SUGAR BOARD OF TANZANIA

SOIL SURVEY AT MTIBWA AREA PROPOSED SITE FOR NEW SUGAR FACTORY INVESTMENT

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Table of Contents

Acronyms

AMSP	Accompanying Measures Sugar Protocol
Ca	Calcium
CEC	Cation Exchange Capacity
Cu	Copper
ESP	Exchangeable Sodium Percentage
EU	European Union
Fe	Iron
K	Potassium
Mg	Magnesium
Mn	Manganese
MSE	Mtibwa Sugar Estate
Na	Sodium
P	phosphorus
SBT	Sugar Board of Tanzania
TIC	Tanzania Investment Center
TN	Total Nitrogen
URT	United Republic of Tanzania
Zn	Zinc

LIST OF TABLES

List of figures

Appendices

1.0. INTRODUCTION

1.1. Background

Agriculture is the major employer in Tanzania, accounting for over 60% of the total national employment (URT, 2016.). Most of the employment is attributed to food crops production, mainly done by small scale farmers. Efforts are being done by the government in collaboration with other development partners to improve involvement of small scale holders in cash crop production. The cash crops include sugar cane. The sugar industry is a major employer with direct labour force of approximately 18,000 people, indirect labour force of 57,000 people with 75,000 households and dependants (BACAS, 2015). The current annual demand of sugar in Tanzania is estimated at 590,000 mt, whereas the production is 300,000 mt of raw sugar annually. The deficit of about 290,000 mt is met through importations.

Large-scale plantations have been the predominant model for sugarcane production in Tanzania and elsewhere in Sub-Saharan Africa. However, due to limited land for horizontal expansion of sugarcane estate farming, the sugar companies in Tanzania specifically Kilombero Sugar Company Limited (KSCL) and Mtibwa Sugar Estate in Morogoro region have strongly encouraged outgrowers production (Chongela, 2015). Outgrowers schemes in Tanzania account for approximately 27% of all cane production and 48% respective mills' throughput. However, their efficiency is hampered by several factors. Outgrowers production in Tanzania is constrained by several factors the main ones being poor management of outgrowers' associations, poor infrastructure and haulage facilities, poor cane husbandry practices, lack of access to finance to invest in sugarcane production, high harvesting and production costs, and fire outbreaks in outgrowers' fields before harvesting, and dependence on rain-fed agriculture. Despite the challenges faced, outgrower production is seen as an appropriate model to increase sugarcane production hence fill the existing supply gap of sugar in the country (UNCTAD, 2006).

In general, small scale sugar cane outgrowers fields are performing badly in terms of crop performance compared to the large scale plantations they surround (Massawe and Mhoro, 2017). This is mainly due to poor agronomic practices and unguided decisions on soil fertility management. Large scale plantations perform routine soil tests which help them make informed decision on soil fertility management; something which is generally lacking in case of small scale outgrowers. Accurate information on soil types and their distribution on land is important for identifying potential of the soils and the soil-related constraints to high and sustainable production of sugarcane.

Many outgrowers of Mtibwa are currently abandoning sugar cane production mainly because of unreliable market of the cane. The Sugar Board of Tanzania (SBT) reports that the miller at Mtibwa Sugar Estate is currently underperforming resulting to unreliable market to outgrowers cane. In response to this, SBT in collaboration with Tanzania Investment Centre (TIC) is advocating starting of a mini sugar cane milling industry in Mtibwa area to increase market reliability of outgrowers' harvested sugar cane. To appeal to investors, SBT found it of importance to do soil survey in outgrowers farms around proposed investment site to establish the suitability and potential of the area for sugar cane production.

1.2. Objectives

This report gives information on the assignment which intended to carry out soil survey at Mtibwa area proposed site for new sugar factory investment. The specific objectives of the assignment were to generate:

- Detailed soil map of the proposed area.
- Detailed information on the physical and chemical characteristics of soil in the proposed area.
- Recommendations on the best use of the land according to the types of soil and their composition for sugarcane farming

2.0. METHODOLOGY

2.1. Study area demarcation

The study area was identified by guidance of SBT local staff and outgrowers' leaders based in Kwadoli and Kanga villages. Guiding location coordinate points were taken using a hand held GPS (Garmin *e*Trex) piece. The coordinates were then plotted on Tanzania shapefile indicating administrative boundaries to ward level. A polygon covering the areas indicated as proposed site for outgrowers to supply the new mini plant was digitized onscreen using QGIS software (QGIS development team, 2014)

2.2. Soil base map preparation

The base map was prepared in order to provide guidance for field investigation and sampling of soils. SRTM (USGS, 2000) Digital Elevation Model (DEM) at a spatial resolution of 90 m was used to generate terrain attributes of the study area. The altitude ranges, slope gradients, land use types, soil colour, soil texture and vegetation cover; among visible land characteristics were used to group soils for initial observations. The efforts to produce base map involved desktop work and field visits to confirm and adjust the boundaries. The final boundaries were digitized using on-screen digitization on QGIS software to produce soil units.

2.3. Soil sampling

Two types of soil samples were taken. The first was by using soil profiles. Soil profiles were excavated to about 180 cm or limiting layer, described and sampled on the designated genetic horizons following FAO (2006) guideline for soil profile description. The second sampling was done using augers at three depths: 0 – 20 cm, 20 – 40 cm, and 40 – 60 cm. Samples were submitted for physical and chemical analysis to the SUA soil laboratory.

2.4. Generation of physical and chemical properties of soil

2.4.1. Morphological and soil physical parameters

Some of the physical and morphological properties were recorded in the field using a standard form. These included soil depth, soil colour, soil drainage, soil consistence, soil structure, presence and type of weatherable minerals, presence of mottles, soil erosion, surface cracking, shrink/swell properties, porosity and rooting density. These parameters were recorded following guidelines described in the FAO guideline for soil profile description (FAO, 2006)

Other physical parameters were analysed and recorded in the laboratory including soil texture by hydrometer method and bulk density by core method.

2.4.2. Soil chemical parameters

Standard laboratory procedures were used to analysed the soil for chemical properties as summarized in National Soil Survey manual (NSS, 1990). Organic carbon (OC) was measured using the dichromate oxidation method; Total nitrogen (TN) by Kjeldahl method; Available phosphorus by Bray-I (for soil pH less than 7) and Olsen (for soil pH greater than 7) methods; Exchangeable bases (Ca2+ and Mg2+) by atomic absorption spectrophotometer; Exchangeable Na+ and K+ by flame photometer; Cation Exchange Capacity (CEC) by using Ammonium Acetate; pH in water by normal laboratory pH meter and saturated electrical conductivity (ECe) by conductivity meter in a 1:2.5 soil-water suspension. Extractable micro nutrients including Cu, Fe, Mn and Zn were extracted using DTPA solution and determined by Flame Emission - Atomic Absorption Spectrophotometer (FE-AAS).

2.5. Soil classification

Base on the field and laboratory data, Soils were classified using World Reference Base for soil resources (FAO, 2015)

2.6. Data interpretation and recommendations

This was done based on the field and laboratory information. Soil data was interpreted based on the levels of nutrients observed against optimum sugar cane production requirements. Expert knowledge, local and international references were used for interpretation

3.0. FINDINGS AND DISCUSSIONS

3.1. Soil map production

3.1.1. Soil units descriptions

A total of 13 soil units were established for the study area. The spatial distribution of the soil units is shown on a map on Figure 1. Table 1 briefly describes the soil unit symbols and the type of sampling done to represent the soil units. Soil classification representing the soil units is also indicated in the table. Details for each of soil unit are given below:

3.1.2. Highlands and steep slopes (HL & SS)

These are the mountainous areas within the study area. They rise from 410 to 1100 m above sea level (asl). They include Kanga and Nguu elevated areas, making mostly the northern boundary of the study area. The slopes dominantly range from 30 to 60 degrees making it difficult to access and mechanize. With this sharp increase in altitude, the weather elements, especially rainfall and temperature are greatly affected within a short distance.

The common land use types in the HL & SS are forest, charcoal burning, and food crops production; the most popular being banana. Population in the unit is generally low, except in isolated low slope gradient spots.

Given the prohibitive terrain for sugar cane production, no soil sample was taken from this unit. Soils are, however, generally very shallow to rocky and less developed due to constant removal by water and gravity, except in a few concave slopes.

The soils of this unit can generally be classified as a complex of *Leptosols* and *Regosols*

