Characterization, fertility capability and land suitability classifications for cassava production in Ugep-Yakurr Local Government Area, Cross River State – Nigeria

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Abstract

Ugep is famous for its annual 'New Yam Festival' which gives the people the opportunity to showcase their cultural heritage and agricultural produce. As the farmers attempt to meet-up with this annual-ritual, they continuously cultivate the soil resulting in soil nutrient exhaustion. This study characterized the major soil units in Ugep and focused on the fertility capability classification (FCC) as well as land suitability evaluation for cassava production. With the aid of the geology- and topo- maps, two profile pits were sunk in the soils over alluvium (AL), sandstone (ST) and dolerite (DO) resulting in six profiles. The results present loam, sandy loam and clay loam textures in the surface soils, while bulk density was < 1.8 Mgm^{-3} and organic carbon, available P and total N recorded 2.0-37.3 g/kg, 1.25-36.12 mg/kg and 0.1-2.1 g/kg, respectively. Exchangeable bases were comparatively higher in DO, with a rating of high for exchangeable Ca^{2+} and Mg^{2+}, while exchangeable acidity was due to H^+. FCC indicated L (loam-surface and subsurface) in AL with limitations due to low K reserve (k), CEC (e), organic carbon (m) and gleying. DO qualified as LC (Loam-surface and clay-subsurface) with limitations of high gravel (r) as well as k, e and m, while ST qualified as SL (sand-surface and loam-subsurface) and L (loam-surface and subsurface) with limitations of k, e and m. By the parametric approach, current and potential aggregate suitability of moderately or highly suitable for ST had less limitations than marginally suitable classifications of AL for cassava production.

Keywords: Ugep, Cassava, Fertility capability classification, Land suitability classification, Dolerite

Introduction

The extent to which a soil is productive is based on its characteristics. Most soils in the tropics are highly weathered as a result of high precipitation and temperatures; this results in intensely weathered soils that are deep, high in sesquioxides, low in organic matter, acidic in reaction and low in exchangeable cations (Agboola and Akinnfesi, 1991). Babechuk *et al.* (2014) and Ofem *et al.*(2020a) attributed low exchangeable Na and K in some tropical soils to high precipitation and the highly mobile nature of the cations during chemical weathering of ferromagnesian minerals to kaolinites, Fe and Al oxides and oxyhydroxides. In the tropical humid region, inventories of the soil productive capacity indicate severe degradation on more than 10 % of the earth's vegetative cover as a result of soil erosion, atmospheric pollution, excessive tillage, overgrazing, land clearing and desertification (Wood *et al.*, 2000).

Besides the inherent fertility challenges of tropical soils in sub-Saharan Africa, primary issues are centered on availability of qualitative data and land evaluation reports. This is particularly obvious in rural areas where land use is based on inherited information, and little interest is placed on scientific processes. In recent times, a number of attempts have been made to identify the problems associated with agricultural soils in the tropics mainly to ameliorate their fertility limitations. One of such attempts is the fertility capability classification (FCC). Fertility capability classification is the first technical soil classification system that categorizes soils according to their fertility constraints in a qualitative manner and emphasizes topsoil and subsoil properties directly relevant to plant growth (Buol and Couto, 1980). The system is a guide for the extrapolation of the fertilizer response based on soil parameters (Buol and Couto, 1980). The FCC does not evaluate land for specific needs, while land suitability does. Land suitability evaluation has been defined as the process of estimating the potentials of land for alternate kinds of use (Ibanga, 2006) to identify the best kind of land for what purpose, and interpret the land resource inventories, as well as compare the features of soil, climate, vegetation, and hydrology as land quality parameters in relation to the requirements of land use (Ojanuga *et al.*, 1981).

Soil parent materials are an important factor of soil formation that determine soil type (Ibanga, 2006; Ekwueme, 2004) and contribute to soil differentiation as their weathering gives rise to the soil mass and releases nutrient elements to the soils for crop use. However, even parent materials that are high in basic nutrients do not have the capacity to release all its nutrients to the soil, since not all minerals in parent rocks are found in soil (Asadu *et al.*, 2012). It appears clearer and easier for a local farmer to identify and differentiate soils based on lithology than considering the concept of mapping units, hence the adoption of parent materials as a means of differentiating between the soils.

Ugep is an agrarian community with keen interest in the production of food crops like yam, cassava, rice and maize, as well as tree crops like oil palm, mango etc. Furthermore, the continuous year-in-year-out cultivation of the land to grow cassava and other food crops to sustain its growing population has resulted in nutrient exhaustion or nutrient-impoverished condition and vulnerability to the agents of degradation. In the Ugep area, cassava and yam are the commonly grown and celebrated food crops at the annual ritual of Yakurr New Yam festival. For sustained production of these crops, land evaluation is indispensable. Land evaluation will provide a guide for policy makers on land use and aid in proper land management and planning for increased productivity (Aiboni, 1985; Ibanga, 2003; Ofem *et al.*, 2022).

The current study was conceived as an easy means of identifying soils with limitations and potentials for agriculture via characterization and fertility capability classification and to evaluate the tracts of land for their suitability with the view to identify the most suitable tracts for cassava production in Ugep.

