Soil morphology, physico-chemical properties, classification and potential of selected soils in Kenya

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ABSTRACT (ARIAL, BOLD, 11 FONT, LEFT ALIGNED, CAPS)

Four soil profiles (Yala, Galana, Baringo and Bondo) that represent different ecology, physiography and pedological variability were described to study their morphology, soil physico-chemical characteristics and to classify them using two internationally known soil classification systems. Soil samples were taken from designated pedogenic horizons for physical and chemical analysis in the laboratory. These soils are deep to very deep (> 110 cm) and well-drained except in Galana which was imperfectly drained, with varying textures. In Bondo, the soils are moderately acid (pH 5.6 – 6). In Baringo, the soil profile is acidic (< 5.0) while in Galana moderately alkaline (pH 7.3 - 8.3) and Yala soils are strongly acid. The organic carbon (< 0.6 %) and organic matter levels (1 – 2 %) were low and decreased down the profiles in all. The soils have low to moderate fertility. The base saturation of the studied soils is rated as very high (> 80%) in Galana and Baringo and low (< 50 %) in Yala and Bondo pedons. The soils are non-saline as indicated by the low values of electrical conductivity (< 1.7dS/m) in the pedons. The soils are non-sodic (ESP < 6 %) in Bondo and Yala, however moderately sodic (ESP 11-15 %) in Galana and Baringo. Ochric horizon was the main diagnostic epipedon while ferralic, argillic and cambic horizons were the diagnostic B horizons. According to USDA Soil Taxonomy, the soils were classified as *Typic Haplustox* (Yala), *Typic Haplocalcids* (Galana), *Typic Eutrudepts* (Baringo) *and Plinthic Haplustults* (Bondo) corresponding to *Haplic Ferralsols, Luvic Calcisols, Haplic Cambisol* and *Cutanic Plinthic Acrisols* in the WRB for Soil Resources. The general fertility of the soils of the areas is discussed highlighting their potentials and constraints.

Keywords: Soil morphology; physico-chemical properties; soil classification; soil fertility evaluation

1. INTRODUCTION (ARIAL, BOLD, 11 FONT, LEFT ALIGNED, CAPS)

Sustainable production in agriculture needs to be prioritized to increase the biological and economic yield per unit area (intensification) while ensuring the sustainability of the land resource [1]. Maintaining agricultural land at an optimum level of fertility and productivity, great attention has been given to assess the physical and biochemical properties under different farm fields [2]. Soil information gathered by systematic identification, grouping, and delineation of different soils is required when sound interpretations towards land use potential are to be made [3]. 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. This information is generated by a detailed biophysical characterization of the soils [3, 4].

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Pedological characterization provides vital information and knowledge on soil characteristics and gives a clear understanding on soil genesis, morphology, classification and spatial distribution of soils in an area [3, 1, 4, 5, 6, 7]. Soil characterization data helps in the correct classification of the soil to serve as a basis for a more detailed evaluation of the soil as well as gather preliminary information on nutrient, physical or other limitations needed to produce a capability class for crop production [8, 2, 4]. Pedological information is important to land users especially farmers who use the data to decide on what crops and management practices are best suited for the optimal and sustainable production of crops [6].
Soil classification is the systematic arrangement of soils into groups or categories based on their characteristics [1, 3]. Two internationally known soil classification systems have been used to classify soils namely the United States Department of Agriculture (USDA) Soil Taxonomy and World Reference Base for Soil Resources (WRB). 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 behavior, (b) identifying their best uses, (c) estimating their productivity and (d) providing objects or units for research and for extending and extrapolating research results. For this kind of purpose, soil survey forms an essential link for its practical application and aids in the creation of databases on soil morphology, physical and chemical properties [3, 1, 4]. A soil profile representative of typical soils is dug to study its morphology, soil physico – chemical characteristics and hence classified [1, 4,]. Therefore, it is important to carry out site-specific characterization to establish the prevailing heterogeneity of the soil pattern so that the required information may be generated for the potential of the soils and appropriate soil management practices [3, 1, 4, 7].

The current study aimed at the characterization of selected soils in Kenya 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 areas that will guide activities related to the management of the existing land resources. This study envisages that soil characterization data accruing would provide users with the needed information on soils and related attributes of their land holdings for farm planning purposes.

