



Soil Morphology, Physico - Chemical Properties and Classification of Typical Soils of Mwala District, Kenya

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Authors' contributions

This work was carried out in collaboration between all authors. Author ANK designed the study, managed soil analyses and wrote the first draft of the manuscript. Authors CKKG and BMM wrote the protocol. Authors ANK and CKKG performed pedological field study. Authors BMM and CKKG managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

A soil profile representative of typical soils of Mwala District, Kenya, was dug to study its morphology, soil physico-chemical characteristics and to classify it using two internationally known soil classification systems. Disturbed and undisturbed soil samples were taken from designated pedogenic horizons for physical and chemical analysis in the laboratory. Soil morphological observations revealed that the pedon is well drained and very deep with dark brown to dark yellowish brown topsoil overlying brown to strong brown sandy clay loam to sandy clay subsoil.

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Clay eluviations - illuviation is a dominant process influencing soil formation in the study area as indicated by the clay gradient between the eluvial and illuvial horizons and the presence of clay cutans in the subsoil. The soil is characterized by weak fine subangular blocky throughout its pedon depth. Laboratory analysis indicates that the soil is very strongly acid (pH 4.6–5.0) throughout the profile, has very low N (<0.1%) and low OC (0.6-1.25%). The pedon has low CEC (6.0-12.0 cmol (+) kg⁻¹) and low base saturation (<50%). Available P is rated as high (>20mg kg⁻¹) in the topsoil while it is low (7-20mg kg⁻¹) in the major part of the subsoil. Using field and laboratory analytical data, the representative pedon was classified to the subgroup level of the USDA Soil Taxonomy as *Typic Haplustults* and to Tier-2 of WRB as *Haplic Cutanic Acrisols (Humic, Hyperdystric, Endosiltic)*. The general fertility of the soils of the area is discussed highlighting their potentials and constraints.

Keywords: Soil characterization; soil morphological properties; soil physical properties; soil chemical properties; soil classification; soil fertility evaluation.

1. INTRODUCTION

Given the increasing population in the arid and semi arid lands (ASALs) of Kenya, coupled with low and erratic rainfall, fragile environment and low soil fertility, agricultural practices need to be prioritized [1]. The agricultural priority would be to increase the biological and economic yield per unit area (intensification), while ensuring sustainability of the land resource [2,3]. The intensification of agriculture on land will require a thorough knowledge of the soil as a resource and attributes of the land, its potential and constraints for appropriate soil and water management systems [4]. However, acquisition of this information is a challenge due to the limited information on crop nutrient requirements, characteristics of soils and high level of variation in soil properties that are experienced across many areas in Kenya [5]. Assessment of the potentials and limitations of soil for the different land uses provides the basis for formulating the appropriate management strategies which target specific management problems to improve crop production and soil and water conservation strategies. This information is generated by a detailed biophysical characterization of the soils [2,4].

Soil classification is the systematic arrangement of soils into groups or categories on the basis of their characteristics [6]. Two internationally known soil classification systems have been used to classify soils namely the United States Department of Agriculture (USDA) Soil Taxonomy [7] and World Reference Base for Soil Resources [8]. The main purpose of any classification is to establish groups or classes of soils under study in a manner useful for practical and applied purposes in (a) Predicting their behaviour, (b) Identifying their best uses, (c)

Estimating their productivity and (d) providing objects or units for research and for extending and extrapolating research results [6-8]. For this kind of purpose, soil survey forms an essential link for its practical application. A soil profile or pedon representative of typical soils is dug to study its morphology, soil physico - chemical characteristics and hence classified.

The current study aimed at the characterization of the soils in Mwala District to provide the needed basic information of the soil and ecological conditions. Specifically, the study was done to (i) Characterize the soils based on their morphology, physicochemical properties and hence their general fertility (ii) Classify the soils using the 'United States Department of Agriculture (USDA) Soil Taxonomy' and the 'World Reference Base for Soil Resources' scheme of classification and (iii) provide basic soils information to researchers working in the study area that will guide activities related to the management of the existing land resources.

2. MATERIAL AND METHODS

2.1 Study Site Description

The study was conducted in Mbiuni Location, Mwala District, Machakos County, Eastern Kenya. Fig. 1 gives the location while Table 1 describes some pertinent site features of the area. The representative profile is developed on metamorphic rocks comprising mainly gneisses and migmatites and is situated on upland at an altitude of slightly above 1200m a.s.l. The slope on site is <2%. The area is characterized by low, erratic and poorly distributed rainfall that makes crop production difficult under rain fed conditions. Although the mean annual rainfall for Mwala District is 596.7 mm [9], rainfall data close to the

study area, Kabaa Catholic Mission at an altitude of 1220m a.s.l. (Fig. 2) gives a mean annual rainfall of 793mm and a mean annual temperature of 21.3 to 22°C [10]. The rainfall distribution is bimodal with two distinct rainy seasons, the short and long rains and a dry season separating the two rainy seasons. In this area, the short rains (October to December) are more reliable, evenly distributed and adequate for crop production [11]. However, very high soil moisture deficits experienced in these areas usually result in significant decreases in crop production under rain fed conditions [3].