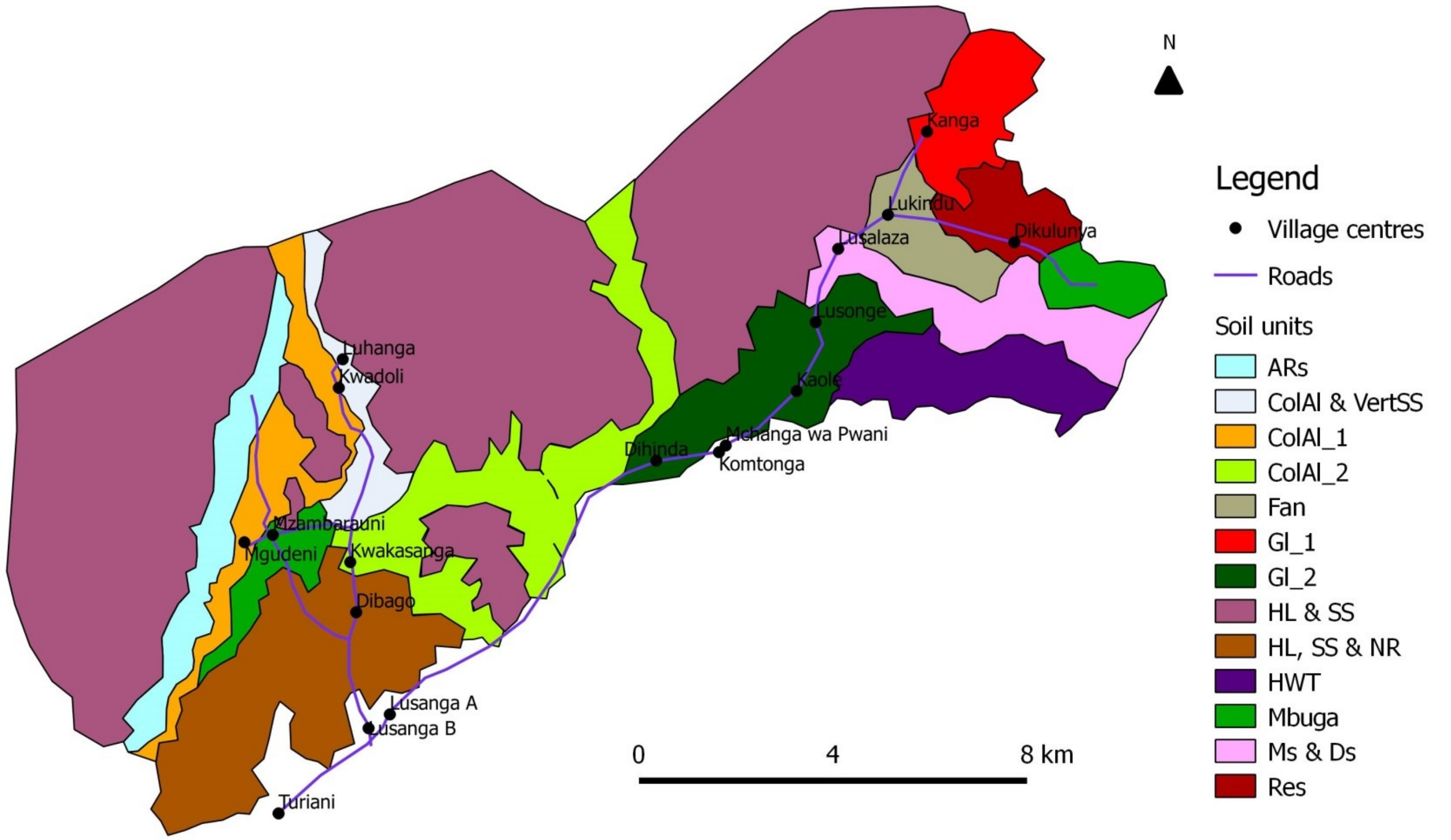

FIGURE 1. MAP OF SOIL UNITS

TABLE 1. SOIL UNITS DESCRIPTION AND SOIL CLASSIFICATION

S/N	Soil unit symbol	Soil unit description	Soil classification (WRB)	Representative sampling	Type of sampling
1	HL & SS	Highland and steep slopes	Leptosols	None	None
2	HL; SS & NR	Highlands with steep slopes and narrow valleys between the higlands	Complex of Leptosols and Phaeozems	LUS_A1	Auger
3	ARs	Alluvial soils with stratifications	Dystric Fluvisols (loamic, oxyaquic)	KWAD_P1	Soil profile
4	ColAl_1	Colluvial - Alluvial soils	Eutric Fluvisols (loamic, oxyaquic)	KWAD_P2	Soil profile
5	ColAl_2	Colluvial - alluvial with less influence of river	Eutric Fluvisols (loamic, oxyaquic)	KWAD_P2	Soil profile
6	ColAl & VertSS	Colluvial - alluvial with vertic subsoil	Haplic Umrisols (abruptic, loamic)	KWAD_P3	Soil profile
7	Mbuga	Heavy clay; black cotton soil	Sodic Vertisols (gleyic, humic) and Sodic Vertisols (hypereutric)	MZA_P1 , LUK_P3	Soil profile
8	Ms & Ds	Midslopes deep soil with gleyic subsoil	Gleyic Umbrisols (loamic)	KAN_P1	Soil profile
9	Gl_1	Dark surface gleyic subsurface upper slopes	Gleyic Umbrisols (loamic)	KAN_P1	Soil profile
10	Gl_2	Deep dark soils with gleyic subsoils	Gleyic Umbrisols (loamic)	KAO_A1	Auger
11	Fan	Fans; complex of shallow and deep soils	Chromic Cambisols (loamic)	LUK_P1	Soil profile
12	Res	Relatively Highly weathered reddish soils	Haplic Phaeozems (clayic, chromic)	LUK_P2	Soil profile
13	HWT	Deep; high water table soils	Gleyic Umbrisols (loamic)	KAO_P1	Soil profile

3.1.3. Highlands with steep slopes and narrow valleys between the higlands (HL,SS & NR)

This unit covers area with relatively low hills and generally less steep compared to HL & SS unit. Another differentiating characteristic is presence of narrow valleys interspacing the hills. The hills are generally not cropped due to the relatively steep slope gradient and shallow rocky soils. The valleys are cropped and have soil formed from colluvial – alluvial depositions generated predominantly from nearby hills. The soils are generally deep, especially towards the middle of the valleys and are generally well to somewhat well drained with deep water tables. Records show that parts of the valleys within the unit were used for sugar cane production by the outgrowers, but currently changed to other crops including maize and rice due to un-assuring sugar cane market.

Samples were taken at Lusanga area to represent the *HL,SS & NR* unit. Auger was used to take samples at three different depths: 0 – 20 cm, 20 – 40 cm and 40 – 60 cm, and chemical properties are presented by sampling reference LUS_A1 (Appendix 2).

The soils on the hills can be classified as *Leptosols* and *Regosols*, while those in the valleys, though not from soil profile description, can be classified as *Phaeozems* based on base saturation, soil colour, topsoil depth and soil organic carbon content.

3.1.4. Alluvial soils with stratifications (ARs)

This unit represents soils along river Mjonga. The unit *ARs* lies immediately after unit *HL & SS* along Nguu Mountains which supply the river with water through numerous streams running down slope. The soils of this unit have stratified profile as a result of cyclic deposition of alluvial materials carried by the river. The soils have reddish to reddish brown sandy subsoil with black, loamy sand topsoil. The soils are deep with a buried surface horizon at a depth of about 100 cm. The unit experiences seasonal flooding which recedes laterally and vertically after a few days due to the generally coarse soil texture of the landscape. More morphological characteristics for this soil are presented on the description of soil profile KWAD_P1 in appendix 1. The profile is shown in a photo on Figure 2.

The soils of this unit are classified as *Dystric Fluvisols (loamic, oxyaquic)*

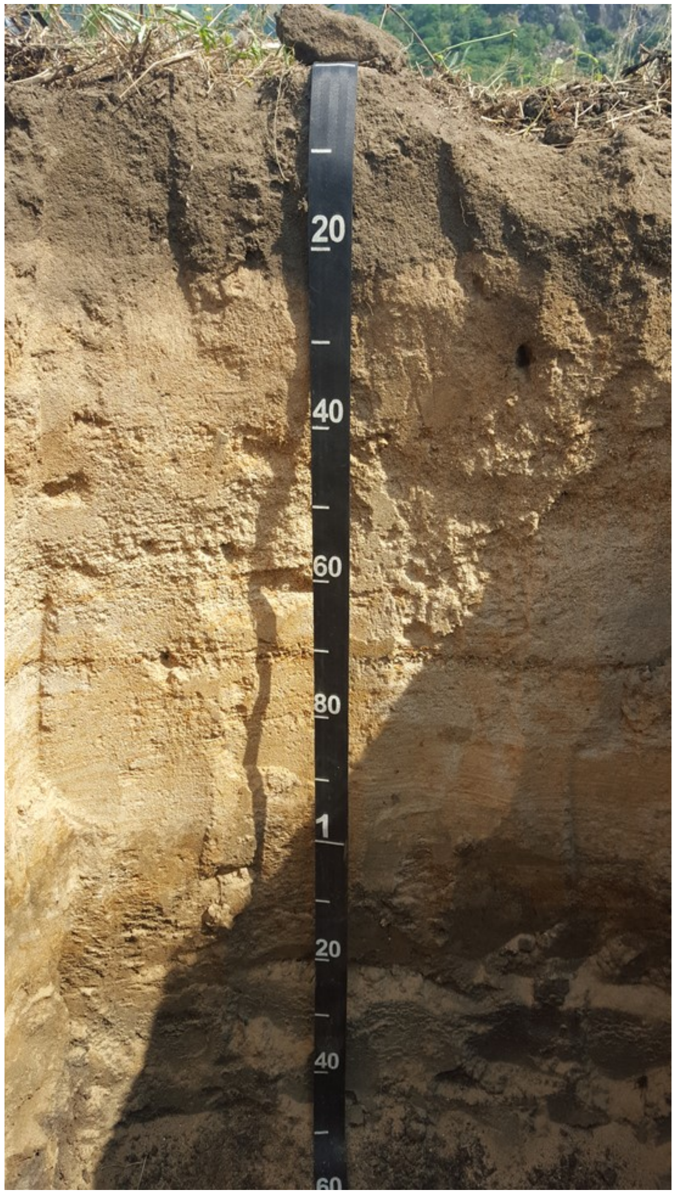

FIGURE 2. SOIL PROFILE KWAD_P1

3.1.5. Colluvial - Alluvial soils (ColAl_1) KWAD_P2

The unit ColAl_1 covers soils which have been formed from colluvial and alluvial deposition, with the alluvial being a more dominant factor. These soils are represented by soil sampling reference KWAD_P2. The morphological features of this unit are presented on Appendix 1 and shown on Figure 3, while the chemical features are presented in Annex 2. Stratifications are visible from 50 cm depth, and the soils are generally well drained. However, the water table was found at about 112 m. the soils are deep with sandy to sandy clay loams grey to dark brown subsoils and black loamy sands to sandy clay loams top soils. The soils of the units are generally friable when moist and slightly sticky and slightly plastic, thus presenting a good workability but relatively weak structure which can easily be compacted.

