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Pedological Characterization of Some Typical Soils of Busia County, Western Kenya: Soil Morphology, Physico-chemical Properties, Classification and Fertility Trends

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Authors' contribution

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

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ABSTRACT

Standard soil survey was carried out in Western Kenya to establish representative research sites on the basis of landforms and other physiographic attributes. Soil profiles were characterized at Emalomba (Nambale District) designated (EMA-P1) and at Bukhalalire (Butula District) named BUMA-P1. Both pedons formed from in-situ weathering of granitic rocks under ustic moisture and iso-hyperthermic temperature regimes. Fourteen soil samples from genetic horizons were analyzed for physico-chemical properties. Both pedons had dark brown sandy clay and sandy clay loam topsoils overlying dominantly clayey subsoils. Both pedons indicate clay eluviation-illuviation as a

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dominant pedogenic process with strong acidic soil conditions and available phosphorus of < 7 mg/kg soil. Organic carbon (OC) is high in EMA-P1 and medium to very low in BUMA-P1 while total nitrogen is medium and low to very low. EMA-P1 and BUMA-P1 have C/N ratios of 8.6 - 9.6 and 12.9 - 24.8 respectively. Both pedons have low to very low exchangeable bases with cation exchange capacity (CEC) < 16 cmol(+)/kg soil. CEC_{clay} values in both pedons are < 24 cmol(+)/kg with BUMA-P1 having < 10 cmol(+)/kg. Both soils are highly weathered with BUMA-P1 depicting more advanced stage of weathering. In the USDA Soil Taxonomy, EMA-P1 was classified as *Kanhaplic Haplustults* and BUMA-P1 as *Typic Kandiustults*, both corresponding to *Haplic Cutanic Acrisols* in WRB. As regards soil fertility trends, OC showed positive correlation with calcium and magnesium indicating organic matter as the main source of plant nutrients. The two pedons differed noticeably in terms of physico-chemical characteristics emphasizing the need to characterize soils before fertilizer recommendations are made. Organic fertilizers are recommended to increase organic matter content and intercropping of cereals with nitrogen fixing legumes to enhance nitrogen in the soils. Use of non-acidifying inorganic fertilizers and lime as soil amendments should also be considered to correct acidity.

Keywords: Pedological characterization; soil morphology; physico-chemical properties; soil classification; soil fertility trends, Busia County, Kenya.

1. INTRODUCTION

Pedological characterization provides valuable information and knowledge on soil characteristics and gives clear understanding on soil genesis, morphology, classification and spatial distribution of soils in an area. According to [1], climate, parent material, biota, relief and time are soil forming factors that influence the morphological, physical, chemical and biological characteristics of soil. Understanding of soil genesis, morphology and other key soil properties is a pre-requisite to sustainable use of soil resources [2] and thus detailed knowledge about them is essential. The authors emphasized the need to have well characterized and defined ecological conditions to aid soil fertility specialists and other stakeholders of soil information to transfer agronomic technologies from one area to another. Well prepared soil resource inventories are a benchmark in determining the potential and management requirements of specific areas for various land uses.

Soil survey works carried out covering the study area of Busia County are limited and are typically of exploratory and/or reconnaissance scales. For example the work of [3] at a scale of 1:1 000 000 described the soils of Busia County (then, Busia District) as well drained, moderately deep to very deep, reddish brown to yellowish brown, friable clay, over petro-plinthite (OrthicFerralsols, partly petroferric phase; with OrthicAcrisols). The coarse scale nature of this work gives limited information on forecasting the agricultural potential and limitations of the soils of the County. Soil characterization of selected areas in Kenya was carried by [4] and gave general information that cannot be extended to other related diverse soils in the County. According to [5], the soils of Western Kenya vary both in their physical and chemical properties and agricultural production is governed by major soil types and precipitation patterns.

Due to limitations pointed above, it is important therefore, to carry out site specific characterization in order 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. Furthermore agronomic technologies developed on such well characterized soils can easily be extrapolated to other areas with similar ecological conditions [2]. Similar report has also been shown by other workers [6] who have pointed out the necessity to carry out site specific soil characterization taking into account that crop production is a function of soil properties. Further to this, site soil resource information is required by agricultural extension staff and farmers as a tool for soil fertility management. Thus, knowledge of site characterized soil physical and chemical properties with other ecological conditions will aid in determining the correct type and amounts of fertilizer to be applied for optimum crop production and sustenance of improved soil fertility. Apart from the soil and ecological attributes, socio-economic factors also influence agricultural production, thus, they have also to be considered when appraising the potential of a given piece of land for various uses.

The current study reports on site identification, description and characterization of some typical soils of Busia County in terms of their morphological characteristics, physico-chemical properties and their classification according to the United States Department of Agriculture (USDA) Soil Taxonomy [7] and the FAO-World Reference Base [8]. It also reports on the soil fertility trends of the County. The results obtained are anticipated to aid in land use planning and sustainable agricultural production.