2.2 Field Methods

Through a reconnaissance field survey using transect walks, auger observations and

descriptions; a site for a soil profile representative of the major soils of Mwala District was identified. A soil profile pit was dug, geo-referenced using Global Positioning System (GPS) (model OREGON 400t), studied and described according to the FAO Guidelines for Soil Description [12].

Site characteristics such as slope gradient, erosion, natural drainage, natural vegetation and land use were recorded. Soil profile morphological characteristics studied included soil color, texture, consistence, structure, porosity and effective depth. Soil color was determined by Munsell soil color charts [13]. From the soil profile, disturbed soil samples were taken from designated genetic horizons for physico - chemical analysis in the laboratory.

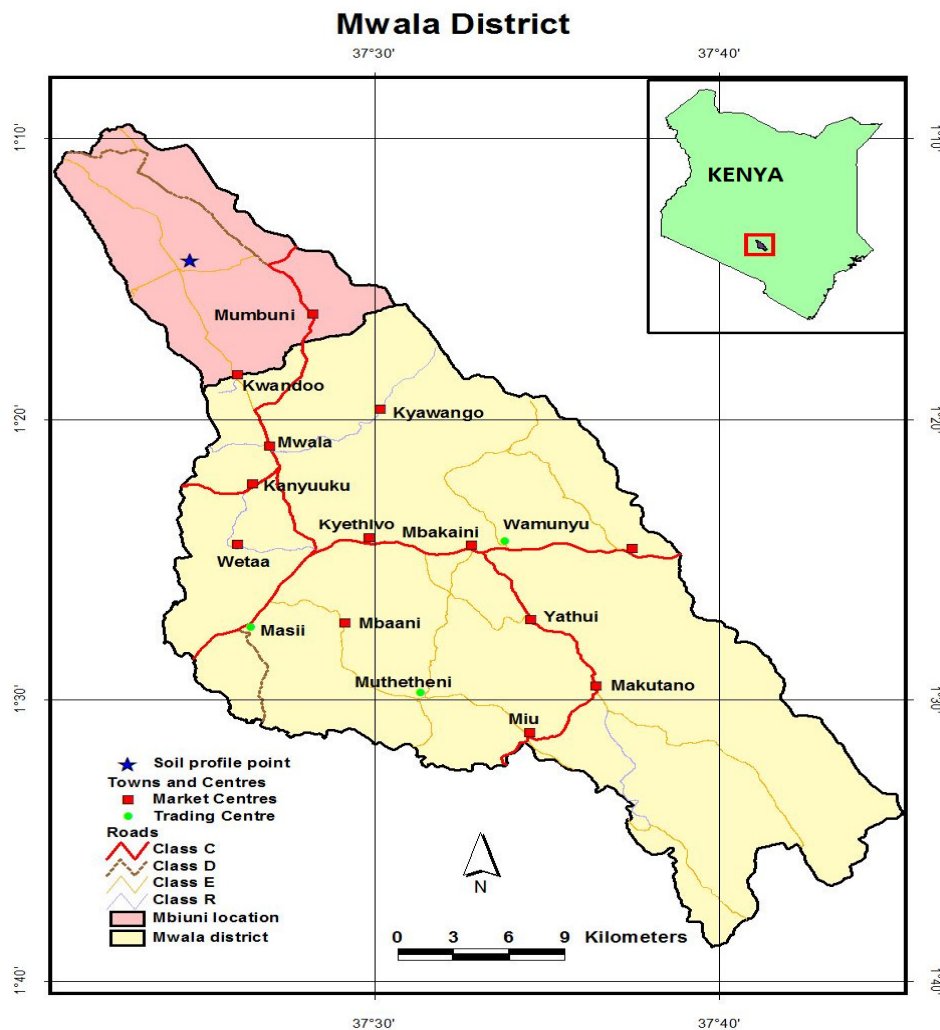


Fig. 1. Location map of the study area showing soil profile site

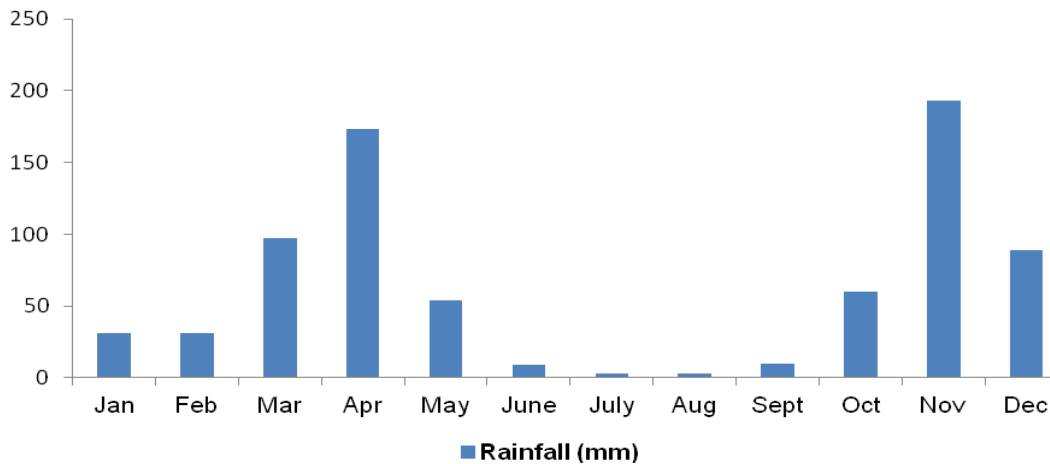


Fig. 2. Rainfall data collected from Kabaa Catholic Mission, a centre nearest to the study site

Undisturbed cores samples were also taken for the determination of bulk density, saturated hydraulic conductivity and soil water retention properties. For soil fertility evaluation composite soil samples from the 0-30cm depth were collected from the experimental field after four seasons of experimentation.