The soils of this unit are classified as *Eutric Fluvisols (loamic, oxyaquic).*

FIGURE 3. SOIL PROFILE KWAD_P2

3.1.6. Colluvial - alluvial with less influence of river (ColAl_2)

In this soil unit, the influence of alluvial soil forming factors, though still dominant, are less dominant than in ColAl_1. The unit is generally away from the permanent rivers. However, the soil profile indicated similar horizon formation to ColAl_1, except that the ground water table was not reached when excavated to 160 cm deep. The morphological and chemical properties are therefore presented by soil profile KWAD_P2, and thus the soil classifies as *Eutric Fluvisols (loamic, oxyaquic).*

The opened profile for this unit is shown on Figure 4.

FIGURE 4. SOIL PROFILE REPRESENTING SOIL UNIT COLAL_2

3.1.7. Colluvial - alluvial with vertic subsoil (ColAl & VertSS)

The *ColAl & VertSS* is formed under somewhat equally colluvial and alluvial influences. These soils were found to have vertic subsoils, but the indications were not evident at the surface of the soil. The morphological and chemical information of the unit are documented under soil sampling reference KWAD_P3. The drainage can be described as somewhat well, but the water table was found at 140 cm depth. The soils are generally deep with gleyic properties below the vertic subsoil starting at 86 cm deep. The vertic properties start at 33 cm depth. The subsoils are therefore black, clayey, hard when dry and very sticky and very plastic when wet. The topsoils are dark grayish brown in colour sandy clay loams; friable when moist and slightly sticky and slightly plastic when wet.

The soil of this unit are classified as Haplic *Umbrisols (abruptic, loamic)* and is presented by soil profile on Figure 5.

FIGURE 5. SOIL PROFILE KWAD_P3

3.1.8. Heavy clay; black cotton soil (Mbuga) MZA_P1 , LUK_P3

The mbuga (heavy clay black cotton soil) is presented by two soil profiles. MZA_P1 represent mbuga soils which are dominated by fluvial and alluvial activities from surrounding hills around Mzambarauni and Kwadoli areas. These soils were generally wetter and contained more clay as compared to the mbuga soils represented by soil sampling reference LUK_P3 which are present to the south of Kanga village. The soil presented by LUK_P3 are generally on depressions on a lowly undulating landscape, not very much affected by fluvial activities as compared to MZA_P1. The water tables were below 150 cm for both settings. Soils from both representative profiles have swelling – shrinking 2:1 clays which result to cracking of the soils when dry.

The Lukindu *mbuga* soils presented by soil profile LUK_P3 (Figure 6) are classified as *Sodic Vertisols (hypereutric)* while those of Mzambarauni represented by soil profile MZA_P1 (Figure 7) are classified as *Sodic Vertisols (gleyic, humic)*

FIGURE 6. SOIL PROFILE LUK_P3

FIGURE 7. SOIL PROFILE MZA_P1

3.1.9. Midslopes deep soils with gleyic subsoil (Ms & Ds)

This unit represents deep soils with gleyic subsoils on alluvial colluvial mid slope plains. These soils are generally moist throughout the year and have a shallow water table which was found to be around 70 cm from the soil surface during the study. The water table is expected to be shallower during the rain season. The land is currently under rice production.

The soil have very dark greyish brown, sandy clay loam subsoils and very dark grey sandy clay loam topsoils. The physical and chemical parameters of the soil are detailed in appendices 1 and 2 under soil reference KAN_P1 (Figure 8).

The soils of this unit are classified as *Gleyic Umbrisols (loamic).*

FIGURE 8. SOIL PROFILE KAN_P1

3.1.10. Dark surface gleyic subsurface upper slopes (Gl_1)

The difference between this unit *(Gl_1)* and the *(Ms & Ds)* is their location setup. While the *(Ms & Ds)* are present midslopes altitude wise, the Gl_1 are located in the upper slopes altitude wise. Since there is no significant slope gradient variation between the two settings, the units are represented by the same soil profile (KAN_P1).

The soils of this unit are therefore, also classified as *Gleyic Umbrisols (loamic).*

3.1.11. Deep dark soils with gleyic subsoils (Gl_2)

This unit represents dark soils located between the lowest landscape of the study area and the Kanga Mountain around Lusonge and Kaole areas. The soils are mostly moist as they receive the drainage from the mountain. They have water table close to the surface. The water table at the time of the study (July) was found to be around 80 cm from the soil surface. Due to alternating drying and saturation, the soil has gleyic subsurface indicating periods of reducing and oxidizing soil conditions. The chemical properties of the unit are presented by ager sampling KAO_A1 (Appendix 2). The sampling was taken at 4 soil depth intervals: 0-20 cm, 20 – 40 cm, 40 – 60 cm, 60 – 80 cm

Although soil profile was described in this unit, based on the observed morphology and soil chemical properties, the soils of the unit can be broadly classified as *Gleyic Umbrisols.*

3.1.12. Deep; high water table soils (HWT)

This unit represents deep, high water table soils located on lowest landscapes of the study area, generally south of Kaole and Lusalaza areas. The soils are generally moist throughout the year and the water table is around 84 cm from the soil surface. The soils are poorly drained.

The subsoils are very dark grey sandy clay loam while the topsoils are black sandy clay loams. The soil is friable when moist and slightly sticky/plastic when wet. The morphological and chemical properties are presented by soil reference KAO_P1 (Figure 9)

The soils of this unit are classified as *Gleyic Umbrisols (loamic).*

FIGURE 9. SOIL PROFILE KAO_P1

3.1.13. Fans; complex of shallow and deep soils (Fan) LUK_P1

The *Fan* soil unit represents areas covered by a complex of shallow and deep soil around Lukindu area. They are generally colluvial alluvial, forming convex raised areas generally used for settlement and upland crops

The soils are generally compacted and hard to open. They have dark brown sandy loam subsoils and very dark greyish brown sandy loam topsoils. They are slightly sticky and slightly plastic when wet. They are well drained and generally dry. Rain water flows outward due to compaction and convexity. The unit is represented by soil profile LUK_P1 shown on Figure 10.

The soils of this unit are classified as *Chromic Cambisols (loamic).*

FIGURE 10. SOIL PROFILE LUK_P1

3.1.14. Relatively highly weathered reddish soils (Res) LUK_P2

The *Res* soil unit comprises highly weathered very deep reddish soils present to the south of Lukindu area, Kanga village. The soils have weathered in situ and connects to the complex of shallow and deep soils (*Fan*) at the north. The soils are well drained and present on a gently undulating landscape.

The soils have dark red to dark reddish brown sandy clay subsoils and very dark brown sandy clay loam topsoils. The soil have a stone line of consisting of quartz and manganitic minerals at depth from 158 – 160+ cm. the morphological and chemical characteristics of the unit are detailed under LUK_P2 (Appendix 1 and 2). The profile is shown on Figure 11.

The soils of this unit are classified as *Haplic Phaeozems (clayic, chromic).*

FIGURE 11. SOIL PROFILE LUK_P2

3.2. Soil units properties and their implication for sugar cane production

3.2.1. Physical properties

Terrain

Terrain affects the use of machinery in sugar cane production. Despite the fact that most of sugar cane field production operations under outgrowers are not heavily mechanized, operations like cultivation, irrigation, loading and haulage are specifically affected in the semi intensive system employed by Tanzanian outgrowers. The large machinery used in sugarcane production is most efficient when operated on extensive areas of level ground or gentle slopes.

This, therefore makes soil units *HL & SS* in particular to be not suitable for sugar cane production due to its steep slope gradient. Parts of soil unit *HL, SS & NR* are also not suitable because they contain crests and steep slopes. However, the valleys between the hills in this soil unit have a terrain suitable for mechanization, and hence can be used for sugar cane production.

The rest of soil units in the study area have terrain suitable for mechanization. Their slope gradients are generally below 5 degrees (Appendix 1). FAO (2017) reports that surface systems require terrain with gradients between 0 and 5 for efficient mechanization.

Soil workability

Soil workability is related to its hardness, depth, stickiness, slipperiness, and a moisture range in which the farm operations can be done efficiently. These properties limit the choice of farm implements and amount of soil moisture required for the field operations. Heavy clay soils (vertisols) for example, can only be cultivated over a narrow moisture range below which they are very hard and above which they are very sticky and slippery. Compacted layers also will need more power to work, likewise, shallow and stony/rocky soils.

The soil units classified as *mbuga* in this study are having heavy clays, and therefore the workability is limited within certain moisture ranges. When it rains and are wet they become very sticky and slippery, thus farm implements get stuck. When they are dry they become very hard and forms cracks. The cracking has effect of damaging lateral roots.

Soil unit *ColAl & VertSS* have vertic subsoil starting at the depth 33 cm (refer soil profile KWAD_P3). This might not directly impact workability, however, may impact rooting of the crop.

Soil unit *Fan* is generally compacted and may need subsoiling to loosen the soil

Soil depth

Soil depth affects rooting characteristics, water holding and cultivation practices.

Except for the mountainous units which have already been judged as not suitable for commercial sugar cane production in this study, the rest of soil units have soils deep enough to support sugar cane growth.

Soil texture

Sugar cane requires well drained soils with an adequate balance between pores of various sizes (Sugarcane Production Handbook, 2001; NETAFIM, 2017). Such types include clay loams, silty loams, sandy clay loams, silty clay loams and loams.

Two extremes of soil texture are present our study area. Clays which holds water and may result to ponding. Clays are present throughout the soil profile depth in the *mbuga* soil unit in Mzambarauni area. They are also present in the subsoils of KWAD_P3 soil profile representing *ColAl & VertSS* soil unit around Kwadoli area. Else, they are occurring in a few soil horizons and account for about 8% of samples collected (Figure 12)

Sand soil texture group is found on subsoils, mainly of stratified soil profiles resulting from fluvial activities. They are recorded in soil units *ARs, ColAl_1* and *ColAl_2*. These horizons have poor loose soil, structure and allow maximum water infiltration thus water loss. However, because they are present in the subsoils, the effects can be contained by maintaining the topsoil with high soil organic matter and avoiding compaction. The sand texture accounts for about 8% of the soil samples collected and analysed in this study (Figure 12).

