SOILS OF KITULANGHALO FOREST RESERVE AREA, MOROGORO DISTRICT, TANZANIA

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This report includes 4 maps

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EXECUTIVE SUMMARY

The report presents the results of a detailed soil survey (publication scale 1:1,000) of 12 ha of land in the Kitulanghalo Forest Reserve in Morogoro, Tanzania.

The objective of the study was to make an inventory of the soils of the area in terms of their properties and ecological conditions; classify them using the existing soil classification systems; and present on a map the spatial distribution of the various soil types to assist in the selection of a site for the **Land Development Project for Sustainable Agriculture** at the Sokoine University of Agriculture, in Morogoro, Tanzania.

Climate
The climate of the place is hot and humid all the year round with a mean annual precipitation ranging from 700-1000 mm. The rainfall commences in October and ends in May. The driest months are June, July, August and September. The soil moisture regime, in general, is ustic, although in the valley bottoms aquic soil moisture regime may prevail. Mean annual air temperature of the Morogoro District is about 24°C and therefore the soil temperature regime can be described as isohyperthermic.

Geology and landform
The geology of the Kitulanghalo hill and the surrounding areas is described as Precambrian Usagaran metasedimentary rocks consisting of garnet-biotite gneisses with some kyanite bearing bands. In some places the rocks have been migmatized with the introduction of microcline and muscovite. In the low lying areas, mixed alluvial and colluvial deposits derived from the above mentioned rocks are present. The topography of the area has a rolling to steep convex slopes (10-20%) and undulating to rolling (slightly to highly dissected) linear slopes with shallow and deep gullies. Valley bottoms occur in between the convex slopes.

Vegetation
Three main vegetation types were identified:
Acacia-Combretum Woodland which is dominated mainly by *Acacia sp.* and *Dombeya sp.*; Semi-deciduous woodland dominated by *Scorodophloeus fischeri, Manilkara sulcata* and *Dobera loranthifolia*; and Zambezian miombo woodland dominated mainly by *Brachystegia spp.*

Soils
Thirteen mapping units were distinguished in the area and their distribution and extent are shown on the soil map which is presented at the scale of 1:1000. The soils of Kitulanghalo area are categorized into three groups including, (a) very deep, well drained, dark reddish brown to dark brown, sandy clay loams and

sandy clays on the steep convex slopes (b) very deep, well drained, dark brown to dark red, sandy clay loams and sandy clays on the linear slopes and (c) 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 were classified as Isohyperthermic, deep, mixed, Kanhaplic Haplustalfs and Isohyperthermic, deep, mixed Oxic Ustropepts. They represent 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 were classified as Isohyperthermic, deep, mixed, Typic Argiustolls, Isohyperthermic, deep, mixed, Typic Tropaquepts and Isohyperthermic, deep, mixed, Fluventic Ustropepts. These soils are grouped together as soils with low to intermediate pedogenic development. They have relatively lower Fe, Al and Ti contents and both high Si and Si/Al ratios. X-ray diffraction analysis indicated that the studied soils have a mixed clay mineralogy including kaolinite and mica. In one of the profiles with alkaline subsoil reaction, small amounts of smectite were identified.

The bulk densities of the surface horizons are relatively lower than those of the subsoil ranging from 1.1 to 1.6 g/cm^3 (surface) and from 1.4 to 1.9 g/cm^3 (subsoil). Total porosity ranged from 40-58% in the surface soils and from 28-32% in the subsoil. Available water holding capacities of the soils are between 155 and 248 millimeters per meter of soil.

The soils have overall poor supply of major nutrients i.e. nitrogen and phosphorus. The C/N ratios range from 8-12 which indicates good quality organic matter. Most of the basic cations e.g. Ca^{++}, Mg^{++} and K^{+} are medium to high in both surface horizons and subsoil. The capacity of the soils to retain nutrient agianst leaching is very low (CEC values ranges between 6 and 13 m.e./100g soil).

1. 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 when sound interpretations towards land use potential are to be made. 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. Proper site selection and soil characterization are also basic to the success of agronomic experiments and to the effectiveness of extending research results to a large number of farmers. 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.

The current study aims mainly at pedological characterization of a site for a project on land management techniques for sustainable agriculture. It forms a base for project site selection as it also encompasses spatial distribution of different soil types. In order that technologies emanating from different land management techniques become useful it was felt necessary that they should be carried out on a well characterized site to allow transfer of agro-technology to other areas with similar soil and ecological conditions.

Although there has been a considerable amount of research on the effects of different land-clearing methods and post-clearing soil management techniques on soil properties and crop performance (IBSRAM, 1989) there is still an urgent need for local verification on well known soils to permit widespread application of the results obtained.

The specific objectives of this study were therefore three-fold:

1. to make an inventory of the soils of Kitulanghalo area in terms of their properties and ecological conditions (including climate, geology, landforms and vegetation) using standard field and laboratory methods,

2. 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,

3. to present on a map the spatial distribution of the various soil types to assist in the selection of project site.

2. MATERIALS AND METHODS

2.1. Pre-field work

The following documents on the soils and the physical environment of the study area were used:

- Soil properties under five forest and woodland types in the Morogoro area, Tanzania (Fleetwood, 1981).
- Soils, physiography and agroecological zones of Tanzania (De Pauw, 1984).
- Pedological and edaphological properties of the soils of two soil associations in the Morogoro area, Tanzania (Moberg *et al.*, 1982).
- Study of the soils of a toposequence on metasedimentary rocks of the Morogoro Region (Tanzania) with special attention to texture determination and soil classification (Msanya, 1980).
- Mineralogy of some soils developed on metasedimentary rocks of Morogoro Region Tanzania (Msanya and Msaky, 1983).
- Potentials and constraints of the Kilosa area (Tanzania) for rainfed agriculture with emphasis on maize (Kimaro, 1989).
- Review of soil surveys (soil resource inventories) in Tanzania (Msanya and Magoggo, 1993).
- Soils and land suitability for irrigated rice cultivation of the Mkindo village irrigation scheme Morogoro (National Soil Service, 1986).

2.2. Field work

Before the commencement of the soil mapping, a topographic survey of the study area was carried out to obtain a topographic map for subsequent use in the field. A topographic map at scale 1:1000 (Map No. 1) was prepared with contour interval of 1 m, and served as the base map for the soil survey. Concurrently, a vegetation map (Map No. 2) was produced to show the distribution of plant species. Details about the various species are given in Appendix 1.

Soils were examined by means of hand augering. Grid soil survey method was used, whereby individual soil properties including thickness of topsoil, soil texture and color were recorded in a grid pattern. Lines were spaced at 10 m interval to obtain square grids on which observation points were to be located. The grids were plotted on the topographic map of the area. Each square grid on the topographic map was allocated observation number corresponding with an observation point on the ground. A total of 1,300 auger observations were described to a depth of 120 cm.

Comparison of the described soil augerings enabled soils similar in characteristics and in arrangement of soil layers (horizons) to be singled out and mapped. In this way 13 soil mapping units (section 3.2.6.) were distinguished and delineated on the topographic base map.

The next stage of the field survey involved selection of representative soils for which soil profile pits (8) were dug to a depth of 150 to 200 cm, examined and described in detail to further characterize the soil mapping units. The Guidelines for Soil Profile Description (FAO, 1990) were used for the description and measurement of soil characteristics. Soil colors were determined using Munsell Color Charts (Munsell Color, 1975). After soil profile description, soil samples from the different soil horizons were taken for physical, chemical and mineralogical analysis. Undisturbed (core) samples were also taken from each profile pit for the determination of bulk density and water retention characteristics. Appendix 2 presents the soil profile descriptions and their corresponding laboratory data. Appendix 3 provides a guide to general evaluation of soil chemical and physical properties.

2.3. Post-field work

2.3.1. Laboratory and office work

Analysis of chemical and physical properties of soils was as follows:
pH was measured potentiometrically in water and in 1M KCl at the ratio of 1/2.5 soil-water and soil-KCl respectively. Organic carbon was determined by the 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 absorbed NH_4^+ displaced by K^+ using 1M KCl and then determined by Kjeldal 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. CEC of clay was calculated using the formula developed by Baize (1993) which corrects for the CEC contributed by organic matter (OM) as follows:
$CEC_{clay} = \{[CEC_{soil} - (\%\ OM \times 2)]/\%\ clay\} \times 100$. Texture was determined by Bouyoucos hydrometer method (Day, 1965) after dispersing soil with sodium hexametaphosphate (calgon). Bulk density was determined using core sample method (Blake, 1965). Soil moisture characteristics were determined using pressure plate and membrane apparatus (Klute, 1986).

Samples for clay mineralogical analysis were prepared following the procedure outlined by Msanya *et al.* (1994) 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 vibrations for 5 minutes at 4000 rpm to allow thorough dispersion. The suspensions were transferred to glass cylinders and their volumes made up to 1000 ml and then allowed to settle. At appropriate time interval and depth, clay samples were siphoned out of the cylinders into glass beakers. The clay samples were mounted on glass slides for x-ray diffraction analysis. 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), transferred 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.

2.3.2. Preparation and presentation of soil map and legend

The soil map (Map No. 3) was produced at the scale of 1:1000 using a topographic base map of the same scale obtained during a topographic survey of the study area. On the soil map various mapped soil units are represented by different map polygons. On each map polygon a code representing a soil unit is indicated. Each map polygon and a code represent a soil mapping unit. Each mapping unit is briefly described in the map legend in terms of depth, drainage conditions, color and texture. The mapping units are considered to be homogeneous with regard to soil morphological characteristics and slope gradients. The units may contain some dissimilarities especially near the transitions to other units. These dissimilarities however, do not exceed 15 percent of a unit. Since the different soil types in Kitulanghalo were observed to be closely related to their topographic positions in the landscape, the mapping units are therefore grouped according to the topographic positions they occupy. The following topographic units were recognized:

S - convex slopes
D - dissected linear slopes (backslopes)
C - concave slopes

In the legend and on the map every mapping unit has a code referring to the topography. Further subdivision is based on slope and soil characteristics and is indicated by a number following the

capital letter. The column "soil description" in the legend gives the main field characteristics of the soil types i.e. soil depth, drainage, color, texture, and other diagnostic characteristics that separate each soil type from all other soil types described.

2.3.3. Soil classification and data processing

Using both field and laboratory data the identified soil types 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. This information is also included in the description of map units. Data processing and report writing was done using computer software available at Sokoine University of Agriculture, Morogoro.

3. RESULTS AND DISCUSSION

3.1. Physical environment

3.1.1. Location

The study area is located in the Kitulaghalo Forest Reserve about 40 km away from Morogoro Municipality towards Dar es Salaam. The forest reserve 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 boundaries of the study area of about 12.5 ha are as follows: the western boundary is at longitude E 37° 56' 27" and the eastern boundary (i.e. towards Dar es Salaam) is at longitude E 37° 56' 48". The southern boundary is the Morogoro-Dar es Salaam Highway running along latitude S 06° 42' 27". The northern boundary is about 160 m from the southern boundary. The centre of the experimental site is located at longitude E 37° 56' 39" and latitude S 06° 42' 29". Figure 1 presents the location of the study area.

3.1.2. Climate

The climate is hot and humid all the year round. The patchy rainfall data (Table 1) available from Kinonko Sisal Estate adjacent to the forest reserve indicate that the area has 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 will prevail. Such kind of regime is characterized by having 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.

3.1.3. Geology and landform

The underlying geology of Kitulaghalo Hill and surrounding area as indicated in the Morogoro Quarter Degree Sheet No. 183 (Sampson and Wright, 1961) can be described as Precambrian Usagaran metasedimentary rocks consisting of garnet-biotite gneisses with some kyanite bearing bands and in some places extensively migmatized with the introduction of microcline and muscovite. The

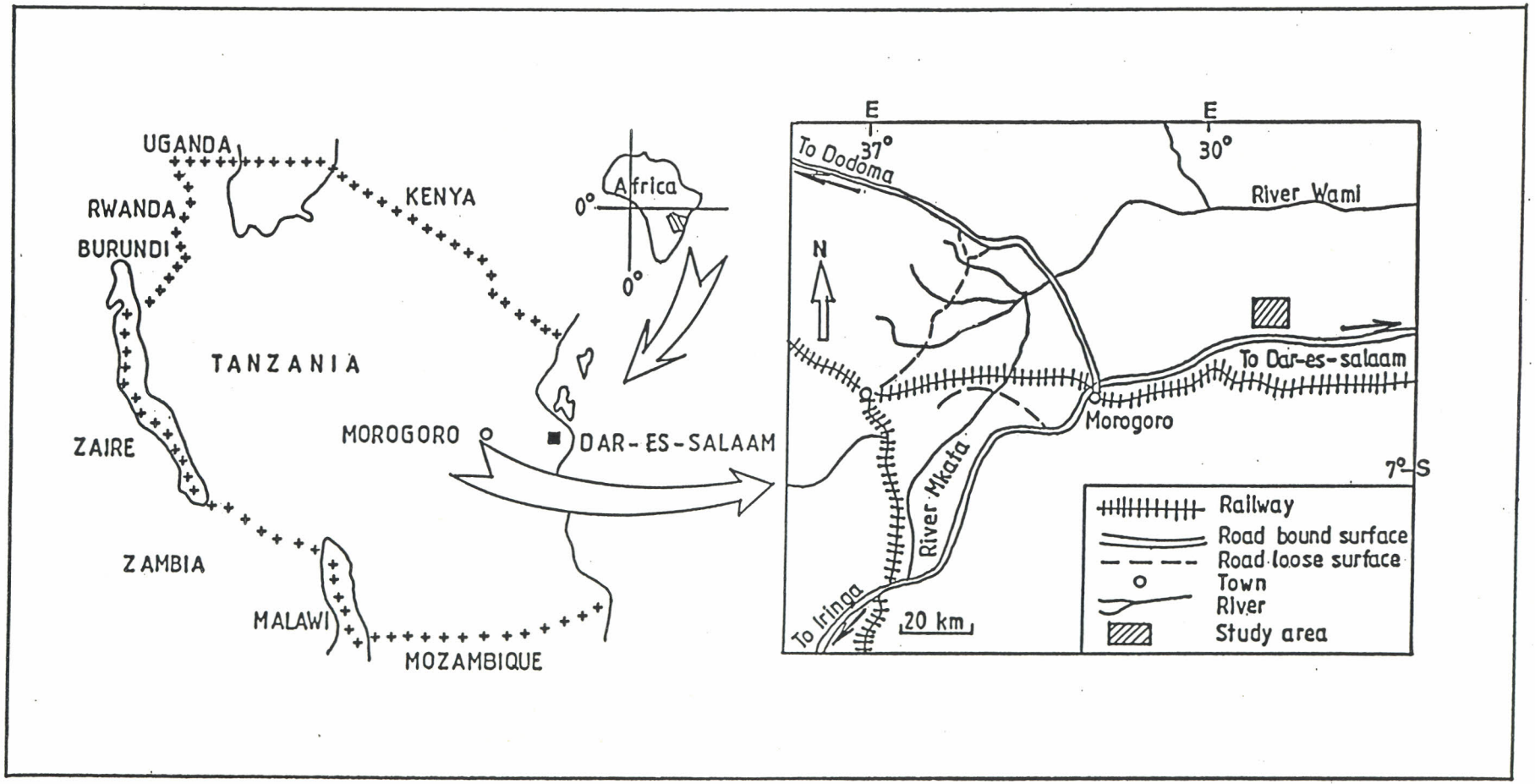


Figure 1. Location of the study area

formation may grade westwards into the migmatites of the Mindu-Nguru ya Ndege-Lolamahando area. Little graphite also occurs. In the valley bottoms mixed alluvial and colluvial deposits derived from the above mentioned rocks are present. These deposits are stratified with clayey, sands and loamy layers.