Table 1. Site characteristics of the studied soil profile

Attribute	Description
Coordinates	E 37° 25' S 01°15'
AEZ	4 (LM 4)
Altitude (m a.s.l.)	1220
Landform	Upland
Geology / Lithology	Acid metamorphic rocks comprising mainly of gneiss and migmatite
Slope%	<2
Land use / Vegetation	Agriculture (maize, beans, pigeon peas, cowpeas, green grams and chickpeas and livestock). Dominant vegetation includes horticultural fruit trees such as oranges (<i>Citrus sinensis</i>), mangoes (<i>Mangifera indica</i>) and pawpaw (<i>Carica papaya</i>) and <i>Acacia</i> and <i>Euphorbia</i> trees.
Mean annual rainfall (mm)	793
SMR	Ustic (transitional to aridic)
Mean annual temperature °C	21.3 -22°C
STR	Iso - hyperthermic

AEZ* = agro-ecological zone [10], LM4 = lower midland AEZ 4, SMR = soil temperature regime, STR = soil temperature regime

2.3 Laboratory Methods

Undisturbed core samples were used for the determination of bulk density, saturated hydraulic conductivity and moisture retention characteristics. Bulk density was determined using core sample method [14]. Total porosity was then calculated from the bulk density using the equation of $(1-pb/ps)$ where pb is the bulk density and ps is the average particle density ($2.65Mg/m^3$). Saturated hydraulic conductivity (Ksat) determinations were done in the laboratory using the constant head method as described by Klute and Dirksen [15]. The Atterberg limits were measured as described by McBride [16]. Liquid limit was determined with Casagrande apparatus (ASTM D 4318). The flocculation index, which is a good measure of erosion, was determined by the equation of $100(1 - natural\ clay\%/total\ clay\%)$ in which total clay is obtained by using a dispersing agent and for natural clay, no dispersion agent was used in the determination [17].

Disturbed soil samples were air-dried, ground and passed through a 2-mm sieve to obtain the fine soil fractions for determination of physical and chemical soil properties. Texture was determined by Bouyoucos hydrometer method [18] after dispersing soil with sodium hexametaphosphate. Electrical conductivity (EC) was measured on a 1:2.5 ratio extract with an EC meter. The pH was measured potentiometrically in water and in 1M CaCl₂ at the ratio 1/2.5 soil-water and soil - CaCl₂. Organic carbon was determined by wet oxidation method of Walkley and Black [19] and converted to organic matter (OM) by multiplying by a factor of 1.724. Kjeldahl

method [20] was employed to determine total nitrogen.

Phosphorus was extracted by the Mehlich method and determined spectrophotometrically [21,22]. The cation exchange capacity (CEC) and exchangeable bases were extracted by saturating soil with neutral 1M NH₄OAc (ammonium acetate) [23] and the adsorbed NH₄⁺ displaced with K⁺ using 1M KCl and then determined by micro-Kjeldahl distillation method for the estimation of CEC of soil. The bases Ca²⁺, Mg²⁺, Na⁺, and K⁺, displaced by NH₄⁺ were measured by atomic absorption spectrophotometer (AAS). The exchangeable sodium percentage (ESP) was calculated by dividing the exchangeable Na by CEC (× 100), which is a measure of the sodicity of the soil. For soil fertility evaluation the composite soil samples were air-dried, ground and passed through a 2-mm sieve for laboratory analysis.

2.4 Classification of the Soil Profile

Using the field and laboratory data, the representative soil were then classified to the subgroup level of the Soil Taxonomy [7] and to Tier-2 of the World Reference Base for Soil Resources [8].

3. RESULTS AND DISCUSSION

3.1 Soil Morphological Properties

Key morphological properties of the profile are shown in Table 2. This profile is well drained with friable moist consistency and slightly hard to hard when dry. The profile is very deep (>120cm), with weak fine subangular blocky structure with dark brown to strong brown colours (Table 2). Soil horizons were quite distinct ranging from abrupt to clear with smooth horizon topography. Soil pores were common and well distributed within the profile. The soils were also well developed with a weak argillic B-horizon.

