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, 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 Haplusteps, II and III as Lithic Haplusterts and V as a Kanhaorphic Haplustalf. Under WRB, pedons I and IV classified as Eutric Regosols (arenic), II and III as Endo-pisolithic Cambisols (arenic) and V as a Glyacic Lithosol (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 (Olaniany 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 (Osujiike 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 (Olaniany and Ogunwale, 2006).

Various approaches have been used to assess soil quality for sugarcane cultivation. 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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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 riverbanks; *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++, Mg2+ 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
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:

\[
IP = A \times B/100 \times C/100 \ldots F/100 \ldots \ldots (1)
\]

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 (pisolithite 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 suitability of the lands (soils) for sugarcane cultivation varies from 16.80 to 29.32% in USRF1 and 5.31 to 7.86% in USRF2. 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 (H₂O) 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 (H₂O) of pedon V (USRF2) on the other hand, ranged from 6.7 in the Ap horizon to 7.5 in the Bt3 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.

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

| Pedon | Horizon | 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      | LS            | massive    | Friable             | V        |
|       | AB      | 43–120     | Strong brown   | 7.5YR5/6 | 85.58    | 4.00     | 10.42      | LS            | massive    | Friable             | V        |
| II    | Ap      | 0–25       | Weak brown     | 7.5YR4/4 | 83.56    | 5.00     | 11.44      | LS            | massive    | Friable             | V        |
|       | ABdc    | 25–80      | Yellowish red  | 5YR4/6   | 86.74    | 3.00     | 10.26      | LS            | massive    | Friable             | V        |
| III   | Ap      | 0–15       | Strong brown   | 7.5YR3/4 | 71.41    | 5.00     | 22.69      | LS            | massive    | Friable             | V        |
|       | ABdc    | 15–65      | Red 2.5 YR3/4  |          | 72.42    | 6.00     | 21.58      | LS            | massive    | Friable             | V        |
| IV    | Ap      | 0–50       | Light brown    | 5YR3/1   | 82.54    | 5.00     | 12.46      | LS            | massive    | Friable             | V        |
|       | AB      | 50–90      | Strong brown   | 7.5YR5/6 | 80.63    | 6.00     | 13.37      | LS            | massive    | Friable             | V        |
| V     | Ap      | 0–42       | Dark brown     | 7.5YR5/2 | 67.80    | 12.00    | 20.19      | LS            | sub-ab     | Firm                | IV       |
| II    | Bt1     | 42–74      | Greyish brown  | 5YR 5/6  | 59.52    | 16.00    | 24.48      | GLS           | sub-ab     | Firm                | IV       |
|       | Bt2     | 74–130     | Greyish brown  | 2.5 YR4/6| 49.52    | 14.00    | 36.46      | LS            | 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 | Horizon | pH | Exchangeable bases (cmol(+) kg⁻¹) | Exchangeable acidity (cmol(+) kg⁻¹) | BS (%) | Cu mole fraction | 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                     |
| II    | 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 frn 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, Ca²⁺ was the highest in all the soils. Its content in USRF1 ranged from 0.7 to 1.9 cmol kg⁻¹ whereas in pedon V (USRF 2) it was 2.8 to 5.6 cmol kg⁻¹. Pedon V also contained higher amounts of Mg²⁺ (0.6-1.3 cmol kg⁻¹), K⁺ (0.4-1.0 cmol kg⁻¹) and Na⁺ (0.21-0.31 cmolc kg⁻¹) than the soils from USRF1. The levels of Mg²⁺, K⁺ and Na⁺ in the URSF1 soils were 0.3-0.9, 0.3-0.8 and 0.02-0.21 cmolₖg⁻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 3.21 mg 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⁻¹P 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 Usterts 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 pisoplinthitic horizon at a depth < 100 cm from the soil surface. The two pedons were given Endo-Pisoplinthic principal qualifier because of their subsurface pisoplinthitic layer (> 50 cm from the soil surface). The two pedons were given arenic supplementary qualifier because of their loamy sand texture. Pedons I, 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 gleicy properties, the soil was given gleicy principal qualifier. It was given loamic supplementary qualifier because of its loamy texture. Pedon V was therefore classified as a gleicy Lixisol (loamic).