The Kitulanghalo Study Area is located on a piedmont plain (footslope) of the Kitulanghalo Hill (elevation 762 m asl). The general topography of the area has a rolling to steep convex slopes (10 - 22 percent) and undulating to rolling (slightly to highly dissected) linear slopes with shallow and deep gullies. Valley bottoms occur in between the convex slopes. They are concave in cross-section with fairly uniform sloping topography (5 - 12 percent). The altitude of the convex slopes ranges between 420 and 460 m asl and the dissected linear slopes between 420 and 430 m asl. The valley bottoms are 20 - 10 m lower than the convex slopes. A schematic cross-section indicating the variation in topography of the area is presented on the topographic map (Map No. 1) given in the back cover of this report.

3.1.4. Vegetation

Three main vegetation types were identified:

1. **Acacia - Combreturm woodland** which is dominated by *Acacia polyacantha, A. gerrardii, A. nigrescens, A. nilotica, Combretum molle, C. zeyheri, C. adenogonium, C. sp., Albizia anthelmintica, A. harveyi* and *Harrisonia abyssinica*.

2. **Semi-deciduous woodland** which is dominated by *Scorodophloeus fischeri, Manilkara sulcata, Dobera loranthifolia, Teclea nobilis, T. simplicifolia, Elaedendron buchananii, E. schlechteranum, Dombeya shupangae, Pteleopsis myrtifolia* and *Suregada zanzibariensis*.

3. **Zambezian miombo woodland** which is dominated by *Brachystegia boehmii, B. bussei, Julbernardia globiflora, Pterocarpus angolensis, Xeroderris stuhlmannii, Diplorhynchus condylocarpon, Afzelia quanzensis* and *Pseudolachnostylis maprouneifolia*.

Table 1. Rainfall figures (mm) of Kinonko Sisal Estate

Year	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sep	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	354	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

3.2. Soils

3.2.1. Physical properties

Four main soil physical properties, i.e. texture, bulk density, porosity (Table 2) and water retention characteristics (Figures 2 and 3) are presented and discussed.

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 densities of the topsoils are relatively lower than those of the subsoils; ranging from 1.1 to 1.6 g/cm^3 (topsoils) and 1.4 to 1.9 g/cm^3 for the subsoils. Profile KP1 has the highest bulk densities (1.6 -1.9 g/cm^3) while profiles KP4 and KP5 have the lowest bulk densities (1.2 -1.5 g/cm^3). Profiles KP7 and KP8 have relatively constant bulk densities throughout the profile (1.4 g/cm^3). Total porosity ranges from 40-58% in the topsoils and from 28-32% 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 2 shows the moisture characteristics of three depths (surface horizon, intermediate horizon and subsoil) of the studied profiles. Generally at any given water potential the volume fraction of water in the surface layer was 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 pore system is dominated by macropores. The intermediate and subsoil horizons have similar shapes of soil moisture characteristics to the surface horizons but differ by having lower water contents held at any water potential. This is mainly due to the reduction of total porosity in the subsoil.

Figure 3 shows water retention characteristics and pore size distribution of the studied soil profiles. The pattern is very similar to the one displayed by the moisture release curves. Generally the air-filled porosity values are high. Air-filled porosities vary from 12 to 17 percent (Table 2) in profiles KP1 and KP2 and from 15 to 23 percent in profiles KP3 to KP8. Profile KP1 has the lowest air-filled porosity values particularly in the subsoil (Table 2). The high air-filled 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 millimeters (Table 2).

3.2.2. Chemical properties

The analytical data of the studied soil profiles are given in Appendix 2. Table 3 and 4 present the chemical analytical data of topsoils and subsoils of Kitulanghalo soils. The following chemical properties are presented and discussed:

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 (map unit C5) 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 me/100 g soil).

Organic matter and nitrogen

Organic matter contents are generally medium to high corresponding to organic carbon levels between 1.5 to 3.0 percent in topsoils. The levels of organic matter in the subsoils are very low (less than 0.6 percent organic carbon). The soils of profile KP1 (map unit C5) are very low in organic matter (less than 0.4 percent organic carbon). In most soils absolute nitrogen levels are generally low (less than 0.2 percent). However, the quality of organic matter for these soils is good (C/N ratios of 10 to 15). The soils of profile KP1 have high C/N ratios.

Available phosphorus

All soils have low levels of available phosphorus (ranging from less than 1 to 7 mg P/kg). An 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 levels (17 and 9 mg P/kg respectively) of available phosphorus.

Cation exchange capacity (CEC)

The CEC reflects the capacity of the soil to retain nutrients against leaching. CEC values of most soils are very low to low ranging from 5 to 12 me/100g soil. The topsoil of profile KP8 has CEC values of 15 me/100g soil. The high CEC values are related to high organic matter content in this horizon. The subsoil of profile KP1 has CEC values ranging between 13 and 15 me/100g soil. The high CEC values are related to high amounts of calcium and sodium in the deeper subsoil of this profile.

Table 2. Texture, bulk density, total porosity, available water capacity and air capacity of selected soils of Kitulanghalo Forest Reserve

Profile No.	Depth (cm)	Texture (class)	Bulk density (g/cm3)	Total porosity (vol.%)	Air filled porosity (%)	Available water capacity (mm)	Available water capacity (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	61	

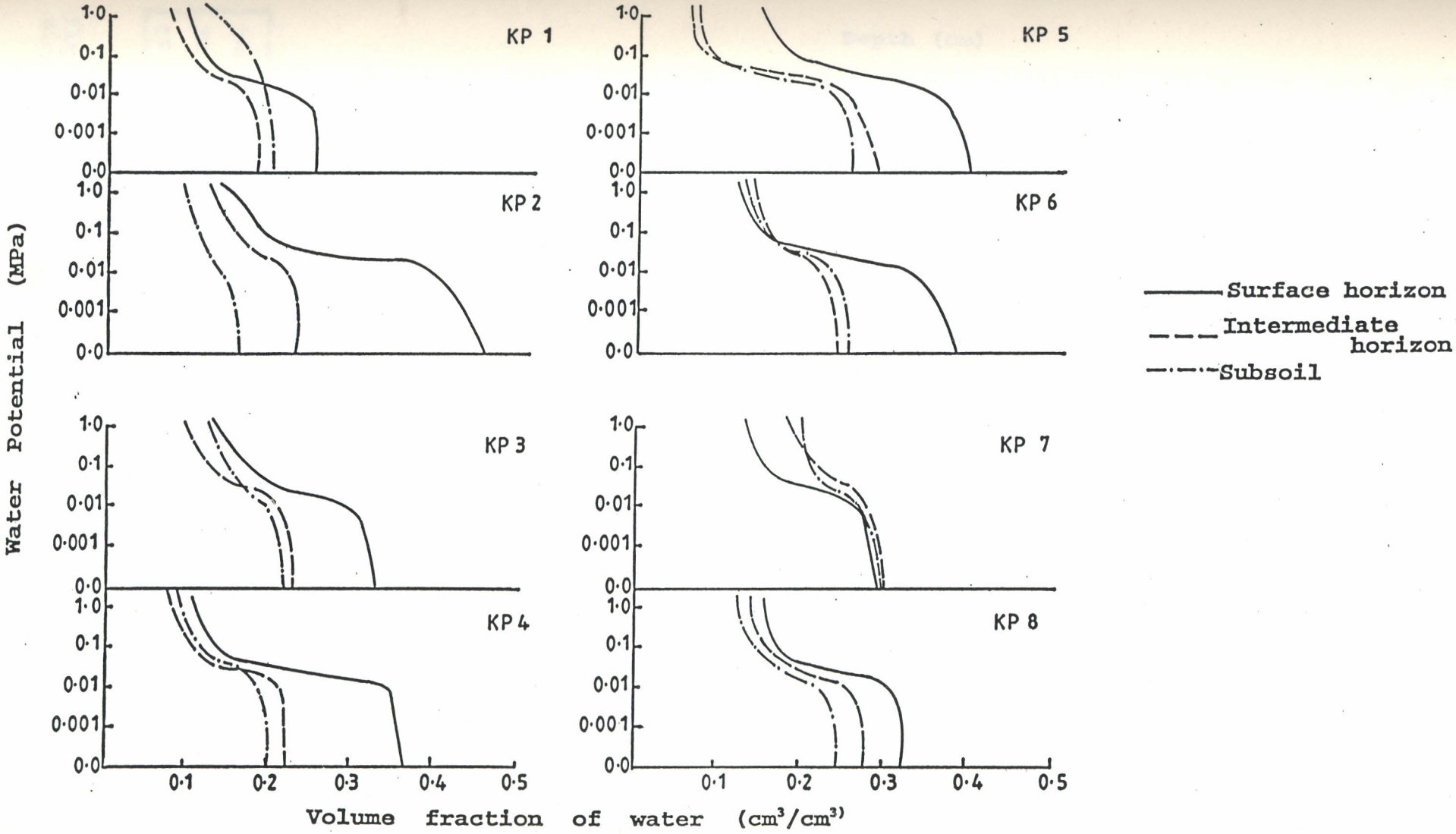
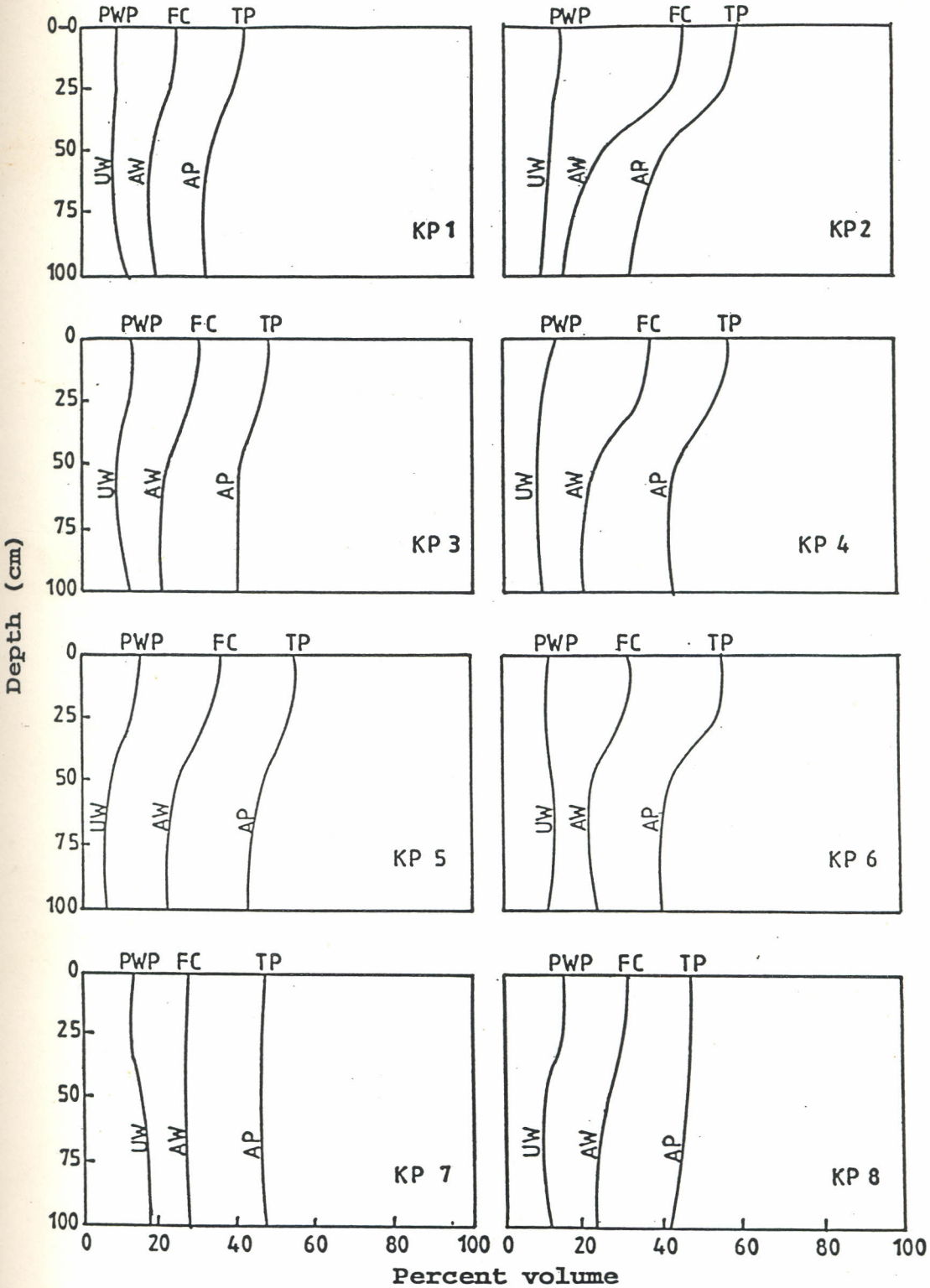


Figure 2. Moisture release characteristics of some soil profiles of Kitulanghalo Forest Reserve



PWP = Permanent Wilting Point	UW = Unavailable Water
FC = Field Capacity	AW = Available Water
TP = Total Porosity	AP = Air-filled Pores

Figure 3. Water retention characteristics and pore size distribution of some soil profiles of Kitulanghalo Forest Reserve

Table 3. Some chemical analytical data of Kitulanghalo Forest Reserve soils

Profile No.	Depth	pH_{H20}	Org. C (%)	Total N (%)	C/N	Available P mgP/kg	CEC me/100g	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 Kitulanghalo Forest Reserve soils

Profile No.	Map Unit	Exchangeable Calcium (me/100g soil)		Exchangeable Magnesium (me/100g soil)		Exchangeable Potassium (me/100g soil)		Exchangeable Sodium (me/100g soil)	
		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	C5	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	C3	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	C4	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	C1	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	C2	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	D1	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	S2	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	S3	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)

Exchangeable Calcium (Ca), Magnesium (Mg) and Potassium (K)

Table 4 presents the topsoil and subsoil exchangeable cations (Ca, Mg, and K) levels of Kitulanghalo soils. It appears that the levels of exchangeable Ca and Mg are medium to very high. Exchangeable K levels are medium in most topsoils. The levels of exchangeable K in profile KP1 (map unit C5) are low.

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

Sodium levels in the study area are very low (Table 4). They range from 0.01 to 0.17 me/100g soil both in topsoils and subsoils. The subsoils of profile KP1 (map unit C5) have high exchangeable sodium levels ranging from 1 to 5 me/100g soil. Generally soils with exchangeable sodium levels of more than 1 me/100g soil should be regarded as potentially sodic. Exchangeable sodium percentage (ESP) of most soils are non - sodic. The subsoils of profile KP1 (map unit C5) are moderately sodic to extremely sodic (ESP 13 to 40 percent).

Nutrient balance

In most soils calcium, magnesium and potassium are well balanced with calcium higher than magnesium and magnesium higher than potassium. Ca/Mg ratios are 2 and 3 which is considered to be an optimal range. The K levels are medium for most of the soils. The overall K/TEB (total exchangeable bases) ratios are above 2 percent which is said to be favourable for most tropical crops.

3.2.3. Soil clay mineralogy

The x-ray diffractograms of the studied soils are presented in Figure 4. 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; the peaks of 10Å and 3.3Å represent mica and those of 17Å and 12.4Å are those of Na-smectite.

