Pedological Characterization, Clay Mineralogy and Classification of Some Soils of Mikese Area, Morogoro District, Tanzania

[1]Msanya*, B.M., D.N. Kimaro[2], A.J. and G.G. Kimbi[3]
[1]Soil Science Department, Sokoine University of Agriculture, P.O. Box 3008, Morogoro, Tanzania
[2]National Soil Service, Ministry of Agriculture, P.O. Box 5088, Tanga, Tanzania
[3]Institute of Continuing Education, Sokoine University of Agriculture, P.O. Box 3044, Morogoro, Tanzania

Abstract

A study was carried out in Mikese Ward, Morogoro District, with the objective to make an inventory of the soils of the area, to determine their physico-chemical and mineralogical properties and to classify them. Eight soil profiles were identified and form three major groups of soils namely, very deep, well drained, dark reddish brown to dark brown, sandy clay loams and sandy clays on the steep convex slopes; very deep, well drained, dark brown to dark red, sandy clay loams and sandy clays on the linear slopes; and very deep, well and imperfectly drained sandy loams to sandy clay loams and sandy clays in the valley bottoms. The soils of the convex and linear slopes classified as Isohyperthermic, deep, mixed, Kanhaplic Haplustalfs and Isohyperthermic, deep, mixed Oxic Ustropepts representing a relatively advanced pedogenic development as indicated by high contents of Fe, Al and Ti and relatively low Si/Al ratios. The soils of the valley bottoms classified as Isohyperthermic, deep, mixed, Typic Argiustolls, Isohyperthermic, deep, mixed, Typic Tropaquepts and Isohyperthermic, deep, mixed, Fluventic Ustropepts. These soils are of low to intermediate pedogenic development as indicated by the relatively lower Fe, Al and Ti contents and both high Si and Si/Al ratios. X-ray diffraction analysis revealed that the studied soils have a mixed clay mineralogy including kaolinite and mica. Small amounts of smectite were identified in one profile with alkaline subsoil reaction. Bulk densities of surface horizons are relatively lower than those of subsoils ranging from 1.1 to 1.6 Mg/m^3 in topsoils and from 1.4 to 1.9 Mg/m^3 in subsoils. Total porosity ranged from 40 to 58% in surface soils and from 28 to 32% in subsoils. Available water holding capacities of the soils are between 155 and 248 mm/m of soil. The soils have overall poor supply of N and P. The basic cations Ca^{++}, Mg^{++} and K^{+} are medium to high throughout the profiles. The CEC of the soils is very low with values ranging from 6 to 13 cmol(+)/kg soil). These results imply that continuous utilization of the soils for crop production without proper management will result into a drastic loss of soil fertility.

Key words: Pedological characterization, mineralogy, soil classification, Morogoro

Introduction

Soil information gathering by systematically identifying, grouping and delineating different soils according to their genesis, physico-chemical characteristics and overall ecological conditions is a pre-requisite for sound interpretations of land use potentials. Socio-economic factors also form an important element 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 (Msanya *et al.*, 1998). Fertilizer and other agronomic trials carried out on uncharacterized soils are not very useful because their results are of local value (i.e. they are specific to the trial site) and have low transferability to other areas.

In Tanzania only about 10,000 km^2 have been surveyed in detail in terms of soils and land resources (Msanya and Magoggo, 1993;

* Corresponding author

Kauzeni *et al.*, 1993). A wide range of small areas have been covered this way by detailed surveys including land evaluation studies of estates, irrigation schemes and village areas (Kaaya *et al.*, 1994; Kips and Ngailo, 1990). In Morogoro, there is no adequate soils and land resources information for comprehensive land use planning neither at district nor at regional level (Kaaya, 1997). The area known in detail is negligible taking into consideration the large size of the country. This is a bottleneck to the formulation of proper national land management programmes. With the ever-increasing population and food demands, there is a serious need to characterize soils and other land resources so that they can be used more efficiently for food production. In order that technologies emanating from different land management techniques become useful it is necessary that they should be carried out on well characterized soils to allow transfer of agro-technology to other areas with similar soil and ecological conditions. Mineralogical characterization is essential for grouping similar soils as well as for predicting their behaviour under different management systems (Moberg *et al.*, 1982; Msanya and Msaky, 1983; Kaaya *et al.*, 1998; Msanya *et al.*, 1998)

The current study is part of an ongoing project on soils and land resources of Morogoro District. It focuses mainly on pedological characterization of the soils of the study area to facilitate their classification and to assess their potentials and limitations for agricultural production. The study will also contribute to more knowledge on the soil types and their distribution in the District. The specific objectives of this study were therefore to:

1. investigate the physical and chemical characteristics of the soils;
2. study the clay mineralogical properties of the soils;
3. 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; and
4. to provide data for the Morogoro District soils and land resources inventory.

Materials and methods

Physical environment of the study area

The study area is located in Mikese Ward about 40 km from Morogoro municipality towards Dar es Salaam. The area is bordered in the south by the Morogoro-Dar es Salaam highway and in the north by the Sangasanga river. The main reference point is the Kitulanghalo Hill whose map coordinates are E 37° 57'45" and S 06° 41' 00".

