PEDOLOGICAL STUDIES AND CHARACTERIZATION OF SOME BENCHMARK SOILS OF MOROGORO DISTRICT, TANZANIA

Balthazar M. Msanya
Abel K. Kaaya
Gerson I. Nyadzi

Department of Soil Science, Sokoine University of Agriculture, P.O. Box 3008, Morogoro

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EXECUTIVE SUMMARY

A detailed characterization of soils earmarked as "Benchmark Soils of Morogoro District" in Tanzania was carried out to provide basic data required in planning and execution of soil fertility studies in the area. Benchmark soils are defined as those occuring 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 some existing soils information coupled with reconnaissance soil auger observations. Representative soil profiles for the benchmark sites were excavated and described in detail following the standard FAO (1977) guidelines. Both disturbed and undisturbed soil horizon samples were taken for laboratory studies including physico-chemical and mineralogical characterization of the soils.

The field and laboratory data were used to classify the soils in detail using two international soil classification systems commonly used in Tanzania, namely the United States Department of Agriculture Soil Taxonomy (up to family level) and the FAO-Unesco Soil Classification System (up to level 2).

The soils have been classified as follows (with FAO-Unesco names in brackets):

Pedon 1 Kingolwira: **Very fine clayey, acid, iso-hyperthermic, deep, kaolinitic, Rhodic Haplustox (Rhodic Ferralsol)**

Pedon 2 Mlali: **Very fine clayey, acid, iso-hyperthermic, deep, kaolinitic, Typic Kanhaplustult (Haplic Acrisol)**

Pedon 3 Wami-Vijana Prison: **Clayey over sandy, non-acid, non-calcareous, iso-hyperthermic, deep, mixed, Vertic Fluvaquent (Eutric Fluvisol)**

Pedon 4 Dakawa Research Station: **Very fine clayey, non-acid, non-calcareous, iso-hyperthermic, deep, mixed, Vertic Tropaquept (Gleyic Cambisol)**

Pedons 5 and 6 SUA Farm and Magadu: **Fine clayey, acid, iso-hyperthermic, deep, kaolinitic, Kanhaplic Haplustult (Haplic Acrisol)**

Pedon 7 Mkundi: **Very fine clayey, acid, iso-hyperthermic, deep, mixed, Tropaquent (Dystric Regosol)**

Pedon 8 Melela: **Fine clayey, non-acid, calcareous, iso-hyperthermic, deep, smectitic, Paleustollic Pellustert (Eutric Vertisol)**

Pedon 9 Mvomero: **Clayey over sandy, non-acid, non-calcareous, iso-hyperthermic, deep, mixed, Fluvaquentic Haplaquoll (Eutric Fluvisol)**

Pedon 10 Pangawe: **Fine clayey, non-acid, non-calcareous, iso-hyperthermic, deep, smectitic, Vertic Ochraqualf (Vertic Luvisol)**

Pedon 11 Dakawa Rice Farms: **Fine clayey, non-acid, calcareous, iso-hyperthermic, deep, mixed, Typic Pellustert (Calcic Vertisol)**

Clay mineralogy, total elemental analysis and the physico-chemical data group together pedons 1, 2, 5 and 6 as the highly weathered soils. They are clayey, dominantly kaolinitic and their overall inherent chemical fertility is low. Non-acidifying N and P

fertilizers and liming are deemed necessary for optimal crop production on these soils.

Pedons 3, 4, and 11 are deep clayey soils with vertic properties and a mixed clay mineralogy (kaolinite, smectite and mica). These soils can be said to be of high chemical fertility due to their high BS and CEC. Their main limitation may be difficult workability due to their firm consistence. Moreover N and P contents are low and there is need for fertilization.

Pedon 7 is a deep soil with a mixed mineralogy and a friable to very friable sandy loam to sandy clay loam topsoil overlying a firm clayey subsoil. The topsoil BS and CEC are low while in the subsoil their values are medium to high. The low to very low N and P contents in this soil calls for substantial fertilizer additions to supply these nutrients. The topsoil is easily workable.

Pedon 8 like pedons 3, 4 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 and well developed gilgai micro-relief as a result of the dominantly smectitic clay mineralogy. Workability may be a big problem because of soil's firm consistence.

Pedon 9 is a stratified soil with a friable sandy loam topsoil overlying friable sandy clay loam to sandy clay subsoil. The soil has a mixed clay mineralogy and 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. There is a clear need for N and P fertilization due to the

low levels of these nutrients.

Pedon 10 is a deep soil with a cracking firm sandy clay topsoil and a predominantly clayey subsoil. The mineralogy which is smectitic poses some problems as far as workability of the soil is concerned. BS is high to very high throughout the profile and the CEC is medium throughout. There is also a need for N and P fertilization due to the low values of these nutrients in the soil.

INTRODUCTION

Soil information by systematically identifying, grouping and delineating different soils according to their formation and physico-chemical characteristics is required when sound interpretations towards land use potential are to be made. In addition, climatic and 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 badly need well characterized sites in order to carry out meaningful fertilizer trials with similar soil and ecological conditions.

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.*, 1993), 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 land resources. The few existing soil resource inventories are characterized by the 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.

The current thinking is that there is need for more efforts to be invested in coordinated and systematic inventorying of the country's soil and land resources to facilitate land use planning activities. There is also a general feeling that fertilizer trials should be done on well characterized soils to enhance transferability of information from one place to another.

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

Selection of benchmark soils is very crucial and requires rigorous soil inventorying and mapping to show their spatial distribution. In this particular study to due limited base information, the selection has been done using mainly simple field observation techniques based on local experience on the soils of the study area. Up to date there is no regional or district soils map of Morogoro on which to base the selection of the benchmark soils, although preliminary studies geared towards district inventory of soils started several years ago.

The specific objectives of this study are three-fold:

i. to make an inventory of the ecological conditions of the

benchmark sites including climate, geology, geomorphology etc.,

ii. to characterize the benchmark soils using standard field and laboratory methods, and

iii. to classify the soils using two international classification systems commonly used in Tanzania namely, the United States Department of Agriculture Soil Taxonomy and the FAO-Unesco Classification System.

The results of the pedological characterization were deemed necessary as a base for subsequent studies on soil fertility and crop response to fertilizers.

MATERIALS AND METHODS

1. Field methods

Selection of benchmark sites was done using some 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 assist the selection. As mentioned in the introductory section, the selection should have been based on/or involved a detailed soils mapping of Morogoro District. Nevertheless, eleven soil profiles were identified, excavated, described and sampled following standard procedures (FAO, 1977; Munsell Color Company, 1954; Soil Survey Staff, 1951) to represent the benchmark sites on which fertility trials have been carried out. Exact locations of the sites in terms of

international coordinates were determined using Sony Global Positioning System Receiver. Figure 1 shows the locations of the selected sites and Appendix 1 gives detailed field profile descriptions of the studied pedons.

2. Routine laboratory methods

Chemical and physical analyses were done as follows: pH was measured potentiometrically in water and in 1N KCl at the ratio 1/2.5 soil-water and soil-KCl. Organic carbon was determined by wet oxidation method of Walkley and Black (Nelson and Sommers, 1982) and converted to organic matter by multiplying by a factor of 1.724. Kjeldal 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 Kjeldal 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. CEC of clay was calculated using the formula of Baize (1993) which corrects for the CEC contributed by organic (OM) as follows:

CEC_{clay} = {[CEC_{soil} - (% OM x 2)]/% clay} x 100. 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).