3.2 Soil Physical Properties

3.2.1 Soil particle distribution (texture) and silt/clay ratio

Table 3 presents the data on soil texture. The soil texture was sandy loam in the upper horizons, sandy clay loam in the mid horizons and sandy clay in the lowest horizon, with an overall average texture of sandy clay loam (72.4% sand, 25.2% clay, 2.4% silt). These coarse textures control the variability of nutrient storage capacity, limit the water holding capacity and roots may grow under sub-optimal soil water due to water deficits [24]. The textural classes observed coupled with the low CEC (<12 cmol (+)/kg) suggest potential leacheability of nutrient elements especially nitrogen as nitrate [25,26]. The sand content decreased gradually with depth as the proportion of finer particles increased, partially due to illuviation and argillation in the Bt horizons [27]. Soil texture is the most stable physical characteristic of the soils which has influence on a number of other soil properties including structure, soil moisture availability, erodibility, root penetration and soil fertility [4,28]. This is because texture is a composite of the coarse fraction (sand) and the finer fractions (silt and clay) and an increase or decrease in one component imparts the opposite effect on the other and hence affects physico-chemical properties of the soils [27]. Clay for example has been reported to interact with organic matter and increase water and nutrient holding capacity [28]. Wakindiki and Ben-Hur [29] expressed that in soils containing more than 20% clay, the clay particles act as a cementing agent and will increase aggregate stability against raindrops and decrease surface sealing. The silt/clay ratio, an indicator of soil susceptibility to detachment and transport, was less than the threshold of 0.4 [30] implying moderate resistance to erosion.

Table 2. Main morphological features of the pedon at Mbiuni location, Mwala District

Horizon	Depth (cm)	Texture ¹⁾	Moist colour ²⁾	Consistence ³⁾	Structure ⁴⁾	Horizon boundary ⁵⁾
Ap	0 – 10	SL	db (10YR 3/3)	fr, s&p	w-f, sbk	ai
AB	10 -20	SL	dyb (10YR3/4)	fr, s&p	w-f, sbk	cs
Bt ₁	20 – 45	SCL	b-db (7.5YR4/3)	fr, s&p	w-f, sbk	cs
Bt ₂	45 – 90	SCL	sb (7.5YR4/6)	fr, s&p	w-f, sbk	cs
Bt ₃	90– 156	SC	sb (7.5YR5/6)	fr, ss&sp	w-f, sbk	as

1) SC = sandy clay; SCL = sandy clay loam; SL = sandy loam, 2) db = dark brown; dyb = dark yellowish brown; sb = strong brown; b = brown, 3)fr = friable; s = sticky; ss = slightly sticky; p = plastic

4) sbk = fine sub-angular blocky; w-f = weak fine, 5) a = abrupt; c = clear; i = irregular; s = smooth

3.2.2 Bulk density and total porosity

Results on bulk density and total porosity are presented in Table 3. The mean bulk density ranged from 1.16Mg/m³ in the lowest horizon (Bt₃) to 1.54Mg/m³ in the surface horizon (Ap), with an overall average of 1.28Mg/m³ (Table 3). The high bulk density in the plough layer (Ap) can be attributed to continuous tillage at the same depth season after season thus creating a compact layer, which has an effect on the hydraulic conductivity as indicated by the low Ksat value of 0.37 cm/h obtained (Table 4). According to [28], soil bulk density has a major impact on the dynamics of water and air in the soil and crop root development which ultimately affects crop growth and yield. Therefore, deep subsoiling is required to improve the bulk density and thus soil water uptake [28,31]. The values of <1.30Mg/m³ observed in the subsurface horizons suggest root growth and development is not restricted in this soil [28]. The porosity was > 40% in all the horizons, with an overall average of 52%, thus not liable to restrict crop growth [24]. Since porosity is calculated from the relation between bulk density and particle density of soil, it is very much influenced by the soil bulk density as the particle density is not greatly altered by agricultural manipulations [32]. For any given soil, the higher the bulk densities, the more compacted the soil is and the lower the pore space as also observed in this profile. This also affects the soil water transmission properties [33,34].

3.2.3 Hydraulic properties of the studied pedon

Table 4 presents results on hydraulic properties of the studied pedon. The Ksat values increased from very slow (<0.8cm/h) to moderate (2.0-6.0 cm/h) down the profile with an average of 2.3 cm/h [28] (Table 4). The low topsoil Ksat value is

due to its high bulk density (1.54Mg/m³). Based on the soil texture, the Ksat values in the subsoil were within the sandy loam values (2-3cm/h) [28]. The soil water content decreased as the suctions increased from saturation to permanent wilting point (pF 0 – pF 4.2) (Table 4). The plant available water (PAW) ranged from 10.5–14.6 %. The differences in the readily available water (RAM) values down the profile can also be attributed to the differences in the textural class (sandy loam - sandy clay loam - sandy clay) down the profile. The mean RAM values ranged from 16.6% in the topsoil to 26.6% in the subsoil. Soil moisture characteristics curves are mostly affected by the soil texture [28]. Soils with more clay tend to have more moisture at any suction. The Bt horizon that had more clay than the overlying horizon thus had more moisture at any suction. The gradual decrease in soil water content with increasing matric suction associated with clay soils is due to the pore size distribution and the adsorptive forces holding the water. In a sandy loam soil, like in this profile, the pores are relatively large thus likely to be emptied at low matric suctions leaving small amounts of water to be released at high suctions [27,28,32].

3.2.4 Atterberg limits and flocculation index of the studied pedon

Table 5 gives results on consistency/Atterberg limits of the studied pedon. Atterberg limits measures the quantity of water that must enter the soil before it loses coherence and are used to estimate the strength and settlement characteristics of soils. They characterize and define the behavior of soil by measuring liquid, sticky and plastic limits. The limits were uniform at all depths with an average of 20% for plastic, 27 % for liquid and 28% for sticky limit. In this profile, the plastic index was an average of 7.2%, an indication of low plasticity (5-10%) according to Burmister [35].