2. MATERIAL AND METHODS

2.1 DESCRIPTION OF THE STUDY AREAS

The study was carried out in four different areas in Kenya (Yala, Galana, Baringo, and Bondo) that represent different ecology, physiography and soil pedological variability. A representative soil pedon was dug in each study area. Table 1 present the location details of the study sites. The pedons were developed from granites (Yala), assorted sedimentary rocks (Galana), alluvium and colluviums derived from gneisses and basalts (Baringo) and Kavirondian system rocks (Bondo). The altitude across the study areas ranges from 172 to 1400 m.a.s.l. whereas rainfall ranges from 150 to 1700 mm. The pedons in Yala and Bondo have a thermic moisture regime (mean annual soil temperature of equal or greater than 15^{0}C but less than 22 ^{0}C) while Galana and Baringo have iso-hyperthermic moisture regime (mean annual soil temperature of 22 ^{0}C or more), respectively.

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Table 1: Site characteristics of the studied soil profiles

Soil pedon/ district	Coordinates	Altitude (m.a.s.l)	ACZ[1)]	MAR[2)] mm	Landform	Geology /lithology	Slope %	SMR [3)]	STR[4)]	Land use/ vegetation
Yala	034º 3.583'E, 00º 02.386ºN	1 363	II - 3	1500 - 1700	Upland	Granites	5 – 7	Ustic	Thermic	Subsistence farming
Galana	UTM 37M 0557441, 9699939	172	VII – 1	150 - 350	Plain	Assorted sedimentary rocks	0 – 1	Aridic	Iso-hyperthermic	Rangeland
Baringo	797 Eastings 076 Northings	1 850	IV	1000 - 1500	Piedmont plain	Alluvium and colluviums derived from gneisses and basalts	1 – 2.5	Udic	Iso-hyperthermic	Cultivation of cotton *(Gossypium)* and groundnuts (*Arachis*

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										hypogea)
Bondo	034° 14.282′E 00°2.615′N 01°15′	1247	AEZ 2-3	800 - 1600	Upland	Kavirondian system rocks, various volcanic rocks	3 - 5	Ustic	Thermic	Subsistence farming

1) ACZ = Agroclimatic zone , 2) MAR = mean annual rainfall, 3) SMR = soil moisture regime, 4) STR = soil temperature regime

2.2 FIELD METHODS

A reconnaissance field survey was carried out using transect walks, auger observations and descriptions to establish representative study sites. Four representative soil profiles, one for each site (Yala, Galana, Baringo, and Bondo), occurring on different physiography were studied for soil pedological variability. Soil profile pits were dug, geo-referenced using Global Positioning System (GPS) (model OREGON 400t), studied and were described according to the FAO Guidelines for Soil Description [9]. Site characteristics such as slope gradient, erosion, natural drainage, natural vegetation, and land use were recorded.

Soil profile morphological characteristics studied include soil color, texture, consistence, structure, porosity and effective depth. Soil color was determined by the Munsell soil color chart [10]. Disturbed soil samples were taken from designated genetic horizons of the profiles for physico - chemical analysis in the laboratory.

2.3 LABORATORY METHODS

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. The texture was determined by Bouyoucos hydrometer method [11] after dispersing soil with sodium hexametaphosphate. Electrical conductivity (EC) was measured on a 1:2.5 ratio extract with an EC meter[12]. The pH was measured potentiometrically in water at the ratio of 1/2.5 soil water. Organic carbon was determined by the wet oxidation method of Walkley and Black

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[13] and converted to organic matter (OM) by multiplying by a factor of 1.724. The cation exchange capacity (CEC) and exchangeable bases were extracted by saturating the soil with neutral 1M NH_4OAc (ammonium acetate) [14] and the adsorbed NH_4^+ was displaced with K^+ using 1M KCl and then determined by micro-Kjeldahl distillation method for the estimation of CEC of soil [15]. The bases Ca^{2+}, Mg^{2+}, Na^+, and K^+, displaced by NH_4^+ were measured by the atomic absorption spectrophotometer (AAS) [14] . 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 [14]. The total exchangeable bases (TEB) were calculated arithmetically as a sum of the four exchangeable bases (Ca^{2+}, Mg^{2+}, K^+, and Na^+) for a given soil sample. Other parameters that were calculated included the base saturation percentage (BS %).

