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Mapping and characterization of some soils of the northern part of Morogoro District, Tanzania

by

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ABSTRACT:

Combining air-photo interpretation and field investigations, a soil survey was carried out in the northern part of Morogoro District, Tanzania. General environmental features of the area including geology, geomorphology, climate and vegetation are described. Thirteen mapping units and 12 soil profiles were described from two toposequences containing the most common soils of the area. The soils fall in the orders Vertisols, Alfisols Inceptisols and Ultisols of the US Soil Taxonomy (Soil Survey Staff; 1996), which can be correlated to Vertisols, Lixisols, Cambisols, Leptosols, Luvisols and Acrisols great groups of the FAO-Unesco (1988) system.

Parent material, relief and climate are major factors of soil development in the study area. Some general data on morphology and physico-chemical properties of the studied soil profiles are presented. The gently undulating to undulating plains have very deep, well drained slightly acid to strongly acid soils with relatively low CEC levels. Soils in river valleys and topographic depressions are also deep, imperfectly to poorly drained and with neutral to moderately alkaline soil reaction and relatively high levels of CEC. Fertility status and sustainable agricultural potential of the soils are assessed based on these properties and climatic data. Some soil management practices are suggested. General soil maps produced for the two selected toposequences namely Magadu and Lubungo-Mkata are presented.

4. **Key words:**

Morogoro, Tanzania
Toposequences
Mapping units
Soil survey and classification
Soil profile characterization
Soil fertility and management

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FOREWORD

In Tanzania, there is insufficient knowledge about soils regarding their geographical distribution, physico-chemical characteristics, and their potential and constraints for agricultural use. This report presents basic data for my Dr. Scient. Dissertation project titled '**Soil genesis and classification of two toposequences in Morogoro District, Tanzania**'. This study was carried out in order to expand the knowledge of soils in the district.

ACKNOWLEDGMENTS

I wish to extend my deep appreciation to all individuals and institutions that in many direct and indirect ways have helped in bringing this work to its present stage. I am especially grateful to Assoc. Professor Rolf Sørensen of Institute of soil and Water Sciences, Agricultural University of Norway (AUN), for his inspiration, constant guidance and supervision throughout the period of this work. His constructive criticism and suggestions helped to improve the original draft of this report. His assistance in modification of the geological map and taking of the photos in the field is highly appreciated.

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This work was financed by NORAD through SUA-NORAD collaborative project TAN 091 in the Department of Soil Science (SUA). Grateful acknowledgments are due to Dr. J.P. Mrema, Coordinator of project TAN 091, and Head of Department, Department of Soil Science, Sokoine University of Agriculture (SUA) for providing administrative support including transport and equipment during the field work in Morogoro; and for his permission to use facilities in the Soil Science Laboratories at SUA for soil analysis. Most of the soil analyses were carried out by laboratory technical staff of the Department of Soil Science (SUA), Tanzania. Their help is highly appreciated.

Last but not least I am grateful to the Department of Soil and Water Sciences at AUN for providing laboratory and office facilities that created a conducive environment for compilation and writing of this report.

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1. INTRODUCTION

Morogoro District is one of the areas in Tanzania where most of the people depend on agriculture for their living. The cultivated crops include maize, sorghum, pigeon peas, millet, bananas, cassava, sisal, irrigated rice and vegetables. As population increases demand for food increases and therefore the need of expanding agricultural land and improving the existing production systems. Expansion of agricultural land by rural community has mainly been by clearing of natural vegetation without proper land use planning. Charcoal burning and extensive grazing of cattle and goats are also important activities of the rural community in this area. These land use types together with the associated frequent bush fires are detrimental to environment and are not sustainable. They contribute significantly to environmental degradation by increasing the danger of soil erosion and nutrient depletion. Comprehensive land use planning and management is required in order to minimize or reverse the environmental degradation effects in the district.

Soil data are essential facets of natural resource base inventories. Information that can be used to systematically identify, group and delineate different soils according to their morphological, physical and chemical characteristics is required in formulating a sustainable land use and management plan. Morogoro is one of the regions with neither district nor regional soil map which could be a primary source of resource information for comprehensive land use planning. Although Tanzania has a long history (more than 50 years) of collecting basic information on land resources through soil surveys and mapping the existing reports show that these investigations were carried out with different and varied objectives. The only available soil map relevant to Morogoro region is the national soil map of Tanzania (De Pauw, 1984) at scale of 1:2 mill. This was compiled with the purpose of establishing major regions for agricultural planning at national level. Its mapping units are based on physiographic units delineated from satellite imagery and topographic maps. This soil map was basically a result of compilations and extrapolations of the scattered soil information available at larger scales. As a result, only limited information can be obtained from such maps about distribution, extent, types and characteristics of soils in Morogoro District. These reconnaissance national soil maps are useful only for broad land use planning and are insufficient in providing information relevant to land resource management or land use planning at the district, village or farm level. More detailed soil reports and maps which are required at this level of land use planning are very few covering only about 1 % of the country's total area (Msanya and Magogo, 1993), hence the need for carrying out more detailed soil mapping at district level.

Other documented pedological studies around the study areas have been carried out with different purposes. In their experimental use of the 7th Approximation of the Soil Taxonomy, Kesseba et al (1972) classified some soils on the plains around the Uluguru mountains as Alfisols, Ultisols and Oxisols. Moberg *et al.* (1982), with the aim of expanding knowledge of the soils in Morogoro area, investigated pedological and edaphological properties of two soil associations forming a continuum from the Uluguru mountain ranges to the Mindu mountain. They classified soils on the slopes of the Uluguru mountains as Inceptisols and Alfisols, on the plains as Oxisols and Ultisols, and those on the Ngerengere river plain as Inceptisols while those on the slopes of the Mindu mountain were classified as Entisols. With the aim of generating basic soils data required for planning and execution of soil fertility studies in Morogoro

District, Msanya, *et al.* (1994) carried out characterization of some benchmark soils of the district. The soil profiles selected on important agricultural soils in the district were classified as Oxisols, Ultisols, Alfisols, Inceptisols, Entisols and Vertisols. Mpepo (1986) and Kaaya *et al.* (1994) carried out detailed soil survey and land evaluation of the Sokoine University of Agriculture farm and they classified soils under orders Oxisols, Ultisols, Alfisols, Inceptisols and Entisols. Kaaya et al. (1996) reported some chemical and mineralogical studies of some soil profiles between Uluguru mountains and Mindu hills.

The present study was therefore aimed at providing more understanding of the soil types and their distribution on the north west side of the Uluguru mountains and those on the western side of the Mindu mountains down to 'mbuga' soils of Mkata plains. The investigation included identification, grouping and delineation of different soils in these areas according to their morphological, physical and chemical characteristics. The information can be used by the land use planning units of the district as one of the inputs in formulating a sustainable district land use plan aimed at minimum damage to soils and environment. The information obtained will also be one of the inputs in compiling soil map of Morogoro District later.

This survey was carried out in two selected areas namely Lubungo-Mkata and Magadu in Morogoro District. These areas were selected because they are representative of similar soil associations which occur extensively in the district, and also they represent the soils developed on the three main groups of parent materials found in the northern Morogoro District. The Magadu area represents the alluvial/colluvial fans on granulitic rocks of the NW footslopes of Uluguru mountains, whereas the Lubungo-Mkata area represent the biotite-hornblende gneisses on the gentler slopes NW of Lugala hills and Mindu mountains and the banded muscovite-biotite migmatites on the Sangasanga ridge SW of Mindu. Characterization of the soils of this areas could therefore contribute positively to transfer of agro-technology to the areas with similar environmental conditions within the district. The specific objectives of the study were:

1. to carry out a general purpose soil survey and produce a soil map for each of the selected areas based on different relief units delineated by aerial photo interpretation, followed by soil investigations in field.

2. to characterize the soil types on different land units of the study areas according to their morphological, physical and chemical characteristics so as to form a basis for further mineralogical studies, detailed soil classification and discussions on genesis of the soils developed from the different parent materials.

3. to classify the soils of the study areas using the USDA Soil Taxonomy and the FAO-Unesco legend of the Soil Map of the World.

4. to assess the natural fertility status of the soils of different land units and discuss the existing land use problems.

2. ENVIRONMENTAL FEATURES OF THE STUDY AREAS

2.1 Geographical location

Morogoro District is located in Morogoro region, Tanzania, approximately 200 km west of Dar es Salaam. Morogoro town is connected to Dar es Salaam by the central railway line and the Tanzania Zambia highway. The study areas are located on the western side of the Uluguru mountains within Latitudes 37° 15' E and 37° 42' E and Longitudes 6° 45' S and 7° 00' S (Fig. 2.1). The areas are covered by the topographic map sheets numbers 182/4 (Mkata) and 183/3 (Morogoro).

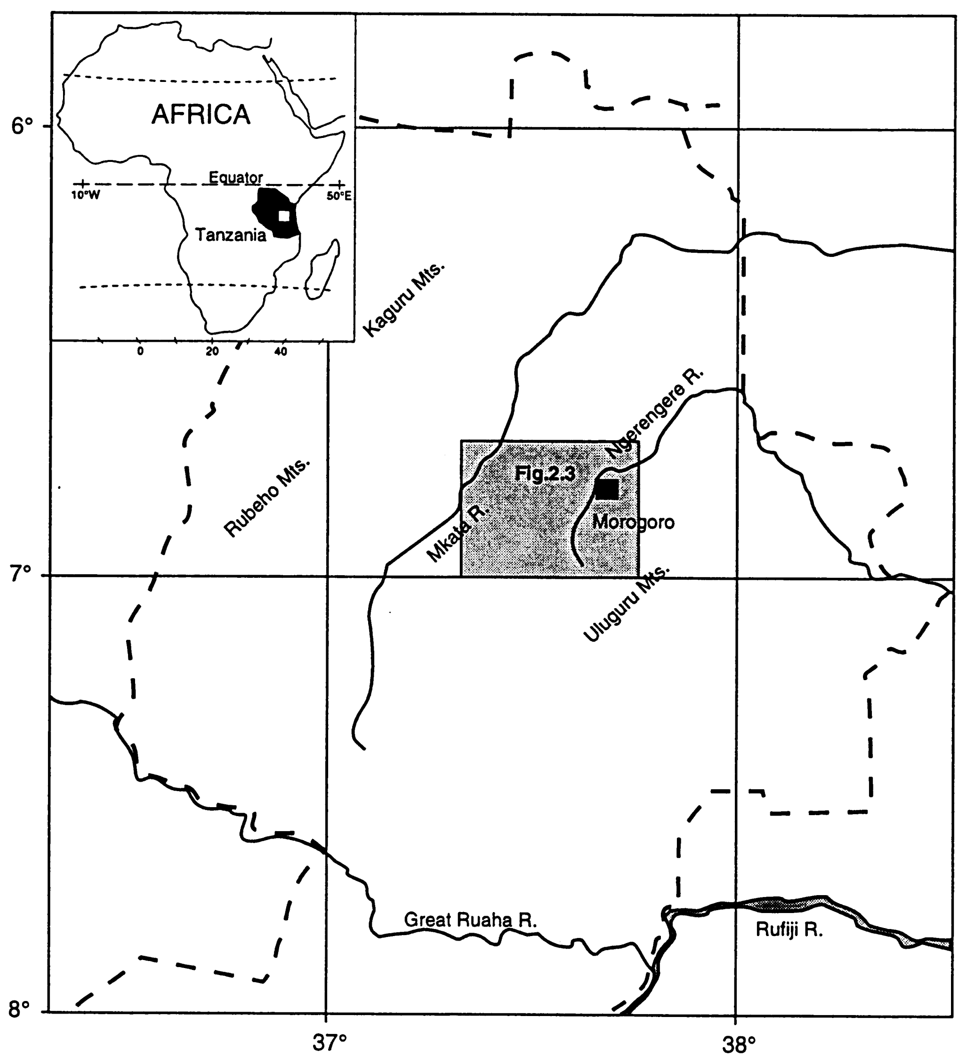

Figure 2.1 Location of the study areas in the northern Morogoro District, Tanzania

2.2 Climate

The intensity and duration of wet-dry oscillations and responses of hillslopes and river systems during the late Quaternary period in the humid and sub-humid tropics is still poorly understood (Thomas and Thorp, 1996). During the Last Glacial Maximum (22,000 to 13,000 years BP) the environmental changes in the humid tropics resulted in the uplands becoming cold and the lowlands becoming dry, the conditions which were marked by semi-arid landforms with reduced stream activity (Thomas and Thorp, 1996). They estimated rainfall reduction of 30 - 66 % during this period compared to present day values for the lowland tropics. This conforms with paleoclimatic estimates of mean annual temperature and rainfall by Vinces, *et al.* (1993) which indicate that the cooling and aridity which occurred in East Africa during this period, resulted in decrease of mean annual temperature of about 4.2° C and decrease of mean annual precipitation of 180 mm relative to modern values. Warmer and wetter conditions were established after 13,000 BP and these were followed by several wet-dry oscillations which continue to the present day (Thomas and Thorp, 1996).

The present day climate in Morogoro is of sub-humid type. The climatic conditions are very variable and this variation is associated with the marked variation in the relief features. The uneven distribution of rainfall in the area is due to the constant easterly direction of the rain carrying winds (Pócs, 1976) combined with the NE orientation of the Uluguru mountain ranges. The annual rainfall on the mountains and on the eastern slopes of the Uluguru mountains is generally over 1320 mm (Sampson and Wright, 1964; De Pauw, 1984) and is generally higher than in the plains on the western side of the mountains. These plains including the survey areas are in the rain-shadow and they receive annual rainfall of less than 800 mm (De Pauw, 1984). There are also marked local variations in climatic conditions within the plains. The amount of rainfall in the plains has a general tendency of decreasing with increasing distance westwards from the Uluguru mountains. This is supported by Moberg *et al.* (1982) who reported average annual rainfall of 917 mm (average of 9 to 10 years) at Sokoine University of Agriculture, near the lower footslopes of the Uluguru mountains and 795 mm (average of 5 years), at former Mafiga Sisal Estate, near Ngerengere river and 751 mm (average of 8 years) reported by Msanya *et al.* (1994) at Melela village on Mkata plains.

Some climatic data obtained from Morogoro meteorological station (at 579 m asl) near Sokoine University of Agriculture are presented in Figure 2.2. Although the rainfall amounts tend to vary locally and generally decrease gradually with increasing distance from the Uluguru mountains, the pattern of variation of climatic conditions in the plains west of the Uluguru mountains is generally similar. Figure 2.2 shows that the area experiences three rainfall seasons namely the heavy rainy season from March to May, the only season when precipitation exceeds evapotranspiration, followed by dry season from June to October and then a moderate rainfall season from November to February. Soil moisture regime is therefore ustic for the study areas because there is at least one rainy season of at least 3 months (Soil Survey Staff, 1996). There has often been a short dry spell in February but masked in Figure 2.2. because the onset of the heavy rainfall season is unreliable and varies irregularly from year to year. For the last decade this short dry spell has been longer than previous years, a probable indication of change of climate.

From Figure 2.2, the mean monthly air temperature recorded for 57 years range from 21.1° C in July to 26.5° C in December with mean annual air temperature of 24.3° C. This implies a small seasonal variation in temperature. Variation of the monthly minimum and maximum temperatures are shown in Figure 2.2. The mean annual soil temperature has been estimated to be 25.3° C after adding 1° C to the mean annual air temperature (Soil Survey Staff, 1975). Moberg, *et al.*, 1982 reported a soil temperature amplitude of 2 - 4° C lower than the air temperature at 50 cm depth in a profile near the Morogoro Meteorological station. The soil temperature regime for the surveyed areas is therefore classified as iso-hyperthermic.

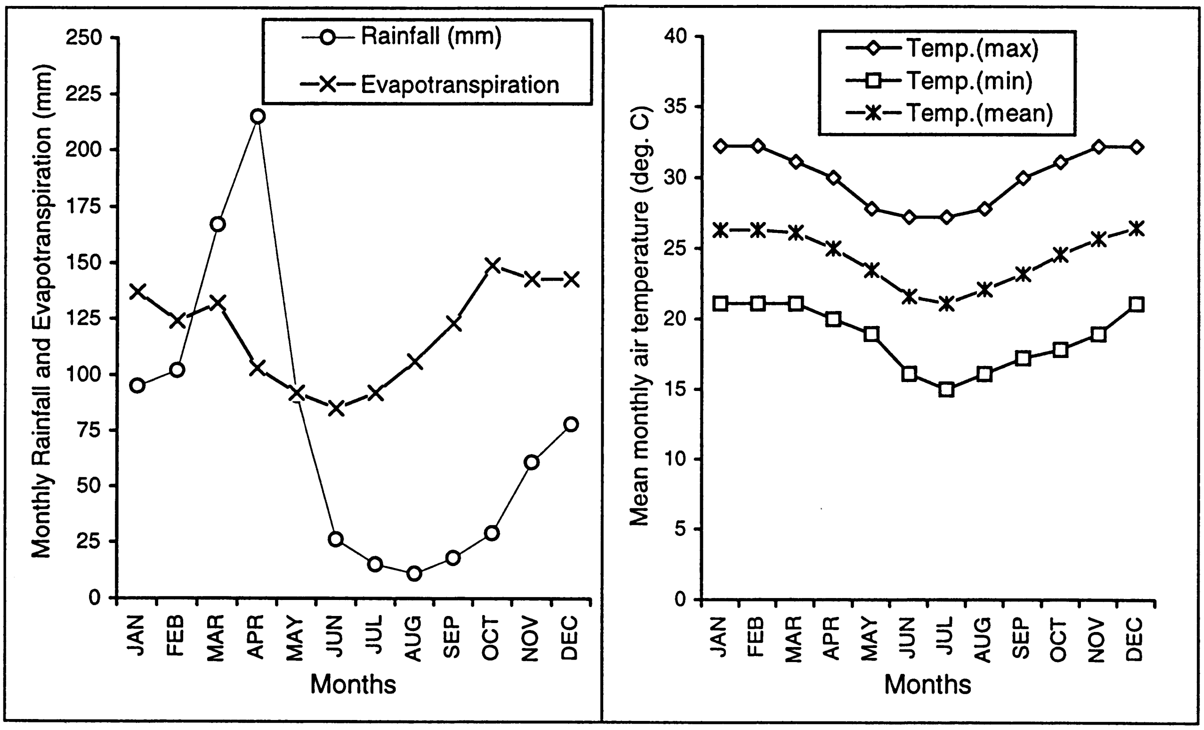

Figure 2.2 Some climatic data from Morogoro meteorological station near Sokoine University of Agriculture
(Average of 65 years for rainfall, 57 for temperature and 41 for evapotranspiration)

2.3 Vegetation

Vegetation map of the northern Uluguru mountains by Pócs (1976) and observations made in the field during this study indicate that the natural vegetation in the areas is very variable. The natural vegetation of the surveyed areas located on the western side of the Uluguru mountains main ridge, is mainly woodland on the slopes and savanna woodlands on the plains. This is mainly due to influence of environmental factors especially climate, physiography and soil physical properties and human activities (Pócs, 1976; Fleetwood, 1981). Most of these woodlands have been replaced by cultivated land. The main crops include maize, cassava, millet, pigeon peas, sorghum, banana, sisal, sweet potato and beans. On the river valleys, most of the valley grassland has gradually been replaced by swamp rice, sugarcane and sweet potatoes. The surviving woodlands are used in different ways including wood and fuel production, extensive animal (cattle and goats) grazing and seasonal cash-cropping. Pócs (1976) noted that these savanna-like vegetation types could be products of fire rather than climatic climaxes because they are associated with frequent bush fires.

The Mindu and Lugala hill ridges and the upper parts of the slopes around them are characterized by miombo woodland with good growth on well drained sandy soils whereas the middle and lower parts of the slopes are dominated by Combretum woodland with poor growth on clay soils (Pócs, 1976). The valleys and depressions are dominated by groundwater forest or riverine vegetation. Montane rain forest covers the upper parts of the Uluguru mountains above 1500 m asl, below which lies submontane Pterocarpus-Combretum woodland at 900 - 1500 m asl. Most of this woodland has been cleared and is now dominated by grass fallow and cultivation. Below 900 m asl is miombo woodland with *Brachystegia boehmii* and *B. bussei* as characteristic tree species and tussock grasses dominated by *Hyparrhenia rufa* and *Panicum maximum.*

On the Mkata plains the vegetation is mostly Acacia-savanna woodland with wooded species being dominated by *Acacia nigrescens, Dalbergia melanoxylon, Harrisonia abyssinica* and *Cussonia arborea.* Some places in the Mkata plains are dominated by Hyparrhenia-Combretum woodland whereby *Hyperrhenia rufa* dominates the herbaceous species and Combretum tree species are scattered.

2.4 Geology

The Precambrian rocks of the Uluguru mountains form a part of the inselberg chain on the eastern border of the Central African Plateau. The geology of the surveyed area has been described by Sampson *et al.* (1961), Sampson and Wright (1964), Fozzard (1965) and Muhongo (1995). Figure 2.3 shows the geological map of Morogoro including the surveyed areas as modified from Sampson *et al.* (1961), Sampson and Wright (1964), and Fozzard (1965).

