

Suitability Assessment of Arable Ferralitic Soils for Maize and Cassava Production in Uganda



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Abstract In Uganda, crop yields continue to decline due to soil degradation. This has led to large scale and continuous conversions of natural habitats into land for crop growing to feed the increasing human and livestock populations. The suitability of available arable soils for crop growth is critical for conservation of natural habitats. The study was aimed at ascertaining the suitability of Makerere University Agricultural Research Institute, Kabanyolo (MUARIK) arable soils for Maize (*Zea mays L.*) and Cassava (*Manihot esculenta*) production. A total of 30 composite samples were collected from 6 blocks and taken to Makerere University School of Agricultural Sciences (Soil, Water and Plant analytical laboratory) where soil physical and chemical properties were determined. Results show that the soils were generally acidic, with pH of 5.1 to 5.8. Soil Organic Carbon (SOC) and Nitrogen (N) were medium, while available P (Phosphorus) and Calcium (Ca) were deficient in the soil. Potassium (K) was low to high in content. The soil texture was clay. The soils at MUARIK are Ferrallitic (Oxisols). Analysis of variance showed that available P and soil pH were significantly different between the study blocks ($p < 0.05$). The rest of the soil properties were not significantly different across the site. The MUARIK soil's modest suitability for producing maize and cassava was determined through comparisons to the agronomic growth requirements for those crops. This soil's limited availability of P and K for growing maize is a severe constraint and the clayey texture and low calcium levels of the soils are a constraint for cassava growing.

Keywords Ferralsols · Arable land · Land degradation · Maize · Cassava

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1 Introduction

About 11% of the earth's surface is currently cultivated (1406 Mha) and about 24% is potentially arable, most of which (2500 Mha) is composed of acid soils, with 1700 Mha located in the humid tropics (Anusha et al. 2023). Thus, tropical acid soils, mainly Ultisols and Oxisols, represent the largest remaining soils potential for future agriculture. Acidity is a major determinant of soil fertility across the globe (Bharti et al. 2017; Ismaili et al. 2023). Given the effect of soil acidity on crop growth, such as aluminium toxicity, nutrient availability and microbial activities, a great challenge is likely to be encountered in future agriculture.

Almost 50% of the world's arable land is in Sub-Saharan Africa (SSA), yet only a small percentage of it meets the requirements for agricultural crop production. Present crop yields in Sub-Saharan Africa are low and frequently much below the potential yields due to water limitations and climate change effects (Badapalli et al. 2023). In many smallholder farms in the savannah zone of West Africa, for example, decline in soil fertility, resulting in low crop production, is a major reason affecting food security (Keson et al. 2023) because sustainable crop intensification cannot be achieved if farmers cultivate inherently infertile soils that are deficient in essential nutrients such as nitrogen and phosphorus (Soropa et al. 2019; Bhular et al. 2023). This under performance is due to several factors. FAO & ITPS (2015) pointed out ten of the threats to soil functions and they include: soil erosion, Soil Organic Carbon (SOC) loss, nutrient imbalance, soil acidification, soil contamination, water-logging, soil compaction, soil sealing, salinization and loss of soil biodiversity. In Sub-Saharan Africa, soil erosion is regarded as one of the primary causes of stagnant or declining agricultural output, the lack of proper supply of additional ecosystem services, as well as the depletion of soil organic matter, soil nutrients and soil biodiversity (Tamene and Le 2015). The effects of soil degradation are felt most keenly in developing nations where a sizeable section of the population depends directly on the land for their livelihoods, as is the situation in SSA (Tully et al. 2015). Ssali (2000) revealed that Uganda's soils were initially considered fertile and little was done to improve productivity in a systematic way. However, confirmatory research on land suitability evaluation frameworks with special focus on the significance of soils in crop cultivation is missing (Sharififar et al. 2016). Yet knowledge of the kind of soils and the extent of their distribution are pre-requisites in developing rationale and local level land use plans for agriculture, forestry and other land uses (Radocaj and Jurisic 2022). Semalulu and Kaizi (2015) noted the difficulties facing soil resources in general, including land degradation, a lack of understanding about good soil or land use practises, population pressure and soil pollution, among other issues. Continued land degradation is due to lack of environmental awareness among farmers, traditional agricultural practices, minimal inorganic fertilizer use and little to no use of improved crop varieties (Minai 2015). Proper interventions need to be undertaken to ensure that crop production is increased to match the rapidly increasing population of Uganda. One of such interventions is '**soil suitability evaluation**'. Soil suitability is a pre-requisite for sustainable agriculture and plays a pivotal role in crop

