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PEDOLOGICAL CHARACTERISTICS, GENERAL FERTILITY AND CLASSIFICATION OF SOME BENCHMARK SOILS OF MOROGORO DISTRICT, TANZANIA

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ABSTRACT:- *A detailed characterization of soils earmarked as "Benchmark Soils of Morogoro District", Tanzania, was carried out to provide data required for planning and execution of soil fertility studies and transfer of agro-technology in the area. Benchmark soils are defined as those occurring in extensive areas and whose comprehensive characterization could contribute substantially to transfer of agro-technology from one area to another. Eleven sites were selected as "Benchmark Sites" of the district based on existing soils information coupled with reconnaissance field soil survey. Soil samples representative of the benchmark soil profiles were described and analysed for their chemical, physical and mineralogical characteristics. Based on these data, general fertility is discussed for the various soils pointing out their potentials and constraints. The data also permitted classification of the soils using international soil classification systems i.e. the United States Department of Agriculture Soil Taxonomy and the FAO-UNESCO Soil Classification System. The soils were classified into different categories reflecting their differences in potentials and constraints and hence use and management. The data obtained through this study presents a substantial base for sound land use planning and will facilitate transfer of technology from one area to another with similar ecological conditions.*

Key words: Pedological characteristics, fertility, soil classification, benchmark soils, Morogoro District, Tanzania

INTRODUCTION

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. In addition, climatic and other ecological characteristics as well as socio-economic factors are also important elements in land management. A good data bank on soil properties and related site characteristics is inevitable for one to be able to advise both current and potential land users on how to use the land in the best possible way. Soil fertility specialists need well characterized sites with similar soil and other ecological conditions in order to carry out meaningful fertilizer trials.

Although Tanzania has long history of collecting basic information on soil characterization in the form of soil surveys (Msanya *et al*., 1991; Msanya and Magoggo, 1993; Kilasara *et al*., 1994), this has only been concentrated in a few selected high potential areas. Thus, the available information remains rather scanty relative to the large size of the country and its diverse soil and other land resources. The few existing soil resource inventories are characterized by their small scale nature with high level of generalization, being based on rather few observations scattered over large areas. Moreover, these works have been done using different methodologies and criteria. Inevitably, most existing studies cannot easily be correlated and do not have sufficient predictive value. There is need for more efforts to be invested in coordinated and systematic inventory of the country's soils and other land resources to facilitate land use planning activities. There is also a strong feeling that fertilizer trials should be done on well characterized soils to enhance transferability of information from one place to another.

This study dwells on pedological characterization and general fertility evaluation of "Benchmark Soils of Morogoro District". By definition benchmark soils are those occurring in extensive areas so that their comprehensive characterization will contribute substantially to agricultural and other developments of the district. Information on benchmark soils and the results of experiments carried out on them can be extended to many of those soils closely related in classification and geography. Such soils can be used as standards for widespread application and are key to agro-technology transfer.

Selection of benchmark soils is very crucial and requires rigorous soil mapping to show their spatial distribution. Although at the inception of the project there was limited base information on geographical distribution of land resources, current developments in the mapping of soils and other land resources of Morogoro rural and urban districts (Kimaro *et al*., 2001; Msanya *et al*., 2001a,b,c) has greatly facilitated to show their spatial distribution and consequently simplified land use planning exercises for the area.

The specific objectives of this study were three-fold:

1. to characterize the benchmark soils in terms of their chemical, physical and mineralogical characteristics and hence their general fertility;
2. to classify the soils using the United States Department of Agriculture (USDA) Soil Taxonomy and the FAO-Unesco Classification System;
3. to provide data that will be utilized for development of soil/land management technologies such as fertilizer application, soil conservation and improved tillage methods.

MATERIALS AND METHODS

The study area

The study area is located in the north-western part of Morogoro District, Tanzania. Figure 1 presents the location of the studied soil profiles, while Table 1 gives details of the site characteristics. The climate of Morogoro District can generally be described as a sub-humid tropical type. The mean annual rainfall of the studied sites varies from about 750 mm (Melela) to about 1050 mm (Pangawe). Most areas in the district experience bimodal rainfall pattern characterized by two rainfall peaks in a year with a definite dry season separating the short and long rains. The short rain season is from October to December while the long rain season starts from March and ends in May. The onset of both rains and their distribution are irregular and unreliable. The soil moisture regime in most places is *ustic* except where there are local effects of flooding and water-logging. Figure 2 gives rainfall data for the various studied sites. Information on temperatures (Kaaya *et al.*, 1994) shows that the mean annual air temperature (MAAT) for most places in the district is about 24°C and the mean annual soil temperature (MAST) is characterized as *iso-hyperthermic.*

Field methods

Selection of benchmark sites was done using existing soil information on Morogoro soils (De Pauw, 1984; Kaaya *et al*., 1994; Moberg *et al*., 1982; Msanya, 1980 & 1991; Msanya and Msaky, 1983; National Soil Service, 1986 & 1988) coupled with reconnaissance field observations in various parts of the district. Geological and geomorphological parameters were used to facilitate the selection. Eleven soil profiles were identified, excavated, described and sampled following standard procedures (FAO, 1977; Munsell Color Company, 1954; Soil Survey Staff, 1951). Exact locations of the sites in terms of international coordinates were determined using Sony Global Positioning System (GPS) Receiver.