2. MATERIALS AND METHODS

2.1 Description of the Study Sites

The study areas in Busia County, Kenya are located at Emalomba in Nambale District with a pedon designated as EMA-P1 and at Bukhalalire in Butula District with a pedon named BUMA-P1. Table 1 gives the pertinent site characteristics of the study areas. The elevations of the sites are 1222 m and 1306 m above sea level respectively. Both pedons are developed from granitic rocks of pre-Cambrian age. In terms of physiography, the soils are formed on peneplains with gradients ranging between 2 and 2.5%. Surface characteristics depicted slight interill/sheet erosion with no deposition in the identified sites. It was noted that EMA-P1 profile had slow run-off and moderately slow infiltration in contrast to BUMA-P1 profile that had moderately rapid run-off and rapid infiltration.

The climatic conditions of study area are summarized in Fig. 1. The study sites experience bimodal rainfall distribution with the long rains having a peak in April-May while the short rains show a peak in October. The maximum temperatures vary between 26.1℃ to 29.6℃ and minimum temperature range between 13.5℃ to 14.9℃ [9].The maximum temperatures are within the rating of land use requirements for rain fed sorghum and maize production [10].

2.2 Field Methods

Reconnaissance field survey was carried out using transect walks, auger observations and descriptions to establish representative study sites on the basis of landforms and other physiographic attributes. Data on landform, soil morphological characteristics, elevation, slope gradient, parent material (lithology), vegetation and land use/crops were collected from two observation sites that were selected to represent major landforms and soils as identified from the reconnaissance survey. The data were filled on field description forms designed based on the FAO Guidelines for Soil Description [11]. Two representative soil profiles, one from each site, were identified and excavated to represent the major soil types. Soil profile pits measuring of 250 cm by 150 cm were laid out in the east – west direction using GPS compass and dug to a depth of 200+ cm. The soil profile pits were studied, described and sampled according to FAO Guidelines for Soil Profile Description [11]. The soil profiles were geo-referenced using Global Positioning System (GPS) (model OREGON 400t).

Soil colours were determined by Munsell soil colour charts [12]. In each profile pit, undisturbed (core) soil samples at depths of 0-5 cm, 45-50 cm and 95-100 cm) were sampled, while disturbed samples were taken from all the designated natural horizons for laboratory physical and chemical analysis.

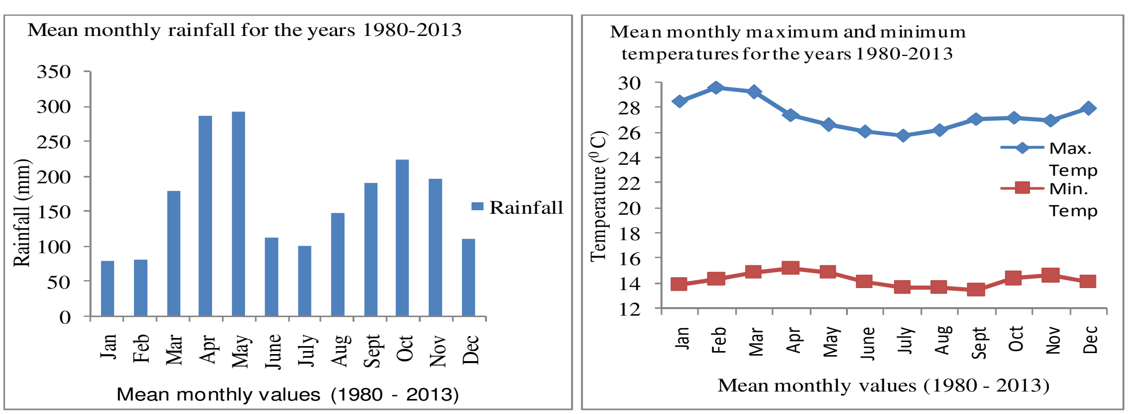

Fig. 1. Mean monthly rainfall and temperature data for the study sites from 1980-2013
(Source: [9])

Table 1. Site characteristics of the studied soils

Pedon	Location	AEZ	Altitude m asl	Landform	Geology / lithology	Slope %	Land use / Vegetation	SMR	STR
EMA-P1	N 00°25′ 28.9″ E 034°15′ 51.8″	LM1 (Humid Lower Midland Zone)	1222	Peneplain	Pre- Cambrian rocks of the basement complex, comprising mainly granites	2	Agriculture (sugarcane, maize, sweet potatoes, bananas, upland rice (Nerica) and livestock). Dominant vegetation includes *Albizia falcataria, Jacaranda mimosifolia*, *Tithonia diversifolia, Eucalyptus spp.,Grevillea robusta, Azadirachta indica* (neem tree).	Ustic	Iso-hyperthermic
BUMA-P1	N 00°19′ 10.1″ E 034°16′ 26.4″	LM1(Humid Lower Midland Zone)	1306	Peneplain	Pre-Cambrian rocks of the basement complex, comprising mainly granites	2.5	Agriculture (maize, sugarcane, sweet potatoes, bananas, groundnuts, Bambara nuts, upland rice (Nerica) and livestock). Dominant vegetation includes *Albizia falcataria*, *Jacaranda mimosifolia*, *Tithonia diversifolia*, *Eucalyptus spp.,Grevillea robusta, Azadiracta indica* (neem tree), *Croton megalocarpus* (Musine in Luhya)	Ustic	Iso-hyperthermic

m asl = metres above sea level AEZ = Agro-ecological zone (after Jaedzold, 2006) SMR = soil moisture regime STR = soil temperature regime

