for each soil type at the various physiographic positions to ensure the sustainable use of soil resources.

Conflict of interest: None existed before, during and after the research work.

Author contributions: F.O.A was responsible for the selection of the study site, topic, performing all the laboratory analyzes, writing and submitting the manuscript. O.J.O. & M.S.A was involved in the collation and analysis of the results and proof reading of the whole manuscript. All authors read and approved the final manuscript.

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