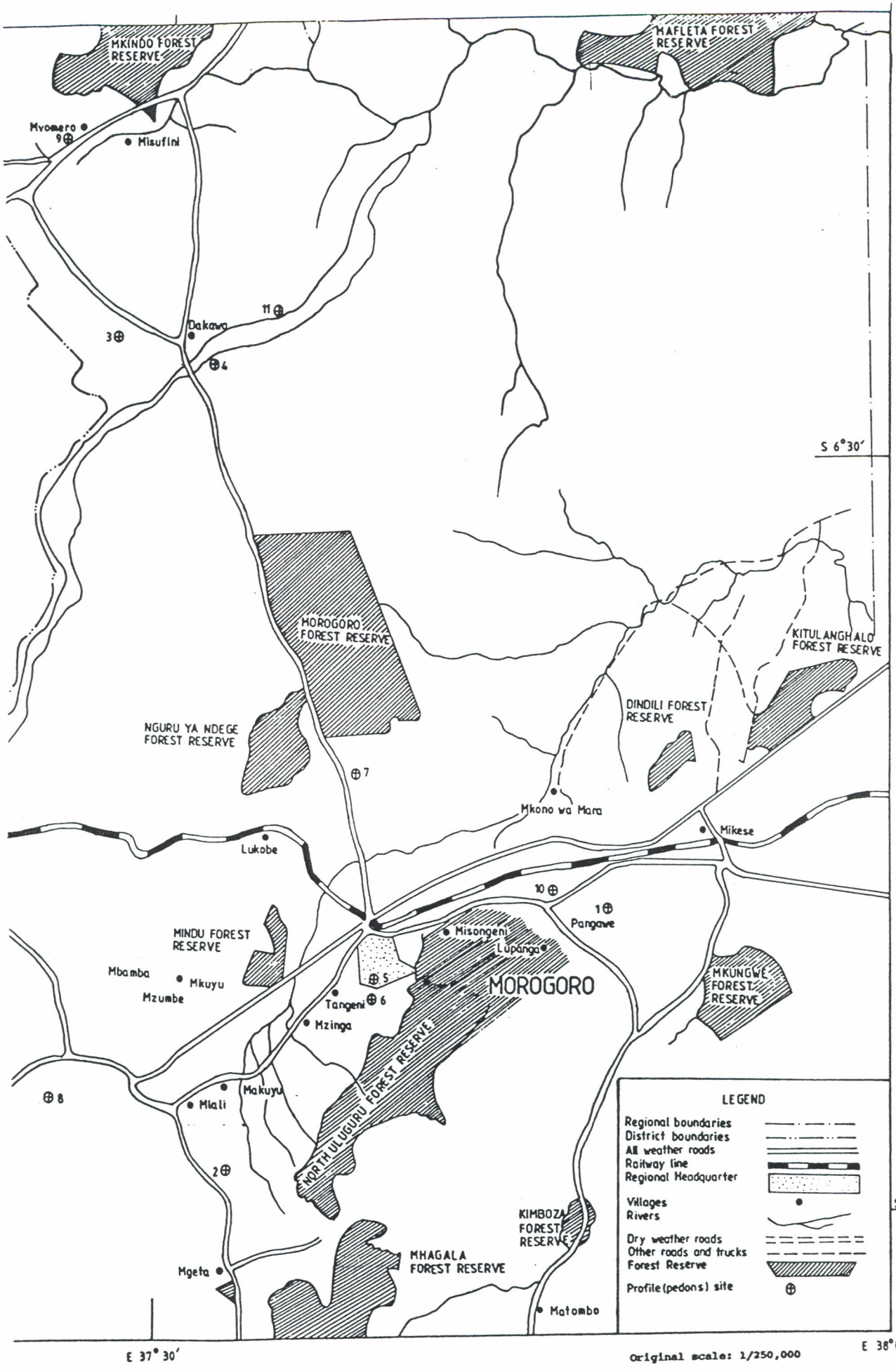

Figure 1. Location of the studied soil profiles (pedons)

3. Clay mineralogy and total elemental analysis

Samples for clay mineralogical analysis were prepared as follows:

About 20 gm of fine-earth subsoil samples (from a depth of 50 cm) were first treated with 30% H_2O_2 in glass beakers to remove organic matter and the excess H_2O_2 evaporated on a hot plate. To each of the samples 1 ml of 1N NaOH (dispersing agent) and then 300 ml of deionised water were added. The suspension were then subjected to ultra-sonic vibarations for 5 minutes at 4000 rpm to allow thorough dispersion. The suspensions were transfered 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. Six treatments were applied, namely Mg saturation, Mg + glycol saturation, K saturation, K saturation + 110°C, K saturation + 350°C and K saturation + 550°C. X-ray diffractometer model Rigaku D/Max-1000 series was used for the analysis and the x-ray diffractograms plotted by computer model Rigaku 2050/32.

The total elemental composition of fine-earth subsoil samples (from a depth of 50 cm) was determined by x-ray florescence spectrometry using a Rigaku-denki KG-4 x-ray spectrometer. Soil samples were ignited in a furnace for 4 hours at a temperature of 1000-1100°C, then cooled and ground into fine powder using a Spex mill. Powder samples were mixed with Lithium-borate mixture ($Li_2B_4O_7$-Li_2CO_3-Li_2O_3), transfered into platinum crucibles and melted

at 1100°C in a special furnace. The melts were allowed to cool to form glass discs (pellets) which were used in the analysis. Ten elements namely Fe, Ti, Mn, Ca, K, P, Si, Al, Mg and K were determined and expressed in the form of oxides.

4. 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 DISCUSSION

1. Climate of the studied area

The climate of Morogoro District can generally be described as a sub-humid tropical climate. 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. Experience shows that the onset of both rains and their distribution are irregular and unreliable. The soil moisture regime in many places is thus ustic except where there are local effects of flooding and waterlogging. Table 1 presents rainfall data for the various studied sites. The mean annual rainfall of the studied sites varies from about 750 mm (Melela) to about 1050 mm (Pangawe).

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. The mean annual soil temperature (MAST) can be estimated as 25°C by adding 1°C to the MAAT (after Soil Survey

Table 1. Rainfall (mm) of the studied sites

Site	No. of yrs	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Tot
Kingolwira	31	115	85	126	134	67	16	16	14	20	45	74	113	825
Mlali	26	121	103	144	214	60	13	7	3	15	39	75	108	902
Wami-Vijana Prison	23	149	107	151	205	106	18	14	8	18	43	68	150	1037
Dakawa Res. Station	5	122	122	90	163	87	7	13	9	8	24	75	109	829
SUA Farm	65	95	102	167	215	91	26	15	11	18	29	61	78	908
Magadu	65	95	102	167	215	91	26	15	11	18	29	61	78	908
Mkundi	39	124	91	133	155	65	19	16	11	15	30	49	95	803
Melela	8	80	75	128	168	71	4	2	2	10	31	55	125	751
Mvomero	21	84	85	182	203	83	16	13	10	12	30	78	107	903
Pangawe	12	101	110	159	198	74	27	27	16	26	67	117	135	1057
Dakawa Rice Farms	5	122	122	90	163	87	7	13	9	8	24	75	109	829

Staff, 1975) and is thus the soil temperature regime is classified as iso-hyperthermic.

2. Chemical and physical characteristics of the soils

The chemical and physical properties of the studied soils are presented in table 2 and partly in appendix 1. General soil fertility was evaluated based on the standards set by EUROCONSULT (1989) and Landon (1991).

Pedons 1, 2, 5 and 6 are 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 concern. 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 deep and imperfectly drained, predominantly clayey soils with low to very low OC, N and P and having 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 may be 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

Table 2. Chemical and physical characteristics of the studied soils

Pedon 1. Kingolwira

Horizon Depth (cm)	Ap 0–22	Bt1 22–40	Bt2 40–97	Bt3 97–153	Bt4 153–205+
pH 1:2.5 water	5.5	5.0	4.9	5.1	5.6
1:2.5 KCl	4.5	4.0	4.1	4.1	4.2
Organic carbon (%)	1.84	0.86	0.55	0.51	0.22
Organic matter (%)	3.17	1.48	0.95	0.88	0.38
Total nitrogen (%)	0.22	0.11	0.07	0.07	0.04
Available P (mg/kg)	4.2	0.6	0.6	0.6	3.0
Exchangeable bases (cmol$^+$/kg soil)					
Ca^{2+}	3.25	2.25	2.00	1.00	2.05
Mg^{2+}	2.93	1.01	1.46	2.31	2.25
Na^+	0.21	0.31	0.23	0.36	0.36
K^+	0.71	0.17	0.17	0.21	0.23
Σ exchangeable bases	7.10	3.74	3.86	3.88	4.89
CEC (cmol$^+$/kg soil)	15.30	15.80	11.30	10.70	9.30
CEC (cmol$^+$/kg clay)	15.18	21.05	14.46	13.14	12.38
Base saturation (%)	46.4	23.7	34.2	36.3	52.6
Texture: Clay (%)	59	61	65	68	69
Silt (%)	9	3	3	6	3
Sand (%)	32	36	32	26	28
Textural class	C	C	C	C	C
Bulk density (g/cc)	1.12	1.38	1.25	1.22	1.24

Table 2. continued

Pedon 2. Mlali

Horizon Depth (cm)		Ap 0-10	ABmh 10-20	Btms 20-55	Bt1 55-73	Bt2 73-113	Bt3 113-132	Bt4 132-178
pH 1:2.5 water		5.9	5.9	5.5	5.3	5.4	5.8	5.3
1:2.5 KCl		4.8	4.8	4.5	4.6	5.0	5.4	4.6
Organic carbon (%)		1.17	1.12	0.57	0.43	0.24	0.24	0.16
Organic matter (%)		2.02	1.93	0.98	0.74	0.41	0.41	0.28
Total nitrogen (%)		0.11	0.12	0.08	0.06	0.04	0.04	0.03
Available P (mg/kg)		9.8	2.4	1.7	1.3	1.3	0.8	2.2
Exchangeable bases (cmol$^+$/kg soil)	Ca^{2+}	2.38	5.60	2.65	2.00	1.40	2.00	1.05
	Mg^{2+}	1.21	1.51	1.58	1.67	1.96	2.33	1.17
	Na^+	0.07	0.08	0.18	0.25	0.23	0.10	0.15
	K^+	1.69	1.10	1.00	0.53	0.34	0.36	0.76
Σ exchangeable bases		5.35	8.29	5.41	4.45	3.93	4.79	3.13
CEC (cmol$^+$/kg soil)		11.40	11.50	10.20	12.00	12.10	8.40	8.00
CEC (cmol$^+$/kg clay)		19.89	16.25	11.44	17.24	15.67	10.68	10.63
Base saturation (%)		46.9	72.1	53.0	37.1	32.5	57.0	39.1
Texture: Clay (%)		37	47	72	61	72	71	70
Silt (%)		7	4	2	2	4	2	4
Sand (%)		56	49	26	37	24	27	26
Textural class		SC	SC	C	C	C	C	C
Bulk density (g/cc)		1.26	1.60	1.4	1.22	1.16	n.d	1.24