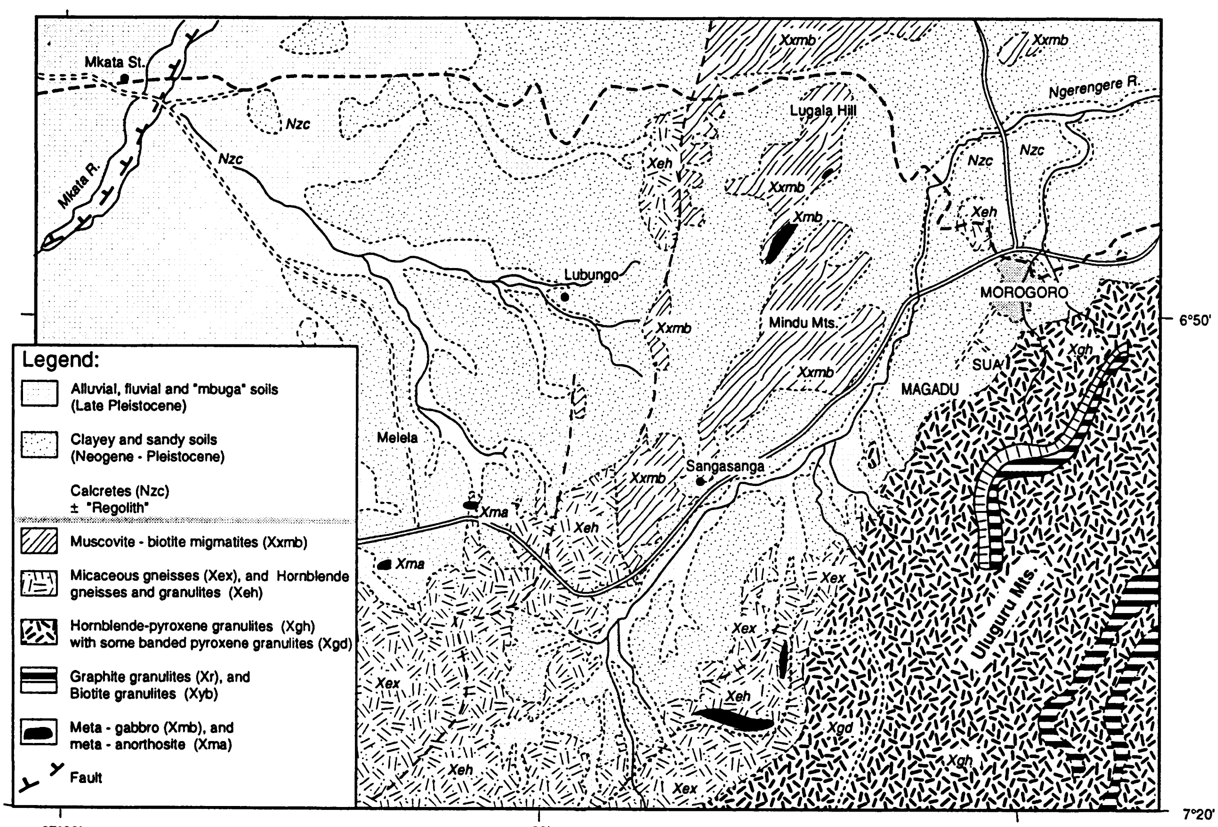

Figure 2.3 Geological map of Northern Morogoro District including the study areas
(modified from Sampson et al. (1961), Sampson and Wright (1964) and Fozzard (1965))

The major lithologic unit of the Uluguru mountains is hornblende-pyroxene granulites (*Xgh*) with some banded pyroxene granulite. The normal mineral assemblage in these rocks is oligoclase, quartz, hornblende, garnet and pyroxenes (hypersthene and diopside). The Mindu mountains and Lugala hills west of Morogoro are composed of muscovite-biotite migmatites (*Xxmb*) with microcline-quartz as dominant minerals. These rocks extend eastwards and underlie most of the clayey and sandy soils (Neogene-Pleistocene) on the plain between the Uluguru and the Mindu mountains and the alluvial, fluvial and "mbuga" soils (Late Pleistocene deposits) on the Ngerengere river plain. To the west they are bounded by hornblende gneisses and granulites (*Xeh*) also underlying the clayey and sandy soils (Neogene-Pleistocene deposits) around Lubungo area. Further west on the Mkata river plains these rocks underlie the alluvial, fluvial and "mbuga" soils (Late Pleistocene deposits). Garnet and amphibole are some of the common minerals in these rocks. Clayey and sandy soils as well as alluvial, fluvial and "mbuga" soils cover most of the plains in the surveyed area.

2.5 Geomorphology and hydrology

The surveyed areas lie to the north west of the Uluguru mountains. The high Uluguru mountains (over 2000 m asl) descend sharply to a plain between 500 and 600 m asl where the residual hills Mindu and Lugala separate the Mkata plain from the head waters of the Ngerengere River. Figures 2.4 and 2.5 show typical landscape features of the Magadu and Mkata plains, respectively.

Most of the surveyed areas lie on a dissected peneplain north west of the Uluguru mountains. This peneplain extends west and north of Morogoro and finally merge into the plain of the Mkata and Wami rivers and therefore called the 'Mkata surface'. The Mkata surface is typically covered with thick red soil

Figure 2.4 Landscape features of Magadu area as seen from Mindu mountains
(Ngerengere River in the shady area in the lower part of the photo and the NW slopes of the Uluguru mountains in the background)

Figure 2.5 Landscape features of the Mkata plains as seen from Sangasanga ridge
(the background shows the Rubeho and Ukaguru mountains)

and is characterized by residual hills rising sharply out of it. These residual hills including Mindu (1370m asl) and Lugala (985 m asl) have extensive pediments of coarse sandy soils and some superficial limestone in the forms of calcretes. The average depth of dissection of the large remnant of the Mkata surface to the west of Mindu mountain is about 70 m (Sampson and Wright, 1964). The Ngerengere river occupies the gap between Mindu mountains and the Uluguru mountains. This river is actively producing a lower surface by dissection of the '650 m surface' in the north, but it displays much less power of erosion in the surveyed area. This reflects the difference in rainfall between the wet eastern area and the rain-shadow area west of the Uluguru mountains. Consequently, parts of the higher Mkata surface (650 m asl) still remain in Magadu area. Further details about geology and landscape development in these areas are presented by Sørensen and Kaaya (in prep.). Landform features of different land units in the study areas are described separately under each land unit in section 4 below.

3. MATERIALS AND METHODS

3.1 Choice of soil survey method

In less developed countries of the tropics, reconnaissance surveys still play a major role in soil investigations (Young, 1976) because of problems associated with conducting more detailed soil surveys in these areas. The two most distinctive field soil survey methods used in the tropics include the use of traverses (transects) cut on pre-set bearings and the combination of aerial photo interpretation with field observations (Acres et al., 1993). Other factors which determine the choice of survey method include the nature of terrain, available time, available staff and size of the area to be surveyed. Having considered theses factors, the second method was chosen as recommended by Young (1976) and Acres et al., (1993). The survey activities were then carried out as described by Dent and Young (1981). Phase one involved aerial photo interpretation, phase two was field survey and phase three was comparison of the results whereby the mapping units obtained during aerial photo interpretation were matched with field observations and revised whenever necessary.

3.2 Aerial photo interpretation

Stereoscopic study of aerial photos was carried out in order to get a general impression of features which are commonly related to kinds of soils. Land units were identified based on relief features and then delineated on the aerial photos. Aerial photos taken in 1964 at an approximate scale of 1:35.000 were used in this study. The area covered in the Lubungo-Mkata area is 415 km^2 and in the Magadu area is 73.3 km^2. Aerial photo interpretation was carried out using a Leica APT2 stereoscope. During this phase, the surveyed areas were first delineated into land units (or geomorphic units). Land units in this context were defined as areas of land having a recurring pattern of landform (similar relief, slope, drainage pattern and density) and an association of soils that differ in kind from other land units. The geomorphic units established during aerial photo interpretation were then used to predict broad soil patterns and the associated range of soil properties. This is based on the fact that the processes responsible for landform features are known to have strong influence on parent materials and soils. The resulting soil landscape mapping units represent associations and/or complexes of soils described and delineated by means of geomorphic units. These were then scaled down and transferred to a base maps obtained from the available topographical maps at a scale of 1:50 000. Field survey and soil investigations were then based on this map.

3.3 Development of legend and description of the mapping units

Based on the approach used in this survey, each mapping unit is described in terms of land (geomorphic) unit, soils and vegetation. Soils are described in terms of their drainage conditions, effective soil depth, subsoil and topsoil texture, colour, consistence (moist conditions), stoniness if present and cracking if present. In addition, a higher level of soil classification both in Soil Taxonomy and FAO-Unesco legend is presented.

3.4 Field survey and revision of mapping units

Based on the distribution of land units (mapping units) obtained during aerial photo interpretation, and considering the time limitation and the large area to be covered, it was decided that the catenary approach could be a quick method of carrying out field soil observations, and provide general information about the soil properties and their distribution pattern on each geomorphic unit. One main transect was identified in each survey area running along the catena. Along this transect, soils were examined systematically by hand augering at an interval of 1 km in the Lubungo - Mkata area and 200 m in the Magadu area. Augering was to a depth of 100 cm except where there was a limitation by bedrock. Additional auger hole observations were made across some few selected interfluves wherever considered necessary. The information recorded at each auger hole included vegetation type, slope (%), soil drainage, soil colour (topsoil and at 50 cm depth), soil texture (topsoil and subsoil), soil structure (moist), soil consistence (moist), surface cracks (if present) and surface stoniness (if present). This information was then used to make the general description of soils of each mapping unit. The information obtained by this approach was only sufficient to characterize the most common soils in the different mapping units. It was not sufficient to quantitatively estimate the proportions of different soils within different mapping units and therefore, reliability or purity of the established soil mapping unit could not be attempted.

Based on the information from auger hole observations in different delineated land units, representative soil profiles of the major soil types were excavated, examined and their morphology described. The descriptive terminology applied during auger holes investigations and in profile description is largely based on the Guidelines for Soil Profile Description (FAO, 1990). Moist and dry soil colours were described using Munsell Soil Color Charts (1992). Soil profiles were dug to a depth of 200 cm except where soil depth was limited by bedrock or strongly cemented material. Soil samples were then taken from each soil horizon for physical, chemical and mineralogical analysis in the laboratory. Undisturbed (core) soil samples were also taken from some selected horizons of a few soil profiles for bulk density determination and water retention characteristics.

3.5 Soil analysis

3.5.1 Preparation of soil samples

Bulk soils samples from each horizon were air-dried, crushed and sieved to obtain the < 2-mm fraction on which the analysis were carried out. Most of the laboratory analyses were carried out at the Department of Soil science, Sokoine University of Agriculture, except where mentioned otherwise.

3.5.2 Analysis of some soil physical properties

Particle size analysis was carried out by hydrometer method after dispersion with sodium hexametaphosphate/sodium carbonate and shaking at high speed overnight (Gee and Bauder, 1986). There was no need of pretreatment to remove organic matter because its content is too low. Iron oxides were not removed because they were considered to be important minerals in these soils. Bulk density was determined in duplicate from the dry weight of 100 cm^3 undisturbed core samples taken at field moisture conditions (Blake and Hartge, 1986). The water content at 33 and 1500 kPa was estimated using a pressure plate and pressure membrane apparatus following the procedure described by Klute (1986). The water held between 33 and 1500 kPa pressure was used to estimate the available water capacity. Mineralogical analysis of selected soil profiles was carried out at Agricultural University of Norway using X-ray diffraction techniques described by Whittig and Allardice (1986). The results of mineralogical characterization will be presented by Kaaya and Jørgensen (in prep.)

3.5.3 Analysis of some soil chemical properties

The soil pH was determined with a pH meter (combination electrode) in the supernatant suspension of a 1:2.5 soil:liquid mixture as outlined by McLean (1982). This was done both in water and in 1 *M* KCl solution.

Organic carbon was determined following the Walkley-Black procedure which applies wet combustion of the organic matter with a potassium dichromate-sulphuric acid mixture followed by titration of residual dichromate with ferrous sulphate (Nelson and Sommers, 1982). Organic matter percentage was estimated by multiplying the percent organic carbon by 1.724.

Total nitrogen was determined by regular Kjeldahl method (Bremner and Mulvaney, 1982). Available phosphorus in soils with $pH < 7.0$ was extracted using Bray and Kurtz (1945) method, whereas Olsen method of using $NaHCO_3$ for extraction was employed in neutral and alkaline soils as outlined by Olsen and Sommers (1982).

Exchangeable bases were extracted with ammonium acetate at pH 7 following the Büchner funnel filtration procedure (Thomas, 1982) and then Ca, Mg, K and Na were determined in the filtrate by using atomic absorption spectrophotometer. After filtration the samples were then washed free of the excess salt and then the adsorbed NH_4^+ was displaced with 1 *M* KCl. The displaced NH_4^+ was determined by regular Kjeldahl distillation (Bremner and Mulvaney, 1982) and used to estimate the cation exchange capacity. Exchangeable Al was extracted from the soil sample by 1 *M* KCl and determined by titration (Barnhisel and Bertsch, 1982).

Effective cation exchange capacity (ECEC) was determined by summation of exchangeable bases and exchangeable Al (FAO, 1988). Percent base saturation was calculated as proportion of the CEC that is occupied by exchangeable bases.

Cation exchange capacity of clay was estimated using the relationship proposed by Baize (1993) as follows:

$$CECclay = \frac{\{CECsoil - (\%OM \times 2)\}}{\%clay} \times 100$$ where, *OM* is organic matter.

3.5.4 Soil classification

Soils were classified according to the revised legend of the FAO-Unesco Soil Map of the World (FAO, 1988) and the US Soil Taxonomy (Soil Survey Staff, 1996) to subgroup level. These are the two most common soil classification systems used in Tanzania. Detailed soil classification will be made separately by Kaaya and Sørensen (in prep.).

4. RESULTS AND DISCUSSION

Results of this study include a general purpose soil map produced for each of the two study areas, namely Lubungo-Mkata and Magadu presented in Appendices 2.1 and 2.2, respectively. Each of the produced soil maps (Appendices 2.1 and 2.2) is accompanied by a legend providing description and explanatory notes about the land unit, soils, vegetation/land use and the area occupied by each mapping unit. The total surveyed areas include 73.3 km^2 in Magadu area and 415 km^2 in Lubungo-Mkata area.

4.1 Mapping units of the Lubungo - Mkata soil map (Appendix 2.1)

4.1.1 Mapping unit I.1a

4.1.1.1 Description of the land unit

The major part of this unit include the Mkata river plain. It is formed by flat to almost flat alluvial plains with slopes 0 - 2% at an altitude of 400 - 440 m asl. It is mainly a depositional area of materials transported from higher geomorphic units and it occupies an area of about 66.5 km^2 i.e. 16% of the Lubungo - Mkata soil map. Most of the minor streams are seasonal and at some points they are underground. The natural vegetation is mainly savanna woodland dominated by *Acacia nigrescens*, *Dalbergia melanoxylon*, *Harrisonia abyssinica* and *Cussonia arborea* trees on river plains, the rest is Hyparrhenia-Combretum woodland. Figure 4.1 shows the environmental features of mapping unit I.1a around soil profile LUB 1.

4.1.1.2 Morphological characteristics and some physical properties of the soils

The soils are moderately deep to deep, imperfect to moderately well drained, dark gray to black cracking clays developed from alluvial/fluvial deposits overlying hornblende-biotite gneisses. The effective soil depth is locally restricted by an impervious subsoil. The soils of mapping unit I.1a are represented by soil profiles MK 2 and LUB 1. Field descriptions of these profiles are presented in Appendices 1.1 and 1.2, respectively. These two soil profiles were classified as Vertisols both in the US Soil Taxonomy (Soil Survey Staff, 1996) and in the FAO-Unesco (1988) system. Figure 4.2 shows morphological features of soil profile LUB 1.

The surface of these soils are characterized by low gilgai microrelief occurring nearly everywhere on this mapping unit. Deep, closely to moderately widely spaced wide cracks are common during dry seasons due to alternate swelling and shrinking of the expanding clays. The soils are black to dark gray in colour and the texture is clay throughout the profiles. The structure of the topsoil is mainly moderate to strong fine angular blocky, while most of the subsoil horizons have strong coarse prismatic structures and a few of them are angular blocky. Throughout the profile the consistence is very hard when dry, firm when moist and very sticky and plastic when wet. The effective soil depth range from moderately deep to deep. Calcium carbonate concretions are common in the subsoil of this mapping unit. Calcretes form petrocalcic horizon below 90 cm in the soils represented by profile LUB 1 and these calcretes emerge to the soil surface in the area around a gravel pit near Mkata ranch.

Figure 4.1 Environmental features of mapping unit I.1a around soil profile LUB 1
(Vegetation is an open Hyperrhenia - Combretum woodland affected by bush fires)

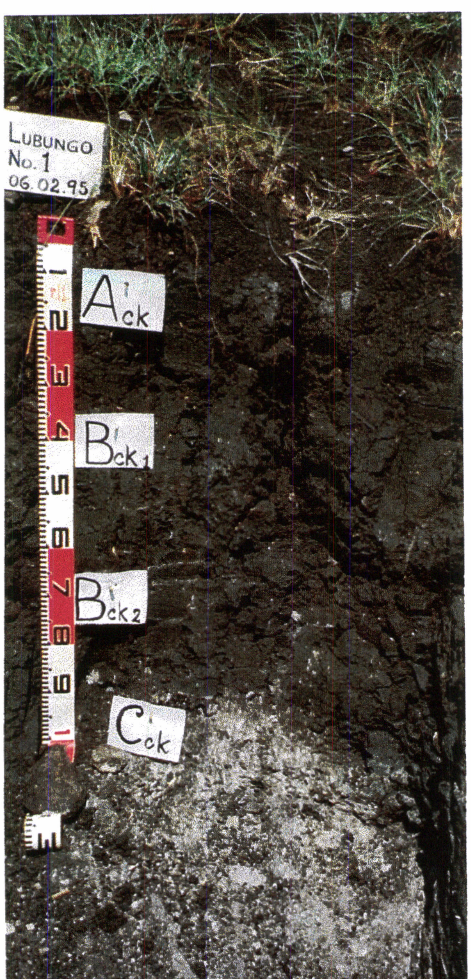

Figure 4.2 Soil profile LUB 1
(ST: *Petrocalcic Calciustert;* FAO: *Calcic Vertisol*)

Figure 4.3 show the particle size analysis of the soil profiles MK 2 and LUB 1 in mapping unit I.1a.. The texture of the soils is clay throughout the profiles. The silt content is relatively low in these soils.

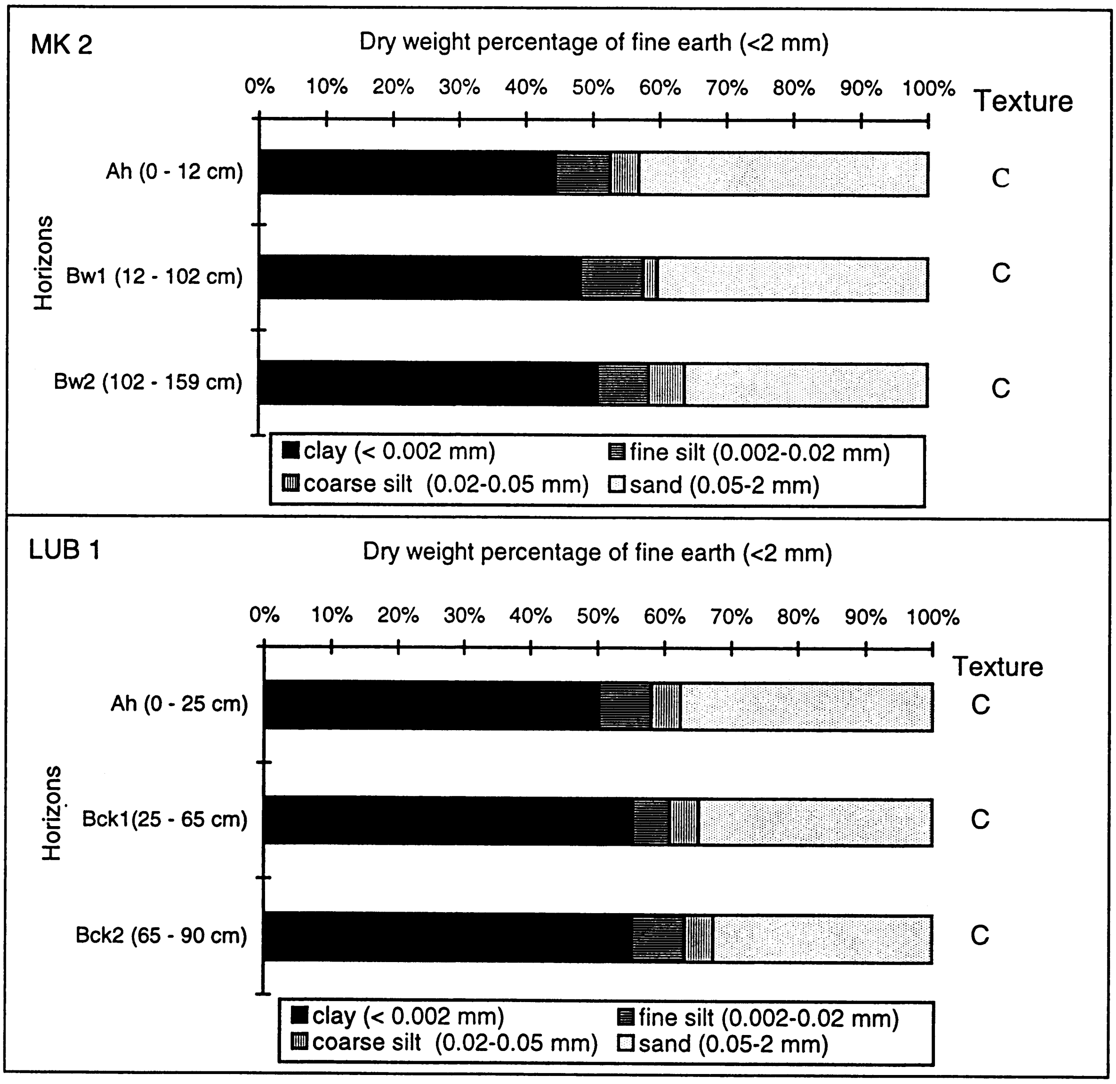

Figure 4.3 Particle size analysis of soil profiles MK2 and LUB 1

4.1.1.3 Soil chemical properties

The analyzed physico-chemical properties of the soil profiles MK 2 and LUB 1 in mapping unit I.1a are presented in Appendices 1.1 and 1.2, respectively. Cation exchange properties of these profiles are also presented in Figure 4.4. The soils have high cation exchange capacity (CEC) and high percent base saturation indicating that the soils are generally fertile in terms of macronutrients. This is a general characteristic of most Vertisols. The topsoil CEC values range from 27.3 cmol(+)kg^{-1} in soil profile MK 2 to 43.0 cmol(+)kg^{-1} in soil profile LUB 1. The CEC increases with soil depth to 34.3 cmol(+)kg^{-1} in soil profile MK 2 and 57.0 cmol(+)kg^{-1} in soil profile LUB 1. Their base saturation is > 90 % throughout the profiles with Ca and Mg dominating the exchange sites. The Ca:Mg ratio range from 1.5 to 3.2 throughout the soil profiles indicating possible P inhibition and Ca deficiency. The CEC of clay is fairly high in these soils suggesting high contents of smectite in the clay fraction. The levels of exchangeable sodium in the topsoil is generally low with values ranging from 3.3 cmol(+)kg^{-1} in soil profile LUB 1 to 3.5 cmol(+)kg^{-1} in soil profile MK 2. These levels increase with soil depth in both profiles to 12.6 and 16.9 cmol(+)kg^{-1} in profiles LUB 1 and MK 2, respectively which is generally high.