2.3 Laboratory Methods

2.3.1 Pedological characterization

Undisturbed (core ring) samples were used for determination of bulk density, porosity and moisture retention characteristics. Bulk density was determined by the core method [13]. Water holding characteristics were determined by pressure plate/pressure membrane apparatus [14]. Disturbed soil samples were air-dried, ground and passed through a 2-mm sieve for physical and chemical soil properties. Particle size distribution was determined by hydrometer method [15] after dispersing soil with sodium hexametaphosphate and textural classes determined using the USDA textural triangle [16]. Soil pH in water was measured potentiometrically using a soil: water ratio of 1:2.5 weights to volume basis [17]. Potentiometric method was used to determine electrical conductivity while available phosphorus was extracted using Mehlich-3 extraction method [18] and determined by spectroscopy at 884 nm following colour development by the Molybdenum blue method [19]. Organic carbon was determined by Walkey-Black wet oxidation method [20] and total nitrogen was determined by micro-Kjeldahl digestion method [21].

Cation exchange capacity of the soil (CEC*soil*) and exchangeable bases were determined by saturating soil with neutral 1M NH_4OAc (ammonium acetate) and the adsorbed NH_4^+ were displaced by using 1M KCl and then determined by Kjeldahl distillation method for estimation of CEC of the soil [22]). The exchangeable bases (Ca^{2+}, Mg^{2+}, Na^+ and K^+) were determined by atomic absorption spectrophotometer [23]. 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 which were calculated include C/N ratio, exchangeable sodium percentage (ESP) and base saturation percentage (BS %).

2.3.2 Determination of soil fertility levels in Busia County

Fertility topsoil samples (0-15 cm depth) were collected from ten (10) selected areas from five districts of Busia County and mixed thoroughly to obtain representative composite samples. The samples were air-dried, ground and passed through a 2-mm sieve for laboratory analysis as in the case of disturbed samples for pedological characterization. The analyses were done to assess the general soil fertility trends in the County.

2.3.3 Statistical data analysis

Soil fertility trends analytical data were subjected to Spearman's rank correlation to show the relationship among the soil parameters.

2.3.4 Classification of soils

Using field and laboratory analytical data for pedological characterization, the soils were classified to family level of the USDA Soil Taxonomy [7] and toTier-2 of the FAO World Reference Base [8].

3. RESULTS AND DISCUSSION

3.1 Morphological Characteristics

Salient morphological characteristics of the studied profiles are given in Table 2. EMA-P1 profile is a very deep, well drained pedon, with dark brown sandy clay topsoils overlying dark reddish brown to red clayey subsoils. Abundant distinct clay cutans were observed in the subsoil indicating that eluviation-illuviation has been a dominant pedogenic process. Profile BUMA-P1 is similar to profile EMA-P1 in many respects. Unlike profile EMA-P1, this profile has fewer and fainter clay cutans, but richer in sesquioxides as indicated by much redder subsoil colours. The subsoil structure of this profile is weaker breaking into powder indicating a stronger weathering and a more advanced stage of pedogenic development.

3.2 Soil Physical Characteristics

3.2.1 Soil particle size distribution (texture)

Textural data of the studied pedons are presented in Fig. 2 and Table 3. Fig. 2 gives the particle size distributions in relation to depth, which clearly indicates that the distribution patterns of the textural separates are similar for both pedons. This supports the fact that the two pedons have developed largely under same soil forming factors and have attained comparable degree of pedogenesis.

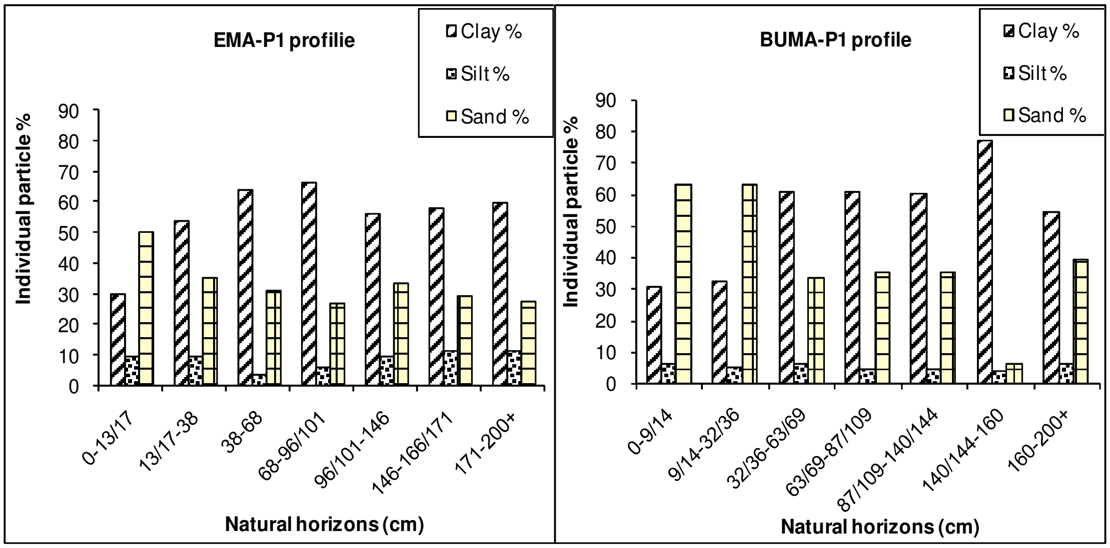

Fig. 2. Individual soil particle distribution of the studied soils

Despite the fact that EMA-P1 has sandy clay topsoil, and BUMA-P1 sandy clay loam topsoil, the two pedons have dominantly clayey subsoils. The silt/clay ratios particularly for subsoils of the two pedons are very low, indicating that the two pedons are highly weathered. The silt/clay ratios in BUMA-P1 are relatively lower than those in EMA-P1 indicating that the former pedon is slightly more weathered than the latter.

