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# CHARACTERIZATION, CLASSIFICATION AND SUITABILITY EVALUATION OF SOILS UNDER SUGARCANE (*Saccharum officinarum L.*) CULTIVATION AT THE SUGAR RESEARCH FARM, UNIVERSITY OF ILORIN, NIGERIA

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## ABSTRACT
***A reconnaissance survey conducted at the University of Ilorin Sugar Research Farm (USRF) revealed four dominant soils at Site 1 (USRF1) and one at Site 2 (USRF2). The soils were characterized and classified according to both the Soil Taxonomy (ST) and the World Reference Base for Soil Resources (WRB). Also, the suitability of the soils for sugarcane cultivation was evaluated using the limitation approach. While the USRF1 soils were reddish, the USRF2 soil was greyish due to poor drainage. The USRF1 soils were loamy sand with the AB-horizons of pedons II and III being gravelly. Pedon V had sandy loam surface, sandy clay loam subsurface and clay loam subsoil. The USRF1 soils were moderately acid while the USRF2 soil was slightly acid to slightly alkaline. Exchangeable calcium ($Ca^{2+}$) content of the USRF2 soil which averaged 4.00 $cmol_c\ kg^{-1}$ was 2-3 times higher than that of the USRF1 soils. The USRF2 soil also contained higher $Mg^{2+}$, $K^+$ and $Na^+$, 2-3 folds higher effective cation exchange capacity and > 10 folds higher soil organic carbon (with mean of 11.60 $g\ kg^{-1}$) and total nitrogen (mean of 0.94 $g\ kg^{-1}$). Under ST, pedons I and IV classified as Typic Haplustepts, II and III as Lithic Haplustepts and V as a Kanhaplic Haplustalf. Under WRB, pedons I and IV classified as Eutric Regosols (arenic), II and III as Endo-pisoplinthic Cambisols (arenic) and V as a Gleyic Lixisol (loamic). Pedon V was highly suitable (85.25%), I and IV moderately suitable (64.53%), II marginally suitable (47.40%) and III unsuitable (35.62%) for sugarcane cultivation.***

**Key words:** limitation approach, reconnaissance survey, soil suitability, sugarcane cultivation, *UNILORIN*

## INTRODUCTION
Agriculture provides food for humans and domesticated animals, raw materials for industries and helps to accelerate economic growth of developing countries (Sajjad *et al.,* 2014). Agriculture is the predominant economic activity in Nigeria because of the ever-increasing demand for food (Obasi *et al.,* 2016). Consequently, there have been many studies on soil characterization and suitability for various crops including cashew (Olaniyan and Ogunwale, 2006), cocoa (Ajiboye *et al.,* 2015), rice (Ajiboye *et al.,* 2011; Osinuga *et al.,* 2020) and cowpea (Ogunwale *et al.,* 2009). Also, detailed information on soil properties is required to determine their potential for food, fodder and fiber production (Osujieke *et al.,* 2018). Basic soil information enables the creation of functional classification schemes for the management of soils in an ecosystem (Lekwa *et al.,* 2004).

Soil characterization, soil mapping and land evaluation are very useful for achieving food security and environmental sustainability (Obasi *et al*., 2016). According to Stewart (1968) and van Diepen *et al.* (1991), land evaluation is the assessment of suitability of land for potential use in agriculture, forestry, engineering, hydrology, regional planning, and recreation, among others. Ogunkunle (2005) also described land evaluation as an applied classification system that assesses the capacity of soils for their variable uses, while aiming at deriving maximum benefits with minimum degradation. Soil characterization, on the other hand, is the measurement of soil properties by laboratory procedures and other standard methods using soil samples from pedons for the purposes of soil classification (Buol *et al.,* 1997). It thus provides information on properties of soils that could be used in designing strategies for managing crop production, forests and grasslands (Ogunkunle, 2005). Characterization is also considered as a major step in classifying soils and understanding their properties and the environment in which they occur (Esu, 2005). The characteristics of a soil determine its suitability for crop production, and they are an agglomeration of the properties of each horizon in its profile (Olaniyan and Ogunwale, 2006).

Various approaches have been used to assess soil quality for sugarcane production. The methods include using algorithms to develop the Soil Management Assessment Framework (SMAF) (Cherubin *et al.,* 2016) as well as use of the Agricultural Production Systems SiMulator (APSIM) model (Peng *et al.,* 2020), Geographic Information System (GIS) and remote sensing (Subramani *et al.,* 2017; Mubashir *et al.,* 2017), the parametric approach (Neswati *et al.,* 2016) and the

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FAO's (1976) Framework for Land Evaluation guidelines used by Chartres (1981). The one to use would largely depend on resources available to the researcher.

Sugarcane is a warm-temperate and subtropical crop which requires warm, sunny, and moist climate and fertile, deep, and well aerated soils (Glyn, 2004). The crop cycle, growth and maturation are largely influenced by climatic conditions, especially moisture and heat. Dry sunny periods and low night temperatures are favourable for maturation and sugar accumulation (Glyn, 2004). The crop is sensitive to frost and hurricanes or typhoons (Purseglove, 1976; Willy, 2005). Each cultivar of sugarcane requires specific ecological conditions. The wild species of *Saccharum officinarum* L. thrives best under open field conditions; *S. robustum* grows best along river-banks; *S. spontaneum* proliferates mainly in warm temperate regions and can tolerate a much wider range of conditions (Willy, 2005; Fábio *et al.,* 2008). *S. officinarum* is essentially tropical, while *S. barberi and S. sinense* can be grown in subtropical and temperate countries (Willy, 2005). New hybrids have been developed which are adapted to a shorter growth cycle in subtropical areas (Willy, 2005). Unfavourable physical conditions such as soil compaction especially due to intense mechanization could be limiting to sugarcane cultivation (Fábio *et al.,* 2008). Thus, for sustainable sugarcane production, it is very important to select sites with favourable soil fertility and physical properties. Site suitability studies guide the choice of crops to grow on soil units to maximize production per unit land (land use), labour and inputs (Thangasamy *et al.,* 2005; Obasi *et al.,* 2016; Mahesh *et al.,* 2018).