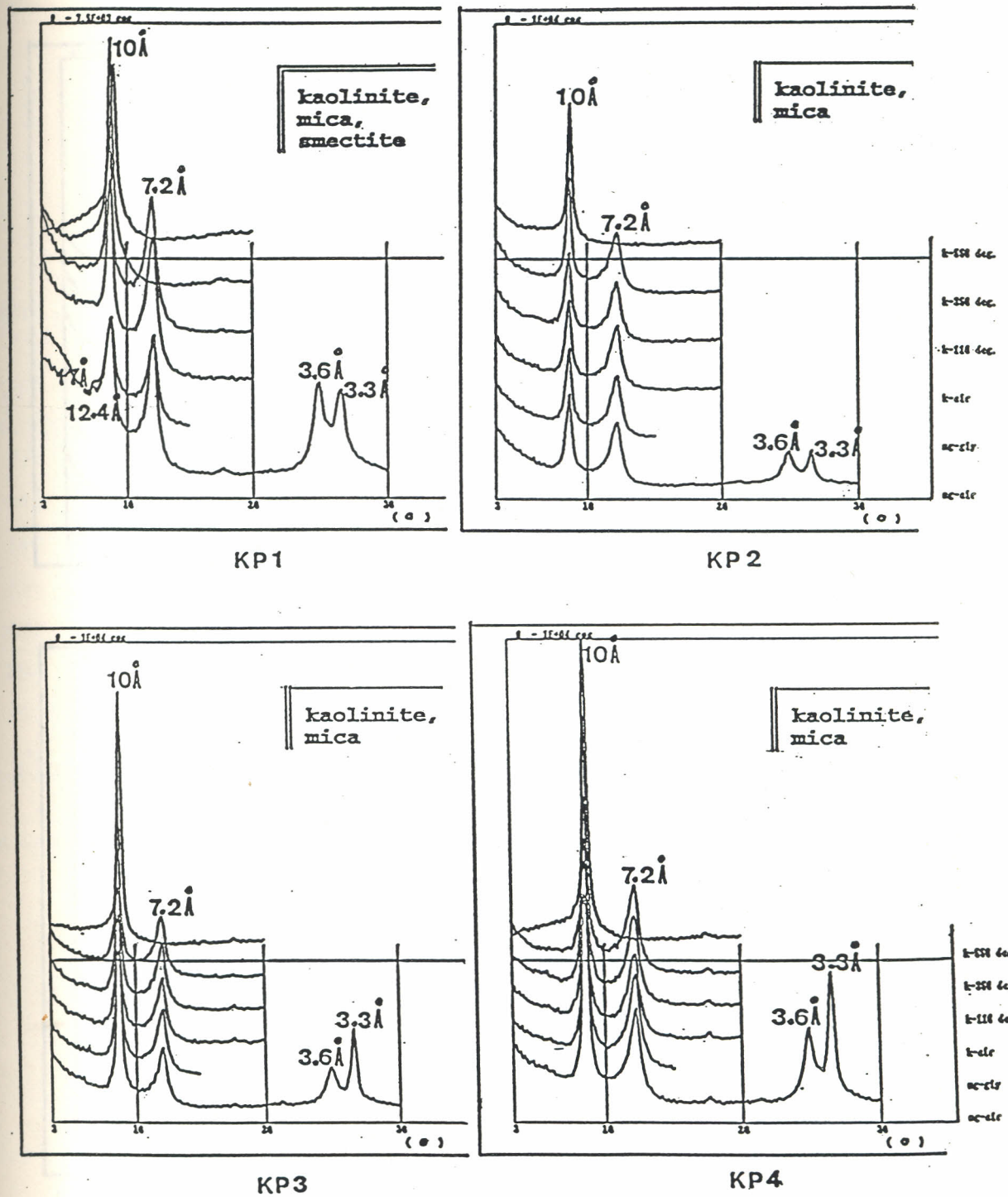


Figure 4. X-ray diffractograms of clay fractions of subsoil samples

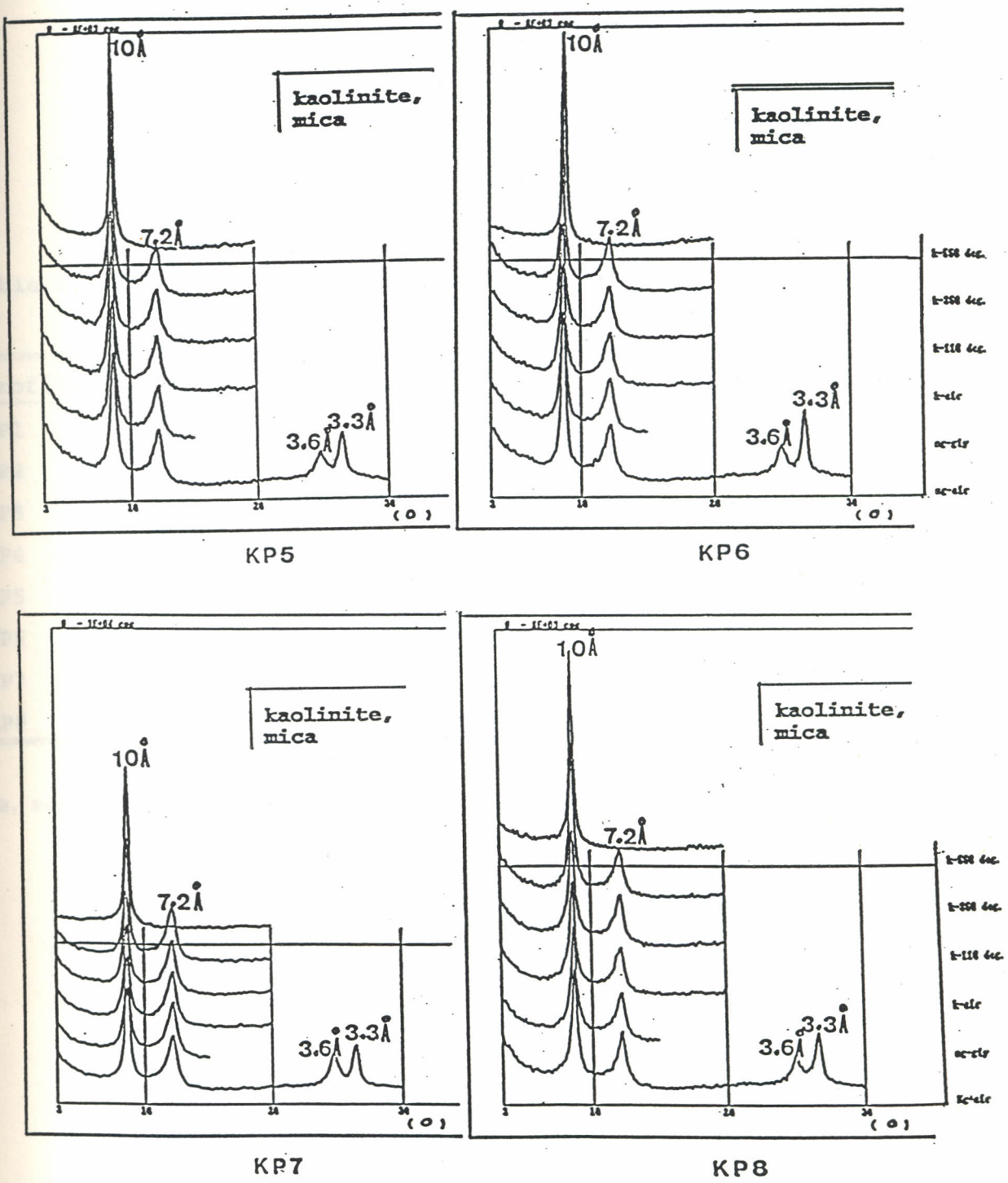


Figure 4. cont. X-ray diffractograms

Table 5. Relative mineralogical composition of subsoil clay fractions of Kitulanghalo Forest Reserve soils

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

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

3.2.4. 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 can be said to 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.

3.2.5. Soil classification

Table 7 gives a summary of the salient soil morphological and diagnostic features used in classifying the soils. Table 8 gives the soil names according to the two systems of classification used. The soils were categorized into three soil orders of the USDA Soil Taxonomy namely Inceptisol (KP1, KP4, KP5, KP8), Mollisol (KP2, KP3) and Alfisol (KP6, KP7) which respectively correspond to Cambisol, Phaeozem and Lixisol in the FAO-Unesco Classification.

Table 6. Total chemical analysis (% oxides) of the studied soils

Soil profile	Fe_2O_3	TiO_2	MnO_2	CaO	K_2	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 representative 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 USDA and/or in FAO-Unesco Systems.

Table 8. Classification of the studied representative soils

Profile	USDA Soil Taxonomy					FAO-Unesco Classification	
	Order	Suborder	Greatgroup	Subgroup	Family	Level-1	Level-2
KP1	Inceptisol	Aquept	Tropaquept	Typic Tropaquept	Isohyperthermic, deep, mixed, Typic Tropaquept	Cambisol	Gleyic Cambisol (CMg), sodic phase
KP2	Mollisol	Ustoll	Argiustoll	Typic Argiustoll	Isohyperthermic, deep, mixed, Typic Argiustoll	Phaeozem	Luvic Phaeozem (PHl)
KP3	Mollisol	Ustoll	Argiustoll	Typic Argiustoll	Isohyperthermic, deep, mixed, Typic Argiustoll	Phaeozem	Luvic Phaeozem (PHl)
KP4	Inceptisol	Tropept	Ustropept	Fluventic Ustropept	Isohyperthermic, deep, mixed, Fluventic Ustropept	Cambisol	Eutric Cambisol (CMe)
KP5	Inceptisol	Tropept	Ustropept	Fluventic Ustropept	Isohyperthermic, deep, mixed, Fluventic Ustropept	Cambisol	Eutric Cambisol (CMe)
KP6	Alfisol	Ustalf	Haplustalf	Kanhaplic Haplustalf	Isohyperthermic, deep, mixed, Kanhaplic Haplustalf	Lixisol	Haplic Lixisol (LXh)
KP7	Alfisol	Ustalf	Haplustalf	Kanhaplic Haplustalf	Isohyperthermic, deep, mixed, Kanhaplic Haplustalf	Lixisol	Haplic Lixisol (LXh)
KP8	Inceptisol	Tropept	Ustropept	Oxic Ustropept	Isohyperthermic, deep, mixed, Oxic Ustropept	Cambisol	Ferralic Cambisol (CMo)

3.2.6. Description of soil mapping units

Each mapping unit is described in a defined order. The first paragraph outlines the setting (landform and vegetation cover) of the unit. The second paragraph outlines the field characteristics of the soil profile; the major soil horizons are described in terms of color, texture, structure and thickness or depth range of the horizon. Soil names according to USDA Soil Taxonomy are given, together with the FAO-Unesco equivalents in brackets. Physical properties (drainage, effective rooting depth, bulk density, available water capacity) are discussed in the third paragraph. The fourth paragraph concerns the chemical properties of the soil. Physical and chemical properties are described in relative terms. Absolute values are presented under the chapters discussing the physical and chemical properties respectively.

Mapping unit S1

Very deep, well drained, dark reddish brown, sandy clays with thick to very thick, brown sandy clay loam topsoils; developed on colluvium derived from acid gneisses.

Setting:
This unit is on the piedmont plain (footslope) of Kitulanghalo hill. It occupies the lower part of the sloping to moderately steep convex slopes. The slopes are between 10 and 14 percent at mean elevation of about 425 m asl. The unit is occupied by dry miombo woodland (*Brachystegia, Acacia, Combretum*) with less dense grass vegetation (*Hyparrhenia, Panicum*) as undergrowth.

Soil profile characteristics:
The topsoil (more than 15cm thick) is brown, very friable, sandy clay loam and it is weakly structured. The subsoil to a depth of 150 cm and deeper is very friable, dark reddish brown, sandy clay and it is moderately structured. In the deeper subsoils, small and hard clay nodules are common. The soil classifies as **Kanhaplic Haplustalf (Haplic Lixisol)** and profile **KP7** is representative.

Soil physical properties:
The soil is well drained and the rooting depth is more than 150 cm. The available water capacity is high (156 mm/m). Bulk density is medium throughout the profile (1.4 g/cm^3).

Soil chemical properties:
Organic matter contents are moderate and very low in the subsoil. Nitrogen levels are low in the topsoils and very low in the subsoils. The available phosphorus is generally very low. Both topsoil and subsoil are slightly acid. The soil has high calcium and medium magnesium levels. Potassium levels are medium in the topsoil and low in the deeper subsoil. The overall capacity of the soil to retain nutrient is low.

Mapping unit S2

Very deep, well drained, dark reddish brown, sandy clays, with thick, very dark brown, sandy clay loam topsoils; developed on colluvium derived from acid gneisses.

Setting:
The unit occupies the same geomorphic position as unit S1. It occupies the middle part of the rolling convex slopes. The dominant slopes are between 14 and 18 percent and the mean elevation is at about 435 m asl. Typically the soil surface is stony (covering less than 1 percent of the soil surface). The unit is occupied by wet miombo woodland (*Brachystegia, Acacia, Combretum*) and grasses (*Hyparrhenia, Panicum*) as undergrowth. In some places the unit is planted with forest trees (pines and teaks).

Soil profile characteristics:
The topsoil 10 to 15 cm thick, is very dark brown, sandy clay loam and is weakly structured. The subsoil to a depth of 180 cm is very friable, dark reddish brown sandy clay and moderately structured. In the subsoil small and hard clay nodules are common. The soil classifies as **Kanhaplic Haplustalf (Haplic Lixisol)** and profile **KP7** is representative.

Soil physical properties:
The soil is well drained and the rooting depth is more than 120 cm. The available water capacity is high (156 mm/m). Bulk densities are medium (1.4 g/cm^3). Total porosity of these soils is high (47 percent).

Soil chemical properties:
In this soil phosphorus and nitrogen are clearly deficient with levels varying from very low to low. Topsoils have medium amounts of good quality organic matter. The soil is slightly acid. The soil has high calcium and medium magnesium levels. The capacity of the soil to retain nutrient is low.

Mapping unit S3

Very deep, well drained, dark brown to brown and dark reddish brown sandy clay loams with thin, very dark brown sandy clay loam topsoils; developed on colluvium derived from acid gneisses.

Setting:
The unit is on the same geomorphic position as unit S1. It occupies the upper part of the steep convex slopes. The dominant slopes are generally between 18 and 22 percent and the mean elevation is at about 445 m asl. The soil surface is stony covering about 1 percent of the soil surface. The unit is occupied by wet miombo woodland (*Brachystegia, Acacia, Combretum*) and grasses (*Hyparrhenia, Panicum*) as undergrowth.

Soil profile characteristics:
The topsoil (less than 10 cm thick) is very dark brown, friable, sandy clay loam and moderately structured. The subsoil to a depth of 25 cm is very dark grayish brown, very friable, sandy clay loam. In the deeper subsoil (50 cm and more) the soil is very friable, dark brown to brown and dark reddish brown, sandy clay loam. It is moderately structured and contains weathered, small and medium gneissic fragments and few hard clay nodules. The soil classifies as **Oxic Ustropept (Ferralic Cambisol)** and profile **KP8** is representative.

Soil physical properties:
The soil is well drained, the root zone extends to a depth of 150 cm and deeper. Available water capacity is high (181 mm/m). Bulk density is medium (1.4 g/cm^3) in the topsoil and high (1.5 g/cm^3) in the subsoil. Total porosity is high (47%) in the topsoil and medium in the subsoil (43%).