2.3 CLASSIFICATION OF THE SOIL PROFILES

Using the field and laboratory data, the representative soil was classified up to the subgroup level of the Soil Taxonomy [16] and Tier-2 of the World Reference Base for Soil Resources [17].

3. RESULTS AND DISCUSSION

3.1 SOIL MORPHOLOGICAL PROPERTIES

The key morphological properties of the studied profiles are presented in Table 2. The soils are deep to very deep (> 110 cm) and well-drained except in Galana which was imperfectly drained. The pedons had mostly friable moist consistence and sticky and plastic when wet throughout their profile depths. Soil horizons were quite distinct ranging from clear to gradual with smooth to wavy horizon topography. Soil pores were common and well distributed within the profile. Soil structures varied among and within soil pedons ranging from angular blocky and subangular blocky. Concretions of iron and manganese oxides and sesquioxides, which are products of Fe/Al- rich primary silicates formed through chemical weathering, were observed in Baringo and Bondo pedons and soft powdery lime in Galana pedon.

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Table 2: Some morphological features of the studied soil pedons in selected counties in Kenya

Location	Horizon	Depth (cm)	Moist Colour[1)]	Consistence[2)]	Structure[3)]	Horizon boundary[4)]
Yala	Ap	0 - 20	drb (5YR 3/3)	fr, s & p	mo, me, sbk	cs
	Bt1	20 - 63	drb (5YR 3/3)	-	mo, me, ab	cs
	Bt2	63 - 115	dr (2.5 YR 3/6)	fr, s & p	mo, me, ab & sbk	gs
	Bt3c3	115 -150	dr (2.5 YR 3/6)	fr, s & p	w-mo, me, ab & sbk	-
Galana	A	0 - 11	b-db (10YR 4/3)	f, s & p	mo, me, sbk	gs
	Bt1	11 - 33	dgb (10YR 4/2)	fr, s & p	mo, f-me, sbk	cs
	Bt2k	33 - 65	dgb (10YR 4/2)	fr, s & p	mo, f-me, sbk	cs
	Bt3k	65 - 120	b (10YR 5/3)	fr, s & p	mo, f, ab	-
Baringo	A	0 – 30	drb (2.5YR 3/4)	fr, s & p	mo, me - c, sbk	gw
	Bcs1	30 – 64	dr (2.5YR 3/6)	fr, s & p	mo-st, vf-f, sbk	cs
	Bcs2	64 – 90	dr (2.5YR 3/6)	fr, s & p	mo, vf-me, sbk	cs
	Bu	90 -139+	drb (2.5YR 3/4)	fr, s & p	mo, vf-c, sbk	-
Bondo	Ap	0 – 21	b-db (7.5YR 4/4)	fr, s & p	w, me, sbk	cs
	Bt1	21 – 49	b-db (7.5YR 4/4)	fr, s & p	mo, me, ab & sbk	cs

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Bt2	49 – 75	b (7.5YR 5/4)	fr, s & p	w, me, sbk	cw
Bcs	75 -110+	yr (5YR 6/6)	fr, s & p	w-mo, f-me, sbk	cw

1) drb = dark reddish brown; dgb = dark greyish brown; dr = dark red; b = brown; b-db =brown to dark brown; dgb = dark grayish brown; yr = yellowish red, 2) fr = friable; s = sticky; p = plastic, 3) Grade: w = weak; mo = moderate; st = strong, Class: vf = very fine, f = fine, me = medium, c = coarse, vc = very coarse, Type: sbk = sub angular blocky; ab = angular blocky

4) c = clear; s = smooth; g = gradual; w = wavy, (-) = not determined

3.2 PHYSICO-CHEMICAL PROPERTIES OF THE STUDIED PEDONS

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

Table 3 presents the data on soil texture. The pedons in Yala, Galana and Baringo had variable textures within their profiles indicative of lithological discontinuity. The pedon in Bondo was clayey throughout the profile depths. The sand content decreased gradually with depth as the proportion of finer particles increased, partially due to illuviation and argillation in the Bt horizons in Yala and Bondo [18] while the clay content is generally higher in B horizons than in A horizons (Table 5). Higher sand content was observed in Galana while high silt levels were observed in Bondo and Baringo. Soil texture is the most stable physical characteristic of the soils which influences several other soil properties including structure, soil moisture availability, erodibility, root penetration and soil fertility [1]. 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 [18]. The silt/clay ratio, an indicator of soil susceptibility to detachment and transport, was less than the threshold of 0.4 in Yala and Galana implying moderate resistance to erosion [19]. In Baringo and Bondo, the silt/clay ratio was > 0.4 implying high susceptibility to erosion.