The Sugar Research Institute of the University of Ilorin has about 15,000 ha of land dedicated to sugarcane production. However, soils of the Research Farm have not been characterized and classified. Thus, the objectives of this study were to characterize and classify the soils according to Soil Taxonomy and the World Reference Base for Soil Resources and evaluate the suitability of the soils for sustainable sugarcane production.

## MATERIALS AND METHODS

### Study Sites

This study was carried out at the Research Farm of the Sugar Research Institute, University of Ilorin (UNILORIN). The University of Ilorin Sugar Research Farm (USRF) is located along the banks of the Oyun River. There were two study sites, USRF1 and USRF2, which were about 2 km apart. The USRF1 site was 50 ha and situated along the road to the university. Four dominant soils (pedons I, II, III and IV) were identified at USRF1. The site was bounded by latitudes 8° 28' 15" and 8° 29' 45" N and longitudes 4° 39' 44" and 4° 40' 03" E. The soils were generally developed from a basement complex of rocks with dominant sandstone and quartzite. Pedons I and IV were located on a nearly flat to gently sloping (0-5%) positions and on the middle slope to lower slope of a gently undulating landscape. Pedons II and III were located on nearly flat (0-2%) positions and on an upper slope to middle slope of an almost flat landscape. There was only one dominant soil (pedon V) at the second site, USRF2, which was located near the Teaching and Research Farm of the University. USRF2 occupied an area of 15 ha and was bounded by latitudes 8° 27' 25.89" N and 8° 27' 19.65" N, and longitudes 4° 39' 52.38" E and 4° 39' 49.80" E. Pedon V was located on an almost flat (0-2%) position and at the bottom slope of a landscape that was nearly flat to gently undulating. The Research Farm lies in the southern guinea savannah zone of Nigeria and with a climate characterized by wet and dry seasons. The dominant plant at both sites was *Chromolaena odorata* although USRF2 had a denser vegetation cover. Cultivation of sugarcane at USRF1 started in 2005 and predated that at USRF2 by about eight years. The temperature of Ilorin ranges from 25 to 30°C in the wet season and from 32 to 34°C in the dry season. Rainfall shows wide variability both temporally and spatially. On the average, annual rainfall ranges from 1000 to 1200 mm, starting from April till October. The relative humidity in the wet season ranges between 75 to 80%, while in the dry season, it falls to about 65% (Olaniran, 2002).

### Soil Sampling

Reconnaissance surveys of the soils were carried out at both sites (USRF1 and USRF2). Then, the different soils at the two sites were identified and profile pits dug. Four pits were dug at USRF1 and one at USRF2 representing the different soils identified at the study sites. The profile pits were described, and soil samples collected from the genetic horizons according to the guidelines of FAO (1977; 2006) and Schoeneberger (2012). The morphological properties determined included soil colour according to the Munsell colour charts, soil structure, consistence, and drainage. The soil samples collected from the genetic horizons of the soil profiles were put into labelled polythene bags and taken to the laboratory for analysis.

### Laboratory Analyses

The soil samples were air-dried for seven days, ground and sieved with a 2-mm sieve. Routine analyses were carried out using standard analytical procedures. Particle size distribution was determined with the hydrometer method (Gee and Or, 2002). Exchangeable bases ($Na^+$, $Ca^{2+}$, $Mg^{2+}$ and $K^+$) were extracted with ammonium acetate buffered at pH 7. (Thomas, 1982) and their concentrations measured with the Atomic Absorption Spectrophotometer (AAS 210/211 Vap Buck Scientific). Exchangeable acidity was determined according to the method described by McLean (1982). Soil reaction (pH) was determined in a 1:2.5 soil-water ratio and measured with a pH meter (model-4070) (Thomas, 1996).

Available phosphorus was determined using the Bray I method (Olsen and Sommers, 1982). Organic carbon content of the soils was determined according to the digestion method described by Nelson and Sommers (1996). Total Nitrogen was determined according to the micro-kjeldahl digestion technique (Bremner, 1996). Effective cation exchangeable capacity (ECEC) was determined by summation of the exchangeable bases ($Ca^{2+}$ $Mg^{2+}$ $K^{+}$ $Na^{+}$) and exchangeable acidity. Calcium mole fraction was calculated as the fraction of exchangeable $Ca^{2+}$ of ECEC. Percentage base saturation (BS) was determined as the percentage of the total exchangeable bases of the ECEC.