production, especially in degraded lands (Mustafa et al. 2016; Li et al. 2023). In this study, the suitability of arable ferralitic soils for the growth of Maize (*Zea mays* L.) and Cassava (*Manihot esculanta*) was assessed at Makerere University Agricultural Research Institute, Kabanyolo (MUARIK) by identifying the various physical and chemical characteristics of the soils and then comparing them with agronomic growth requirements for maize and cassava.

2 Materials and Methods

2.1 Description of the Study Area

MUARIK is located 21 km north of Kampala, the capital city of Uganda, along the Gayaza-Namulonge road on spatial coordinates 0°27'60"N, 32°36'24"E at an altitude range of 1250 to 1320 m above sea level. It receives an average annual precipitation of 1218 mm and slightly drier periods from June to July and December to February. The average annual temperature is 21.5 °C. Bananas are the main food crop and Robusta coffee is the main cash crop. Maize is the secondary cash crop and sweet potatoes are a secondary food crop (UBOS 2022). The vegetation is mainly forest savannah with pastures suitable for intensive livestock production.

2.2 Soil Sampling

Composite soil samples were collected following the standard procedures as explained in Okalebo et al. (2002). Sub-samples were collected to a depth of about 30 cm (effective rooting depth) from randomly selected locations and thoroughly mixed to obtain 5 representative composite samples from each block so that analysis of these samples gives average values for the entire block. Soil samples were collected using a hand hoe and trowel, placed in labelled plastic containers and transported to the laboratory for analysis. A total of 30 samples were collected from the 6 blocks in five (5) replicates (Table 1).

2.3 Laboratory Analyses

The soil samples were air-dried at room temperature for three consecutive days, sieved through a 2 mm sieve and then analysed for pH, organic carbon, available P, total N, exchangeable cations (Ca, Na and K) and texture. Soil pH was determined in a soil: water solution at a ratio of 1:2.5 using a pH meter. Available Phosphorus (P) was determined by using the Bray and Kurtz No. 1 method. The soil was extracted

Table 1 Soil samples collected at Makerere University Agricultural Research Institute Kabanyolo (MUARIK)

Block (s)	Soil samples				
A (Maize)	A1	A2	A3	A4	A5
B (Banana plantation)	B1	B2	B3	B4	B5
C (Cassava plot)	C1	C2	C3	C4	C5
S (Sorghum plot)	S1	S2	S3	S4	S5
W (Water melon plot)	W1	W2	W3	W4	W5
CB (Cassava-banana intercrop)	CB1	CB2	CB3	CB4	CB5

using Bray 1 solution and the P determined by the calorimetric procedure using a spectrophotometer. Soil texture was determined using the hydrometer method as described by Okalebo et al. (2002). The percentages of sand, silt and clay were obtained and the soil textural class ascertained using the textural triangle. Exchangeable K, Ca and Na were obtained by treating the soil samples with excess 1 M ammonium acetate solution. Later, the concentrations of exchangeable Na and K in the extract were measured by flame photometer and the concentration of Ca was measured by atomic absorption spectrophotometry. The Kjeldhal method of determining nitrogen was used due to its convenience and provision of fast results, while the quantitative Black and Walkley method of determining Total Organic Carbon (TOC) was used because of its accuracy and quick generation of results as outlined by Okalebo et al. (2002).

2.4 Data Analysis

Laboratory data on soil physical and chemical properties was entered into MS Excel to generate frequencies, means, standard errors of the means, coefficients of variation, percentages and correlation coefficients as explained by Tashayo et al. (2020). The data was fed into GenStat® (12th edition) statistical software and analysis done for one-way analysis of variance (ANOVA) (in randomised blocks) at 5% significance level to ascertain the significance of variations in soil properties between the blocks. Correlations were run to ascertain the strengths and directions of association between soil physical and chemical parameters.