Routine laboratory methods

Chemical and physical analyses were done as follows: pH was measured potentiometrically in water and in 1M KCl at the ratio 1/2.5 soil-water and soil-KCl. Organic carbon was determined by wet oxidation method of

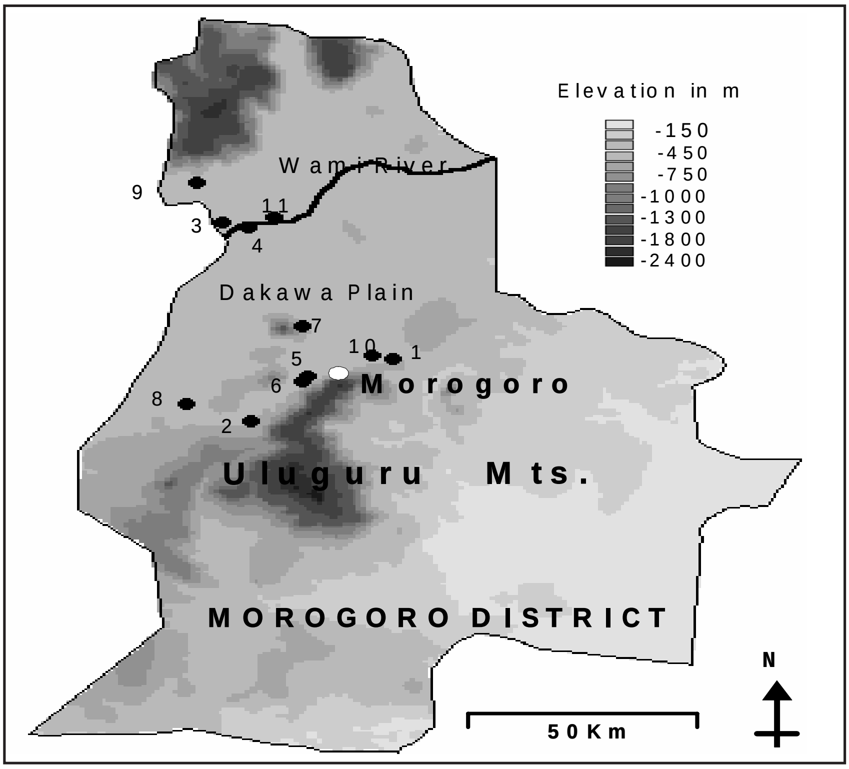

Fig. 1: Location of studied soil profiles

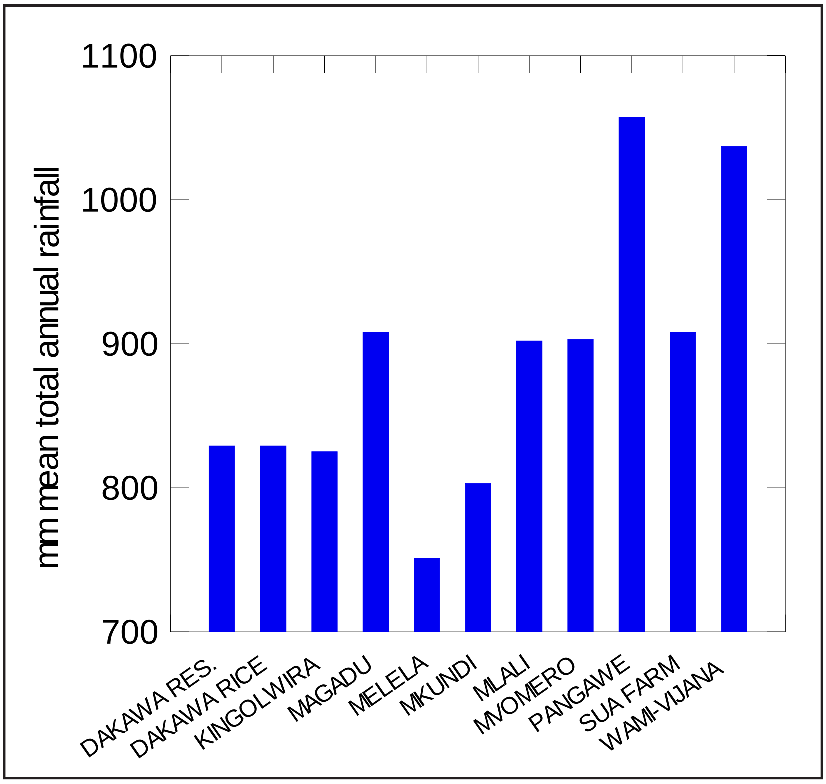

Fig. 2: Rainfall data for the studied sites

Table 1. Detailed sites characteristics of the district

Pedon no.	Site name	Location	Altitude (m asl)	Physiography	Soil parent materials	Vegetation / land use	Soil moisture regime
1	Kingolwira	S06^{0} 47' 35.2"; E37^{0} 48' 26.6"	490	Plain, almost flat, slope < 2%	Neogene colluvium derived from metasedimentary rocks rich in garnet-biotite gneisses with microcline and muscovite	Maize crop (already harvested)	ustic
2	Mlali	S 06^{0} 57' 49.3"; E 370 32' 44.0"	590	Almost flat to flat land, slope about 2%	Neogene colluvium derived from micaceous gneisses and hornblende gneisses and granulites	Grass and bush fallow with *Hyperrhenia* grass and *Acacia spp*.	ustic
3	Wami-Vijana Prison	S 06^{0} 24' 46.5"; E 37^{0} 28' 16.9"	380	Part of Wami Flats, flat land, slope < 1%	Neogene complex alluvium of diverse origin and composition	Sorghum	aquic
4	Dakawa Res. Station	S 06^{0} 25' 35.1"; E 37^{0} 32' 28.8"	360	Mbuga flat (part of Wami flats), slope < 1%	Neogene alluvium of diverse origin forming mbuga soils with deep wide cracks	Irrigated rice	aquic
5	SUA Farm	S 06^{0} 50' 24.7"; E 37^{0} 38' 59.8"	526	Colluvial plain, almost flat, slope 1%	Neogene colluvium derived from plagioclase and quartz-rich metasedimentry rocks	7 year fallow; currently under *Eucalyptus spp*. and *Hyperrhenia spp*.	ustic
6	Magadu	S 06^{0} 51' 15.0"; E 37^{0} 38' 33.1"	540	Undulating convex land, slope at site about 4%	Neogene colluvium derived from plagioclase and quartz-rich metasedimentary rocks	Maize	ustic
7	Mkundi	S 06° 42' 01.4"; E 37° 38' 22.5	576	Undulating concave land, slope at site 3-4%	Neogene alluvio-colluvial superficial sands and sandy hillwash derived from banded muscovite-boitite migmatites	Maize, sorghum and cassava	ustic
8	Melela	S 06° 54' 57.2"; E 37° 25' 30.6"	490	Alluvial plain, almost flat with a gentle slope of about 1 %	Neogene alluvium of diverse origin comprising superficial deposits of mbuga and alluvial soils	Cotton, sorghum, and maize	ustic
9	Mvomero	S 06° 18' 04.6"; E 37° 26' 38.7"	414	Almost flat land, slope 0 - 1 %	Mica-rich alluvium of diverse origin	Maize, mangoes, coconuts	aquic
10	Pangawe	S 06° 47' 01.5"; E 37° 46' 11.1"	530	Almost flat land, slope at site about 1 %	Neogene alluvio-colluvium derived from metasedimentary rocks rich in hornblende-pyroxene granulites	Maize	ustic