The dominant soil texture is sandy clay loam followed by sandy clay accounting respectively for 41 and 21% of the samples analysed.

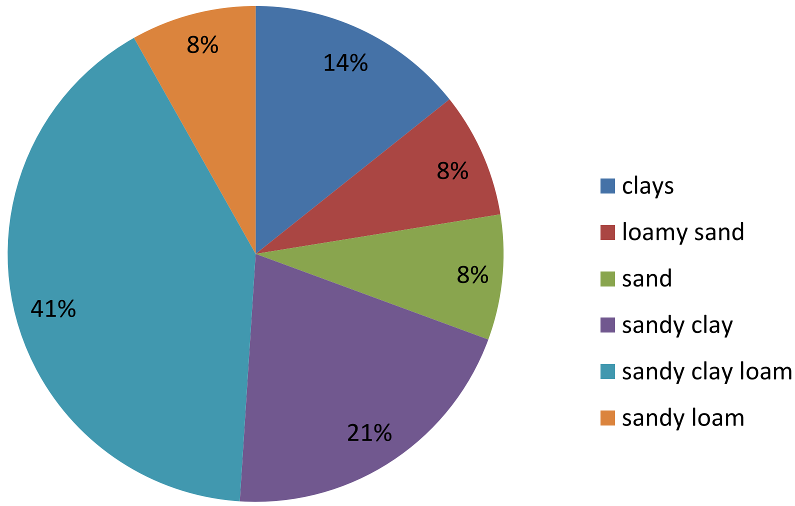

FIGURE 12. SOIL TEXTURE DISTRIBUTION

3.2.2. Soil fertility characteristics

Soil pH

The optimum soil pH for sugarcane is about 6.5-7 (Barnes, 1974; Sugarcane Production Handbook, 2001). However, sugarcane can grow in soils with pH in the range of 5 to 8.5 (NETAFIM, 2017).

The soil pH of the study area ranges from 5.0 to 8.6 (Table 2). The average soil pH is 6.6. About 15% of the samples analysed have soil pH values less than 6.2 while about 75% of analysed samples have pH values below 6.9.

The frequency distribution of soil pH is depicted on Figure 13 where pH values around 6.5 occur more frequently.

High soil pH are recorded in soil units around Kaole and south Lukindu areas. Soil profile LUK_P2 representing *Res* soil unit has soil pH higher than 7 throughout the depth but not exceeding 7.4. Soil profile LUK_P3 representing *mbuga* soil unit around Lukindu has soil pH higher than 7 in the subsoil and increase with depth. Calcites were observed below 100 cm depth and are responsible for the higher soil pH reaching above 8. The subsoils of soil profile KAO_P1 are also having pH above 7, reaching 8 below 180 cm depth. These soil units may result to micronutrients deficiencies to the sugar cane due to high soil pH.

TABLE 2. SOIL PH STATISTICS

Variable	Mean	Minimum	Q1	Q3	Maximum	Range
pH (H_2O)	6.6	5.0	6.2	6.9	8.6	3.6

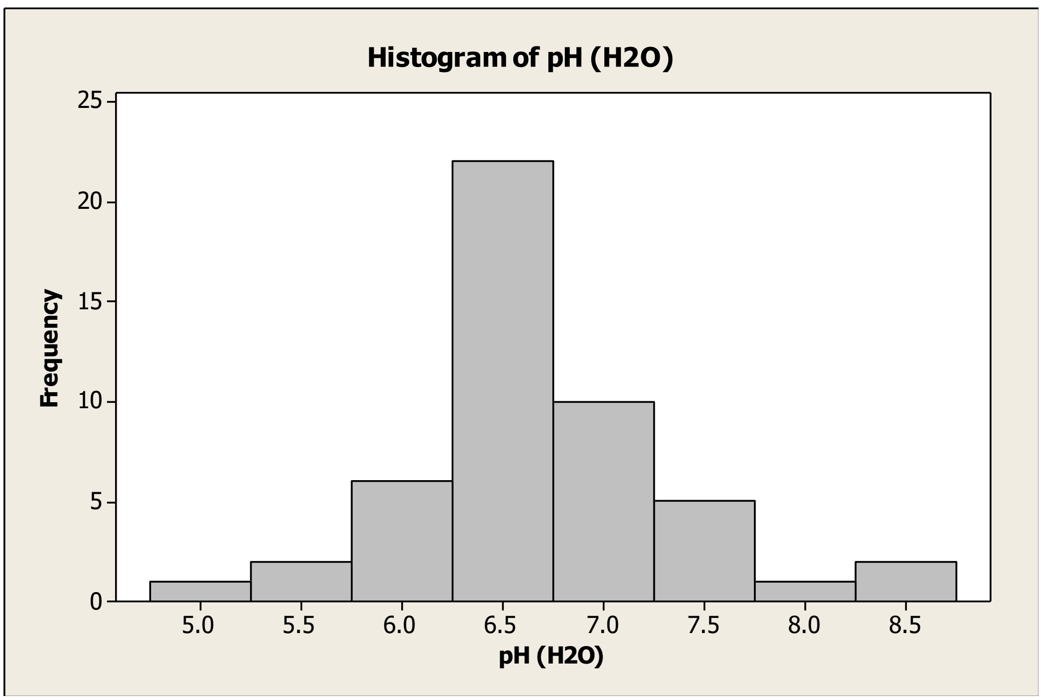

FIGURE 13. SOIL PH VALUES FREQUENCY

Electrical conductivity (EC)

The electrical conductivity (EC) values are used to estimate salinity problems. Samples with EC values above 1500 uS/cm can be suspected to have salinity problems. The values of all samples from the study area have EC values ranging from 92.6 to 840 uS/cm (Table 3). These values are indicating no salinity problem that would affect sugar cane production in any of the sampled soil units in the study area.

TABLE 3. ELECTRICAL CONDUCTIVITY STATISTICS

Variable	Mean	Minimum	Q1	Q3	Maximum	Range
EC (uS/cm)	92.6	12.4	21.1	65.8	840	827.6

Soil organic carbon

The soil organic carbon which is determined as a proxy to soil organic matter is important in improving soil structure, cation exchange capacity (CEC), nutrient addition through decomposition and mineralization and soil colour among other things. Soil organic carbon values below 1.25% are considered low, and 3.5% is considered high (Landon, 1991).

According to the values obtained from the samples, over 70% (Figure 14) of the samples have organic carbon values which are considered low to very low and the rest have medium values

Addition of soil organic matters in different forms (e.g. organic fertilizers) will improve the soil organic carbon to enable the soil get the benefits mentioned above. This needs to be done in all soil units.

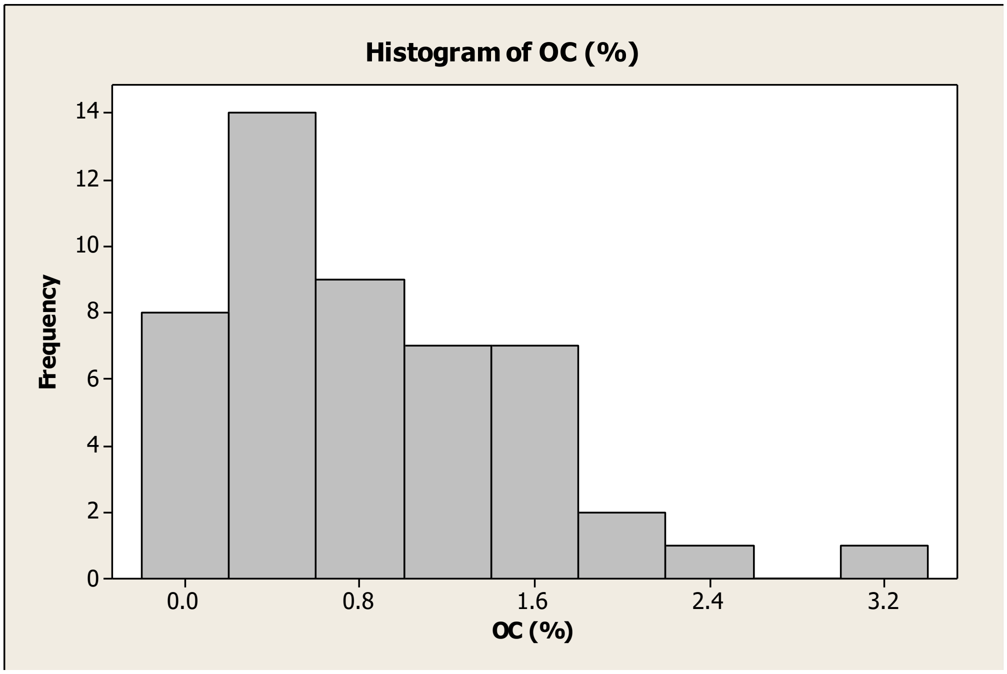

FIGURE 14. SOIL ORGANIC CARBON VALUES FREQUENCY

Total Nitrogen (TN)

Total nitrogen values below 0.2% are considered low (Isitekhale et al., 2014). The highest value of the total nitrogen in the study area was recorded to be 0.2% (Table 4, Annex 2). The levels of nitrogen are therefore generally low with over 75% of the analysed samples having total nitrogen values between 0.03 and 0.1% (Figure 15).

Nitrogen containing fertilizers will therefore need to be applied for a good yield of sugar cane in all studied soil units. Application rates will depend on the cultivar as they differ in uptakes.