3 Results and Discussion

3.1 Soil Chemical Properties

3.1.1 Soil pH

Soil pH ranged from 4.9 to 6.2 (Table 2). The average soil pH for the blocks was 5.5. Analysis of variance showed significant differences in soil pH between blocks (Table 3). Soil pH was generally moderately acidic. The results on soil pH concur with those of Okiror et al. (2017) and Majaliwa (1998) who reported MUARIK soils to be acidic; this is probably caused by one or a combination of factors such as crop removal (the depletion of basic cations in crop harvest), continuous cultivation practices, leaching of basic cations, continuous use of only two acidifying fertilizers (urea and di-ammonium phosphate) coupled with the decomposition of organic residues that produce organic acids such as carbonic acid (Radocaj and Jurisic 2022; Badapalli et al. 2023). Base-rich nutrients get absorbed by plants rapidly, while leaving acid concentration behind. Frequent cultivation may result in rapid decomposition of organic matter and weakening of soil structure, which later results into lowering of soil pH (Vasu et al. 2018). According to FAO (1998), moderately acidic soils may be deficient in phosphorus, calcium, magnesium and molybdenum; this may be the reason for low P and Ca in our study blocks. The low pH can also be attributed to rainfall that is naturally acidic because of the presence of carbonic acid, which results from the atmosphere's carbon dioxide and moisture; MUARIK is located near Kampala Capital City where the atmosphere has more sulphuric and nitric acids from burning fossil fuels and acid rains from the highly polluted city (UBOS 2022).

Table 2 Means of SOC, N and P in the different blocks at MUARIK

BLOCKS		SOC	N	P
	pH	%		ppm
A	5.57 ± 0.105	1.71 ± 0.010	0.20 ± 0.006	4.21 ± 2.060
B	5.43 ± 0.188	1.69 ± 0.218	0.20 ± 0.028	3.39 ± 1.172
C	5.83 ± 0.128	1.69 ± 0.102	0.21 ± 0.020	1.42 ± 0.338
S	5.76 ± 0.079	1.58 ± 0.214	0.21 ± 0.014	2.64 ± 0.841
W	5.51 ± 0.147	1.60 ± 0.110	0.19 ± 0.010	5.21 ± 1.485
CB	5.14 ± 0.131	1.42 ± 0.198	0.17 ± 0.005	12.11 ± 3.721
Grand mean	5.54	1.62	0.20	4.83
lsd (5%)	0.424	0.474	0.049	5.165
p-value	0.045	0.786	0.520	0.005
Critical levels*	5.5–6.5	1.5–3	0.12–0.25	15

*Okalebo et al. (2002)

Table 3 Summary of ANOVA for soil physical and chemical properties at MUARIK

Source of variation	df	pH	SOC	N	P	K	Na	Ca	sand	silt	clay
Sample	4	*	ns	ns	**	ns	ns	ns	ns	ns	*
Blocks	5										
Residual	20										
Total	29										

* and ** show significant differences at $\alpha = 0.05$ and $\alpha = 0.01$, respectively, and ns means not significant and df means degrees of freedom

According to Wanyama et al. (2021), maize cultivation may be feasible at a pH range of 5.0 to 8.0. The 5.1 to 5.8 pH range found in the soils at MUARIK indicates that these soils are excellent for producing maize. Yet according to Ogunde and Olanbo (2017) and Nanganoa et al. (2020), this soil pH is only moderately favorable for cassava production.