Table 2. continued

Pedon 3. Wami-Vijana Prison

Horizon Depth (cm)		Ap 0-14	BAg 14-45	Bg 45-61	2Cg 61-106	2C 106-155	3Btg 155-180+
pH 1:2.5 water		6.4	6.3	6.9	6.8	7.0	6.6
1:2.5 KCl		5.2	5.0	5.4	5.2	5.4	6.0
Organic carbon (%)		1.57	0.71	0.55	0.10	0.08	0.40
Organic matter (%)		2.71	1.22	0.95	0.17	0.14	0.69
Total nitrogen (%)		0.13	0.09	0.06	0.04	0.01	0.05
Available P (mg/kg)		10.2	1.5	1.3	4.5	1.7	1.5
Exchangeable bases (cmol$^+$/kg soil)	Ca^{2+}	6.50	8.63	5.25	2.75	1.38	6.88
	Mg^{2+}	4.92	6.33	3.67	1.21	0.67	7.33
	Na^+	0.76	0.64	0.65	0.49	0.54	0.82
	K^+	1.56	0.33	0.43	0.26	0.10	0.38
Σ exchangeable bases		13.74	15.94	10.00	4.71	2.69	15.41
CEC (cmol$^+$/kg soil)		21.90	22.40	15.30	5.80	3.80	21.60
CEC (cmol$^+$/kg clay)		28.91	29.79	31.16	42.00	50.29	35.51
Base saturation (%)		62.7	71.2	65.4	81.2	70.8	71.3
Texture: Clay (%)		57	67	43	13	7	57
Silt (%)		12	2	15	1	2	2
Sand (%)		31	31	42	86	91	41
Textural class		C	C	C	LS	S	C
Bulk density (g/cc)		1.35	1.42	1.51	1.57	1.58	1.46

Table 2. continued

Pedon 4. Dakawa Research Station

Horizon Depth (cm)	Apg 0-21	Bg 21-68	Btg1 68-127	Btg2 127-190+
pH 1:2.5 water	6.5	7.7	8.2	8.6
1:2.5 KCl	5.4	6.3	6.6	6.9
Organic C (%)	1.25	0.67	0.45	0.31
Organic matter (%)	2.16	1.16	0.78	0.53
Total N (%)	0.15	0.07	0.08	0.04
Available P (mg/kg)	0.5	0.5	0.5	1.5
Exchangeable bases ($cmol^+/kg$ soil)				
Ca^{2+}	12.00	10.55	11.50	9.80
Mg^{2+}	6.42	8.44	9.00	9.17
Na^+	0.73	2.03	2.94	2.83
K^+	0.51	0.33	0.39	0.24
Σ exchangeable bases	19.64	21.35	23.83	21.99
CEC ($cmol^+/kg$ soil)	26.10	22.50	30.70	25.70
CEC ($cmol^+/kg$ clay)	39.60	33.08	44.83	50.29
Base saturation (%)	75.2	94.9	77.6	85.6
Texture: Clay (%)	55	61	65	49
Silt (%)	26	15	23	8
Sand (%)	19	24	12	43
Textural class	C	C	C	C
Bulk density (g/cc)	1.43	1.49	1.37	1.47

Table 2. continued

Pedon 5. SUA Farm

Horizon Depth (cm)		Ap1 0-9	Ap2 9-23	BA 23-40	Bt1 40-63	Bt2 63-138	Bt3 138-180+
pH 1:2.5 water		5.3	4.7	4.5	4.9	5.3	5.9
1:2.5 KCl		4.2	4.7	3.8	3.9	3.9	3.9
Organic C (%)		1.53	1.02	0.67	0.37	0.35	0.20
Organic matter (%)		2.64	1.76	1.16	0.64	0.60	0.34
Total nitrogen (%)		0.15	0.13	0.11	0.08	0.12	0.04
Available P (mg/kg)		9.0	1.8	1.8	1.2	3.0	1.2
Exchangeable bases (cmol$^+$/kg soil)	Ca^{2+}	1.28	2.00	2.00	1.25	2.23	1.75
	Mg^{2+}	1.71	3.83	1.17	1.42	1.29	0.92
	Na^+	1.47	0.49	0.52	1.68	1.58	0.76
	K^+	3.00	0.67	5.58	0.26	0.33	0.33
Σ exchangeable bases		7.46	6.99	4.27	4.61	5.43	3.76
CEC (cmol$^+$/kg soil)		15.20	16.60	16.20	13.80	10.20	10.80
CEC (cmol$^+$/kg clay)		49.60	29.07	28.33	22.76	17.31	24.68
Base saturation (%)		49.1	42.1	26.4	33.4	53.2	34.8
Texture: Clay (%)		20	45	49	55	52	41
Silt (%)		7	19	18	12	14	16
Sand (%)		73	36	33	33	34	43
Textural class		SCL	C	C	C	C	C
Bulk density (g/cc)		1.16	1.52	1.31	1.20	1.32	1.49

Table 2. continued

Pedon 6. Magadu

Horizon Depth (cm)	Ap 0–18	Bt1 18–45	Bt2 45–105	Bt3 105–160+
pH 1:2.5 water	4.8	4.7	4.6	4.8
1:2.5 KCl	3.8	3.8	3.8	3.8
Organic C (%)	1.17	0.59	0.45	0.18
Organic matter (%)	2.02	1.02	0.78	0.31
Total nitrogen (%)	0.13	0.08	0.06	0.07
Available P (mg/kg)	3.0	1.2	1.8	2.5
Exchangeable bases ($cmol^+/kg$ soil)				
Ca^{2+}	4.43	1.00	0.45	0.45
Mg^{2+}	1.17	0.80	1.42	1.21
Na^+	1.58	0.49	0.60	0.82
K^+	1.43	0.30	0.18	0.26
Σ Exchangeable bases	8.61	2.62	2.65	2.74
CEC ($cmol^+/kg$ soil)	13.60	12.30	12.10	15.00
CEC ($cmol^+/kg$ clay)	22.23	16.28	15.97	21.15
Base saturation (%)	63.0	21.3	21.9	18.3
Texture: Clay (%)	43	63	66	68
Silt (%)	3	4	4	5
Sand (%)	54	33	30	27
Textural class	SC	C	C	C
Bulk density (g/cc)	1.49	1.39	1.35	1.36

Table 2. continued

Pedon 7. Mkundi

Horizon Depth (cm)		Ap 0-18	BA 18-30	Bg1 30-56	Bg2 56-101	Bg3 101-160	BC 160-175
pH 1:2.5 water		6.1	5.7	5.7	6.7	6.4	8.3
1:2.5 KCl		4.9	4.5	3.9	4.0	4.7	7.0
Organic carbon (%)		0.82	0.37	0.39	0.39	0.31	0.02
Organic matter (%)		1.41	0.64	0.67	0.67	0.53	0.03
Total nitrogen (%)		0.12	0.09	0.08	0.09	0.09	0.06
Available P (mg/kg)		1.4	0.7	1.4	1.4	0.7	1.4
Exchangeable bases							
($cmol^+/kg$ soil)	Ca^{2+}	2.00	2.00	1.00	4.75	4.75	9.00
	Mg^{2+}	0.88	1.13	1.58	4.92	4.50	5.83
	Na^+	0.57	0.46	0.46	2.34	3.37	4.57
	K^+	0.36	0.30	0.23	0.26	0.50	0.32
Σ exchangeable bases		3.81	3.89	3.27	12.27	13.12	19.72
CEC ($cmol^+/kg$ soil)		10.10	9.90	8.80	19.30	18.10	21.40
CEC ($cmol^+/kg$ clay)		66.18	35.92	13.56	26.41	26.63	43.55
Base saturation (%)		37.7	39.3	37.2	53.6	72.5	92.1
Texture: Clay (%)		11	24	55	68	64	49
Silt (%)		12	8	30	15	12	11
Sand (%)		77	68	15	17	24	40
Textural class		SL	SCl	C	C	C	C
Bulk density (g/cc)		1.38	1.34	1.39	1.48	1.43	1.40