3.2.2 Bulk density, total porosity and available moisture content

The analytical results on bulk density, total porosity and available water content of the described profiles are given in Table 3. Bulk density determines the magnitude of particle-to-particle contacts and is related to total porosity and has an influence on available soil moisture [24]. Both profiles have low bulk density (below 1.3 g cm^{-3}) indicating soils that disintegrate into numerous fragments after application of weak pressure [11]. These analytical results support the field data on soil structure presented in Table 2. In comparison, the bulk density in EMA-P1 is lower in the topsoil and increases with depth while that in BUMA-P1 is higher in the topsoil and decreases with depth. The high bulk density value in topsoil may likely reduce water infiltration and favour surface water run-off while an increase of the same with depth could result to poor root growth, reduced aeration and decreased water infiltration. Evaluation of bulk density in relation to soil texture in both pedons reveals a 4 % more clay content in EMA-P1 pedon in the approximately 80 cm of the sub-horizons (Table 3) and has a direct relationship with the available moisture content and consequently water retention capacity (Fig. 3). EMA-P1 pedon also depicted higher organic carbon in comparison to BUMA-P1 (Table 5) suggesting a probable influence on bulk density. According to [25] bulk density is influence by the amounts of organic matter in the soil.

3.2.3 Penetrometer resistance

Table 4 presents the penetrometer resistance of the two studied pedons. Soil resistance increases with increase in bulk density with decrease in total porosity and soil available moisture content due to increased capillary cohesion [24]. EMA-P1 soil profile depicts low penetrometer resistance in the upper top-soil and this is attributed to low bulk density (Table 3) and reduced matric potential (Fig. 3) suggesting reduced capillary cohesion due to high available moisture content. BUMA-P1 profile has increasing penetrometer resistance in the representative depths that correlate with the data in Table 3, and increased matric potential (Fig. 3) due to probably increased particle-to-particle cohesion. The results further point out possible soil compaction in the BUMA-P1 profile and which may cause slow growth and development of crops.

Table 2. Salient morphological features of the studied soil profiles

Pedon	Horizon	Depth	Texture[1)]	Moist colour[2)]	Consistence[3)]	Structure[4)]	Horizon boundary[5)]
EMA-P1	Ap	0 - 13/17	SC	rdb (7.5YR2.5/3)	fr, s&p	w-m, m, cr	cw
	Bt_1	13/17- 38	C	db (7.5YR3/3)	fr, s&p	m c, sbk	gs
	Bt_2	38-68	C	drb (5YR3/4)	fr, s&p	m c&m, a&sbk	gs
	Bt_3	68-96/101	C	drb (5YR3/4)	vfr, s&p	s m&f, sbk	aw
	CB	96/101-146	C	drb (2.5YR3/4)	fr, ss&sp	w f&p, sbk	as
	$2Bt_1$	146 - 166/171	C	rb (2.5YR4/4)	vfr, s&p	w-m, f&c, sbk	cw
	$2Bt_2$	171 - 200+	C	drb (2.5 YR3/4)	vfr, s&p	w f&m, sbk	-
BUMA-P1	Ap	0 - 9/14	SCL	db (7.5YR3/3)	fr, ss&p	w f&m, cr&sbk	gw
	BA	9/14 - 32/36	SCL	b (7.5YR4/3)	fr, s&p	m m&c, sbk	cw
	Bt_1	32/36 - 63/69	C	rb (5YR4/4)	f, s&p	m m&c, sbk	gw
	Bt_2	63/69 - 87/109	C	rb (5YR4/4)	vfr,ss&p	w-m m&c, sbk-p	gw
	Bts_1	87/109 - 140/144	C	drb (2.5YR3/4)	vfr,ss&p	w m&c, sbk-p	dw
	Bts_2	140/144 – 160	C	rb (2.5YR4/4)	vfr, ss&p	w-m, m, sbk-p	aw
	CB	160 - 200+	C	r (2.5YR4/6)	fr, ss&p	Mass	-

[1)] SC=sandy clay; SCL=sandy clay loam; C= clay. [2)]rdb= reddish dark brown; db=dark brown; drb=dark reddish brown; rb=reddish brown; b=brown; r=reddish
[3)]vfr= very friable; fr=friable; s=sticky; ss=slightly sticky; p=plastic. [4)] EMA-P1: w-m, m, cr =weak to moderate medium crumby; m c, sbk = moderate coarse subangular blocky; m c&m, a&sbk = moderate coarse & medium angular &subangular blocky; s m & f, sbk = strong medium & fine subangular blocky; w f&p, sbk = weak fine & powdery subangular blocky; w-m, f&c, sbk = weak to moderate fine and coarse subangular blocky; w f&m, sbk = weak fine & medium subangular blockyBUMA-P1: w f&m, cr&sbk = weak fine & medium crumby; m m&c, sbk = moderate medium & coarse subangular blocky; w-m m&c, sbk-p = weak to moderate medium & coarse subangular blocky; w m&c, sbk-p = weak medium & coarse subangular blocky breaking into powder; w-m, m, sbk-p = weak to moderate medium subangular blocky breaking into powder; mass = massive. [5)]a= abrupt; c=clear; d=diffuse; g=gradual; s= smooth; w=wavy