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Table 3: Selected physical properties of the studied pedons in selected counties in Kenya

Location	Horizon	Depth (cm)	Particle size distribution (%)			Textural class[1)]	Silt/clay ratio
			Sand	Clay	Silt		
Yala	Ap	0 - 20	48	40	12	SC	0.3
	Bt1	20 - 63	40	52	8	C	0.15
	Bt2	63 - 115	32	58	10	C	0.2
	Bt3c3	115 -150	42	50	8	C	0.2
Galana	A	0 - 11	72	22	6	SCL	0.27
	Bt1	11 - 33	66	30	4	SCL	0.13
	Bt2k	33 - 65	60	36	4	SC	0.11
	Bt3k	65 - 120	56	36	8	SC	0.22
Baringo	A	0 – 30	34	18	48	L	2.7
	Bcs1	30 – 64	34	18	48	SiL	2.7
	Bcs2	64 – 90	34	18	48	L	2.7
	Bu	90 -139+	30	18	52	SiL	2.8

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Bondo	Ap	0 – 21	26	46	28	C	0.6
	Bt1	21 – 49	18	58	24	C	0.4
	Bt2	49 – 75	16	64	20	C	0.3
	Bcs	75 -110+	14	50	36	C	0.3

[1)] SC = sandy clay; C = clay; SCL = sandy clay loam; L = loam; SiL = silty loam

3.2.2 Soil reaction (pH), organic C and organic matter (OM)

Selected soil chemical properties of the studied pedons are presented in Table 4. In Bondo, the soils are moderately acid (pH 5.6 – 6). In Baringo, the soil profile is very strongly acidic (< 5.0) while in Galana moderately alkaline (pH 7.3 - 8.3) and Yala soils are moderate to strongly acid (5.1 – 5. 7) [20]. This shows that the soils may present some limitations to crop production such as low availability of both the macro and micro plant nutrients for uptake by crops [21]. From the results, there is a need to consider the application of liming materials to raise soil pH to the optimal levels of about 6.5 to 7.5 to minimize nutrient imbalances, toxicity, and unavailability in Yala, Baringo, and Bondo. It will also help to improve soil microbial activities that work best under such neutral pH conditions.

The organic carbon (< 0.6 %) and organic matter levels (1 – 2 %) were low and decreased down the profiles in all the soils. The low organic matter observed may be attributed to low pH or high pH which restricts microbial activities. The consistently low OM of the soils is presumed to be a result of rapid humification and mineralization as conditioned by high radiation in the areas. For pH values of about 5.5 and below, bacterial activity is reduced and nitrification of organic matter is significantly retarded [20, 1]. The high pH values in Galana can be attributed primarily to a low rainfall environment which has allowed large amounts of calcium carbonate to accumulate.

3.2.3 Exchangeable bases, Cation Exchange Capacity (CEC), Base saturation (BS) and Electrical Conductivity (EC)

The CEC is low to moderate (< 24 cmol (+)/kg) in all profiles except in Galana which is high (> 25 cmol(+)/kg). The CEC levels observed in these pedons indicate that the soils have low to high nutrient retention capacity [20]. The low CEC levels observed in the studied pedons could also be attributed to strong leaching of the bases down the pedon [3]. The CEC is associated with the exchangeable cations (Ca, Mg and K) in the soil and protects soluble cations from leaching out of the plant root zone which helps soils resist changes in pH [4,22]. The observed low CEC values imply that all fertilizers except P have to be applied in split applications to reduce nutrient losses through leaching. The high CEC values in Galana can be attributed to high calcium carbonate content in the pedon. The CEC of soils is affected mainly by the amount and kind of organic matter and clay. The CEC also depends on texture, type of clay and amount of organic matter in the soil with CEC of < 16cmol/kg considered not to be fertile soils as was observed in Yala, Baringo, and Bondo. Such soils are usually

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highly weathered. Therefore, the addition of organic matter to the soil is important as it increases the CEC hence improving soil fertility [23]. Non - acidifying N and P fertilizers and liming will be necessary for optimal crop production on these soils.

