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Pedological Characterization and Classification of Typical Soils of Lupane District, Zimbabwe

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Authors' contributions

This work was carried out in collaboration between all authors. All authors designed the study, wrote the protocol and managed soil analyses. Authors NN, AMM and LM conducted the field study. Authors CSM and LM performed the statistical analyses. All authors managed the literature searches and wrote the first draft. All authors read and approved the final manuscript.

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ABSTRACT

Pedological characterization and classification of soils is key for land resource planning and development of soil management interventions for improving agricultural productivity. A study was conducted in Bubi area of Lupane District, Zimbabwe, to examine soil morphological, physical and chemical attributes and to classify soils for land use planning and determining area specific soil management strategies. A detailed soil survey was conducted using a free survey method. Five soil mapping units M1, M2, M3, M4 and M5 were delineated and mapped based on field observations and laboratory analysis results. Soil samples were collected from representative profiles of each mapping unit for soil physical and chemical analyses. Sandy and loamy sand textures were dominant for surface soils while sandy clay loam and sands were dominant in subsurface soils. Mapping unit M3 had an abruptic textural change with sandy surface textures overlying sandy clay loam subsurface soils. Soil pH was alkaline (7.0 – 7.4) in deeper subsurface layers of M1, M2 and M4 mapping units. Exchangeable magnesium (Mg^{2+}) and calcium (Ca^{2+}) were the dominant

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exchangeable cations. The level of exchangeable Ca^{2+} for both surface and subsurface soils was low (< 5 cmol(+)kg^{-1}). Clay content had highly significant positive correlations with cation exchange capacity (CEC), exchangeable Ca^{2+}, Mg^{2+} and soil pH. CEC had highly significant positive correlations with silt, soil pH, exchangeable Ca^{2+}, Mg^{2+} and Na^{+}. According to the 'World Reference Base for Soil Resources' classification system, soil units M1, M2, M3, M4 and M5 were classified as Calcic VERTISOLS, Haplic LUVISOLS, Haplic LIXISOLS (abruptic), Luvic CALCISOLS (Chromic) and Rubic ARENOSOLS (dystric) respectively. Clay content and CEC significantly correlated with most soil chemical properties in the study area. Liming, split fertilizer application and organic matter additions was recommended to address fertility issues related to high sand content, soil acidity, low CEC, low exchangeable Ca^{2+} and K^{+} constraints identified in some mapping units.

Keywords: Survey; catena; physical properties; chemical properties; morphology.

1. INTRODUCTION

Agriculture plays a significant role in the economy and livelihoods of people in Zimbabwe [1]. Improving the productivity of the agriculture sector of the country is greatly dependent on efficient utilization and management of soils [2]. Sustainable utilization of agricultural lands require a thorough knowledge and inventory of soil resources and hence there is need to characterize and classify soils in farming areas of Zimbabwe.

Soil characterization and classification helps to generate information which is required for land use planning and soil management purposes. Soil surveys are important for soil characterization and classification purposes and aids in the creation of data bases on soil morphology, physical and chemical properties [3-5]. This information is important for determining agricultural potential, limitations and possible management options for the soils in a particular area thereby helping in selection of the best agricultural enterprises suitable for that area [6,7]. Irrigation projects can be planned and developed based on information obtained from soil characterization and classification. Area specific soil fertility management strategies, aimed at increasing crop production, can be developed for a particular area using soil survey data instead of using general fertilizer recommendations. Information on soil characterization and classification can be utilized widely by land use planners, agriculture researchers, extension staff, development agents and farmers in order to sustainably increase agriculture production in Zimbabwe.

National soil mapping exercise conducted in Zimbabwe in the1970s, which included Lupane district, was mapped at a scale of 1:1,000 000 [8]. Such a reconnaissance survey provides limited information which cannot be used to make site specific recommendations and decisions. Effective area specific soil management strategies can only be crafted from data obtained from detailed soil surveys. Agriculture plays an integral part in the Lupane district in Zimbabwe and yet there have been no detailed soil survey studies conducted to characterize and classify the soils in this area. There is limited information available for assessing agricultural potential and limitations of the soils in the Lupane district and hence there is need to conduct detailed soil surveys for soil characterization and classification purposes. The objectives of the study were to characterize the soils of Lupane district by determining their soil morphology, physical and chemical attributes, to classify the soils of the Lupane district using the 'World Reference Base for Soil Resources' classification system and to generate soils information required for land use planning and soil management strategies in the study area.