Soil chemical properties:
The soil has overall poor supply of major nutrients i.e. nitrogen, phosphorus. Potassium levels are high in the topsoil and low in the subsoil. The soil reaction is slightly acid. Topsoil has good quality organic matter. Calcium and magnesium levels are high. The soil has low capacity to retain nutrients.

Mapping unit S4

Very deep, well drained, dark brown, sandy clay loams and sandy loams with thin very dark grey sandy loam and sandy clay loam topsoils with pieces of weathering gneissic rocks in the deeper subsoils; developed on colluvium/alluvium derived from acid gneisses.

Setting:
The unit represents the old shallow incised gullies. The slopes are between 10 and 18 percent. The unit is covered by dense mixed vegetation including wet miombo woodland.

Soil profile characteristics:
The topsoil (less than 10 cm thick) is brown and very dark grey sandy loam and sandy clay loam. The subsoil is dark brown sandy clay loam and sandy loam with pieces of gneissic rocks.

Soil physical properties:
The rooting depth is good but may be impaired by the pieces of gneissic rocks occurring in the deeper subsoils. The unit is limited by severe rill and gully erosion.

Mapping unit D1

Very deep, well drained, dark brown, sandy clay loams with thick, black, sandy loam to sandy clay loam topsoils; developed on colluvium derived from acid gneisses.

Setting:
The unit occupies the lower part of the dissected straight slope (backslopes) of the piedmont plain (footslope) of Kitulanghalo hill. The slopes are between 6 and 15 percent and the mean elevation is at about 415 m asl. The lands are covered with dry miombo woodland mainly *Acacia* and less dense grass (*Panicum maximum*) vegetation as undergrowth.

Soil profile characteristics:
The topsoil is thick (10 to 15 cm thick) and the colour is black. Textures are sandy loam to sandy clay loam. The soil is friable and weakly structured. The subsoil is friable, dark brown, sandy clay loam and is moderately structured. It contains few weathered and fresh quartz and gneiss rock fragments. The soil classifies as **Kanhaplic Haplustalf (Haplic Lixisol)** and the profile **KP6** is representative.

Soil physical properties:
The soil is well drained. The rooting depth extends to a depth of 150 cm and deeper. Available water capacity is high (181 mm/m). Bulk density is low (1.2 g/cm^3) in the topsoil and high (1.5 to 1.6 g/cm^3) in the subsoil.

Soil chemical properties:
The soil has overall low supply of major nutrients i.e. nitrogen and phosphorus. Potassium levels are medium. Topsoils have moderate quality of organic matter. The soil reaction is slightly acid. Calcium and magnesium levels are medium to high. This soil has low capacity to retain nutrients.

Mapping unit D2

Very deep, well drained, dark red, sandy clays with thin brown to dark reddish brown sandy loam topsoils; developed on colluvium derived from acid gneisses.

Setting:
The unit occupies the upper part of the dissected straight slope (backslopes) of the piedmont plain (footslopes) of Kitulanghalo hill. The dominant slopes are between 15 and 19 percent and the mean elevation is at about 430 m asl. The unit is covered by both wet miombo woodland (*Brachystegia boehmii, Julbernardia globiflora, Pterocarpus angolensis, Xeroderris stuhlmannii*) and coastal forest element i.e. semi-deciduous woodland (*Scorodophloeus fischeri, Manilkara sulcata, Dobera loranthifolia, Teclea nobilis*) with grasses (*Panicum maximum, Sacciolepis curvata*) as undergrowth.

Soil profile characteristics:
The topsoil (less than 10 cm thick) is brown to dark reddish brown, very friable, sandy loam and is weakly structured. The subsoil is dark red, very friable, sandy clay and moderately structured.

Soil physical properties:
The drainage is well drained, and the rooting depth is more than 120 cm. The unit is severely affected by rill and gully erosion.

Mapping unit D3

Very deep,well drained, reddish brown, sandy clays to clays and sandy clay loams with thin brown sandy loam and sandy clay loam topsoils; developed on colluvium/alluvium derived from acid gneisses.

Setting:
The unit represents the old shallow and very deep incised gullies. The slopes are between 10 and 15 percent. The lands are covered with dense mixed vegetation including wet miombo woodland, semi-deciduous woodland and dry miombo woodland i.e. Acacia - Combretum woodland.

Soil profile characteristics:
The topsoil (less than 10 cm thick) is brown, sandy loam and sandy clay loam. The subsoil is reddish brown sandy clay to clay and sandy clay loam. In place the subsoil is dark brown to yellowish brown, mottled sandy clay.

Soil physical properties:
The unit is severely limited by gully erosion.

Mapping unit C1

Very deep, well drained, very dark greyish brown to dark yellowish brown, sandy loams with very thick, black sandy loam topsoils; developed on alluvium/colluvium derived from acid gneisses.

Setting:
The unit comprises the sloping concave valley bottoms on the piedmont plain (footslopes) of the Kitulanghalo hill. The mean elevation ranges between 415 and 420 m asl. The slopes are between 5 and 13 percent. The lands of this unit are covered with dry miombo woodland i.e. Acacia - Combretum woodland (*Acacia polyacantha, Acacia gerrardii, Acacia nilotica, Combretum molle, Albizia anthelmintica, Albizia harveyi*) with dense grass vegetation (*Panicum maximum, Themeda triandra, Hyparrhenia sp.*) as undergrowth.

Soil profile characteristics:
The topsoil is very thick (20 to 30 cm), black, friable, sandy loam, with weak structure. The subsoils are very dark greyish brown, very friable, sandy loam, with moderate and weak structure. Goethite fragments, clay nodules and features of clay movement in the deeper subsoil are common. The soil classifies as **Fluventic Ustropept (Eutric Cambisol)** and profile **KP4** is representative.

Soil physical properties:
The soil is well drained and the rooting depth is deeper than 150 cm. The available water capacity is high (200 mm/m). Bulk density is low (1.2 g/cm^3) in the topsoil and high (1.5 g/cm^3) in the subsoil.

Soil chemical properties:
The topsoils have high contents of organic mater and medium supply of major nutrients i.e. nitrogen, phosphorus and potassium. Soil reaction is slightly acid. Calcium and Magnesium levels are medium to high. The soil has low capacity to retain nutrients.

Mapping unit C2

Very deep, well drained to somewhat excessively drained, very dark greyish brown to dark yellowish brown, sandy loams to sandy clay loams with thick, black, sandy loam topsoils; developed on alluvium/colluvium derived from acid gneisses.

Setting:
The setting of this unit is similar to unit C1.

Soil profile characteristics:
The topsoil (10 to 20 cm thick) is black, very friable, sand loam and is moderately structured. The subsoil is very dark greyish brown to dark yellowish brown, very friable, sandy loam to sandy clay loam and weakly structured. In the deeper subsoils clay nodules and features of clay movement are common. The soil classifies as **Fluventic Ustropept (Eutric Cambisol)** and profile **KP5** is representative.

Soil physical properties:
The soil has very high (248 mm/m) water holding capacity. The soil is well drained to somewhat excessively drained and the rooting depth is more than 150 cm. Bulk density is low to medium (1.2 to 1.4 g/cm^3) in the topsoil and upper subsoil respectively. Bulk density is high (1.5 g/cm^3) in the deeper subsoils below a depth of 90 cm .

Soil chemical properties:
The topsoil have medium contents of organic matter and low to very low supply of major nutrients i.e. nitrogen and phosphorus. Potassium levels are medium to high. Calcium and magnesium levels are high. Soil reaction is slightly acid. The capacity of the soil to retain nutrients is low.

Mapping unit C3

Very deep, moderately well drained, dark brown sandy clay loams with black, sandy loam to sandy clay loam topsoils; developed on alluvium/colluvium derived from acid gneisses.

Setting:
The setting of this unit is similar to unit C1.

Soil profile characteristics:
The topsoil (10 to 15 cm thick) is black, friable, sandy loam to sandy clay loam and is weakly structured. The subsoil to a depth of 130 cm is dark brown, friable, sandy clay loam and moderately structured. In this horizon iron and clay nodules are common. In the deeper subsoil below a depth of 130 cm there is a dark red, extremely hard, massive, sandy clay layer. The soil classifies as **Typic Argiustoll (Luvic Phaeozem)** and profile **KP2** is representative.

Soil physical properties:
The soil has high (155 mm/m) water holding capacity. It is moderately well drained and the favourable rooting depth is 130 cm. Bulk density is low (1.1 g/cm^3) in the topsoil and high to very high (1.6 to 1.9 g/cm^3) in the subsoil.

Soil chemical properties:
The topsoil has high contents of organic matter with a good supply of major nutrients i.e. nitrogen, phosphorus and potassium. Nitrogen and phosphorus levels in the subsoil are very low. Calcium and magnesium levels are high. The capacity of this soil to retain nutrients against leaching is low.

Mapping unit C4

Very deep, moderately well drained, dark brown, sandy clay loams with thick black, sandy clay loam topsoils; developed on alluvium/colluvium derived from acid gneisses; with mixed, mottled, dark brown and dark yellowish brown, sandy clay loams and sandy loams in the deeper subsoils.

Setting:
The setting of this unit is similar to unit C1.

Soil profile characteristics:
The surface horizon is thick (20 cm) and colour is black. Textures are sandy clay loam. The soil is friable and weakly structured. The subsoil to a depth of 110 cm is dark brown, friable, sandy clay loam. The structure is moderate. In the deeper subsoil below a depth of 110 to 190 cm the soil is a friable, mixed, mottled, dark brown and dark yellowish brown sandy clay loams and sandy loams. The structure of this horizon is mixed (weak and massive). The soil classifies as **Typic Argiustoll (Luvic Phaeozem)** and profile **KP3** is representative.

Soil physical characteristics:
The soil has high (184 mm/m) water holding capacity. It is moderately well drained and the rooting depth is more than 120 cm. Bulk density is medium (1.4 g/cm^3) in the topsoil and high (1.6 g/cm^3) in the subsoil.

Soil chemical properties:
Organic contents of this soil is medium in the topsoil and low in the subsoil. The soil has low to very low nitrogen levels. Phosphorus and potassium are medium in the topsoil and low to very low in the subsoil. Calcium levels are medium in the topsoil and low in the subsoil. The soil has medium to high magnesium levels. The overall capacity to retain nutrients is very low.

Mapping unit C5

Very deep, imperfectly drained, very dark brown to very dark greyish brown, mottled sandy loams to sandy clay loams and sandy clays with thick black sandy loam topsoils; developed on alluvium/colluvium derived from acid gneisses.

Setting:
The setting of this unit is similar to unit C1.

Soil profile characteristics:
The topsoil (10 to 20 cm thick) is black, friable, sandy loam and weakly structured. The subsoil below a depth of 20 to 55 cm is very dark grey to very dark greyish brown, friable, mottled sandy loam to sandy clay loam and is weakly structured. In the deeper subsoil below a depth of 55 to 190 cm the soil is very dark greyish brown, extremely hard and very firm, mottled, sandy clay. The structure is massive. Clay and carbonate nodules are common. The soil classifies as **Typic Tropaquept (Gleyic Cambisol, Sodic phase)** and profile **KP1** is representative.

Soil physical properties:
The soil is imperfectly drained. Rooting conditions are restricted by the poor aeration and high sodium levels in the subsoils. Available water capacity is high (162 mm/m). Total porosity is low (32 percent). The soil has high (1.6 to 1.8 g/cm^3) bulk density.

soil chemical properties:
Organic matter content of this soil is very low. Nitrogen, phosphorus and potassium levels are very low. Calcium and magnesium levels are medium to high. Soil reaction is slightly acid in the topsoil and mildly alkaline in the subsoil. Exchangeable sodium percentage (ESP) is high (13 to 40 percent) in the subsoil. The subsoil is slightly to extremely sodic.

Mapping unit C6

Very deep, imperfectly drained, dark brown to very dark grey, mottled, sandy loams to sandy clay loams and sandy clays with thin very dark grey topsoils; developed on alluvium/colluvium derived from acid gneisses.

Setting:
This unit comprises the shallow incised gullies on the sloping valley bottoms. Other setting conditions of this unit are similar to unit C1

Soil profile characteristics:
The topsoil less than 10 cm thick is very dark grey, friable sandy loam and is weakly structured. The subsoil is dark brown to very dark grey, friable, mottled sandy loam to sandy clay loam and sandy clay and is weakly structured.

Soil physical properties:
The soil is imperfectly drained. The rooting depth is restricted by poor aeration of this soil. The unit is limited by rill and gully erosion.

4. CONCLUDING REMARKS

Based on the patchy climatic data available, the studied 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 January) and long rains crop (February to May).

On the basis of the existing topography, the area can be divided into three topographic levels:
- convex slopes (10 to 12%)-rolling to steep relief
- dissected linear slopes(6 to 19%)-undulating to rolling relief
- valley bottoms (5 to 12%)-fairly uniform slope.

The dissected linear slopes may be too eroded to be useful for crop production. The convex slopes on the other hand, could with careful management be utilized for crop production. The areas with steep relief could or should be reserved for catchment forest or recreation. Apart from localized areas where drainage is imperfect due to poor soil physical conditions the valley bottoms could present a very high potential for crop production. Experience from similar areas near Kitulanghalo (Rubungo, Fulwe and Maseyu villages) has shown that the valley bottoms are extensively being used for crop production throughout the year. During the seasons, the valley bottoms are used to grow vegetable crops and maize and during the rainy seasons, they are cropped with rice.

In general the soils of the Kitulanghalo Forest Reserve 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 the piedmont of Kitulanghalo hill. The Mollisols and Inceptisols occur in the gently undulating concave valley bottoms. 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.

Generally in most of the studied soils, the textures of the topsoils are predominantly sandy loam grading to sandy clay loam and sandy clay with depth. Moreover, they are well drained and well aerated, especially those occurring on the convex slopes and linear slopes. Because of the sandy texture and relatively low subsoil organic matter content, the soils have poor nutrient retention and have overall low supply of major nutrients i.e. Nitrogen and Phosphorus.

Most of the soils are slightly acid in reaction 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.

Continuous utilization of the soils for crop production without proper management could result into drastic reduction of organic matter and ultimately create nutrient imbalance. It would be recommended therefore to use some amounts of inorganic fertilizers from the very beginning if these soils are to be used for crop production. Reduction of soil organic matter through cultivation could also lead to the deterioration of the soil structure thus causing surface runoff and accelerated soil erosion.

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APPENDICES

Appendix 1. Vegetation species of Kitulanghalo Forest Reserve

REPORT ON A SURVEY OF SPECIES IN KITULANGHALO FOREST RESERVE - AUGUST 1992

SUMMARY

A survey of plant species mainly shrubs and trees was done in 20 blocks at Kitulanghalo where the Department of Soil Science, SUA intends to establish some research trials. Some grasses and all trees and shrubs were identified by Dr. R.P.C. Temu and Mr. C.K. Ruffo using experience and field keys. Some difficult species were collected and identified at Dar es Salaam University herbarium. Three main vegetation types were identified:

1. **Acacia - Combreturm woodland** which is dominated by *Acacia polyacantha, A. gerrardii, A. nigrescens, A. nilotica, Combretum molle, C. zeyheri, C. adenogonium, C. sp., Albizia anthelmintica, A. harveyi* and *Harrisonia abyssinica*.