The climate is hot and humid all the year round (Msanya *et al.*, 1995). The available rainfall data (Table 1) from Kinonko Sisal Estate which is adjacent to the study area indicate that Mikese receives rainfall from October to May. Rainfall maps of Tanzania (Nieuwolt, 1973) show that the area is in the 700 - 1000 mm rainfall belt with at least two months with surplus rainfall over potential evaporation. The driest months are June, July, August and September. According to Van Wambeke (1982) the soil moisture regime (SMR) of the study area is *ustic* (one in which moisture is limiting, but is available when conditions are suitable for plant growth). In the depressions (valley bottoms) conditions may be different and *aquic* SMR prevails. Such kind of regime is characterized by water-logging conditions. Information on temperatures (Kaaya *et al.*, 1994; Msanya *et al.*, 1994) shows that the mean annual air temperature (MAAT) for most areas of Morogoro District is about 24°C. The mean annual soil temperature (MAST) is thus estimated as 25°C by adding 1°C to the MAAT (after Soil Survey Staff, 1975) and hence the soil temperature regime is described as *iso-hyperthermic*.

The underlying geology of study area is described as Precambrian Usagaran metasedimentary rocks consisting of garnet-biotite gneisses with some kyanite bearing bands (Sampson and Wright, 1961). In the valley bottoms mixed alluvial and colluvial deposits derived from the above mentioned rocks are present. These deposits are stratified with clayey, sandy and loamy layers.

The study area is located on the piedmont plain of Kitulanghalo Hill (elevation 762 m a.s.l.). The general physiography of the area has a rolling to steep convex slopes (10 - 22%)

and undulating to rolling linear slopes with shallow and deep gullies. Valley bottoms occur in between the convex slopes. These are concave in cross-section with fairly uniform slopes (5 – 12%). The altitude of the convex slopes ranges between 420 and 460 m a.s.l. and the dissected linear slopes between 420 and 430 m a.s.l. The valley bottoms are 20 - 10 m lower than the convex slopes.

Field methods

Existing information on the study area was sought by consulting various documents (Fleetwood, 1981; De Pauw, 1984; Moberg *et al.*, 1982; Msanya, 1980; Msanya and Msaky, 1983; Kimaro, 1989; Msanya and Magoggo, 1993).

Topographic survey of the study area was carried out to obtain a topographic map at a scale of 1:1 000 which was used as a base map for soil survey. Soils were examined by means of hand soil augering following grid soil survey method (Dent and Young, 1981) with observation interval of 10 m. Eight soil profiles representing the various mapping units were dug, examined and described following the Guidelines for Soil Profile Description (FAO, 1990) to characterize the soil mapping units. Soil colours were determined using Munsell Color Charts (Munsell Color, 1975). Soil samples from the different soil horizons were taken for physical, chemical and mineralogical analyses. Undisturbed soil samples were taken using 100 cc steel cores at 0 - 5 cm, 45 - 50 cm and 95 -100 cm depths for the determination of bulk density and water retention characteristics.

Laboratory methods

Texture was determined by Bouyoucos hydrometer method (Day, 1965) after dispersing soil with calgon. Bulk density was determined using core sample method (Blake, 1965). Soil moisture characteristics were determined using pressure plate and membrane apparatus (Klute, 1986). Available water capacity (AWC) was calculated as the difference between water contents at 33 kPa and 1500 kPa tensions.

pH was measured in water at the ratio of 1/2.5 soil-water. Organic carbon was determined by the Walkley and Black method (Nelson and Sommers, 1982). Kjeldahl method (Bremner and Mulvaney, 1982) was used 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 CEC and exchangeable bases were extracted by saturating soil with neutral 1M NH_4OAc (Thomas, 1982) and the absorbed NH^{4+} displaced by K^+ using 1M KCl and then determined by Kjeldahl distillation method for the estimation of CEC of soil. The bases Ca^{2+}, Mg^{2+}, Na^+, and K^+, displaced by NH^{4+} were measured by atomic absorption spectrophotometer.

Samples for clay mineralogical analysis were prepared following the procedure outlined by Msanya *et al.*, (1994) as 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 vibration for 5 minutes at 4000 rpm after adding 1 ml of 1N NaOH (dispersing agent) and 300 ml of deionised water. The suspensions were transferred to glass cylinders and their volumes made up to 1000 ml and then al-

Table 1: Rainfall figures (mm) of Kinonko Sisal Estate, Morogoro

Year	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sept	Oct	Nov	Dec	Total
1962	311	42	-	-	-	7	60	-	-	-	74	200	826
1963	26	78	237	245	7	-	-	-	3	274	180	234	1284
1964	25	122	140	254	37	10	5	-	16	139	7	132	987
1965	42	65	6	152	93	-	-	6	-	133	81	147	725
Total	404	307	515	751	137	10	12	66	19	546	342	713	3822
Mean	101	77	129	188	34	3	3	17	5	137	86	178	958

lowed 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 series was used for the analysis.

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.

Soil classification

Using both field and laboratory data the mapped soils were classified up to family level of the USDA Soil Taxonomy (Soil Survey Staff, 1990) and to level-2 of the FAO-UNESCO Soil Classification System (FAO, 1988).

Results and Discussion

Physical properties

Table 2 and Figure 1 present some physical properties of the studies soils.

Soil texture, bulk density and total porosity

The dominant texture of the studied soils is sandy clay loam except for profiles KP4 and KP5 in which the texture is predominantly sandy loam. The bulk density (BD) values of topsoils are relatively lower than those of subsoils; ranging from 1.1 to 1.6 Mg/m^3 for topsoils and 1.4 to 1.9 Mg/m^3 for subsoils. Profile KP1 has the highest BD values (1.6 to1.9 Mg/m^3) while profiles KP4 and KP5 have the lowest BD values (1.2 to1.5 Mg/m^3). Profiles KP7 and KP8 have relatively constant values of BD throughout the profile (1.4 Mg/m^3). Total porosity ranges from 40 to 58% in topsoils and from 28 to 32% in the subsoil. Bulk density and total porosity of the soils are mainly influenced by texture and to some extent by the organic matter content of the soils.