2. MATERIALS AND METHODS

2.1 Description of Study Area

This study was conducted in Bubi area, Lupane district (S18056'0" E270 46'0") in Zimbabwe. The study area covered an area of about 250 ha. Zimbabwe is divided into five natural agro-ecological regions [9,10] and this study site is located in agro-ecological region IV. The site has got a unimodal rainy season and receives an average annual rainfall of 400 mm, with most of the rain falling between November to April. The geology of the area is made up of mainly sandstone. The topography of the area is gently undulating with slopes mainly ranging from 2 – 5% in most parts, slopes of 1 - 2% are found in areas close to the Bubi River. The most

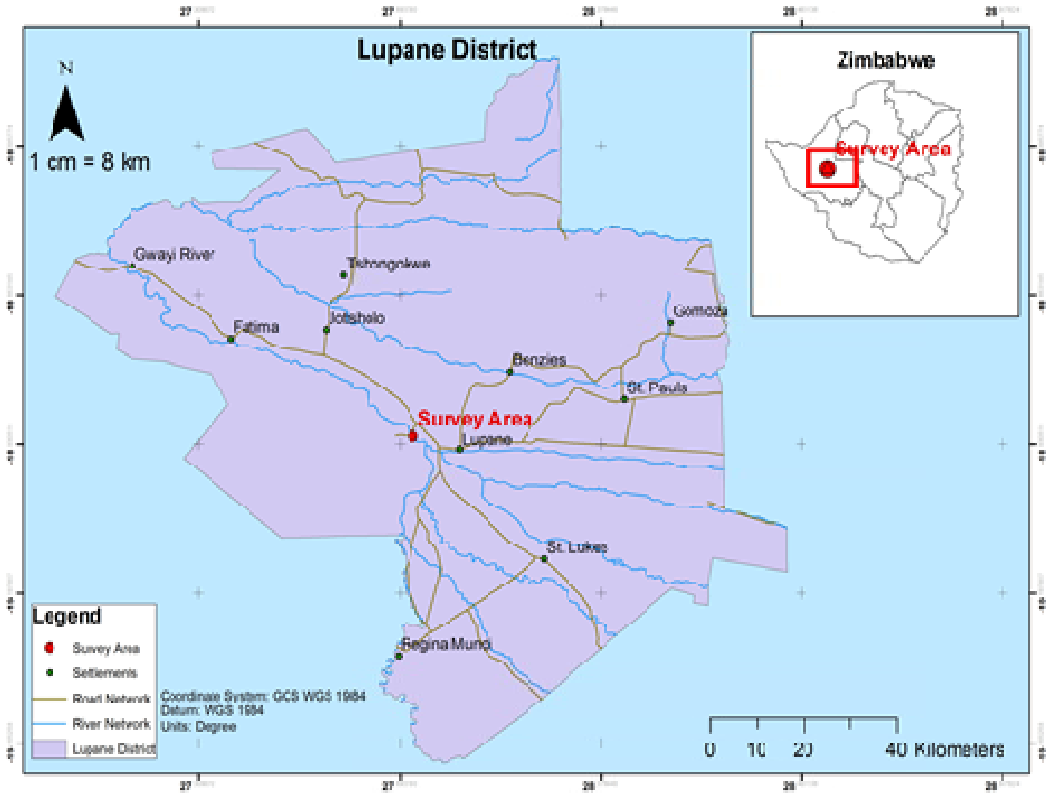

Fig. 1. Map of the study area

dominant woody vegetation species in the area are Terminaria sericia, Colophospermum mopane, Acacia species and Combretum species. The main farming system in the area is crop and livestock production.