The soils have low to moderate fertility [23]. The low amounts of exchangeable bases and the predominance of exchangeable acidity on the exchange complex in all the soils is an indication of leaching and erosion processes as depicted by the presence of gullies and rills in the sites except in Galana [24].

Base saturation (BS) is the percentage of cation exchange capacity that is saturated with potassium, calcium, magnesium and sodium ions and indicates how closely nutrient status approaches potential fertility [24, 25]. The base saturation of the studied soils is rated as very high (> 80%) in Galana and Baringo and low (< 50 %) in Yala and Bondo pedons. The high base saturation observed at the pedons can be attributed to higher CEC values which give the soils a greater capacity to retain bases [7]. When the soil pH is above 7.2, there is a free solution of Ca and Na unattached to the soil exchange complex that is unavoidably extracted. This could be the reason for the high BS above 100 % in some horizons, notably in Galana and Baringo [26]. Low base saturation levels of < 60 % may result in very acid soils and potentially toxic cations such as Aluminium and Manganese from the soil [19]. 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 a low level of bases in most soils [1]. According to [20], a relatively high base saturation of 70 to 80 % should be maintained for the good performance of most cropping systems.

The soils are non-saline as indicated by the low values of electrical conductivity (< 1.7dS/m) in the pedons. 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 [20], which was not observed in these pedons.

The soils are non-sodic (ESP < 6 %) in Bondo and Yala, however moderately sodic (ESP 11-15 %) in Galana and Baringo [20,27, 28]. The slightly sodic conditions (< 15 %) in the pedons can result in up to a 50 % yield reduction of the sensitive crops, maize, and beans. Sodic conditions in soils have a marked influence on the physical soil properties. As the proportion of exchangeable sodium increases, the soil tends to become more dispersed which results in the breakdown of soil aggregates and lowers the permeability of the soil to air and water [29]. Dispersion also results in the formation of dense, impermeable surface crusts that hinder the emergence of seedlings. It can also result to plant injury or reduced growth and even death due to the accumulation of certain elements in plants at toxic levels. Application of amendments like gypsum and pyrite on the surface horizon can help in correcting the sodicity by removing the exchangeable sodium ions [30].

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Table 4: Selected chemical properties of the studied pedons in selected counties in Kenya

Location	Horizon	Depth (cm)	pH (H_20)	OC %	OM%	K	Na	Ca	Mg	TEB	CEC	BS (%)	EC dS/m	ESP (%)
						$cmol(+)kg^{-1}$								
Yala	Ap	0 - 20	5.7	1.52	2.62	0.76	0.59	2.11	0.65	4.11	7.36	56	0.08	8.0
	Bt1	20 - 63	5.1	1.18	2.03	0.16	0.24	2.07	0.41	2.88	9.45	30	0.04	2.0
	Bt2	63 - 115	5.3	0.67	1.16	0.22	0.24	2.52	0.31	3.29	7.09	46	0.02	3.0
	Bt3c3	115 -150	5.7	0.83	1.43	0.16	0.24	1.73	0.25	2.38	8.33	29	0.02	3.0
Galana	A	0 - 11	7.4	0.5	0.86	3.10	2.10	33.8	4.90	43.9	28.1	100+	2.62	7.0
	Bt1	11 - 33	8.7	0.4	0.69	2.00	2.60	71.10	5.70	81.4	29.5	100+	2.09	9.0
	Bt2k	33 - 65	8.1	0.3	0.52	1.70	5.10	122.4	5.40	134.6	35.3	100+	5.71	14.0
	Bt3k	65 - 120	8.6	0.2	0.34	1.70	6.10	87.40	5.20	100.4	29.5	100+	3.33	21.0
Baringo	A	0 – 30	4.7	0.7	1.21	1.70	1.60	2.30	1.30	6.90	11.0	62	0.08	14.0