Water retention, available water and air capacity

Figure 1 shows the moisture characteristics of three depths (surface horizon, intermediate horizon and subsoil) of the studied soil profiles. Generally, at any given water potential the volume fraction of water in the surface layer is

Table 2: Some physical properties of selected soils of Mikese Area, Morogoro

Profile No.	Depth (cm)	Texture	BD Mg/m3)	Total porosity (vol.%)	Air filled porosity %	AWC (mm)	AWC (mm/m)
KP1	0-20	SL	1.6	40	15	52	
	34-55	SL-SCL	1.8	32	14	64	162
	100-120	SC	1.8	32	12	85	
KP2	0-15	SL-SCL	1.1	58	16	46	
	35-55	SCL	1.6	40	17	65	155
	80-100	SCL	1.9	28	13	44	
KP3	0-20	SCL	1.4	47	16	50	
	29-60	SCL	1.6	40	18	80	184
	107-119	SC	1.6	40	20	54	
KP4	0-20	SL	1.2	55	20	57	
	60-80	SL	1.5	43	21	114	200
KP5	0-20	SL	1.2	55	20	50	
	50-70	SL-SCL	1.4	47	22	124	248
	90-110	SL	1.5	43	20	74	
KP6	0-14	SL-SCL	1.2	55	22	36	
	30-50	SCL	1.6	40	18	55	181
	90-110	SCL	1.5	43	19	90	
KP7	0-15	SCL	1.4	47	20	30	
	30-50	SC	1.4	47	19	53	156
	100-120	SC	1.4	47	19	73	
KP8	0-7	SCL	1.4	47	15	16	
	45-65	SCL	1.4	47	20	104	181
	80-100	SCL	1.5	43	19		

SL = sand loam SC = sand clay SCL = sandy clay loam; AWC = available water capacity

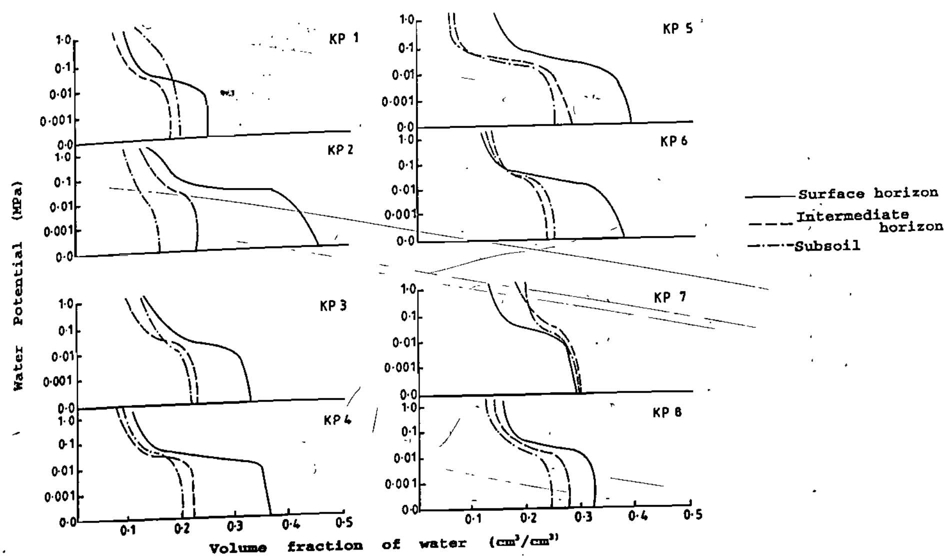


Figure1: Moisture release characteristics of some soils of Mikese Area, Morogoro

higher than that of the intermediate layer and subsoil. The surface horizons of most profiles with high amount of sand (sand loams) have chair-shaped curves. They contain much water at saturation which is slowly released until water potential reaches -0.01 MPa, after which a small rise in water potential causes a considerable discharge of water. At water potential of -0.1 MPa or less water release is slowed down. The shape of the curves clearly indicates that the soil's pore system is dominated by macropores. The intermediate and subsoil horizons have soil moisture characteristic curves similar to those of the surface horizon, but differ by having lower water contents held at any water potential. This is mainly due to the reduction of total porosity owing to the finer textures (SCL, SC) of the intermediate and subsoil layers. The high air-filled SL = sandy loamSC = sandy clay SCL = sandy clay loam AWC = available water capacity

porosity values indicate that most of the soils are unlikely to be waterlogged or to have poor aeration. Available water capacity per meter of soil ranges from 155 to 248 mm (Table 2) which is rated as high to very high (Msanya *et al.*, 1996).

Chemical properties

Table 3 and 4 present the chemical analytical data of topsoils and subsoils of the study area .

Soil reaction

Soil pH values are slightly acid to very slightly acid in most soils ranging from 6.0 to 6.8. The subsoils of profile KP1 are mildly alkaline (pH values 7.8). The high pH values in this soil are mainly due to the presence of large amounts of sodium (1 to 5 cmol (+)/kg soil).

Organic matter (OM) and nitrogen (N)

Organic matter contents are generally medium to high corresponding to organic carbon (OC) levels of between 1.5 and 3.0% in topsoils. The levels of OM in the subsoils are very low (less than 0.6% OC). The soils of profile KP1 are very low in OM (less than 0.4% OC). In most soils absolute N levels are generally low (less than 0.2%). However, the quality of organic matter of these soils is high (C/N ratios of 10 to 15).