Table 3. Some physical properties of the studied profiles

Pedon	EMA-P1							BUMA-P1						
Soil depth (cm)	0-13/17	13/17-38	38-68	68-96/101	96/101-146	146-166/171	166/171-200+	0-9/14	9/14-32/36	32/36-63/69	63/69-87/109	87/109-140/144	140/144-160	160-200+
Texture:	**SC**	**C**	**C**	**C**	**C**	**C**	**C**	**SCL**	**SCL**	**C**	**C**	**C**	**C**	**C**
Clay %	30.5	54.1	64.5	66.5	56.5	58.5	60.2	30.5	32.1	60.5	60.5	60.1	77.2	54.5
Silt %	9.8	10.1	3.8	6.2	9.8	11.8	11.8	6.2	4.9	6.2	4.2	4.6	3.8	6.2
Sand %	50.3	35.8	31.7	27.3	33.7	29.7	28.0	63.2	62.9	33.3	35.3	35.3	19.0	39.3
Silt/clay	0.32	0.19	0.06	0.09	0.17	0.20	0.20	0.20	0.15	0.10	0.07	0.08	0.05	0.11
Bulk density	1.14	-	1.20	1.23	-	-	-	1.30	-	1.16	1.11	-	-	-
Total porosity	47.9	-	53.2	49.2	-	-	-	46.8	-	48.6	53.6	-	-	-
Av. moisture content (% vol/vol)	54.4	-	64.0	60.7	-	-	-	59.0	-	56.3	59.4	-	-	-