Materials and Methods

Location, climate and geology of the study area

The study was located in Ugep - Yakurr Local Government Area of Cross River State. The area lies between latitude 5° 32' N and longitude 8° 11' E and at elevation of 830 feet above sea level with an estimated population of 38,742 people. Ugep is one of the units that constitutes Yakurr Local Government Area and has a land mass area of 30.50 km^2 and located to the west of Yakurr LGA (Figure 1). Ugep has humid tropical climate with a short span of harmattan period which transits the wet season to the dry season. Rainfall amounts have a range of 1760.3–3770.8 mm/annum, while temperature varies from 22.56 to 31.95 °C in the study area (Sambo *et al.*, 2016). Rainfall is least in December, with an average of 12 mm, while most rainfall occur in September with an average of 3,019 mm per year and relative humidity of 70 – 85%. The geology of the area is mainly that of Sedimentary rock formation of Cretaceous Tertiary age with the soils mainly developed on sandstone as well as scattered and sparsely distributed dolerite. Recent alluvium is common at lowlands supporting rice production which are often irregularly distributed in the area.

Field studies

Reconnaissance visit was carried out to areas of Ugep underlain by alluvium, sandstone and dolerite to verify the content of the geology map. Two profile pits were sited each in the summit of soils overlying sandstone and dolerite, whereas those over alluvium were basically in the poorly-drained rice supporting soils. Two of the profile pits over each parent material were at a distance of at least 200 m apart, resulting in six profile pits in all (Figure 1).

Soil samples were collected from the horizons bottom-top based on the natural boundaries. The soil samples were put in well labelled polythene bags, transported to the laboratory and processed under laboratory conditions for laboratory analyses. Undisturbed core samples were also collected from the profile pits for bulk density determination. Profile pits were described using soil description sheets according to the guidelines of Schoeneberger *et al.* (2012). Sixteen soil samples were obtained and used for the analyses.

Laboratory analysis

Particle size distribution was determined by the Bouyoucos hydrometer method using sodium hexametaphosphate as the dispersing agent, while soil pH was determined potentiometrically in a soil to water ratio of 1:2.5 using a glass electrode pH meter. Soil organic carbon was determined by Walkley and Black wet oxidation method using diphenolamine as indicator and potassium dichromate as the oxidizing agent. Total N was determined by the macro-Kjeldahl digestion method, while available P was determined with the use of Bray 1 solution as extractant and the content of P was determined colorimetrically. Exchangeable bases such as Ca^{2+}, Mg^{2+}, K^+ and Na^+ were determined by leaching the soil sample with 1*N*

NH_4OAc at pH 7.0. Exchangeable K^+ and Na^+ were determined by flame photometry, whereas Mg^{2+} and Ca^{2+} were determined by atomic absorption spectrometry. Cation exchange capacity at pH 7.0 was determined by the neutral NH_4OAc method, while exchangeable acidity was determined by titration. All analyses were determined by the procedures and standards described by the Soil Survey Staff (2014).

Fertility capability procedures

Data used in evaluating the soils for Fertility Capability Classification are as outlined by Sanchez *et al.* (1982, 2003). The system recognizes three categories: 'type', (texture of plough layer or top 20.00 cm), 'substrata type' (texture of subsoils) and 'modifiers' (conditions which act as constraints to crop performance). The type is determined by the average texture of the plough-layer, while the substrata type is the average texture of the subsoil assessed at the depth of 20.00 to 50.00 cm and used wherever variation exists in soil texture within the defined limits of 20.00-50.00 cm. Otherwise, the name of this category shall not appear. The condition modifiers signify fertility limitations, and are represented by small letters. The modifiers and their meanings are as reported in Sanchez *et al.* (1982, 2003).

Land suitability evaluation procedure for cassava

Land evaluation for cassava production was in accordance with the requirements of Sys (1985). Land requirements and limitations for cassava production are presented in Table 1. Furthermore, actual land qualities as obtained from the field and laboratory studies are presented in Table 2 and corrected to 100 cm for cassava production and presented in Table 5. Generally, risk in production is minimized by matching the requirement for land use to actual land characteristics; hence, the profile pits were placed in suitability classes by comparing the data obtained in the study area to cassava requirements (Ofem *et al.*, 2022).

Ratings that indicate the adequacy or inadequacy of land qualities for cassava production were used to explain the extent of the limitations, while the most limiting factor was assumed to determine the overall suitability ratings in accordance with Liebig's law of minimum (Ofem *et al.*, 2016).

For the parametric method, the index of productivity (IP) for each pedon was computed using the equation:

$$IP = A \times \sqrt{B/100 \times C/100 \ldots \times E/100}$$

Where:
A = Overall lowest characteristics rating
B, C…E = The lowest characteristics rating for each land quality group.

For the purpose of this study, the land quality groups were wetness (w), physical soil characteristics (s), chemical soil fertility (f), and salinity and alkalinity (a). Since there are often strong correlations within a land quality group, only one member in each of w, s, f and a were used for the rating.

Results and discussion

Morpho-physical properties of the soils

The morpho-physical properties of the studied soils are presented in Table 2. Soils developed over alluvium (AL) were dark grey (5YR 4/1) to dark brown (7.5YR 3/2) in the surface soils with slight variation in the subsurface soils leading to pinkish grey (5YR 7/2). Soils developed from dolerite (DO) were either dark brown (7.5YR 3/2) or brown (7.5YR 5/4) with slight or no variation in soil colour with increasing soil depth. On the other hand, brown (7.5YR 4/3) and black (7.5YR 2.5/1) depicted the surface soils developed from sandstone (ST) and brown (7.5YR 5/4) in the subsurface soils. Uniform dark brown matrix colours over dolerite imply uniform or near uniform depth-wise distribution and movement of organic matter and ferromagnesian minerals as the parent rock is mafic. On the other hand, grey colours typify poorly drained soils that have experienced prolong reduction process. Such grey colours have been attributed to minerals leaching and reduction conditions (Nsor and Ibanga, 2008). This indicates that the soils had periods of inadequate aeration or reduction during some period of the year leading to cycles of oxidation-reduction reactions.