Table 3: Chemical data of some soil profiles of Mikese Area, Morogoro

Profile No.	Depth	PH (H2O)	OC (%)	Total N (%)	C/N	Available P mg P/kg	CEC cmol(+)/kg soil	BS (%)
KP1	Topsoil	6.2	0.41	0.02	21	4.5	6.54	90
	Subsoil	7.8	0.28	0.02	14	0.8	12.97	100
KP2	Topsoil	6.6	2.44	0.23	11	17.3	12.18	81
	Subsoil	5.7	0.32	0.04	8	1.2	6.46	69
KP3	Topsoil	6.7	2.40	0.20	12	9.1	12.02	96
	Subsoil	6.2	0.61	0.01	9	0.7	7.60	81
KP4	Topsoil	6.2	2.19	0.30	12	8.1	9.45	75
	Subsoil	6.1	0.53	0.06	9	1.9	5.93	82
KP5	Topsoil	6.6	1.83	0.15	12	3.4	10.78	86
	Subsoil	6.3	0.59	0.04	15	2.5	6.23	77
KP6	Topsoil	6.3	2.45	0.19	13	7.5	8.05	84
	Subsoil	6.1	0.43	0.04	11	0.7	7.40	87
KP7	Topsoil	6.4	1.69	0.16	11	3.9	9.84	80
	Subsoil	6.2	0.20	0.02	10	1.2	8.18	78
KP8	Topsoil	6.2	3.14	0.20	16	7.9	15.46	97
	Subsoil	6.3	0.48	0.05	10	0.5	7.23	74

Table 4: Interpretation ratings for exchangeable cations for the soils of Mikese Area, Morogoro

	Exch. Ca cmol(+)/kg soil		Exch. Mg cmol(+)/kg soil		Exch. K cmol(+)/kg soil		Exch. Na cmol(+)/kg soil	
Profile No.	Topsoil (0-20cm)	Subsoil (30-150cm)	Topsoil (0-20cm)	Subsoil (30-150cm)	Topsoil (0-20cm)	Subsoil (30-150cm)	Topsoil (0-20cm)	Subsoil (30-150cm)
KP1	Medium (3.4)	High (2.4-5.6)	High (2.1)	Medium to high (2.0-2.1)	Low (0.37)	Low (0.12-0.18)	Very low (0.04)	High to very high (1.0-5.0)
KP2	Very high (9.2)	Medium to high (3.0-5.1)	High (3.4)	Medium (1.3-2.5)	Medium (0.62)	Low to Medium (0.19-0.48)	Very low (0.02)	Very low (0.02-0.11)
KP3	Medium (8.3)	Low to medium (3.0-5.4)	Medium (2.6)	Medium to high (2.2-2.7)	Medium (0.78)	Low (0.19-0.40)	Low (0.13)	Very low to low (0.03-0.13)
KP4	High (4.5)	Medium (2.4-2.5)	High (2.1)	Medium to high (2.0-2.1)	Medium (0.39)	Medium (0.39-0.44)	Very low (0.06)	Very low to low (0.03-0.13)
KP5	Very high (6.6)	Medium to high (1.2-3.0)	High (2.2)	Medium to high (1.5-2.7)	Medium (0.41)	Very low to low (0.10-0.24)	Very low (0.02)	Very low (0.01-0.09)
KP6	Medium (4.0)	Medium to high (2.8-4.9)	High (2.2)	Medium to high (1.6-2.2)	Medium (0.54	Medium (0.18-0.64)	Very low (0.01)	Very low to low (0.01-0.12)
KP7	High (4.5)	High (3.2-4.4)	High (2.8)	Medium (1.3-1.9)	Medium (0.50)	Low to medium (0.11-0.54)	Very low (0.02)	Very low to low (0.02-0.17)
KP8	Very high (10.2)	High (3.1-3.8)	High (3.7)	Medium to high (1.4-3.0)	High (0.91)	Low to medium (0.09-0.60)	Low (0.22)	Very low to low (0.03-0.16)

Available phosphorus (P)

All the studied soils have low levels of available P (ranging from less than 1 to 7 mg P/kg). Average phosphorus levels of more than 7 mg P/kg are considered to be optimum, below which P-deficiency symptoms are likely to occur in many crops. The topsoils of profile KP1 and KP3 have medium P levels (17 and 9 mg /kg respectively).

Cation exchange capacity (CEC)

The CEC reflects the capacity of the soil to retain nutrients against leaching. CEC values of most of the studied soils are very low to low ranging from 5 to 12 cmol(+)/kg soil. The topsoil of profile KP8 has CEC value of 15 cmol(+)/kg soil. The high CEC value is related to high organic matter content in this horizon. The subsoil of profile KP1 have CEC values ranging between 13 and 15 cmol(+)/kg soil. The high CEC values are related to high amounts of calcium and sodium in the deeper subsoils of this profile.

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

Table 4 presents the levels of topsoil and subsoil exchangeable cations (Ca, Mg, and K) of the studied soils. The levels of exchangeable Ca and Mg can be rated as medium to very high. Exchangeable K levels are medium in most topsoils. The levels of exchangeable K in profile KP1 are low.

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

Sodium levels in the study area are very low (Table 4) ranging from 0.01 to 0.17 cmol(+)/kg soil both in topsoils and subsoils. The subsoils of profile KP1 have high exchangeable sodium levels ranging from 1 to 5 cmol(+)/kg soil. Generally, soils with exchangeable sodium levels of more than 1 cmol(+)/kg soil are regarded as potentially sodic. The levels of ESP suggest that most of the studied soils are non-sodic. The subsoils of profile KP1 (map C5) are moderately sodic to extremely sodic (ESP 13 to 40%).