11	Dakawa Rice Farms	S 06° 23' 55.7"; E 37° 35' 12.4"	360	Flat land (part of Wami flats), slope < 1 %	Neogene alluvium of diverse origin which on site form gray and black mbuga soils	Rice, currently abandoned due to salt	aquic

Walkley and Black (Nelson and Sommers, 1982) and converted to organic matter by multiplying by a factor of 1.724. Kjeldahl method (Bremner and Mulvaney, 1982) was employed to determine total nitrogen. Phosphorus was extracted by Bray and Kurtz-1 method (Bray and Kurtz, 1945) and determined spectrophotometrically (Murphy and Riley, 1962; Watanabe and Olsen, 1965). The cation exchange capacity (CEC) and exchangeable bases were extracted by saturating soil with neutral 1M NH_4OAc (Thomas, 1982) and the adsorbed NH_4^+ displaced with K^+ using 1M KCl and then determined by Kjeldahl distillation method for the estimation of CEC of soil. The bases Ca^{++}, Mg^{++}, Na^+, and K^+, displaced by NH_4^+ were measured by atomic absorption spectrophotometer. Texture was determined by Bouyoucos hydrometer method (Day, 1965) after dispersing soil with sodium hexametaphosphate. Bulk density was determined using core sample method (Blake, 1965).

Clay mineralogy and total element analysis

Samples for clay mineralogical analysis were prepared using the method outlined by Msanya *et al*. (1998) follows: fine-earth subsoil samples were first treated with 30% H_2O_2 to remove organic matter. The samples were then thoroughly dispersed by ultra-sonic vibrations for 5 minutes after adding 1 ml of 1M NaOH (dispersing agent) and then 300 ml of deionised water. The suspensions were transferred to glass cylinders and their volumes made up to 1000 ml and then allowed to settle. At appropriate time interval and depth, clay samples were siphoned out of the cylinders into glass beakers. The clay samples were mounted on glass slides for x-ray diffraction analysis. X-ray diffractometer model Rigaku D/Max-1000 was used for the analysis and the x-ray diffractograms plotted by computer model Rigaku 2050/32. The relative quantitative mineralogical compositions were estimated from the diffractograms.

The total elemental composition of fine-earth subsoil samples was determined by x-ray florescence spectrometry using a Rigaku-denki KG-4 x-ray spectrometer (Dixon and Weed, 1989). Ten elements namely Fe, Ti, Mn, Ca, K, P, Si, Al, Mg and K were determined and expressed in the form of oxides.

Classification of the studied soils

Using both field and laboratory data the soils were classified up to family level of the USDA Soil Taxonomy (Soil Survey Staff, 1990) and to level-2 of the FAO-Unesco (1989) Soil Classification System.