2.2 Field Sampling and Laboratory Analysis

A detailed soil survey was conducted in Bubi area, Lupane district in Zimbabwe after identifying the area on topographic map (scale 1:50,000). The free survey method was used for surveying the area using aerial photographs at a scale of 1; 10 000 having been enlarged from photographing/capturing scale 1:25 000. Desktop demarcation of preliminary boundaries was done based on photo tone and stereo pairs observations. A detailed soil survey was then carried whereby 45 auger observations were made to confirm boundaries and 6 representative profile pits were dug, described and soil samples were collected for laboratory analysis. The soil profiles were described according to FAO Guidelines for Soil Profile Description [11] and soil samples were collected from all the horizons of the profiles. The following soil parameters were checked in the field, slope percentage, slope position, Munsell soil colour [12], texture, depth, structure, test, drainage, permeability, dry and wet consistence, root density and pores. Global Positioning System (GPS) (model Garmin etrex) coordinates of all observation positions were captured with coordinates for soil profile pits being M1 (S18055’02.3” E027043’08.0”), M2 (S18055’19.3” E27043’21.4”), M3a (S18055’13.2” E027043’ 26.8”), M3b (S18054’15.2” E027042’53.6”), M4 (S18054’55.2” E027043’06.1”) and M5 (S180 55’20.7” E0270 44’ 20.2”). Based on field observations and laboratory analysis data, five mapping units were identified and demarcated. Soils having similar properties were then grouped into the following mapping units M1, M2, M3, M4 and M5. At least one representative pit was dug in each soil unit for soil profile characterization.

Soils in the study site were derived from the parent material and aeolian deposition hence did not have any catena toposequence. Mapping units M1 and M4 were on lower slope positions while M2, M3 and M5 were on middle to lower, middle and upper slope positions respectively.

Middle and upper slope positions (M2, M3 and M5) had soils which were significantly influenced by deposition of sands by south westerly winds bringing Kalahari sands whereas M1 and M4 shows properties typical of the in situ geology.

The soil samples collected were air dried, grounded and then passed through a 2mm sieve before analysis. Particle size distribution was determined by the Bouyoucos hydrometer method [13] and textural classes were determined using the USDA textural triangle [4]. Soil pH was determined in suspension of 1:5 soil to 0.01M $CaCl_2$ ratio using a glass electrode pH meter. Cation exchange capacity and exchangeable bases (Ca^{2+}, $Mg^{2+,}$ K^+ and Na^+) were extracted using neutral 1M ammonium acetate Concentrations of exchangeable K^+ and Na^+ were determined by flame photometry while Ca^{2+} and Mg^{2+} were determined by atomic absorption spectrophotometry. Percent base saturation was determined by dividing total exchangeable bases (Ca^{2+}, Mg^{2+}, K^+ and Na^+) by cation exchange capacity and multiplying by 100.

2.3 Statistical Analysis

Pearson's correlation coefficient and stepwise multiple regression analyses were carried out to evaluate the relationships within soil physical and chemical properties by using Microsoft Excel 2013 Analysis ToolPak. Mapping units were compared to each other by referring to the critical values for the selected physical and chemical properties.

3. RESULTS AND DISCUSSION

3.1 Soil Morphology

The main morphological properties of the soil mapping units are summarized in Table 1. Soils in M1 unit were moderately deep. The moist soil colour was dark grey (10YR4/1) at the surface and very dark grey (10YR3/1) for subsurface soils. The soils had a moderately medium to coarse subangular blocky structure at the surface and moderately medium angular blocky structure in subsurface. Texturally, the soils were sandy clay in the surface changing to clay in the subsurface. Moderate carbonates were noted in the subsurface soils.

In M2 mapping unit, the moist soil colour at the surface was very dark greyish brown (10YR3/2) and dark grey (2.5Y4/1) at the subsurface. M2 soils had moderately developed fine sub-angular blocky structure in surface soil and strongly developed medium angular blocky structure in subsurface. The soil texture was loamy sand in the top soil overlying sandy clay loams in the subsurface horizons.

Soils in M3a soil unit were moderately deep having dark brown (10YR 3/3) moist soil colour for the surface soil and changing to dark reddish brown (5YR3/3) and strong brown (7.5YR 4/6) for subsurface. The soil structure was very fine and fine subangular blocky for surface soils and mostly medium subangular blocky in the subsurface. In M3b the moist soil colour for the surface soil was dark greyish brown (10YR 4/2) and very dark greyish brown (10YR3/2) and very dark grey (10YR3/1) subsurface soils with strong brown colour mottles (7.5YR4/6). The presence of mottles was indicative of poor drainage [14]. The soil structure was single grained at the surface soil with subangular blocky and angular blocky structure in subsurface.

Soils in M4 unit were moderately deep having a brown (7.5YR4/3) moist soil colour for the surface soil and changing to dark yellowish brown (10YR4/6) for subsurface with yellowish red colour mottles (5YR4/6) in the subsurface. M4 soils had a single grained soil structure at the soil surface overlying weakly developed fine subangular blocky and massive soil structures at the subsurface. The presence of carbonates was noted in the subsurface soils.