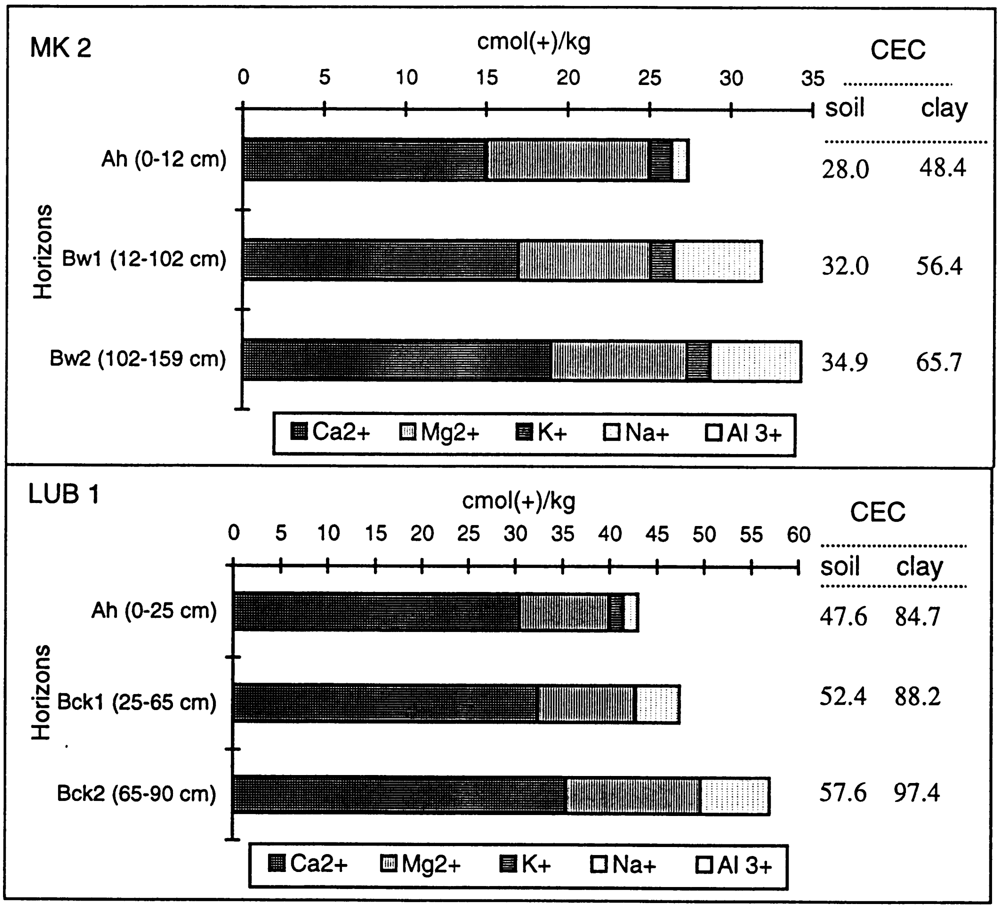

Figure 4.4 Cation exchange properties of soil profiles MK 2 and LUB 1

Soil pH, organic matter and total nitrogen contents of soil profiles MK 2 and LUB 1 are presented in Figure 4.5. The soil pH (KCl) is lower than pH (H_2O) throughout the profiles indicating that the soils have a net negative charge. The topsoil is mildly alkaline (pH 7.5 - 7.6) and pH values of the studied soil profiles increase gradually with depth to moderately and strongly alkaline (pH 8.0 - 8.5) in the subsoil. The fertility problems associated with soils containing such high pH values include decreased availability of P and most of the micronutrients such as B, Co, Cu, Fe, Mn and Zn. The available P (determined by Olsen method) in the topsoil range from 1.4 mg kg^{-1} in profile MK 2 to 2.5 mg kg^{-1} in profile LUB 1, and these values are generally very low indicating the need of P fertilization. The levels of total N and organic C are generally low to very low in the topsoil and they are very low in the subsoil.

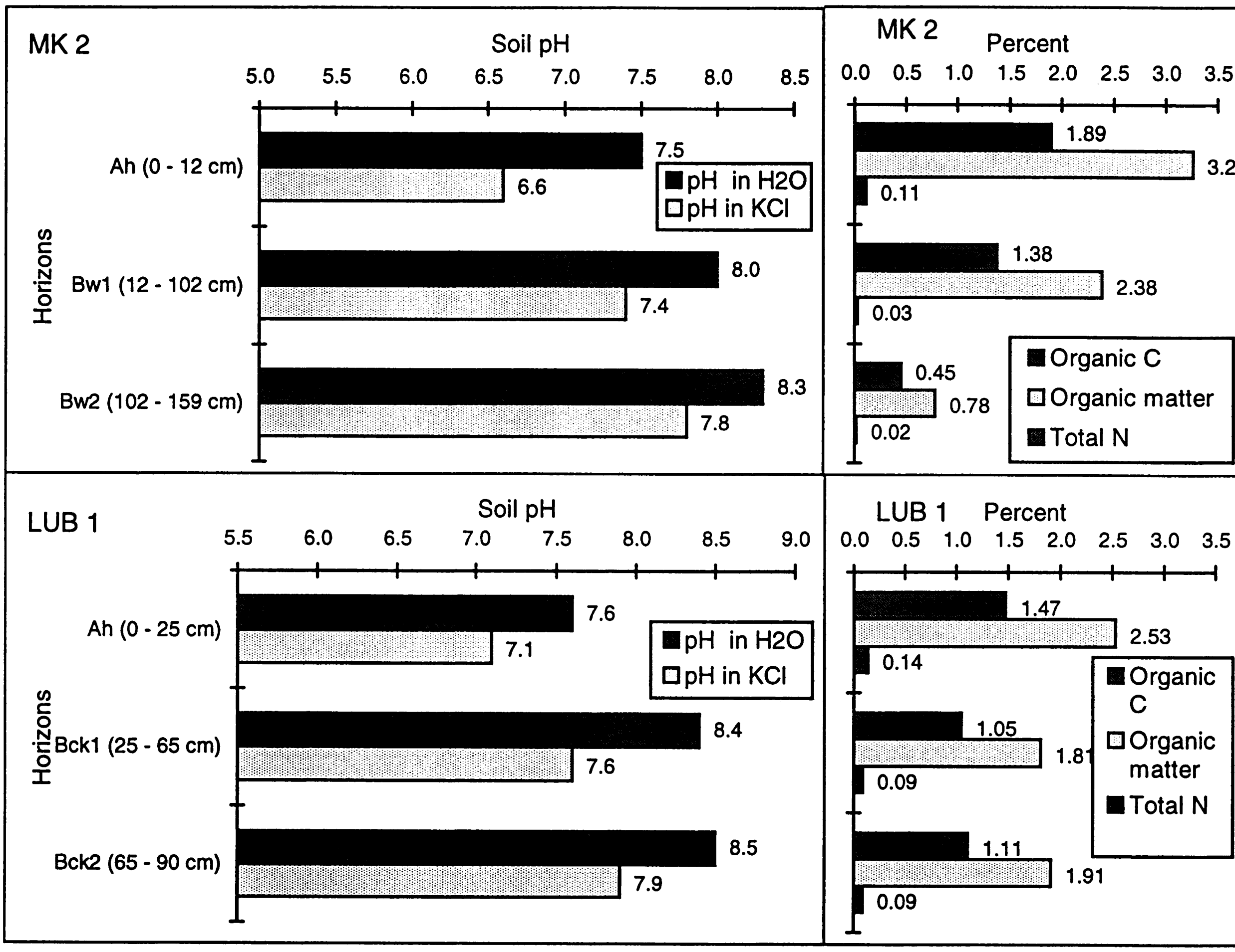

Figure 4.5 Soil pH, Organic matter and total nitrogen contents of soil profiles MK 2 and LUB 1.

With their high agricultural potential, vertisols require special management practices for optimal rainfed or irrigated agriculture. They have relatively high chemical fertility but their workability is poor due to their poor physical properties. Poor infiltration of water and high vulnerability to erosion are the major problems associated with poor physical properties of these soils. Management practices should therefore aim at increasing infiltration rates of water as well as reducing erosion hazard in these soils. Mulching with crop residues, contour cultivation and contour bunding are some of the recommended management practices for successful crop production in soils of mapping unit I.1a because they improve water infiltration rates into the soil and therefore reduce soil erosion. Alternatively, these soils are very productive if they are utilized for irrigated rice production. Successful small scale irrigated rice production is practiced near the river plains where irrigation water is available. In Wami flats these soils are used for large scale irrigated rice production.

4.1.2 Mapping unit I.1b

4.1.2.1 Description of the land unit

Mapping unit I.1b is formed by flat to almost flat fluvial/alluvial plains with slopes 0 - 2 % at an altitude of 400 - 440 m asl. It covers an area of 31.5 km^2 i.e. 7.6 % of the surveyed area in the Lubungo-Mkata soil map. It is mainly a depositional area receiving materials transported from higher geomorphic units. The natural vegetation is mixed woodland composed of various species including Hyphaene palm, *Combretum spp., Acacia xanthoghloea, Annona senegalensis, Flacourtia indica* and grass species dominated by *Hyparrhenia rufa*. Figure 4.6 shows the environmental features of mapping unit I.1b and Figure 4.7 shows morphological features of its representative soil profile LUB 2.

4.1.2.2 Morphological characteristics and some physical properties of the soils

Soils of this mapping unit are complex. They have developed from alluvial/fluvial deposits overlying hornblende-biotite gneiss bedrock. They range from deep moderately well drained friable dark reddish brown stratified sands and sandy clays near river plains to the dominant moderately deep and deep, imperfectly drained, firm dark grayish calcareous sandy clay to dark cracking clays in depressions. The effective soil depth is restricted by an impervious subsoil or a high ground water table near the river plains. In the river plains, the soils are characterized by fluvic properties as indicated by stratification in the upper 100 cm of the soil profile. The soils on this unit fall under the orders Inceptisols, Entisols and Vertisols in the US Soil Taxonomy (Soil Survey Staff, 1996) and under soil units Cambisols, Fluvisols and Vertisols in the FAO-Unesco (1988) system. Field description of the soil profile LUB 2 and the corresponding physico-chemical data are presented in Appendix 1.3. This profile was classified as Fluventic Ustropepts in the US Soil Taxonomy (Soil Survey Staff, 1996) and as Eutric Cambisols in the FAO-Unesco (1988) system.

The soils represented by profile LUB 2 are characterized by black to very dark grayish brown sandy clay topsoils with angular blocky structure and dark yellowish brown to light olive brown clayey subsoils with subangular structure. The wet consistence is sticky and plastic in the topsoil and very sticky and very plastic in the subsoil. When dry the soil is very hard throughout the profile. Occurrence of reddish brown mottles in the B horizon indicates seasonal fluctuation of the groundwater table up to a depth of 40/48 cm in the profile. The profile is characterized by occurrence of calcareous nodules in the B horizon which increase in size (from fine to medium) and in quantity (from few to many) with profile depth. The subsoil overlies a light olive brown massive moderately calcareous parent material.

Some soils on depressions are characterized by wide cracks occurring during dry seasons due to alternate swelling and shrinking of the expanding clays. The soils are mainly black or dark gray clays and are very sticky and plastic when wet and very hard when dry. They are mainly Vertisols or other soils with vertic properties.

Figure 4.6 Environmental features of mapping unit I.1b
(Mixed secondary woodland around the profile and riverine forest the Mbesegera river in the background)

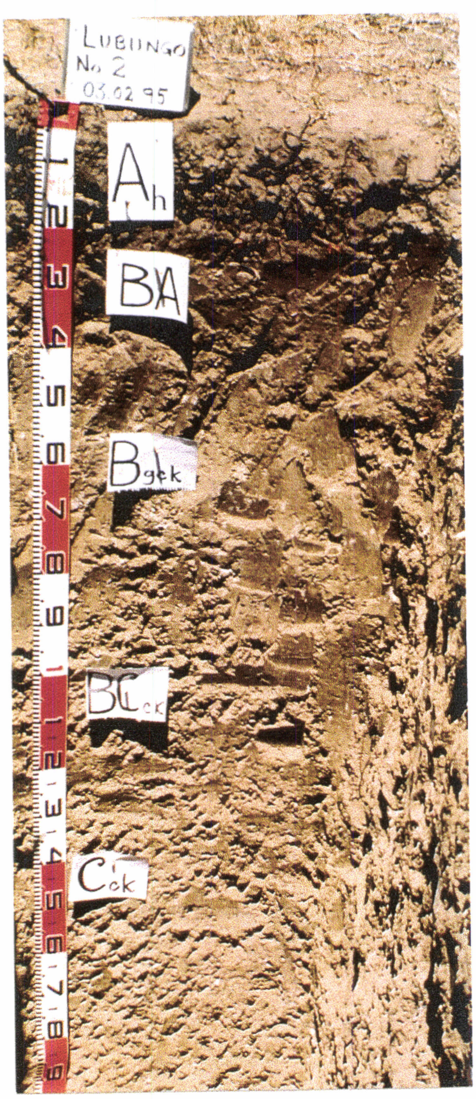

Figure 4.7 Soil profile LUB 2
(ST: *Fluventic Ustropept*; FAO: *Eutric Cambisol*)

The surface horizon of soil profile LUB 2 is sandy clay and the clay content increases slightly in the B horizon, below which the texture changes to sandy clay in the C horizon. Variation of soil texture with soil depth and horizons in soil profile LUB 2 is presented in Figure 4.8.

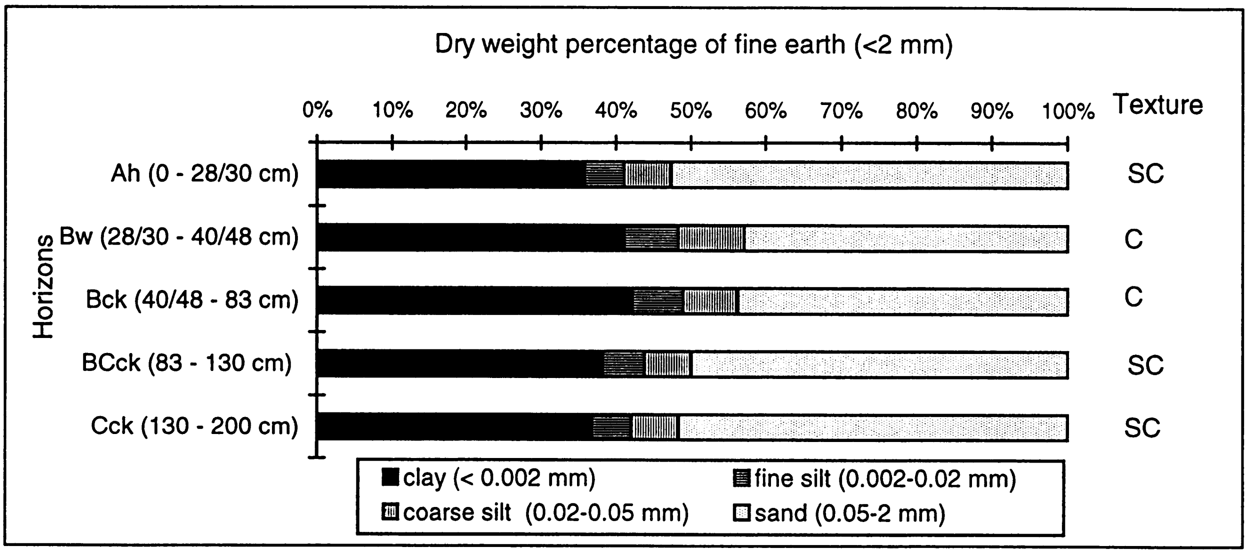

Figure 4.8 Particle size analysis of soil profile LUB 2

4.1.2.3 Soil chemical properties

The analyzed chemical properties of the soil profile LUB 2 are presented in Appendix 1.2. The cation exchange properties of different horizons of soil profile LUB 2 are also presented in Figure 4.9. The soils have medium to high cation exchange capacity (CEC) and high percent base saturation indicating that they are generally fertile in terms of macronutrients. The topsoil CEC of profile LUB 2 is 19.2 cmol(+)kg^{-1} which is medium and this has a general tendency of increasing with profile depth to 28.0 cmol(+)kg^{-1} in the subsoil. The clay CEC is relatively high suggesting dominance of illite and smectite in the clay fraction The base saturation is > 90 % throughout the profiles with Mg and Ca dominating the exchange sites. The Ca:Mg ratio is < 3:1 throughout the profile indicating possible P inhibition. The levels of exchangeable sodium in the topsoil is high and they increase with soil depth indicating possibility of sodicity problems.

Figure 4.10 shows variation of soil pH, organic matter and total nitrogen contents of profile LUB 2. The soil pH (KCl) is lower than pH (H_2O) throughout the profile indicating that the soils have a net negative charge. The topsoil is mildly alkaline (pH 7.4) and the subsoil is moderately to strongly alkaline (pH 8.1 - 8.5). Like soils of mapping unit I.1a, the possible fertility problems associated with these soils include decreased availability of P and most of the micronutrients such as B, Co, Cu, Fe, Mn and Zn. The topsoil available P determined by the Olsen method in profile LUB 2 is 8.5 mg kg^{-1} soil which is moderate, indicating the need of low levels of P fertilization. The levels of total N and organic C are generally low to very low in the topsoil and they are very low in the subsoil.