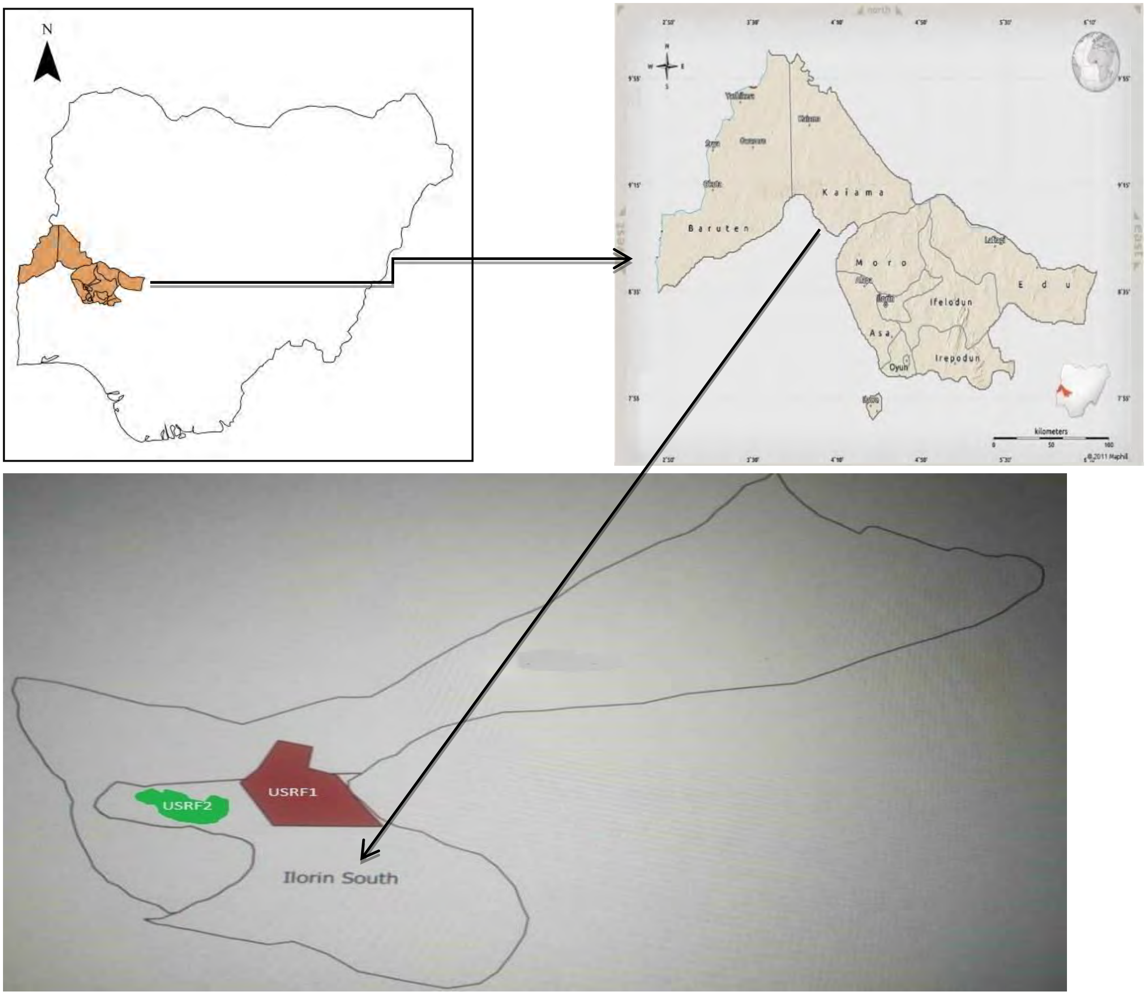


**Figure 1a:** Map of Nigeria showing the Kwara State and the study sites


**Figure 1b:** Aerial photograph (Google Earth) of the University of Ilorin and locations of study sites

**Classification of Soils**

The soils were classified according to Soil Taxonomy (Soil Survey Staff, 2014) and World Reference Base (WRB) for Soil Resources (IUSS Working Group, 2015).

**Method of Soil and Land Suitability Evaluation**

The suitability of the lands (soils) for sugarcane cultivation was evaluated following the method described by Ogunkule (1993) and modified by Olaniyan and Ogunwale (2006). The method of evaluation followed the guidelines of Sys *et al.* (1991) on land evaluation. Each pedon was assigned a suitability class by matching its properties following the ratings of limiting characteristics. Based on the law of minimum, the most limiting characteristic in a group determined the class of pedon. The groups of qualities considered for evaluation were climate (c), topography (t), soil physical characteristics (s), wetness (w), chemical fertility (f), and salinity and alkalinity (n). However, calcium mole fraction was not included as a parameter under fertility index because sugarcane belongs to the grass family. Index of productivity (IP) was calculated for each pedon from the data generated using Equation 1 as described by Storie (1978) below:

$$IP = A \times B/100 \times C/100 \ldots F/100 \quad \ldots\ldots (1);$$

where A is the overall lowest rating characteristic, and B, C … F are the lowest rating characteristics for each land quality group. From this equation, the potential index of productivity (IPp) as well as the actual (current) index of productivity (IPc) was calculated. In determining IPp, length of rainy season was not included in the climate (c) group and calcium mole fraction, available phosphorus (P) and organic matter were not included in the fertility (f) group. They were, however, included in the calculation of IPc. In all, the suitability ratings viz highly suitable (S1), moderately suitable (S2), marginally suitable (S3) and currently unsuitable (N) were directly equivalent to IP values of 75-100%, 50-74%, 25-49%, and 0-24%, respectively (Olaniyan and Ogunwale, 2006). This method has been used to determine soil suitability for various crops including sugarcane (Neswati *et al.,* 2016), cashew (Olaniyan and Ogunwale., 2006), cowpea (Ogunwale *et al.,* 2009), cocoa (Ajiboye *et al.,* 2015), and rice (Ajiboye *et al.,* 2011; Osinuga *et al.,* 2020).

## RESULTS AND DISCUSSION

**Morphological and Physical Properties of the Soils**

The morphological and physical properties of the soils are presented in Table 1. At USRF1, the depth of the pedons ranged from 65 to 120 cm. Pedons II (80 cm deep) and III (65 cm deep) were relatively shallow due to the presence of subsurface petroplinthite (pisoplinthite under WRB). Pedon V at USRF2 was 130 cm deep. Although soil depth > 1 m is ideal (Schulze *et al.,* 1997), all the soils were generally deep enough for sugarcane cultivation. However, the depths of pedons II and III could be limiting due to possible water logging and runoff especially under heavy rainfall or flood irrigation conditions.