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	Bcs1	30 – 64	4.5	0.2	0.34	0.50	0.70	2.90	1.70	5.80	6.00	88	0.18	10.0
	Bcs2	64 – 90	4.5	0.3	0.52	0.60	0.80	3.70	1.50	6.60	7.00	97	0.17	12.0
	Bu	90 -139+	5.5	0.3	0.52	0.80	1.00	4.90	1.20	7.90	7.00	100+	0.09	15.0
Bondo	Ap	0 – 21	6.2	1.64	2.83	0.36	0.27	2.80	1.27	4.70	10.24	46	0.08	2.0
	Bt1	21 – 49	5.4	1.07	1.84	0.24	0.31	3.54	2.75	6.84	11.81	58	0.04	3.0
	Bt2	49 – 75	5.5	0.76	1.31	0.42	0.45	2.21	1.73	4.81	13.68	35	0.09	3.0
	Bcs	75 -110+	5.7	0.66	1.14	0.16	0.28	3.55	3.15	7.14	12.46	7	0.02	2.0

TEB = total exchangeable bases, CEC = cation exchange capacity, BS = base saturation, EC = electrical conductivity, ESP = exchangeable sodium percentage

3.2.4 Nutrient balance in the studied pedons

The soil nutrient ratios in the studied pedons are presented in Table 4. The availability of nutrients for uptake by plants depends not only upon absolute levels of nutrients but also on the nutrient ratios [1,31]. Nutrient imbalances influence nutrient uptake by inducing deficiencies of nutrients that may be present in the soil in good quantities [31]. It is therefore important to consider the individual nutrient ratios i.e. Ca/Mg ratio, Mg/K ratio and K/TEB which are indicators of nutrient uptake [3].

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The Ca/Mg ratio of the soils in Baringo and Bondo pedons ranged between 2 and 4, which are considered favorable for most tropical crops [4]. While in Galana and Yala pedons, the ratios were greater than 5 which implies a deficiency of magnesium for plant uptake [26]. The deficiency of Mg can be attributed to heat stress, droughty soil and high levels of competing elements particularly Ca and this results in the decrease of Mg^{2+} availability to plants, lower accumulation of Mg in seeds, marked inhibition of plant growth, acceleration of aging, and reduced productivity and quality in agriculture [32]. Excessive Ca content in the soil also causes precipitation of P, S, and Zn [33]. Fertilization using iron and phosphorus fertilizers, soil acidification, cultural practices such as irrigation, mulching, deep ripping, the addition of organic matter amendments and mycorrhizal treatments are recommended to effectively minimize the adverse effects of high calcium content [34].

In the case of Mg/K ratios, the Bt1 and Bcs horizon in Bondo portray unfavorable ratios of > 11 outside the optimal range and hence unfavorable. All the other pedons had Mg/K ratios within the optimal range of between 1 and 4. The Ca/ TEB ratios were > 0.5 which may affect the uptake of other bases, particularly Mg and/or K, as calcium-induced deficiency of Mg and /or K may appear. The K/TEB ratios, expressed as a percent, for all the studied pedons were above 2 % in most horizons, which is considered favorable for most tropical crops [26] except in the lower horizons of Galana pedon (< 2%). From these results, it is apparent that nutrient imbalances observed in these pedons will influence nutrient availability. Nutrient availability determines the yield potential of crops and can be improved by manuring, application of inorganic fertilizers and crop rotation [1,35].

Table 5: Soil nutrient ratios of the studied pedons in selected counties in Kenya

Location	**Horizon**	**Depth (cm)**	**K**	**Na**	**Ca**	**Mg**	**TEB**	**Ca/Mg**	**Mg/K**	**Ca/TEB**	**%K/TEB**
			$cmol(+)kg^{-1}$								
Yala	Ap	0 - 20	0.76	0.59	2.11	0.65	4.11	3.25	0.86	0.51	18.49
	Bt1	20 - 63	0.16	0.24	2.07	0.41	2.88	5.05	2.56	0.72	5.56
	Bt2	63 - 115	0.22	0.24	2.52	0.31	3.29	8.13	1.41	0.77	6.69

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	Bt3c3	115 -150	0.16	0.24	1.73	0.25	2.38	6.92	1.56	0.73	6.72
Galana	A	0 - 11	3.10	2.10	33.8	4.90	43.9	6.90	1.58	0.77	7.06
	Bt1	11 - 33	2.00	2.60	71.10	5.70	81.4	12.47	2.85	0.87	2.46
	Bt2k	33 - 65	1.70	5.10	122.4	5.40	134.6	22.67	3.18	0.91	1.26
	Bt3k	65 - 120	1.70	6.10	87.40	5.20	100.4	16.81	3.06	0.87	1.69
Baringo	A	0 – 30	1.70	1.60	2.30	1.30	6.90	1.77	0.76	0.33	24.64
	Bcs1	30 – 64	0.50	0.70	2.90	1.70	5.80	1.71	3.40	0.50	8.62
	Bcs2	64 – 90	0.60	0.80	3.70	1.50	6.60	2.47	2.50	0.56	9.09
	Bu	90 -139+	0.80	1.00	4.90	1.20	7.90	4.08	1.50	0.62	10.13
Bondo	Ap	0 – 21	0.36	0.27	2.80	1.27	4.70	2.20	3.53	0.60	7.66
	Bt1	21 – 49	0.24	0.31	3.54	2.75	6.84	1.29	11.46	0.52	3.51