Table 3. Selected soil physical properties of pedon at Mbiuni location, Mwala District

Horizon	Depth (cm)	% Sand	% Clay	% Silt	Textural class	Silt/clay ratio	BD Mg /m ³	% Porosity
Ap	0 – 10	78.0	18.0	4.0	SL	0.22	1.54	41.9
AB	10 – 20	82.0	16.0	2.0	SL	0.13	1.25	52.8
Bt ₁	20 – 45	72.0	26.0	2.0	SCL	0.08	1.20	54.7
Bt ₂	45 – 90	68.0	30.0	2.0	SCL	0.07	1.25	52.8
Bt ₃	90 – 156	62.0	36.0	2.0	SC	0.06	1.16	56.2

Table 4. Soil water retention characteristics of the pedon at Mbiuni location, Mwala District

Horizon	Depth (cm)	Saturation	R. A. M				D.A.M	P.W.P	P.A.W	Saturated hydraulic conductivity (Ksat) (cm/h)
			Field capacity							
			pF 0	pF 2.0	pF 2.3	pF 2.5				
Ap	0 – 10	25.6	19.55	16.6	16.00	8.10	5.95	13.60	0.37	
AB	10 – 20	31.85	19.20	15.55	14.95	9.38	8.70	10.50	2.88	
Bt ₁	20 – 45	41.20	27.65	24.00	17.70	11.70	9.95	17.70	2.12	
Bt ₂	45 – 90	38.60	25.65	22.20	21.55	14.60	13.40	12.25	3.03	
Bt ₃	90 – 156	41.95	30.05	24.95	24.70	18.15	15.45	14.60	2.98	

R.A.M = Readily Available Moisture (Field Capacity), D.A.M = Difficultly Available Moisture, P.W.P = Permanent Wilting Point, P.A.W = plant available water

The limits are also linked to erodibility of the soil and their properties depend on the amount of clay, silt, organic matter and type of minerals. A low plastic index (0 to 10) indicates silt, while a high plastic index (>35) indicates clay. All the limit values increased down the profile, indicative of the influence of clay increase down the profile [36]. The Atterberg limits are a function of the distribution of the fine grained clays and the clay mineralogy, reflecting the increasing trend of plastic index with increasing liquid limit as noted in this study [37].

According to [38], the estimated mineralogy of the soil is a mixture of 1:1 and 2:1 clays due to the sticky and plastic wet consistence and a moist color matrix of 10 YR in the upper horizons and 7.5 YR in the lower horizon (Table 2). However, clay mineralogical analyses are required to verify these estimates. According to work done by [39], low organic carbon has a positive correlation with Atterberg limits. An increase in organic carbon increases the CEC levels, which holds more water adsorption and water retention. In the current study, low organic carbon levels (<1%) and low CEC values (<12 cmol (+)/kg) were noted and could explain the lower Atterberg limits observed. Higher values for Atterberg limits (plastic limits, liquid limits and

plastic index) are associated with lower dispersion and erodibility; hence more stability of the soil aggregates [37]. The organic matter content and the flocculation index are indicators for the aggregate stability, bulk density for generalized infiltration properties, and the silt/clay ratio for the susceptibility to sealing [40]. Flocculation is the process where individual soil primary particles 'clump' or group together to form aggregates. Thus, flocculation index (FI) is a measure of flocculation [28]. The flocculation index (Table 5) decreased with depth from the topsoil (Ap and AB) to the Bt₁ and thereafter increased with depth to the lower subsoil. The high flocculation in the lowest horizon (72.2 %) could be attributed to the high clay content of 36%. A high FI (low natural clay %) indicates a high stability of the clay fraction, where clay occurs in floccules (pseudo-silt fractions) and is less water dispersed thus water stable [16]. The low flocculation index (<50%) in the upper horizons could be attributed to the medium content of the divalent cations (Ca²⁺ and Mg²⁺) observed in the pedon (Table 6). Higher amounts of the cations in soil causes soil particles to 'flocculate' or clump together, thus increasing the formation of stable aggregates [27,34]. However, this was not observed in this pedon.

Table 5. Atterberg limits and the structural stability indices of the pedon at Mbiuni location, Mwala District

Horizon	Depth (cm)	Natural clay (%)	Flocculation index (%)	Silt/clay ratio	Consistency/Atterberg Limits (%)			
					Liquid	Plastic	Sticky	Plasticity index (%)
Ap	0 – 10	10.0	44.4	0.22	20.32	14.81	20.20	5.51
AB	10 – 20	8.0	50.0	0.13	22.27	14.93	22.47	7.34
Bt ₁	20 – 45	16.0	38.5	0.08	28.56	18.89	29.97	9.67
Bt ₂	45 – 90	12.0	60.0	0.07	31.01	23.41	30.77	7.60
Bt ₃	90 – 156	10.0	72.2	0.06	34.16	28.51	35.02	5.65

3.3 Soil Chemical Properties

Some selected soil chemical properties of the studied pedon are presented in Table 6.