The colour of the soils varied from light (5YR3/1) to strong brown (7.5YR5/6) in pedon I; weak brown (7.5.YR4/4) to yellowish red (5YR4/6) in pedon II; strong brown 7(.5YR3/4) to red (2.5YR3/4) in pedon III; light (5YR3/1) to strong brown (7.5YR5/6) in pedon IV and dark brown (7.5YR5/2) through greyish dark brown (5YR5/6) to greyish brown (2.5YR4/6) in pedon V. The dark brown surface soil of pedon V could be due to dominant organic matter decomposition as had been reported by Okenmuo *et al.* (2020). Also, the greyish colour of the subsurface and subsoil horizons of pedon V was probably due to poordrainage and more hypoxic conditions at USRF2. Osujieke *et al.* (2018) had attributed differences in the colour of some soils in a comparable environment in north-eastern Nigeria to differences in drainage.

The soils contained high amounts of sand: USRF1 (71.41-86.74%) and USRF2 (49.52-79.52%). The very high sand content of the soils especially at USRF1 could be attributed to their sandstone and quartzite parent materials. The clay content of the soils from USRF1 ranged from 10.26 to 22.69% while that of the soil from USRF2 ranged from 20.19 to 36.46%. The soils contained very small amounts of silt (USRF1: 3-6%; USRF2: 12-16%). Thus, while the soils from USRF1 contained predominantly high amounts of sand, the soil from USRF2 contained relatively more silt and clay fractions. With increasing clay content with depth, pedon V showed an argillic horizon. Pedons I and IV were loamy sand throughout their profiles while pedons II and III were loamy sand in the A-horizon but gravelly loamy sand in their subsurface soil. Pedon V was sandy loam in the surface soil, sandy clay loam in the subsurface soil and clay loam in the subsoil. The higher clay content of the subsurface and subsoil horizons of pedon V could be attributed to illuviation which resulted in the formation of an argillic horizon. Nuga *et al.* (2008) had reported similar properties for soils on a catena at Ikwuano, Abia State, Nigeria. Due to its higher clay content, pedon V (USRF2) would have higher water holding capacity and a different irrigation regime compared to the soils at USRF1(Kramer and Boyer, 1995; Brady and Weil, 2008). Although clay loams are reportedto be the best for sugarcane production (Mubashir *et al.,* 2017), soils with other textures could be used with some management.

The percentage gravel content of the soils varied from 16.80 to 29.32% in USRF1 and 5.31 to 7.86% in USRF 2. Pedons II and III had impervious layers at depths of 80 and 65 cm respectively. The high gravel content of the subsurface soils of pedons II and III was due to the large amounts of ironstone concretions lying above the petroplinthite layers in these soils. It is noteworthy to indicate that the name *Ilorin* derived from “abundance of ironstone concretions in the land (soil)” in Yoruba language. The high sand content of the soils at USRF1 indicates that they would have low water holding capacity (Kramer and Boyer, 1995; Brady and Weil, 2008) and may be prone to erosion (Salako, 2003). These soils may also be more susceptible to leaching of nutrients from the surface horizons than the soil from USRF2 (pedon V).

Apart from the subsurface horizons of pedons II and III which had granular structure due to the high amounts of gravels they contained, all the soils at USRF1 were massive in structure. Pedon V, on the other hand, had sub-angular blocky structure in all the horizons which makes the soil more agronomically desirable (Hillel, 2004). The higher clay and organic carbon contents (Table 2) of pedon V might have in part contributed to the sub-angular blocky structure of all the horizons of the profile (Hillel, 2004). Soil structure is one of the most important properties affecting crop production because it determines the depth to which roots can penetrate and proliferate, the amount of water that can be stored and the movement of air, water, and soil fauna (Hermavan and Cameron, 1993; Langmaack, 1999). The consistence of the soils from USRF1 was friable while that of the soil from USRF2 was firm. The horizons of the soils from USRF1 were well-drained. On the other hand, the Ap and Bt1 -horizons of pedon V were imperfectly drained while the Bt2 horizon was poorly drained.

**Chemical Properties of the Soils**

The chemical properties of the soils are presented in Table 2. The pH ($H_2O$) of the USRF1 soils ranged from 5.3 in the Ap horizon of pedon II to 6.2 in the AB horizon of pedon III. The pH ($H_2O$) of pedon V (USRF2) on the other hand, ranged from 6.7 in the Ap horizon to 7.5 in the $Bt_2$ horizon. Thus, while the pH of the USRF1 soils was moderately acid, that of the USRF2 soil was slightly acid to slightly alkaline. The pH range of 5.3-7.5 obtained in this study is likely to support sugarcane production. Mubashir *et al.* (2017) had reported that a pH range of 6.5 to 8.5 was the most suitable for sugarcane cultivation in the Bijnor District of India. However, for crop growth in general, total acidity (i.e., sum of exchangeable aluminium ($Al^{3+}$) and hydrogen ($H^+$) should range from 0.2 to 10.4 cmolc $kg^{-1}$ to avoid aluminum toxicity (Ogunkunle, 2005).