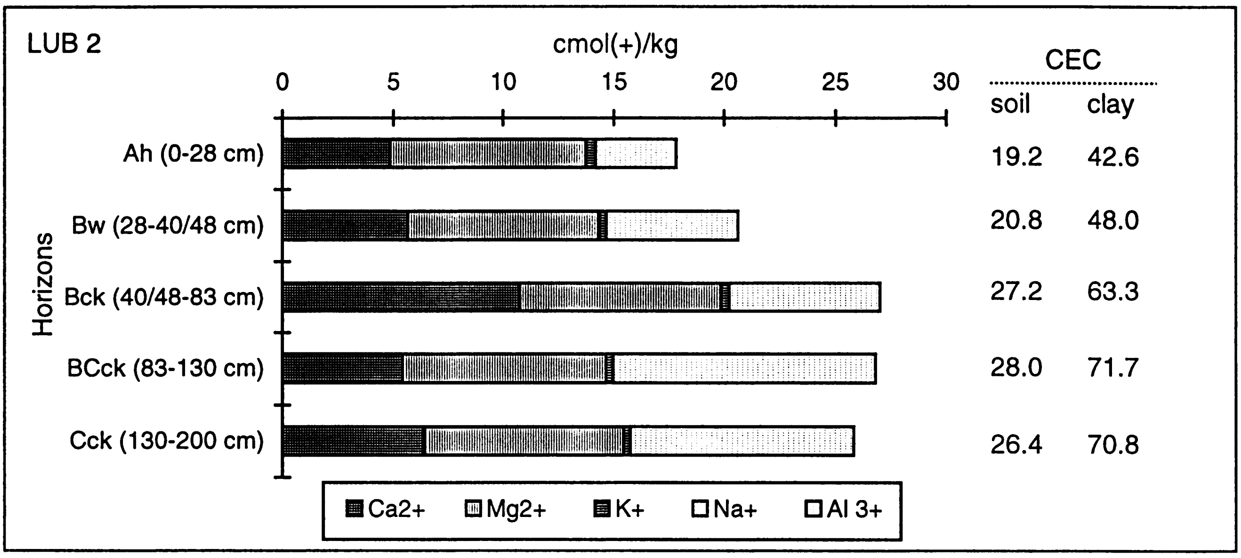

Figure 4.9 Cation exchange properties of soil profile LUB 2

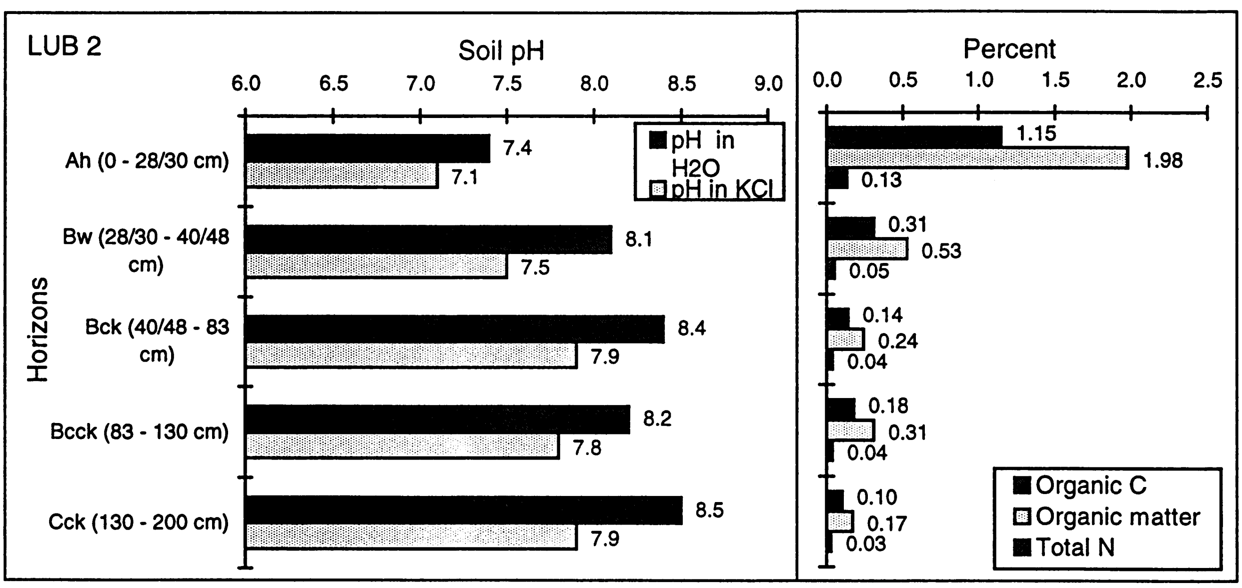

Figure 4.10 Soil pH, organic matter and total nitrogen contents of soil profile LUB 2

The overall soil fertility status is generally high. The soils can be highly productive if properly managed. Management practices which improve soil organic matter and increase infiltration rates of the soils are required. Where irrigation water is available these soils are highly productive under paddy rice.

4.1.3 Mapping unit I.2a

4.1.3.1 Description of the land unit

Mapping unit I.2a is composed of gently undulating to undulating plains with slopes 2 - 5% at an altitude of 420 - 540 m asl. It covers an area of 133.6 km^2 i.e. 32.2 % of the total surveyed area in the Lubungo-

Mkata area. The main geomorphic process is peneplanation. According to King (1976), the term peneplanation is considered as the slow flattening of the divide slopes resulting in multi-convex profiles. This has resulted in the formation of wide interfluves with an average width of 3.2 km and long gentle convex slopes running from the tops of the interfluves towards the stream valleys (Kaaya, 1996). Moderate sheet erosion dominates on these long slopes. Bedrock is exposed in most seasonal stream channels and ravines. The most common exposed rocks are biotite gneisses but amphibolites were also observed in some places. The natural vegetation is mainly Combretum woodland composed of *Combretum spp., Acacia spp., Stercularia spp.* and grass species dominated by *Hyparrhenia rufa*. Figures 4.11 and 4.13 show the environmental features of mapping unit I.2a around soil profiles LUB 3, and LUB 4, respectively. The environmental features around soil profile LUB 5 are almost similar to those around soil profile LUB 4. Figures 4.12, 4.14 and 4.15 show morphological features of soil profiles LUB 3, LUB 4 and LUB 5, respectively.

Most of the area on the lower parts of the slopes is utilized for subsistence cultivation of various food crops including maize, sorghum, cassava, groundnuts, and pigeon peas, all under rain-fed conditions. The need of more land for cultivation has resulted in replacement of the natural vegetation gradually from the lower parts towards higher parts of the landscape. Extensive grazing, clearing of the woody vegetation for fire wood and charcoal burning are the most of important human activities in upper parts of the landscape.

4.1.3.2 Morphological and physical properties of the soils

The unit is dominated by deep to very deep, well drained soils with a friable dark reddish brown sandy clay loam to clay topsoil with weak to moderate structure overlying a very friable dark red clay subsoil. The soils have developed from colluvial deposits overlying micaceous gneisses and hornblende gneisses. LUB 3 is a representative soil profile of the soils on the lower parts of the slope, and soil profiles LUB 4 and LUB 5 represent the dominant soils on this mapping unit. Field descriptions of the soil profiles LUB 3, LUB 4 and LUB 5 and the analyzed physico-chemical data are presented in Appendices 1.4, 1.5 and 1.6, respectively. The soil structure is weak to moderate, resulting into low aggregate stability. This enhances the susceptibility of these soils to erosion. Management practices aimed at improving the soil structure and control of soil erosion are therefore necessary. These may include terracing, contour ploughing, minimum tillage and mulching. It is also advised to discourage cultivation of tuber crops such as cassava and sweet potatoes, or groundnuts which increase the danger of soil deterioration and erosion. On the lower parts of the slopes (soil profile LUB 3), the soils are characterized by occurrence of plinthite layer or ironstone in the subsoil which limits their effective depth.

Figure 4.11 Environmental features of mapping unit I.2a around soil profile LUB 3
(foreground showing the agricultural fields near Lubungo village)

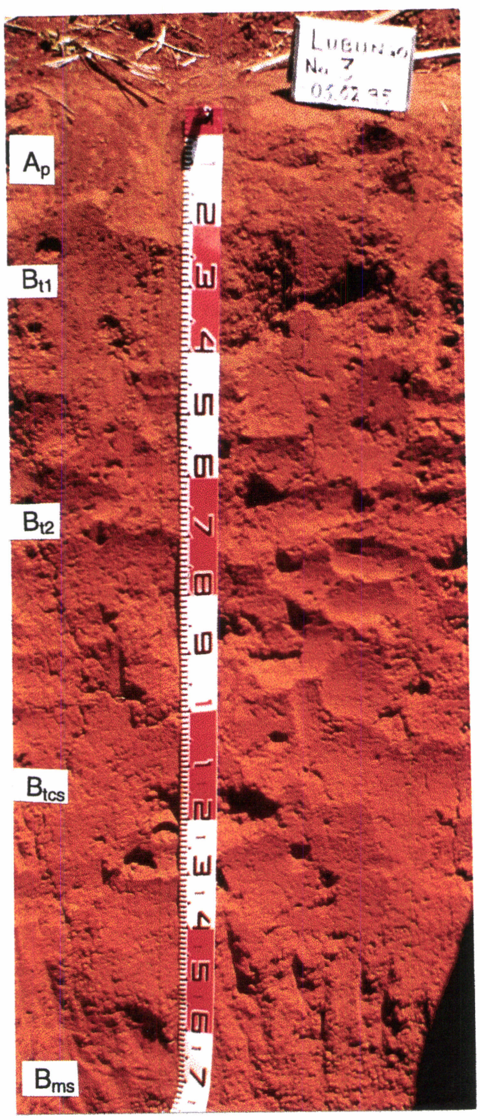

Figure 4.12 Soil profile LUB 3
(ST: *Kandic Paleustalf;* FAO:*Haplic Lixisol)*

Figure 4.16 shows variation of bulk density with horizons in these soil profiles. The bulk density are generally low to medium for mineral soils with values ranging from 1.18 to 1.33 g cm^{-3} in the topsoil, and from 1.23 to 1.43 g cm^{-3} in the subsoil.

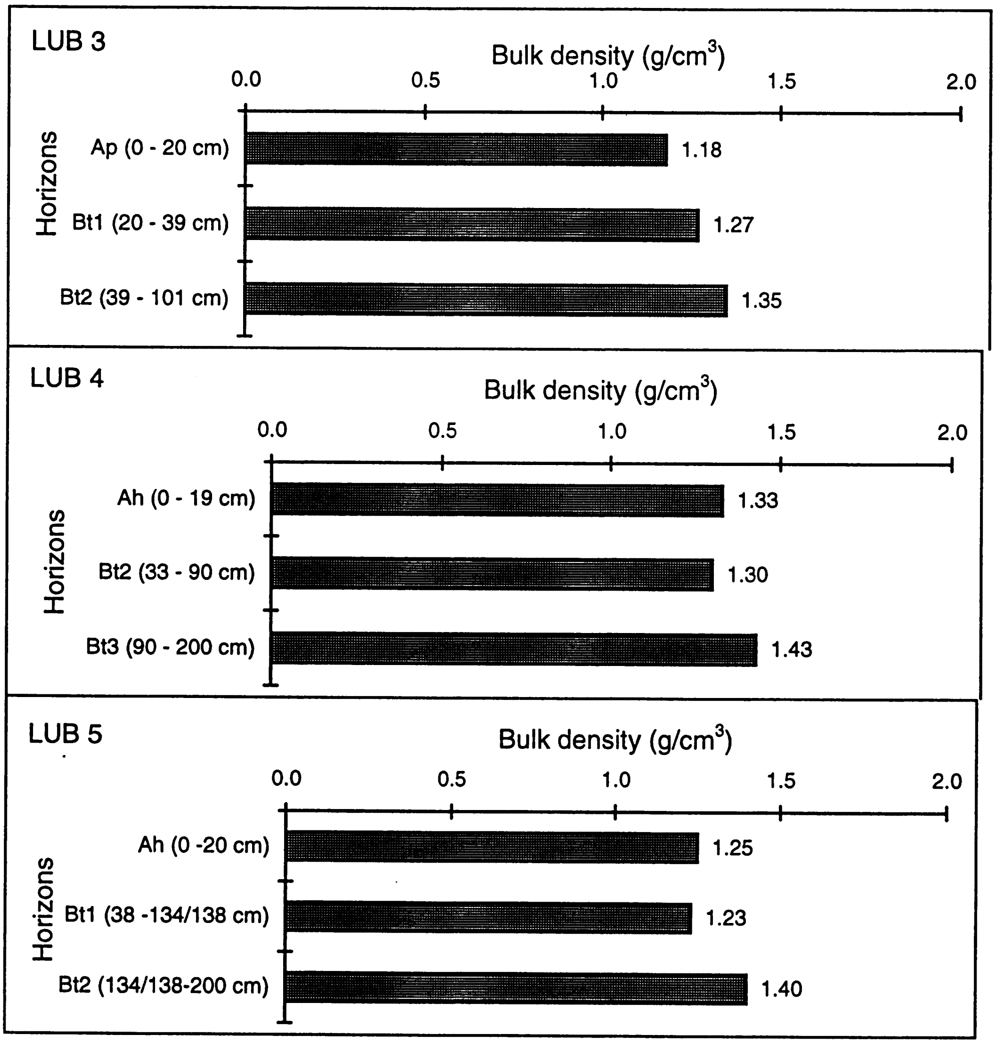

Figure 4.16 Soil bulk density of some horizons of the soil profiles LUB 3, LUB 4 and LUB 5

Generally, the clay content increases with soil depth in this mapping unit. Variation of soil texture with depth for profiles LUB 3, LUB 4 and LUB 5 are presented in Figure 4.17. In the US Soil Taxonomy (Soil Survey Staff, 1996), profiles LUB 3 and LUB 4 are classified as Kandic Paleustalfs and profiles LUB 5 as Rhodic Kandiustalf. These three profiles were classified as Haplic Lixisols in the FAO-Unesco (1988) system.

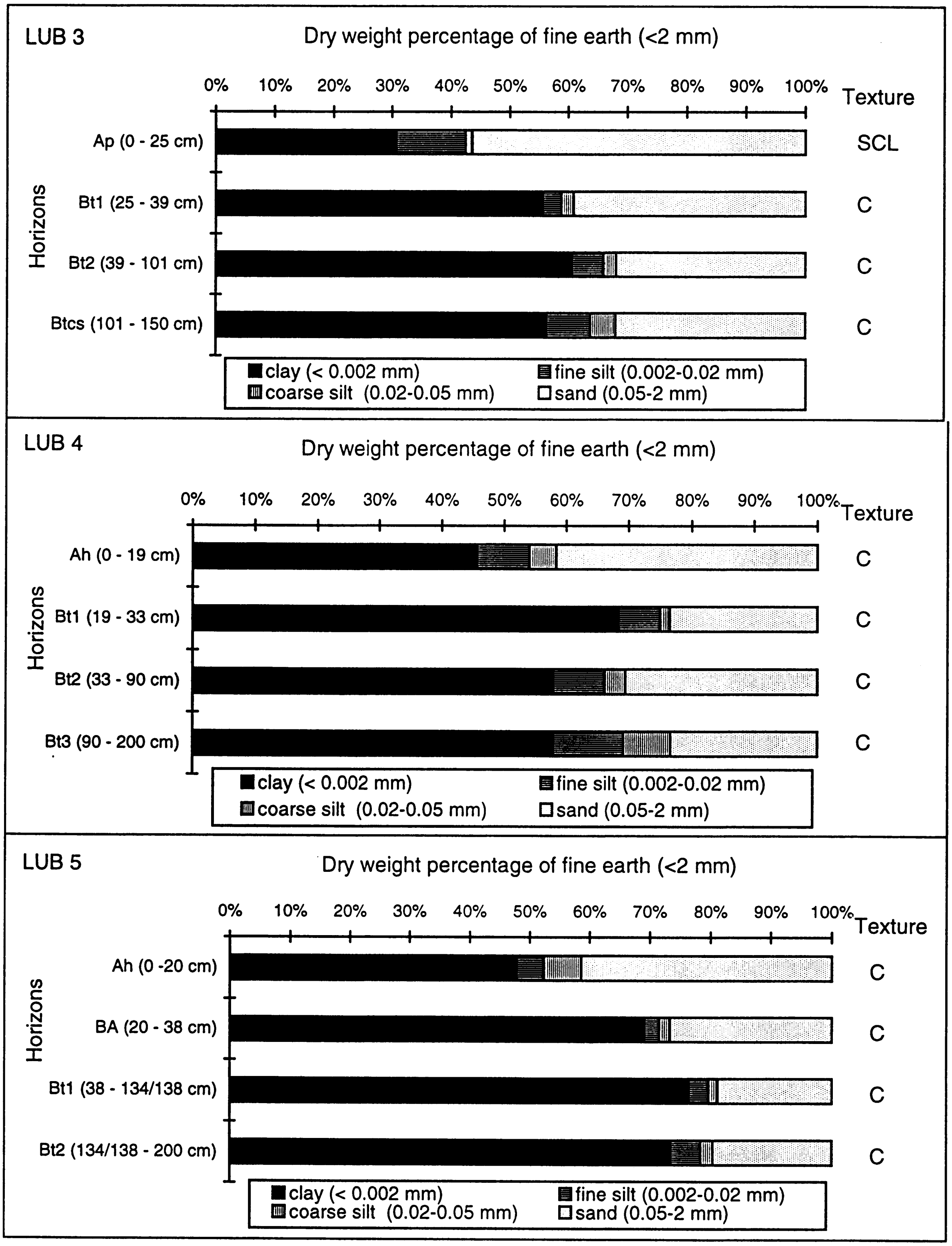

Figure 4.17 Particle size analysis of soil profiles LUB 3, LUB 4 and LUB 5

4.1.3.3 Soil chemical properties

Figure 4.18 shows cation exchange properties of soil profiles LUB 3, LUB 4 and LUB 5. Throughout these soil profiles, the soil CEC is low with values varying from 8.6 to 15.6 cmol(+)kg^{-1} soil. This shows that these soils have low levels of available nutrients and low nutrient reserves. The CEC of clay is variable with values ranging from 10.7 cmol(+) kg^{-1} in some subsurface horizons of the soils on the higher parts of the landscape (profile LUB 5) to 35.4 cmol(+) kg^{-1} in the surface horizon of the soils of the lower parts of the landscape (profile LUB 3). There is a general trend of decreasing values of the CEC of clay from the lower parts of the landscape to higher parts in this mapping unit. With exception of the clay CEC of the surface horizon of profile LUB 3, the clay CEC values are relatively low in all three

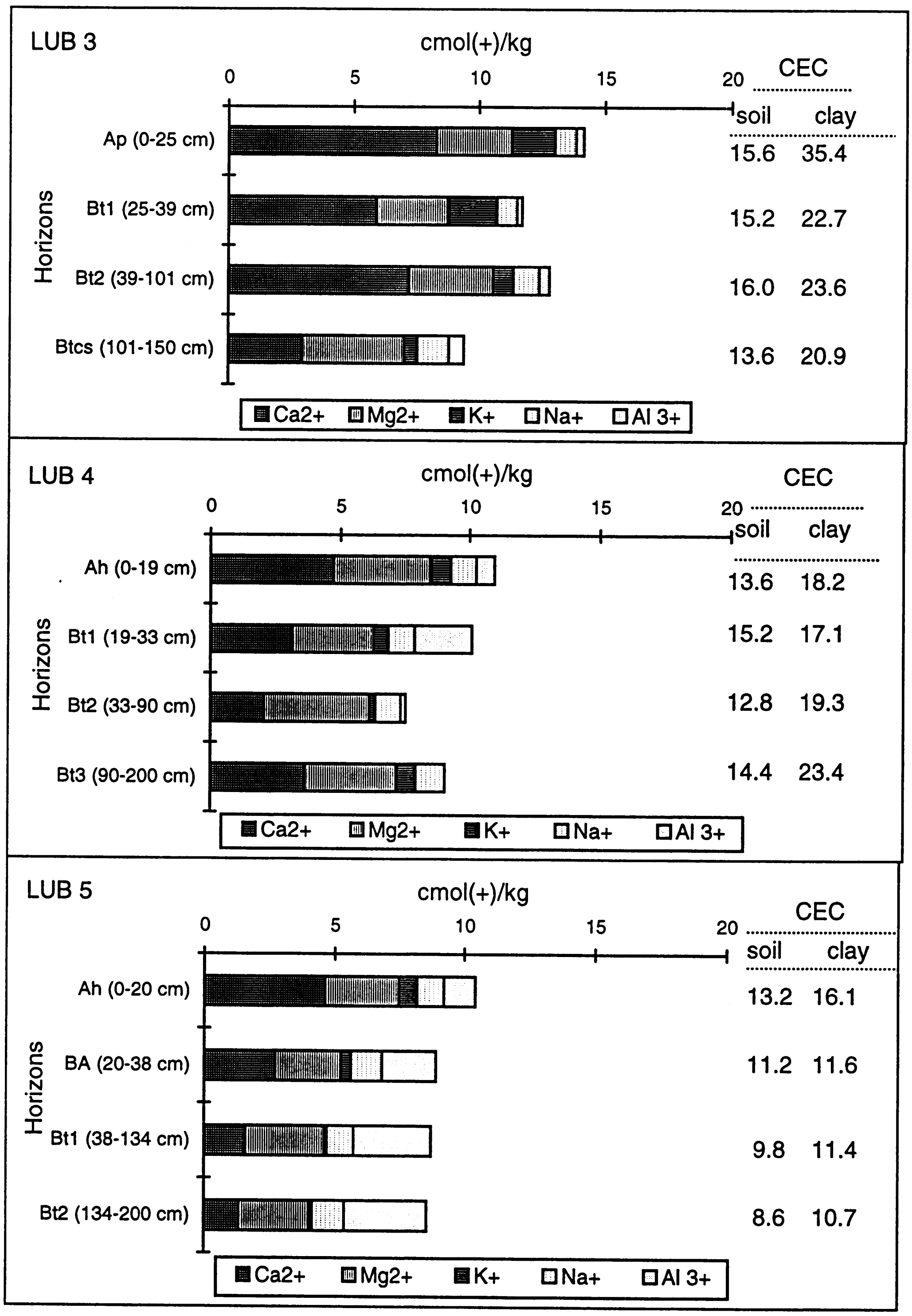

Figure 4.18 Cation exchange properties of soil profiles LUB 3, LUB 4 and LUB 5

profiles, suggesting dominance of kaolinite in the clay fraction. The base saturation is > 50 % throughout the profiles with Mg and Ca dominating the exchange sites.