2. **Semi-deciduous woodland** which is dominated by *Scorodophloeus fischeri, Manilkara sulcata, Dobera loranthifolia, Teclea nobilis, T. simplicifolia, Elaedendron buchananii, E. schlechteranum, Dombeya shupangae, Pteleopsis myrtifolia* and *Suregada zanzibariensis*.

3. **Zambezian miyombo woodland** which is dominated by *Brachystegia boehmii, B. bussei, Julbernardia globiflora, Pterocarpus angolensis, Xeroderris stuhlmannii, Diplorhynchus condylocarpon, Afzelia quanzensis* and *Pseudolachnostylis maprouneifolia*.

The following tables show lists of plant species which were identified in 20 different blocks.

Table 1: Species found in block 1

Botanical name	Habitat	Family
Acacia polyacantha ssp. campylacantha	T	Leguminosae-Mimosoideae
Brachystegia boehmii	T	Leguminosae-Caesalpinioideae
Combretum adenogonium	T	Combretaceae
Flueggea virosa	S,ST	Euphorbiaceae
Dombeya shupangae	ST	Sterculiaceae
Harrisonia abyssinica	S,ST	Simaroubaceae
Acacia gerrardii	ST	Leguminosae-Mimosoideae
Dalbergia melanoxylon	T	Leguminosae-Papillionoideae
Hyparrhenia sp.	G	Poaceae
Commiphora africana	ST	Burseraceae
Indigofera rhinchocarpa	S	Legum inosae-Papillionoideae
Markhamia obtusifolia	ST	Bignoniaceae
Elaedendron buchananii	T	Celastraceae
Dalbergia nitidula	ST	Leguminosae-Papillionoideae
Caturanegam spinosa	ST	Rubiaceae
Annona senegalensis	S,ST	Annonaceae
Sclerocarya birrea ssp. caffra	T	Anacardiaceae
Dichrostachys cinerea	S,ST	Leguminosae-Mimosoideae
Bridelia cathartica	S,ST	Euphorbiaceae
Tamarindus indica	T	Leguminosae-Caesalpinioideae
Pteleopsis myrtifolia	T	Combretaceae
Panicum maximum	G	Poaceae
Euphorbia candelabrum	T	Euphorbiaceae
Rhus natalensis	S,ST	Anacardiaceae
Sideroxylon inerme ssp. diospyroides	T	Sapotaceae
Grewia similis	S	Tiliaceae
Euclea sp.	ST	Ebenaceae
Boscia salicifolia	T	Capparidaceae
Lonchocarpus bussei	T	Leguminosae-Papillionoideae

Table 2: Block 2

Botanical name	Habit	Family
Combretum zeyheri	T	Combretaceae
Harissonia abyssinica	S,ST	Simaroubaceae
Flueggea virosa	S,ST	Euphorbiaceae
Acacia gerrardii	T	Leguminosae-Mimosoideae
Annona senegalensis	S,ST	Annonaceae
Acacia nigrescens	T	Leguminosae-Mimosoideae
Markhamia obtusifolia	ST	Bignoniaceae
Hyphaene coriacea	T	Palmae
Combretum adenogonium	T	Combretaceae
Acacia polyacantha ssp. campylacantha	T	Leguminosae-Mimosoideae
Dombeya shupangae	ST	Sterculiaceae
Albizia harveyi	T	Leguminosae-Mimosoideae
Caturanegam spinosa	ST	Rubiaceae
Diplorhynchus condylocarpon	T	Apocynaceae

Table 3: Block 3

Botanical name	Habit	Family
Acacia nigrescens	T	Leguminosae-Mimosoideae
Dombeya shupangae	ST	Sterculiaceae
Brachystegia boehmii	T	Leguminosae-Caesalpinioideae
Flueggea virosa	S,ST	Euphorbiaceae
Hyparrhenia sp.	G	Poaceae
Panicum maximum	G	Poaceae
Pterocarpus angolensis	T	Leguminosae-Papillionoideae
Annona senegalensis	S,ST	Annonaceae
Combretum zeyheri	ST	Combretaceae
Markhamia obtusifolia	ST	Bignoniaceae
Commiphora africana	ST	Burseraceae
Themeda triandra	G	Poaceae

Table 4: Block 4

Botanical name	Habit	Family
Pterocarpus angolensis	T	Leguminosae-Papillionoideae
Combretum zeyheri	ST	Combretum
Dombeya shupangae	ST	Sterculiaceae
Indigofera rhinchocarpa	S	Leguminosae-Papillionoideae

Acacia gerrardii	T	Leguminosae-Mimosoideae
Hyparrhenia sp.	G	Poeceae
Caturanegam spinosa	ST	Rubiaceae
Albizia harveyi	T	Leguminosae-Mimosoideae
Terminalia mollis	T	Combretaceae
Combretum collinum	T	Combretaceae
Acacia polyacantha spp. campylacantha	T	Leguminosae-Mimosoideae
Vernonia cotorata	S	Compositae
Brachystegia boehmii	T	Leguminosae-Caesalpinioideae
Combretum adenogonium	T	Combretaceae
Annona senegalensis	S,ST	Annonaceae
Rytigynia sp.	S	Rubiaceae
Xeroderris stuhlmanaii	T	Leguminosae-Papillionoideae
Combretum sp.	ST	Combretaceae
Afzelia quanzensis	T	Leguminosae-Caesalpinioideae
Elaedendron buchanannii	T	Celastraceae
Tamanindus indica	T	Leguminosae-Caesalpinioideae
Dombeya shupangae	ST	Sterculiaceae

Table 5: Block 5

Botanical name	Habit	Family
Terminalia sambesiaca	T	Combretaceae
Panicum maximum	G	Poaceae
Combretum sp.	ST	Combretaceae
Pteleopsis myrtifolia	T	Combretaceae
Asparagus falcatus	S/C	Liliaceae
Scorodophloeus fischeri	T	Leguminosae-Caesalpinioideae
Acacia pentagona	S/C	Leguminosae-Mimosoideae
Hippocratea sp.	S	Celastraceae
Dalbergia sp.	C	Leguminosae-Caesalpinioideae
Clerodendrum capitatum	S	Verbanaceae
Tamarindus indica	T	Leguminosae-Caesalpinioideae
Allophylus africanus	S,ST	Sapindaceae
Brachystegia boehmii	T	Leguminosae-Caesalpinioideae
Tylosema fassoglensis	C	Leguminosae-Caesalpinioideae
Grewia plantyclada	S	Tiliaceae

Ochna sp.	ST	Ochnaceae
Lecaniodiscus flaxinifolius	ST	Sapindaceae
Hippocratea buchananii	S	Celastraceae
Commiphora eminii ssp. zimermannii	T	Burseraceae
Dobera loranthifolia	T	Salvadoraceae
Brachystegia boehmii	T	Leguminosae-Caesalpinioideae
Dombeya shupangae	ST	Sterculiaceae
Pseudolachnostylis maprouneifolia	T	Euphorbiaceae

Table 6: Block 6

Botanical name	Habit	Family
Rhus natalensis	S,ST	Anacardiaceae
Dombeya shupangae	ST	Sterculiaceae
Acacia nigrescens	T	Leguminosae-Mimosoideae
Albizia anthelmintica	T	Leguminosae-Mimosoideae
Hyparrhenia sp.	G	Poaceae
Diospyros fischeri	S,ST	Ebenaceae
Brachystegia boehmii	T	Leguminosae-Caesalpinioideae
Commiphora africana	T	Burseraceae
Rhus natalensis	S,ST	Anacardiaceae
Acacia nilotica	ST	Leguminosae-Mimosoideae
A. gerrardii	T	Leguminosae-Mimosoideae
A. polyacantha ssp. campylacantha	T	Leguminosae-Mimosoideae
Lonchocarpus bussei	T	Leguminosae-Papillionoideae
Flueggea virosa	S,ST	Euphorbiaceae
Combretum collinum	T	Combretaceae
Xeroderris stuhlmannii	T	Leguminosae-Papillionoideae
Margaritaria discoidea	ST	Euphorbiaceae
Acacia nilotica	ST	Leguminosae-Mimosoideae
Terminalia mollis	T	Combretaceae
Dombeya shupangae	ST	Sterculiaceae
Senna petersiana	ST	Leguminosae-Caesalpinioideae
Ziziphus mucronata	ST	Rhamnaceae
Pavetta sp.	S	Rubiaceae
Dalbergia sp.	S	Leguminosae-Papillionoideae

Harrisonia abyssinica	S,ST	Simaroubaceae
Ficus stuhlmannii	T	Moraceae
Grewia sp.	S	Tiliaceae
Socrodophloeus fischeri	T	Leguminosae-Caesalpinioideae
Manilkara sulcata	T	Sapotaceae
Euphorbia nyikae	T	Euphorbiaceae
Steganotaenia araliacea	ST	Umbelliferae
Sclerocarya birrea ssp. caffra	T	Anacardiaceae
Commiphora sp.	T	Burseraceae

Table 7: Block 7 - 8

Botanical name	Habit	Family
Socrodophloeus fischeri	T	Leguminosae-Caesalpinioideae
Asteranthe asterials	S	Annonaceae
Uvaria lucida ssp. lucida	S	Annonaceae
Teclea nobilis	ST	Rutaceae
Abutilon sp.	S	Malvaceae
Lecaniodiscus flaxinifolius	ST	Sapindaceae
Panicum maximum	G	Poaceae
Boscia salicifolia	T	Capparidaceae
Euclea sp.	ST	Ebenaceae
Acacia nigrescens	T	Leguminosae-Mimosoideae
Elaedendron schlechteranum	T	Celastraceae
Dombeya shupangae	ST	Sterculiaceae
Sterculia quingueloba	T	Sterculiaceae
Dichrostachys cinerea	S,ST	Leguminosae-Mimosoideae
Sclerocarya birrea ssp. caffera	T	Anacardiaceae
Combretumn sp.	ST	Combretaceae
Hoslundia opposita	S	Labiatae

Table 8: Block 9 - 10

Botanical name	Habit	Family
Sacciolepis curvata (Ukoka)	G	Poaceae
Dombeya shupangae	ST	Sterculiaceae
Indigofera rhinchocarpa	S	Leguminosae-Papillionoideae
Acacia gerrardii	T	Leguminosae-Mimosoideae
Combretum zeyheri	ST	Combretaceae
Markhamia obtusifolia	ST	Bignoniaceae
Senna petersiana	ST	Leguminosae-Caesalpinioideae
Flueggea virosa	S,ST	Euphorbiaceae

Lannea schweinfurthii var. stuhlmannii	T	Anacardiaceae
Combretum molle	T	Combretaceae
Vernonia colorata	S	Compositae
Cussonia arborea	T	Araliaceae
Dombeya shupangae	ST	Sterculiaceae
Acacia polyacantha ssp. campylacantha	T	Leguminosae-Mimosoideae
Grewia bicolor	S,ST	Tiliaceae
Albizia versicolor	T	Leguminosae-Mimosoideae
Dobera loranthifolia	T	Salvadoraceae
Bauhinia loeseniana	S	Leguminosae-Caesalpinioideae
Afzelia quanzensis	T	Leguminosae-Caesalpinioideae
Uvaria lucida	S	Annonaceae
Dombeya cincinnata	S,ST	Sterculiaceae
Suregada zanzibariensis	S,ST	Euphorbiaceae
Steculia africana	T	Sterculiaceae
Euphorbia candelabrum	T	Euphorbiaceae
Dobora loranthifolia	T	Salvadoraceae
Cussonia arborea	T	Araliaceae
Erythroxylum emarginatum	S	Erythroxylaceae
Croton polytrichus	S	Euphorbiaceae
Lecaniodiscus flaxinifolius	ST	Sapindaceae
Cissus oliveri	HC	Vitaceae

Table 9: Block 11 - 12

Botanical name	Habit	Family
Dobera loranthifolia	T	Salvadoraceae
Teclea nobilis	ST	Rutaceae
Scorodophloeus fischeri	T	Leguminosae-Caesalpinioideae
Erythroxylum emarginatum	S	Erythroxylaceae
Apocynaceae genus nov.	ST	Apocynaceae
Teclea simplicifolia	ST	Rutaceae
T. nobilis	ST	Rutaceae
Lannea schiweinfurthii ssp. stuhlmannii	T	Anacardiaceae
Adansonia digitata	T	Bombacaceae
Manilkara sulcata	T	Sapindaceae
Commiphora eminii ssp. zimmermannii	T	Burswraceae
Panicum maximum	G	Graminae/Poaceae
Albizia anthelmintica	ST	Leguminosae-Mimosoideae
Dombeya shupangae	ST	Sterculiaceae

Albizia petersiana	T	Leguminosae-Mimosoideae
A. harveyi	T	Leguminosae-Mimosoideae
Combretum zeyheri	ST	Combretaceae
Pteleopsis myrtifolia	T	Combretaceae
Annona senegalensis	S,ST	Annacardiaceae Papilionoideae
Xeroderris stuhlmannii	T	Legumimosae
Combretum adenogonium	T	Combretaceae
Combretum sp.	ST	Combretaceae

Table 10: Block 13 - 14

Botanical name	Habit	Family
Markhamia obtusifolia	ST	Bignoniaceae
Combretum molle	T	Combretaceae
Julbernerdia globiflora	T	Leguminosae-Caesalpinioideae
Monodora grandidieri	S	Annonaceae
Grewia bicolor	S,ST	Tiliaceae
G. platyclada	S	Tiliaceae
Lannea schweinfurthii ssp. stuhlmannii	T	Anacardiaceae
Scorodophloeus fischeri	T	Leguminosae-Caesalpinioideae
Lannea schimperi	T	Anacardiaceae
Combretum molle	T	Combretaceae

Table 11: Block 15-16

Botanical name	Habit	Family
Xeroderris stuhlmannii	T	Leguminosae-Papillionoideae
Julbernardia globiflora	T	Leguminosae-Caesalpinioideae
Acacia nigrescens	T	Leguminosae-Mimosoideae
A. gerrardii	T	Leguminosae-Mimosoideae
Albizia harveyi	T	Leguminosae-Mimosoideae
Dombeya shupangae	ST	Sterculiaceae
Brachystegia boehmii	T	Leguminosae-Caesalpinioideae
Combretum molle	T	Combretaceae
Boscia salicifolia	T	Capparidaceae
Pteleopsis myrtifolia	T	Combretaceae
Pterocarpus angolensis	T	Leguminosae-Papillionoideae
Grandidiera boirinii	S,ST	Flacourtiaceae

Bridelia cathartica	S,ST	Euphorbiaceae

Table 12 Block 17 - 18

Botanical name	Habit	Family
Brachystegia boehmii	T	Leguminosae-Caesalpinioideae
B. bussei	T	Leguminosae-Caesalpinioideae
Pterocarpus angolensis	T	Leguminosae-Papillionoideae
Panicum maximum	G	Graminae/Poaceae
Themeda triandra	G	Graminae/Poaceae
Combretum molle	T	Combretaceae
Indigofera rhinchocarpa	S	Leguminosae-Papillionoideae
Dombeya shupangae	ST	Sterculiaceae
Xeroderris stuhlmannii	T	Leguminosae-Papillionoideae
Dalbergia melanoxylon	T	Leguminosae-Papillionoideae
Diplorynchus condylocarpon	T	Apocynaceae
Sclerocarya birrea ssp. caffra	T	Anacardiaceae
Flueggea virosa	S,ST	Euphorbiaceae
Acacia nilotica	ST	Leguminosae-Mimosoideae
Boscia salicifolia	T	Capparidaceae
Rhus natalensis	S,ST	Anacardiaceae
Acacia polyacantha ssp. campylacantha	T	Leguminosae-Mimosoideae
Brachystegia boehmii	T	Leguminosae-Caesalpinioideae
Julbernardia globiflora	T	Leguminosae-Caesalpinioideae
Acacia gerrardii	T	Leguminosae-Caesalpinioideae