**Table 1:** Morphological and physical properties of the soils

| Pedon | Hori-zon | Depth (cm) | Colour (moist) | Sand | Silt (%) | Clay | Gravel (%) | Textural class | Structure | Consistence (moist) | Drainage |
|---|---|---|---|---|---|---|---|---|---|---|---|
| I | Ap | 0–43 | Light brown 5YR3/1 | 84.48 | 5.00 | 10.52 | 18.29 | LS | massive | Friable | V |
| | AB | 43–120 | Strong brown 7.5.YR5/6 | 85.58 | 4.00 | 10.42 | 21.05 | LS | massive | Friable | V |
| II | Ap | 0–25 | Weak brown 7.5.YR4/4 | 83.56 | 5.00 | 11.44 | 21.25 | LS | massive | Friable | V |
| | ABdc | 25–80 | Yellowish red 5YR4/6 | 86.74 | 3.00 | 10.26 | 28.94 | GLS | granular | Friable | V |
| III | Ap | 0–15 | Strong brown 7.5YR3/4 | 71.41 | 5.00 | 22.69 | 17.50 | LS | massive | Friable | V |
| | ABdc | 15–65 | Red 2.5 YR3/4 | 72.42 | 6.00 | 21.58 | 29.32 | GLS | granular | Friable | V |
| IV | Ap | 0–50 | Light brown 5YR3/1 | 82.54 | 5.00 | 12.46 | 16.80 | LS | massive | Friable | V |
| | AB | 50–90 | Strong brown 7.5YR5/6 | 80.63 | 6.00 | 13.37 | 18.86 | LS | massive | Friable | V |
| V | Ap | 0–42 | Dark brown 7.5YR5/2 | 67.80 | 12.00 | 20.19 | 7.86 | SL | sub-ab | Firm | IV |
| | Bt1 | 42–74 | Greyish dark brown 5YR 5/6 | 59.52 | 16.00 | 24.48 | 6.19 | SCL | sub-ab | Firm | IV |
| | Bt2 | 74–130 | Greyish brown 2.5 YR4/6 | 49.52 | 14.00 | 36.46 | 5.31 | CL | sub-ab | Firm | II |

LS is loamy sand, SCL is sandy clay loam, CL is clay loam, GLS is gravelly loamy sand, sub-ab is sub-angular blocky, II is poorly drained, IV is imperfectly drained, V is well drained

**Table 2:** Chemical properties of the soils

| Pedon | Hori-zon | pH | Exchangeable bases $Ca^{2+}$ | $Mg^{2+}$ (cmol$_c$ kg$^{-1}$) | $K^+$ | $Na^+$ | Exchangeable acidity (cmol$_c$ kg$^{-1}$) | ECEC (cmol$_c$ kg$^{-1}$) | BS (%) | Ca mole fratn | Organic carbon (g kg$^{-1}$) | Total nitrogen (g kg$^{-1}$) | Available phosphorus mg kg$^{-1}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| I | Ap | 5.50 | 1.40 | 0.60 | 0.50 | 0.06 | 0.83 | 3.39 | 75.50 | 0.41 | 0.82 | 0.05 | 10.40 |
| | AB | 5.70 | 0.80 | 0.30 | 0.30 | 0.04 | 0.85 | 2.29 | 62.90 | 0.35 | 0.71 | 0.05 | 6.18 |
| II | Ap | 5.30 | 1.80 | 0.70 | 0.50 | 0.04 | 1.25 | 4.29 | 70.80 | 0.42 | 0.92 | 0.06 | 7.72 |
| | ABdc | 5.60 | 1.30 | 0.50 | 0.40 | 0.02 | 1.46 | 3.68 | 60.30 | 0.35 | 0.74 | 0.06 | 5.34 |
| III | Ap | 5.80 | 1.50 | 0.90 | 0.80 | 0.15 | 0.94 | 4.29 | 78.10 | 0.35 | 0.86 | 0.04 | 8.37 |
| | ABdc | 6.20 | 0.70 | 0.60 | 0.50 | 0.21 | 1.11 | 3.12 | 64.40 | 0.22 | 0.82 | 0.04 | 6.13 |
| IV | Ap | 5.90 | 1.60 | 0.70 | 0.50 | 0.20 | 1.04 | 4.04 | 74.30 | 0.40 | 0.95 | 0.06 | 5.21 |
| | AB | 6.10 | 1.90 | 0.50 | 0.80 | 0.21 | 0.54 | 3.95 | 86.30 | 0.48 | 0.83 | 0.05 | 6.20 |
| V | Ap | 6.70 | 3.60 | 1.30 | 1.00 | 0.21 | 0.88 | 6.99 | 87.40 | 0.52 | 15.40 | 1.03 | 8.12 |
| | Bt1 | 7.30 | 5.60 | 0.90 | 0.70 | 0.31 | 1.76 | 9.27 | 81.00 | 0.60 | 10.60 | 0.92 | 6.20 |
| | Bt2 | 7.50 | 2.80 | 0.60 | 0.40 | 0.26 | 1.84 | 5.90 | 68.80 | 0.47 | 8.80 | 0.90 | 3.21 |

BS is base saturation, ECEC is effective cation exchangeable capacity, Ca mole fratn is fraction of exchangeable Ca and ECEC.

The soils were not likely to be saline judging from their pH and the low levels of exchangeable sodium. The exchangeable sodium percentage (ESP) of the soils ranged from 0.54 to 6.73% (not shown) which was less than the 15% critical level for sodic soils (US Salinity Laboratory Staff, 1954). Hence, none of the soils was likely to have salt problems under rainfed conditions. Among the basic cations, $Ca^{2+}$ was the highest in all the soils. Its content in USRF1 ranged from 0.7 to 1.9 $cmol_c\ kg^{-1}$ whereas in pedon V (USRF 2) it was 2.8 to 5.6 $cmol_c\ kg^{-1}$. Pedon V also contained higher amounts of $Mg^{2+}$ (0.6-1.3 $cmol_c\ kg^{-1}$), $K^+$ (0.4-1.0 $cmol_c\ kg^{-1}$) and $Na^+$ (0.21-0.31 cmolc $kg^{-1}$) than the soils from USRF1. The levels of $Mg^{2+}$, $K^+$ and $Na^+$ in the URSF1 soils were 0.3-0.9, 0.3-0.8 and 0.02-0.21 $cmol_c\ kg^{-1}$, respectively. Although none of the exchangeable cations would be limiting in the soils for sugarcane production (FPDD, 1989), the levels of K may have to be augmented especially for a second season cultivation (Oliveira *et al.,* 2016).