Clay content in the soils over alluvium (AL) was low (90-280 g/kg) and varied irregularly, compared to values in the soils over dolerite (DO) which had the highest (150-480 g/kg), and then in the soils over sandstone (ST) (70-400 g/kg) with regularly increasing values. Ranges of 480-690, 380-490 and 450-800 g/kg for sand in AL, DO and ST, respectively indicate clear dominance of the soils over sandstone by sand. In the Bekwarra area of Cross River State, 460-790 g/kg was reported for the soils developed from sandstone, while those developed over alluvium had a range of 390-620 g/kg for sand content (Ofem *et al.*,2020b). Sandy loam in ST, clay to loam in DO and sandy loam to loam in AL were obtained as textural classes. The comparatively higher clay content in DO imply that the soils should hold more nutrients on the exchange complex. However, high clay amount makes tillage difficult, results in low porosity and infiltration rate. Bulk density in the studied soils was ≤ 1.6 Mg/m^3 except in the subsurface of DO where 1.7 Mg/m^3 was obtained. The surface mean values were within 1.1 – 1.4 Mg/m^3 suggested for cultivated loams (Donahue *et al.*, 1983), with most values <1.60 Mg/m^3. This implies optimum air and water movement in the soils for plant growth (Esu, 2010). Ranges of 1.26-1.65 and 1.09-1.51 Mg/m^3 were reported as ranges or soils over sandstone and alluvium, respectively in the Bekwarra area of Cross River State (Ofem *et al.*, 2020a).

Total porosity exceeded 45 % in all the Ap horizons with overall values exceeding 35 % in the studied soils. Least values of total porosity were obtained in the subsurface of DO where the highest amount of clay was reported. Also, the total porosity of AL and ST were comparatively higher than values in DO probably due to the higher sand content as sand dominated soils tend to be more porous. Total porosity for most of the surface soils was > 50 % recommended for silty loam surface soils (Brady, 1974). Such values may result in extremely porous soils (Pagliai, 1988). Root size and number decreased with soil depth in the entire soils with common distribution of ants in the entire studied soils. However, flakes of weathered rock in and on the surface soils as well as cracks, charcoal, and concretions of Mn and Fe in the subsurface soils characterized the soils formed over dolerite.

Chemical properties of the studied soils

Chemical properties of the studied soils are presented in Table 3. Soil pH (H_2O) ranges of 4.4-5.4, 5.6-6.4 and 4.8-6.1 were obtained for AL, DO and ST, respectively. The poorly drained condition of AL appears to have exposed the soils to reduction resulting in the least values compared to DO and ST. On the scale of Holland *et al.* (1989), AL was within the very strongly acid range, whereas DO and ST were slightly to moderately acid, respectively. Slightly to very strongly acid conditions indicate that significant amounts of exchangeable Al^{3+} and H^+ ions are present to affect plant growth (Kamprath, 1967). Alumina becomes insoluble at pH range of 5-9, in which DO and ST were found, while silica becomes more soluble at such range (Tan, 1998). This results in the leaching of more soluble silica and formation of kaolinite and gibbsite (Ollier, 1975). Soil pH controls the rate of organic matter decomposition, activities of microorganisms, nutrient availability and uptake by crops (Agbede, 2009).

Organic carbon was generally less than 4.0 g/kg with irregular decrease in values with soil depth, but with relatively high values in AL compared to DO and ST indicating relative accumulation. Similarly, total N was less than 0.70 g/kg in the soils and had a trend similar to that of organic carbon. On the scale of Holland *et al.* (1989), the studied soils were rated very low in organic carbon and total N. Low organic carbon may be due to the effects of erosion and tropical condition of the area as well as reduced vegetation cover. Low values of total nitrogen may imply slow rate of organic matter decomposition for the release of total N which facilitates the build-up of soil bacteria and protozoa (Agbede, 2009). In AL, DO and ST, available P had values with ranges 9.62-28.5, 1.25-4.25 and 2.5-28.5 mg/kg, respectively. Available P was predominantly medium in AL and ST, and low in DO on the scale of Holland *et al.* (1989). These low to medium values of phosphorus observed in the study area agrees with the findings of Eshett (1987) who remarked that most Nigerian soils have low phosphate reserves. According to Nsor and Ibanga (2008), available P is rated low in sandstone derived soils. Consequently, Ofem *et al.* (2020b) reported ranges of 0.3-11.0 and 0.87-5.50 mg/kg for some sandstone and alluvial soils, respectively in Bekwarra.