3.1.2 Soil Organic Carbon (SOC)

SOC ranged from 0.8 to 2.9% (Table 2). Block A had the largest mean SOC (1.7%), followed by Blocks B, W, S and CB which had the lowest SOC (1.4%). There were no significant differences in SOC between any of the sample blocks (Table 3). SOC was generally medium in content at MUARIK, according to classification of soil properties by Abegunde et al. (2015) (Table 4). SOC pool is the most reliable indicator for monitoring soil degradation, especially that caused by accelerated erosion (Lal 2015). According to Purnamasari et al. (2022), increase in the amount of clay increases the amount of carbon retained in soil because clay constitutes organo-mineral complexes. It combines with SOC in soil and helps to retain carbon within the soil for long periods. In this study, %clay and SOC had a significant negative correlation, meaning that the observed SOC cannot be attributed to the high clay content. Crop residues are normally used as animal feed during the dry season and also as a source of fuelwood; this has led to massive removal of crop residues (Bhullar et al. 2023). Climate also affects SOC content; according to Choudhary et al. (2023), SOC stocks increase based on annual precipitation and biomass amounts and decrease relative to temperature. Furthermore, high precipitation causes temperatures to decrease to some extent. SOC content decreases with increases in the annual temperature as reported by Sanchez et al. (2014) and Everest and Sungur (2021). Abagyeh et al. (2016) indicated that SOC level from 0.8% and above may be suitable for maize production. Since the SOC in this study ranges from 1.4 to 1.7%, it means that MUARIK soils are highly suitable for maize growing (Abegunde et al. 2015). However, this observed SOC is moderately suitable for cassava production according to Imakumbili et al. (2019).

Table 4 Average exchangeable bases (K, Na and Ca) at MUARIK

Block (s)	K	Na	Ca
	Cmol(+)/kg		
A	0.15 ± 0.025	0.05 ± 0.012	0.08 ± 0.004
B	0.21 ± 0.056	0.03 ± 0.002	0.08 ± 0.015
C	0.25 ± 0.025	0.04 ± 0.004	0.11 ± 0.016
S	0.15 ± 0.037	0.44 ± 0.409	0.25 ± 0.155
W	0.24 ± 0.054	0.04 ± 0.001	0.08 ± 0.005
CB	0.12 ± 0.011	0.04 ± 0.004	0.07 ± 0.009
Grand mean	0.18	0.11	0.11
lsd (5%)	0.117	0.490	0.192
p-value	0.148	0.445	0.390
Critical levels	2.0	< 1	0.8

3.1.3 Soil Nitrogen (N)

There was no significant difference in soil N content among the blocks (Tables 2 and 3). Soil N content varied from 0.12 to 0.28%. Nitrogen is the most critical element obtained by plants from the soil and is a bottleneck in plant growth. N content of soils generally ranges from less than 0.02% in sub-soils to more than 2.5% in peat soils (Tashoya et al. 2020). The medium to slightly high total N content in top soils in this study could be attributed to the poor drainage conditions of the soil that reduces the rate of organic matter decomposition as well as the addition of farmyard manure and plant residues that are rich in carbon and nitrogen (Choudhary et al. 2023). The observed nitrogen content, according to Nuga and Akinbola (2015), may probably be due to the medium level of SOC content and the main reason for this is high precipitation. Based on these soil nitrogen results, maize can be grown with ease because the nitrogen content highly suits maize production (Wanyama et al. 2021). However, there is need to increase the soil nitrogen content for cassava production because the observed nitrogen level in this study is a bit low for cassava production according to Purnamasari et al. (2022).

3.1.4 Available Phosphorus (P)

The overall mean for P was 4.83 ppm (below the critical level) (Table 2). Available P was generally low in the study area (grand mean is 4.83 ppm). Low P in soil causes lack of phosphorus in crops; this may prevent other nutrients from being acquired because P has a stimulating effect on root growth, since it is usually concentrated in the root tips of most plants (Tashayo et al. 2020). Low P might be due to soil erosion that washes away the top soils with relatively higher amounts of available P. Tillage has significant effects on the content of total, organic and available P (Everest and Sungur 2021). Therefore, low available P at MUARIK may probably be due to the

tillage activities that are performed every year on the arable land. Low available P may also be due to the soil inherent low P content, high P-fixation by Al and Fe oxides and hydroxides that are predominant in the Oxisols at MUARIK and complete removal of biomass from the fields (Nigussie and Kissi 2012). Phosphorus sorption to Fe and Al oxides generally predominates in acid ($\text{pH} < 7.0$) to neutral soils (Nanganoa et al. 2020). Other studies have also demonstrated that acidic soils are generally deficient in available P (Vasu et al. 2018). These soils would most likely respond to judicious phosphorus-containing fertilizer application (Imakumbili et al. 2019). The available P recorded in this study is marginally suitable for maize production but is in moderate levels for cassava production (Li et al. 2023).