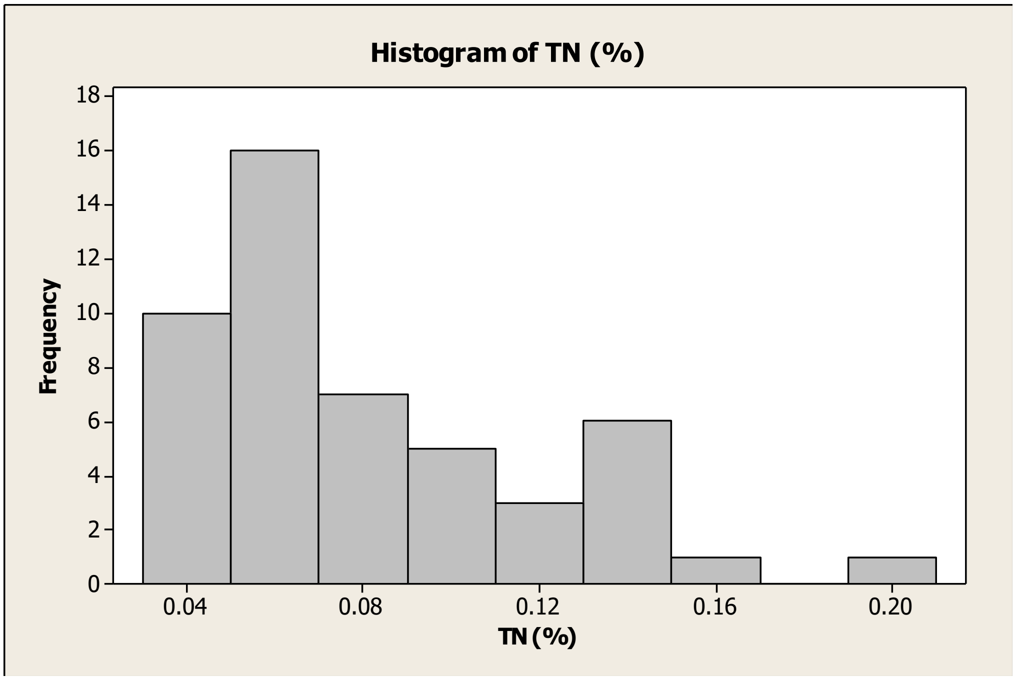

FIGURE 15. TOTAL NITROGEN VALUES FREQUENCY

TABLE 4. TOTAL NITROGEN STATISTICS

Variable	Mean	Minimum	Q1	Q3	Maximum	Range
TN (%)	0.07694	0.03	0.05	0.1	0.2	0.17

Available phosphorus (P)

Available phosphorus below 7 mg/kg is considered low (landon, 1991). Over 75% of soil samples analysed have low available phosphorus (Table 5). The soil units around Kwadoli and Mzambarauni have relatively higher available soil phosphorus compared to those around Kanga, Lukindu and Kaole. KWAD_P1 (soil unit *ARs*) has medium amount of available phosphorus throughout the depth. KWAD_P2 (soil unit *ColAl_1*) topsoil has high (18 mg/kg) phosphorus, while the subsoils have low amount. KWAD_P3 (soil unit *ColAl & VertSS*) topsoil has the highest amount of available phosphorus (43.7 mg/kg), while MZA_P1 (soil unit *mbuga*), the soil immediately below the topsoil has medium amount (11.8 mg/kg)

The soils in Kanga, Kaole, and Lukindu will generally require higher amount of phosphorus application, while those of Lusanga, Kwadoli and Mzambarauni will generally require less amounts.

TABLE 5. AVAILABLE PHOSPHORUS STATISTICS

Variable	Mean	Minimum	Q1	Q3	Maximum	Range
Available P (mg/kg)	4.51	0.19	0.865	5.67	43.75	43.56

Exchangeable Potasium (K)

Potassium is essential for plant growth and photosynthesis by being involved in chlorophyll development in the leaves. Potassium promotes root development and allows plants to take up water and nutrients (Rashid et al., 1990).

About 60% of samples have potassium value below 0.25 (Cmol (+)/kg) which is considered low in loamy soils (Landon, 1991). Adequate values are from 0.8 Cmol(+)/kg and above.

The subsoils of all units have been recorded to have low potassium contents comparing to the topsoils (Appendix 2). Soils with high potassium content in their topsoils are LUS_A1 (*HL, SS & NR* soil unit) with 0.75 Cmol(+)/kg; MZA_P1 (*mbuga* soil unit) with 0.97 Cmol(+)/kg; LUK_P2 (*Res* soil unit) with 0.65 Cmol(+)/kg; KWAD_P2 (*ColAl_1 and ColAl_2* soil units) with 0.91 Cmol(+)/kg and KWAD_P3 (*ColAl & VertSS* soil unit) with 1.25 Cmol(+)/kg. Generally soils representing soil units of Mzambarauni, Lusanga and Kwadoli areas have higher topsoil potassium values comparing to the rest.

Exchangeable Calcium

Calcium is essential for the growth and development of the spindle, leaves and roots. Calcium comprises part of the cell walls, thus strengthening the plant. The nutrient plays an important role in nitrogen metabolism. For sustainable cane yield, 1.5 cmol(+)/kg Ca has been established as the safety value below which soil calcium should not be allowed to fall (Roy et al., 2006).

Most of the soils samples have calcium values above 1.5 Cmol(+)/kg (Fig…) except the sandy subsoils of KWAD_P1 (Appendix 2).

Magnesium (Mg)

Magnesium is an essential constituent of chlorophyll where photosynthesis takes place to underpin sugar production and other growth processes. Magnesium is needed for movement of phosphorus in the plant and is involved in plant respiration and protein synthesis (Muhammad et al., 2000). Magnesium deficiency generally occurs when levels fall below 0.5 cmol(+)/kg (Roy et al., 2006). Excessive levels of soil magnesium may interfere with the uptake of potassium by the plant. Fovourable Mg/K ratios for most crops are in the range of 1 to 4.

Magnesium is in adequate levels in all soil units except the subsurface soils of KWAD_P1 (ARs soil unit) and KWAD_P2 (*ColAl_1 and ColAl_2* soil units) where it is in low amount below 1.5 Cmol(+)/kg. It is also low in the topsoil of LUK_P1 (*Fan* soil unit). Over 75% of sampled soils have adequate levels of Magnesium for sugar cane production.

Sodium

Sodium helps in osmo-regulation in plants and may act as a substitute in case of potassium deficiency. Sodium does not need to be applied to sugarcane but needs to be reduced when the levels are high. High sodium causes destruction of soil structure and imbalances in the Na/K, Na/Ca, Na/Mg ratios and may cause salt injury to sugarcane (Marschner, 1986).

The sodium levels in the studied units are generally low and have no effect to sugar cane production. However, subsoils of mbuga soils were found to have high sodium levels leading to sodic soils. In MZA_P1, soils below 68 cm were having high sodium leading to strong sodic (Exchangeable sodium percentage (ESP) = 19.4) and very strong sodic (ESP = 27.8) soils. In the LUK_P3, soils below 39 cm were also classified as very strong sodic (ESP = 23.3 and 31.9)

Cation exchange capacity (CEC)

The CEC values signify the ability of the soil to retain nutrients. Soils with low CEC hold little nutrients, and if fertilizers are applied the nutrients can easily be leached beyond the root zone because they are not retained by the soil. Fine textured soils especially the 2:1 clays have higher CEC than the coarse soils. Also soils with high soil organic matter have higher CEC values than those with low soil organic matter.

CEC values below 12 Cmol(+)/kg are considered low (Landon). About 50% of studies soils have high CEC (Appendix 2) High CECs are recorded in soil units represented by KAN_P1 (*Ms & Ds* soil unit), LUS_A1 (*HL, SS & NR* soil unit), KAO_P1 (*HWT* soil unit), KAO_A1 (*Gl_1* soil unit), MZA_P1 and LUK_P3 (*mbuga* soil units). High CECs are also recorded on clayey subsoils of KWAD_P1 (ARs soil units) and KWAP_P3 (*ColAl & VertSS* soil unit)

4.0. OBSERVED SOIL UNITS' CONSTRAINTS AND SOLUTIONS

List of constraints observed in the studied soil units and proposed solutions are shown on Table 6.

As shown in the Table, some nutrients are deficient in some soil units and will need to be applied for optimum performance of sugar cane. Application rates will depend on the type of sugar cane cultivar, application method and target of yield. Nitrogen is a common constraint to all soil units. This is a mobile nutrient in soil and need to be applied as per the demand of crop cultivar.

Application of soil organic matter will solve a number of problems in the long run for soils of this area. It will increase soil fertility through decomposition and release of plant nutrients. It will improve soil CEC and thus ability of soil to retain nutrients. It will improve soil structure. It will improve soil microbiology. It will improve soil colour and thus improve soil microclimate.

Soil unit *ARs* has sandy subsoil. This may lead to quick water loss and compaction if heavy machinery is used for farm activities. Efforts should be concentrated in maintaining and improving the quality of the topsoil by improving soil organic matter. Minimum mechanization is also advised.

The *mbuga* soil units have two major constraints: heavy clays and sodic subsoils. Heavy clays limit workability as they are very hard when dry and very sticky and slippery when wet. Apart from developing cracks when dry - which damages roots, this type of soil also holds soil moisture tightly, challenging the availability to plant roots. Sodic soils can be ameliorated by controlling soil moisture as indicated in the table.

TABLE 6. LIST OF CONSTRAINTS AND PROPOSED SOLUTIONS

S/N	Soil unit	Constraint to sugar cane production	Proposed solution
1	HL & SS	Steep slopes and shallow soils	Leave the unit under trees and natural vegetation
2	HL; SS & NR	Steep slopes and shallow soils; low N, low CEC	Conserve the steep slope, apply soil organic matter to increase CEC, apply fertilizers to supply deficient nutrients
3	ARs	Sandy subsoil, flooding, low N, low CEC	Minimum tillage, apply soil organic matter to increase CEC, apply fertilizers to supply deficient nutrients
4	ColAl_1	low N, low CEC	Apply soil organic matter to increase CEC, apply fertilizers to supply deficient nutrients
5	ColAl_2	low N, low CEC	Apply soil organic matter to increase CEC, apply fertilizers to supply deficient nutrients
6	ColAl & VertSS	Clayey subsoil, low N	Control amount of water to avoid flooding, apply fertilzers to supply nutrients
7	Mbuga	Clayey soil, sodic subsoil, low P, low N	Encourage infiltration or flash soil using uncontaminated water, apply fertilizers to supply deficient nutrients
8	Ms & Ds	Low P, low N, low CEC	Apply soil organic matter to increase CEC, apply fertilizers to supply deficient nutrients
9	Gl_1	Low P, low N, low CEC	Apply soil organic matter to increase CEC, apply fertilizers to supply deficient nutrients
10	Gl_2	Low P, low N	Apply fertilizers to supply deficient nutrients
11	Fan	Compacted soil, low P, low N, low CEC	Subsoiling, apply soil organic matter to increase CEC, apply fertilizers to supply deficient nutrients
12	Res	Low P, low N, low CEC	Apply soil organic matter to increase CEC, apply fertilizers to supply deficient nutrients
13	HWT	Low P, low N	Apply fertilizers to supply deficient nutrients

5.0. CONCLUSIONS

The site proposed to supply sugar cane for new sugar industry has 13 major soil units.