Table 2. continued

Pedon 8. Melela

Horizom Depth (cm)		Ap 0-20	Bk 20-68	Bwk 68-104	BCk 104-140	Ck 140-195+
pH 1:2.5 water		8.1	8.6	8.8	9.0	9.5
1:2.5 KCl		7.0	7.3	7.4	7.3	7.4
Organic carbon (%)		1.47	0.76	0.47	0.04	0.04
Organic matter (%)		2.53	1.31	0.81	0.07	0.07
Total nitrogen (%)		0.15	0.09	0.06	0.02	0.06
Available P (mg/kg)		10.8	1.2	3.0	2.3	1.8
Exchangeable bases ($cmol^+/kg$ soil)	Ca^{2+}	24.75	20.50	13.50	12.49	8.63
	Mg^{2+}	7.67	6.63	7.62	7.90	7.19
	Na^+	1.36	3.80	10.20	14.48	14.17
	K^+	0.84	0.26	0.17	0.42	0.20
Σ exchangeable bases		34.63	31.19	31.49	35.20	30.19
CEC ($cmol^+/kg$ soil)		36.10	31.50	31.50	35.30	30.20
CEC ($cmol^+/kg$ clay)		79.59	67.16	103.03	78.13	83.50
Base saturation (%)		95.9	99.0	100.0	99.7	100.0
Texture: Clay (%)		39	43	29	45	36
Silt (%)		10	8	18	8	20
Sand (%)		51	49	53	47	44
Textural class		SC	SC	SCL	SC	CL
Bulk density (g/cc)		1.42	1.47	1.40	1.54	1.50

Table 2. continued

Pedon 9. Mvomero

Horizon Depth (cm)	Ap 0-16	Bwg1 16-54	Bwg2 54-88	2C 88-170+
pH 1:2.5 water	6.4	6.5	6.4	6.9
1:2.5 KCl	5.7	5.2	5.0	5.2
Organic carbon (%)	1.41	1.23	1.39	0.08
Organic matter (%)	2.43	2.12	2.40	0.14
Total nitrogen (%)	0.13	0.13	0.13	0.08
Available P (mg/kg)	4.8	3.0	3.6	1.8
Exchangeable bases ($cmol^+/kg$ soil)				
Ca^{2+}	4.95	5.50	6.38	0.65
Mg^{2+}	1.88	3.00	3.75	0.19
Na^+	0.82	0.44	0.71	0.98
K^+	1.22	0.31	0.17	0.08
Σ exchangeable bases	8.87	9.25	10.30	1.90
CEC ($cmol^+/kg$ soil)	11.90	13.70	19.20	1.98
CEC ($cmol^+/kg$ clay)	37.05	33.79	32.00	34.00
Base saturation (%)	74.5	67.5	53.6	96.0
Texture: Clay (%)	19	28	45	5
Silt (%)	12	23	6	2
Sand (%)	69	49	49	93
Textural class	SL	SCL	SC	S
Bulk density (g/cc)	1.32	1.23	1.38	1.47

Table 2. continued

Pedon 10. Pangawe

Horizon Depth (cm)		Ap 0-19	Bg 19-55	Btc1 55-101	Btc2 101-127	Btc3 127-188+
pH 1:2.5 water		6.7	6.5	7.8	8.5	8.7
1:2.5 KCl		5.2	5.0	6.1	7.0	7.3
Organic carbon (%)		1.67	0.89	0.45	0.26	0.24
Organic matter (%)		2.88	1.53	0.78	0.45	0.41
Total nitrogen (%)		0.17	0.13	0.08	0.05	0.05
Available P (mg/kg)		1.5	0.5	1.0	2.5	4.2
Exchangeable bases ($cmol^+/kg$ soil)	Ca^{2+}	7.75	6.50	7.50	7.00	9.65
	Mg^{2+}	4.92	5.17	7.00	9.83	11.89
	Na^+	0.65	0.68	1.14	2.01	3.04
	K^+	0.64	0.26	0.21	0.18	0.20
Σ exchangeable bases		13.96	12.61	15.85	19.02	24.78
CEC ($cmol^+/kg$ soil)		23.00	19.00	17.50	20.70	24.80
CEC ($cmol^+/kg$ clay)		46.59	37.07	29.52	34.74	47.96
Base saturation (%)		60.7	66.4	90.6	92.0	99.9
Texture: Clay (%)		37	43	54	57	50
Silt (%)		8	6	9	14	16
Sand (%)		51	51	37	29	34
Textural class		SC	SC	C	C	C
Bulk density (g/cc)		1.55	1.37	1.59	1.57	1.55

Table 2. continued
Pedon 11. Dakawa Rice Farms

Horizon Depth (cm)		Apk 0-12	Bwk 12-79	BCgk 79-108	Cgk1 108-178	Cgk2 178-196+
pH 1:2.5 water		8.4	8.1	7.8	8.5	8.7
1:2.5 KCl		7.1	7.1	7.2	7.2	7.5
Organic carbon (%)		0.50	0.65	0.30	0.09	0.09
Organic matter (%)		0.86	1.12	0.52	0.16	0.16
Total nitrogen (%)		0.07	0.07	0.04	0.04	0.07
Available P (mg/kg)		1.8	2.8	1.4	1.4	0.7
Exchangeable bases ($cmol^+/kg$ soil)	Ca^{2+}	21.87	24.00	21.23	21.70	18.68
	Mg^{2+}	11.85	8.33	11.32	12.67	8.82
	Na^+	3.17	2.72	3.32	5.70	5.18
	K^+	0.36	0.39	0.38	0.40	0.10
Σ exchangeable bases		37.25	35.44	36.25	40.02	32.78
CEC ($cmol^+/kg$ soil)		38.00	36.00	37.00	40.50	32.90
CEC ($cmol^+/kg$ clay)		98.05	75.02	73.39	78.78	83.54
Base saturation (%)		98.0	98.4	98.0	98.8	98.0
Texture: Clay (%)		37	45	49	51	39
Silt (%)		12	12	8	10	12
Sand (%)		51	43	43	39	49
Textural class		SC	C	C	C	SC
Bulk density (g/cc)		1.50	1.46	1.48	1.50	n.d.

N.B. Textural classes: C=clay; SC=sandy clay; SCL=sandy clay loam; CL=clay loam; S=sand; LS=loamy sand; SL=sandy loam

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 Nand P may be necessary for optimal plant growth.

Pedon 7 is a 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 may require substantial fertilizer additions to supply these nutrients. Ca and Mg are probably 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 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 may be a need for N and P fertilization for optimal plant growth. Ca, Mg and K are adequate, although 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 soil with a friable sandy loam topsoil overlying friable and loose subsoil layers of sandy clay loam, sandy clay and sand 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 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) values calculated from the exchangeable Na and the CEC show that these values are smaller than the critical value of 15 for most of the soils. ESP may pose a 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.

3. Clay mineralogy of the studied soils

The x-ray diffractograms of the studied soils are presented in appendix 2. The estimation of the relative mineralogical compositon of the clay fractions is based on these diffractograms and the results are presented in table 3. The mineralogy of four pedons namely, Kingolwira, Mlali, SUA Farm and Magadu is 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 Wami-Vijana Prison, Dakawa Research Station, Mkundi and Dakawa Rice Farms are predominantly

Table 3. Relative mineralogical composition of clay fractions

Pedon	Kaolinite	Smectite	Mica
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	+++	+	++

N.B. Relative amounts of minerals based on total score of 6+; tr=trace

kaolinitic but with subordinate amounts of both mica and smectite; Mvomero predominantly kaolinitic but with subordinate amounts of mica; Melela predominantly smectitic with small amounts of kaolinite; and Pangawe also predominantly 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 as shown by their firm moist consistence and hard to very hard dry consistence (see profile descriptions in appendix 1.). However, in terms of fertility they are generally more fertile (having higher CEC and BS) than the highly weathered kaolinitic soils.

4. Total chemical analysis

The data on total chemical analysis expressed as % oxides is presented in table 4.

There is some limitation on the use of these data to discuss seriously the genesis of the studied soils because only one horizon per pedon was analyzed. However, 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 situation that characterizes a relatively younger degree of weathering.

(c) Pedons 3 and 4 are high in base content, high in Fe and Al

Table 4. Total elemental 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	100.00
2. Mlali	11.38	1.51	0.047	0.07	0.19	0.061	60.01	26.50	0.19	0.05	100.00
3. Wami-Vijana Prison	13.04	1.30	0.140	0.92	1.80	0.054	53.53	26.24	1.78	1.22	100.01
4. Dakawa Research Station	10.58	1.08	0.092	1.56	1.88	0.125	57.33	24.26	1.50	1.59	99.99
5. SUA Farm	15.11	2.00	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	0.00	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	68.80	19.37	0.83	1.13	100.00
8. Melela	6.11	1.09	0.100	4.15	1.12	0.001	66.27	16.53	1.77	2.86	100.01
9. Mvomero	9.98	1.84	0.122	3.16	1.14	0.034	69.35	9.67	3.02	1.68	100.00
10. Pangawe	10.34	1.46	0.170	3.16	0.51	0.001	62.73	18.21	1.35	2.05	99.99
11. Dakawa Rice Farms	6.27	0.72	0.070	2.03	1.25	0.04	69.64	17.04	1.33	1.64	99.99

content and have a low Si/Al ratio, a situation that may represent an intermediate degree of weathering or could be a reflection of the nature of the parent materials.

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

5. Soil classification

The field and office data (see appendix 1.) and laboratory data (see tables 1, 2 and 3) were used to classify the soils. Table 5 provides an inventory of 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 the 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.