Table 13: Block 19

Botanical name	Habit	Family
Julbernardia globiflora	T	Leguminosae-Caesalpinioideae
Dombeya shupangae	ST	Sterculiaceae
Brachystegia boehmii	T	Leguminosae-Caesalpinioideae
Acacia gerrardii	T	Leguminosae-Caesalpinioideae
A. senegalensis	ST	Leguminosae-Mimosoideae

Xeroderris stuhlmannii	T	Leguminosae-Papillionoideae
Acacia nigrescens	T	Leguminosae-Mimosoideae
Margaritaria discoidea	ST	Euphorbiaceae
Dalbergia melanoxylon	ST	Leguminosae-Papillionoideae
Pseudolachnostylis maprouneifolia	T	Euphorbiaceae

Table 14: Block 20

Botanical name	Habit	Family
Acacia nilotica	T	Leguminosae-Mimosoideae
A. polyacantha ssp. campylacantha	T	Leguminosae-Mimosoideae
A. gerrardii	T	Leguminosae-Mimosoideae
Harrisonia abyssinica	S,ST	Simaroubaceae
Brachystegia boehmii	T	Leguminosae-Caesalpinioideae

Key:- C = limber
CH = Climbing herb
G = Grass
S = Shrub
ST = Small tree
T = Tree

Appendix 2. Soil profile descriptions and analytical data

Profile number : KP1 Mapping unit: C5 Agro-ecol. zone:
Survey area : Kitulanghalo forest reserve
Region : Morogoro
District : Morogoro
Map sheet no. : 183/2
Location : 40km from Morogoro town, 150m from Morogoro-Dar Highway
Elevation : 430 m asl.
Parent material: alluvial/colluvial.
Landform: piedmont (valley bottom); Gently undulating.
Slope: 7 % concave
Erosion: severe.
Vegetation/land use : miombo woodland/forest reserve
Natural drainage class : imperfectly drained
Described by B.M. MSANYA, D.N. KIMARO A.J. SHAYO-NGOWI and J. J. MSAKY on 11/08/92

Soil: Very deep, imperfectly drained, very dark brown to very dark greyish brown, mottled, sandy clays, with thick black sandy loam topsoils.

Ah 0 - 20 cm: grey (10YR4/1) dry, black (10YR2/1) moist; sandy loam; soft dry, friable moist, non-sticky and non-plastic wet; weak fine granular and coarse and medium subangular blocks; many fine and very fine pores; few coarse and many fine and very fine roots; clear smooth boundary to

B/Ag 20 - 34 cm: dark grey (10YR4/2) dry, very dark grey (10YR3/1) moist; sandy loam; common fine distinct clear 10YR3/3 mottles; hard dry, friable moist, non-sticky and non-plastic wet; weak coarse and medium subangular blocks; many fine and very fine pores; few coarse and fine and very fine roots; gradual smooth boundary to

Bwg 34 - 53 cm: greyish brown (10YR5/2) dry, very dark greyish brown (10YR3/2) moist; sandy loam to sandy clay loam; common fine distinct clear 10YR3/2 mottles; slightly hard dry, friable moist, non-sticky and non-plastic wet; weak coarse and medium subangular blocks; few medium and many fine and very fine pores; very few medium fine and very fine roots; abrupt smooth boundary to

2Cg1 53 - 82 cm: very dark greyish brown (10YR3/2) dry, very dark brown (10YR2/2) moist; sandy clay loam; few fine distinct clear 10YR5/6 mottles; extremely hard dry, firm moist, slightly sticky and slightly plastic wet; common fine pores; frequent medium angular hard clay nodules; few cracks <1 cm; very few fine roots; gradual smooth boundary to

3Cg1 82 - 145 cm: very dark greyish brown (10YR3/2) moist; sandy clay; many fine distinct clear 10YR5/6 mottles; extremely hard dry, very firm moist, sticky and plastic wet; few fine pores; frequent medium spherical hard clay nodules; few cracks <1 cm; few fine roots; gradual smooth boundary to

3Cg2k 145 - 185 cm: yellowish brown (10YR5/6) moist; sandy clay; many medium distinct clear 10YR5/6 mottles; extremely hard dry, very firm moist, sticky and plastic wet; massive; few fine pores; frequent medium spherical hard carbonates nodules; few cracks <1 cm.

SOIL CLASSIFICATION:
FAO legend 1989 : Gleyic Cambisol
USDA taxonomy : Isohyperthermic, deep, mixed, Typic Tropaquept

ANALYTICAL DATA FOR PROFILE KP1

Horizon		Ah	BAg	Bwg	2Cg1	3Cg1	3Cg2
Depth (cm)		0 - 20	20 - 34	34 - 53	60 - 80	100 - 120	160 - 180
Clay	%	18	18	20	34	40	40
Silt	%	10	12	8	4	8	10
Sand	%	72	70	72	62	52	50
Texture class		SL	SL	SL	SCL	SC	SC
pH H2O	1:2.5	6.2	6.3	6.2	6.8	7.8	7.8
pH KCl	1:2.5	5.3	4.8	4.7	5.1	6.3	6.3
Organic C	%	0.4	0.4	0.3	n.d	n.d	n.d
Total N	%	0.02	0.02	0.02	n.d	n.d	n.d
C/N		20	20	15	n.d	n.d	n.d
Available P	mg/kg	4.5	2.2	1.2	0.8	0.2	0.2
CEC NH4OAc	me/100g	6.5	5.7	5.4	10.3	13.0	15.0
Exch. Ca	me/100g	3.4	2.5	2.4	4.7	6.5	6.2
Exch. Mg	me/100g	2.1	2.1	2.0	2.4	4.9	5.6
Exch. K	me/100g	0.37	0.31	0.18	0.17	0.12	0.13
Exch. Na	me/100g	0.04	0.16	0.26	1.37	5.22	5.05
TEB	me/100g	5.9	5.1	4.8	8.6	16.7	17.0
Base saturation	%	91	89	90	84	100	100
CECclay	me/100g	28.4	24.3	22.1	30.2	32.4	37.4
ESP	%	0.6	2.8	5	13	40	34

n.d = not determined

Profile number : KP2 Mapping unit: C3 Agro-ecol. zone:

Survey area : Kitulanghalo forest reserve
Region : Morogoro
District : Morogoro
Map sheet no. : 183/2
Location : 40 km from Morogoro town, 45 m from the Morogoro-Dar Highway
Elevation : 420 m asl.
Parent material: alluvial/colluvial
Landform: piedmont (valley bottom); gently undulating.
Slope: 5 %; concave
Erosion: severe.
Vegetation/land use : miombo woodland
Natural drainage class : moderately well drained
Described by B.M. MSANYA, D.N. KIMARO and J.J. MSAKY on 12/08/92

Soil: Very deep, moderately well drained, dark brown,sandy clay loams, with thick sandy loam to sandy clay loam topsoils.

Ah 0 - 15 cm: dark grey (10YR4/1) dry, brown (10YR2/1) moist; sandy loam; soft dry, friable moist, non-sticky and non-plastic wet; weak fine granular,coarse and medium subangular blocks; many fine and very fine pores; few coarse and common fine and very fine roots; gradual smooth boundary to

AB 15 - 29 cm: very dark greyish brown (10YR3/2) dry, very dark grey (10YR3/1) moist; sandy clay loam; hard dry, friable moist, slightly sticky and slightly plastic wet; moderate coarse and medium subangular blocks; many fine and very fine pores; few coarse and fine very fine roots; clear smooth boundary to

Bt1 29 - 60 cm: dark brown (10YR3/3) dry, dark brown (7.5YR3/4) moist; sandy clay loam; hard dry, friable moist, sticky and plastic wet; moderate coarse and medium subangular blocks; many fine and very fine pores; few small spherical hard clay nodules; few very coarse and few fine very fine roots; few quartz fragment; clear smooth boundary to

Bt2 60 - 110/130 cm: dark yellowish brown (10YR4/4) dry, dark brown (7.5YR3/4) moist; sandy clay loam; slightly hard dry, friable moist, sticky and plastic wet; moderate coarse and medium subangular blocks; many fine and very fine pores; few small spherical hard clay nodules; few fine and very fine roots; common quartz fragments; clear wavy boundary to

2C 110/130 - 180 cm: dark red (2.5YR3/6) dry, dark red (2.5YR3/6) moist; sandy clay; extremely hard dry, firm moist, sticky and plastic wet; maasive; many fine and very fine pores; few small spherical hard clay nodules; few fine and very fine roots

SOIL CLASSIFICATION:
FAO legend 1989 : Luvic Phaeozem
USDA taxonomy : Isohyperthermic, deep, mixed Typic Argiustoll

ANALYTICAL DATA FOR PROFILE KP2

Horizon		Ah	AB	Bt1	Bt3	Bt2	2C
Depth (cm)		0 - 15	15 - 29	35 - 55	60 - 80	80 - 100	130 - 150
Clay	%	20	24	32	32	30	44
Silt	%	10	6	8	4	4	6
Sand	%	70	70	60	66	66	50
Texture class		SL	SCL	SCL	SCL	SCL	SC
pH H2O	1:2.5	6.9	6.6	6.3	5.7	5.7	6.6
pH KCl	1:2.5	6.6	6.2	5.3	4.5	4.3	4.8
Organic C	%	2.4	1.1	1.0	0.3	n.d	n.d
Total N	%	0.23	0.09	0.08	0.04	n.d	n.d
C/N		10	12	13	8	n.d	n.d
Available P	mg/kg	17.3	3.5	1.6	1.2	0.7	0.4
CEC NH4OAc	me/100g	12.2	8.3	8.3	6.5	6.7	11.2
Exch. Ca	me/100g	9.2	5.1	3.6	2.0	3.0	7.7
Exch. Mg	me/100g	3.4	1.3	2.4	2.0	2.5	1.6
Exch. K	me/100g	0.62	0.33	0.48	0.42	0.19	0.11
Exch. Na	me/100g	0.02	0.02	0.03	0.05	0.11	0.23
TEB	me/100g	13.2	6.7	6.5	4.5	5.8	9.6
Base saturation	%	100	81	78	69	87	86
CECclay	me/100g	18.8	18.7	15.1	16.8	22.5	25.5

n.d = not determined

Profile number : KP3 Mapping unit: C4 Agro-ecol. zone:

Survey area : Kitulanghalo forest reserve
Region : Morogoro
District : Morogoro
Map sheet no. : 183/2
Location : 40 km from Morogoro town, 200 m from Morogoro-Dar Highway
Elevation : 430 m asl.
Parent material: alluvial/colluvial
Landform: piedmont (valley bottom); gently undulating.
Slope: 8 %; concave
Erosion: severe.
Vegetation/land use : miombo woodland
Natural drainage class : moderately well drained
Described by D.N. KIMARO, B.M. MSANYA and A.J. SHAYO-NGOWI on 13/08/92

Soil: Very deep, moderately well drained, dark brown, friable, sandy clay loams with thick, black sandy clay loam topsoils; with mixed, mottled, dark brown and dark yellowish brown, sandy clay loams and sandy loams in the deeper subsoils.

Ah 0 - 20 cm: very dark grey (10YR3/1) dry, black (10YR2/1) moist; sandy clay loam; soft dry, friable moist, non-sticky and non-plastic wet; weak fine granular, coarse and medium subangular blocks; many fine and very fine pores; few coarse and many fine and very fine roots; abrupt smooth boundary to

AB 20 - 39 cm: dark greyish brown (10YR4/2) dry, very dark brown (10YR2/2) moist; sandy clay loam; hard dry, friable moist, slightly sticky and slightly plastic wet; weak coarse and medium subangular blocks; common fine and very fine pores; few coarse and many fine and very fine roots; clear smooth boundary to

Bt 39 - 60 cm: dark brown (7.5YR4/2) dry, dark brown (7.5YR3/2) moist; sandy clay loam; hard dry, friable moist, slightly sticky and slightly plastic wet; moderate coarse and medium subangular blocks; many fine and very fine pores; few coarse and very fine roots; gradual smooth boundary to

Btg1 60 - 107 cm: brown (7.5YR4/4) dry, dark brown (7.5YR3/4) moist; sandy clay loam; few fine faint clear mottles; hard dry, friable moist, slightly sticky and slightly plastic wet; moderate coarse and medium subangular blocks; few medium and common fine and very fine pores; few small weathered round gethite fragments; few coarse and very fine roots; gradual smooth boundary to

2Btg2 107 - 119 cm: dark brown (10YR3/3) dry, very dark brown (10YR2/2) moist; sandy clay; common fine faint diffuse mottles; hard dry, friable moist, slightly sticky and slightly plastic wet; moderate coarse and medium subangular blocks; patchy thin clay + iron (hydr)oxide cutans; common fine and very fine pores; few small irregular weathered quartz fragments; few small irregular hard clay nodules; few fine and very fine roots; crotovinus & piece of charcoal; abrupt smooth boundary to

3Btg3 119 - 134 cm: dark yellowish brown (10YR4/4) dry, dark brown (10YR3/3) moist; sandy clay loam; many fine faint diffuse mottles; hard dry, friable moist, slightly sticky and slightly plastic wet; weak coarse and medium subangular blocks; patchy thin clay + iron (hydr)oxide cutans; common fine and many very fine pores; few small irregular weathered quartz fragments; few small spherical hard nodules; few fine and very fine roots; abrupt smooth boundary to

4Btg4 134 - 145 cm: dark yellowish brown (10YR3/4) dry, dark brown (10YR3/3) moist; sandy clay loam; few fine faint diffuse mottles; slightly hard dry, friable moist, slightly sticky and slightly plastic wet; weak coarse subangular blocks; patchy thin clay + iron (hydr)oxide cutans; common fine and very fine and few medium pores; few small irregular weathered quartz fragments; fine and few coarse roots; abrupt smooth boundary to

5C 145 - 160 cm: brown (10YR4/4) dry, dark yellowish brown (10YR3/4) moist; sandy loam; soft dry, very friable moist, non-sticky and non-plastic wet; few fine and very fine pores; few very fine roots; abrupt wavy boundary to

6C 160 - 185 cm: dark yellowish brown (10YR3/4) dry, very dark greyish brown (10YR3/2) moist; sandy clay loam; common medium distinct sharp mottles; hard dry, very friable moist, slightly sticky and slightly plastic wet; few medium and common fine and very fine pores; frequent small irregular weathered quartz fragments; few very fine roots

SOIL CLASSIFICATION:
FAO legend 1989 : Luvic Phaeozem
USDA taxonomy : Isohyperthermic, deep, mixed, Typic Argiustoll

ANALYTICAL DATA FOR PROFILE KP3

Horizon		Ah	AB	Bt	Btg1	2Btg2	3Btg3	4Btg4	5C	6C
Depth (cm)		0-20	20-39	39-60	70-90	107-119	119-134	134-145	145-160	160-185
Clay	%	22	24	28	28	36	28	28	14	32
Silt	%	12	14	8	6	8	8	8	4	8
Sand	%	66	62	64	66	56	64	64	82	60
Texture class		SCL	SCL	SCL	SCL	SC	SCL	SCL	SL	SCL
pH H2O	1:2.5	6.7	6.7	6.2	6.2	6.9	6.3	6.2	6.2	6.1
pH KCl	1:2.5	5.8	5.9	5.5	5.0	4.9	4.8	4.8	4.9	4.8
Organic C	%	2.4	1.1	0.6	0.1	n.d	n.d	n.d	n.d	n.d
Total N	%	0.20	0.09	0.05	0.01	n.d	n.d	n.d	n.d	n.d
C/N		12	12	12	10	n.d	n.d	n.d	n.d	n.d
Available P	mg/kg	9.1	3.2	1.6	0.7	0.8	0.7	1.9	0.6	4.2
CEC NH4OAc	me/100g	12.0	9.5	8.2	7.6	9.3	6.8	6.7	2.6	8.1
Exch. Ca	me/100g	8.3	5.3	3.4	3.3	5.4	3.2	3.4	1.3	4.3
Exch. Mg	me/100g	2.4	2.6	2.3	2.4	2.7	2.3	2.2	0.5	2.4
Exch. K	me/100g	0.78	0.38	0.40	0.35	0.27	0.20	0.19	0.10	0.15
Exch. Na	me/100g	0.13	0.07	0.05	0.09	0.12	0.08	0.05	0.01	0.10
TEB	me/100g	11.6	8.4	6.1	6.1	8.5	5.8	5.8	1.9	6.9
Base saturation	%	97	88	75	81	91	85	87	73	86
CECclay	me/100g	17.2	23.9	21.7	26.0	25.8	24.3	23.9	12.8	25.4

n.d = not determined

Profile number : KP4 Mapping unit: C1 Agro-ecol. zone:

Survey area : Kitulanghalo forest reserve
Region : Morogoro
District : Morogoro
Map sheet no. : 183/2
Location : 40 km from Morogoro town, 180 m from Morogoro-Dar Highway
Elevation : 420 m asl.
Parent material: alluvial/colluvial.
Landform: piedmont (valley bottom); gently undulating.
Slope: 9 %; concave
Erosion: severe.
Vegetation/land use : Miombo woodland/forest reserve
Natural drainage class : well drained
Described by D.N. KIMARO, B.M. MSANYA and A.J. SHAYO-NGOWI on 13/08/92

Soil: Very deep, well drained, very dark greyish brown to dark yellowish brown, sandy loams, with very thick, black, sandy loam topsoils.