3.1.5 Exchangeable Cations (K, Na and Ca)

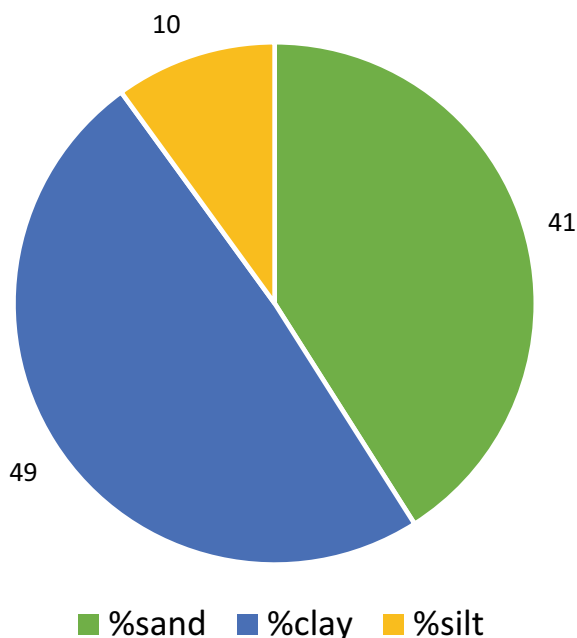
K values in the different blocks did not significantly differ from one another (Table 4). These results show that K, just like P, is a deficient nutrient at MUARIK for production of maize i.e. the soil K in this area is marginally suitable for maize growing (Anusha et al. 2023). Imakumbili et al. (2019) indicated that soil K levels from 0.15 to 0.25 Cmol(+)/kg are high for cassava production. Therefore, the soil K levels in this study are high for cassava production. K is essential for the general vigour of plants, supports development of a strong root system and increases resistance to certain diseases (Nanganoa et al. 2020). Analysis of variance showed no significant differences in soil Na levels between different blocks (Table 4). Soils are considered healthy and productive when they contain < 1 Cmol(+)/kg of Na and this renders MUARIK soil Na content suitable for majority of the crops, including maize. According to Keson et al. (2023), Na level < 2.0 Cmol(+)/kg is considered medium for cassava production and therefore the Na level in this study is suitable for cassava growing as well. Ca levels were far below the critical levels and not significantly different between blocks (Table 4). Ca was very low, much as Ca is present in adequate amounts in most soils (Li et al. 2023); this is because it is a component of several primary and secondary minerals in the soil, which are essentially insoluble. If the soil is made from limestone or another high calcium material, it will usually have more calcium; and if the soil is made from sandstone or shale, it will usually have lower levels of Ca (Choudhary et al. 2023). According to McLaughlin (2014), acid soils have less Ca and high pH soils normally have more. Therefore, the low Ca levels in MUARIK soils may be attributed to their acidic pH levels.

3.2 Soil Physical Properties

3.2.1 Texture

While there was no significant difference in the percentages of sand and silt between the blocks, there was a significant difference in the proportion of clay. Clay content

Fig. 1 Soil texture at MUARIK



was the highest (grand mean: 49%), followed by sand content (grand mean: 41%) and silt content (grand mean: 10%). For all the blocks, the soil's textural classification was clay (Fig. 1).

The general clay texture recorded in this study was also previously reported by Okiror et al. (2017). According to Nanganoa et al. (2020), clay percentage gives a clear indication of the problem nature of soils. A 10% clay threshold has been used as an indicator of the expansion potential, whilst 32% clay content exhibits extreme expansion potential (Bhullar et al. 2023). Such clay content has implications for the shrink-swell properties of the soil. Ismaili et al. (2023) agree that fine-textured clayey soils have small pores and release water gradually, which renders them susceptible to water logging because of their high-water retention capacity. Such soils may not be suitable or may be marginally suitable (depending on the type of clay) for cassava production which requires well drained soils for the cassava root tubers growth, but it is highly suitable for maize production (Nanganoa et al. 2020).