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

Pedon	Diagnostic horizons	Other diagnostic features	Particle size class	Calcareous 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<16cmol⁺/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	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 horizon sequence	Very fine clayey	Acid	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	Deep	Mixed(kao-linite, 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	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	Deep	Kaolinitic
6 Magadu	Ochric epipedon (*pchric 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	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	Deep	Mixed(kaolinitic, 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	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	Deep	Mixed(kao-linite, 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>24cmol*/kg clay in B horizon	Fine clayey	Non-acid, non-calcareous	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	Deep	Mixed(kao-linite, mica, smectite)

N.B. terminology particularly used in the FAO-Unesco Classification; those without * are used in the USDA Soil Taxonomy*

Table 5. continued

Pedons 3 and 7 are fairly young soils with no doagnostic horizon other than an ochric epipedon, and hence have been classified as Entisols (USDA Soil Taxonomy). However, due to their different 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 above 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 development in structure, color, consistence etc. They are therefore younger than Ultisols and Oxisols.

Pedons 8 and 11 have ochric epipedon as a diagnostic horizon together all the vertic characteristics including slickensides, deep wide cracks, gilgai micro-relief etc. In soils of this kind there is constant physical and biological churning of the soil materials thereby resulting in partial inversion of the soil and homogenization of the profile. 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 (USDA Soil Taxonomy and FAO-Unesco Classification). Genetically Vertisols do not have ample chance of development because of the regular

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 Res. 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	*not yet defined	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, smectitic, Paleustollic 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)

*N.B. * Subgroups of Tropaquent have not been defined as yet in the USDA Soil Taxonomy*

Table 6. continued

pedoturbation taking place in these soils. 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 organic matter content and high base saturation). These soils are not highly weathered and their relative pedogenic age may range from that of Entisols to that of 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 should 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.

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Appendix 1. Soil profile descriptions

Pedon 1: Kingolwira

Date of description and sampling: 17/08/1990

Authors: B.M. Msanya, A.K. Kaaya & K. Kucey

Survey area/district: Kingolwira/Morogoro

Location: S 06° 47′ 35.2" E 37° 48′ 26.6"; 20 m from the Pangawe-Mtego wa Simba Road on the right side, 40 m from the village houses

Altitude: 490 m asl

Geological formation: Neogene system comprising red and reddish brown soils

Parent materials: Originally colluvial materials derived from metesedimentary rocks rich in garnet-biotite gneisses with some microcline and muscovite. Profile features show evidence of strong in-situ pedogenesis

Physiography: Plain, almost flat, slope at site < 2%

Land use/vegetation: Maize crop (already harvested)

Soil temperature regime: iso-hyperthermic

Soil moisture regime: ustic

Horizon features:

Ap **0 - 22 cm**: Dark reddish brown (2.5 YR 2/4, moist), dark reddish brown (2.5 YR 3/4, dry); clay; weak medium fine crumby structure; slightly hard when dry, friable when moist, slightly sticky and plastic when wet; many fine, few fine, few medium tubular pores; many very fine roots; abrupt smooth boundary.

Bt1 **22 - 40 cm**: Dark reddish brown (2.5 YR 3/4, moist), dark red (2.5 YR 3/6, dry); sandy clay; moderate medium fine angular blocky structure; hard when dry, firm when moist, slightly sticky and slightly plastic when wet; many fine and very fine,

few medium tubular pores; few very fine roots; broken moderately thick clay cutans; clear smooth boundary.

Bt2 **40 - 97 cm:** Dark red (2.5 YR 3/6, moist), red (2.5 YR 4/8, dry); clay; weak medium fine subangular blocky structure; slightly hard when dry, friable when moist, slightly sticky and slightly plastic when wet; many fine and very fine, few medium tubular pores; few very fine roots; broken moderately thick clay cutans; gradual smooth boundary.

Bt3 **97 - 153 cm:** Dark red (2.5 YR 3/6, moist), red (2.5 YR 4/8, dry); clay; weak medium fine subangular blocky structure; slightly hard when dry, friable when moist; non-sticky and non-plastic when wet; few medium tubular pores; very few very fine roots; broken moderately thick clay cutans; gradual smooth boundary.

Bt4 **153 - 205+ cm:** Dark red (2.5 YR 3/6, moist), red (2.5 YR 4/8, dry); clay; moderate medium subangular blocky structure; slightly hard when dry, friable when moist, slightly sticky and slightly plastic when wet; many fine and very fine, few medium tubular pores; broken moderately thick clay cutans.

Pedon 2: Mlali

Date of description and sampling: 09/08/1990

Authors: B.M. Msanya & A.K. Kaaya

Survey area/district: Mlali/Morogoro

Location: S 06^0 57′ 49.3" E 37^0 32′ 44.0"; Mlali Primary School about 300 m north of the Roman Catholic Church, 500 m east of Mlali-Mgeta Road

Altitude: 590 m asl

Geological formation: Neogene system comprising red and reddish brown soils

Parent materials: originally colluvium derived from micaceous gneisses and hornblende gneisses and granulites. Profile features indicate strong in-situ pedogenesis

Physiography: almost flat to flat land neighboured by some mountains, slope at site about 2%

Land use/vegetation: currently under grass and bush fallow consisting mainly of Hyperrhenia grass and Acacia bushes, nearby area normally growing pigeon peas, previous year cultivated with sorghum and maize

Soil temperature regime: iso-hyperthermic

Soil moisture regime: ustic

Horizon features:

Ap **0 - 10 cm:** Dark reddish brown (5 YR 3/3, moist), dark reddish brown (5 YR 3/4, dry); sandy clay loam; moderate fine to medium crumby structure; slightly hard when dry, friable when moist, sticky and plastic when wet; many very fine to fine, few medium to coarse continuous tubular random pores; common very fine to fine, few medium roots; clear smooth boundary.

Abmh **10 - 20 cm:** Dark reddish brown (5 YR 3/3, moist), dark reddish brown (5 YR 3/4, dry); sandy clay; strong fine to medium angular to subangular blocky structure; hard when dry, firm when moist, sticky and plastic when wet; many very fine to

fine, few medium and coarse tubular continuous and discontinuous pores; few medium, few very fine to fine roots; many insect nests and animal burrows; hardened layer due mostly to organic matter, clay and iron; clear smooth boundary.

Btms **20 - 55 cm:** Dark red (2.5 YR 3/6, moist), dark red (2.5 YR 3/6, dry); clay; strong medium angular and subangular blocky structure; very hard when dry, firm when moist, sticky and plastic when wet; many very fine to fine, few medium and coarse tubular continuous and discontinuous pores; few very fine to fine, few medium, very few coarse roots; broken moderately thick clay-sesquioxidic cutans on vertical and horizontal ped faces; many insect nests and animal burrows; hardened layer due mostly to sesquioxides and clay, clear smooth boundary.

Bt1 **55 - 73 cm:** Dark red (2.5 YR 3/6, moist), red (2.5 YR 4/8, dry); clay; moderate fine subangular structure; slightly hard when dry, friable when moist, slightly sticky to sticky and plastic when wet; many very fine to fine tubular continuous and discontinuous pores; many very fine and fine, very few medium roots; patchy moderately thick clay-sesquioxidic cutans on vertical and horizontal ped faces; gradual smooth boundary.

Bt2 **73 - 113 cm:** Red (2.5 YR 4/8, moist), red (2.5 YR 5/8, dry); clay; moderate fine to medium subangular blocky structure; soft when dry, very friable when moist, slightly sticky to sticky and plastic when wet; many very fine to fine, few medium continuous and discontinuous pores; many very fine and

fine, very few medium roots; patchy moderately thick clay-sesquioxidic cutans on vertical and horizontal ped faces; gradual smooth boundary.

Bt3 **113 - 132 cm:** Red (2.5 YR 4/8, moist), red (2.5 YR 5/8, dry); clay; moderate fine to medium subangular blocky structure; slightly hard when dry, friable when moist, slightly sticky to sticky and plstic when wet; many very fine to fine tubular continuous and discontinuous pores; many very fine and fine, very few medium roots; patchy moderately thick clay sesquioxidic cutans on vertical and horizontal ped faces; gradual smooth boundary.

Bt4 **132 - 178+ cm:** Red (2.5 YR 4/8, moist); clay; moderate fine to medium subangular blocky structure; slightly hard when dry, friable when moist; slightly sticky to sticky and plastic when wet; common very fine and fine tubular continuous and discontinuous pores; very few fine and medium roots; patchy moderately thick clay-sesquioxidic cutans on vertical and horizontal ped faces.

Pedon 3: Wami-Vijana Prison

Date of description and sampling: 13/08/1990

Authors: B.M. Msanya & A.K. Kaaya

Survey area/district: Wami/Morogoro

Location: S 06^0 24′ 46.5"·E 37^0 28′ 16.9"; 2 km from Morogoro-Dodoma Road

Altitude: 380 m asl

Geological formation: Neogene superficial deposits

Parent materials: complex alluvial materials of diverse origin and composition

Physiography: Part of Wami Flats, flat land, slope at site < 1%

Land use/vegetation: sorghum (awaiting harvesting)

Soil temperature regime: iso-hyperthermic

Soil moisture regime: aquic

Horizon features:

Ap **0 - 14 cm:** Very dark gray (10 YR 3/1, moist), very dark grayish brown (10 YR 3/2, dry); clay; moderate medium and coarse crumby and granular structures; hard when dry, firm when moist, sticky and plastic when wet; common medium tubular pores, many very fine and fine tubular pores; common very fine and fine roots; clear smooth boundary.