Ah 0 - 27 cm: dark grey (10YR4/1) dry, black (10YR2/1) moist; sandy loam; soft dry, friable moist, non-sticky and non-plastic wet; weak fine granular, coarse and medium subangular blocks; many fine and very fine pores; few coarse and common fine and very fine roots; clear smooth boundary to

AB 27 - 45 cm: dark greyish brown (10YR4/2) dry, very dark brown (10YR2/2) moist; sandy loam; hard dry, very friable moist, non-sticky and non-plastic wet; weak coarse and medium subangular blocks; many fine and very fine pores; few coarse and few fine and very fine roots; clear smooth boundary to

Bw1 45 - 91 cm: dark brown (10YR3/3) dry, very dark greyish brown (10YR3/2) moist; sandy loam; slightly hard dry, friable moist, slightly sticky and slightly plastic wet; weak coarse and medium subangular blocks; many fine and very fine pores; very few coarse and very few very fine roots; diffuse smooth boundary to

Bw2 91 - 133 cm: dark brown (10YR4/3) dry, dark yellowish brown (10YR3/4) moist; sandy loam; hard dry, friable moist, slightly sticky and non-plastic wet; weak coarse and medium subangular blocks; patchy thin clay cutans; many fine and very fine pores; ; few small weathered round goethite fragments; few small angular hard clay nodules; few fine and very fine roots; diffuse smooth boundary to

Bw3 133 - 175 cm: dark brown (10YR3/3) dry, very dark greyish brown (10YR3/2) moist; sandy loam; hard dry, friable moist, slightly sticky and non-plastic wet; weak coarse and medium subangular blocks; patchy thin clay cutans; few medium and many fine and very fine pores; few small weathered round goethite fragments; few small spherical hard clay nodules; very few fine and very fine roots

SOIL CLASSIFICATION:
FAO legend 1989 : Eutric Cambisol
USDA taxonomy : Isohyperthermic, deep, mixed, Fluventic Ustropept

ANALYTICAL DATA FOR PROFILE KP4

Horizon		Ah	AB	Bw1	Bw2	Bw3
Depth (cm)		0 - 20	27 - 45	60 - 80	100 - 120	140 - 160
Clay	%	16	18	18	20	18
Silt	%	12	10	14	12	10
Sand	%	72	72	68	68	72
Texture class		SL	SL	SL	SL	SL
pH H2O	1:2.5	6.2	6.2	6.1	6.1	6.3
pH KCl	1:2.5	6.2	5.2	5.0	4.8	4.9
Organic C	%	1.5	0.5	0.5	n.d	n.d
Total N	%	0.30	0.12	0.06	n.d	n.d
C/N		5	4	8	n.d	n.d
Available P	mg/kg	8.1	2.2	1.9	1.5	0.7
CEC NH4OAc	me/100g	9.5	5.9	5.9	5.7	5.5
Exch. Ca	me/100g	4.5	2.5	2.4	2.5	2.2
Exch. Mg	me/100g	2.1	2.1	2.0	2.2	2.1
Exch. K	me/100g	0.39	0.44	0.42	0.29	0.35
Exch. Na	me/100g	0.06	0.03	0.05	0.10	0.13
TEB	me/100g	7.0	5.1	4.9	5.1	4.8
Base saturation	%	74	86	83	89	87
CECclay	me/100g	26.1	23.9	22.8	28.5	30.6

n.d = not determined

Profile number : KP5 Mapping unit: C2 Agro-ecol. zone:

Survey area : Kitulanghalo forest reserve
Region : Morogoro
District : Morogoro
Map sheet no. : 183/2
Location : 40 km from Morogoro town, 170 km from Morogoro-Dar Highway
Elevation : 420 m asl.
Parent material: Alluvial/Colluvial.
Landform: piedmont (valley bottom); gently undulating.
Slope: 8 %; concave
Erosion: severe.
Vegetation/land use : Miombo woodland/forest reserve
Natural drainage class : well drained
Described by D.N. KIMARO, B.M. MSANYA, A.J. SHAYO-NGOWI and J. J. MSAKY on 13/08/92

Soil: Very deep, well drained, to somewhat excessively drained, very
dark greyish brown to dark yellowish brown, sandy loams to sandy clay loams with thick, black sandy loam topsoils.

Ah 0 - 20 cm: dark grey (10YR3/1) dry, black (10YR2/1) moist; sandy loam; soft dry, very friable moist, non-sticky and non-plastic wet; moderate fine granular, coarse and medium subangular blocks; few medium and many fine and very fine pores; few coarse and many fine and very fine roots; clear smooth boundary to

Bw1 20 - 39 cm: dark greyish brown (10YR4/2) dry, very dark grey (10YR3/1) moist; sandy loam; slightly hard dry, very friable moist, non-sticky and non-plastic wet; weak coarse and medium subangular blocks; many fine and very fine pores; few coarse and common fine and very fine roots; clear smooth boundary to

Bw2 39 - 84 cm: dark brown (10YR3/3) dry, very dark greyish brown (10YR3/2) moist; sandy loam to sandy clay loam; slightly hard dry, very friable moist, non-sticky and non-plastic wet; weak coarse and medium subangular blocks; many fine and very fine pores; few coarse and many fine very fine roots; diffuse smooth boundary to

Bw3 84 - 116 cm: brownish red (10YR4/3) dry, dark yellowish brown (10YR3/4) moist; sandy loam; slightly hard dry, very friable moist, non-sticky and non-plastic wet; weak coarse and medium subangular blocks; many fine and very fine pores; few coarse and common fine and very fine roots; diffuse smooth boundary to

Bw4 116 - 147 cm: brownish red (10YR5/3) dry, very dark greyish brown (10YR3/2) moist; sandy loam; slightly hard dry, very friable moist, non-sticky and non-plastic wet; weak coarse and medium subangular blocks; many fine and very fine pores; frequent large spherical and irregular hard clay nodules; few medium and few fine and very fine roots; abrupt smooth boundary to

Cg 147 - 175 cm: dark brown (10YR4/3) dry, very dark greyish brown (10YR3/2) moist; sandy clay loam; common fine faint clear mottles; extremely hard dry, firm moist, sticky and plastic wet; massive; many fine and very fine pores; few small spherical hard clay nodules; few medium roots

SOIL CLASSIFICATION:
FAO legend 1989 : Eutric Cambisol
USDA taxonomy : Isohyperthermic, deep, mixed, Fluventic Ustropept

ANALYTICAL DATA FOR PROFILE KP5

Horizon		Ah	Bw1	Bw2	Bw3	Bw4	Cg
Depth (cm)		0 - 20	20 - 39	50 - 70	90 - 110	120 - 140	150 - 170
Clay	%	16	18	20	18	18	28
Silt	%	6	6	8	10	10	4
Sand	%	78	76	72	72	72	68
Texture class		SL	SL	SL	SL	SL	SCL
pH H2O	1:2.5	6.6	6.8	6.3	6.1	6.6	6.4
pH KCl	1:2.5	5.9	5.7	5.4	4.2	4.3	4.4
Organic C	%	1.8	0.3	0.6	n.d	n.d	n.d
Total N	%	0.15	0.02	0.04	n.d	n.d	n.d
C/N		12	15	15	n.d	n.d	n.d
Available P	mg/kg	3.4	1.8	2.5	1.9	1.6	0.4
CEC NH4OAc	me/100g	10.8	5.8	6.0	5.0	5.0	6.7
Exch. Ca	me/100g	6.6	3.0	2.7	2.4	1.9	2.7
Exch. Mg	me/100g	2.2	1.5	1.8	1.2	1.7	2.2
Exch. K	me/100g	0.41	0.24	0.30	0.11	0.12	0.10
Exch. Na	me/100g	0.02	0.01	0.03	0.01	0.09	0.60
TEB	me/100g	9.2	4.8	4.8	3.7	3.8	5.6
Base saturation	%	85	82	81	74	76	84
CECclay	me/100g	28.0	27.2	21.0	27.6	27.7	23.8

n.d = not determined

Profile number : KP6 Mapping unit: D1 Agro-ecol. zone:

Survey area : Kitulanghalo forest reserve
Region : Morogoro
District : Morogoro
Map sheet no. : 183/2
Location : 40 km from Morogoro Town, 20 m from Morogoro-Dar Highway
Elevation : 420 m asl.
Parent material: colluvial/alluvial.
Landform: piedmont (dissected backslopes); undulating.
Slope: 6 %; straight
Vegetation/landuse : miombo woodland/forest reserve
Natural drainage class : well drained
Described by D.N. KIMARO, B.M. MSANYA, A.J. SHAYO-NGOWI and J. J. MSAKY on 13/08/92

Soil: Very deep, well drained, dark brown sandy clay loams with thick
black sandy loam to sandy clay loam topsoils.

Ah 0 - 14 cm: dark greyish brown (10YR4/2) dry, black (10YR2/1) moist; sandy loam to sandy clay loam; soft to slightly hard dry, friable moist, non-sticky and non-plastic wet; weak fine granular coarse and medium subangular blocks; few medium and many fine and very fine pores; few coarse and many fine and very fine roots; abrupt smooth boundary to

AB 14 - 30 cm: dark brown (10YR3/3) dry, very dark greyish brown (10YR3/2) moist; sandy loam to sandy clay loam; hard dry, friable moist, slightly sticky and slightly plastic wet; weak coarse and medium subangular blocks; many fine and very fine pores; few coarse and medium and many fine and very fine roots; clear smooth boundary to

Bt1 30 - 50 cm: dark brown (7.5YR4/4) dry, dark brown (7.5YR3/4) moist; sandy clay loam; hard dry, friable moist, slightly sticky and slightly plastic wet; moderate coarse and medium subangular blocks; patchy thin clay cutans; many fine and very fine pores; few coarse and medium and common fine and very fine roots; diffuse smooth boundary to

Bt2 50 - 80 cm: dark brown (7.5YR3/4) dry, dark brown (7.5YR3/4) moist; sandy clay loam; hard dry, friable moist, sticky and plastic wet; moderate coarse and medium subangular blocks; patchy thin clay cutans; many fine and very fine pores; very few small irregular weathered gneiss fragments; few coarse and fine aand very fine roots; diffuse smooth boundary to

BC1 80 - 120 cm: strong brown (7.5YR4/6) dry, dark brown (7.5YR3/4) moist; sandy clay loam; slightly hard dry, friable moist, sticky and plastic wet; moderate coarse and medium subangular blocks; patchy thin clay cutans; many fine and very fine pores; few small irregular weathered gneiss fragments; frequent small spherical hard clay nodules; few fine and very fine roots; diffuse smooth boundary to

BC2 120 - 160 cm: strong brown (7.5YR4/6) dry, dark brown (7.5YR3/4) moist; sandy clay loam; slightly hard dry, friable moist, slightly sticky and slightly plastic wet; moderate coarse and medium subangular blocks; patchy thin clay cutans; many fine pores; few small irregular weathered gneiss fragments; frequent small irregular hard clay nodules; few fine and very fine roots

SOIL CLASSIFICATION:
FAO legend 1989 : Haplic Lixisol
USDA taxonomy : Isohyperthermic, deep, mixed, Kanhaplic Haplustalf

ANALYTICAL DATA FOR PROFILE KP6

Horizon		Ah	AB	Bt1	Bt3	BC1	BC2
Depth (cm)		0 - 14	14 - 30	30 - 50	55 - 75	90 - 110	130 - 150
Clay	%	20	20	24	30	30	32
Silt	%	4	8	4	6	9	8
Sand	%	76	72	72	64	61	60
Texture class		SL	SL	SCL	SCL	SCL	SCL
pH H2O	1:2.5	6.3	6.4	6.4	6.1	6.4	7.2
pH KCl	1:2.5	5.5	5.0	4.8	4.9	4.9	5.0
Organic C	%	1.5	0.4	0.4	0.4	n.d	n.d
Total N	%	0.19	0.03	0.03	0.04	n.d	n.d
C/N		8	13	13	10	n.d	n.d
Available P	mg/kg	7.5	6.2	1.5	0.7	1.5	1.2
CEC NH4OAc	me/100g	8.1	6.8	6.3	7.4	6.8	7.2
Exch. Ca	me/100g	4.0	2.8	3.4	3.1	3.2	4.9
Exch. Mg	me/100g	2.2	1.7	1.6	2.8	2.2	2.2
Exch. K	me/100g	0.54	0.64	0.36	0.39	0.18	0.18
Exch. Na	me/100g	0.01	0.01	0.02	0.12	0.09	0.13
TEB	me/100g	6.8	5.1	5.4	6.4	5.7	7.4
Base saturation	%	83	76	85	87	83	100
CECclay	me/100g	14.4	26.9	20.3	19.7	22.6	22.6

n.d = not determined

Profile number : KP7 Mapping unit: S2 Agro-ecol. zone:

Survey area : Kitulanghalo forest reserve
Region : Morogoro
District : Morogoro
Map sheet no. : 183/2
Location : 40 km from Morogoro Town, 50 m from Morogoro-Dar Highway
Elevation : 450 m asl.
Parent material: colluvial/alluvial.
Landform: piedmont plain (convex summit); undulating.
Slope: 14 %; convex
Erosion: severe.
Vegetation/land use : miombo woodland/forest reserve
Natural drainage class : well drained
Described by B.M. MSANYA, D.N. KIMARO, A.J. SHAYO-NGOWI and J. J. MSAKY on 14/08/92