Irrespective of lithology, exchangeable Ca was more dominant in the soils, with comparatively higher exchangeable bases in the soils developed over dolerite. Exchangeable Ca had ranges of 2.8-7.6, 8.0 -14.2, 1.6-2.6, while Mg had ranges of 0.4-1.4, 2.8-5.8, 0.4-1.6 cmol/kg in AL, DO and ST, respectively. DO was comparatively higher in exchangeable Ca^{2+} and rated high on the scale of Holland *et al.* (1989) compared to AL and ST which were rated as moderate and low, respectively. The high exchangeable Ca in DO may be due to the relatively high organic matter content in the soils. High exchangeable Ca has been reported in soils over alluvium and sandstone (Nsor, 2011). Exchangeable Mg was rated high in DO, while AL and ST were moderate on the scale of Holland *et al.* (1989). The high values of exchangeable Mg in DO may be due to the high content of magnesium in the parent rock. This disagrees with the work of Best (1989) on the chemical composition of rocks. Low K content in adsorbed form in the soils is as a result of its low content in the parent material, and the smaller capacity of adsorption compared to Ca and Mg, and so it is often easily expelled from the soil adsorption complex and leached away from plant root zone (Markoski*et al.*, 2018). Such low values may be attributed to leaching occasioned by high rainfall in the region.

Exchangeable acidity of the soils was dominated by exchangeable H^{+}, such that its values ranged from 1.36 to 2.04 cmol/kg in the entire studied soils with irregular distribution in values with soil depth. Variation between soils over different parent materials was not significant. This implies a more pronounce influence of the similar climate compared to the dissimilar parent material in the area. A predominance of H^{+} in the exchangeable complex of most soils in Cross River State has been reported by Amalu (1998). Except for one soil horizon, exchangeable Al^{3+} was < 2.1 cmol/kg as recommended by Holland *et al.* (1989) for most arable crops and are not likely to be toxic to plant roots as to affect roots proliferation.

Cation exchange capacity had ranges of 9-17, 20-26 and 9-12 cmol/kg in AL, DO and ST, respectively with values that regularly decreased with depth in AL, and increased in DO and ST. These values are rated moderate to high in AL and DO and, low in ST on the scale of Holland *et al.* (1989). The relatively high CEC in DO is the direct consequence of their possession of high content of organic matter (Forth, 1991) and ferromagnesian minerals (Russell, 1973; Eshett, 1987). The low values of CEC in ST are indicative of the low nutrient reserves of these soils. This is caused by the intense leaching due to the coarse textures and high rainfall experienced in this area (Jones, 1973). The values of CEC obtained in the alluvial soils are lower than values reported by Nsor (2011) for some alluvial soils in Nigeria, while Ofem *et al.* (2020a) obtained CEC > 14.0 cmol/kg in sandstone and alluvial soils in Bekwarra, Cross River State. Base saturation values indicate moderate rating in AL and high to very high in ST and DO on the scale of Holland *et al.* (1989). This implies that the soils in the study area will release cations to growing crops in this order; DO> ST> AL. This finding agrees with the reports of Eshett (1987) and Enwezor *et al.* (1981), and with that of Nsor (2011) for soils developed on alluvial deposit.

Fertility capability classification (FCC) of the soils

The FCC of the studied soils are presented in Table 4. Soils developed from alluvium (AL) were rated as Lkmg as the soils belong to loamy type and substrata type. The soils' condition modifiers include aquic soil moisture regime depicted by high water table which results in gleying (g). Also, moderate CEC, low organic carbon (m) and low exchangeable K (k) characterized the soils. The soils qualified in FCC as Lkmg. The FCC implies that the soils are low in nutrient content (particularly exchangeable K), soil aeration is retarded, with moderate CEC and organic carbon. Low organic carbon content and moderate CEC can be ameliorated by the careful use of crop residue, farm yard manure, green manure and compost. The wetness condition can be removed by drainage for a wider agricultural value or cultivated to water tolerant crops like paddy rice or sugar cane. Low exchangeable K reserve may be improved by the use of potassic fertilizers.

FCC rated DO as LCrkm as the soils belong to loamy type and clay substrata, with condition modifiers of gravels (r), low K reserve (k), moderate CEC (e) and low organic carbon (m). This implies that loamy type and clay substrata were limited by r, k and m. Potassic fertilizers and organic matter application will ameliorate the low exchangeable K, moderate CEC as well as low organic carbon content. However, high gravel content can barely be removed, and may be considered a permanent limiting factor of the soils.

Soils developed from sandstone; ST-1 and ST-2 were rated as SLkem (sandy type over loamy substrata type) and Lkem (loamy type and loamy substrata), respectively. The soils had the best FCC rating compared to AL and DO due to the condition modifiers of k, e and m acting as the major limitations. However, other soils were limited by some more condition modifiers in addition to the above k, e, and m modifiers. For instance, DO (soils developed from dolerite) were either too clayey or limited by gravels or conventional tillage operation, while AL (soils derived from alluvium) had high water table, seasonally flooded condition and gleying as the major limitation.

Land Suitability Evaluation for Cassava

When compared with values given by Sys *et al.* (1993), land characteristics reported in Table 5 gave rise to the suitability classes and scores in Table 6. Furthermore, aggregate index of productivity for the pedons were calculated and the scores/indices used to establish suitability classes. The results are presented in Table 7.

Land requirement for cassava

Climate: Temperature and rainfall characteristics were evaluated for climate quality. In Ugep, the characteristics were optimum for the cultivation of cassava (Table 6), with suitability scores ranging from S_1(90) for mean annual temperature to S_1(95) for mean annual rainfall. Climate did not constitute a limitation for the cultivation of cassava. However, the ratings were less than 100 % as rainfall was above 1400 – 1800 mm/annum recommended as the optimum range for cassava production (Sys *et al.*, 1993).

Cassava is very tolerant and has the ability to grow on marginal land compared to other food crops. But for high yield and productivity moderate climate conditions are crucial. Onwueme (1978) noted that the best climate for cassava is a warm and moist condition with daily temperature of 25-29 °C. Irrespective of the parent material, climate is not a limiting factor for cassava production in Ugep.