RESULTS AND DISCUSSIONS

Chemical and physical characteristics and general fertility of the soils

The chemical and physical properties of the studied soils are presented in Table 2. General soil fertility was evaluated based on the standards set by EUROCONSULT (1989) and Landon (1991).

Pedons 1, 2, 5 and 6 are very deep and well drained, predominantly clayey soils with very low organic carbon and phosphorus contents and low to very low nitrogen contents. Exchangeable K, Ca and Mg appear to be adequate at present although the subsoil acidity may cause some alarm. In pedons 5 and 6 the subsoils are marginal to deficient in Ca and Mg. Both topsoil and subsoil have a friable consistence. The base saturation in the four pedons can be rated as medium in the epipedons and low in the subsoils, whereas the CEC is mostly low throughout the profiles. Non-acidifying N and P fertilizers and liming will be necessary for optimal crop production on these soils.

Pedons 3, 4 and 11 are very deep and imperfectly drained, predominantly clayey soils with low to very low OC, N and P and have firm to very firm consistence. Pedon 3 has adequate amounts of K, Ca and Mg and a favourable pH. In the case of pedon 4, Ca, Mg and K are adequate, although there is an imbalance of K and Mg. In pedon 11, Ca and Mg are adequate while K is marginal with a possibility of imbalance with Mg. The base saturation in the three pedons is high to very high throughout the profiles, while the CEC is medium in the upper 50 cm and low in the subsoil of pedon 3 and medium to high throughout pedons 4 and 11. Fertilization to supply N and P may be necessary for optimal plant growth.

Pedon 7 is a very deep soil showing evidences of somewhat poor drainage and having a friable to very friable sandy loam to sandy clay loam topsoil overlying a firm clayey subsoil. The soil has very low N and P contents and will require substantial fertilizer additions to supply these nutrients. Ca and Mg levels are adequate but K appears marginal. The base saturation is low in the upper 50 cm and high to very high deeper in the profile while the CEC is low in the upper 50 cm and medium deeper down the profile.

Pedon 8 is a very deep black mbuga soil with a firm consistence and a predominantly sandy clay topsoil and subsoil texture. There are clear evidences of wide and deep cracking and gilgai micro-relief. OC, N and P contents are low and there is a need for N and P fertilization for optimal plant growth. Ca, Mg and K are adequate, but there is a possibility of K imbalance with Mg. Base saturation and CEC are respectively very high and high throughout the profile.

Pedon 9 is a poorly drained and stratified very deep soil with friable sandy loam topsoil overlying friable and loose subsoil layers of sandy clay loam, sandy clay and sandy textures. N content is low and OC and P are very low. There is a clear need for N and P fertilization for optimal crop growth. Ca, Mg and K contents are adequate. Base saturation is high to very high throughout the profile while CEC is low to medium in the upper 1 m of the soil.

Pedon 10 is a very deep imperfectly drained soil with a firm sandy clay topsoil and a predominantly clayey subsoil. The soil has cracks as wide as 2 cm on the surface. The N content is low while the OC and P contents are very low. N and P fertilization will be necessary for optimal plant growth. Ca, Mg and K are adequate. Base saturation is high to very high throughout the profile and the CEC is medium throughout the profile.

Exchangeable Na does not seem to be a problem in most of the studied soils particularly when considering the upper 100 cm of the soil. Exchangeable Sodium Percentage (ESP) levels are lower than the critical value of 15 for most of the soils. However, ESP may pose a