### Suitability Ratings

The climate of the study sites was favourable for sugarcane cultivation. A mean annual temperature (30-31°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 (Griffie, 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.
Characterization, Classification and Suitability Evaluation of Soils under Sugarcane at Ilorin, Nigeria

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

| Land quality                        | Highly suitable (S1) (85–95%) | Moderately suitable (S2) (60–85%) | Sub-moderately suitable (S2) (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 (°C)| >29                           | 29–27                             | 24–27                                | 22–24                            | -                                 | >22                               |
| Average daily minimum temperature (°C)| >20                        | 18–20                             | 16–18                                | 14–16                            | -                                 | >14                               |
| Mean annual temperature (°C)        | >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.                            | Colum.                           |
| Depth (cm)                          | >100                          | 90–100                            | 50–90                                | 25–50                            | 15–25                             | 5–15                              |
| Soil chemical (fertility) properties (F) |                         |                                   |                                      |                                  |                                   |                                   |
| Organic carbon (%)                  | >1.5                         | 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 0–30 cm | >20                           | 16–20                             | 12–16                                | 8–12                             | 4–8                               | >4                                |
| Salinity and alkalinity (dS/m)      | <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, column. - 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 (mm)                          | 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 (°C)          | 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) | S1 (100)| S2 (74) |
| Texture                                       | S2 (72) | S2 (55)  | S3 (54)   | S2 (70)  | S2 (70) |
| Structure                                     | S2 (68) | S2 (70)  | S2 (65)   | S2 (70)  | S2 (70) |
| Volume of coarse fragments                    | S1 (100)| S2 (55)  | S2 (59)   | S2 (59)  | S2 (59)| S1 (100) |
| Soil depth                                    | S1 (100)| S3 (54)| S3 (53)   | S3 (53)  | S3 (53)| S1 (100) |
| pH (H₂O)                                      | S2 (70) | S2 (70)  | S2 (70)   | S2 (70)  | S2 (70) |
| ECEC                                          | S3 (54) | S3 (53)  | S2 (60)   | S2 (60)  | S2 (94) |
| Base saturation                               | S3 (52) | S3 (52)  | S2 (68)   | S2 (70)  | S1 (95) |
| Organic carbon                                | N2 (19) | N2 (15)  | N2 (19)   | N2 (19)  | N2 (19)| S1 (100) |
| Available phosphorus                          | S2. (60)| S2. (60)| S2. (65)  | S2. (65) | S2. (65)|
| Aggregate suitability (%)                     | Potential | 64.53     | 47.40     | 35.62    | 64.53   | 85.25 |
|                                             | Actual    | 16.90     | 0.72      | 10.68    | 12.36   | 40.15 |

Explanations of S1, S2, 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 Haplusterts, Pedons II and III as Lithic Haplusterts 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 ranked 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.
REFERENCES

Abekoe M.K. (1989). The Role of Concretions in Phosphorus Availability in a Typical Concretionary Soil of Northern Ghana. MPhil Thesis, Department of Soil Science, University of Ghana. http://ug.edu.gh

Abekoe M.K. and Sakhrwawat K.L. (2001). Phosphate retention and extractability in soils of the humid zone in West Africa. Geoderma, 102, 175-187

Ajiboye G.A., Alabi K.O., Adesodun J.K. and Aiboni V.U. (2011). Classification and suitability evaluation of the soils of a toposequence at Odeda, Ogun State for the production of rice (Oryza sativa). Niger. J. Soil Sci., 21 (2), 142-155