Soils in M5 were moderately deep. The moist soil colour was brown (7.5YR4/4) for the top soil and changed to strong brown (7.5YR5/6) and yellowish red (5YR4/6) at the subsurface horizons. The soils in M5 unit were sands throughout the whole soil profile and had a single grained soil structure. In the study area, soil colour varied from yellowish reddish (5YR4/6) on upper slope to very dark gray (10YR 3/1) on lower slope due to good and poor drainage respectively. Poor drainage is further indicated by the presence of mottles in the lower slope positions [14].

3.2 Soil Texture

The sand grain was the dominant fraction in all the soil units followed by clay and silt fraction (Table 2). The soils had high sand content at the surface soils which decreased with depth in all the profiles. The sand content in the soil units ranged from 50 – 96% for surface soils and from 38 – 95% for subsurface. There was a regular

Table 1. Main morphological characteristics of soils located in Bubi area, Lupane district

Soil unit	Depth (cm)	Soil colour (moist)[1]	Texture[2]	Structure[3]	Consistency[4]	[5]Horizon boundary
M1	0 - 16	dg(10YR 4/1)	SC	mo me; sbk	vfr, pl&st	cs
	16 - 43	vdg(10YR 3/1)	SC	st co; sbk	vfi, pl&st	gs
	43 - 82	vdg (10YR3/1)	C	mome ; abk	vfi, vst&pl	d
	82 - 120	vdg (10YR3/1)	C	mome ; abk	vfi, vst&pl	-
M2	0-15	vdgb (10YR3/2)	LS	mo fi; sbk	vfr, pl&st	aw
	15-33	vdgb (10YR3/2)	SCL	st me ; abk	vfr, pl&st	gw
	33-61	dg(10YR4/1)	SCL	st me ; abk	fr, pl&st	gw
	61-100	dg(2.5Y4/1)	SCL	st me; abk	fr, pl&st	-
M3a	0-12	db (10YR 3/3)	S	we ff; sbk	fr, npl&nst	aw
	12-40	db(10YR3/3)	LS	we me; sbk	vfr, npl&nst	gs
	40-80	drb (5YR3/3)	SCL	mo me; sbk	fr, pl&st	cs
	80-111	sb(7.5YR 4/6)	SL	we me; sbk	vfr; spl&st	-
M3b	0-11	dgb (10YR 4/2)	S	sg	lo ,npl&nst	cs
	11-28	vdgb (10YR3/2)	S	sg	vfr, npl&nst	gs
	28-51	vdgb(10YR3/2)	S	we fm; sbk	vfr, sst&npl	gs
	51-82	vdg(10YR3/1) sb(7.5YR4/6)*	SCL	mo me; abk	vfi, st&pl	-
M4	0-12	b (7.5YR4/3)	LS	sg	lo; npl&nst	gs
	12-27	b (7.5YR4/4)	SCL	we fm; sbk	vfr, npl&sst	aw
	27-77	sb (7.5YR4/6)	SCL	ma	fr, pl&st	d
	77-105	dyb(10YR4/6) yr(5YR4/6)*	SCL	ma	fr, pl&st	d
	105-124	b (10YR4/3)yr (5YR4/6)*	SCL	ma	fr, pl&st	-
M5	0-16	b (7.5YR4/4)	S	sg	lo, npl&nst	gw
	16-37	sb (7.5YR5/6)	S	sg	lo, npl&nst	d
	37-82	sb (7.5YR4/6)	S	sg	lo, npl&nst	d
	82-125	yr (5YR4/6)	S	sg	lo, npl&nst	-

*[1)]b=brown; sb=strong brown; db=dark brown ; drb=dark reddish brown ; dyb=dark yellowish brown; dg=dark grey ; vdg=very dark grey; dgb=dark greyish brown ; vdgb=very dark greyish brown ; yr=yellowish red; *=mottles colour, [2)]SC=sandy clay; SCL=sandy clay loam; LS=loamy sand; C=clay; SL=sandy loam; S=sand; LS= loamy sand, [3)] sbk=sub angular blocky; abk=angular blocky ; ma=massive; sg=single grain; we=weak; mo=moderate; st=strong; fi=fine; me=medium; co=coarse; ff=very fine and fine; fm=fine and medium, [4)]vfr= very friable; fr=friable; fi=firm; vfi= very firm; lo=loose; st=sticky; vst= very sticky ; sst=slightly sticky; nst= none sticky ; pl=plastic ; spl = slightly plastic ; npl=none plastic , [5)]c=clear; d=diffuse; g=gradual; s= smooth; w=wavy*