BAg **14 - 45 cm:** Very dark grayish brown (10 YR 3/2, moist), dark brown (10 YR 3/3, dry); common fine faint clear reddish mottles; clay; moderate medium angular and subangular blocky structures; very hard when dry, very firm when moist, very sticky and very plastic when wet; few fine and very fine tubular pores; few very fine roots; clear smooth boundary.

Bg **45 - 61 cm:** Dark brown (10 YR 3/3, moist), dark brown (10 YR 4/3, dry); clay; many medium distinct clear yellowish and red mottles; moderate medium angular blocky structure; very hard when dry, very firm when moist, sticky and plastic when wet; few fine and many very fine tubular pores; few very fine roots; abrupt smooth boundary.

2Cg **61 - 106 cm:** Dark brown (10 YR 3/3, moist), dark brown (10 YR

4/3, dry); many medium prominent clear reddish mottles; loamy sand; massive; slightly hard when dry, very friable when moist, nonsticky and nonplastic when wet; many very fine and fine tubular pores, few very coarse tubular pores; very few fine roots; many fine mica flakes; gradual wavy boundary.

2C **106 - 155 cm**: Strong brown (7.5 YR 5/6, moist), strong brown (7.5 YR 5/8, dry); sand; massive; slightly hard when dry, very friable when moist, nonsticky and nonplastic when wet; many very fine and fine tubular pores, few coarse tubular pores; many fine and very fine roots; many fine mica flakes; abrupt smooth boundary.

3Btg **155 - 180+ cm**: Dark brown (10 YR 3/2, moist), few medium distinct clear reddish mottles; clay; strong fine and medium angular blocky structure; very firm when moist, very hard when dry, very sticky and very plastic when wet; common very fine and fine tubular pores, few medium tubular pores; broken thick clay cutans.

Pedon 4: Dakawa Research Station

Date of description and sampling: 26/02/1991

Authors: A.K. Kaaya & B.M. Msanya

Survey area/district: Dakawa/Morogoro

Location: S 06° 25′ 35.1" E 37° 32′ 28.8"; 0.5 km south of Dakawa Research Station offices

Altitude: 360 m asl

Geological formation: Neogene system comprising mostly mbuga soils and alluvium

Parent materials: alluvium of diverse origin derived from nearby hills/mountains

Physiography: flat, (part of Wami flats), slope at site < 1%

Land use/vegetation: irrigated rice cultivation, natural vegetation includes wild rice and elephant grass.

Surface characteristics: cracks 3 cm wide observed on the surface

Soil temperature regime: iso-hyperthermic

Soil moisture regime: aquic

Horizon features:

Apg **0 - 21 cm:** Very dark grayish brown (10 YR 3/2, moist), dark brown (10 YR 3/3, dry); common fine distinct clear brownish mottles; clay; strong coarse and medium granular structure; very hard when dry, firm when moist, very sticky and plastic when wet; common very fine pores, few fine to medium pores; many fine roots; clear smooth boundary.

Bg **21 - 68 cm:** Brown (7.5 YR 4/4, moist); few fine faint brown mottles; clay; strong medium angular blocky structure; very hard when dry, firm when moist, very sticky and very plastic when wet; common very fine and medium pores; few small soft irregular and round black (Mn) concretions, few small soft irregular and round brownish (sesquioxide) concretions; diffuse smooth boundary.

Btg1 **68 - 127 cm:** Very dark grayish brown (10 YR 3/2, moist); common fine faint clear brownish mottles; clay; strong coarse and medium angular blocky structure; very hard when dry, firm when moist, very sticky and very plastic when wet; few very

fine and medium pores; few small soft irregular and round black (Mn) concretions, few small soft irregular and round brownish (sesquioxide) concretions; broken thick clay and organic matter cutans (argillans and organs); diffuse smooth boundary.

Btg2 **127 - 190+ cm:** Very dark gray (10 YR 3/1, moist); common fine and medium distinct clear brownish mottles; clay; strong coarse angular blocky structure; very hard when dry, firm when moist, very sticky and very plastic when wet; few very fine and medium pores; broken thick clay and organic matter cutans (argillans and organs); few small soft irregular and round black (Mn) and brownish (sesquioxide) concretions.

Pedon 5: SUA Farm

Date of description and sampling: 21/12/1990

Authors: B.M. Msanya & A.K. Kaaya

Survey area/district: Sokoine University of Agriculture Farm/Morogoro

Location: S 06^0 50′ 24.7" E 37^0 38′ 59.8"; 0.5 km West of Morogoro Iringa Road

Altitude: 526 m asl

Geological formation: Neogene system comprising red and reddish brown soils

Parent materials: originally colluvium derived from plagioclase and quartz-rich metasedimentry rocks but profile features show advanced degree of in-situ pedogenesis

Physiography: plain, almost flat, slope at site < 1%

Land use/vegetation: fallow for about 7 years; currently under Eucalyptus trees and Hyperrhenia grass

Soil temperature regime: iso-hyperthermic

Soil moisture regime: ustic

Horizon features:

Ap1 **0 - 9 cm:** Dark red (2.5 YR 3/6, moist), red (2.5 YR 4/6, dry); sandy clay loam; moderate fine and medium crumby structure; slightly hard when dry, firm when moist, slightly sticky and slightly plastic when wet; many very fine and fine pores; many very fine and fine roots; clear smooth boundary.

Ap2 **9 - 23 cm:** Dark red (2.5 YR 3/6, moist), red (2.5 YR 4/6, dry); sandy clay; strong fine and medium subangular blocky structure; common very fine to fine and few medium pores; many very fine to fine and few medium roots; gradual smooth boundary.

BA **23 - 40 cm:** Dark red (2.5 YR 3/6, moist), red (2.5 YR 4/6, dry); clay; moderate fine to medium subangular blocky structure; slightly hard when dry, friable when moist, slightly sticky and slightly plastic when wet; many very fine to fine pores; many very fine to fine and few medium roots; gradual smooth boundary.

Bt1 **40 - 63 cm:** Dark red (2.5 YR 3/6, moist), red (2.5 YR 4/6, dry); clay; moderate fine subangular blocky structure; soft when dry, friable when moist, slightly sticky and slightly plastic when wet; moderately thick clay-sesquioxidic cutans; many very fine to fine and few medium pores; very few small

hard spherical glaebules; common very fine to fine roots; gradual smooth boundary.

Bt2 **63 - 138 cm**: Red (2.5 YR 5/6, moist), red (2.5 YR 4/7, dry); clay; moderate fine subangular blocky structure; soft when dry, friable when moist, slightly sticky and slightly plastic when wet; broken moderately thick clay-sesquioxidic cutans; many very fine to fine and few medium pores; common very fine to fine roots; clear smooth boundary.

Bt3 **138 - 180+ cm**: Dark red (2.5 YR 3/6, moist), red (2.5 YR 4/6, dry); clay; moderately strong medium to coarse subangular blocky structure; slightly hard to hard when dry, friable when moist, slightly sticky and slightly plastic when wet; broken moderately thick clay-sesquioxidic cutans; many very fine to fine and few medium pores; very few small hard spherical glaebules; very few very fine roots.

Pedon 6: Magadu

Date of description and sampling: 23/02/1991

Authors: A.K. Kaaya & B.M. Msanya

Survey area/district: Magadu/Morogoro

Location: S 06^0 51′ 15.0" E 37^0 38′ 33.1"; about 0.5 km from Shazo bridge on Morogoro-Mzinga Road, 0.25 km west of the road

Altitude: 540 m asl

Geological formation: Neogene system comprising red and reddish brown soils

Parent materials: Colluvium derived from plagioclase and quartz-rich metasedimentry rocks

Physiography: Undulating convex landform, slope at site about 4%

Land use/vegetation: Under maize cultivation; surrounding vegetation includes kapok trees and Hyperrhenia grass

Soil temperature regime: iso-hyperthermic

Soil moisture regime: ustic

Horizon features:

Ap **0 - 18 cm:** Yellowish red (5 YR 4/6, moist), Yellowish red (5 YR 5/6, dry); clay loam; moderate fine to medium granular and crumby structures; slightly hard when dry, friable when moist, sticky and plastic when wet; many very fine to fine and few medium pores; many very fine and few fine to medium roots; abrupt smooth boundary.

Bt1 **18 - 45 cm:** Yellowish red (5 YR 4/6, moist), reddish yellow (5 YR 6/8, dry); sandy clay loam; moderate very fine to fine subangular blocky structure; slightly hard when dry, friable when moist, slightly sticky and slightly plastic when wet; many very fine to fine and few medium pores; common very fine to fine roots; clear smooth boundary.