Ajiboye G.A., Ijaaiboja J.O., Olaniyan J.O. and Olaya A.O. (2015). The characteristics and suitability of the soils of some major cocoa growing areas of Nigeria: Etung Local Government area of Cross River State. Agrosearch, 15 (1), 101-116. doi:10.4314/agrosh.v15i1.7

Blume H. (1985). Geography of Sugarcane, Verlag Dr. Albert Bartens, Berlin, pp. 1-21

Brady N.C. and Weil R.R. (2008). Soil Fertility and Stewardship. 11th ed. Pearson Prentice Hall, NJ, p. 527

Buol S.W., Hole F.D., MaCracken R.J. and Southard R.J. (1991). Soil Genesis and Classification (4th ed.). Iowa State University Press, Ames, pp. 221-224

Chartres C.J. (1981). Land resources assessment for sugarcane cultivation in Papua New Guinea. Appl. Geo., 1, 259-271

Cherubin M.R., Karlen D.L., Franco A.L., et al. (2016). A soil management assessment framework (SMAF) evaluation of Brazilian sugarcane expansion on soil quality. Soil Sci. Soc. Am. J., 80, 215-226

Cornland D., Johnson F., Yamba F., et al. (2001). Sugarcane Resources for Sustainable Development: A Case Study in Luena Zambia. Stockholm Environment Institute, Stockholm, p. 94

Dai Y., Qiao X. and Wang X. (2018). Study on cation exchange capacity of agricultural soils. IOP Conf. Series: Material Sci. Eng. DOI: 10.1088/1757-899X/392/4/042039

Esu E. (2005). Soil characterization and mapping for food security. Keynote Address, 29th Ann. Conf. Soil Sci. Soc. Nigeria, Abeokuta, 6-10 Dec., 2005

Fábio R.M., Maria L.L., Eduardo D.A., Carlos E.V. and Marcelo C.S. (2008). Sugarcane crop efficiency in two growing seasons in São Paulo State, Brazil. Pesq. Agropecu. Bras., (43), 11. DOI: 10.1590/S0100-204X200801100002

FAO AGL (2002). Crop water management. Agriculture Land and Water Division, Food and Agriculture Organization, Rome. Accessed: 23/07/2007: http://www.fao.org/ag/agl/aglw/cropwater/sugarcane.stm

FAO (1976). A framework for land evaluation. Food and Agriculture Organization (FAO), Rome

FAO (1977). Guidelines for soil profile description (2nd ed.). Soil Resources Development and Conservation Service, Land and Water Development Division, Food and Agriculture Organization (FAO), Rome

FAO (2006). Guidelines for soil description (4th ed.). Food and Agriculture Organization (FAO), Rome

FAO (2007). Land evaluation towards a revised framework. Land and Water Discussion Paper No. 6. Food and Agriculture Organization (FAO), Rome

FPDD (1989). Fertilizer use and management practices for crops in Nigeria. Fertilizer Procurement and Distribution Division, Federal Ministry of Agriculture and Rural Development, Lagos, Nigeria, Series 2, p.188

Gee G. and Or G. (2002). Particle size. In: Dane J.H. and Topp G.C. (eds.), Methods of Soil Analysis, Part 4: Physical Methods (pp. 255-293). Madison WI: Soil Sci. Soc. Am. Book Series No. 5

Glyn J. (2004). Sugarcane. Blackwell Publishing, Wiley-Blackwell, Oxford, UK, p. 224

Gravois K. (2021). Sugarcane fertilizer recommendations for 2021. LSU AgCenter, USA

Griffie P. (2000). Ecology of sugarcane. Accessed from: https://www.ecoport.org/EP.exeSearch?ID=1884, 15/06/2007

Haifa Group (2021). Using the right fertilizers in order to provide the sugar cane necessities. Matam-Haifa, 51905 Israel, https://www.haifa-group.com

Herman B. and Cameron K.C. (1993). Structural changes in a silt loam under long-term conventional or minimum tillage. Soil Till. Res., 26, 139-150