Nutrient balance

In most of the soils Ca, Mg and K are well balanced with Ca > Mg > K. Ca/Mg ratios are 2 and 3, which are within the optimal range. The K levels are medium for most of the soils. The overall K/TEB (total exchangeable bases) ratios are above 2% which are considered favourable for most tropical crops.

Soil clay mineralogy

The x-ray diffractograms of the studied soils are presented in Figure 2. The estimation of the relative mineralogical composition of the clay fractions is based on these diffractograms and the results are presented in Table 5. The subsoil clay mineralogy of the studied soils is predominantly mixed, whereby KP1 has kaolinite, mica and some smectite and the other profiles have only kaolinite and mica in varying proportions. The peaks of 7.2Å and 3.6Å are those of kaolinite; 10Å and 3.3Å represent mica; 17Å and 12.4Å are of Na-smectite.

Total chemical analysis

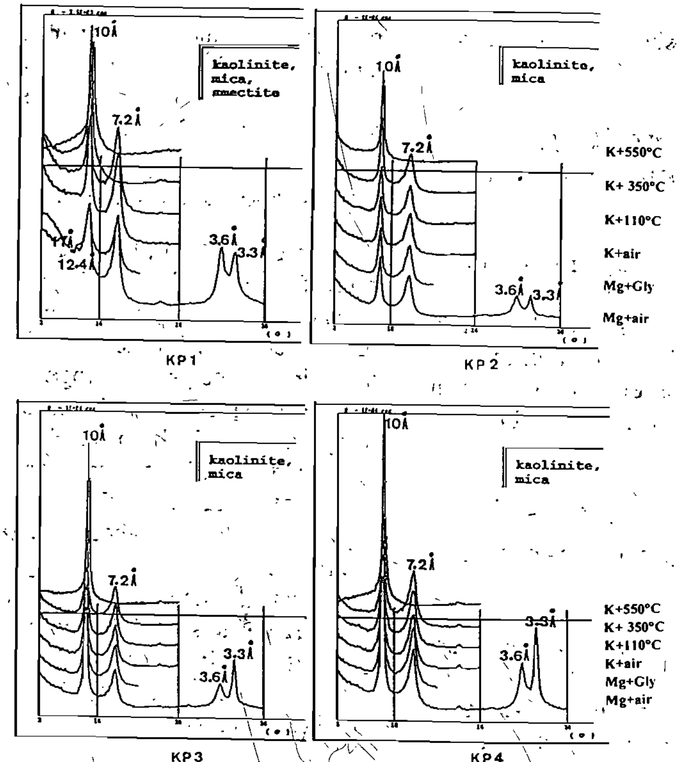
The data on total chemical analysis expressed in form of oxides is presented in Table 6. The following statements can be made about the studied soils: Profiles KP1, KP2, KP3, KP4 and KP5 can be grouped together as soils with low to intermediate pedogenic development. They have relatively lower Fe, Al and Ti contents, and both high Si content and Si/Al ratios. On the other hand, profiles KP6, KP7 and KP8 represent more advanced pedogenic development as indicated by much higher contents of Fe, Al and Ti and relatively low Si/Al ratios. Generally, the soils have both low Fe/Al and Mg/K ratios indicating that they have been formed from materials which are relatively rich in felsic minerals.

Soil classification

Both field and laboratory analytical data were used to classify the soils. Table 7 gives a summary of the soil morphological and diagnostic features used to classify the soils. Soil names according to two systems of classification are presented in Table 8. The soils have been categorized into three soil orders of the USDA Soil Taxonomy namely Inceptisols (KP1, KP4, KP5, KP8), Mollisols (KP2, KP3) and Alfisols (KP6, KP7) which respectively correspond to Cambisols, Phaeozems and Lixisols in the FAO-UNESCO Classification System. The soil profiles are variably located in different slope facets in the landscape. Profiles KP1, KP2, KP3, KP4 and KP5 occupy valley bottoms, profile KP6 occupies linear slope; while profiles KP7 and KP8 occupy convex slopes.

Conclusions

i. The available climatic data suggest that the study area has medium to high potential for agricultural production. With proper selection of crops there can be two cropping seasons in one year: short rains crop (October to



'igure 2: X-ray diffractograms of subsoil clay fractions of the soils of Mikese Area, Morogoro

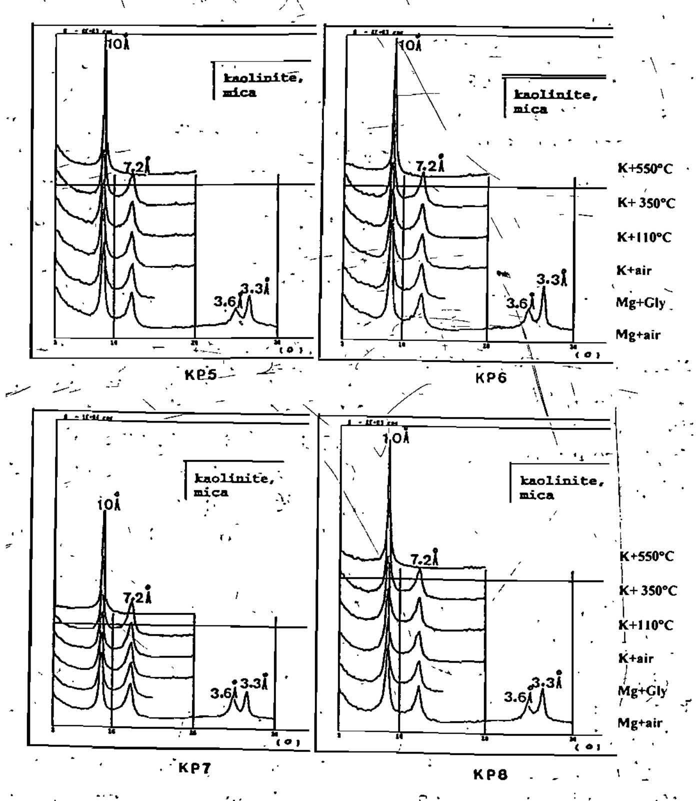


Figure 2: X-ray diffractograms of subsoil clay fractions of the soils of Mikese Area, Morogoro