Topography: The slope of the study area was highly suitable and optimum for cassava cultivation with a suitability score ranging from S_1(90) in AL to S_1(98) in ST and DO. With the somewhat stable topography, there is bound to be minimal influence of surficial erosion and leaching of nutrients. In such a situation, cassava is most likely to make optimum use of the available nutrient, as steep-sloped areas generally experience soil erosion (Heumann*et al.*, 2011). Some steeper slopes reduce the amount of water percolating through the soil and accelerate erosion. Wood *et al.* (1987) observed that percolating water will remove all soluble products of weathering from the soil on the upper slopes but the laterally moving water carries some of these into and through the profiles on lower slope.

Wetness: Soils in higher elevation ranges (DO and ST) have suitability scores of S_1(100) for the drainage and flooding characteristics. This implies that the soils had minimal limitations related to drainage and flooding. On the other hand, AL had rating of N_1(40) for flooding and drainage characteristics. The wetness quality was the most limiting quality for cassava production in AL. Such poorly drained and flooded soils are likely to cause root-rot in cassava, and bring about losses to farmers. This indicates that AL is less suitable than DO and ST soils for the production of cassava. Udoh *et al.* (2005) remarked that cassava is drought tolerant but is extremely susceptible to excessive wetness or flooding, whereas Purseglove (1972) noted that water-logged conditions could cause the rotting of cassava tubers. Furthermore, Onwueme (1978) observed that cassava performs poorly when grown on poorly drained or clay soils due to root growth hindrance and rotting of tubers.

Soil physical characteristic: Amongst the physical properties, soil texture was optimum or near optimum for cassava production with ratings of S1(95 to 98) for AL, S1(95) for ST and S1(85) for DO. The textures of AL and ST were relatively more suitable for cassava production. Depth of the studied soils was highly suitable and exceeded 100 cm with ratings ranging from S1(90) to S1(100) except in DO-1 which had a rating of S2(75). According to Esu (2010) such soils are deep and will encourage the proliferation of roots. Cassava grows best on light, sandy loams or on loamy sands which are moist, fertile and deep, and also does well on soils with sand to clay textures (Sys *et al.*, 1993).

Soil fertility characteristics

Soil pH was optimum in ST and DO with the rating of S1(90 to 100), while AL had pH limitation with ratings of S2(80) and S3(55). Values of pH below 5.0 promote the replacement of Ca^{2+}, Mg^{2+} and K^{+} by H^{+} and Al^{3+} and the solubility of elements that can be toxic to plants, such as Al, Mn and Fe, and removal of basic cations from the exchange complex (Esu, 2010). These toxic elements can cause reduced growth of roots and shoots, leaf chlorosis, and small but not deformed young leaves (Howeler, 2002).

Though low in the soils, organic carbon was highly suitable for cassava production in the studied soils with ratings of S1(85 to 100), except in ST-1 where slight limitation was experienced resulting in S2(75). This indicates that the quality and quantity of soil organic carbon influences cassava production. It is crucial because it improves soil management, increases cassava yield and also enhances infiltration rate of the soils.

The entire studied soils were optimum for cassava production in terms of CEC with suitability scores of S_1(85-100). Soils with large quantities of negative charge are more fertile because they retain more cations, whereas those with low CEC are more likely to develop deficiencies in K, Mg and other cations. Cassava growing soils with high CEC are less susceptible to the leaching of cations (CUCE, 2007).

Irrespective of the parent material, the base saturation was > 50 % in the studied soils and optimum for the production of cassava with suitability score of S_1(100). According to Sys *et al.* (1993) the values were rated high for cassava production. The high values of CEC are the direct consequence of their possession of high organic matter (Forth,1991). The higher the organic matter contents of a soil, the higher the CEC. Brady (1974) observed that the CEC of most soils increase with pH.

Major limitation to suitability for cassava production

Wetness quality was highly suitable with respect to flooding and drainage characteristics, mainly for DO and ST. However, AL was majorly impacted by flooding and drainage limitations to the tune of currently not suitable. The soils may therefore be made more suitable for cassava production either by surface drainage or cultivation on raised mounds. When cassava is cultivated on raised mounds, the contact between the root-tubers and water is severed, and root-rot is avoided.

The suboptimal depth of DO-1 at 90 cm resulted in its slight limitation (S2;75) to cassava production. Though suboptimal, the soil was still moderately suitable for cassava production.

The soils were partly limited by soil pH and organic carbon. For instance, soil pH in DO and ST was without limitations that could affect cassava production, while its values in AL were either marginal (AL-2) with severe limitation or moderate (AL-1) with slight limitation to cassava production.

Suitability classes

Suitability classification and scores of individual pedons are presented in Table 6. The aggregate rating was done for current and potential suitabilities using the parametric and non-parametric methods, summarized in Table 7 and presented in Figures 2 and 3.

Parametric method

For this method, each characteristic was rated and the index of productivity (IP) for each pedon was calculated using square root method by Sys *et al.* (1993). The suitability classes by the parametric approach are presented in Table 6. Currently, the poorly drained and low elevation soils of AL were the two marginally suitable soils (S3) with aggregate suitability index of < 35%, while DO and ST were moderately suitable (S2) with aggregate suitability index of > 35 < 75 %.