Except for the mountainous and steep slope unit, the other units are generally suitable for sugar cane production. However, measures such as subsoiling, fertilizer application and minimum tillage in some units need to be applied to optimize production.

The soils have been classified to five major soil groups: Fluvisols, Umbrisols, Vertisols, Cambisols and Phaeozems.

Soils of areas influenced by Nguu Mountains and river Mjonga i.e. Kwadoli, Mzambarauni and Lusanga areas have better soil qualities for sugar cane production than those in Kanga area, specifically those of Lukindu area.

6.0. REFERENCES

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7.0. APPENDICES

APPENDIX 1. SOIL MORPHOLOGICAL CHARACTERISTICS

Profile number : KWAD_P1 Mapping unit: *ARs*
Region : Morogoro
District : Mvomero
Map sheet no. :
Coordinates : 6.05050 S 37.62341 E
Location : Kwa Agustino area, Kwadoli village, near River Mjonga, Turiani
STR: isohyperthermic SMR: udic
Elevation : m asl.
Parent material: alluvial
Landform: Flood plain of river Mjonga.
Slope: 2 %; straight
Surface characteristics : Erosion: none. Deposition: evident.
Natural drainage class : somewhat well drained. Vegetation: reeds, grasses
Land use: abondoned sugar cane fields.
Ground water level:
Stratifications visible
Burried surface horizon visible at 100 cm

Described by Boniface H J Massawe and Louis Mdoe on 26/7/2018

Ap 0 - 20 cm: very dark greyish brown (10YR 3/2) dry, black (10YR2/1) moist; loamy sand; soft friable, slightly sticky slightly plastic; weak fine granular, many fine pores, many fine roots; clear wavy boundary to

BC 20 - 38 cm: reddish brown (5YR 5/3) dry, dark reddish brown (5YR3/2) moist; sand; soft friable, non sticky non plastic; weak fine granular, many fine pores, many fine roots; abrupt smooth boundary to

C1 38 - 50 cm: light reddish brown (5YR 6/3) dry, reddish brown (5YR4/3) moist; sand; loose, non sticky non plastic; single grain, many fine pores, few fine roots; abrupt smooth boundary to

C2 50 - 73 cm: pinkish grey (5YR 6/2) dry, reddish brown (5YR5/3) moist; sand; loose, non sticky non plastic; single grain, many fine pores, few fine roots; abrupt smooth boundary to

C3 73 - 100 cm: reddish brown (5YR5/3) moist; sand; loose, non sticky non plastic; single grain, many fine pores, very few fine roots; common medium faint yellowish brown mottles; abrupt smooth boundary to

Ab 100 - 112 cm: brown (7.5YR5/2) moist; sand; friable, non sticky slightly plastic; weak fine granular; many fine pores, very few fine roots; common medium distinct yellowish brown mottles; clear smooth boundary to

Bg1 112 - 125 cm: dark brown (7.5YR3/2) moist; sandy loam; friable, non sticky slightly plastic; moderate medium subangular blocky; many fine pores, very few fine roots; many medium distinct reddish brown mottles; many mica flakes; clear smooth boundary to

Bg2 125 - 150+ cm: black (7.5YR2.5/1) moist; clay; friable, slightly sticky slightly plastic; moderate medium subangular blocky; common fine pores, very few fine roots; few fine faint reddish brown mottles; many mica flakes

Profile number : KWAD_P2 Mapping unit: *ColAl_1*
Region : Morogoro
District : Mvomero
Map sheet no. :
Coordinates : 6.05048 S 37.63248 E
Location : Kwadoli village, at Mr Kisome farm towards river Mjonga, Turiani
STR: isohyperthermic SMR: ustic
Elevation : m asl.
Parent material: colluvio-alluvial
Landform: Flood plain of river Mjonga.
Slope: 2 %; straight
Surface characteristics : Erosion: slight sheet erosion. Deposition: evident.
Natural drainage class : somewhat well drained.Vegetation: maize
Land use: maize fields.
Ground water level: 112 cm
Stratifications visible at deeper soil depths

Described by Boniface H J Massawe and Louis Mdoe on 26/7/2018

Ap 0 - 17 cm: dark greyish brown (10YR 4/2) dry, black (10YR2/1) moist; sandy clay loam; hard dry, friable moist, slightly sticky slightly plastic wet; moderate medium subangular blocky, common fine pores, many fine few medium roots; many mica; diffuse smooth boundary to

A2 17 - 50 cm: dark greyish brown (10YR 4/2) dry, black (10YR2/1) moist; loamy sand; hard dry, friable moist, slightly sticky slightly plastic wet; moderate medium subangular blocky, many fine pores, many fine roots; few mica; clear smooth boundary to

AC 50 - 61 cm: very dark grey (10YR3/2) moist; sandy clay loam; loose, friable moist, non sticky non plastic wet; weak, fine, granular to single grain; many fine pores; very few fine roots; clear smooth boundary to

C1 61 - 80 cm: brown (7.5YR4/3) moist; loamy sand; loose, non sticky non plastic; weak fine granular to single grain, many fine pores, few fine roots; clear smooth boundary to

C2 80 - 103 cm: dark brown (10YR3/3) moist; sand; loose, non sticky non plastic; weak fine granular to single grain, many fine pores, few fine roots; few mica present; clear smooth boundary to

Profile number : KWAD_P3 Mapping unit: *ColAl & VertSS*
Region : Morogoro
District : Mvomero
Map sheet no. :
Coordinates : 6.06599 S 37.64052 E
Location : Kwadoli village, near Kwadoli Primary School, Turiani
STR: isohyperthermic SMR: ustic
Elevation : m asl.
Parent material: alluvio-colluvium.
Landform: Valleys between hills.
Slope: 2 %; concave - convex
Surface characteristics : Erosion: none or slight. Deposition: evident.Natural drainage class : well drained.Vegetation: elephant grass and sugar cane
Land use: abandoned sugar cane field.
Ground water level: 140 cm

Described by Boniface H J Massawe and Louis Mdoe on 26/7/2018

Ap 0 - 33 cm: dark grayish brown (10YR4/2) moist; sandy clay loam; friable moist, slightly sticky and slightly plastic wet; moderate medium granular and sub angular blocks; many fine and medium pores; many fine and medium roots; few mica flakes; clear smooth boundary to

Bss1 33 - 62 cm: dark brown (10YR3/3) moist; clay; firm moist, very sticky and very plastic wet; strong medium wedge and medium subangular blocky with slinkesides; few medium distinct brownish mottles, many fine, few coarse and medium (cracks) pores; many fine roots; few mica flakes; diffuse smooth boundary to

Bss2 62 - 86 cm: very dark greyish brown (10YR3/2) moist; clay; firm moist, very sticky and very plastic wet; moderate medium wedge and subangular bocky with slinkesides; many medium distinct yellowish brown mottles; many fine and medium (cracks) pores, few medium pores; frequent small spherical hard nodules; many fine roots; few manganese spots and few mica flakes; clear smooth boundary to

Bg1 86 - 107 cm: dark yellowish brown (10YR4/4) moist; sandy clay; slightly friable moist, sticky and plastic wet; moderate medium subangular blocks; abundant medium distinct yellwish brown mottles; many fine pores; few manganese spots, many mica flakes; many fine roots; clear smooth boundary to

Bg2 107 – 150+ cm: reddish brown (5YR4/3) moist; sandy clay loam; friable moist, non sticky and non plastic wet; weak fine granular; many medium distinct reddish brown mottles; many fine and medium pores; many mica flakes; few fine roots;

Profile number : MZA_P1 Mapping unit: *mbuga*
Region : Morogoro
District : Mvomero
Map sheet no. :
Coordinates : 6.08214 S 37.62837 E
Location : Dibago area, Mzambarauni village, at Mr Msuya's farm, Turiani
STR: isohyperthermic SMR: udic
Elevation : m asl.
Parent material: alluvio-colluvium.
Landform: Valleys between hills.
Slope: 2 %; concave
Surface characteristics : Wide cracks due to vertic characeristics. Erosion: none. Deposition: evident.
Natural drainage class : somewhat well drained.Vegetation: rice
Land use: rice field.
Ground water level:

Described by Boniface H J Massawe and Louis Mdoe on 26/7/2018

Ap 0 - 19 cm: black (10YR2/1) moist; clay; hard dry, friable moist, sticky and plastic wet; moderate and strong medium granular; many medium pores; common fine distinct yellowish mottles; many fine and medium roots; diffuse smooth boundary to

Bss 19 - 68 cm: black (10YR2/1) moist; clay; hard dry, friable moist, sticky and plastic wet; strong and moderate medium few granular and wedge to subangular blocky with few slinkensides; few medium faint reddish brown mottles; many medium pores; many fine roots; clear smooth boundary to

Bssg1 68 - 120 cm: very dark grey (10YR3/1) moist; clay; hard dry, friable moist, sticky and plastic wet; strong and moderate medium wedge with slinkensides; few fine faint light brown mottles; common fine and medium pores; few fine roots; clear smooth boundary to

Bssg2 120 – 150+ cm: grayish brown (10YR5/2) moist; clay; hard dry, friable moist, sticky and plastic wet; strong medium wedge with slinkensides; many medium distinct yellowish brown mottles; many fine and medium pores; very few very fine roots