Table 5: Relative mineralogical composition of clay fractions of soils of Mikese Area, Morogoro

Profile	Kaolinite	Mica	Smectite
KP1	+++++	++++	
KP2	+++++	+++++	
KP3	++++	++++++	
KP4	++++	++++++	
KP5	++++	++++++	
KP6	++++	++++++	
KP7	++++	++++++	
KP8	+++++	+++++	

N.B. Relative amounts based on total score of 10+

Table 6: Total chemical analysis (% oxides) of the soils of Mikese Area, Morogoro

Soil profile	Fe_2O_3	TiO_2	MnO_2	CaO	K_2O	P_2O_5	SiO_2	Al_2O_3	MgO	Na_2O	Total
KP1	1.70	0 23	0 032	2 40	0 72	0 003	79 60	11 87	0 40	3 05	100 01
KP2	2.79	0 34	0 062	3 07	0 89	0 093	77 12	12.34	0 634	2.67	100 01
KP3	3.10	0 40	0 057	2 61	1 23	0 063	74 23	14 74	0 82	2 75	100 01
KP4	1.75	0.25	0 048	2 17	0.88	0 088	80 17	11 71	0 38	2 65	100 01
KP5	1.73	0.23	0 043	2 19	0 85	0 004	80 93	11 07	0 39	2.55	99 99
KP6	3.23	0.37	0 067	3 14	0 2	0 042	72.52	15 51	0.80	3.39	99 99
KP7	3.74	0 48	0 065	2 61	0 95	0 026	72 98	15 40	0 76	2 99	100 01
KP8	4.81	0 59	0 085	3.43	1 14	0 075	69 24	16.55	1 20	2.88	100 01

Table 7: Summary of salient morphological and diagnostic features of the studied soils

Profile	Diagnostic horizons	Other diagnostic features	Soil depth	Mineralogy class
KP1	Ochric epipedon (*ochric A), cambic horizon (*cambic B)	Aquic SMR(*gleyic properties), isohyperthermic STR, * >6% ESP within 100 cm	Deep	Mixed (kaolinite, mica, smectite)
KP2	Mollic epipedon (*mollic A); argillic horizon (*argic B)	Ustic SMR, isohyperthermic STR	Deep	Mixed (kaolinite, mica)
KP3	Mollic epipedon (*mollic A), argillic horizon (*argic B)	Ustic SMR, isohyperthermic STR	Deep	Mixed (kaolinite, mica)
KP4	Ochric epipedon (*ochric A), cambic horizon (*cambic B)	Ustic STR, %BS=or>50 in the subsoil, isohyperthermic SMR, OC decreases irregularly with depth, slopes=or<25%	Deep	Mixed (kaolinite, mica)
KP5	Ochric epipedon (*ochric A), cambic horizon (cambic B)	Ustic SMR, %BS=or>50 in the subsoil, isohyperthermic STR, OC decreases irregularly with depth, slopes=or<25%	Deep	Mixed (kaolinite, mica)
KP6	Ochric epipedon (*ochric A), argillic horizon (*argic B)	Ustic SMR, isohyperthermic STR, CEC<24 cmol(+)/kg clay in major part of argillic horizon	Deep	Mixed (kaolinite, mica)
KP7	Ochric epipedon (*ochric A), argillic horizon (*argic B)	Ustic SMR, isohyperthermic STR, CEC<24 cmol(+)/kg clay in major part of argillic horizon	Deep	Mixed (kaolinite, mica)
KP8	Ochric epipedon (*ochric A); cambic horizon (*cambic B)	Ustic SMR, %BS=or>50 in the subsoil, isohyperthermic STR, CEC<24 cmol(+)/kg clay in major part of subsoil	Deep	Mixed (kaolinite, mica)

NB.* terminology used particularly in the FAO-Unesco classification; those without* are of the USDA Soil Taxonomy

January) and long rains crop (February to May).

ii. On the basis of the physiography of Mikese, the *dissected linear slopes* may be too eroded to be useful for crop production, while the *convex slopes* on the other hand, could, with careful management be utilized for crop production. The areas with steep relief should be reserved for catchment forestry or for recreation. Apart from localized areas where drainage is imperfect due to poor soil physical conditions, the valley bottoms present a very high potential for crop production.

iii. Generally, the soils of the study area are relatively uniform in both physical and chemical properties. There is a close relationship between the main soils of the area and the topography. The more developed soils, i.e. Alfisols, occur on the undulating to rolling convex slopes on piedmonts. The Mollisols and Inceptisols occur in the gently undulating concave valley bot-