Upon removing some of the basic limitations based on soil management, there was an improvement on the suitability rating for cassava production in the area, potentially. Therefore, two pedons (AL-1 and AL-2) (aggregate suitability index of < 35%) were marginally suitable (S_3), while 2 pedons (ST-2 and DO-1) (aggregate suitability index of 67.5 to 74.7 %) were moderately suitable. Furthermore, 2 pedons (ST-1 and DO-2) (aggregate suitability index of > 75%) were highly suitable for cassava production. From the above, two pedons (ST-1 and DO-2) were upgraded to the status of high suitability for cassava production.

The marginal suitability of the two pedons (AL-1, AL-2) is solely due to poor drainage and flooding limitation which result in the lowering of soil pH (Table 6). The acidic nature of the soils may be due to poor drainage and high rainfall in the area which leaches basic cations away from the plant root zone. Soil acidity may also be due to the effects of cultivation which gradually depletes the soil of its nutrients via plant root uptake. Enwezor *et al.* (1981) stated that, leaching of Ca is largely responsible for acid soil development.

Non-parametric

By the non-parametric method, the soils were more suitable for cassava production, potentially; more than the ratings obtained by the parametric approach. This was only possible after the removal of limitations. In situations where the main limitation was caused by a physical soil property such as soil depth (in DO-1) or wetness (in AL-1 and AL-2), the ratings mainly remained unchanged; potentially. This is because it is nearly impossible to remove rock restricting layers leading to soil depth limitation. Also, the wetness limitation encountered in AL can be removed either by artificial drainage or making mounds. Besides mounds making, other procedures are quite expensive. The cost implication of removing the limitation exceeds the risk in cultivating with such limitations, particularly if the land use type should be changed for optimum benefits. For instance, by the non-parametric approach, AL-1 and AL-2 were currently rated as S2w and S2wf, respectively.

Potentially, the fertility limitation caused by low soil pH may be removed by the careful application of the required lime. However, the process does not necessarily remove or solve the wetness limitation, hence the unchanged rating. In DO and ST, the potential rating was either improved when fertility limitation was removed as in ST-1 or unchanged as in ST-2, DO-1 and DO-2.

Ranking the pedons for cassava production by their scores using the parametric approach (Table 6) indicated that the currently 4 best pedons were well-drained and found in higher elevations (DO and ST), while the 2 worst of them were poorly drained, located in the lowest elevation and influenced by regular flooding (AL). This suggests that, wetness quality (drainage and flooding) was a major constraint to cassava production in the poorly drained soils of Ugep in Yakurr Local Government Area of Cross River State.

Though the parcels of land overlying the three parent materials had not degraded to the not-suitable subclass, it is recommended that the land use type of the soils in the lowest elevation (AL-1 and AL-2) be changed and used for more water tolerant crops like rice paddy and sugar cane. This is so because of the expenses that may be incurred during the installation of drainage facilities, if it must be used for the production of cassava. The economic implication of the installation may outweigh the benefits that will accrue from the installation process. However, if the limitations of poor drainage and high acidity are removed through proper drainage and liming, a parametric index of productivity of 70 % is possible, thus making these soils moderately suitable (S2) for cassava production.

Conclusions and recommendations

Some morpho-physical and chemical properties were assessed according to standard procedures. Bulk density values were < 1.8 Mgm^{-3} in the soils, while organic carbon and available Pwere in the range of 2.0-37.3 g/kg and 1.25-36.12 mg/kg, respectively. Soil over dolerite were highest in exchangeable bases, cation exchange capacity and base saturation while exchangeable Al^{3+} contributed the most to exchangeable acidity. The soils were classified into four fertility capability classes viz; Lkemg, LCrkem, SLkem and Lkem. The commonest of the limitations were low K reserves (k), low CEC (e), low organic carbon (m) and gleying (g).

The climate, slope, wetness qualities as well as physicochemical characteristics of AL, DO and ST were used for land suitability evaluation for cassava production in Ugep. Wetness quality (flooding and drainage characteristics) was a major problem that limits land suitability for cassava production while, climate, topography and most physico-chemical properties are not limiting. However, low soil pH in AL-2, soil depth and high amount of clay in DO may affect the root-tubers of cassava. It is recommended that, while enhancing exchangeable potassium and organic matter in the soils, farmers in the area should focus more on cultivating the soils developed from sandstone for the production of cassava.

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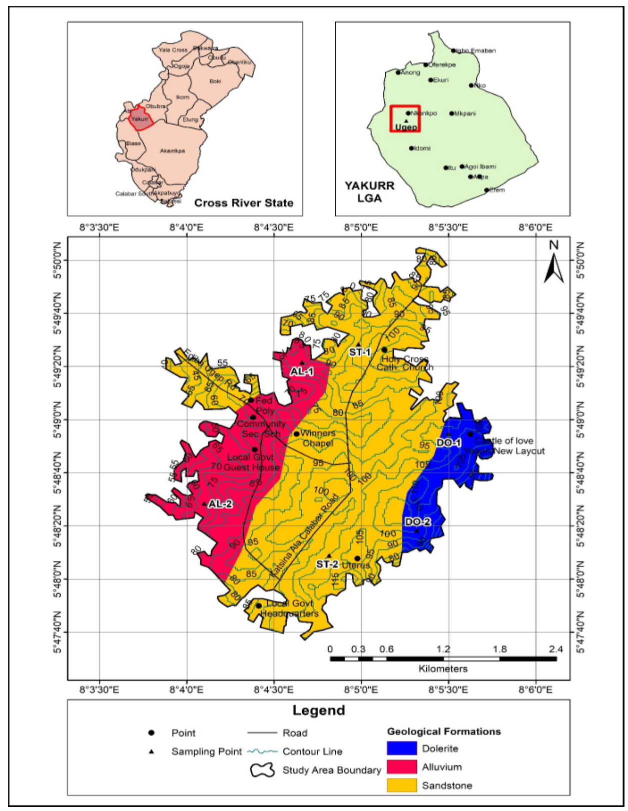