Soil: Very deep, well drained, dark reddish brown sandy clays with
thick, very dark brown sandy clay loam topoils

Ah 0 - 15 cm: dark brown to brown (10YR4/3) dry, very dark brown (10YR2/2) moist; sandy clay loam; soft dry, friable moist, non-sticky and non-plastic wet; weak fine granular and coarse medium subangular blocks; few medium and many fine and very fine pores; few coarse, few medium and many fine and very fine roots; few ant and termite nests; clear smooth boundary to

Bt1 15 - 29 cm: dark reddish brown (5YR3/3) dry, dark reddish brown (5YR3/2) moist; sandy clay loam; slightly hard dry, friable moist, slightly sticky and slightly plastic wet; moderate coarse and medium subangular blocks; patchy thin clay cutans; few medium and many fine and very fine pores; few small spherical hard clay nodules; few coarse and medium and common fine and very fine roots; clear smooth boundary to

Bt2 29 - 51 cm: reddish brown (5YR4/4) dry, dark reddish brown (5YR3/3) moist; sandy clay; slightly hard dry, very friable moist, slightly sticky and slightly plastic wet; moderate coarse and medium subangular blocks; patchy thin clay cutans; few medium and common fine and very fine pores; few small spherical hard clay nodules; few medium and common fine and very fine roots; gradual smooth boundary to

Bt3 51 - 91 cm: yellowish red (5YR4/6) dry, dark reddish brown (5YR3/3) moist; sandy clay; slightly hard dry, very friable moist, slightly sticky and slightly plastic wet; moderate coarse and medium subangular blocks; broken thin clay cutans; few medium and common fine and very fine pores; frequent small spherical hard clay nodules; common medium fine and very fine roots; few krotovinas; diffuse smooth boundary to

Bt4 91 - 131 cm: yellowish red (5YR4/6) dry, dark reddish brown (5YR3/4) moist; sandy clay; slightly hard dry, very friable moist, slightly sticky and slightly plastic wet; moderate coarse and medium subangular blocks; broken thin clay cutans; few medium common fine and very fine pores; frequent small spherical hard clay nodules; fine medium fine and very fine roots; diffuse smooth boundary to

Bt5 131 - 180 cm: yellowish red (5YR4/6) dry, yellowish red (5YR3/4) moist; sandy clay; slightly hard dry, very friable moist, slightly sticky and slightly plastic wet; moderate coarse and medium subangular blocks; broken thin clay cutans; few medium and common fine and very fine pores; frequent small spherical hard clay nodules; very few medium fine and very fine roots

SOIL CLASSIFICATION:
FAO legend 1989 : Haplic Lixisol
USDA taxonomy : Isohyperthermic, deep, mixed, Kanhaplic Haplustalf

ANALYTICAL DATA FOR PROFILE KP7

Horizon		Ah	Bt1	Bt2	Bt3	Bt4	Bt5
Depth (cm)		0 - 15	15 - 29	30 - 50	60 - 80	100 - 120	140 - 160
Clay	%	22	34	42	42	44	42
Silt	%	8	6	6	4	6	4
Sand	%	70	60	52	54	50	54
Texture class		SCL	SCL	SC	SC	SC	SC
pH H2O	1:2.5	6.4	6.0	6.1	6.2	6.9	6.6
pH KCl	1:2.5	5.6	4.7	4.5	4.3	4.4	4.5
Organic C	%	1.7	0.5	0.4	0.2	n.d	n.d
Total N	%	0.16	0.05	0.03	0.02	n.d	n.d
C/N		11	10	13	10	n.d	n.d
Available P	mg/kg	3.9	1.7	1.0	1.2	0.4	0.4
CEC NH4OAc	me/100g	9.8	8.0	8.3	8.2	8.1	8.0
Exch. Ca	me/100g	4.5	3.3	3.5	4.0	4.4	3.2
Exch. Mg	me/100g	2.8	2.3	1.3	1.4	1.7	1.9
Exch. K	me/100g	0.55	0.54	0.54	0.36	0.14	0.11
Exch. Na	me/100g	0.02	0.02	0.04	0.05	0.17	0.36
TEB	me/100g	7.9	6.2	5.4	5.8	6.4	5.6
Base saturation	%	80	77	65	71	79	70
CECclay	me/100g	18.3	18.6	16.2	17.9	18.4	19.1

n.d = not determined

Profile number : KP8 Mapping unit: S3 Agro-ecol. zone:

Survey area : Kitulanghalo forest reserve
Region : Morogoro
District : Morogoro
Map sheet no. : 183/2
Location : 40 km from Morogoro, 180 m from Morogoro-Dar Highway
Elevation : 460 m asl.
Parent material: colluvial/alluvial
Landform: piedmont (convex summit); undulating.
Slope: 20 %; convex
Erosion: severe.
Vegetation/land use : miombo woodland
Natural drainage class : well drained
Described by D.N. KIMARO, B.M. MSANYA, A.J. SHAYO-NGOWI and J. J. MSAKY on 14/08/92

Soil: Very deep, well drained, dark brown to brown and dark reddish
brown sandy clay loams with thin very dark brown sandy clay loam topsoils.

Ah 0 - 7 cm: dark greyish brown (10YR4/3) dry, very dark brown (10YR2/2) moist; sandy clay loam; soft dry, friable moist, non-sticky and slightly plastic wet; moderate fine and medium granular; many fine and medium pores; few coarse and many fine very fine roots; abrupt smooth boundary to

Bw1 7 - 23 cm: dark brown (10YR3/3) dry, very dark greyish brown (10YR3/2) moist; sandy clay loam; slightly hard dry, friable moist, slightly sticky and slightly plastic wet; moderate coarse and medium subangular blocks; many fine and very fine pores; few coarse and medium many fine and very fine roots; clear smooth boundary to

Bw2 23 - 42 cm: dark brown to brown (7.5YR4/4) dry, dark brown to brown (7.5YR3/4) moist; sandy clay; slightly hard dry, very friable moist, slightly sticky and slightly plastic wet; moderate coarse and medium subangular blocks; many fine and very fine pores; few small spherical weathered gneiss fragments; few coarse fine and very fine roots; gradual smooth boundary to

Bw3 42 - 75 cm: strong brown (7.5YR4/6) dry, dark brown to brown (7.5YR3/4) moist; sandy clay loam; slightly hard dry, very friable moist, slightly sticky and slightly plastic wet; moderate coarse and medium subangular blocks; many fine and very fine pores; few small spherical hard clay nodules; few coarse fine and very fine roots; diffuse smooth boundary to

Bw4 75 - 103 cm: yellowish red (5YR4/6) dry, dark reddish brown (5YR0/3) moist; sandy clay loam; slightly hard dry, very friable moist, slightly sticky and slightly plastic wet; moderate coarse and medium subangular blocks; patchy thin clay cutans; many fine and very fine pores; frequent small spherical weathered gneiss fragments; few small spherical hard clay nodules; few coarse fine very fine roots; few krotovinas; diffuse smooth boundary to

Bw5 103 - 132 cm: reddish brown (5YR4/4) dry, dark reddish brown (5YR3/4) moist; sandy clay loam; slightly hard dry, very friable moist, slightly sticky and slightly plastic wet; moderate coarse and medium subangular blocks; patchy thin clay cutans; many fine and very fine pores; few small spherical weathered gneiss fragments; few small spherical hard clay nodules; very few very fine roots; diffuse smooth boundary to

Bw6 132 - 170 cm: reddish brown (5YR4/4) dry, dark reddish brown (5YR3/4) moist; sandy clay loam; slightly hard dry, very friable moist, slightly sticky and slightly plastic wet; moderate coarse and medium subangular blocks; patchy thin clay cutans; many fine and very fine pores; few small spherical weathered gneiss fragments; few small spherical hard clay nodules; very few very fine roots

SOIL CLASSIFICATION:
FAO legend 1989 : Ferralic Cambisol
USDA taxonomy : Isohyperthermic deep, mixed oxic ustropept

ANALYTICAL DATA FOR PROFILE KP8

Horizon		Ah	Bw1	Bw2	Bw3	Bw4	Bw5	Bw6
Depth (cm)		0 - 7	7 - 23	23 - 42	45 - 65	80 - 100	110 - 130	140 - 160
Clay	%	34	32	36	34	34	32	32
Silt	%	14	8	4	6	4	6	10
Sand	%	52	60	60	60	62	58	58
Texture class		SCL	SCL	SC	SCL	SCL	SCL	SCL
pH H2O	1:2.5	7.0	6.2	6.2	6.2	6.3	6.4	6.4
pH KCl	1:2.5	6.7	5.5	5.0	4.7	4.6	4.7	4.8
Organic C	%	3.1	1.5	0.5	0.5	n.d	n.d	n.d
Total N	%	0.20	0.14	0.06	0.05	0.01	n.d	n.d
C/N		16	11	8	10	n.d	n.d	n.d
Available P	mg/kg	7.9	1.6	0.80	0.4	0.5	0.5	0.34
CEC NH4OAc	me/100g	15.5	11.3	9.0	8.4	7.3	6.9	7.5
Exch. Ca	me/100g	10.2	3.8	3.1	3.8	3.4	3.5	5.3
Exch. Mg	me/100g	3.7	3.0	3.0	2.2	2.5	2.4	1.4
Exch. K	me/100g	0.91	0.59	0.60	0.17	0.11	0.09	0.09
Exch. Na	me/100g	0.22	0.03	0.04	0.03	0.13	0.11	0.16
TEB	me/100g	15.0	7.4	6.7	6.2	6.1	6.1	6.9
Base saturation	%	97	66	75	74	84	88	93
CECclay	me/100g	13.6	18.8	20.0	19.7	21.3	21.7	23.4

Appendix 3. Guide to general evaluation of some soil chemical and physical properties

1. Organic matter and total nitrogen

	Very low	Low	Medium	High	Very high
Organic matter %	<1.0	1.0-2.0	2.1-4.2	4.3-6.0	> 6.0
Organic C %	<0.60	0.60-1.25	1.26-2.50	2.51-3.50	> 3.50
Total N %	<0.10	0.10-0.20	0.21-0.50	> 0.50	

C/N ratios give more information about the availability of nitrogen than total N levels only.
C/N ratios indicate the quality of the organic matter:
C/N 8 - 13 : good quality
C/N 14 - 20: moderate quality
C/N > 20 : poor quality

2. Soil reaction

Soil reaction (pH H_2O) is classified as follows:

extremely acid	pH below 4.5	neutral	pH 6.6 to 7.3
very strongly acid	pH 4.5 to 5.0	mildly alkaline	pH 7.4 to 7.8
strongly acid	pH 5.1 to 5.5	moderately alkaline	pH 7.9 to 8.4
medium acid	pH 5.6 to 6.0	strongly alkaline	pH 8.5 to 9.0
slightly acid	pH 6.1 to 6.5	very strongly acid	pH above 9.0

The neutral class, if necessary, can be subdivided into:

very slightly acid	pH 6.6 to 6.9
neutral	pH 7.0
very mildly alkaline	pH 7.1 to 7.3

3. Available phosphorus

mg/kg	Low	Medium	High
Avail. P (Bray-Kurtz I)	<7	7-20	>20
Avail P. (Olsen)	<5	5-10	>10

Available phosphorus is determined by the Bray-Kurtz I method if the pH H_2O of the soil is less than 7.0. In soils with a pH H_2O of more than 7.0 the Olsen method is used.

4. Cation exchange capacity (CEC)

me/100 g	Very low	Low	Medium	High	Very high
CEC	<6.0	6.0-12.0	12.1-25.0	25.0-40.0	>40.0

CEC is determined using 1M ammonium acetate in soils with pH less than 7.5. In soils with pH greater than 7.5 CEC is determined using 1M sodium acetate.

5. Exchangeable calcium

me/100 g	Very low	Low	Medium	High	Very high
Ca (clayey soils rich in 2:1 clays)	<2.0	2.0-5.0	5.1-10.0	10.1-20.0	>20.0
Ca (loamy soils)	<0.5	0.5-2.0	2.1-4.0	4.1-6.0	>6.0
Ca (kaolinitic and sandy soils)	<0.2	0.2-0.5	0.6-2.5	2.6-5.0	>5.0

6. Exchangeable magnesium

me/100 g	Very low	Low	Medium	High	Very high
Mg (clayey soils)	<0.3	0.3-1.0	1.1-3.0	3.1-6.0	>6.0
Mg (loamy soils)	<0.25	0.25-0.75	0.75-2.0	2.1-4.0	>4.1
Mg (sandy soils)	<0.2	0.2-0.5	0.5-1.0	1.1-2.0	>2.0

The desired saturation level of exchangeable Mg is 10 to 15 percent; for sandy and kaolinitic soils 6 to 8 percent Mg saturation is still sufficient.
Ca/Mg ratios of 2 to 4 are favourable.

7. Exchangeable K

me/100 g	Very low	Low	Medium	High	Very high
K (clayey soils)	<0.20	0.20-0.40	0.41-1.20	1.21-2.00	>2.00
K (loamy soils)	<0.13	0.13-0.25	0.26-0.80	0.81-1.35	>1.35
K (sandy soils)	<0.05	0.05-0.10	0.11-0.40	0.41-0.70	>0.70

The desired saturation level of exchangeable K is 2 to 7 percent.
Favourable Mg/K ratios for most crops are in the range of 1 to 4.

8. Exchangeable sodium

me/100 g	Very low	Low	Medium	High	Very high
Na	<0.10	0.10-0.30	0.31-0.70	0.71-2.00	>2.00

More important than the absolute level of exchangeable Na is the exchangeable sodium percentage ESP) calculated by dividing exchangeable Na by CEC (x 100). ESP values are a measure of the sodicity of the soil.

9. Soil sodicity

	Non-sodic	Slightly sodic	Moderately sodic	Strongly sodic	Very strongly sodic	Extremely sodic
ESP %	<6	6-10	11-15	16-25	26-35	>35

ESP <15% -up to 50 percent yield reduction of sensitive crops (maize, beans)
ESP 16-25% -up to percent yield reduction of semi-tolerant crops (rice, wheat, sorghum, sugarcane)
ESP 35% -up to 50 percent yield reduction of tolerant crops (barley, cotton)

10. Basic infiltration rate (IR)

IR <0.1 cm/h	extremely slow
IR 0.1-0.3 cm/h	very slow
IR 0.3-0.5 cm/h	slow
IR 0.5-2.0 cm/h	moderately slow
IR 2.0-6.5 cm/h	moderate
IR 6.5-12.5 cm/h	moderately rapid
IR 2.5-25.0 cm/h	rapid
IR >25.0 cm/h	very rapid

Basic infiltration rate is the constant rate at which water enters the (pre-wetted) soil and which develops after 3 to 5 hours of infiltration.

11. Available water capacity (AWC)

AWC	<25 mm/m	extremely low
AWC	25-50 mm/m	very low
AWC	50-100 mm/m	low
AWC	100-150 mm/m	medium
AWC	150-200 mm/m	high
AWC	>200 mm/m	very high

Available water capacity is the capacity of the soil to store water that is readily available for uptake by plant roots; usually expressed in millimeters of water per metre depth of soils; technically the difference between the percentage of soil water at field capacity (normally taken as the water content at pF 2.2) and the percentage at wilting point (taken as the water content at pF 4.2).

*Compiled from Baize (1993), EUROCONSULT (1989) and Landon (1991).