Table 2: Chemical and physical characteristics of the studied soils

Pedon	Hori-.	Depth	pH		%	%	%	mg/kg	Bases and CEC (cmol(+)/kg					%	%Texture			Text.	BD
No.	zon	(cm)	H2O	KCl	OC	OM	N	Av. P	Ca	Mg	Na	K	CEC	BS	Clay	Silt	Sand	class	(g/cc)
1	Ap	0-22	5.5	4.5	1.8	3.1	0.22	4.2	3.25	2.93	0.21	0.71	15.3	46.4	59	9	32	C	1.12
	Bt1	22-40	5	4	0.9	1.6	0.11	0.6	2.25	1.01	0.31	0.17	15.8	23.7	61	3	36	C	1.38
	Bt2	40-97	4.9	4.1	0.6	1	0.07	0.6	2	1.46	0.23	0.17	11.3	34.2	65	3	32	C	1.25
	Bt3	97-153	5.1	4.1	0.5	0.9	0.07	0.6	1	2.31	0.36	0.21	10.7	36.3	68	6	26	C	1.22
	Bt4	153-205+	5.6	4.2	0.2	0.3	0.04	3	2.05	2.25	0.36	0.23	9.3	52.6	69	3	28	C	1.25
2	Ap	0-10	5.9	4.8	1.2	2.1	0.11	9.8	2.38	1.21	0.07	1.69	11.4	46.9	37	7	56	SC	1.26
	ABmh	20-Oct	5.9	4.8	1.1	1.9	0.12	2.4	5.6	1.51	0.08	1.1	11.5	72.1	47	4	49	SC	1.6
	Btms	20-55	5.5	4.5	0.6	1	0.08	1.7	2.65	1.58	0.18	1	10.2	53	72	2	26	C	1.4
	Bt1	55-73	5.3	4.6	0.4	0.7	0.06	1.3	2	1.67	0.25	0.53	12	37.1	61	2	37	C	1.22
	Bt2	73-113	5.4	5	0.2	0.3	0.04	1.3	1.4	1.96	0.23	0.34	12.1	32.5	72	4	24	C	1.16
	Bt3	113-132	5.8	5.4	0.2	0.3	0.04	0.8	2	2.33	0.1	0.36	8.4	57	71	2	27	C	nd
	Bt4	132-178	5.3	4.6	0.2	0.3	0.03	2.2	1.05	1.17	0.15	0.76	8	39.1	70	4	26	C	1.24
3	Ap	0-14	6.4	5.2	1.6	2.8	0.13	10.2	6.5	4.92	0.76	1.56	21.9	62.7	57	12	31	C	1.35
	BAg	14-45	6.3	5	0.7	1.2	0.09	1.5	8.63	6.33	0.64	0.33	22.4	71.2	67	2	31	C	1.42
	Bg	45-61	6.9	5.4	0.6	1	0.06	1.3	5.25	3.67	0.65	0.43	15.3	65.4	43	15	42	C	1.51
	2Cg	61-106	6.8	5.2	0.1	0.2	0.04	4.5	2.75	1.21	0.49	0.26	5.8	81.2	13	1	86	LS	1.57
	2C	106-155	7	5.4	0.1	0.2	0.01	1.7	1.38	0.67	0.54	0.1	3.8	70.8	7	2	91	S	1.58
	3Btg	155-180+	6.6	6	0.4	0.7	0.05	1.5	6.88	7.33	0.82	0.38	21.6	71.3	57	2	41	C	1.46
4	Apg	0-21	6.5	5.4	1.3	2.2	0.15	0.5	12	6.42	0.73	0.51	26.1	75.2	55	26	19	C	1.43
	Bg	21-68	7.7	6.3	0.7	1.2	0.07	0.5	10.55	8.44	2.03	0.33	22.5	94.9	61	15	24	C	1.49
	Btg1	68-127	8.2	6.6	0.5	0.9	0.08	0.5	11.5	9	2.94	0.39	30.7	77.6	65	23	12	C	1.37
	Btg2	127-190+	8.6	6.9	0.3	0.5	0.04	1.5	9.8	9.17	2.83	0.24	25.7	85.6	49	8	43	C	1.47
5	Ap1	0-9	5.3	4.2	1.5	2.6	0.15	9	1.28	1.71	1.47	3	15.2	49.1	20	7	73	SCL	1.16
	Ap2	23-Sep	4.7	4.7	1	1.7	0.13	1.8	2	3.83	0.49	0.67	16.6	42.1	45	19	36	C	1.52
	BA	23-40	4.5	3.8	0.7	1.2	0.11	1.8	2	1.17	0.52	5.58	16.2	26.4	49	18	33	C	1.31
	Bt1	40-63	4.9	3.9	0.4	0.5	0.08	1.2	1.25	1.42	1.68	0.26	13.8	33.4	55	12	33	C	1.2
	Bt2	63-138	5.3	3.9	0.4	0.5	0.12	3	2.23	1.29	1.58	0.33	10.2	53.2	52	14	34	C	1.32
	Bt3	138-180+	5.9	3.9	0.2	0.3	0.04	1.2	1.75	0.92	0.76	0.33	10.8	34.8	41	16	43	C	1.49
6	Ap	0-18	4.8	3.8	1.2	2.1	0.13	3	4.43	1.17	1.58	1.43	13.6	48.6	43	3	54	SC	1.49
	Bt1	18-45	4.7	3.8	0.6	1	0.08	1.2	1	0.8	0.49	0.3	12.3	21.3	63	4	33	C	1.39
	Bt2	45-105	4.6	3.8	0.5	0.9	0.06	1.8	0.45	1.42	0.6	0.18	12.1	21.9	66	4	30	C	1.35
	Bt3	105-160+	4.8	3.8	0.2	1.7	0.07	2.5	0.45	1.21	0.82	0.26	15	18.3	68	5	27	C	1.36

problem in the deep subsoils of pedons 7, 8, 9 and 11 where it may have adverse effect not only to deep-rooted crops but also to the physical conditions of the soils.

Clay mineralogy of the studied soils

The results on the estimation of the mineralogical composition of the soil clay fractions are presented in Table 3. The mineralogy of four pedons namely, 1 (Kingolwira), 2 (Mlali), 5 (SUA Farm) and 6 (Magadu) is almost purely kaolinitic. These pedons represent the red and relatively highly weathered and friable soils of Morogoro district. The rest of the pedons are of mixed mineralogy whereby pedons 3 (Wami-Vijana Prison), 4 (Dakawa Research Station), 7 (Mkundi) and 11 (Dakawa Rice Farms) are predominantly kaolinitic but with subordinate amounts of both mica (illite) and smectite; pedon 9 (Mvomero) is also predominantly kaoinitic but with subordinate amounts of only mica (illite); pedon 8 (Melela) is largely smectitic with small amounts of kaolinite; and pedon 10 (Pangawe) is also largely smectitic but with subordinate amounts of kaolinite and traces of mica.

The pedons which are smectitic or having some amounts of smectite, present some problems of workability due to their firm moist consistence and hard to very hard dry consistence. However, in terms of fertility they are generally more fertile (having higher CEC and BS) than the highly weathered kaolinitic soils.