Figure 1: Topographic map over the geology of Ugep indicating sampling points

Table 1: Land use requirements for suitability classes for cassava cultivation (limitation-parametric method of evaluation)

Class, degree of limitation and rating scale						
Land		**S1**	**S2**	**S3**	**N1**	**N2**
Characteristics	**0**	**1**	**2**	**3**		**4**
	100-95	**95-85**	**85-60**	**60-40**	**40-25**	**25-0**
Suitability to land use:	High	Moderate	Marginal	Currently		Permanently
Climate (c)						
MAR(mm/yr)	1600-1400	1400-1800	1000-600	600-500	-	<500
	1600-1800	1800-2400	>2400			
MAT (^{o}C)	23-20	20-18	18-16	16-12	-	<12
	23-26	26-30	>30			
Topography (t)						
Slope (%)	0-1	1-2	2-4	4-6	-	>6
	0-2	2-4	4-8	8-16	-	>16
	0-4	4-8	8-16	16-30	30-50	>50
Wetness (w)						
Flooding	Fo	-	-	-	F2	F1
Drainage	Good	-	Moderate	Imperfect	Poor but drainable	Poor, not drainable
Physical characteristics (s)						
Texture	L, SCL	SL, C <60s,Sl C, Co, CL Sl, CL, SC	C>60s, Lfs,C<60v, Lcs, LS, FS	C<60v, S, CS	-	Cm,Sicm
Soil fertility (f)						
CEC (cmol/kg)	>16	Any	-	-	-	-
BS (%)	>35	35-20	<20	-	-	-
pH (H_2O)	6.0-5.5	5.5-5.2	5.2-4.8	4.8-4.5	<4.5	-
	6.0-6.5	6.5-7.0	7.0-7.6	7.6-8.2	-	>8.2
Mg:K	>3.5	3.5-2	<2	-	-	-
Org. C (%)	>1.5	1.5-0.8	<0.8	-	-	-
Alkalinity (n)						
ESP (%)	0-1	1-2	2-3	3-4	4-6	>6

Table 2: Morpho-physical properties of the studied soils

Profiles	Horizon	Depth (cm)	Soil colour (moist)	Particle Size Distribution (g/kg)			Texture	Bd	%Tp	Other characteristics
				Clay	Silt	Sand		Mg/m^3		
						Soils developed from alluvium				
AL_1	Ap	0-30	5YR 4/1 (Dark grey)	180	280	540	SL	1.0	63	Many fine to medium roots; few ant
	AB	30-77	5YR 7/2 (Pinkish grey)	90	220	690	SL	1.6	40	Fine to very few roots
AL_2	Ap	0-30	7.5YR 3/2 (Dark brown)	240	280	480	L	0.7	74	Few medium roots, few ants
	AB	30-53	7.5YR 4/1 (Dark grey)	280	120	600	SCL	1.5	44	Few medium pores
						Soils developed from dolerite				
DO_1	Ap	0 – 20	7.5YR 3/2 (Dark brown)	290	320	390	CL	1.3	51	Many fine to medium pores; many Fine to medium roots
	Bt1	20 – 60	7.5YR 3/2 (Dark brown)	430	190	380	C	1.5	44	Many fine to medium pores; many Fine to medium roots
	[illegible]	[illegible]	7.5YR 3/2 [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Few fine pores; presence of charcoal, [illegible]

Table 4: Soil fertility capability classification for soils of the study areas

Pedon/ type	Type	Sub type	Condition modifiers r	K	e	A	n	m	g	SFCC unit	Interpretation	Management options
			Soils developed on alluvium									
AL-1	L	L	-	+	-	-	-	+	+	Lkmg (0-2%)	Loamy topsoil and subsoil, wet, low K, and low organic carbon on 0-2% slope landscape.	Application of appropriate fertilizer and organic matter.
AL-2	L	L	-	+	-	-	-	+	+	Lkmg (0-2%)	Loamy topsoil and subsoil, wet, low K and organic carbon. Soils on 0-2% slope topography.	Application of appropriate fertilizer and organic matter.
			Soils developed on dolerite									
DO-1	L	C	+	+	-	-	-	+	-	LCrkm (0-2%)	Loamy top and clay sub soils, gravel limitation, low K reserves,and low organic carbon on 0-2% slope landscape.	Application of appropriate fertilizer, organic matter, cover cropping and crop rotation
DO-2	L	C	+	+	-	-	-	+	-	LCrkm (0-2%)	Loamy surface and clay subsurface, gravel limitation, low k reserve, low organic carbon.	Application of appropriate fertilizer and organic matter, cover cropping and crop rotation
			Soils developed on sandstone									
ST-1	S	L	-	+	+	-	-	+	-	SLkem (2-4%)	Sandy top and loamy sub soils, low K reserve, low CEC, and low organic carbon on 2-4% slope landscape.	Fertilizer application, organic matter incorporation into the topsoil. Cover cropping and crop rotation.
ST-2	L	L	-	+	+	-	-	+	-	Lkem (2-4%)	Loamy top over loamy subsoil, low K reserve, low CEC, low organic carbon, on 2-4% slope	Application of appropriate fertilizer, and organic matter.