Profile number : LUK_P1 Mapping unit: *Fan*
Region : Morogoro
District : Mvomero
Map sheet no. :
Coordinates : 6.02500 S 37.74010 E
Location : Lakiloya's farm, Lukindu area, Kanga village, Turiani
STR: isohyperthermic SMR: ustic
Elevation : m asl.
Parent material: colluvio-alluvial
Landform: fan
Slope: 2 %; straight
Surface characteristics :
Erosion: slight sheet erosion. Deposition:
Natural drainage class : well drained.
Vegetation: grasses, coconut trees
Land use: fallow field.
Ground water level: 70 cm

Described by Boniface H J Massawe and Louis Mdoe on 27/7/2018

Ap 0 - 22 cm: dark greyish brown brown (10YR4/2) dry, very dark greyish brown (10YR3/2) moist; sandy loam; slightly hard dry, friable, slightly sticky and slightly plastic wet; moderate medium subangular blocky, many fine pores; many fine roots; diffuse smooth boundary to

Bw 22 - 50 cm: brown (7.5YR4/3) dry, dark brown (7.5YR3/2) moist; sandy loam; slightly hard dry, friable, slightly sticky and slightly plastic wet; weak medium subangular blocky, many fine pores; common fine roots; clear smooth boundary to

BC1 50 - 94 cm: red (2.5YR4/6) dry, reddish brown (2.5YR4/4) moist; sandy clay; hard dry, friable, sticky and plastic wet; weak medium granular, few fine pores; few fine roots; very gravely; clear wavy boundary to

BC2 94 - 128 cm: red (2.5YR4/6) moist; sandy clay; slightly hard dry, friable, sticky and plastic wet; weak medium granular, few fine pores; few fine roots; gravely; clear wavy boundary to

C 128 - 145+ cm: red (2.5YR4/6) moist; sandy clay; slightly hard dry, friable, sticky and plastic wet; saprolite

Profile number : LUK_P2 Mapping unit: *Res*
Region : Morogoro
District : Mvomero
Map sheet no. :
Coordinates : 6.02658 S 37.76043 E
Location : Malenga area, Kanga village, Turiani
STR: isohyperthermic SMR: ustic
Elevation : m asl.
Parent material: colluvium
Landform: plain
Slope: 2 %; convex, complex
Surface characteristics :
Erosion: slight sheet and rill erosion. Deposition: none.
Natural drainage class : well drained.
Vegetation: grasses
Land use: maize field.
Ground water level:
Presence of 1:1 clays?

Described by Boniface H J Massawe and Louis Mdoe on 27/7/2018

Ap 0 - 20 cm: dark brown (7.5YR3/3) dry, very dark brown (7.5YR2.5/2) moist; sandy clay loam; slightly hard dry,friable moist, slightly sticky and slightly plastic wet; moderate medium subangular blocky, many fine pores; few coarse, many fine roots; clear smooth boundary to

BA 20 - 60 cm: dark red (2.5YR3/6) dry, dark reddish brown(2.5YR3/4) moist; sandy clay; hard dry,friable moist, sticky and plastic wet; moderate medium granular and subangular blocky, many fine pores; many fine roots; diffuse smooth boundary to

BO 60 - 158 cm: red (2.5YR4/6) dry, dark red (2.5YR3/6) moist; sandy clay; slightly hard dry,friable moist, sticky and plastic wet; moderate medium granular and subangular blocky, common fine pores; many fine roots; abrupt smooth boundary to

Stone line with quarts and manganitic materials 158 – 160+ cm

Profile number : LUK_P3 Mapping unit: *mbuga*
Region : Morogoro
District : Mvomero
Map sheet no. :
Coordinates : 6.03544 S 37.77799 E
Location : Dikulunya area, Kanga village, Turiani
STR: isohyperthermic SMR: ustic
Elevation : m asl.
Parent material: colluvio-alluvial
Landform: Flood plain/depression
Slope: 2 %; straight
Surface characteristics : cracks
Erosion: slight sheet erosion. Deposition: evident.
Natural drainage class : somewhat poorly drained.
Vegetation: acacia, grasses
Land use: fallow, grazing, sugar cane history.
Ground water level:

Described by Boniface H J Massawe and Louis Mdoe on 27/7/2018

Ap 0 - 17 cm: very dark brown (10YR2/2) dry, black (10YR2/1) moist; sandy clay loam; very hard dry,friable moist, very sticky and very plastic wet; moderate medium granular and subangular blocky, many fine and medium pores; many fine roots; diffuse wavy boundary to

BA 17 - 39 cm: very dark brown (10YR2/2) dry,black (10YR2/1) moist; sandy clay; very hard dry, slightly firm moist, very sticky and very plastic wet; moderate medium subangular blocky, few medium (cracks) and common fine pores; few fine roots; diffuse clear boundary to

Bss 39 - 100 cm: very dark brown (10YR2/2) dry,black (10YR2/1) moist; sandy clay; very hard dry, slightly firm moist, very sticky and very plastic wet; moderate medium subangular blocky and wedge, few medium (cracks) and common fine pores; very few fine roots; diffuse clear boundary to

Bssk 100 - 140+ cm: dark grey (10YR4/1) moist; sandy clay; very hard dry, firm moist, very sticky and very plastic wet; moderate medium subangular blocky and wedge, few medium (cracks) and common fine pores; very few fine roots; calcic materials present

Profile number : KAN_P1 Mapping unit: *Gl_1*
Region : Morogoro
District : Mvomero
Map sheet no. :
Coordinates : 6.00889 S 37.74952 E
Location : Mr Waziri’s farm towards Kanga Hills Secondary School, Kanga village, Turiani
STR: isohyperthermic SMR: udic
Elevation : m asl.
Parent material: colluvio-alluvial
Landform: valley
Slope: 2 %; straight
Surface characteristics :
Erosion: none. Deposition: evident.
Natural drainage class : somewhat poorly drained.
Vegetation: grasses
Land use: rice field.
Ground water level: 70 cm

Described by Boniface H J Massawe and Louis Mdoe on 27/7/2018

Ap 0 - 13 cm: very dark greyish brown (10YR3/2) moist; sandy clay loam; slightly hard dry, soft moist, slightly sticky and slightly plastic wet; moderate medium granular, few fine faint reddish brown mottles; many fine pores; many fine roots; clear smooth boundary to

AB 13 - 26 cm: very dark brown (10YR2/2) moist; sandy clay loam; slightly hard dry, soft moist, slightly sticky and slightly plastic wet; moderate medium sub angular blocky; many medium distinct reddish brown mottles; many fine pores; many fine roots; clear smooth boundary to

Bg1 26 - 47 cm: very dark grey (10YR3/1) moist; sandy clay loam; slightly hard dry, soft moist, slightly sticky and slightly plastic wet; moderate medium sub angular blocky; many medium distinct reddish brown mottles; many fine pores; few fine roots; Ferromagnesia spots; clear smooth boundary to

Bg2 47 - 68 cm: dark grey (10YR4/1) moist; sandy clay loam; slightly hard dry, soft moist, slightly sticky and slightly plastic wet; moderate medium sub angular blocky; many medium distinct reddish brown mottles; many fine pores; very few fine roots; Ferromagnesia spots; clear smooth boundary to

Bg3 68 - 87 cm: dark grey (5Y4/1) moist; sandy clay loam; slightly hard dry, soft moist, sticky and plastic wet; moderate medium sub angular blocky; common medium distinct reddish brown and brownish mottles; few fine pores; very few fine roots; clear smooth boundary to

Bg4 87 - 120+ cm: grey (5Y5/1) moist; sandy clay; slightly hard dry, soft moist, sticky and plastic wet; moderate medium sub angular blocky; common medium distinct reddish brown and yellowish brown mottles; few fine pores; very few fine roots

Profile number : KAO_P1 Mapping unit: *HWT*
Region : Morogoro
District : Mvomero
Map sheet no. :
Coordinates : 6.05463 S 37.73266 E
Location : Gezaulole area, Kaole village, Turiani
STR: isohyperthermic SMR: udic
Elevation : m asl.
Parent material: colluvio-alluvial
Landform: Flood plain
Slope: 2 %; concave
Surface characteristics : Erosion: none. Deposition: evident.
Natural drainage class : somewhat poorly drained.
Vegetation: rice
Land use: rice fields.
Ground water level: 84 cm

Described by Boniface H J Massawe and Louis Mdoe on 27/7/2018

Ap 0 - 50 cm: black (10YR2/1) moist; sandy clay loam; friable moist, slightly sticky slightly plastic wet; moderate medium granular and subangular blocky, few fine faint yellowish brown mottles; many fine pores; many fine roots; diffuse smooth boundary to

Bg1 50 - 96 cm: very dark grey (7.5YR3/1) moist; sandy clay loam; friable moist, slightly sticky slightly plastic wet; moderate medium subangular blocky, few fine faint yellowish brown mottles; common fine pores; few fine roots; diffuse smooth boundary to

Bg2 96 - 137 cm:dark greyish brown (2.5Y4/2) moist; sandy clay loam; friable moist, slightly sticky slightly plastic wet; moderate medium subangular blocky, few fine faint yellowish brown mottles; common fine pores; very few fine roots; abrupt smooth boundary to

Cg 137 - 156+ cm: darg grey (10YR4/1) moist; sandy clay loam; sticky and plastic wet; few fine pores; very few fine roots;