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Bt2	49 – 75	0.42	0.45	2.21	1.73	4.81	1.28	4.12	0.46	8.73
Bcs	75 -110+	0.16	0.28	3.55	3.15	7.14	1.13	19.69	0.50	2.24

TEB = total exchangeable bases

3.3 SOIL CLASSIFICATION

Based on the field and laboratory data (Tables 2 – 5), the pedons were classified up to the subgroup level of the USDA Soil Taxonomy and Tier-2 in the WRB [16, 17]. Ochric horizon was the main diagnostic epipedon while ferralic, argillic and cambic horizons were the diagnostic B horizons. The detailed classification is shown in Table 6.

Table 6: Classification of the studied pedons in selected counties in Kenya

Location	**USDA Soil Taxonomy (Soil Survey Staff, 2014)**					**WRB for Soil resources (IUSS Working group, WRB, 2006)**	
	Diagnostic horizons	**Order**	**Suborder**	**Great group**	**Subgroup**	**Reference Soil Group (Tier-1)**	**WRB Soil name (Tier-2)**
Yala	Ochric epipedon Ferralic horizon	Oxisols	Ustox	Haplustox	Typic Haplustox	Ferralsols	Haplic Ferralsols (dystric, endoclayic, rhodic)

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Galana	Ochric epipedon Argillic horizon	Aridisols	Calcids	Haplocalcids	Typic Haplocalcids	Calcisols	Luvic Calcisols (hyposalic, hyposodic)
Baringo	Ochric epipedon Cambic horizon	Inceptisols	Udepts	Eutrudepts	Typic Eutrudepts	Cambisols	Haplic Cambisols (eutric, hyposodic)
Bondo	Ochric epipedon Argillic horizon	Ultisols	Ustults	Haplustults	Plinthic Haplustults	Acrisols	Cutanic, Plinthic Acrisols (hyperdystric)

4. CONCLUSIONS AND RECOMMENDATIONS

The four pedons that represent different ecology, physiography and soil pedological variability are highly variable in terms of morphological, physical and chemical properties and thus will behave differently about land use and management. However, they share many characteristics such as being well-drained apart from Galana, angular and sub-angular blocky structures, the epipedons and B horizons being friable and having sticky and plastic consistence when wet. The soils of the study areas are deep to very deep hence suitable for the production of both shallow and long-rooted crops. The soils are of low to medium fertility as indicated by the low levels of OC, OM, pH and

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exchangeable bases. Based on the examination of the chemical properties, the soils may exhibit some problems of nutrient imbalance due to unfavorable Ca/Mg, Ca/TEB and Mg/K in some pedons.

Sustainable use of these soils will require deliberate efforts such as preservation of the surface soil with its all-important organic matter (by retention of crop residues, mulching, and green manuring) and preventing erosion as preconditions for farming. Frequent loosening of the topsoil, together with the removal of weeds, will permit rain to infiltrate thus preventing erosion by sheet wash. The introduction of leguminous cover crops in the farming systems and the use of non-acidifying fertilizers in Yala, Bondo and Baringo are advised. In Galana, deep irrigation of the soil with best quality water (EC < 0 .25 mS/cm) to move soluble salts beyond the root zone and mulching to prevent wicking of soluble salts to eliminate the salinity of the soils is required. For soil acidity problems, the practice of either liming, which is important in raising the pH to favorable levels of around pH 6.5 and 7.5, or planting crops that are tolerant to acidity is recommended as the best options for these areas.

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COMPETING INTERESTS

The author has declared that no competing interests exist.

AUTHORS' CONTRIBUTIONS

Author ANK designed the study, managed the soil analyses and literature search, read and approved the final manuscript

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