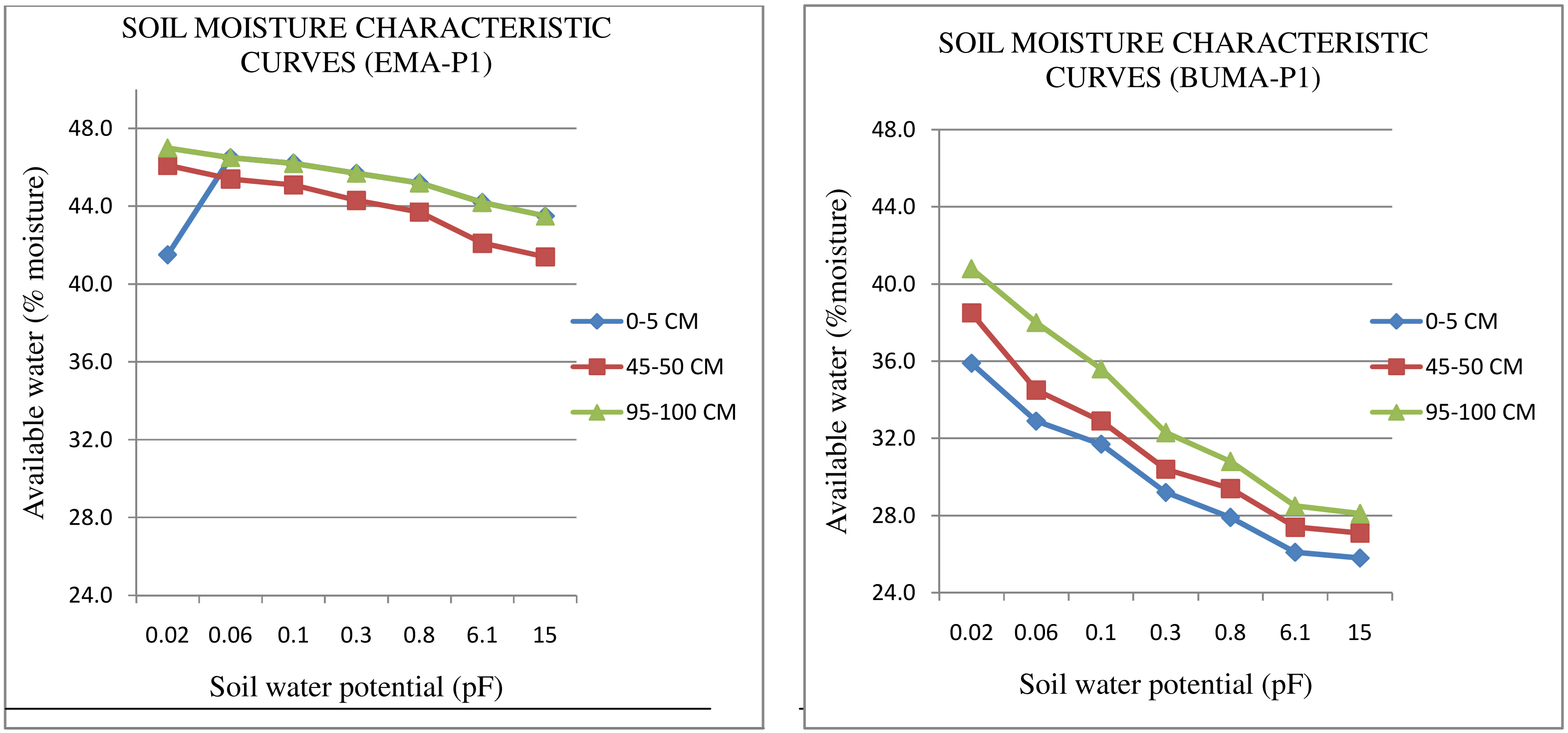

Fig. 3. Soil moisture characteristic curves for the studied soils

Table 4. Penetrometer resistance of the studied profiles

Pedon	Horizon	Penetrometer resistance (kg/cm^2)
EMA-P1	Ap	0.65*
	Bt1	10.42
	Bt2	10.42*
	Bt3	4.19*
	CB	8.21
	2Bt1	3.10
	2Bt2	3.10
BUMA-P1	Ap	4.35*
	BA	14.59
	Bt1	10.42*
	Bt2	15.95*
	Bts1	6.29
	Bts2	3.25
	CB	13.97

** profile depths (0 – 5 cm, 45 – 50 cm and 95 – 100 cm) from which undisturbed core soil samplesfor determination of soil moisture characteristic curves (Fig. 3) were taken*

3.2.4 Soil moisture characteristic curves

Fig. 3 presents results on soil moisture characteristics. The soil moisture of EMA-P1 indicates a higher retention capacity with a gradual decrease as the suction potential increases. BUMA-P1 profile depicts a drastic decrease in available water content as the suction potential increases suggesting an effect of drastic dryness of field crops whenever there is a dry spell during the rainy season consequently causing plants to experience temporal wilting. The trend of the curves concurs with the seemingly rapid run-off and rapid infiltration under natural drainage observed in BUMA-P1 profile during the field study. Soil moisture characteristic curve (pF curve) depends on soil particle size distribution and organic matter content which play an important role especially in low suctions [24].

3.3 Soil Chemical Properties

Some selected soil chemical parameters of the pedons are presented in Table 5.

3.3.1 Soil pH

According to the ratings by [26] and [27] both pedons EMA-P1 and BUMA-P1 have strong acidic pH conditions. The soil pH finding concurs with research from other workers e.g. [28] who reported on low soil pH values in soils of Western Kenya. The results point out the need to consider 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.Low soil pH values below pH < 5.5 have potential to cause toxicity problems and deficiency of some essential plants nutrients as well as affect soil microbial activities [29]. Soil pH < 5.5 could also cause dissolution of aluminum and iron minerals which precipitates with phosphorus effectively causing its fixation and further lowering the soil pH [30].

3.3.2 Available phosphorus (P)

According to [31,32,33], both EMA-P1 and BUMA-P1 pedons have very low P (below <7 mg/kg) and further below the critical level of 2 mg/kg [17]. Low available P in the studied soils may be attributed to low P inherent in the parent materials (which have developed mainly on basement rocks like granite, but also on colluviums from quartzite [5] and because of the effects of low soil pH that normally favours P immobilization [30]. Phosphorus availability to plants is strongly influenced by soil pH, and maximized when pH is between 5.5 and 7.5 [34].

3.3.3 Organic carbon, total nitrogen and carbon: nitrogen ratio

EMA-P1 profile has high to medium organic carbon content, medium total nitrogen and C/N ratios ranging from 8.6 to 9.6 that are within the rating of good quality organic matter. BUMA-P1 has medium organic carbon content, low to very low total nitrogen with C/N ration from 12.9 to 24.8 indicating organic matter of moderate to poor quality [31,32,33]. In both profiles, a correlation between organic carbon and total nitrogen is evident and this agrees with other reports e.g. the works of [35] and [10].

3.3.4 Exchangeable calcium (Ca), magnesium (Mg) and potassium (K)

Table 6 gives a highlight of the exchangeable cations of the studied soils. The exchangeable cations can be rated as low to very low [26,36] and this has direct implications on the cation exchange capacity (CEC), soil pH and ultimately plant nutrient imbalances, unavailability and nutrient induced deficiencies. For example, Mg acts as a phosphorus carrier in plants and therefore, P uptake is influenced by the nutrient [34].

Table 5. Some selected chemical properties of the soil profiles studied

Profile	Horizon	pH		EC (mS/cm)	OC %	OM %	N %	C/N Ratio	Avail.P (Mehlich-3)
		H_20	KCl						
EMA-P1	Ap	5.45	4.50	28.0	2.58	4.45	0.29	8.90	1.44
	Bt_1	5.43	4.41	17.0	2.49	4.29	0.26	9.58	0.49
	Bt_2	5.40	4.25	17.0	2.49	4.29	0.26	9.58	0.44
	Bt_3	5.49	4.70	22.0	1.71	2.95	0.20	8.55	0.21
	CB	5.74	4.71	8.0	1.54	2.65	0.18	8.56	0.24
	$2Bt_1$	5.74	4.84	17.0	1.35	2.33	0.15	9.00	<0.2
	$2Bt_2$	5.84	4.68	12.0	1.31	2.26	0.15	8.73	<0.2
BUMA-P1	Ap	5.11	4.02	28.0	1.95	3.36	0.16	12.90	4.58
	BA	5.01	4.02	24.0	1.64	2.83	0.12	13.67	2.29
	Bt_1	5.15	4.23	20.0	1.45	2.50	0.10	14.50	1.31
	Bt_2	5.35	4.45	15.0	1.21	2.10	0.08	15.13	1.03
	Bts_1	5.34	4.32	21.0	1.06	1.83	0.06	17.67	0.63
	Bts_2	5.36	4.33	23.0	0.99	1.71	0.04	24.75	0.59
	CB	5.63	4.65	30.0	0.92	1.59	0.04	23.00	0.67