Table 8: Classification of representative soils of Mikese Area, Morogoro

Profile	USDA Soil Taxonomy					FAO-Unesco Classification	
	Order	Suborder	Greatgroup	Subgroup	Family	Level-1	Level-2
KP1	Inceptisols	Aquepts	Tropaquepts	Typic Tropaquepts	Isohyperthermic, deep, mixed, Typic Tropaquepts	Cambisols	Gleyic Cambisols (CMg), sodic phase
KP2	Mollisols	Ustolls	Argiustolls	Typic Argiustolls	Isohyperthermic, deep, mixed, Typic Argiustolls	Phaeozems	Luvic Phaeozems (PHl)
KP3	Mollisols	Ustolls	Argiustolls	Typic Argiustolls	Isohyperthermic, deep, mixed, Typic Argiustolls	Phaeozems	Luvic Phaeozems (PHl)
KP4	Inceptisols	Tropepts	Ustropepts	Fluventic Ustropepts	Isohyperthermic, deep, mixed, Fluventic Ustropepts	Cambisols	Eutric Cambisols (CMe)
KP5	Inceptisols	Tropepts	Ustropepts	Fluventic Ustropepts	Isohyperthermic, deep, mixed, Fluventic Ustropepts	Cambisols	Eutric Cambisols (CMe)
KP6	Alfisols	Ustalfs	Haplustalfs	Kanhaplic Haplustalfs	Isohyperthermic, deep, mixed, Kanhaplic Haplustalfs	Lixisols	Haplic Lixisols (LXh)
KP7	Alfisols	Ustalfs	Haplustalfs	Kanhaplic Haplustalfs	Isohyperthermic, deep, mixed, Kanhaplic Haplustalfs	Lixisols	Haplic Lixisols (LXh)
KP8	Inceptisols	Tropepts	Ustropepts	Oxic Ustropepts	Isohyperthermic, deep, mixed, Oxic Ustropepts	Cambisols	Ferralic Cambisols (CMo)

toms. The Alfisols have much higher contents of Fe, Al and Ti and relatively low Si/Al ratios. The Inceptisols and Mollisols show low to intermediate pedogenic development with relatively lower Fe, Al and Ti contents and both high Si and Si/Al ratios.

The topsoil textures of most of the soils are predominantly sandy loam grading to sandy clay loam and sandy clay with depth. These textures together with the relatively low subsoil OM content, imply poor nutrient retention and low supply of N and P.

Most of the soils are slightly acid and have medium to high levels of the essential basic cations for crop production. The ratio of the major nutrient cations i.e Ca, Mg and K are favourable and as such there is no immediate problem of nutrient imbalance. However, continuous utilization of these soils for crop production without proper management could result into drastic reduction of OM. It is therefore recommended that some amounts of inorganic fertilizers should be applied from the very beginning if these soils are to be used optimally for crop production.

Acknowledgements

The authors wish to express their sincere appreciation to the Norwegian Agency for Development Cooperation (NORAD) and the International Board for Soil Research and Management (IBSRAM) for the financial assistance to carry out the research. They are also very grateful to Professors K. Kyuma and S. Araki for providing laboratory facilities at Kyoto University for the determination of total elemental composition of soil samples.

References

Blake, G.R. 1965. Bulk density. In: Methods of Soil Analysis, part 1 (eds. C.A Black, D.D. Evans, J.L. White, L.E. Ensminger and F.E. Clark), pp. 374-390. ASA, Madison, Wisconsin.

Bray, R.H. and Kurtz, L.T. 1945. Determination of total, organic and available forms of phosphorus in soils. Soil Sci: 59:39-45.

Bremner, J.M. and Mulvaney, C.S. 1982. Total nitrogen. In: Methods of Soil Analysis, part 2, 2nd edit. (eds. A.L. Page, R.H. Miller and D.R. Keeney), PP 595-624. ASA, SSSA Monograph no. 9, Madison, Wisconsin.

Day, P.R. 1965. Particle fractionation and particle size analysis. In: Methods of Soil Analysis, (part 1, (eds. C.A. Black, D.D. Evans, J.L. White, L.E. Ensminger and F.E. Clark), pp.545-566. ASA, Madison, Wisconsin.

Dent, D. and Young, A. 1981. Soil survey and land evaluation. E & FN Spon. London, 278 pp. De Pauw, E. 1984. Soils, physiography and agroecological zones of Tanzania. Ministry of Agriculture and Food and Agriculture Organization (FAO), Dar es Salaam.

Dixon, J.B. and Weed, S.B. (eds.) 1989. Minerals in soil environments. 2nd edition. Soil Sci. Soc. Am. Madison, Wisconsin, pp 1051-1087.

EUROCONSULT, 1989. Agricultural compendium for rural development in the tropics and subtropics. Elsevier Science Publishers, Amsterdam. 740 pp.

FAO, 1988. FAO/UNESCO Soil map of the world, revised legend. International Soil Reference and Information Centre, Wageningen. 138pp.

FAO, 1990. Guidelines for soil description 3rd edition (Revised). Soil Resource management and Conservation Service, Land and Water Development Division, FAO, Rome. 70pp.

Fleetwood, E. 1981. Soil properties under five forest and woodland types in the Morogoro Area, Tanzania. Rural Development Studies No. 12. Swedish University of Agricultural Sciences, International Rural Development Centre, Uppsala.

Kaaya, A.K. Msanya, B.M. and Mrema, J.P. 1994. Soils and land evaluation of part of the Sokoine

Kaaya, A.K. 1997. Mapping and characterization of some soils of the northern part of Morogoro District, Tanzania. Report No. 5/1997 (55). Agricultural University of Norway. ISSN 0805-7214. 91 pp.

Kaaya, A.K., Jorgensen, P. and Sorensen, R. 1998. Mineralogical composition and some chemical properties of soils from a toposequence in Magadu area, Morogoro District, Tanzania. Report No. 6/1998 (68). Agricultural University of Norway. ISSN 0805-7214. 29 pp.