Bt2 **45 - 105 cm:** Strong brown (7.5 YR 5/6, moist), reddish yellow (7.5 YR 6/8, dry); clay loam; moderate fine to medium subangular blocky structure; slightly hard when dry, friable when moist, slightly sticky and slightly plastic when wet; patchy thin clay-sesquioxidic cutans; many very fine to fine and few medium pores; very few small hard spherical Fe and Mn nodules; common very fine to fine and very few medium roots; gradual smooth boundary.

Bt3 **105 - 160+ cm:** Strong brown (7.5 YR 5/6, moist), reddish yellow (7.5 YR 6/8, dry); sandy clay; strong medium angular blocky structure; slightly hard when dry, firm when moist, slightly sticky and slightly plastic when wet; patchy thin clay-sesquioxidic cutans; many very fine to fine pores; few krotovinas (about 10 cm diameter); very few very fine roots.

Pedon 7:Mkundi

Date of description and sampling: 13/3/1991

Authors: A.K.Kaaya & B.M. Msanya

Survey area/district: Mkundi Nguvu Kazi Area/ Morogoro

Location: S 06° 42′ 01.4" E 37° 38′ 22.5"; 300 m east of the Morogoro-Dodoma Road, 100 m north-east of the Nguvu Kazi offices

Altitude:576 m asl

Geological formation: Neogene system comprising superficial sands and sandy hillwash derived mostly from Nguvu ya mountains (which are composed predominantly banded muscovite, boitite, magnetites)

Parent materials: Alluvial-colluvial superficial sands and sandy hillwash

Physiography: Undulating landform concave at site, slope 3-4%

Land use/vegetation: Some parts under maize, others under sorghum and cassava. Surrounding vegetation includes different grasses and few scattered Acacia shrubs

Soil temperature regime: iso-hyperthermic

Soil moisture regime: ustic

Horizon features:

Ap **0 - 18 cm:** Very dark gray (10 YR 3/1, moist), dark grayish brown (10 YR 4/2, dry); sandy loam; weak vey fine and fine crumby structure; soft when dry, very friable when moist, nonsticky and nonplastic when wet; few fine and medium pores, many very fine pores; common very fine and fine roots; abrupt smooth boundary.

BA **18 - 30 cm:** Very dark grayish brown (10 YR 3/2, moist) and brown (10 YR 5/3, dry); loamy sand; weak fine crumby structure; slightly hard when dry, friable when moist, nonsticky and nonplastic when wet; many very fine pores; few very fine and very few fine and medium roots; abrupt smooth boundary

Bg1 **30 - 56 cm:** Dark brown to brown (10 YR 4/3, moist), and yellowish brown (10 YR 5/4, dry); common fine and medium distinct, clear yellowish red mottles; sandy loam; weak fine subangular blocky structure; slightly hard when dry, friable when moist, nonsticky and nonplastic when wet; many very fine and few fine pores; very few very fine to medium roots; clear smooth boundary.

Bg2 **56 - 101 cm:** Dark grayish brown (10 YR 4/2, moist), brown (10 YR 5/3, dry); many fine medium, prominent, sharp red mottles; clay; strong fine angular blocky structure; very hard when dry, firm when moist, very sticky and very plastic when wet; common very fine and few fine pores; frequent irregular weathered gravels; very few very fine roots; clear smooth boundary.

Bg3 **101 - 160 cm:** Dark gray (10 YR 4/1, moist), dark gray (10 YR 4/1, dry); many medium distinct clear reddish brown mottles; clay; strong medium and coarse angular blocky structure; very hard when dry, firm when moist, very sticky and very plastic when wet; few fine pores, very irregular weathered gravels; very few very fine roots; gradual smooth boundary.

BC **160 - 175+ cm:** Light olive brown (2.5 Y 5/4, moist), light yellowish brown (2.5 Y 6/4, dry); silt clay; structureless (massive); hard when dry, firm when moist, very sticky and very plastic when wet; very few very fine roots.

Pedon 8: Melela

Date of description and sampling: 11/1/1991

Authors: B.M. Msanya & A.K. Kaaya

Survey area/district: Melela/Morogoro

Location: S 06° 54′ 57.2" E 37° 25′ 30.6"; 1 km north - west of Morogoro-Iringa Road from Melela CCM office, 300 m from Melela village

Altitude: 490 m asl

Geological formation: Neogene system comprising superficial deposit of mbuga and alluvial soils

Parent materials: alluvium of diverse origin transported by Melela river from nearby hills and mountains which are predominantly underlain by gneisses and granulites of the Uluguru block. At site black mbuga soils were observed

Physiography: Part of Mkata plain which is essentially an alluvial plain, almost flat with a gentle slope of about 1 % towards

the river

Land use/vegetation: Cotton, sorghum, and maize cultivation in some places. There are some scattered Acacia bushes

Soil temperature regime: iso-hyperthemic

Soil moist regime: ustic

Horizon features:

Ap **0 - 20 cm:** Black (5 YR 2/1, moist), black (5 YR 2/1, dry); sandy clay; moderate medium granular structure; hard when dry, firm when moist, sticky and plastic when wet; common very fine and fine pores; few very fine to medium roots; clear smooth boundary.

Bk **20 - 68 cm:** Black (5 YR 2/1, moist), black (5 YR 2/1, dry); sandy clay; strong coarse prismatic structure; very hard when dry, firm when moist, very sticky and very plastic when wet; common slickensides; moderate effervescence with HCl; few very fine and fine pores; very few very fine roots; gradual smooth boundary.

Bwk **68 - 104 cm:** Black to very dark gray (7.5 YR 2.5/0, moist), very dark gray (7.5 YR 3/0, dry); gravelly sandy clay loam; strong coarse prismatic structure; very hard when dry, firm when moist, very sticky and very plastic when wet; common slickensides; strong effervescence with HCl; very few fine pores; few angular and weathered gravels (0.2 - 2.0 cm) probably of limestone; gradual smooth boundary.

BCk **104 - 140 cm:** Very dark grayish brown (2.5 Y 3/2) and light olive brown (2.5 Y 5/4) moist, dark grayish brown (2.5 Y 4/2)

and light yellowish brown (2.5 Y 6/4) dry; gravelly sandy clay; strong medium and coarse angular blocky structure; very hard when dry, firm when moist, sticky and very plastic when wet, strong effervescence with HCl; few very fine pores; frequent angular and weathered gravels and stones (0.2 - 5.0 cm); clear smooth boundary.

Ck **140 - 195+ cm:** Light yellowish brown (2.5 Y 6/4) and olive yellow (2.5 Y 6/6) moist; gravelly clay loam; structureless (massive); very hard when dry, firm when moist, sticky and very plastic when wet; strong effervescence with HCl; few very fine pores; few angular and spherical weathered gravels mixed with quartz.

Pedon 9: Mvomero

Date of description and sampling: 09/01/1991

Authors: B.M. Msanya & A.K. Kaaya

Survey area/district: Mvomero/Morogoro

Location: S 06° 18′ 04.6" E 37° 26′ 38.7"; within Mvomero Primary School farm approximately 400 m north of Mvomero village, about 80 m south of a nearby river

Altitude: 414 m asl

Geological formation: Neogene system comprising superficial deposits derived from nearby hills

Parent materials: Mica-rich alluvium of diverse origin

Physiography: Almost flatland, slope at site 0 - 1 %

Land use/vegetation: Maize, mangoes, coconuts; natural vegetation include kapok trees, mkuyu (*Ficus sycomorus*) and mvule

(Milicia excelsa)

Soil temperature regime: iso-hyperthermic

Soil moisture regime: aquic

Horizon features:

Ap **0 - 16 cm:** Very dark grayish brown (10 YR 3/2, moist), dark brown to brown (10 YR 4/3, dry); sandy loam; weak very fine crumby structure; slightly hard when dry, friable when moist, nonsticky and nonplastic when wet; many very fine pores; frequently very fine roots; clear wavy boundary.

Bwg1 **16 - 54 cm:** Dark brown (10 YR 3/3, moist), brown (10 YR 5/3, dry); many fine and medium prominent clear strong brown (7.5 YR 5/8) mottles; sandy clay loam; moderate fine and medium subangular blocky structure; hard when dry, friable when moist, slightly sticky and slightly plastic when wet; common very fine to fine and few medium pores; common very fine and few fine roots; clear smooth boundary

Bwg2 **54 - 88 cm:** Dark brown (7.5 YR 3/2, moist), dark brown (7.5 YR 4/4, dry); common medium faint clear brown (7.5 YR 5/4) mottles; sandy clay; moderately strong medium and coarse angular blocky structure; very hard when dry, friable when moist, slightly sticky and slightly plastic when wet; common very fine to fine and few medium pores; common very fine roots; clear smooth boundary.

2C **88 - 170+ cm:** Strong brown (7.5 YR 5/6, moist and dry); sand; structureless (single grained); loose when dry, loose when moist, nonsticky and nonplastic when wet; few very fine roots.

Pedon 10: Pangawe

Date of description and sampling: 07/03/1991

Authors: B.M. Msanya & A.K. Kaaya

Survey area/district: Pangawe/Morogoro

Location: S 06° 47′ 01.5" E 37° 46′ 11.1"; near experimental site about 1 km north of the Pangawe Army Camp.