3.3.1 Soil reaction (pH), organic C, total N, organic matter (OM) and C/N ratio

According to [28], the soils are rated as very strongly acidic (pH 4.6-4.9) at the surface and subsurface layers, have very low levels of N (<0.1%) and low levels of organic OC (0.6-1.25%). Soil pH is the most important chemical characteristic of the soil solution. The very strongly acid reaction values suggest possible low availability of both the macro and micro plant nutrients for uptake by crops. The low pH may be attributed to leaching of bases, removal of the bases through crop harvests and the farming practices in the study area through the continuous application of DAP fertilizer, an acidifying fertilizer. The low levels of OC and N observed are characteristic of soils in semi arid areas where the high rate of mineralization does not allow high accumulation of carbon [24]. Total nitrogen levels of less than 0.2% and organic carbon values below 0.6% are considered low for agricultural activities [28]. The OC and N levels also decreased with soil depth in the pedon. The low organic carbon and total nitrogen observed may be attributed to low pH which restricts microbial activities. For pH values of about 5.5 and below, bacterial activity is reduced and nitrification of organic matter is significantly retarded [28].

The OM content in the pedon was low (1–2%) and decreased down the profile (Table 6). The OM level in the soil is strongly correlated with the soil's CEC, and is a source of many plant nutrients, particularly nitrogen [27]. The low organic matter noted can be a cause of poor soil structure and low supply of plant nutrients such as nitrogen, phosphorus, and potassium [37]. It is also responsible for low water holding capacity and low infiltration rate which may result in soil erosion by runoff surface water during the rains [25]. Due to the low pH, OC, N and OM values observed, the management recommendation would be to increase the levels of organic matter in the soils by addition of good quality farmyard manure, mulching, compost and addition of non-acidifying chemical fertilizers such as triple super phosphate (TSP), single super phosphate (SSP), compound fertilizers (NPK 23:23:0, 20:20:0, 17:17:17), Calcium ammonium nitrate (CAN) and *Mavuno* fertilizers. *Mavuno* is a multi - nutrient

fertilizer that also contains micronutrients which are necessary for crop growth. This additional supply is necessary for increased crop yield in the area [5,24].

Whereas the C/N ratio of the topsoil (horizons Ap and AB) is on average 12.9 suggesting good quality (ratios of 8-13) of the organic matter, the subsurface Bt horizon had an average of 19.7, indicative of moderate (ratios of 14 - 20) quality of the organic matter. On average, the pedon had 16.9 which indicate moderate quality [41,42]. A ratio of 10 - 12 is normal for an arable soil with a good rate of organic matter decomposition; 15 - 20 indicates slow decomposition of the organic matter. Ratios greater than 25 suggest that the organic matter is not decomposing [28].

3.3.2 Available P

The Ap horizon has high values (31.22mg/kg) of P (Table 6) with moderate average values of 22.45mg/kg in the A horizon (0–20cm depth) where most of the crop roots are located.

The high P values in topsoil could be attributed to the continuous application of DAP fertilizer (DAP 18:46:0) in the study area. In the subsurface horizons, the values of P were low (<11mg/kg). An available P level of 15 mg/kg is generally considered as the critical level below which P deficiency symptoms are likely to occur in many crops [28,43]. Phosphorus is an important plant nutrient necessary for root development, nodulation which is important for nitrogen fixation process, pod formation and filling in legumes [44]. Low available phosphorus in the subsurface layers of the pedon may also be attributed to low soil pH (<5.8) observed and could react with iron (Fe) and aluminium (Al) to produce insoluble Fe and Al phosphates that are not readily available for plant uptake [43]. Addition of organic matter levels can help reduce any P 'fixation' reactions that may be present, by binding Al, Fe and Ca, and forming soluble complexes with P which may be available to plants [43].

3.3.3 Exchangeable bases, Cation Exchange Capacity (CEC), Base Saturation (BS) and Electrical Conductivity (EC)

The CEC is low (6-12cmol (+)/kg) in all horizons except in the Bt3 horizon which is very low (<6cmol (+)/kg). The CEC levels observed in this pedon indicate that the soils have low nutrient retention capacity [28].

Table 6. Some chemical properties of the pedon at Mbiuni location, Mwala District

Horizon	Depth (cm)	pH (H ₂ O)	pH (0.01M CaCl ₂)	OC %	N %	OM %	C/N ratio	P mg kg ⁻¹	K	Na	Ca	Mg	CEC	BS (%)	EC dS/m	ESP (%)
													cmol(+)kg ⁻¹			
Ap	0 – 10	4.94	4.54	0.98	0.07	1.69	14.00	31.22	1.30	0.50	2.10	0.72	10.00	46.20	0.20	5.00
AB	10 - 20	4.91	4.33	0.82	0.07	1.41	11.71	13.83	0.60	0.50	1.95	0.91	9.43	41.99	0.20	5.30
Bt ₁	20 - 45	4.58	4.34	0.78	0.04	1.34	19.50	10.18	0.40	0.50	0.90	0.52	10.12	22.92	0.20	4.94
Bt ₂	45 - 90	4.40	4.03	0.72	0.03	1.24	24.00	10.85	0.10	0.20	0.60	0.41	7.24	18.90	0.30	2.76
Bt ₃	90 - 156	4.16	3.94	0.62	0.04	1.07	15.50	2.00	0.20	0.20	0.50	0.57	5.11	28.77	0.20	3.91

BS = base saturation, EC = electrical conductivity, ESP = exchangeable sodium percentage

The variation of organic carbon in the pedon indicates a relationship with CEC values whereby low OC corresponds with low CEC values explaining the contribution of OM to the CEC of soil.