r – high gravel content, d – dry (ustic soil moisture regime), k – low K reserves, e – low CEC, a – aluminium toxicity (exch. acidity > 60% Al saturation), n – sodium (ESP > 15%), m – low organic carbon, g – gleying or aquic soil moisture regime, AL-1, AL-2 - Alluvium; DO-1, DO-2 –Dolerite; ST-1, ST-2 sandstone. S: sand, L: loam

Table 5: Land characteristics data for the soils

Pedons	MAR mm/yr	MAT °C	Slope %	Flooding	Drainage	Texture	Depth (cm)	CEC cmol/kg	BS %	pH	OC %
Al-1	2,258	27.0	2.0	F3	PD	SL	112	13.0	59.0	4.9	1.33
Al-2	2,258	27.0	2.0	F3	PD	SCL	116	16.5	58.5	4.6	1.96
ST-1	2,258	27.0	4.0	Fo	WD	SL	162	10.0	64.3	5.4	0.41
ST-2	2,258	27.0	4.0	Fo	WD	LS	60	9.3	64.0	5.8	0.79
DO-1	2,258	27.0	2.0	Fo	WD	CL	60	22.3	88.3	6.0	2.10
DO-2	2,258	27.0	2.0	Fo	WD	SC	155	22.3	89.0	5.9	1.55

MAR = mean annual rainfall, MAT = mean annual temperature, WD=well drained, PD= Poorly drained, Fo= No flooding, F3= Severe; Every year, 2-3 months of flood, CEC= cation exchange capacity, BS= Base saturation, OC= organic carbon

Table 6: Suitability classification and scores of the pec

Pedons	MAR mm/yr	MAT °C	Slope %	Flooding	Drainage
Al-1	$S_1(95)$	$S_1(90)$	$S_1(98)$	$N_1(40)$	$N_1(40)$
Al-2	$S_1(95)$	$S_1(90)$	$S_1(98)$	$N_1(40)$	$N_1(40)$
ST-1	$S_1(95)$	$S_1(90)$	$S_1(90)$	$S_1(100)$	$S_1(100)$
ST-2	$S_1(95)$	$S_1(90)$	$S_1(90)$	$S_1(100)$	$S_1(100)$
DO-1	$S_1(95)$	$S_1(90)$	$S_1(90)$	$S_1(100)$	$S_1(100)$
DO-2	$S_1(95)$	$S_1(90)$	$S_1(90)$	$S_1(100)$	$S_1(100)$

MAR= Mean annual rainfall, MAT= Mean annual temperature, BS= base saturation, OC= Organic ca

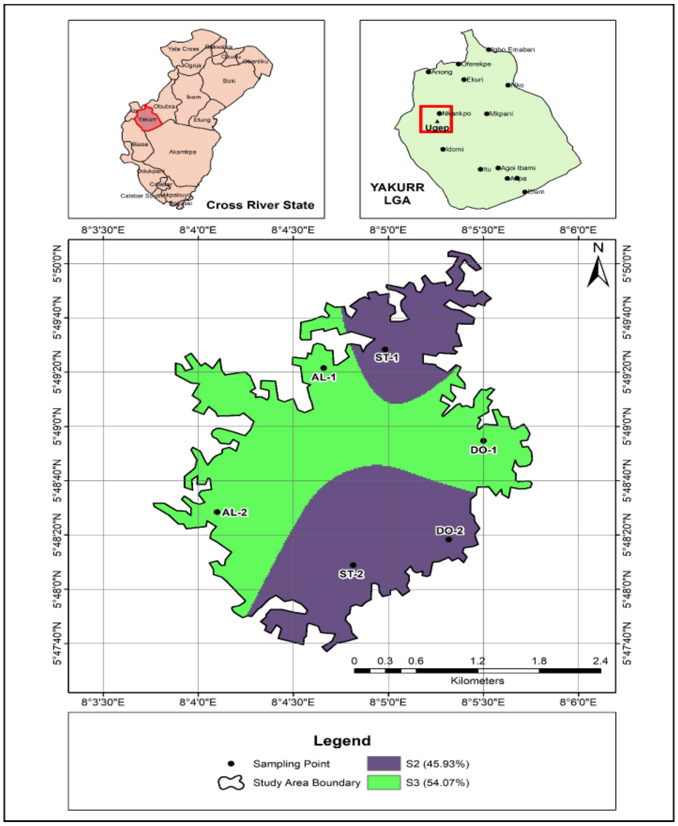

Figure 2: Percent distribution of Current aggregate suitability classes in Ugep

Table 7: Aggregate suitability and classification of the pedons for cassava production

		AL-1	AL-2	ST-1	ST-2	DO-1	DO-2
Potential	Parametric	$S_3(33.6)$	$S_3(34.8)$	$S_1(76.5)$	$S_2(74.7)$	$S_2(67.5)$	$S_1(76.5)$
	Non parametric	S_{2W}	S_{2W}	S_1	S_1	S_{2S}	S_1
Current	Parametric	$S_3(32.0)$	S_3 26.4)	29~$S_2(72.0)$	$S_2(74.7)$	$S_3(67.5)$	$S_2(74.8)$
	Non parametric	S_{2W}	S_{2WF}	S_{2F}	S_1	S_{2S}	S_1

Definition of suitability classes: S_1(100-75), S_2(74-50), S_3(49-25), N (24-0)