Variations of soil pH, organic matter and total nitrogen contents with horizons in profiles LUB 3, LUB 4 and LUB 5 are presented in Figure 4.19. The soil pH (KCl) is lower than pH (H_2O) throughout the profiles indicating that the soils have net negative charge. The topsoil reaction is mildly alkaline (pH 7.6)

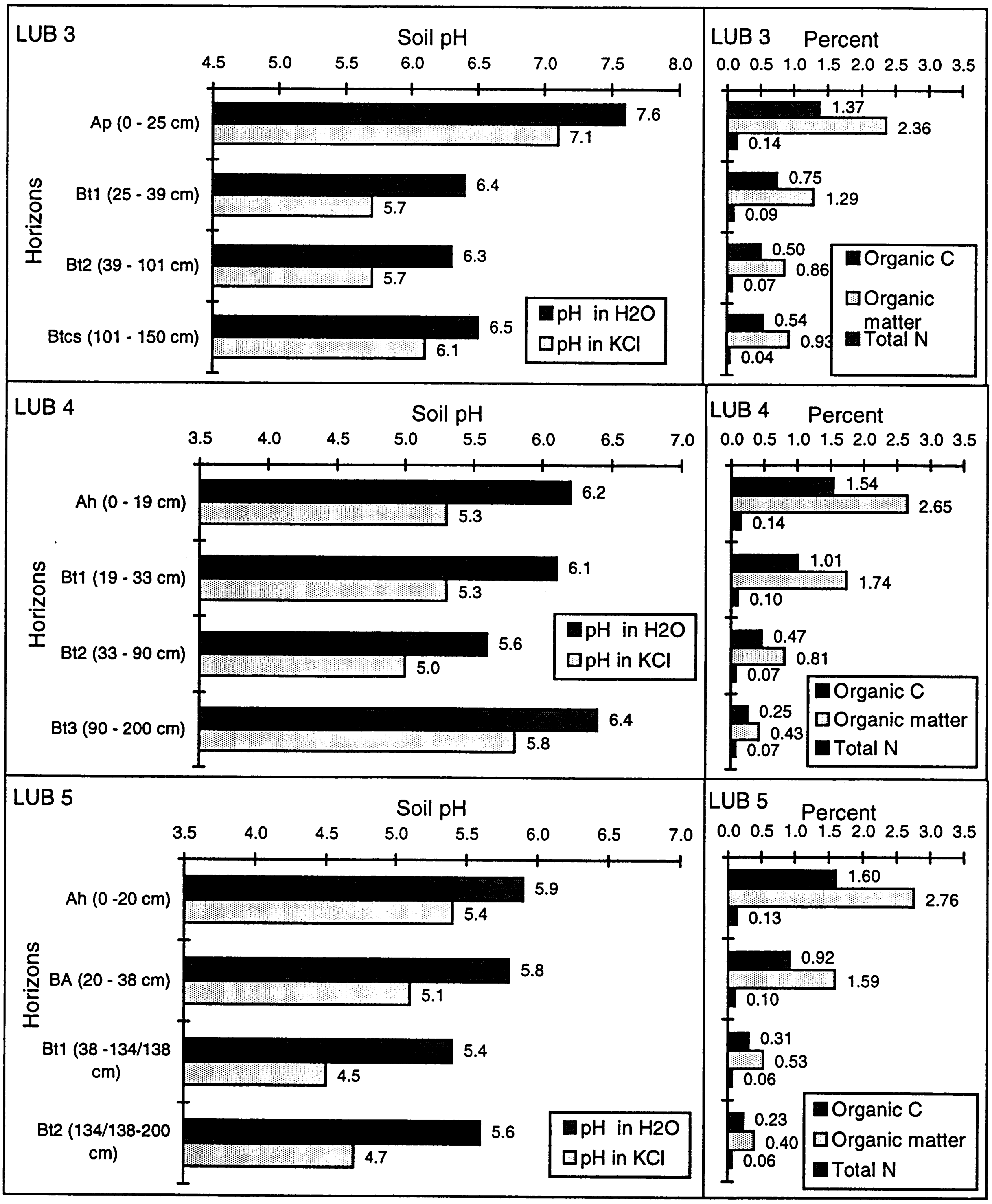

Figure 4.19 Soil pH, organic matter and total nitrogen contents of soil profiles LUB 3, LUB 4 and LUB 5

in the lower parts of the slopes and it changes upwards the landscape to slightly acid (pH 5.9) on the higher parts of the slope. The subsoil acidity vary from strongly acid to slightly acid (pH 5.4 to 6.5) . Variation of subsoil pH with landscape is similar to that of the topsoil. Generally, the soil reaction of this mapping unit is within preferred range for most crops except for the soils where pH is > 7.0 where phosphorus and most of the micronutrients may be deficient. The available P content in the topsoil of the lower parts of the mapping unit is moderate with value of 12.5 mg kg^{-1} soil in surface horizon of profile LUB 3. The levels of available P in profiles LUB 4 and LUB 5, representing the rest of the mapping unit is very low. The levels of total N and organic C are generally low to very low in the topsoil and they are very low in the subsoil.

The low levels of nutrient reserves and available nutrients of soil profiles LUB 3, LUB 4 and LUB 5, indicate that the overall chemical soil fertility of mapping unit I.2a is generally low. Utilization of these soils for crop production requires application of fertilizers. The nutrient holding capacity of these soils is low and therefore split application of fertilizers is recommended in order to minimize nutrient losses by leaching.

4.1.4 Mapping unit I.2b

4.1.4.1 Description of the land unit

Mapping unit I.2b covers an area of 22.2 km^2 i.e. 5.4 % of the surveyed area in the Lubungo-Mkata area. The land unit is similar to mapping unit I.2a in terms of landform, relief, geology and natural vegetation. However, the soils are shallow to moderately deep, well drained red and reddish brown clay loam subsoil under dark reddish brown sandy clay loam topsoil with some gravel and stones. The soils are developed from colluvial deposits overlying hornblende-biotite gneiss. Most of the area is woodland under extensive grazing and charcoal burning. The soils were classified as Inceptisols in the US Soil Taxonomy (Soil Survey Staff, 1996) and as Leptosols or Cambisols in the FAO-Unesco (1988) system.

4.1.5 Mapping unit I.3

4.1.5.1 Description of the land unit

Mapping unit I.3 comprises gently undulating to undulating plains with slopes 2 - 5% at an altitude of 540 - 580 m asl on the Mkata plains. It covers an area of 11.4 km^2 i.e. 2.7% of the surveyed area on the Lubungo-Mkata soil map. The dominant geomorphic processes are pediplanation and peneplanation which have resulted in a complex of multi-concave and multi-convex slopes. The term pediplanation is used in this study as defined by King (1976). It is refers to parallel retreat of hill-slopes with concomitant pediment enlargement resulting in multi-concave profiles. There are a few exposed rocks in the valleys of seasonal streams most of which are micaceous gneisses. The natural vegetation is savanna woodland dominated by a herbaceous layer of *Heteropogon contortus* and a few *Bulbostylus spp*. The scattered trees include *Combretum spp*., *Sclerocarya spp*. and. *Cassia spp*. The land use is mainly subsistence cultivation of various food crops including maize, sorghum, cassava, pigeon peas, beans and groundnuts, all under rain-fed conditions.

4.1.5.2 Morphological properties of the soils

The unit is dominated by moderately deep to deep, well drained soils with a dark grayish brown sandy loam topsoil overlying a yellowish brown to grayish brown sandy clay subsoil. The soils have developed from colluvial deposits overlying hornblende-biotite gneiss. The soil structure is weakly developed. The soils are classified as Inceptisols in the US Soil Taxonomy (Soil Survey Staff, 1996) and as Cambisols in the FAO-Unesco (1988) system.

4.1.6 Mapping unit I.4

4.1.6.1 Description of the land unit

Mapping unit I.4 is composed of dissected undulating to rolling plains around the Sangasanga ridge. It is characterized by short concave and convex moderate slopes ranging from 5 to 15 % at an altitude of 540 - 640 m asl. The average width of interfluves is 1.2 km indicating that the stream frequency is generally high. Mapping unit I.4 covers an area of 37.2 km2 i.e. 9.0% of the Lubungo - Mkata soil map. The dominant geomorphic processes on the surface including valley incision and peneplanation are relatively active as indicated by the presence of numerous ravines and exposed rocks. The underlying bedrock is composed of muscovite-biotite migmatites. The natural vegetation is Combretum woodland composed of *Combretum spp., Acacia spp., Stercularia spp.* and grass species dominated by *Heteropogon contortus*. Figure 4.20 and 4.22 show environmental features of mapping unit I.4 around soil profiles KIP 1 and KIP 3, respectively.

Most of the area is utilized for grazing animals, particularly cattle and goats. The animals from the dairy farm on slopes of the Sangasanga ridge graze in this area. People from the nearby villages obtain firewood and charcoal by clearing of the woody vegetation from this land unit.

4.1.6.2 Morphological and physical properties of the soils

The unit has shallow to deep, well drained soils with a very dark grayish brown sandy loam topsoil overlying a dark reddish brown to yellowish red sandy clay loam subsoil. However, in depressions on some slopes, there could be localized reducing conditions possibly due to the occurrence of a perched water table. This is clearly observed in the subsoil of profile KIP 1. On the lower parts of the slopes the soils are characterized by the occurrence of a plinthite layer or ironstone in the subsoil as in soil profile KIP 1. The soils have developed from colluvial deposits. Rock fragments observed in the C horizon of soil profile KIP 3 were composed of quartz, feldspars and muscovite.

Soil profile KIP 1 represents soils on the middle parts of the slope while soil profile KIP 3 represents the shallow soils on top of the ridges. Field descriptions of soil profiles KIP 1 and KIP 3, and their analyzed physico-chemical data are presented in Appendices 1.11 and 1.12, respectively. Figures 4.21 and 4.23 show morphology of soil profiles KIP 1 and KIP 3, respectively. In the US Soil Taxonomy (Soil Survey Staff, 1996), soil profiles KIP 1 and KIP 3 are classified as Typic Ustropepts, whereas in the FAO-Unesco (1988) system, they are classified as Chromic Cambisols and Eutric Leptosols, respectively.

Figure 4.20 Environmental features of mapping unit I.4 around profile KIP 1
(Vegetation is mainly Combretum woodland with some miombo woodland species)

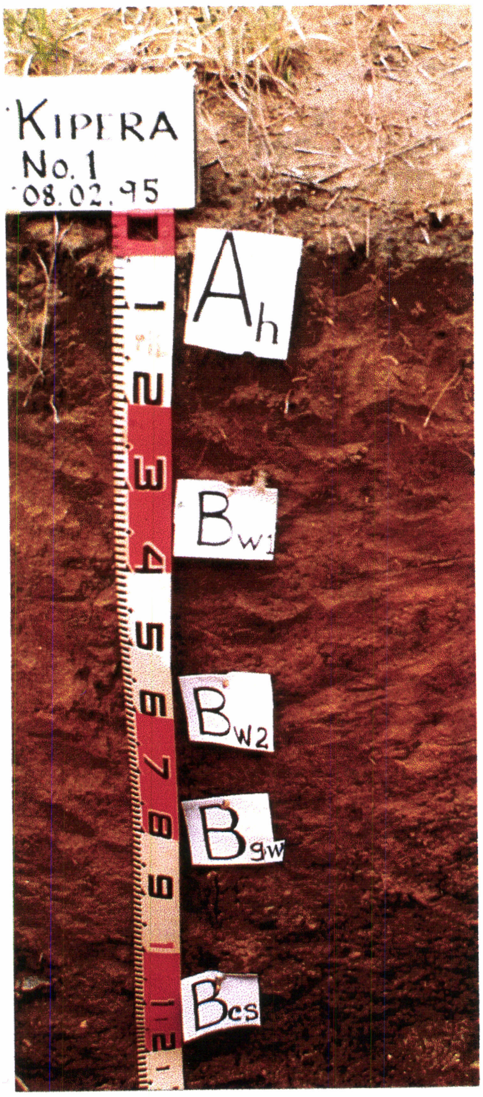

Figure 4.21 Soil profile KIP 1
(ST: *Typic Eutropept;* FAO: *Eutric Cambisol)*

Soil erosion is a threat to the shallow soils on the top of ridges. These soils should therefore not be used for crop cultivation. It is suggested that such soils should be used for wet season grazing of animals or as forest land.

The textural composition of soil profiles KIP 1 and KIP 3 are presented in Figure 4.24. The texture changes from sandy loam in the topsoil to sandy clay loam in the subsoil as clay content increases gradually with soil depth.

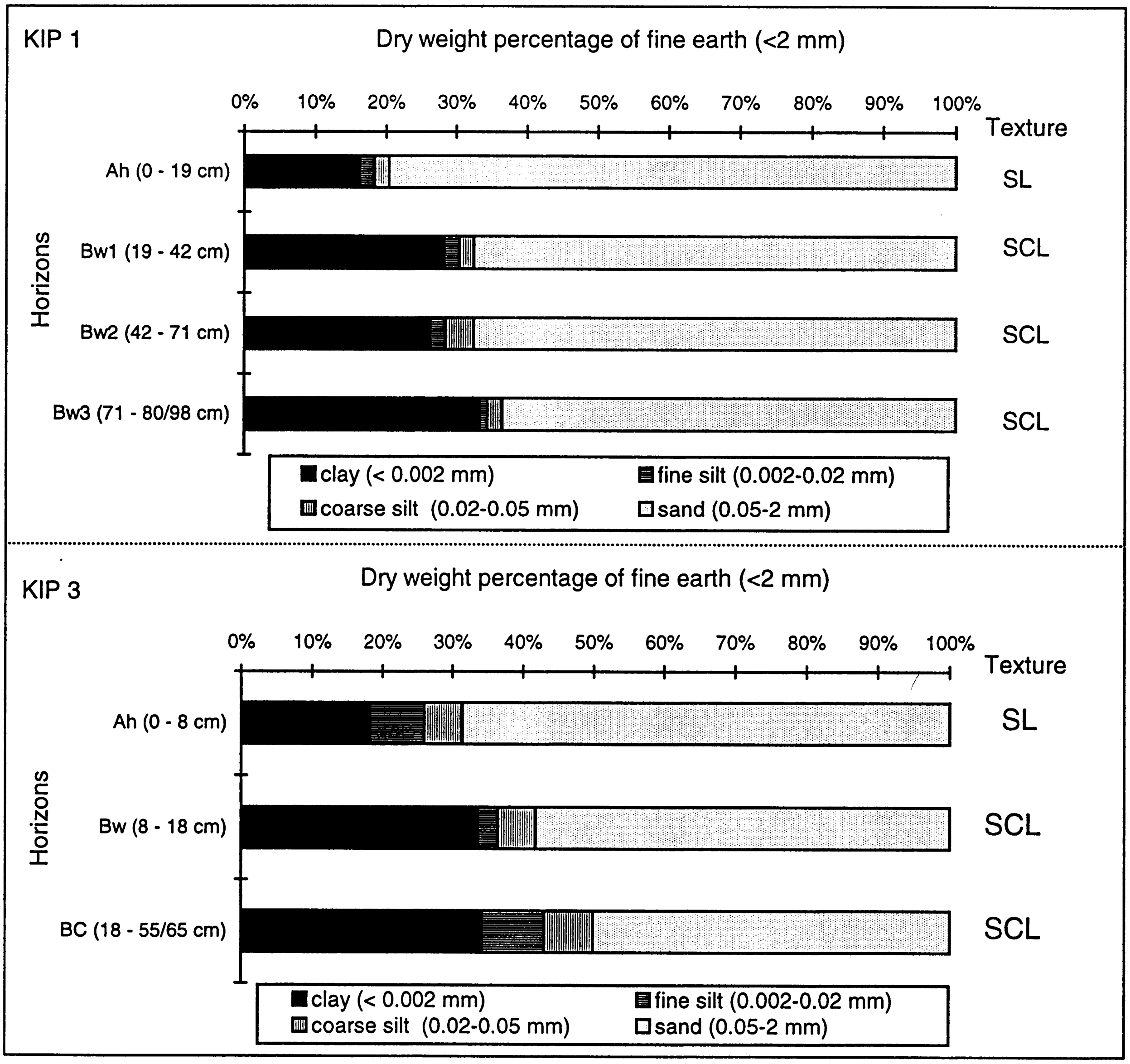

Figure 4.24 Particle size analysis of soil profiles KIP 1 and KIP 3

The dry bulk density of some horizons of soil profile KIP 1 are presented in Figure 4.25. The values are generally high with values ranging from 1.63 g cm^{-3} in the surface horizon to 1.77 g cm^{-3} in the subsoil probably due to relatively high (> 65 %) contents of sand in the whole profile. The increase of bulk density with profile depth is probably due to the decrease of organic matter content with profile depth (Fig.4.27).

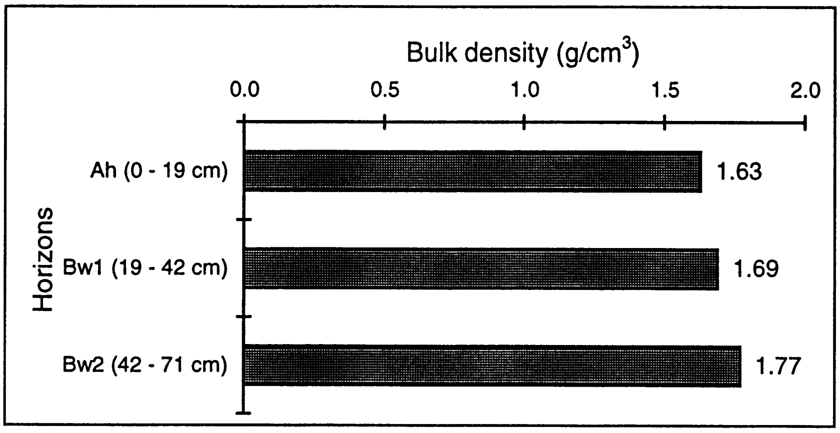

Figure 4.25 Bulk density of the selected horizons of soil profile KIP 1

4.1.6.3 Soil chemical properties

The cation exchange properties of soil profiles KIP 1 and KIP 3 are presented in Figure 4.3. The soil CEC is low throughout the two soil profiles with values varying from 7.2 cmol(+)kg^{-1} soil in the subsoil of soil profile KIP 3 to 13.6 cmol(+)kg^{-1} soil in the subsoil of soil profile KIP 1. This shows

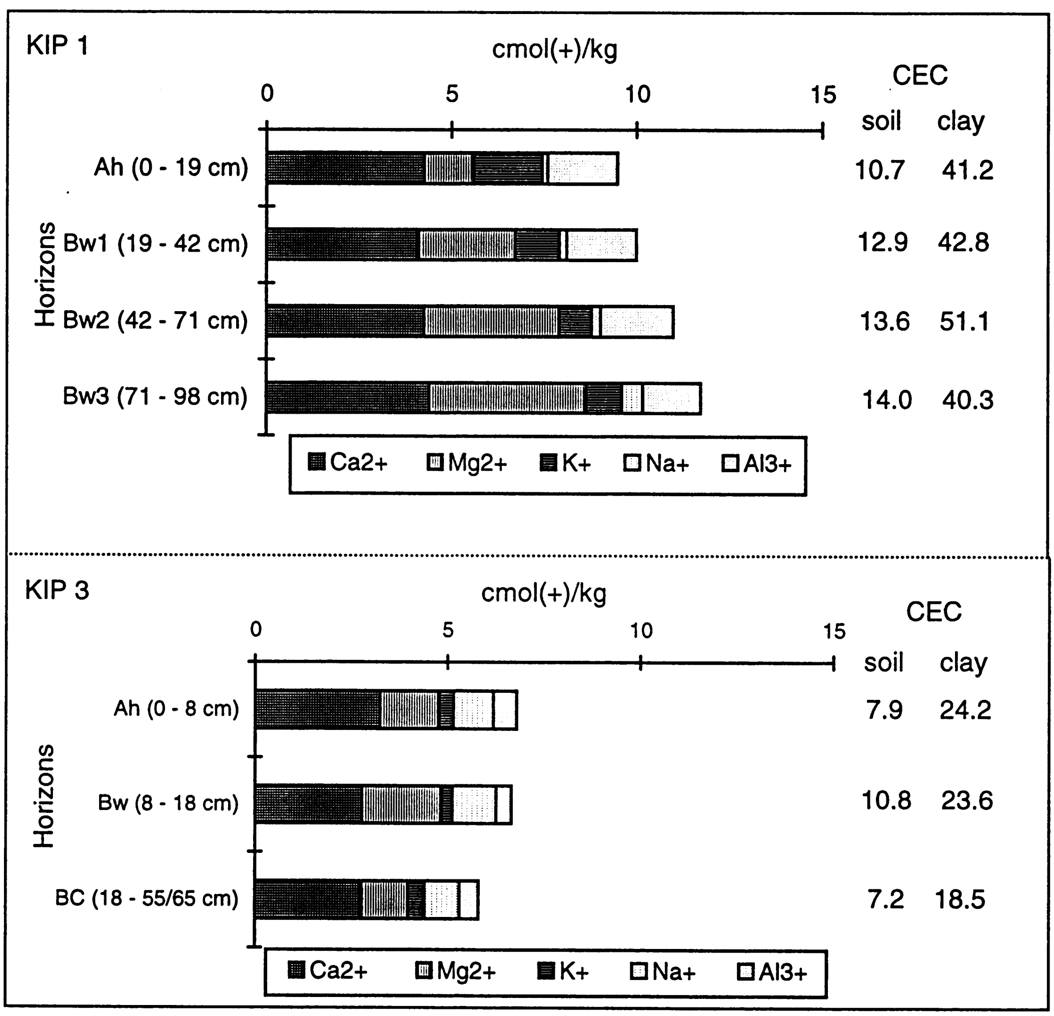

Figure 4.26 Cation exchange properties of soil profiles KIP 1 and KIP 3

that these soils have low levels of available nutrients and low nutrient reserves. However, the CEC of clay is variable with values ranging from 18.5 cmol(+)kg^{-1} clay in some subsurface horizons of soil profile KIP 3 to 51.1 cmol(+)kg^{-1} clay in some subsurface horizons of soil profile KIP 1. The soils of the upper parts of the slopes tend to have lower values of clay CEC than the soils on the lower parts. These data indicate that the clay fractions of the soils on the lower parts of the slopes are dominated by mixtures of smectite, illite and kaolinite and probably vermiculitic minerals. The clay fraction of the soils on the higher parts of the slopes are possibly dominated by kaolinite. The base saturation is > 50 % throughout the two soil profiles with Mg and Ca dominating the exchange sites. Soil profile KIP 1 shows an increase of exchangeable Mg with depth from 1.4 cmol(+)kg^{-1} topsoil to 4.2 cmol(+)kg^{-1} soil in the subsoil, and relatively high levels of exchangeable K. This could be an indication of presence of vermiculite and illite.