Table 2. Physical characteristics of soils located in Bubi area, Lupane district

Soil unit	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Texture
M1	0 - 16	50	10	40	Sandy clay
	16 - 43	47	10	43	Sandy clay
	43 - 82	43	8	49	Clay
	82 - 120	38	11	51	Clay
M2	0-15	79	17	4	Loamy sand
	15-33	75	5	20	Sandy clay loam
	33-61	68	7	25	Sandy clay loam
	61-100	55	16	29	Sandy clay loam
M3a	0-12	94	1	5	Sand
	12-40	82	8	10	Loamy sand
	40-80	63	6	31	Sandy clay loam
	80-111	79	5	16	Sandy loam
M3b	0-11	95	3	2	Sand
	11-28	94	2	4	Sand
	28-51	90	3	7	Sand
	51-82	74	3	23	Sandy clay loam
M4	0-12	89	2	9	Loamy sand
	12-27	81	4	15	Sandy clay loam
	27-77	75	1	24	Sandy clay loam
	77-105	69	6	25	Sandy clay loam
	105-124	68	7	25	Sandy clay loam
M5	0-16	96	1	3	Sand
	16-37	95	1	4	Sand
	37-82	95	2	3	Sand
	82-125	93	4	3	Sand

increase in clay content with depth in all the soil units except M5 unit. The regular increase in clay content with increasing soil depth can be attributed to clay illuviation. Clay content in the soil units ranged from 3 – 40% for surface soils and from 3 – 51% for subsurface. The silt content of the soil profile in most of the soil units was irregular towards the bottom portion. Silt content ranged from 1 – 17% for surface soils and from 1 – 11% for subsurface.

The dominant soil texture in surface soils was sand followed by loamy sand and sandy clay. The dominant soil textures in subsurface soil horizons were sandy clay loam and sand. Soil texture is an important soil physical property which affects water holding capacity, nutrient retention capacity, organic matter content and soil aeration [15,16]. M5 soils are sandy soils which are likely to have challenges of low water holding capacity, low nutrient retention capacity, inherent low fertility and low levels of organic matter due to their very low clay content [17].

3.3 Soil pH

Soil pH varied with mapping units and within horizons (Table 3). Soil pH in the soil units ranged from 4.0 - 6.4 for the surface soils and had a range of 4.7 - 7.4 for subsurface. Soil pH ranged from extremely acid to neutral for the surface soils and strongly acid to strongly alkaline in subsurface according to the ratings of Dhliwayo et al. [18]. The surface layers of M5 soil unit are acidic due to leaching of bases from the top layers. M5 soils are sandy soils which are susceptible to leaching due to their low cation exchange capacity and consequently exchangeable bases are easily leached down the profile creating acidic conditions in the surface soils. Extreme soil acidity in M5 surface soils can inevitably lead to low crop yields attributed to aluminium toxicity, manganese toxicity, magnesium unavailability, phosphorus unavailability and reduced fertilizer use efficiency [2,18-21]. Soil pH was strongly alkaline in subsurface layers of M1 and M4 units. This can be attributed to the presence of carbonates which were identified in the subsurface soils which have an effect of creating alkaline conditions.

3.4 Cation Exchange Capacity

The cation exchange capacity (CEC) in the soil units ranged from 6.5 - 15.3 cmol(+)kg^{-1} for surface soils and had a range of 6.6 - 20 cmol(+)kg^{-1} for subsurface (Table 3). The CEC values ranged from low to moderate for both surface and subsurface soils according to the ratings of Hazelton and Murphy [16]. CEC values had a relationship with clay content in some soil units. Soil units with high clay contents (M1, M2 and M4) generally had CEC values in the moderate range in most soil layers while M5 unit which had very low clay content had low CEC values. Clay particles have negatively charged surfaces which attracts positively charged ions and hence soils with higher clay content tend to have higher CEC values which allows them to retain more nutrients compared to soils with very low clay content [16,22,23]. Low CEC values observed in M5 unit implies that these soils have a low nutrient retention capacity attributed to their low clay content and consequently are susceptible to nutrient leaching.