Table 3. Relative mineralogical composition of clay fractions

Pedon	Kaolinite	Smectite	Mica/Illite
1 Kingolwira	++++++		
2 Mlali	++++++		
3 Wami-Vijana Prison	+++	+	++
4 Dakawa Research Station	+++	+	++
5 SUA Farm	++++++		
6 Magadu	++++++		
7 Mkundi	+++	+	++
8 Melela	+	+++++	
9 Mvomero	++++		++
10 Pangawe	++	++++	tr
11 Dakawa Rice Farms	+++	+	++

Total chemical analysis

On the basis of the data on total chemical analysis presented in Table 4, the following statements can be made about the soils:

(a) Pedons 1, 2, 5 and 6 can be grouped together as highly weathered soils as indicated by the low base (Ca, K, Mg and Na) content, high content of Fe, Ti and Al and low Si/Al ratios.

(b) Pedons 7, 8, 9, 10, and 11 can generally be described as having high base content, low Fe and Al contents, and high Si/Al ratios; a manifestation of a relatively lower degree of weathering.

(c) Pedons 3 and 4 are high in base content and Fe and Al contents, and have a low Si/Al ratio, a condition reflecting an intermediate degree of weathering

(d) The high Fe/Al and Mg/K ratios in pedon 9 indicate that the soil has developed from mafic parent materials while the low Fe/Al and Mg/K ratios in the case of pedon 7 indicate that the soil has developed from felsic parent materials.

Soil classification

Field and laboratory data (Tables 2, 3 and 4) were used to classify the soils. Table 5 presents the salient morphological and diagnostic features used in classifying the soils. Table 6 gives the soil names according to the two systems of classification used. Pedon 1 has an ochric epipedon (ochric A) and a red deep oxic horizon (ferralic B) as the diagnostic horizons and hence has been classified as an Oxisol or Ferralsol according to USDA Soil Taxonomy and FAO-Unesco Classification respectively. Oxic horizons characterize highly weathered soils.

Pedons 2, 5 and 6 have ochric epipedons and low base argillic (argic B) horizons as diagnostic horizons. The profiles show clear clay gradient between eluvial and illuvial horizons together with morphological evidence of illuviation in form of clay cutans. The soils have been classified as Ultisols or Acrisols according to USDA Soil Taxonomy and FAO-Unesco Classification respectively. Ultisols are also highly weathered soils but genetically are not as old as Oxisols.

Pedons 3 and 7 are fairly young soils with no diagnostic horizons other than an ochric epipedon, and hence have been classified as Entisols (USDA Soil Taxonomy).

Table 4. Total element analysis (% oxides) of the studied soils

Pedon	Fe_2O_3	TiO_2	MnO_2	CaO	K_2O	P_2O_5	SiO_2	Al_2O_3	MgO	Na_2O	Total
1. Kingolwira	14.16	2.24	0.052	0.07	0.13	0.076	55.76	27.05	0.27	0.19	100
2. Mlali	11.38	1.51	0.047	0.07	0.19	0.061	60.01	26.5	0.19	0.05	100
3. Wami-Vijana Prison	13.04	1.3	0.14	0.92	1.8	0.054	53.53	26.24	1.78	1.22	100
4. Dakawa Res. Station	10.58	1.08	0.092	1.56	1.88	0.125	57.33	24.26	1.5	1.59	99.99
5. SUA Farm	15.11	2	0.057	0.01	0.47	0.052	54.32	27.48	0.24	0.25	99.99
6. Magadu	12.01	2.14	0.035	0	0.39	0.024	59.92	25.18	0.24	0.06	99.99
7. Mkundi	4.71	0.59	0.049	0.93	2.58	0.001	68.8	19.37	0.83	1.13	100
8. Melela	6.11	1.09	0.1	4.15	1.12	0.001	66.27	16.53	1.77	2.86	100
9. Mvomero	9.98	1.84	0.122	3.16	1.14	0.034	69.35	9.67	3.02	1.68	100
10. Pangawe	10.34	1.46	0.17	3.16	0.51	0.001	62.73	18.21	1.35	2.05	99.99
11. Dakawa Rice Farms	6.27	0.72	0.07	2.03	1.25	0.04	69.64	17.04	1.33	1.64	99.99

Table 5. Summary of salient morphological and diagnostic features of the studied soils