Figure 4.27 shows soil pH, organic matter and total nitrogen contents of soil profiles KIP 1 and KIP 3. The soil pH (KCl) is lower than pH (H_2O) throughout the profiles. This suggests that the soils have a net negative charge. The topsoil is slightly acid in reaction with pH values of 6.4 to 6.5. The soil reaction of KIP 1 subsoil range from neutral (pH 6.6) to slightly acid (pH 6.2) whereas that of KIP 3 subsoil ranges from medium acid (pH 5.9) to slightly acid (pH 6.2). Generally, the soil reaction of this mapping unit is

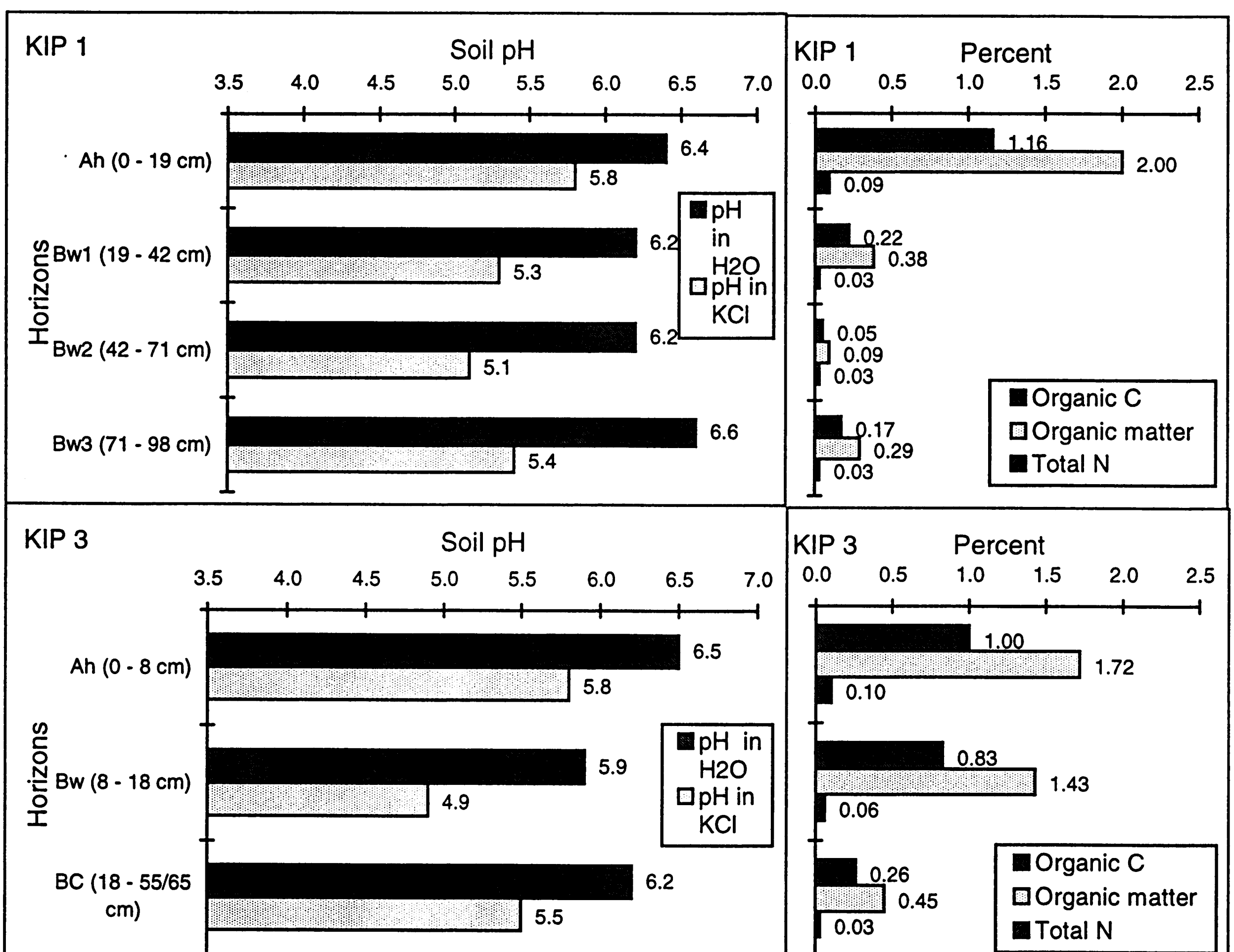

Figure 4.27 Soil pH, organic matter and total nitrogen contents of soil profiles KIP 1 and KIP 3

within the preferred range for most crops. The levels of the topsoil available P is generally low with values of 5.6 mg kg^{-1} soil in soil profile KIP 1 and 4.1 mg kg^{-1} soil in soil profile KIP 3. The levels of total N and organic C are generally low to very low in the topsoil and they are very low throughout the subsoil.

Based on the chemical properties of soil profile KIP 1, the soil chemical fertility of the soils on the lower parts of the landscape are moderately fertile. With fertilizer application and good management practices they can be used for crop production. Improvement and management of soil organic matter and other management practices aimed at minimizing soil erosion are necessary if sustainable crop production is to be realized.

4.1.7 Mapping unit I.5

4.1.7.1 Description of the land unit

Mapping unit I.5 is composed of dissected undulating to rolling plains west of Mindu and Lugala hills characterized by short concave and convex moderate slopes ranging from 5 to 15 % at an altitude of 520 - 680 m asl. It covers an area of 51.5 km2 i.e. 12.4 % of the Lubungo - Mkata soil map. The average width of interfluves is 1.2 km (Kaaya, 1996) indicating that the stream frequency is generally high. The dominant geomorphic processes on the surface include valley incision and peneplanation, which have resulted in the development of numerous dissected ridges separated by active ravines exposing the underlying bedrock. The underlying bedrock is banded muscovite-biotite migmatites of the Mindu and Lugala hills. The natural vegetation is mainly Brachystegia-Julbernardia miombo woodland with a few *Combretum spp.* and *Sterculia spp.* trees and *Heteropogon contortus* as dominant grass species. Most of the area is utilized for grazing animals, particularly cattle and goats. People from the nearby villages obtain firewood and charcoal by clearing of the woody vegetation from this land unit.

4.1.7.2 Morphological and physical properties of the soils

The unit has shallow to moderately deep, well drained soils with a dark grayish brown sandy loam topsoil overlying the friable yellowish brown to grayish brown sandy clay loam subsoil. The soils have developed from colluvial deposits from the Mindu and Lugala hills. Most of the soils are classified in the order Inceptisol in the US Soil Taxonomy (Soil Survey Staff, 1996) and in the FAO-Unesco (1988) system as Cambisols or Leptosols.

4.1.8 Mapping unit I.6

4.1.8.1 Description of the land unit

Mapping unit I.6 is composed of strongly dissected hill-slopes of Mindu and Lugala hills with slopes > 15 % at an altitude of 680 to 1260m asl. It occupies an area of 18.7 km2 i.e. 4.5 % of the Lubungo - Mkata soil map. The dominant geomorphic processes on the surface include valley incision and pediplanation which have resulted in development of complex convex steep slopes. The underlying rocks are mainly muscovite-biotite migmatites of the Mindu and Lugala hills. The natural vegetation is mainly Brachystegia-Julbernardia miombo woodland and a variety of grass species. The lower parts of the slope are utilized for extensive animal grazing, while the higher parts of Mindu mountains and Lugala hills are protected forest reserves. Influence of human activities on the natural forest in the higher parts of this unit is not so pronounced as in the lower parts and in the other land units mainly due to poor accessibility.

4.1.8.2 Morphological and physical properties of the soils

The unit has shallow to moderately deep, well drained soils with a dark grayish brown sandy loam topsoil overlying a friable grayish brown sandy clay loam subsoil. Soil erosion has washed away most of the fine particles and this accounts for the existing sandy and shallow soils. The soils have developed from colluvial deposits from the Mindu and Lugala hills. The soils on this unit are classified in the orders Inceptisol and Entisols in the US Soil Taxonomy (Soil Survey Staff, 1996) and in the FAO-Unesco (1988) system as Cambisols or Leptosols.

4.1.9 Mapping units II.1a and II.2 of the Magadu soil map

Mapping units II.1a and II.2 on the SE part of the Lubungo-Mkata soil map are the continuations of similar mapping units from Magadu soil map (Appendix 2.2). Their soil and land units descriptions are therefore similar to those in sections 4.2.1 and 4.2.3, respectively. Mapping unit II.1a covers an area of 11.8 km^2 i.e. 2.8 % of the Lubungo - Mkata soil map, while mapping unit II.2 occupies an area of 30.6 km^2 i.e. 7.4 % of the same map.

4.2 Mapping units of the Magadu soil map (Appendix 2.2)

4.2.1 Mapping unit II.1a

4.2.1.1 Description of the land unit

Mapping unit II.1a includes flat to almost flat fluvial plains of the Ngerengere river with slopes of 0 - 2% at an altitude of 490 - 520 m asl. It rises to the footslopes of the wide alluvial fans on the NW Uluguru mountains. This mapping unit covers an area of 6.6 km^2 i.e. 9.0 % of the Magadu soil map. It is mainly a depositional area of materials transported by streams from the higher parts of the landscape on the Uluguru mountains. The natural vegetation was described by Pócs (1976) as valley grasslands dominated by *Cyclosorus interruptus*, sedges (*Cyperus exaltatus*) and elephant grass (*Panicum maximum*). Most of the wooded vegetation has been replaced by cultivated land. The common crops include swamp rice and sugar cane.

4.2.1.2 Morphological characteristics of the soils

The soils are deep, imperfectly drained with stratified, very dark grayish brown micaceous silt loam topsoil overlying a mottled dark reddish brown silty clay and clay subsoil. They have developed from alluvial/fluvial deposits. Below 30 cm from the surface the subsoil is characterized by reddish mottles and iron-manganese concretions due to seasonal fluctuations of the groundwater table. The high ground water table restricts the effective soil depth. The soils are classified into the order Entisol in the US Soil Taxonomy (Soil Survey Staff, 1996) and as Eutric Fluvisols in the FAO-Unesco (1988) system.

The soils have high natural fertility and therefore can be put under cultivation of a wide range of crops when the ground water table is low. It is therefore recommended that these soils should be used for paddy rice cultivation during the rainy season followed by other annual crops after the rainy season, that is two crops per year.

4.2.2 Mapping unit II.1b

4.2.2.1 Description of the land unit

Description of mapping unit II.1b is similar to that of mapping unit II.1a above. It covers an area of 5.0 km^2 i.e. 6.8 % of the Magadu soil map. Figure 4.28 shows the environmental features of mapping unit II.1b. Figure 4.29 shows morphological features of its representative soil profile MAG 1.

4.2.2.2 Morphological characteristics and some physical properties of the soils

The soils are deep, imperfectly drained with a weakly developed soil profile. The profile is formed by a very dark brown clayey topsoil overlying a dark brown and dark reddish brown subsoil with texture varying from sandy clay loam to clay. Variation of clay content with profile depth is irregular. The soils have developed from thick alluvial/fluvial deposits. MAG 1 is a representative soil profile for the soils of this mapping unit. Field description of this soil profile and the analyzed physico-chemical data are presented in Appendix 1.7. The genetic horizons are weakly developed and the subsoil structure development varies from one sub-horizon to another, ranging from weak subangular blocky to strong angular blocky. Horizon B_h (95 -110 cm) is characterized by an accumulation of decomposed organic matter. Using ^{14}C-dating of organic material from this horizon (T-12486A), its age has been estimated to be 415 ± 90 years BP (Sørensen and Kaaya, in prep.) indicating a high rate of sediment deposition on this mapping unit. Soil profile MAG 1 was classified as Fluventic Ustropepts in the US Soil Taxonomy (Soil Survey Staff, 1996) and as Chromic Cambisols in the FAO-Unesco (1988) system.

Figure 4.28 Environmental features of mapping unit II.1b
(land under fallow with elephant grass; the background shows the NW slopes of the Uluguru mountains)

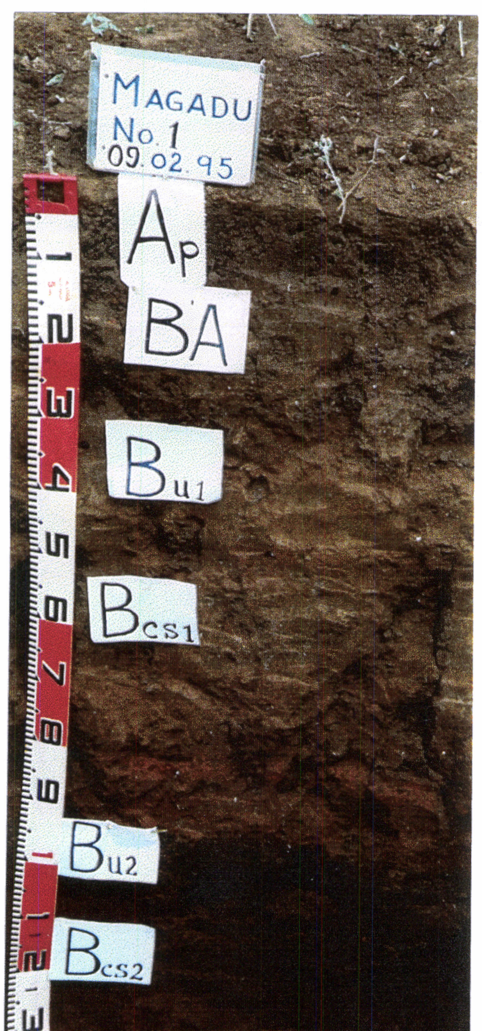

Figure 4.29 Soil profile MAG 1
(ST: *Fluventic Ustropept,* FAO: *Chromic Cambisol)*

Figure 4.30 shows the bulk density of the selected horizons in soil profile MAG 1. The topsoil has lower bulk density than the subsoil. This is probably due to a high organic matter content in the topsoil.

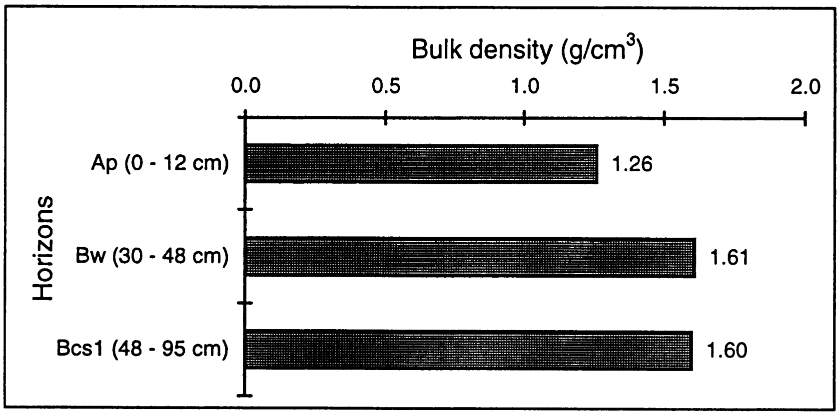

Figure 4.30 Bulk density of the selected horizons of soil profile MAG 1

Textural variation with profile depth (Figure 4.31) is irregular. This is common for the relatively young soils developed from alluvial/fluvial materials. The texture in some subhorizons vary from sandy clay loam to clay.

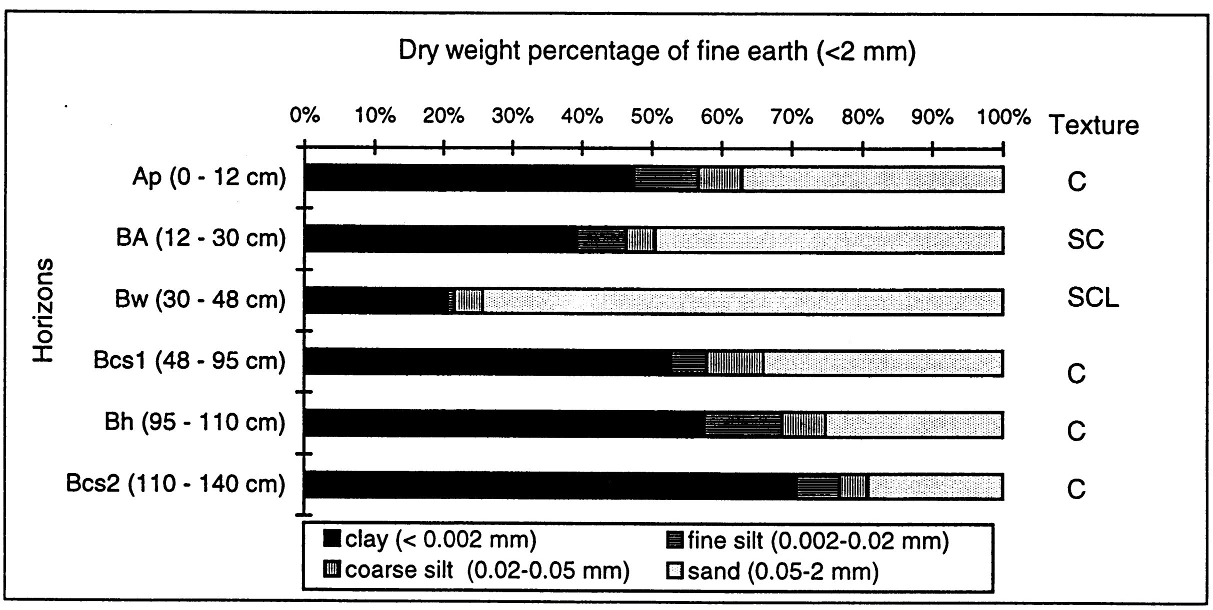

Figure 4.31 Particle size analysis of soil profile MAG 1

4.2.2.3 Soil chemical properties

The data for cation exchange properties of the soil profile MAG 1 are presented in Figure 4.32. The topsoil CEC is 25.5 cmol(+)kg^{-1} soil which is fairly high, and the base saturation is > 50 %. This indicates that these soils have high levels of available nutrients and nutrient reserves in the topsoil. The subsoil CEC varies with clay content in the subhorizons with values ranging from 10.8 cmol(+)kg^{-1} soil in a sandy clay sub-horizon to 24.0 cmol(+)kg^{-1} soil in a clay sub-horizon. Ca and Mg dominate the exchange sites throughout the profile. The clay CEC is medium with values varying from 27.8 to 44.9 cmol(+)kg^{-1} clay. This suggests that the clay fraction is composed of a mixture of kaolinite, illite and some smectite.

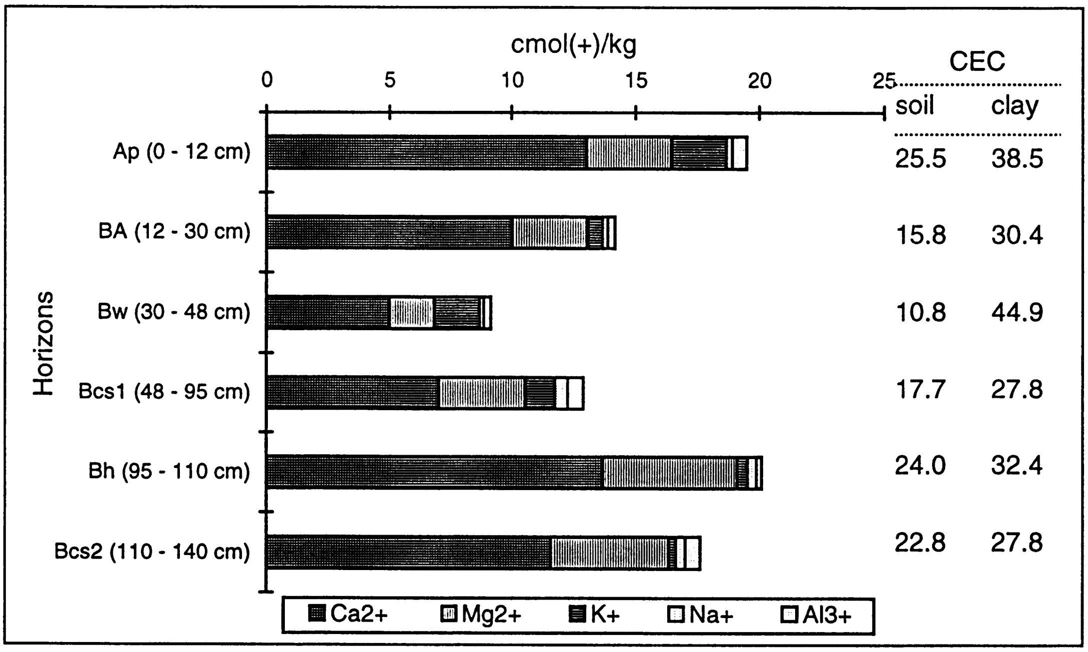

Figure 4.32 Cation exchange properties of soil profile MAG 1

The soil pH, organic matter and total nitrogen contents of soil profile MAG 1 are presented in Figure 4.33. The soil pH (KCl) is lower than pH (H_2O) throughout the profile suggesting that the soils have a net

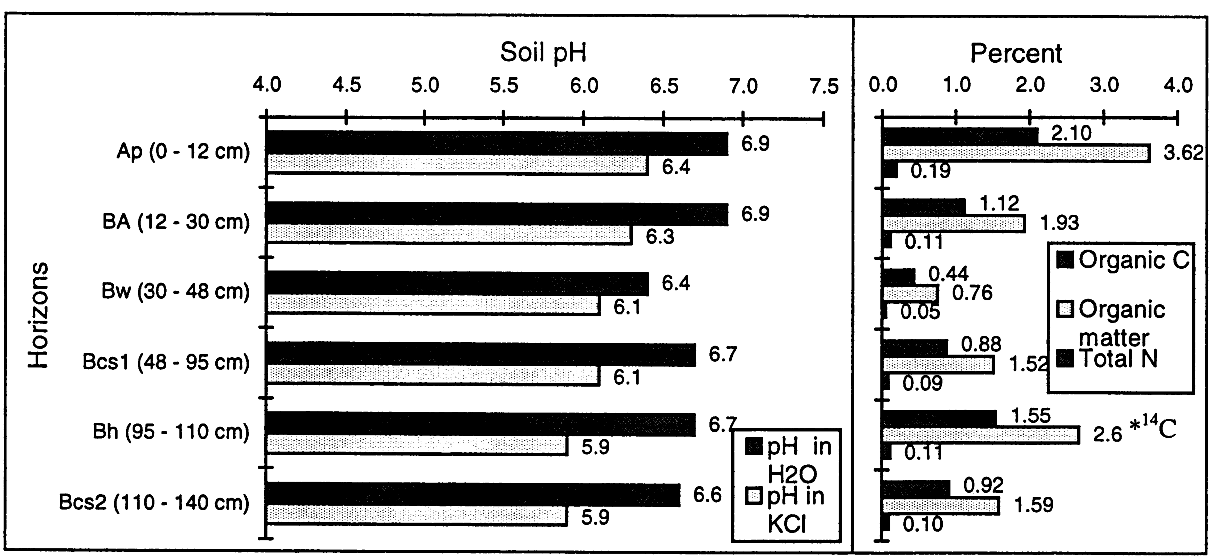

Figure 4.33 Soil pH, organic matter and total nitrogen contents of soil profile MAG 1

*^{14}C-date (T-12486A) = 415 ± 90 years

negative charge. The soils reaction is neutral throughout the profile with pH values ranging from 6.9 in the topsoil to 6.4 in the subsoil. The soils have pH values within the range preferred by most field crops. The topsoil available P is 30.8 mg kg^{-1} soil which is high suggesting that P may not be a limiting factor in crop production. The levels of total N and organic C are generally low and like texture they vary irregularly with profile depth.