Altitude: 530 m asl

Geological formation: Neogene system comprising mostly brown surface soils

Parent material: Alluvial-colluvial material derived from metasedimentary rocks which are predominantly hornblende pyroxene granulites containing garnet

Physiography: Generally undulating landform, slope approximately 3% slope at site almost flat about 1 %

Land use/vegetation: Normally used for maize production

Soil temperature regime: iso-hyperthermic

Soil moisture regime: aquic

Special features: Evidence of cracks (2 cm wide) on the surface

Horizon features:

Ap **0 - 19 cm**: Very dark gray (10 YR 3/1, moist); clay; moderate medium crumby structure; hard when dry, firm when moist, sticky and plastic when wet; many very fine to coarse pores; very fine to fine roots; clear smooth boundary.

Bg **19 - 55 cm**: Very dark grayish brown (10 YR 3/2, moist), brown to dark brown (10 YR 4/3, dry); many fine faint clear yellowish brown mottles; sandy clay; moderate fine subangular

blocky structure; very hard when dry, firm when moist, sticky and plastic when wet; common very fine to fine pores; very few fine to medium and common very fine roots; gradual smooth boundary.

Btc1 **55 - 101 cm:** Very dark grayish brown (2.5 Y 3/2, moist), dark grayish brown (2.5 Y 4/2, dry); common medium faint diffuse yellowish brown mottles; clay; moderate strong medium and coarse angular blocky structure; very hard when dry, very firm when moist, very sticky and very plastic when wet; patchy moderately thick cutans of clay and probably organic matter; very few small hard spherical red ironstone nodules; few very fine pores; few very fine roots; gradual smooth boundary.

Btc2 **101 - 127 cm:** Olive brown (2.5 Y 4/4, moist), olive brown (2.5 Y 4/4, dry); common medium faint diffuse yellowish brown mottles; clay; moderately strong medium angular blocky structure; very hard when dry, very firm when moist, very sticky and very plastic when wet; broken moderately thick cutans of clay with probably iron oxides and hydroxides on ped faces; few very fine pores; very few rounded gravels of probably weathered limestone; few small hard spherical red ironstone nodules,; very few very fine roots; gradual smooth boundary.

Btc3 **127 - 188 + cm:** Light olive brown (2.5 Y 5/4, moist), light olive brown (2.5 Y 5/4, dry); common medium distinct clear brownish yellow mottles; clay; moderate medium angular blocky structure; very hard when dry, firm when moist, very sticky

and very plastic when wet; few very fine and fine pores; few rounded gravels of probably weatherd limestone; few small, hard spherical red ironstone nodules.

Pedon 11: Dakawa Rice Farm

Date of description and sampling: 19/09/1991

Authors: A.K.Kaaya & B.M Msanya

Survey area/district: Dakawa/Morogoro

Location: S 06° 23′ 55.7" E 37° 35′ 12.4"; Dakawa rice farm plot no. 6

Altitude: 360 m asl

Geological formation: Neogene system comprising mbuga soils

Parent materials: Alluvium of diverse origin which on site form generally gray and black mbuga soils

Physiography: Flat land, part of Wami flats, slope < 1 %

Land use/vegetation: Rice cultivation in the past, currently abandoned due to poor perfomance of the crop

Soil temperature regime: iso-hyperthemic

Soil moisture regime: aquic

Special features: presence of pale gray to white patches on the surface most probably due to salt accumulation; presence of very wide and deep cracks

Horizon features:

Ap **0 - 12 cm**: Very dark gray (10 YR 3/1, moist); sandy clay; strong fine and medium angular to subangular blocky structure; very hard when dry, firm when moist, very sticky and very plastic when wet; few rock fragments; slight efferverscence

with HCl; few medium tubular pores, common fine tubular pores; common very fine and fine roots; clear smooth boundary.

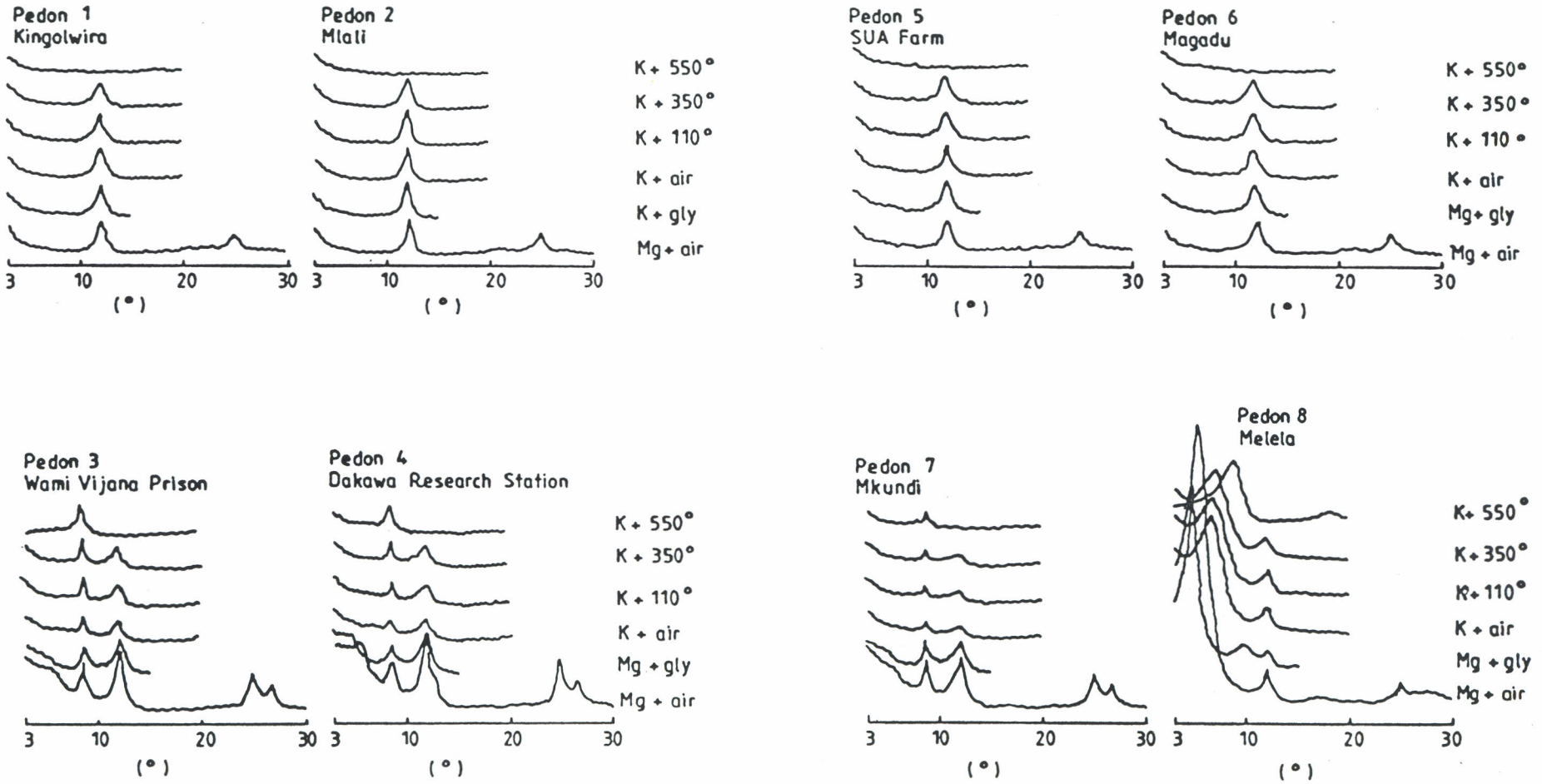
Bwk **12 - 79 cm:** Very dark gray (2.5 Y 3/1, moist); clay; moderate medium to coarse angular to subangular blocky structure; very hard when dry, firm when moist, very sticky and very plastic when wet, common slickensides; few rock fragments; slight effervescence with HCl; few fine tubular pores; few very fine roots; clear smooth boundary.

BCgk **79 - 108 cm:** Dark gray (5 Y 4/1, moist); clay; many medium faint diffuse olive mottles; moderate medium to coarse angular to subangular blocky structure, very hard when dry, firm when moist, very sticky and very plastic when wet; few slickensides; few rock fragments; moderate effervescence with HCl; few medium and few fine tubular pores; very few very fine roots; gradual smooth boundary.

Cgk1 **108 - 178 cm:** Pale olive (5 Y 6/3, moist); clay; many medium faint diffuse olive mottles; structureless (massive); very hard when dry, firm when moist, sticky and plastic when wet; few rock fragments; medium to strong efferverscence with HCl; few medium tubular pores, few fine tubular pores; abrupt smooth boundary.

Cgk2 **178 - 196+ cm:** Pale yellow (5 Y 7/3, moist), coarse calcareous material giving strong efferverscence with HCl.

Appendix 2. X-ray diffractograms of clay fractions of studied soils



Appendix 2. continued