Table 6. Exchangeable cations and related properties of the pedons

Pedon		Exchangeable bases (cmol(+)/kg				ESP	TEB	CEC NH_4OAc cmol(+)/kg	CEC $_{clay}$ cmol(+)/kg	BS%
		Ca	Mg	K	Na					
EMA-P1	Ap	3.00	1.31	0.23	0.23	1.55	4.77	14.6	47.87	32.67
	Bt_1	2.28	1.00	0.07	0.24	2.10	3.59	11.20	20.70	32.05
	Bt_2	2.32	1.03	0.08	0.21	1.81	3.64	11.60	17.98	31.38
	Bt_3	2.50	0.88	0.06	0.16	1.46	3.60	11.0	16.54	32.73
	CB	2.09	0.65	0.04	0.21	2.58	2.99	8.05	14.25	37.14
	$2Bt_1$	2.53	0.86	0.05	0.16	1.66	3.60	9.81	16.77	36.70
	$2Bt_2$	2.95	1.06	0.05	0.28	2.44	4.34	11.2	18.60	38.75
BUMA-P1	Ap	1.14	0.54	0.11	0.27	3.67	2.06	7.32	24.00	28.14
	BA	0.70	0.26	0.10	0.15	3.29	1.21	4.50	14.02	26.89
	Bt_1	1.08	0.33	0.06	0.24	4.01	1.71	5.97	9.87	28.64
	Bt_2	1.31	0.32	0.05	0.21	3.44	1.89	5.98	9.88	31.61
	Bts_1	1.31	0.31	0.04	0.18	3.08	1.84	5.92	9.85	31.08
	Bts_2	1.24	0.31	0.03	0.16	2.93	1.74	5.57	7.22	31.24
	CB	1.37	0.36	0.05	0.16	3.04	1.94	5.41	9.93	35.86

3.3.5 Cation exchange capacity (CEC) of the soils

The CEC_{soil} of EMA-P1 is medium in the top soil and low in the subsoil while that of BUMA-P1 is low in the topsoil and very low (< 6 cmol(+)/kg in the subsoils according to [31,32,33]. The CEC values of the pedons indicate possible negative influence on the buffering capacity of the soil and reduced retention of base cations by the soils studied. CEC protects soluble cations from leaching out of the plant root zone and helps soils resist changes in pH [30,34].

3.3.6 Exchangeable sodium (Na) and exchangeable sodium percentage (ESP)

According to [31,32,33], both EMA-P1 and BUMA-P1 pedons have low sodium values ranging between 0.15 - 0.28 and low ESP values (< 6%). The low ESP implies that both soils are non-sodic.

3.3.7 CEC_{clay}

The calculated subsoil CEC_{clay} values for both EMA-P1 and BUMA-P1 pedons are below 24 cmol(+)/kg and worthwhile noting is that those of BUMA-P1 are even below 10 cmol(+)/kg. This implies that the soils are highly weathered with BUMA-P1 being more weathered than EMA-P1. CEC_{clay} is an important indicator of the type of clay minerals dominating the soil. Soils with low CEC and CEC_{clay} have reached advanced stages of weathering [37]. In addition, soils with low CEC_{clay} values are dominated by 1:1 silicate clay minerals (e.g. kaolinite) that characterize soils that are highly weathered [38].

3.3.8 Nutrient balance

Nutrient ratios of the studied pedons are presented in Table 7. Both profiles have Ca/TEB ratio of more than 0.5 in both topsoils and subsoils. This may affect the uptake of other bases particularly Mg and/or K due to Ca induced deficiency [26,27]. The ratios of Ca/Mg are generally within the optimum range of 2-4 favourable for plant growth and development. However, due to high Ca/TEB ratio, induced deficiency of Mg could be a major limitation in these soils. The Mg/K ratios in both profiles are above the recommended range for optimum nutrient uptake [26,27] implying potential nutrient imbalance and toxicity.

3.4 Soil Classification

On the basis of the diagnostic horizons and other diagnostic features (Table 8), classification of the soils of the study area is as presented in Table 9. EMA-P1 pedon is classified as Kanhaplic Haplustults in USDA Soil Taxonomy corresponding to *Haplic Cutanic Acrisols* in the WRB, while BUMA-P1 pedon is classified as *Typic Kandiustults* in USDA Soil Taxonomy corresponding to *Haplic Cutanic Acrisols* in WRB.