Kauzeni, A.S., Kikula, I.S., Mohamed, S.A., Lyimo, J.G. and Dalal-Clayton, D.B. 1993. Land use planning and resource assessment in Tanzania. A case study. Institute of Resource Assessment, University of Dar es Salaam, Tanzania and International Institute for Environment and Development, London. 128 pp.

Kimaro, D.N. 1989. Potentials and constraints of Kilosa area (Tanzania) for rainfed agriculture with emphasis on maize. MSc thesis. International Institute for aerospace survey and earth sciences, ITC Enschede, the Netherlands.

Kips, Ph.A. and Ngailo, J.A. 1990. Soils and land suitability for irrigated agriculture of Rundugai Irrigation Scheme (Hai District, Kilimanjaro Region). Deatailed soil survey report D29. Ministry of Agriculture, National Soil Service, ARI, Mlingano, Tanga, Tanzania. 25 pp.

Klute, A. 1986. Water retention: Laboratiry methods. In:A. Klute (ed.), 1981. Methods of soil analysis part 1, physical and mineralogical methods.2nd edition. pp. 635-662.

Moberg, J.P. Msanya, B.M. and Kilasara, M. 1982. Pedological and edaphological properties of the soils of two soil associations in the Morogoro Area, Tanzania. Trop. Agric. (Trinidad) 59(2):139-148.

Msanya, B.M. 1980. Study of the soils of a toposequence on metasedimentary rocks of the Morogoro Region (Tanzania), with special attention to texture determination and soil classification. MSc (Soil Science) thesis, State University of Ghent, Belgium.

Msanya, B.M. and Magoggo, J.P. 1993. Review of Soil Surveys (Soil Resource Inventories) in Tanzania. Ecology and Development Paper No. 6. Published by The Ecology and Development Programme, The Agricultural University of Norway, ISSN 0804-2144, A^{0}s,Norway.

Msanya, B.M. and Msaky, J.J. 1983. Mineralogy of some soils developed on metasedimentary rocks of Morogoro Region, Tanzania. Beiträge Trop. Landwirtsch. Veterinärmed. 21(2):181-189.

Msanya, B.M. Kaaya, A.K. and G.I. Nyadzi, 1994. Pedological studies and characterization of some benchmark soils of Morogoro istrict, Tanzania. Department of Soil Science, Sokoine University of Agriculture, Morogoro.

Msanya, B.M. Kimaro, D.N. and Araki, S. 1998. Pedon characteristics and their implications forland management in two villages of Mbinga District, Tanzania.Tanzania J. Agric. Sc.(1998) vol. 1 No. 1, 64-70.

Msanya, B.M. Kimaro, D.N. and Shayo-Ngowi, A.J. 1995. Soils of Kitulanghalo Forest Reserve Area, Morogoro District, Tanzania. Department of Soil Science, Faculty of Agriculture, Sokoine University of Agriculture, Morogoro, Tanzania.

Msanya, B.M. Wickama, J.M. Kimaro, D.N. Magoggo, J.P. and Meliyo, J.L. 1996. Investigation of the environmental attributes for agricultural development in Kitanda Village, Mbinga District, Tanzania. Miombo Woodland Research Project, Natural Resources Study Team Technical Report 5. Department of Soil Science, Faculty of Agriculture, Sokoine University of Agriculture, Morogoro; and Ministry of Agriculture, National Soil Service, Tanga.

Munsell Color Company, 1975. Munsell Soil Color Charts. Munsell Color Co. Inc. Baltimore.

Murphy, J. and Riley, J.P. 1962. A modified single solution method for determination of phosphate in natural waters. Anal. Chim. Acta 27:31-36.

Nelson, D.W. and Sommers, L.E. 1982. Total carbon, organic carbon and organic matter. In: Methods of Soil Analysis, part 2, 2nd edit. (eds. A.L. Page, R.H. Miller and D.R. Keeney), PP. 539 -579. ASA, SSSA Monograph no. 9, Madison, Wisconsin.

Nieuwolt, S. 1973. Rainfall and evaporation in Tanzania. Bureau of Resource Assessment and Land Use Planning (BRALUP) Research Paper No. 24. University of Dar es Salaam.

Sampson, D.N. and Wright, A.E. 1961. Geological survey of Tanganyika, Morogoro QD sheet 183. Ministry of Commerce and Industry, Geological Survey Division, Dodoma.

Soil Survey Staff, 1975. Soil Taxonomy. United States Department of Agriculture. Soil Conservation Services Agriculture Handbook no. 436. Virginia Polytechnic Institute and State University. 754 pp.

Soil Survey Staff, 1990. Keys to Soil Taxonomy. Agency for International Development, United States Department of Agriculture. Soil Management Support Services Technical Monograph no. 19. Virginia Polytechnic Institute and State University. 422 pp.

Thomas, G.W. 1982. Exchangeable cations. In: Methods of Soil Analysis part 2, 2nd edit. (eds. A.L. Page, R.H. Miller and R.D. Keeney), pp. 159-165. ASA, SSSA Monograph no. 9, Madison, Wisconsin.

University of Agriculture Farm Tanzania, for some crops under rainfed conditions. African Study Monographs (Kyoto), 15 (2): 97- 117.

Van Wambeke, A. 1982. Calculated soil moisture and temperature regimes of Africa. Soil Management Support Service (SMSS) Technical Monograph No. 3. Compilation of soil climatic regimes calculated by using a mathematical model developed by F. Newhall (Soil Conservation Service, USDA, 1972). Agency for International Development. Ithaca, NewYork.

Watanabe, F.S. and Olsen, S.R. 1965. Test of an ascorbic acid method for determining phosphorus in water and $NaHCO_3$ extracts from soil. Soil Sci. Soc. Am. Proc. 29:677-678.