All the soils had low levels of ECEC indicating that their exchange complex was likely to be dominated by kaolinite. This inference agrees with the report of Igwe *et al*. (1999), which revealed that some soils at Southeastern Nigeria with low CEC were dominated by kaolinite. The ECEC of the surface and the sub-soil horizons of the USRF1 soils ranged from 3.39 to 4.29 cmolc $kg^{-1}$ and 2.29 to 3.95 cmolc $kg^{-1}$, respectively. In pedon V (USRF2), ECEC was 6.99 cmolc $kg^{-1}$ in the surface soil, increased to 9.27 cmolc $kg^{-1}$ in the Bt1 horizon and decreased to 5.9 cmolc $kg^{-1}$ in the Bt2 horizon. These ECEC levels of the soils were generally adequate for sugarcane production (FPDD, 1989). With higher organic C and clay contents of pedon V, it is expected that the soil would have higher ECEC compared to the soils from USRF1. Similar positive relationships of organic matter and clay contents with CEC (ECEC) had been reported by Parfitt *et al*. (1995), Obalum *et al.* (2013), and Dai *et al*. (2018). However, the effect of organic matter and clay contents on the variability of ECEC with soil depth at both study sites is not clear. Base saturation ranged from 70.8 to 78.1% in the surface soils and 60.3 to 86.3% in the sub-surface soils of USRF1. In pedon V, base saturation ranged from 87.4% in the surface soil to 68.8% in the sub-surface soil. Generally, base saturation of the soils, rated as moderate to high, decreased with increasing depth.

The organic carbon content of the soils from USRF1 was very low (< 0.96g $kg^{-1}$). On the contrary, pedon V (USRF2) had a higher organic C content (8.8–15.4 g $kg^{-1}$), about ten to sixteen folds higher than the levels in the USRF1 soils. The higher organic C content of pedon V was likely to be due to the denser vegetation cover and the relatively shorter period the soils at USRF2 have put under sugarcane cultivation. Also, pedon V had a more favourable soil environment for organic C accretion due its higher clay content. The very low levels of organic C content and the high sand content of the soils from USRF1 could predispose them to erosion and nutrients loss. The soils from USRF1 contained very small amounts of total N which ranged from 0.040 to 0.063 g $kg^{-1}$. Pedon V from USRF2, on the other hand, contained about ten folds higher levels of total N (0.88-1.03 g $kg^{-1}$) than the levels in the soils from USRF1. In all the soils, the level of total N decreased with soil depth in direct relationship with organic C content of the soils. Sugarcane, a member of the grass family, requires substantial amount of nitrogen for its development (Kingston, 2014; Oliveira *et al.,* 2016). Thus, the total N content of the soils from USRF1 would be inadequate to support sugarcane production. Presently, the fertilizer being applied to sugarcane at the study sites is NPK (15-15-15) at a rate of 200 kg per ha. This level of N (30 kg $ha^{-1}$) appears to be low compared to rates recommended for sugarcane elsewhere which ranged from 34 to 400 kg $ha^{-1}$ (Saleem *et al.,* 2012; Mwasinga, 2018; McCray, 2019; Gravois, 2021; Haifa Group, 2021). On the other hand, the total N contents of pedon V and the 200 kg $ha^{-1}$ NPK 15-15-15 may be adequate for sugarcane cultivation at USRF2. Nevertheless, further studies need to be conducted to determine recommended rates of N to apply to the soils at both USRF1 and USRF2.

The available P levels in the soils from USRF1 ranged from 5.21 to 10.4 and 5.34 to 6.20 mg $kg^{-1}$ in the surface and sub-soil horizons, respectively. In pedon V (USRF2), the available P content ranged from 8.12 mg $kg^{-1}$ in the Ap horizon to 3.21mg $kg^{-1}$ in the Bt2 horizon. Comparably, low levels of available P were reported for some concretionary soils in Nigeria (Sobulo, 1982) and Ghana (Oteng and Acquaye, 1971; Kanabo *et al.,* 1978; Nyamekye, 1987; Abekoe, 1989). Phosphorus deficiency in tropical soils with low activity clays has been attributed to high P adsorption (Sanchez and Salinas, 1981; Abekoe and Sahrawat, 2001). Phosphorus is a major plant nutrient responsible for root development so the soils would have to be augmented with P for productive cultivation of sugarcane. The 30 kg $ha^{-1}$ P (from the 200 kg $ha^{-1}$ NPK (15-15-15) being applied at the study sites) would not be adequate for optimum sugarcane production. In a sugarcane response study on clay soils, Mistry *et al.* (2018) reported that 150 kg $ha^{-1}$ of P gave the best result. Gravois (2021) has recommended 50.4 kg $ha^{-1}$P for soils with very low P levels and 0 kg $ha^{-1}$ for soils with low to high levels of P for sugarcane production. Just like N, further study must be conducted to determine recommended rates of P to apply to the soils at both USRF1 and USRF2.

**Classification of the Soils Using the Soil Taxonomy**

The study sites experience about six months of dry season so the upper parts of the moisture control section (upper 50 cm of the soils) would be dry for more than 90 cumulative days in most years. The soils were therefore likely to have ustic soil moisture regime. The soils were iso-hyperthermic because their mean annual temperature was more than 22°C and with a mean hot season and cool season soil temperature differing by less than 5°C at more than 50 cm depth of the soil.