APPENDIX 2. CHEMICAL PROPERTIES OF THE STUDIED SOILS

S/N	Sampling reference	Horizon	Depth (cm)	Textural class	pH (H2O)	EC (uS/cm)	OC (%)	TN (%)	P-Bray (mg/kg)	Ca (Cmol/kg)	K (Cmol/kg)	Na (Cmol/kg)	CEC (Cmol/kg)	Mg (Cmol/kg)	Cu (mg/kg)	Zn (mg/kg)	Fe (mg/kg)	Mn (mg/kg)
1	KWAD_P1	Ap	0 - 20	LS	6.30	43.30	1.00	0.07	20.42	2.68	0.28	0.12	9.60	1.52	1.85	3.67	64.56	13.14
2	KWAD_P1	BC	20 - 38	S	6.69	31.30	0.09	0.04	6.93	0.97	0.11	0.11	6.20	0.55	0.49	0.47	46.67	2.73
3	KWAD_P1	C3	73 - 100	S	6.74	14.72	0.02	0.03	8.30	0.71	0.08	0.13	4.60	0.53	0.94	0.28	78.86	4.46
4	KWAD_P1	Ab	100 - 112	S	6.79	20.70	0.19	0.05	10.25	2.03	0.17	0.12	5.60	0.88	1.76	0.59	107.47	9.67
5	KWAD_P1	Bg1	112 - 125	SL	6.27	23.80	0.45	0.05	3.61	3.61	0.40	0.16	12.00	0.83	3.85	1.17	218.35	43.51
6	KWAD_P1	Bg2	125 - 150+	C	5.80	38.80	1.62	0.11	8.42	9.39	0.48	0.22	25.60	5.84	4.85	1.74	111.05	16.61
7	KWAD_P2	Ap	0 - 17	SCL	6.14	49.70	0.69	0.13	18.71	7.16	0.91	0.19	9.00	3.16	3.03	3.60	221.92	65.20
8	KWAD_P2	A2	17 - 50	LS	6.70	15.46	0.54	0.04	3.16	1.50	0.08	0.13	7.40	1.17	1.76	0.55	86.02	17.48
9	KWAD_P2	AC	50 - 61	SCL	5.01	26.20	1.40	0.10	1.90	5.45	0.26	0.18	16.20	3.26	3.67	0.74	196.89	60.86
10	KWAD_P2	C1	61 - 80	LS	6.89	16.50	0.17	0.03	3.47	2.29	0.10	0.14	6.00	1.10	1.85	0.63	57.40	15.74
11	KWAD_P2	C2	80 - 103	S	6.92	17.76	0.04	0.03	6.36	1.63	0.07	0.13	4.60	0.93	1.12	0.43	53.83	19.21
12	KWAD_P3	Ap	0 - 33	SCL	6.41	55.10	1.75	0.13	43.75	3.34	1.25	0.13	16.40	3.30	2.67	5.29	322.07	36.57
13	KWAD_P3	BSS1	33 - 62	C	6.17	62.20	0.94	0.10	0.19	8.21	0.76	0.20	30.40	5.38	3.21	0.74	43.10	60.86
14	KWAD_P3	BSS2	62 - 86	C	6.42	32.20	0.50	0.08	0.61	5.97	0.31	0.20	12.50	4.92	3.30	0.20	47.94	63.46
15	KWAD_P3	BG1	86 - 107	SC	6.77	21.50	0.51	0.06	0.53	5.05	0.20	0.18	8.30	3.87	2.67	0.86	57.40	61.73
16	KWAD_P3	BG2	107 - 150+	SCL	6.83	14.48	0.03	0.04	2.24	2.68	0.12	0.18	12.90	1.88	2.12	0.90	64.56	22.68
17	LUK_P1	Ap	0 - 22	SL	6.38	22.50	1.10	0.08	1.62	2.55	0.12	0.13	7.40	0.59	2.03	0.63	53.83	128.54
18	LUK_P1	Bw	22 - 50	SL	6.32	17.72	0.61	0.05	0.97	2.29	0.05	0.12	4.20	0.35	1.76	0.28	35.94	98.17
19	LUK_P1	BC1	50 - 94	SC	6.42	12.43	0.37	0.04	0.47	2.42	0.20	0.16	6.60	1.26	1.21	0.24	3.40	10.54
20	LUK_P1	BC2	94 - 128	SC	6.26	14.00	0.40	0.04	0.83	2.82	0.07	0.23	6.60	1.05	0.94	0.46	0.18	15.74
21	LUK_P1	C	128 - 145	SC	6.67	13.78	0.18	0.05	0.54	2.03	0.08	0.19	7.60	1.64	0.31	0.20	4.31	2.70
22	LUK_P2	Ap	0 - 20	SCL	7.27	37.00	1.33	0.10	2.18	4.00	0.65	0.16	11.00	1.48	1.21	1.28	25.77	174.52
23	LUK_P2	BA	20 - 60	SC	7.13	53.00	0.38	0.06	1.48	2.55	0.30	0.18	9.20	1.72	1.12	0.43	12.54	65.20
24	LUK_P2	BO	60 - 158	SC	7.43	14.66	0.31	0.05	1.19	1.89	0.04	0.19	6.20	1.19	0.31	0.20	4.67	14.01
25	LUK_P3	AP	0 - 17	SCL	6.54	34.00	1.70	0.13	3.16	4.66	0.13	0.51	19.40	4.09	1.49	0.74	171.85	46.98
26	LUK_P3	BA	17 - 39	SC	7.23	37.70	0.85	0.07	0.49	5.97	0.08	1.42	30.40	9.41	1.49	0.35	33.28	5.22
27	LUK_P3	BSS	39 - 100	SC	7.53	179.00	0.75	0.06	0.77	7.16	0.08	7.47	32.80	10.93	1.49	0.39	8.24	3.66
28	LUK_P3	BSSK	100 - 140	SC	8.62	370.00	0.82	0.03	0.77	8.08	0.03	8.94	28.40	10.34	1.40	0.35	3.24	8.17

Olsen P (mg/kg)

Appendix 1 (contd) Chemical properties of the studied soils

S/N	Sampling reference	Horizon	Depth (cm)	Textural class	pH (H2O)	EC (uS/cm)	OC (%)	TN (%)	P-Bray (mg/kg)	Ca (Cmol/kg)	K (Cmol/kg)	Na (Cmol/kg)	CEC (Cmol/kg)	Mg (Cmol/kg)	Cu (mg/kg)	Zn (mg/kg)	Fe (mg/kg)	Mn (mg/kg)
29	MZA_P1	Ap	0 - 19	C	6.20	153.30	3.28	0.20	5.90	8.34	0.97	1.01	41.40	8.18	1.67	1.20	93.17	11.40
30	MZA_P1	BSS	19 - 68	C	6.58	123.40	2.11	0.15	11.85	9.92	0.40	1.59	36.20	8.75	2.94	2.28	96.75	26.15
31	MZA_P1	BSSG1	68 - 120	C	5.85	376.00	0.59	0.08	1.56	6.50	0.27	7.99	41.20	9.87	3.39	0.78	79.42	9.82
32	MZA_P1	BSSG2	120 -150+	C	6.42	416.00	0.48	0.06	0.47	5.58	0.24	8.33	30.20	9.39	1.31	0.39	26.84	19.21
33	KAO_A1		0 - 20	SCL	5.45	276.00	1.72	0.11	0.77	3.74	0.06	0.57	14.80	3.76	2.03	1.63	289.88	71.27
34	KAO_A1		20 - 40	LS	5.71	440.00	1.13	0.09	1.67	3.34	0.04	0.88	15.80	4.92	2.30	1.59	186.16	64.33
35	KAO_A1		40 - 60	SCL	5.75	840.00	0.83	0.06	1.11	3.08	0.04	1.68	19.40	5.07	2.12	0.70	78.86	37.43
36	KAO_P1	Ap	0 - 50	SCL	6.32	78.40	2.20	0.14	2.13	4.66	0.11	0.43	23.00	4.94	3.21	2.25	207.62	92.10
37	KAO_P1	BG1	50 - 96	SCL	7.26	65.00	0.70	0.06	0.63	5.97	0.04	0.70	21.60	5.15	1.49	0.20	18.97	19.45
38	KAO_P1	BG2	96 - 137	SCL	7.75	66.60	0.31	0.05	1.05	6.63	0.03	0.70	21.80	4.37	1.40	0.35	11.46	28.76
39	KAO_P1	CG	137 - 156+	SCL	8.36	137.10	0.17	0.06	5.97	8.08	0.01	0.85	21.60	4.00	1.03	0.28	7.17	24.42
40	LUS_A1		0 - 20	SCL	6.67	43.80	1.68	0.13	4.18	4.13	0.75	0.20	14.80	2.14	3.76	2.36	182.58	97.30
41	LUS_A1		20 - 40	SCL	6.75	28.00	1.00	0.10	0.90	5.18	0.33	0.26	18.80	2.35	3.39	0.90	71.71	136.35
42	LUS_A1		40 - 60	SCL	7.13	22.70	0.48	0.06	4.99	2.29	0.23	0.25	10.20	1.83	1.49	0.51	51.88	92.10
43	LUS_A1		60 - 80	SL	7.31	15.64	0.37	0.04	3.50	1.63	0.22	0.22	9.40	1.55	1.40	0.43	42.94	53.92
44	KAN_P1	AP	0 - 13	SCL	6.70	32.20	1.01	0.12	6.13	1.76	0.23	0.31	14.20	3.74	1.76	3.90	232.65	33.96
45	KAN_P1	AB	13 - 26	SCL	6.25	27.20	1.55	0.13	5.44	2.42	0.05	0.32	14.20	3.76	1.85	3.63	214.77	33.96
46	KAN_P1	BG1	26 - 47	SCL	6.58	26.10	1.93	0.08	2.47	1.89	0.03	0.35	12.60	3.90	2.12	2.75	132.51	82.55
47	KAN_P1	BG2	47 - 68	SCL	6.79	21.70	1.29	0.06	3.27	2.29	0.03	0.32	13.60	4.28	2.03	2.36	96.75	79.95
48	KAN_P1	BG3	68 - 87	SCL	6.74	27.30	0.72	0.06	2.47	2.68	0.06	0.43	15.80	7.85	1.40	2.21	50.25	91.23
49	KAN_P1	BG4	87 - 120+	SC	6.49	31.80	0.41	0.08	1.40	2.29	0.05	0.44	16.20	5.58	0.94	1.05	26.13	16.15

Olsen P (mg/kg)