Based on the properties of soil profile MAG 1, the soils of mapping unit II.1b have moderate to high natural fertility. With good soil management they can be used for sustainable production of a wide range of dryland crops under rain-fed conditions.

4.2.3 Mapping unit II.2

4.2.3.1 Description of the land unit

Mapping unit II.2 includes gently undulating to undulating plains on the lower and middle parts of the alluvial fans on the footslopes of the Uluguru mountains, with slopes of 2 -5 % at an altitude of 500 - 560 m asl. It occupies an area of 18.8 km^2 i.e. 25.7 % of the Magadu soil map. The active surface process is mainly peneplanation. This has resulted in the formation of long convex slopes characterizing this mapping unit. The natural vegetation as described by Pócs (1976) is secondary savanna with some scattered trees including *Acacia spp.*, *Cassia spp.* and *Adansonia digitata* and herbaceous layer composed of *Hyparrhenia rufa*. Most of this vegetation has been replaced with cultivated land following the establishment of sisal plantations in the area and hand cultivation of food crops such as maize, beans, cassava and sorghum. Figure 4.34 shows the environmental features of mapping unit II.2 and Figure 4.35 shows morphology of soil profile MAG 2, representing the most dominant soil.

4.2.3.2 Morphological characteristics and some physical properties of the soils

The soils are very deep, well drained with a dark brown to dark reddish brown sandy clay and clay topsoil overlying a friable yellowish red to red clay subsoil. The clay content increases with increasing profile depth. The soils have developed from colluvial deposits from the Uluguru mountains. Figure 4.35 shows soil profile MAG 2, a representative soil profile for this mapping unit. Field descriptions of this soil profile and the analyzed physico-chemical data are presented in Appendix 1.8. The soil profile is classified as Typic Paleustult in the US Soil Taxonomy (Soil Survey Staff, 1996) and as Haplic Acrisol in the FAO-Unesco (1988) system. Previous soil investigations by Moberg *et al.* (1982), Kaaya *et al.* (1994) and Msanya *et al.* (1994) on this land unit but in other locations resulted in classifying the soils into the order Ultisols in the US Soil Taxonomy (Soil Survey Staff, 1996) and correlated with Acrisols in the FAO-Unesco (1988) system. The dominant soil order is therefore Ultisol which is correlated with Acrisols in the FAO-Unesco (1988) system.

Figure 4.34 Environmental features of mapping unit II.2
(under fallow with different bushes, grasses and weeds)

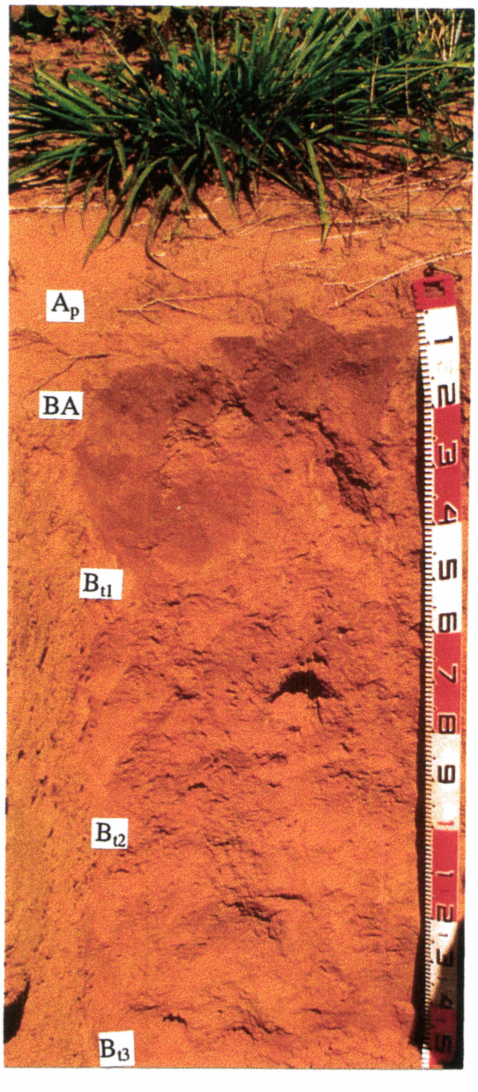

Figure 4.35 Soil profile MAG 2
(ST: *Typic Paleustult*, FAO: *Haplic Acrisol*)

The bulk density of selected horizons of soil profile MAG 1 are presented in Figure 4.36 The surface horizon has a bulk density of 1.35 g cm^{-3} and the values for the subsurface horizons are 1.26 g cm^{-3} in B_{t1} and 1.28 g cm^{-3} in B_{t2} horizons. For mineral soils these values are moderate indicating that the soils are moderately porous. The high clay content in all horizons could possibly account for the moderate bulk density values.

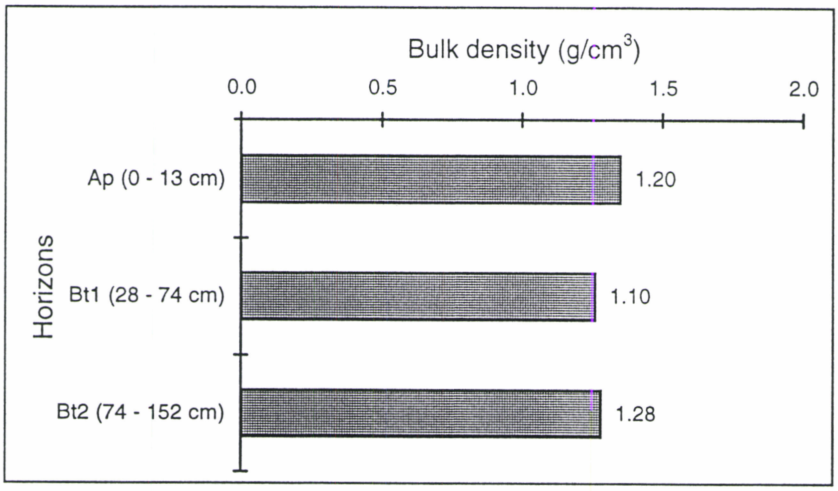

Figure 4.36 Bulk density of the selected horizons of soil profile MAG 2

Figure 4.37 shows the particle size analysis of soil profile MAG 2. The clay content increases with soil depth from 46.8 % in the sandy clay surface horizon to 65.0 % in the clay subsoil horizons. The silt content is very low compared to the clay and sand contents.

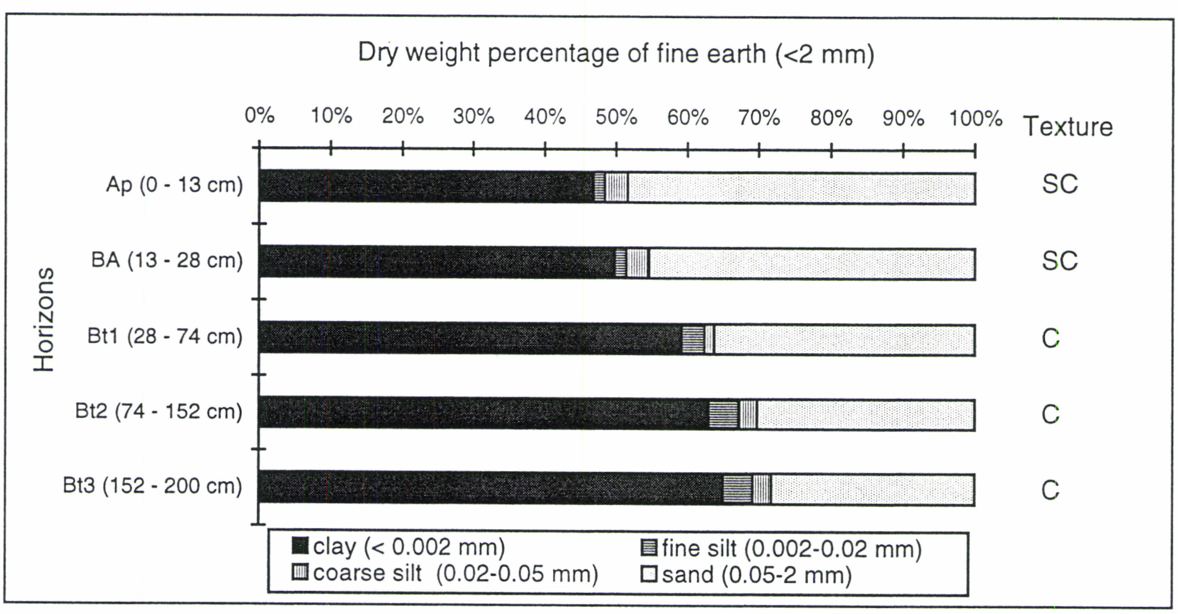

Figure 4.37 Particle size distribution of soil profile MAG 2

4.2.3.3 Soil chemical properties

The cation exchange properties of soil profile MAG 2 is presented in Figure 4.38. The CEC is generally low with values varying from 12.0 cmol(+)kg^{-1} soil in the subhorizons to 13.8 cmol(+)kg^{-1} soil in the topsoil. This indicates that these soils have low levels of available nutrients and low nutrient reserves. The base saturation is < 50 % throughout the profile with high levels of exchangeable Al.

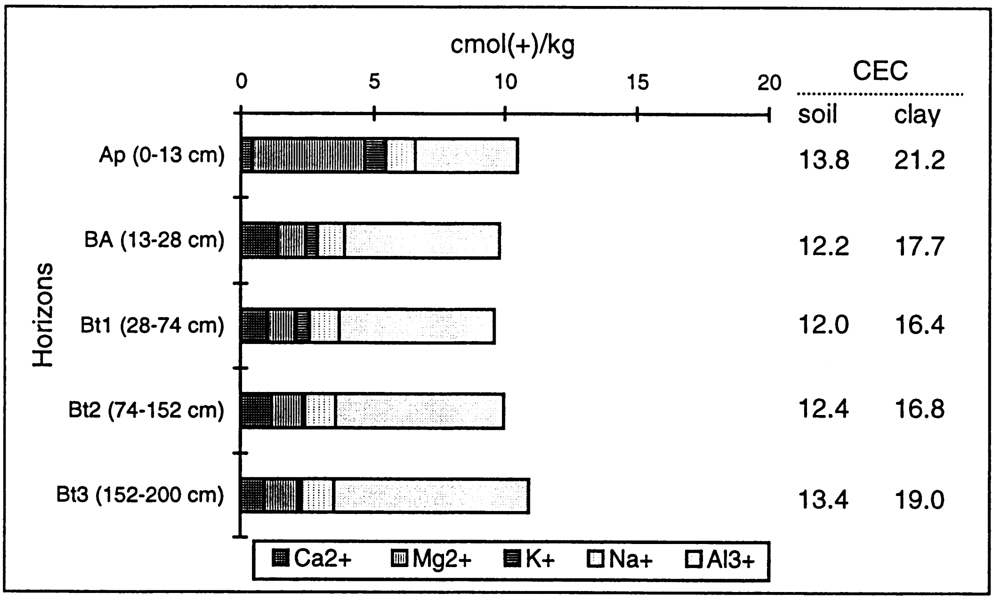

Figure 4.38 Cation exchange properties of soil profile MAG 2

The high levels of exchangeable Al is favored by low soil pH which enhances solubility of aluminum. Low CEC, low levels of exchangeable bases and high levels of exchangeable Al indicate poor chemical fertility. The clay CEC is also low with values ranging from 16.4 to 21.2 cmol(+)kg^{-1} clay in the whole profile. This suggests that the clay fraction is dominated by low activity clays such as kaolinites.

The soil pH, organic matter and total nitrogen contents of soil profile MAG 2 are presented in Figure 4.39. The soil pH (KCl) is lower than pH (H_2O) throughout the profile suggesting that the soils have a net negative charge. The soil reaction is very strongly to strongly acid throughout the profile with pH (H_2O) values ranging from 4.8 in the topsoil to 5.2 in the subsoil. The low soil pH values indicate that these soils will have nutritional problems if utilized for plant production. The associated problems include Al toxicity and strong P fixation. The levels of available P is generally very low throughout the profile with values varying from 3.6 mg kg^{-1} soil in the topsoil to 0.4 mg kg^{-1}soil in the subsoil. This implies that P may be one of the most limiting factors in crop production on this unit. The levels of topsoil total N and organic C are also generally very low and they are very low in the subsoil. Generally these soils have poor chemical characteristics.

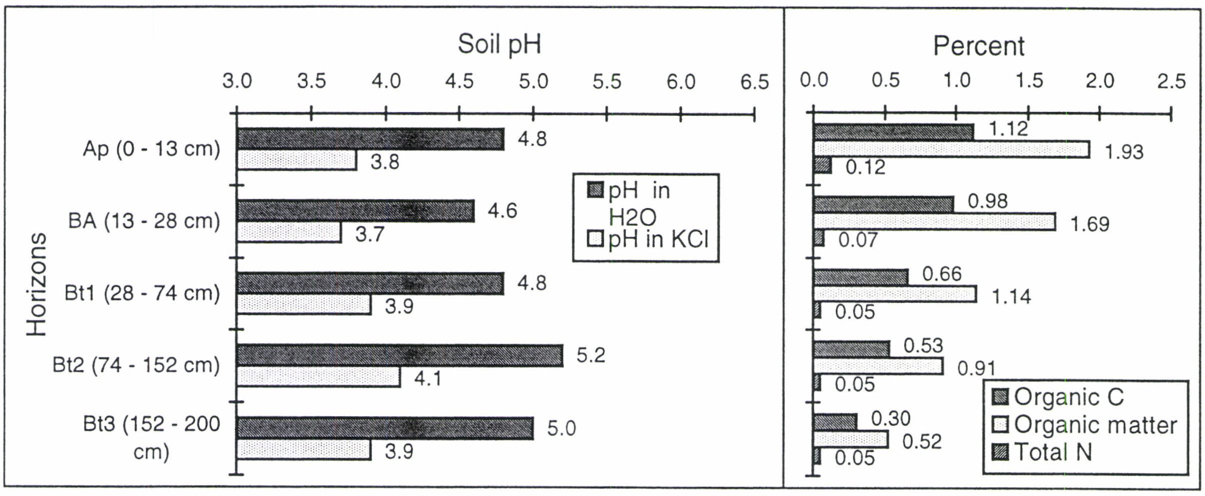

Figure 4.39 Soil pH, organic matter and total nitrogen contents of soil profile MAG 2

The natural fertility of the soils represented by this soil profile is generally low. Their nutritional limitations include aluminum toxicity and strong P-fixation. Acrisols contain low activity clays and due to little biological activity their natural regeneration of the surface soil is also very slow. Management of these soils is therefore difficult. Adapted cropping systems such as shifting cultivation with complete fertilization and careful management are required if such soils are to be used for agricultural crop production (Driessen and Dudal, 1991). Alternatively, undemanding acid-tolerant crops such as cashew nut and pineapples can be grown with success.

4.2.4 Mapping unit II.3

4.2.4.1 Description of the land unit

Mapping unit II.3 includes the dissected undulating to rolling plains on the higher parts of the alluvial fans on the footslopes of the Uluguru mountains with slopes of 5 - 15 % at an altitude of 540 - 600 m asl. It covers an area of 2.9 i.e. 4.0 % of the Magadu soil map. The active geomorphic processes including valley incision and pediplanation have resulted in the formation of dissected ridges with an average width of 380 m and multi-concave slopes (Kaaya, 1996). The rock fragments observed in some of the ravines are mainly composed of quartz, feldspars and micas. Most of the vegetation has been replaced with cultivated land, secondary woodland (Pócs, 1976) and various weed species. Cultivated food crops are mainly at subsistence level and these include maize, beans, cassava, bananas, papaw, groundnuts, sweet potatoes and sorghum. Previously, the natural vegetation was Pterocarpus-Combretum woodland dominated by *Pterocarpus angolensis*, *Combretum spp.* and grass species dominated by *Hyparrhenia rufa* (Pócs, 1976). Other scattered trees include *Julbernardia globiflora* and *Brachystegia spp.*

(ST: Kandic Paleustalf, FAO: Haplic Lixisol)

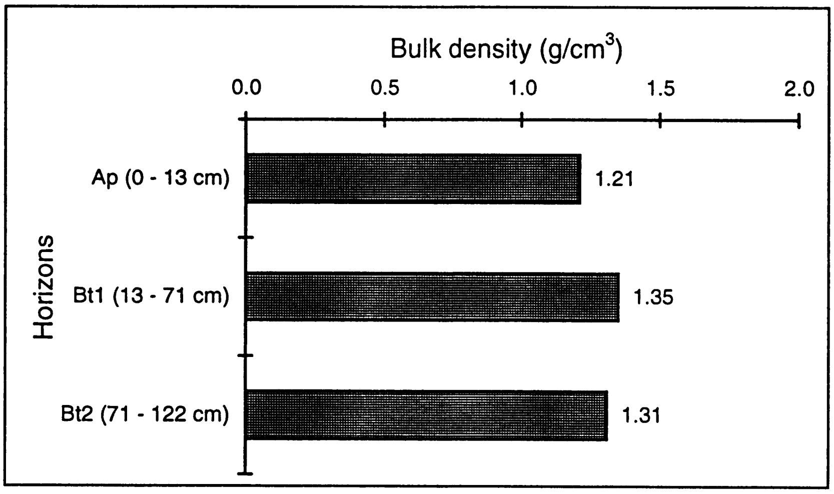

Figure 4.41 Bulk density of selected horizons of soil profile MAG 3

Particle size analysis of soil profile MAG 3 is presented in Figure 4.42. The texture is clay throughout the profile but there is a general increase of clay content with soil depth from 56.7 % in the surface horizon to 73.4 % in the subsurface horizons. The silt content is very low throughout the profile which is normal for strongly weathered soils.