At the order categorical level, all the pedons from USRF1 were classified as Inceptisols while pedon V from USRF2 was classified as an Alfisol (Soil Survey Staff, 2014). Based on their moisture regime, the USRF1 soils were classified as Ustepts at the sub-order level. At the great group level, all the soils from USRF1 were classified as Haplustepts. At the subgroup level, pedons I and IV were classified as Typic Haplustepts while pedons II and III were classified as Lithic Haplustepts due to the presence of a lithic contact created by the subsoil plinthite in these soils. Pedon V from USRF2 was classified as an Alfisol because of its argillic horizon and as an Ustalf at the suborder level because of its ustic moisture regime. At the great group level, it was classified as a Haplustalf and at the subgroup level, as a Kanhaplic Haplustalf due to the low level of ECEC (< 10 cmol $kg^{-1}$).

**Classification of the Soils According to World Reference Base for Soil Resources**

Under the Reference Soil Groups (RSGs), pedons I and IV were classified as Regosols (IUSS Working Group WRB, 2015). Although the two soils were loamy sand, they were not classified as Arenosols because they had coarse fragments (sand + gravel) far in excess of 40% by volume. Though percentage coarse fragment on volume basis was not determined, on weight basis the soils contained > 80% coarse fragments. Moreover, their < 20% clay + silt content (on weight basis) could not constitute more than 60% of their soil volume. Thus, the two soils could not be classified as Arenosols. They were given the principal qualifier eutric because of their effective base saturation was > 50% in all horizons. They were given arenic supplementary qualifier because of their loamy sand texture. The two soils were therefore classified as Eutric Regosols (Arenic).

Pedons II and III keyed out as Cambisols because they had a pisoplinthic horizon at a depth < 100 cm from the soil surface. The two pedons were given Endo-Pisoplinthic principal qualifier because of their subsurface pisoplinthic layer (> 50 cm from the soil surface). The two pedons were given arenic supplementary qualifier because of their loamy sand texture. Pedons II and III were therefore classified as Endo-Pisoplinthic Cambisols (Arenic). Pedon V keyed out as a Lixisol because it had an argic horizon at a depth < 100 cm from the soil surface and CEC (ECEC) < 24 cmolc $kg^{-1}$. Due to its subsurface gleyic properties, the soil was given gleyic principal qualifier. It was given loamic supplementary qualifier because of its loamy texture. Pedon V was therefore classified as a gleyic lixisol (loamic).

**Suitability Ratings**

The climate of the study sites was favourable for sugarcane cultivation. A mean annual temperature (30-31$^{o}$C) was suitable for sugarcane cultivation (Blume, 1985; Tarimo and Takamura, 1998; Cornland *et al.,* 2001). A mean annual rainfall of 1000-1200 mm at the study sites is very close to the recommended 1200-1500 mm for sugarcane cultivation (Blume, 1985; Tarimo and Takamura, 1998; FAO AGL, 2002). However, a rainy season of about seven months duration in Ilorin is not adequate so supplementary water supply would be required for optimal sugarcane production. Length of rainy season was therefore not included in the computation of potential suitability. In the case of current aggregate suitability, length of rainy season was the most limiting climatic characteristic. Relative humidity levels of 75 to 80% in the rainy season and 65% during dry season recorded at the study sites were adequate for sugarcane cultivation (Yates, 1977; Schulze, 1997).

Land requirement for sugarcane production, suitability ratings of the various land characteristics as well as their aggregate ratings (potential and actual) are presented in Tables 3 and 4. Pedon V from USRF2 (total area of 15 ha) was rated best (highly suitable, 85.25%) in terms of potential aggregate suitability. Pedons I and IV whose land coverage were 12 and 16 ha, respectively followed with a suitability of 64.53% (i.e., moderately suitable). Pedon II (land area of 15 ha) had a suitability of 47.40% (marginally suitable). Pedon III (7 ha of land area) had a suitability of 35.62% (unsuitable for sugarcane cultivation). Topography of both sites (< 5% slope) was favourable for sugarcane cultivation (Griffee, 2000). However, while the USRF1 soils were well drained, the USRF2 soils were poorly drained. Shallow depth and high gravel content were the main limitations of pedon III. Water and nutrients should be applied in split doses to the soils of pedons I, II and IV to minimize leaching and runoff. The aggregate suitability ratings of the soils from USRF1 were very low due to their low fertility status and sandy texture. The high sand content of these soils would predispose them to excessive leaching of nutrients and poor moisture retention. The soils from USRF1 were therefore rated as unsuitable for sugarcane production. They could, however, be made suitable through fertilizer application, especially organic amendments, and good residue management practices. Also, supplementary water supply through provision of appropriate irrigation would improve the suitability of the soils from USRF1. Pedon V, on the other hand, was rated suitable for sugarcane production due its better fertility status and more favourable texture. However, drainage at USRF2 would have to be improved for optimal sugarcane production at the site.