Pedon	Diagnostic horizons	Other diagnostic features	Particle size class	Calcareousness and reaction class	Soil depth	Mineralogy class
1 Kingolwira	Ochric epipedon (*ochric A); Oxic horizon (*ferralic B)	Iso-hyperthermic STR; ustic SMR; thick horizon with CEC=or<16 cmol+/kg clay; diffuse particle size boundary; *very low silt-clay ratio<0.2; *no rock structure; >40% clay in the surface 18 cm; color hue of 2.5 YR or redder with moist values of <4 (*red to dusky red ferralic B)	Very fine clayey	Acid	Very deep	Kaolinitic
2 Mlali	Ochric epipedon (*ochric A); Argillic horizon (*argic B)	Iso-hyperthermic STR; ustic SMR; appreciable clay gradient between eluvial and illuvial layer; clay cutans; CEC=or<16 cmol+/kg clay in major part of argillic B (*CEC=or<24cmol+/kg clay in argic B); *BS<50% in some parts of argic B; low OM content; normal	Very fine clayey	Acid	Very deep	Kaolinitic
3 Wami-Vijana Prison	Ochric epipedon (*ochric A)	Iso-hyperthermic STR; aquic SMR(*gleyic properties), Slope<25%; *Fluvic properties (stratification, alluvial deposits, OC decreases irregularly with depth); *BS=or>50% between 20-50cm; cracks during dry season	Clayey over sandy	Non-acid, non-calcareous	Very deep	Mixed (kaolinite, mica, smectite)
4 Dakawa Res. Station	Ochric horizon (*ochric A); Cambic horizon (*cambic B)	Iso-hyperthermic STR; aquic SMR (*gleyic properties); cracks during dry season	Very fine clayey	Non-acid, non-calcareous	Very deep	Mixed (kaolinite, mica, smectite)
5 SUA Farm	Ochric epipedon (*ochric A); Argillic horizon (*argic B)	Iso-hyperthermic STR, ustic SMR; appreciable clay gradient between eluvial and illuvial horizon; clay cutans; low BS<35% by sum of cations; CEC<24 cmol+/kg clay in major part of argillic horizon	Fine clayey	Acid	Very deep	Kaolinitic
6 Magadu	Ochric epipedon (*ochric A); Argillic horizon (*argic B)	Iso-hyperthermic STR; ustic SMR; appreciable clay gradient between eluvial and illuvial horizon; clay cutans; low BS<35% by sum of cations (*BS<50% in argic B); CEC<24 cmol+/kg clay in major part of argillic horizon	Very fine clayey	Acid	Very deep	Kaolinitic
7 Mkundi	Ochric epipedon (*ochric A)	Iso-hyperthermic STR; aquic SMR(*gleyic properties); *BS<50% between 20-50 cm	Very fine clayey	Acid	Very deep	Mixed (kaolinite, mica, smectite)
8 Melela	Ochric epipedon (*ochric A)	Iso-hyperthermic STR; ustic SMR; >30% clay in the upper 18cm(*>35% clay in all horizons); wide deep cracks; gilgai micro-relief; slickensides; prismatic structure; *BS>50%; effervescence with HCl (*calcareous)	Fine clayey	Non-acid, calcareous	Very deep	Smectitic
9 Mvomero	Mollic epipedon (*mollic A)	Iso-hyperthermic STR; aquic SMR (*gleyic properties); dark colored epipedon meeting all the requirements of mollic epi-pedon; BS>50% throughout the profile; *fluvic properties (stratification, OC decreases irregularly with depth); slope <25%	Clayey over sandy	Non-acid, non-calcareous	Very deep	Mixed (kaolinite, mica)
10 Pangawe	Ochric epipedon (*ochric A); Argillic horizon (*argic B)	Iso-hyperthermic STR; aquic SMR (*gleyic properties); appreciable clay gradient between eluvial and illuvial horizon; clay cutans; some vertic properties (cracks on the surface); *high BS>50% and high CEC = or > 24 cmol+/kg clay in B horizon	Fine clayey	Non-acid, non-calcareous	Very deep	Smectitic
11 Dakawa Rice Farms	Ochric epipedon (*ochric A); Cambic horizon (*cambic B)	Iso-hyperthermic STR; aquic SMR (*gleyic properties); *calcaric -presence of lime; vertic properties (slickensides, wide deep cracks); *>35% clay in all sub-horizons to a depth of 5 cm	Fine clayey	Non-acid, calcareous	Very deep	Mixed (kaolinite, mica, smectite)

NB.* terminology particularly used in the FAO-UNESCO Classification; those without * are used in the USDA Soil Taxonomy

However, due to differences in parent materials and modes of formation they have different characteristics. According to the FAO-Unesco Classification System, pedon 3 which is a river deposited soil and showing all evidences of fluvic properties is classified as a Fluvisol while pedon 7 is classified as a Regosol.

Pedon 4 is genetically more developed than pedons 3 and 7 as exhibited by the presence of both an ochric epipedon and a cambic horizon (cambic B). This soil has been classified as an Inceptisol (USDA Soil Taxonomy) or a Cambisol (FAO-Unesco Classification). Inceptisols are soils that have just started to form as may be indicated by modest development of structure, color, consistence etc. They are therefore younger than Ultisols and Oxisols.

Pedons 8 and 11 have ochric epipedons as diagnostic horizons and are also characterized by the presence of vertic characteristics including slickensides, deep wide