3.5 Exchangeable Bases and Exchangeable Sodium Percentage

Exchangeable magnesium (Mg) and calcium (Ca) were the dominant cations in all the soil units (Table 3). Exchangeable Ca ranged between 1.0 - 2.2 cmol(+)kg^{-1} for surface soils and ranged between 0.8 - 5.9 cmol(+)kg^{-1} for subsurface. The level of exchangeable Ca in the soil units, except for the 82 – 120 cm soil profile layer of M1, can be rated as low according to the ratings of Moore [24]. This low rating of exchangeable Ca in the mapping units suggest that these soils are deficient in exchangeable Ca and measures such as addition of gypsum should be taken to address Ca deficiency. Crop responses to addition of calcium is highly likely on these soils.

Exchangeable Mg in the soil units ranged from 1.4 - 3.7 cmol(+)kg^{-1} for surface soils and had a range of 1.3 - 7.6 cmol(+)kg^{-1} for subsurface . The levels of exchangeable Mg ranged from moderate to high for both surface and subsurface soils according to the ratings of Hazelton and Murphy [16]. Based on these ratings, the levels of exchangeable Mg in soil units M1 and M2 are non-limiting and can support crop growth. M5 soils are sandy soils which are susceptible to leaching and hence require additions of Mg to build up levels.

Table 3. Selected chemical characteristics of soils located in Bubi area, Lupane district

Soil unit	Profile depth (cm)	pH	Exchangeable bases (cmol(+) kg^{-1})				CEC (cmol(+)kg^{-1})	PBS	ESP
			Ca	Mg	Na	K			
M1	0 - 16	6.4	1.1	3.7	0.57	0.31	9.4	60.6	6.1
	16 - 43	6.8	4.7	5	1.6	0.2	20	58	8
	43 - 82	7.1	4.9	6.2	0.51	0.26	13.4	88.5	3.8
	82 - 120	7.2	5.9	7.6	0.38	0.32	15.8	89.8	2.4
M2	0-15	5.5	1.4	3.3	0.43	0.37	15.3	36	2.8
	15-33	5.1	1.9	3.4	0.67	0.27	16	39	4.2
	33-61	5.1	2.2	3.8	1.12	0.36	13.5	55.4	8.3
	61-100	7	3.5	3.1	2.05	2.23	18	60.4	11.4
M3a	0-12	5.6	2.2	1.7	0.26	0.23	7	62.7	3.7
	12-40	5	2.1	1.7	0.24	0.22	6.6	64.5	3.6
	40-80	6.8	1.6	3.6	0.31	0.2	7.7	74.2	4
	80-111	5.3	1.3	2.6	0.26	0.18	8.5	51	3.1
M3b	0-11	5.5	1.1	1.6	0.39	0.27	7.2	46.7	5.4
	11-28	5.1	1.1	1.3	0.32	0.21	8.6	34.1	3.7
	28-51	5.3	1.4	1.7	0.34	0.27	8.9	41.7	3.8
	51-82	6.5	3.0	3.3	0.48	0.64	12.2	60.7	3.9
M4	0-12	5.3	1.3	2.4	0.51	0.31	12.7	35.6	4.0
	12-77	5.4	1.1	2	0.48	0.17	9.6	39.1	5
	27-77	6.2	1.4	3.5	0.55	0.2	13.1	43.1	4.2
	77-105	7.3	2	4.1	0.65	0.15	12.6	54.8	5.2
	105-124	7.4	1.7	4.1	0.74	0.26	11.4	59.6	6.5
M5	0-16	4	1	1.4	0.22	0.09	6.5	41.7	3.4
	16-37	4.7	0.9	1.3	0.21	0.1	8.2	30.6	2.6
	37-82	5.3	1	1.6	0.22	0.2	6.6	45.8	3.3
	82-125	5.5	0.8	1.5	0.28	0.06	8.1	32.6	3.5

CEC= cation exchange capacity; PBS= percent base saturation; ESP=exchangeable sodium percentage