The low CEC levels observed in the studied soil could also be attributed to strong leaching of the bases down the pedon [4] as well as to the low clay content (<36%) in the soil [24]. The soils are also moderately supplied with bases (Ca, Mg and K). The observed low CEC values imply that all fertilizers except P have to be applied in split applications so as to reduce nutrient losses through leaching.

The exchangeable calcium in the soils is medium (0.6–2.5cmol (+)/kg) in the upper horizons and low (0.2–0.5cmol (+)/kg) in the lowest horizon (Bt3) with values ranging from 0.5 to 2.1 cmol (+)/kg [28,41,42]. The magnesium levels were medium (0.5 – 1.0cmol (+)/kg) across the profile except in the Bt₂ horizon with 0.41cmol (+)/kg [28,42]. The levels of sodium were medium to low levels down the pedon with values ranging from 0.2-0.5cmol (+)/kg and thus pose no problem to the soils while potassium levels were also low to very high (0.1–1.3cmol (+)/kg [28,42].

The level of exchangeable bases in the soils is a measure of the availability of bases for plant uptake. The base saturation can be rated as medium (<50%) in the epipedon and very low (<30%) in the subsoil. Low base saturation levels may result in very acid soils and potentially toxic cations such as Aluminium and Manganese from the soil [43]. Poor cultivation practices, poor soil and water conservation and inadequate supply of fertilizer to replenish nutrients removed by crops among others are reported to contribute to low level of bases in most soils [45,46]. According to [28], a relatively high base saturation of 70 to 80 % should be maintained for good performance of most cropping systems. The soils are non-saline as indicated by its low values of electrical conductivity (<1.7dS/m) with an average of 0.22dS/m in the pedon. The electrical conductivity is a measure of relative salt concentrations or salinity and too much salt in the soil can interfere with root function and nutrient uptake [43], which was not observed in this pedon. The soils are also non-sodic (ESP< 6%) indicated by the average values of 4.4% in the profile. This indicates that there is no risk of crop injury and yield reduction for the crops grown in the area [28].

3.3.4 Nutrient balance in the studied pedon

The soil nutrient ratios in the studied pedon are presented in Table 7. The availability of nutrients for uptake by plants depends not only upon absolute levels of nutrients but also on the nutrient ratios [47]. Nutrient imbalances influence nutrient uptake by inducing deficiencies of nutrients which may be present in the soil in good quantities [47]. It is therefore important to consider the individual nutrient ratios i.e. Ca/Mg ratio and Mg/K ratio which are indicators of nutrient uptake [43]. The Ca/Mg ratio range of 2 to 4 and Mg/ K in the range of 1 to 4 are considered favorable for most tropical crops [4]. The results showed that Ca/Mg ratio of the soils is lower than the optimum range in the Bt horizon which can limit Mg uptake by the plants [28]. The Ap and AB horizons of the studied horizons have Ca/Mg ratio of 2.92 and 2.14 respectively, which are within the optimum range [28]. As for Mg/K ratio, the Ap horizon portrays an unfavorable ratio of 0.55 and that can limit K uptake while in the Bt₂ horizon the ratio is greater than 4 which can inhibit K uptake by plants [48]. From these results, it is apparent that, nutrient imbalances observed in this study will influence the nutrient availability. Nutrient availability determines the yield potential of crops and can be improved by manuring, application of inorganic fertilizers and crop rotation [6]. The overall K/TEB (total exchangeable bases) ratios are above 2% which is said to be favourable for most tropical crops.

3.4 Soil Classification

Based on the field and laboratory data, the pedon in Mbiuni location, Mwala District was classified to subgroup level of the USDA Soil Taxonomy as *Typic Haplustults*, corresponding to *Haplic Cutanic Acrisols (Humic, Hyperdystric, Endosiltic)* at Tier-2 in the WRB. The detailed classification is shown in Tables 8 and 9.

Ultisols (Acrisols) are characterized by acidic pH, higher clay content in the subsoil than in the topsoil and by low-activity clays in certain depths [8]. They are usually deficient in nutrients thus requiring substantial application of non-acidifying fertilizers to achieve rewarding and productive farming [6]. This fertilizer application should be in small, regular quantities that are applied close to the plants as Acrisols do not have the capacity to hold large amounts of nutrients [6]. Preservation of the surface soil with its all important organic matter (by retention of crop residues, mulching and green manuring) and preventing erosion are

preconditions for farming on Acrisols [8]. In climates with pronounced dry season, as in most semi arid areas of Kenya, Acrisols may become very hard and land preparation for the next rainy season is difficult especially by hand [6]. Elsewhere in this study, the crust strength measured under different tillage practices showed a range of 1.2-1.3 MPa and increased as the cropping season progressed. This increase could be attributed to the natural formation of crust under rainfall impact since there was minimal human interference, only during weeding and data collection. Frequent loosening of the top soil, together with removal of weeds, will permit rain to infiltrate thus preventing erosion by sheet wash. Acrisols are also notorious for their susceptibility to erosion and capping once left bare [8,6].