Table 6: Classification of the studied soils

Pedon	USDA Soil Taxonomy					FAO-Unesco Classification	
	Order	Suborder	Greatgroup	Subgroup	Family	Level-1	Level-2
1 Kingolwira	Oxisol	Ustox	Haplustox	Rhodic Haplustox	*Very fine clayey, acid, iso-hyperthermic, deep, kaolinitic, Rhodic Haplustox*	Ferralsol	*Rhodic Ferralsol(FRr)*
2 Mlali	Ultisol	Ustult	Kanhaplustult	Typic Kanhaplustult	*Very fine clayey, acid, iso-hyperthermic, deep, kaolinitic, Typic Kanhaplustult*	Acrisol	*Haplic Acrisol(ACh)*
3 Wami-Vijana Prison	Entisol	Aquent	Fluvaquent	Vertic Fluvaquent	*Clayey over sandy, non-acid, non-calcareous, iso-hyperthermic, deep, mixed,Vertic Fluvaquent*	Fluvisol	*Eutric Fluvisol(FLe)*
4 Dakawa Research Station	Inceptisol	Aquept	Tropaquept	Vertic Tropaquept	*Very fine clayey, non-acid, non-calcareous, iso-hyperthermic, deep, mixed, Vertic Tropaquept*	Cambisol	*Gleyic Cambisol(CMg)*
5 SUA Farm	Ultisol	Ustult	Haplustult	Kanhaplic Haplustult	*Fine clayey, acid ,iso-hyperthermic, deep, kaolinitic, Kanhaplic Haplustult*	Acrisol	*Haplic Acrisol(ACh)*
6 Magadu	Ultisol	Ustult	Haplustult	Kanhaplic Haplustult	*Very fine clayey, acid, iso-hyperthermic, deep, kaolinitic, Kanhaplic Haplustult*	Acrisol	*Haplic Acrisol(ACh)*
7 Mkundi	Entisol	Aquent	Tropaquent	*	*Very fine clayey, acid, iso-hyperthermic, deep, mixed, Tropaquent*	Regosol	*Dystric Regosol (RGd)*
8 Melela	Vertisol	Ustert	Pellustert	Paleustollic Pellustert	*Fine clayey, non-acid, calcareous, iso-hyperthermic, deep, mixed, Typic Pellustert*	Vertisol	*Eutric Vertisol(VRe)*
9 Mvomero	Mollisol	Aquoll	Haplaquoll	Fluvaquentic Haplaquoll	*Clayey over sandy, non-acid, non-calcareous, iso-hyperthermic, deep, mixed, Fluvaquentic Haplaquoll*	Fluvisol	*Eutric Fluvisol(FLe)*
10 Pangawe	Alfisol	Aqualf	Ochraqualf	Vertic Ochraqualf	*Fine clayey, non-acid, non-calcareous, iso-hyperthermic, deep, smectitic, Vertic Ochraqualf*	Luvisol	*Vertic Luvisol (LVv)*
11 Dakawa Rice Farms	Vertisol	Ustert	Pellustert	Typic Pellustert	*Fine clayey, non-acid, calcareous, iso-hyperthermic, deep, mixed, Typic Pellustert*	Vertisol	*Calcic Vertisol (VRk)*

cracks and gilgai micro-relief. In these soils there is constant physical and biological churning of the soil materials thereby resulting in partial inversion of the soils and homogenization of the profiles. Pedon 11 has also a cambic horizon which is to some degree being masked by the vertic characteristics. The two pedons have been classified as Vertisols in both USDA Soil Taxonomy and FAO-Unesco Classification Systems. Genetically Vertisols do not have much possibility of development because of the regular pedoturbation taking place in them. In terms of age these soils could roughly be compared with Inceptisols.

Pedon 9 has a mollic epipedon (mollic A) as the diagnostic epipedon and has been classified as a Mollisol (USDA Soil Taxonomy) or a Fluvisol (FAO-Unesco Classification) since its mode of formation is fluvial. Mollisols are by definition good soils with soft structure and high inherent fertility (high OM content and high BS). These soils are not highly weathered and their relative pedogenic age may range between that of Entisols and Inceptisols.

Pedon 10 has ochric epipedon and high base argillic horizon (argic B) as the diagnostic horizons and has therefore been classified as an Alfisol (USDA Soil Taxonomy or a Luvisol (FAO-Unesco Classification). Alfisols are soils with a high base illuvial (argillic) horizon. Like the Ultisols, Alfisols must have all the evidences of eluviation-illuviation processes including appreciable clay gradient between eluvial and illuvial layers, and presence of clay skins (argillans) in the illuvial layer. In terms of age, Alfisols are slightly younger than Ultisols but older than the Inceptisols, Mollisols, Vertisols and Entisols.

CONCLUSIONS AND RECOMMENDATIONS

1. The studied soils have varying properties and can be classified into soil categories with different potentials and constraints to use and management.

2. Pedons 1, 2, 5 and 6 are highly weathered kaolinitc soils with low chemical fertility. Non-acidifying N and P fertilizers and liming are deemed necessary for optimal crop production.

3. Pedons 3, 4, 10 and 11 have high chemical fertility as indicated by high BS and CEC values. However, their vertic characteristics and very hard consistence pose problems of difficult workability. Moreover N and P contents are low and there is need for fertilization.

4. Pedon 7 has low topsoil BS and CEC and low to very low N and P contents. Substantial N and P fertilization is required to supply N and P.

5. Pedon 8 like pedons 3, 4, 10 and 11, has high BS and CEC and hence can be said to be of high chemical fertility status. It has more pronounced vertic characteristics manifested by wide deep cracking typical of the smectitic mineralogy. Difficult workability due to the soil's firm consistence poses a big problem.

6. Pedon 9 is a friable soil with a soft structure offering easy workability. The BS is high to very high throughout the soil profile while the CEC is low to medium in the upper 1 m of the profile. N and P fertilization is required due to the low levels of these nutrients in the soil.

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