Table 4. Pearson correlation coefficient among the selected soil properties

	Sand (%)	Silt (%)	Clay (%)	pH	Exch Ca^{2+}	Exch Mg^{2+}	Exch Na^{1+}	Exch K^{1+}	CEC	PBS
							cmol(+) kg^{-1}			
Sand (%)	1									
Silt (%)	-0.672**	1								
Clay (%)	-0.977**	0.497*	1							
pH	-0.781**	0.480*	0.776**	1						
Exch Ca	-0.787**	0.488*	0.781**	0.619**	1					
Exch Mg	-0.914**	0.539**	0.915**	0.756**	0.825**	1				
Exch Na	-0.537**	0.568**	0.464*	0.438*	0.450*	0.346	1			
Exch K	-0.306	0.533**	0.204	0.316	0.304	0.099	0.720**	1		
CEC	-0.679**	0.626**	0.614**	0.515**	0.661**	0.685**	0.761**	0.452*	1	
PBS	-0.764**	0.395	0.780**	0.682**	0.772**	0.746**	0.172	0.181	0.226	1

** Correlation is significant at the 0.05 level, **Correlation is significant at the 0.01 level Exch= exchangeable*

Table 5. Detail of multiple regressions derived for selected soil properties

Soil properties	Multiple regression equation	R^2
CEC	7.0442 + 0.3712(Silt) + 0.1015(Clay)	0.51**
pH	4.33877 – 0.14898(Ca) + 0.52516(Mg) +0.06206(Na) + 0.61433(K)	0.64**
Exchangeable Ca	-3.03878 + 0.16424(CEC) + 0.5539(pH)	0.54**
Exchangeable Mg	-4.31522 + 0.16628(CEC) + 0.93809(pH)	0.69**
Exchangeable Na	-0.54309 + 0.08306(CEC) + 0.02983(pH)	0.58**
Exchangeable K	-0.1265 + 0.020774(CEC) + 0.038394(Silt)	0.31*
PBS	20.3059 + 3.31864(pH) + 0.66533(Clay)	0.62**

** and ** significant at P 0.05 and 0.01 level*

Table 6. Classification of soils located in Bubi area, Lupane district

Soil unit	World reference base for soil resources [14]
M1	Calcic VERTISOLS
M2	Haplic LUVISOLS
M3 (M3a and M3b)	Haplic LIXISOLS (abruptic)
M4	Luvic CALCISOLS (Chromic)
M5	Rubic ARENOSOLS (dystric)

Exchangeable potassium (K) in the soil units was ranged between 0.09 - 0.37 cmol(+)kg^{-1} for surface soils and ranged between 0.06 - 2.23 cmol(+)kg^{-1} for subsurface soils. Exchangeable K in the soil units ranged between very low to medium for surface soils and very low to very high for subsurface soils according to the FAO ratings [17]. K is a major nutrient required by crops and its deficiency affects plant growth [17,23]. Low levels of exchangeable K in surface soils of M5 and M3 cannot support crop growth without application of K fertilizers. Crop response to application of K fertilizers to M5 and M3 soils is very likely because these soils have very low to medium levels of exchangeable K in the soil surface layers.

Exchangeable sodium (Na) in the soil units ranged from 0.22 - 0.57 cmol(+)kg^{-1} for surface soils and ranged between 0.21 - 2.05 cmol(+)kg^{-1} for subsurface soils.Exchangeable Na can be classified as ranging from low to medium for surface soils and low to high for subsurface soils according to the FAO ratings [17]. All the soil units had exchangeable sodium percentage values (ESP) below the critical threshold value of 15% [14] indicating that all these soils are non-sodic.

3.6 Base Saturation

Percent base saturation in the soil units ranged from 35.6 - 62.7% for surface soils and had a range of 30.6 - 89.8% for subsurface soils. Percent base saturation for both surface and subsurface soils ranged from medium to high according to the classification of Moore [24].The lower values of percent base saturation in M5 can be attributed to the fact that M5 soils are sandy soils with low CEC and hence they have limited capacity to retain bases. The data suggests that the levels of exchangeable bases in M5 soil unit cannot sustainably support crop growth without addition of bases. M1 soils had high percentage base saturation values ranging from 58 - 89.8%. This can be attributed to the fact that M1 soils had high clay content and subsequently higher CEC values which gives these soils a greater capacity to retain bases. This suggests that M1 soils are fertile soils with a greater capacity to supply nutrients needed to support crop growth.