3.5 Soil Fertility Evaluation/trends based on the Composite Sample Analysis

Based on the composite samples (0-30cm depth) collected and the initial characterization of the soils before the study, some notable changes were observed after four seasons of experimentation (Table 10). The pH of the soil

has become strongly acidic (<5). The decline in pH can be attributed to the H⁺ released through the nitrification of NH₄⁺. The NH₄⁺ originated from the surface applied nitrogenous fertilizers (DAP 18:46:0) as a soil fertility strategy by the farmers over the four cropping seasons [43]. The low soil pH values suggest possible low availability of both macro and micro nutrients for uptake by crops [26,28]. The basic cations (K, Na) decreased while Ca and Mg increased and can be attributed to the pH. Low pH (<6) values in soils influence the availability of K, Ca and Mg which are generally not available for plant uptake in acid soils since they may have been partially leached out of the soil profile [27]. The lower pH values observed in this study may therefore affect the land quality 'nutrient retention' [28]. Other notable decreases were observed in the low levels of organic carbon and nitrogen. Total nitrogen levels less than 0.2% are considered low for agricultural activities [28] and organic carbon values below 0.6% imply very low organic carbon levels. This means that the soils have a low recovery potential or resilience in terms of the chemical properties and thus raising and maintenance the chemical fertility level is required.

Table 7. Soil nutrient ratios of the pedon at Mbiuni location, Mwala District

Horizon	Depth (cm)	Ca	Mg	K	TEB	Ca/Mg	Mg/K	K/TEB
cmol(+)kg ⁻¹								
Ap	0 - 10	2.10	0.72	1.30	4.62	2.92	0.55	0.28
AB	10 - 20	1.95	0.91	0.60	3.96	2.14	1.52	0.15
Bt ₁	20 - 45	0.90	0.52	0.40	2.32	1.73	1.30	0.17
Bt ₂	45 - 90	0.60	0.41	0.10	1.31	1.46	4.10	0.08
Bt ₃	90 - 156	0.50	0.57	0.20	1.47	0.88	2.85	0.14

TEB = total exchangeable bases

Table 8. Summary of the morphological and diagnostic features of the pedon at Mbiuni location, Mwala District

Diagnostic horizons	Other features: USDA Soil Taxonomy [7]	Diagnostic horizons, properties and materials: [8]
Ochric epipedon, Argillic horizon	Very deep, very strongly acid, ustic SMR (transitional to aridic), iso-hyperthermic STR, Slope <2%, presence of faint clay cutans, adequate clay gradient between eluvial and illuvial horizon, low subsoil CEC (<24 cmol(+)/kg clay in the greater part of the argillic), low BS (<50% throughout)	Argic horizon; prefix qualifiers: cutanic, haplic; suffix qualifiers: hyperdystric, endosiltic

Table 9. Classification of the studied pedon at Mbiuni location, Mwala District

USDA soil taxonomy [7]				FAO - WRB Soil Classification [8]	
Order	Suborder	Greatgroup	Subgroup	Reference Soil Group – Tier 1	Tier - 2 WRB soil name
Ultisols	Ustults	Haplustults	<i>Typic Haplustults</i>	Acrisols	<i>Haplic Cutanic Acrisols (Humic, Hyperdystric, Endosiltic)</i>

Table 10. Comparison of selected chemical properties before and after the trial

Soil property	pH (H ₂ O)	pH (0.01M CaCl ₂)	% OC	% N	cmol(+)/kg ⁻¹					CEC	P mg/kg
					K	Na	Ca	Mg			
Before trial	6.50	5.61	1.1	0.09	2.35	0.46	2.31	0.39	6.70	13.50	
After trial	4.83	4.47	0.58	0.03	1.28	0.38	2.76	0.78	7.42	44.09	

4. CONCLUSION AND RECOMMENDATION

From the soil analysis and classification (Table 1-9), it is clear that the studied soils represent a fragile ecosystem that requires careful management. The soil is acidic with low chemical fertility as indicated by the low CEC values (6–12 cmol (+)/kg) and low base saturation (<50%). This implies that to achieve increased sustainable yields, soil management practices that will increase nutrient availability and enhance uptake are required. Continuous cultivation of the land for four seasons led to reductions in pH, OC, N, K and Na and increases in Ca, Mg, CEC and P. Due to the change in the chemical properties after the four seasons, regular soil testing is thus advised, necessary for monitoring the pH and plant nutrients trends for future soil fertility management. This will also give a direction into specific types of fertilizers suitable for individual farms in future. Based on the findings, the management recommendation would be to increase the levels of organic matter in the soils by, for example, addition of good quality farmyard manure, mulching, compost and addition of non-acidifying chemical fertilizers and *Mavuno* fertilizers.

Though the physical properties of the soil do not pose serious limitations for use and management, there is need to improve on bulk density, Ksat and infiltration through deep tillage. This will help loosening the soil and breaking the plough pan observed hence allows crop roots to penetrate into the soil and explore more nutrients and water. Sowing of deep rooted cover crops such as pigeon pea and lablab and also crop rotations with the cereal crops is an alternative.

Since soil is a multi-dimensional continuum with shape, area and depth, a systematic study of its horizontal variability in a detailed or semi-detailed soil survey of the Mwala soils is imperative to provide additional essential information that would assist in designing more appropriate conservation measures and land use practices.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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