**Table 3:** Land requirements for suitability classes for sugarcane cultivation†

| Land quality | Suitability classes | | | | | |
|---|---|---|---|---|---|---|
| | Highly suitable (S1) (85–95%) | Moderately suitable (S2) (60–85%) | Sub-moderately suitable ($S2_1$) (40–60%) | Marginally suitable (S3) (25–40%) | Currently unsuitable (N1) (25–40) | Permanently unsuitable (N2) (0–25) |
| Climate (C) | | | | | | |
| Annual rainfall (mm) | >1200 | 1000–1200 | 800–1000 | 600–800 | - | >600 |
| Monthly rainfall (mm) | >5 | 4–5 | 3–4 | 2–3 | - | >2 |
| Mean annual maximum temperature (ºC) | >29 | 29–27 | 24–27 | 22–24 | - | >22 |
| Average daily minimum temperature (ºC) | >20 | 18–20 | 16–18 | 14–16 | - | >14 |
| Mean annual temperature (ºC) | >25 | 22–25 | 20–22 | 18–20 | - | >18 |
| Relative humidity (%) | >75 | 70–75 | 65–70 | 60–65 | - | >60 |
| Topography (T) | | | | | | |
| Slope (%) | 0–4 | 4–8 | 8–12 | 12–16 | >16 | - |
| Drainage | I | I | II | III | IV | V |
| Soil physical properties (S) | | | | | | |
| Textural classes | LS | SL | SCL | SC | any | CL, C |
| Coarse fragment vol. % 0–30 cm | 3–10 | 10–15 | 15–35 | 35–55 | - | >55 |
| Structure | Crumbs | Crumb | Sub-ab. | Sub-ab. | Colum. | Colum. |
| Depth (cm) | >100 | 90–100 | 50–90 | 25–50 | 15–25 | 5–15 |
| Soil chemical (fertility) properties (F) | >70 | 60–70 | 40–60 | 20–40 | <20 | <10 |
| Base saturation | >70 | 60–70 | 40–60 | 20–40 | - | 0 |
| pH | >6.0–6.5 | 6.0–7.0 | 5.5–6.0 | 5.0–5.5 | 4.5–5.0 | <4.5–>7.5 |
| Organic carbon (%) 0–30cm | >1.5–2.0 | 1.5–2.0 | 1.25–1.5 | 1.0–1.25 | <1.0 | <1.0 |
| Ca. mole fraction | 0.8–0.9 | 0.7–0.8 | 0.6–0.7 | 0.4–0.6 | 0.2–0.4 | <0.2 |
| Available phosphorus m kg$^{-1}$ 0–30cm | >20 | 16–20 | 12–16 | 8–12 | 4–8 | <4 |
| Salinity and alkalinity (dS/m) (n) | <1 | 1–2 | 2–3 | 3–4 | 4–8 | >8 |

SL - sandy loam, SCL - sandy clay loam, SC - sandy clay, CL - clay loam, C - clay; sub-ab - sub-angular blocky, colum. - columnar; I - well drained, II - moderately drained, III - fairly drained, IV - imperfectly drained, V - poorly drained; †Modified from FAO (2007) and Ogunwale *et al*. (2006)

**Table 4:** Suitability classes of the soils

| Characterization | Pedon I | Pedon II | Pedon III | Pedon IV | Pedon V |
|---|---|---|---|---|---|
| Annual rainfall | S1 (95) | S1 (95) | S1 (95) | S1 (95) | S1 (95) |
| Length of rainy season | S2 (70) | S2 (70) | S2 (70) | S2 (70) | S2 (70) |
| Mean annual maximum temperature | S1 (100) | S1 (100) | S1 (100) | S1(100) | S1 (100) |
| Slope | S1 (100) | S1 (100) | S1 (100) | S1(100) | S1 (100) |
| Drainage | S1 (100) | S1 (100) | S1 (100) | S1(100) | S2 (74) |
| Texture | S2 (72) | $S2_1$ (55) | S3 (54) | S2(70) | S1 (100) |
| Structure | $S2_1$ (68) | S2 (70) | $S2_1$ (65) | S2(70) | S1 (95) |
| Volume of coarse fragments | S1 (100) | $S2_1$ (55) | $S2_1$(59) | S1(100) | S1 (100) |
| Soil depth | S1 (100) | S3 (54) | S3(53) | S1(100) | S1 (100) |
| pH ($H_2O$) | S2 (70) | S2 (70) | S2(70) | S2(70) | S1 (100) |
| ECEC | S3 (54) | S3 (53) | $S2_1$(60) | $S2_1$(60) | S2 (94) |
| Base saturation | S3 (52) | S3 (52) | $S2_1$(68) | S2(70) | S1 (95) |
| Organic carbon | N2 (19) | N2 (15) | N2(19) | N2(19) | S1 (100) |
| Available phosphorus | $S2_1$ (60) | $S2_1$ (60) | $S2_1$(65) | $S2_1$(65) | $S2_1$ (68) |
| Aggregate suitability (%) | | | | | |
| Potential | 64.53 | 47.40 | 35.62 | 64.53 | 85.25 |
| Actual | 16.90 | 10.72 | 10.68 | 12.36 | 40.15 |

Explanations of S1, S2, $S2_1$, S3, N1 and N2 are as stated in Table 3.

## CONCLUSION & RECOMMENDATION

Five different soils from two sites of the UNILORIN Sugar Research Farm (USRF) were characterized and classified according to Soil Taxonomy and the WRB for Soil Resources. Pedons I and IV were classified as Typic Haplustepts, Pedons II and III as Lithic Haplustepts and V as a Kanhaplic Haplustalf (Soil Survey Staff, 2014). With the WRB system, pedons I and IV were classified as Eutric Regosols (Arenic), II and III as Endo-Pisoplinthic Cambisols (Arenic) and V as a Gleyic Lixisol (Loamic).

Pedon V was rated best (highly suitable, 85.25%) in terms of potential aggregate suitability for sugarcane cultivation. Pedons I and IV were rated moderately suitable (64.53%). Pedon II was rated marginally suitable (47.40%) while Pedon III was rated unsuitable (35.62%). The main limitations of pedon II and pedon III were their shallow depths and high gravel contents. The aggregate suitability ratings of the soils from USRF1 were very low due to their low fertility status and their sandy texture. The high sand content of these soils would predispose them to excessive leaching of nutrients and poor moisture retention. It would therefore be advisable to apply nutrients to the soils at USRF1 in split doses and at the time the crop would effectively absorb them.

Furthermore, supplementary provision of water would be required for the soils at USRF1 particularly towards the end of October when rainfall amounts decline. The soils from USRF1 were therefore rated as unsuitable for sugarcane cultivation. They could, however, be made suitable through fertilizer application, especially organic amendments, and good residue management practices as well as supplementary water supply through provision of appropriate irrigation. Pedon V, on the other hand, was rated suitable for sugarcane production due its better fertility status and more favourable loamy texture.

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