3.4.1 Soil fertility trends of the major soils of Busia

Spearman’s rank correlation of the analytical soil fertility data of the major soils of Busia where sorghum is grown is given in Table 10. Percentage sand has negative correlation with sodium and soil pH while silt has positive correlation with calcium, magnesium, phosphorus and potassium. Clay significantly correlates positively with calcium and magnesium as well as sodium showing the role clay plays in either the retention or washing away of these cations and sodium dispersion or flocculation of fine clay particles. Organic matter positively correlates with calcium and magnesium and sodium suggesting organic matter to be the main source of these nutrients. Magnesium and potassium correlate positively indicating the inter-relationship of plant uptake of these bases. Similar findings were reported by [39] who indicated positive correlation between organic carbon with calcium and magnesium as well as magnesium and potassium.

Table 7. Nutrient ratios of top and subsoils of the studied soils

Profile	**EMA-P1**		**BUMA-P1**	
Nutrient ratio	Top soil (0- 13/17 cm)	Subsoil 13/17- +200 cm	Top soil (0-13/17 cm)	Subsoil 13/17- +200 cm
Ca/TEB	0.63	0.64 – 0.70	0.55	0.69 – 0.71
Ca/Mg	2.29	2.25 -2.94	2.11	3.27 – 4.23
Mg/K	5.7	12.88 – 21.2	4.91	5.5 – 10.3
K/TEB	0.05	0.01 – 0.02	0.05	0.02 – 0.04

Table 8. Summary of the morphological and diagnostic features of the studied soils

Profile	**Diagnostic horizons, and other features: USDA Soil Taxonomy (SSS, 2006)**		**Diagnostic horizons, properties and materials: IUSS Working Group WRB (2007)**
EMA-P1	Ochric epipedon, Argillic horizon	Very deep, medium to strongly acid, ustic SMR, iso-hyperthermic STR, Slope 2%, subsoil dominantly clayey, presence of many faint and distinct clay cutans, appreciable clay gradient between eluvial and illuvial horizon, low subsoil CEC (<24 cmol(+)/kg clay)	Argic, ferralic properties, cutanic, humic, hyperdystric, clayic, rhodic, chromic
BUMA-P1	Ochric epipedon, Kandic subsurface horizon	Very deep, strongly acid, ustic SMR, iso-hyperthermic STR, Slope 2.5%, subsoil dominantly clayey, presence of faint clay skins in the subsoil, appreciable clay gradient between eluvial and illuvial horizon, very low subsoil CEC (<< 24 cmol(+)/kg clay)	Argic, ferralic properties, cutanic, humic, hyperdystric, clayic, chromic

Table 9. Classification of the studied soils

Pedon	**USDA Soil Taxonomy (SSS, 2006)**					**FAO- WRB Soil Classification (IUSS Working Group WRB, 2007)**	
	Order	**Suborder**	**Great group**	**Subgroup**	**Family**	**Reference Soil Group – Tier 1**	**Tier 2 WRB soil name**
EMA-P1	Ultisols	Ustults	Haplustults	Kanhaplic Haplustults	Very deep, medium to strongly acid, clayey, iso-hyperthermic, *Kanhaplic Haplustults*	Acrisols	*Haplic Cutanic Acrisols* (Humic, Hyperdystric, Clayic, Rhodic, Chromic)
BUMA-P1	Ultisols	Ustults	Kandiustults	Typic Kandiustults	Very deep, strongly acid, clayey, iso-hyperthermic, *Typic Kandiustults*	Acrisols	*Haplic Cutanic Acrisols* (Humic, Hyperdystric, Clayic, Chromic)

Soil profiles: BUMA-P1=Bumala village EMA-P1=Emalomba village

Table 10. Soil fertility trend of Busia County soils

	% sand	% silt	%clay	% OM	Ca	Mg	P	K	Na	Soil pH
%_sand	1									
% silt	-0.484	1								
%clay	-0.723	-0.166	1							
OM	-0.112	-0.093	0.178	1						
Ca	-0.46	0.309**	0.364**	0.287***	1					
Mg	-0.521	0.33**	0.34**	0.384**	0.847	1				
P	0.199	0.326**	-0.461	-0.116	0.157	-0.008	1			
K	0.075	0.204***	-0.181	-0.108	0.334	0.281***	0.64	1		
Na	-0.195***	0.08	0.198***	0.318**	0.26	0.332**	-0.035	-0.042	1	
Soil pH	-0.233***	0.486	-0.062	-0.069	0.721	0.56	0.473	0.564	0.151	1

*Spearman's rank correlation at 95 % confidence level; (n=50); *** signifies P< 0.001; ** signifies P <0.01*

5. CONCLUSIONS

The following conclusions can be made from the results of the study.

- Soil physico-chemical characteristics differed from one pedon to the other under similar agro-ecological conditions (LM 1).
- Soil physical properties had an influence on the available water content, soil strength and matric potential of which have influence on nutrient uptake and root ramification.
- Soil pH in both sites is strongly acidic with low to very low exchangeable cations that could have implications on the CEC, nutrient uptake and consequently nutrient imbalances and induced toxicities.
- The study sites have low to very low organic carbon and total nitrogen with BUMA-P1 site having very low organic matter of poor quality consequently lowering organic carbon and total nitrogen. Organic matter is the main source of nutrient recycling through microbial decomposition and the quality of the same has an influence on the C/N ratio, rate of decomposition and soil fertility status.
- Both soils are weathered with BUMA-P1 profile showing more advanced stages of weathering thus, necessitating immediate attention to revert the already depleted plant required nutrients.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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