3.7 Correlation and Multiple Linear Regressions Analysis of Selected Soil Properties

Sand content showed highly significant negative correlations with soil pH, CEC, PBS and exchangeable Ca^{2+} and Mg^{2+}. Clay content had highly significant positive correlations with soil pH, Ca, Mg, CEC, PBS and a significant positive correlation with Na. CEC had highly significant positive correlations with silt, clay, pH, exchangeable Ca^{2+}, exchangeable Mg^{2+}, exchangeable Na^{+} and a significant positive relationship with exchangeable K^{+} while sand content had a highly significant negative correlation with CEC. Soil pH had highly positive correlations with exchangeable Ca^{2+}, exchangeable Mg^{2+}, CEC, PBS and a significant correlation with exchangeable Na^{+}. Exchangeable Ca^{2+} and Mg^{2+} had highly significant positive correlations with each other and with CEC and PBS. They also had highly negative correlations with sand content which was highly significant. Exchangeable K^{+} had significant positive correlations with CEC and highly significant correlations with silt and exchangeable Na^{+}. PBS was significantly negatively correlated with sand content and had highly significant positive correlations with clay content, pH, exchangeable Ca^{2+} and Mg^{2+}.

The results of multiple linear regression equations or pedotransfer functions for determining or predicting CEC, PBS, soil pH, exchangeable Ca^{2+}, Mg^{2+}, K^{+} and Na^{+} values are presented in Table 5. Step wise multiple regression indicates that 51% variation in CEC can be explained or predicted by silt and clay content while 62% variation in PBS can be predicted by exchangeable Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}. CEC and soil pH explained or predicted 54%, 69% and 58% variation in exchangeable Ca^{2+}, Mg^{2+} and K^{+} respectively. Soil pH and clay content predicted 31% variation in exchangeable K^{+}.

The results of the study show that an increase in sand content promotes soil acidity, low exchangeable Ca^{2+}, low exchangeable Mg^{2+} and low PBS. Sand content had a negative correlation with CEC because sandy soils have low clay content hence they have less negative charges which can hold exchangeable bases such as Ca^{2+} and Mg^{2+} [16,22,23]. This subsequently makes sandy soils more prone to leaching of basic cations leading to soil acidity. Soils with higher clay content tend to have higher CEC values allowing them to retain exchangeable bases consequently leading to high soil pH values. CEC had highly positive correlations with exchangeable Ca^{2+} and Mg^{2+} because CEC measures the capacity of soil to retain cations. PBS was negatively and positively correlated with sand and clay content respectively because clay particles have negatively charged surfaces which attracts positively charged bases such as Ca^{2+} and Mg^{2+} while sand particles do not have any negative charges which allows them retain exchangeable cations.

3.8 Soil Classification

The soils of the study area were classified according to the World Reference Base for Soil Resources [14] based on field and laboratory data (Table 6). Soil unit M1 was classified as Calcic VERTISOLS because these soils had high clay content (>30%), exhibited shrink-swell properties and had moderate carbonates. Soil unit M2 was classified as Haplic LUVISOLS because it had an argic horizon within 200 cm overlain by loamy sand and also has high base saturation (>50%) in some layers. Soil unit M3 (M3a and M3b) was classified as Haplic LIXISOLS because it had an argic horizon permeated with mottles with an abruptic textural change and high base saturation at some depths. Soil unit M4 was classified as Luvic CALCISOLS because it had a horizon with carbonates within an argic horizon. Soil unit M5 was classified as Rubic ARENOSOLS (dystric) because these are sands throughout the soil profile with low base saturation.

4. CONCLUSIONS

The predominant soil textures of the soils in the study area were sand, sandy clay loam and loamy sand. Sand fraction had highly significant and negative correlations with soil acidity, CEC, PBS and exchangeable bases. Clay content had highly significant positive correlations with CEC, exchangeable bases and pH. CEC had highly significant positive correlations with silt, clay, pH, Ca^{2+}, Mg^{2+} and Na^{+}. Most of the soils had low levels of exchangeable Ca and moderate to high levels of exchangeable Mg and very low to very high levels of exchangeable K. The main limitations identified in some of the soils in the study area were soil acidity, low exchangeable bases, low CEC and poor drainage. To ensure optimum sustainable crop production, it is recommended that split application of inorganic fertilizers should be practiced in upper slope soils to minimize leaching of soil nutrients. Addition of organic matter should also be practiced to increase CEC thereby increasing nutrient retention capacity. Lime application is required to correct soil acidity problem identified. Artificial drainage need to be implemented in the lower slope positions to address poor drainage problems.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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