Hillé D. (2004). Introduction to Environmental Soil Physics, Soil Structure and Aggregation. Elsevier Science, USA, pp. 73-89

Igwe C.A., Akamigbo F.O.R. and Mbagwu J.S.C. (1999). Chemical and mineralogical properties of soils in southern Nigeria in relation to aggregate stability. Geoderma, 92, 111-123

IUSS Working Group WRB (2015). World Reference Base for Soil Resources 2014, Update 2015. Int. Soil Classification Sys. for Naming Soils & Creating Legends for Soil Maps. World Soil Resources Report No. 106, FAO, Rome

Kanabo I., Halm A. and Obeng H. (1978). Phosphorus adsorption by surface samples of five iron pan soils of Ghana. Geoderma, 20, 299-306

Kingston G. (2014). Mineral nutrition of sugarcane. In: Moore P.H. and Botha F.C. (eds.), Sugarcane: Physiology, Biochemistry Functional Biology (Chap. 5). John Wiley & Sons Inc. DOI: 10.1002/9781118771290.ch5

Kramer P.J. and Boyer J.S. (1995). Water Relations of Plants and Soils (1st ed.). Academic Press, San Diego, CA, pp. 84-92

Langmaack M. (1999). Earthworm communities in arable land influenced by tillage, compaction, and soil. Zeitschrift für Ökologie und Naturschutz, 8, 11-21

Lekwa M., Anene B. and Lekwa G. (2004). Chemical and morphological soil characteristics in drainage toposequence in Southeastern Nigeria. In: Ojeniyi S.O. et al. (eds.), Land Degradation, Agricultural Productivity and Rural Poverty, Environmental Implications (pp. 316-322). Proc. 28th Ann. Conf. Soil Sci. Soc. Nig., National Root Crops Res. Inst., Umudike, Nigeria

Mahesh C., Rajeshwar N., Balaguruvaiya D. and Vidyasagar G. (2018). Genesis, classification and evaluation of some sugarcane growing black soils in semi-arid tropical region of Telangana. J. Pharmacog. Phytochem., 7, 81-92

McCray J.M., Morgan K.T. and Baucum L. (2019). Nitrogen fertilizer recommendations for sugarcane production for sugar on Florida sand soils. IFAS Extension, Univ. of Florida, SS-AGR-401, pp. 1-4

McLean E.O. (1982). Aluminum. In: A.L. Pages, R.H. Moore P.H. and Botha F.C. (eds.), Cation Sys. for Naming Soils & Creating Legends for Soil Resources 2014, Update 2015. Int. Soil Classification Sys. for Naming Soils & Creating Legends for Soil Maps. World Soil Resources Report No. 106, FAO, Rome

Mistry P.S., Tripathi S. and Desai L.J. (2018). Response of sugarcane varieties to different levels of phosphorus application on yield and quality parameters of sugarcane under south Gujarat condition. Int. J. Chem. Stud., 9 (3), 1861-1863

Mubashir J., Raihan A. and Haroon S. (2017). Land suitability assessment for sugarcane cultivation in Bijnor district, India using geographic information system and fuzzy analytical hierarchy process. Geo. J. DOI: 10.1007/s10708-017-9788-5

Mwasinga G. (2018). Effects of Nitrogen Fertilizer on Yield and Quality of Introduced Sugarcane (Saccharum officinarum L.) Varieties in Commercial Fields at Kilombero, Morogoro Region, Tanzania. A Case Study in Luena Zambia. Haifa Group (2021). Using the right fertilizers in order to provide the sugar cane necessities. Matam-Haifa, 51905 Israel, https://www.haifa-group.com

Nelson D.W. and Sommers L.E. (1996). Total carbon, organic carbon and quality. In: D.L. Sparks (ed. ), Methods of Soil Analysis, Part 2: Chemical Methods (pp. 978-998). Madison WI: Soil Sci. Soc. America Book Series No. 5, Am. Soc. Agron.