3.3 Results of Correlation Analysis

Sand and clay had the highest negative significant correlation ($r = -0.94$, $p < 0.01$), while Na and Ca had the highest positive significant correlation ($r = 0.99$, $p < 0.01$) (Table 5). pH had a positive significant correlation with SOC and K ($p < 0.05$). OC had a positive significant relationship with N and K ($p < 0.01$), positive significant

Table 5 Spearman's Correlations matrix of soil properties

Parameter	pH	%OC	%N	P	K	Na	Ca	%sand	%clay
pH									
%OC	0.37*	–							
%N	0.31	0.47**	–						
P	–0.31	0.18	–0.23	–					
K	0.41*	0.50**	0.41*	–0.10	–				
Na	0.17	0.25	0.07	0.002	0.12	–			
Ca	0.24	0.29	0.09	0.004	0.20	0.99**	–		
%sand	–0.02	0.38*	0.14	0.016	0.20	–0.06	–0.03	–	
%clay	–0.06	–0.44*	–0.17	0.030	–0.21	0.05	0.04	–0.94**	–
%silt	0.19	0.35	0.14	–0.12	0.15	–0.01	–0.03	0.32	–0.63**

Values with * and ** were significantly correlated at $\alpha = 0.05$ and $\alpha = 0.01$, respectively

correlation with sand and a negative significant correlation with clay ($p < 0.05$). Clay and silt had a negative significant correlation ($p < 0.01$). A high negative significant correlation between sand and clay was also reported by Okiror et al. (2017). This result is not uncommon because these two soil components are complementary to each other (Badapalli et al. 2023). The high positive correlation between Ca and Na can be attributed to the possibility of the two minerals having similar parent material mineralogy. The positive significant correlation between SOC and N concur with findings by Wanyama et al. (2021) where it was found out that increase in SOC increased total nitrogen content in soil.

3.4 Comparison of MUARIK Soil with Requirements for Maize and Cassava Production

Soil characteristics of the MUARIK region were compared to the norms for growing cassava and maize. The soil pH, SOC, OM, N and texture were found to be highly favourable for maize cultivation, while P and K were only marginally favourable for maize production, according to studies by Abagyeh et al. (2016) and Mustafah et al. (2016) (Table 6). Cassava could be grown in soil with moderate/medium pH, P and Na levels. Cassava development required low SOC, OM and N levels. For the production of cassava, soil K level was high and Ca concentration was quite low. If the soil clay is structurally dominant, the texture is marginally to moderately acceptable for cassava development or not suitable.

Table 6 Comparisons of MUARIK soil with requirements for maize and cassava production

Parameter (s)	MUARIK soil	Grand mean	Comparisons	
			Requirements for Maize	Requirements for Cassava
pH	5.14–5.83	5.54	*S1	**3
OC (%)	1.42–1.71	1.62	S1	2
OM (%)	2.44–2.95	2.79	S1	2
N (%)	0.17–0.21	0.20	S1	2
P (ppm)	1.42–12.11	4.83	S3	3
K (Cmol+)/Kg	0.12–0.24	0.18	S3	4
Na (Cmol+)/Kg	0.03–0.44	0.11	S2	3
Ca (Cmol+)/Kg	0.07–0.25	0.11	S3	1
Textural class	Clay	Clay	S1	S2–S3 N

** 1 = Very low; 2 = Low; 3 = Moderate; 4 = High; 5 = Very high for cassava production. *S1 = highly suitable; S2 = Moderately suitable; S3 = Marginally suitable; N = Not suitable for maize or cassava production

4 Conclusion

MUARIK soils were highly and moderately suitable for maize and cassava production, respectively. For successful cassava production at MUARIK, Ca levels should be increased in the soil, preferably by applying gypsum soil amendment (calcium sulphate) to raise the soil pH. Given the low Ca concentration of the soil and the need for fertiliser, Ca-NPK would be a preferable inorganic fertilizer choice. Since most of Uganda is covered by acidic soils, mostly Ferralsols, the significance of our findings is that maize and cassava production should be promoted on a commercial scale so that our farmers can engage in massive production of these two commodities for urban markets and agro-industrial development.

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