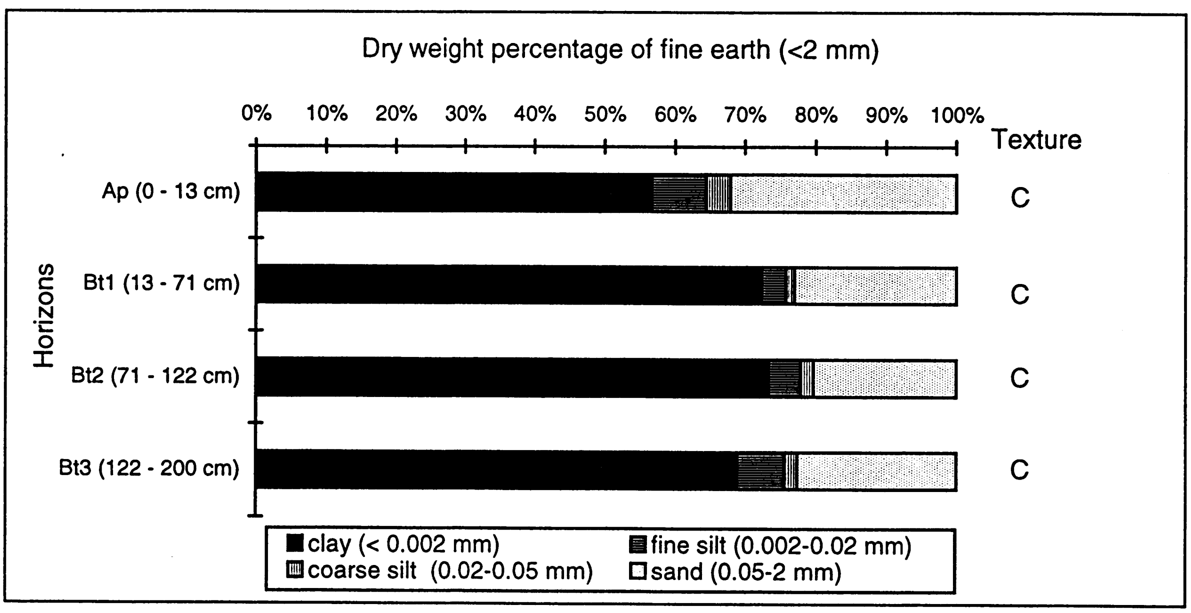

Figure 4.42 Particle size analysis of soil profile MAG 3

4.2.4.3 Soil chemical properties

The cation exchange properties of the soil profile MAG 3 are presented in Figure 4.43. The CEC varies from 13.6 cmol(+)kg^{-1} soil in some subsoil subhorizons to 21.6 cmol(+)kg^{-1} soil in the topsoil. The CEC of the topsoil is medium and throughout the profile the base saturation is > 50 % with Ca and Mg dominating the exchange sites. The levels of exchangeable Al is generally low. These properties indicate that these soils are moderately fertile. Levels of exchangeable Mg decrease with increasing profile depth while those of exchangeable K increase with increasing profile depth. The CEC of the subsoil is generally low indicating low nutrient reserves. The clay CEC is also low with values varying from 16.2 to 25.1 cmol(+)kg^{-1} clay in the whole profile. This suggests that the clay fraction is dominated by kaolinites and also illites due to relatively high levels of exchangeable K compared to other exchangeable cations in the subsoil.

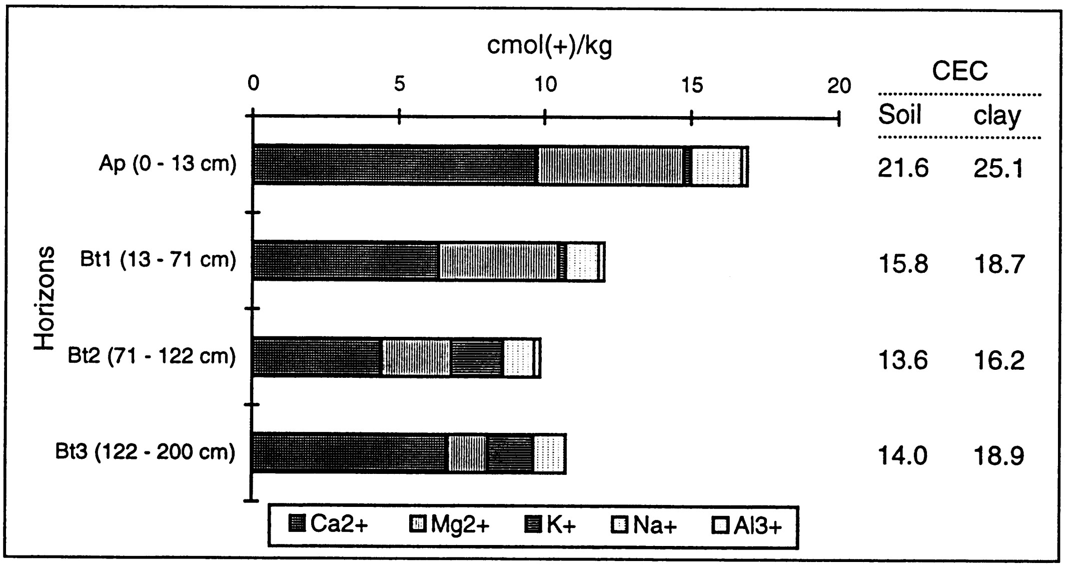

Figure 4.43 Cation exchange properties of soil profile MAG 3

The soil pH, soil organic matter and total nitrogen contents of soil profile MAG 3 are presented in Figure 4.44. The soil pH (KCl) is lower than pH (H_2O) throughout the profile suggesting that the soils have a net negative charge. The soil reaction is slightly acid with soil pH (H_2O) values varying from 6.0 in the subsoil to 6.7 in the surface horizon. These pH values are within the pH range preferred by most crops. The level of available P in the topsoil is 11.9 mg kg^{-1} soil which is rated as medium and it is very low in the subsoil. This implies that P may be one of the limiting factors in crop production on this unit. The levels of topsoil total N and organic C are also generally very low and they are very low in the subsoil.

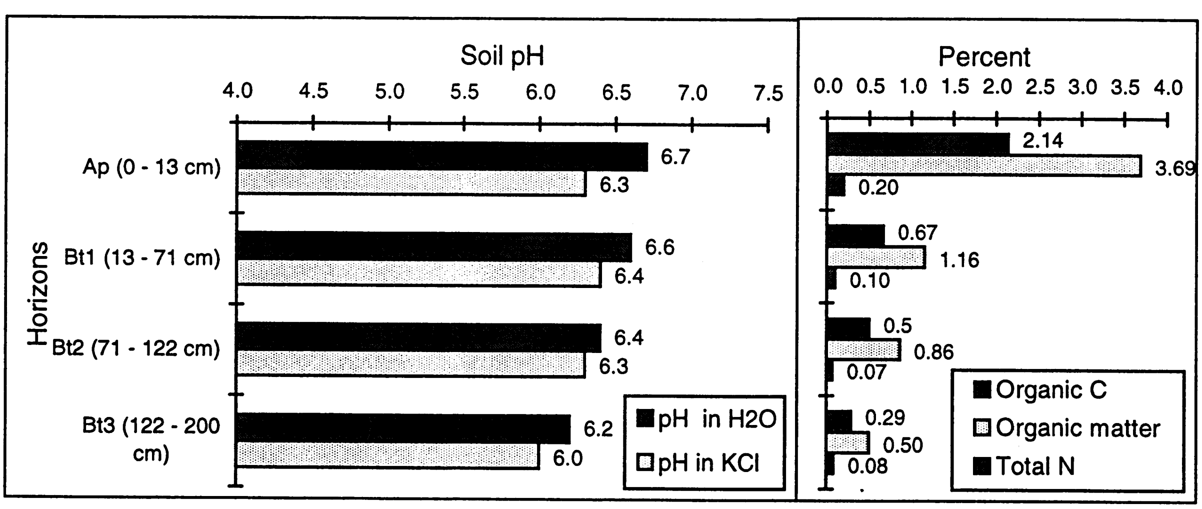

Figure 4.44 Soil pH, organic matter and total nitrogen contents of soil profile MAG 3

Based on the soil chemical properties of profile MAG 3 the natural fertility status of the soils of mapping unit II.3 could be rated as medium. The soils can also be used for a wide range of rain fed crops provided that fertilizers are applied. For sustainable crop production, soil conservation practices such as terracing, contour ploughing, mulching and cultivation of cover crops are recommended.

4.2.5 Mapping unit II.4

4.2.5.1 Description of the land unit

Mapping unit II.4 include the strongly dissected hill-slopes of Uluguru mountains with slopes > 15 % at an altitude of more than 600 m asl. It occupies 24.0 km^2 i.e. 32 % of the Magadu soil map. The most active geomorphic process is valley incision which has resulted in a land unit with narrow ridge crests, v-shaped stream or river valleys and steep convex slopes. Kaaya (1996) estimated the average width of the ridges to be 260 m in the Magadu water catchment. The rock fragments observed in some of the ravines and stream channels are mainly composed of quartz, feldspars and micas. The natural vegetation as described by Pócs (1976) is miombo woodland dominated by *Brachystegia boehmii* and *B. bussei* trees and tussock grasses dominated by *Hyparrhenia rufa* and *Panicum maximum*, which are gradually replaced with cultivated land and grass fallow. Cultivated crops include maize, beans, cassava, bananas, papaw, groundnuts, sweet potatoes and sorghum. Figure 4.45 shows the environmental features of mapping unit II.4 and Figure 4.46 shows morphological characteristics of soil profile MAG 5, typical of soils of the ridge tops in this mapping unit.

4.2.5.2 Morphological characteristics and some physical properties of the soils

The soils are shallow to moderately deep, well drained, with a dark brown to dark reddish brown sandy clay loam to sandy clay topsoil overlying a friable red to dark red clay and sandy clay subsoil. Clay content increases with increasing profile depth. Stone lines dominated by quartz stones is a common feature in most subsoil of these soils. The soils have developed from alluvial/colluvial deposits overlying biotite rich granulitic rocks. Soil profile MAG 5 represents soils on top of the ridges in mapping unit II.4. The parent material in soil profile MAG 5 is mainly biotite gneiss with quartz and feldspars. Detailed field descriptions of this soil profile and the analyzed physico-chemical data are presented in Appendix 1.10. Soil profile MAG 5 is classified as Ultic Paleustalf in the US Soil Taxonomy (Soil Survey Staff, 1996) and as Chromic Luvisol in the FAO-Unesco (1988) system. On this land unit but in another location Moberg *et al.* (1982) also identified soils of the orders Inceptisols and Alfisols in the great group Haplustalf. The major part of the unit is therefore composed of soils on the orders Alfisol and Inceptisol. These can be correlated with Luvisols, Lixisols or Cambisols in the FAO-Unesco (1988) system.

Soil erosion is a threat on this mapping unit mainly because they are on steep slopes. Crop cultivation on these slopes is therefore discouraged in order to conserve the soil. It is recommended to be used as a forest land or for wet season grazing of animals. If cultivated then soil conservation practices suggested for mapping unit II.3 above should be applied.

The dry bulk density of some selected horizons of soil profile MAG 5 are presented on Figure 4.47. The bulk density values increases with profile depth from 1.21 g m^{-3} in the surface horizon to 1.32 g m^{-3} in the subsoil. The values are within the range where the mechanical resistance to root penetration of most field crops is not expected. The low bulk density values in the topsoil could be due to cultivation and the relatively high content of organic matter.

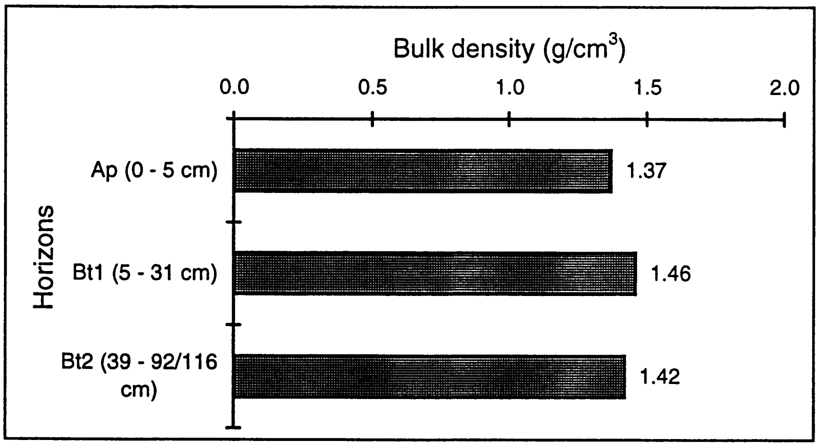

Figure 4.47 Bulk density of the selected horizons of soil profile MAG 5

Particle size analysis of soil profile MAG 5 is presented in Figure 4.48. There is a general increase of clay content with soil depth from 36.5 % in the sandy clay surface horizon to 52.4 % in the clay B horizon. The silt content is very low throughout the profile which is common for strongly weathered soils.

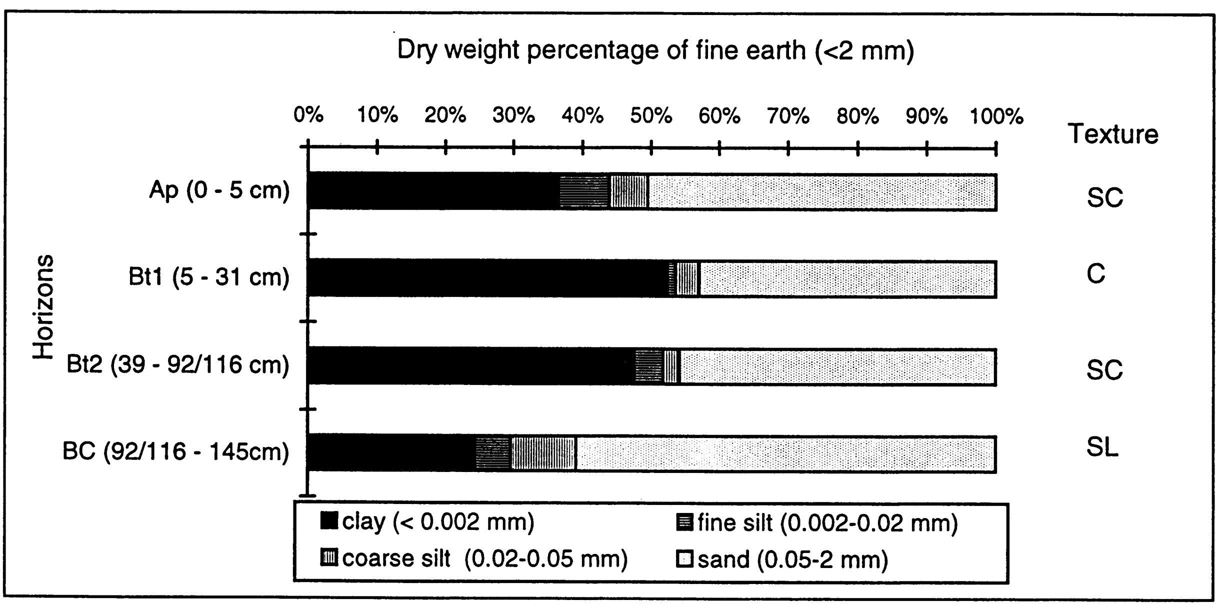

Figure 4.48 Particle size analysis of soil profile MAG 5

4.2.5.3 Soil chemical properties

The data on cation exchange properties of soil profile MAG 5 are presented in Figure 4.49. The CEC is generally low throughout the profile with values varying from 10.3 cmol(+)kg^{-1} soil to 15.2 cmol(+)kg^{-1} soil. The CEC of the topsoil is medium and throughout the profile the base saturation is > 50 % with the exchange sites being dominated by Ca and Mg in the topsoil and Mg and K in the subsoil.

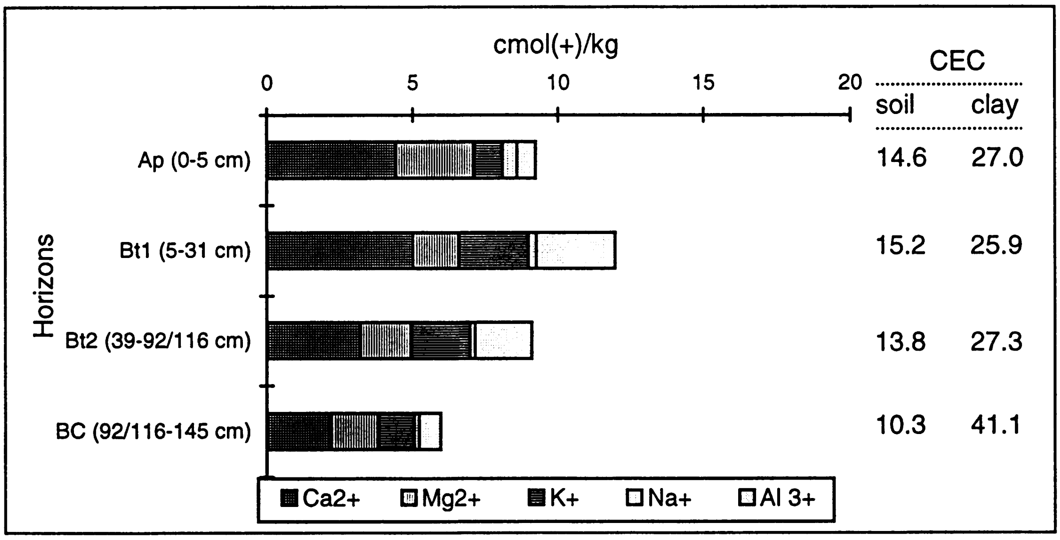

Figure 4.49 Cation exchange properties of soil profile MAG 5

The CEC of clay vary from 25.9 to 41.1 cmol(+)kg^{-1} in the whole profile. The relatively high CEC of the clay and exchangeable Mg suggest a possible presence of vermiculitic minerals in the clay fraction. The relatively high content of exchangeable K in the subsoil suggest the presence of illite in the clay fraction. Kaolinite is also a major component of the clay fraction.

The soil pH, organic matter and total nitrogen contents of soil profile MAG 5 are presented in Figure 4.50. The soil pH (KCl) is lower than pH (H_2O) throughout the profile suggesting that the soils have a net

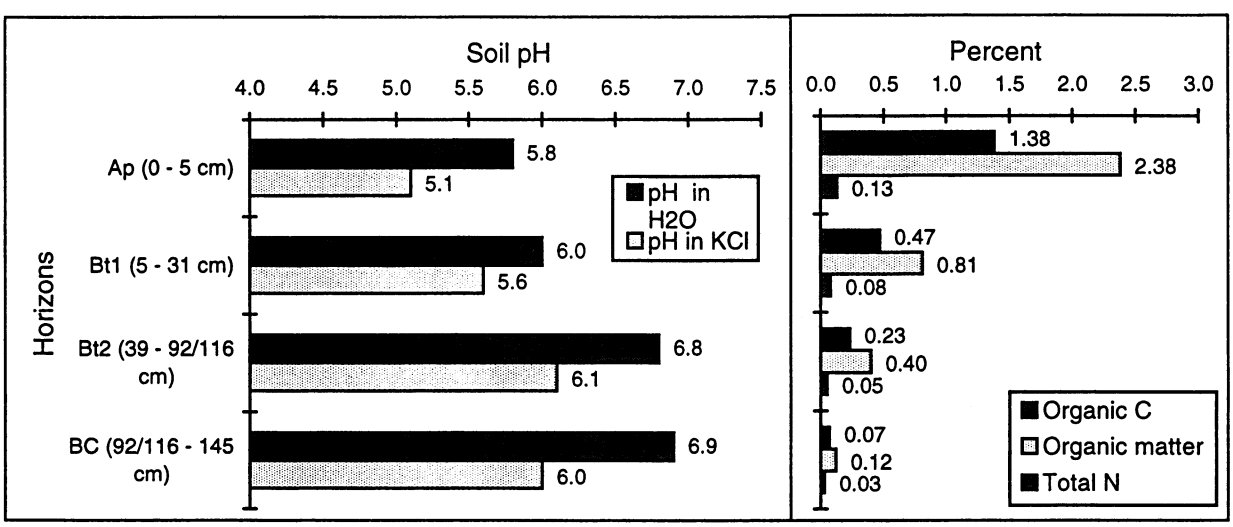

Figure 4.50 Soil pH, organic matter and total nitrogen contents of soil profile MAG 5

negative charge. The topsoil is moderately acid with soil pH (H_2O) values of 5.8 and the subsoil is moderately acid to neutral with pH (H_2O) values varying from 6.0 to 6.9. This pH range is preferred by most crops.

The levels of available P are very low throughout the profile with values ranging from 2.2 to 5.0 mg kg^{-1} soil. This implies that P may be one of the most limiting factors in crop production on this unit. The levels of topsoil total N and organic C are also generally very low and they are very low in the subsoil. Fertility status of theses soils is generally low to moderate.

4.2.6 Mapping units I.3, I.5 and I.6 of the Lubungo - Mkata soil map

Mapping units I.3, I.5 and I.6 are continuations of similar mapping units in the Lubungo-Mkata soil map (Appendix 2.1). Their soil and land unit descriptions are similar to those in sections 4.1.5, 4.1.7 and 4.1.8, respectively. Mapping units I.3, I.5 and I.6 occupy 3.3 km^2, 3.3 km^2 and 9.4 km^2, respectively on the SW part of the Magadu soil map. They represent 4.5 %, 4.5% and 12.8%, respectively of the Magadu soil map.

5. SUMMARY AND RECOMMENDATIONS

This study was carried out in order to map and characterize the major soil types in the northern part of the Morogoro District, Tanzania. The information generated is relevant to various land users including those involved in research and land use planning at district level. Two study areas with soils types developed from alluvial/colluvial deposits on three groups of parent rocks were selected to represent the major soils of the northern part of Morogoro District. Soil mapping was based on land units delineated by aerial photo interpretation, followed by field investigations and description of the soils. Soil associations or complexes identified in each land unit have been characterized in the field in terms of their morphological and physical properties. Soil profiles representative of the major soil types in the mapping units were studied in the field and sampled for more physical and chemical characterization in the laboratory. The results of this investigations indicate that the most influential factors of soil formation to the development of these soils include parent material, relief and climate.

The soil map of Lubungo-Mkata area (Appendix 2.1) shows that the different soil types identified occur in a certain general pattern that bears some relationship with the landscape features of the area. The soils on the higher land units with relatively steep slopes on the western footslopes of the Mindu mountains are well drained, shallow to moderately deep with dark grayish brown sandy loam topsoils and grayish brown sandy clay loam subsoils. Most of them are relatively young soils classified into the orders Entisols and Inceptisols of the US Soil Taxonomy (Soil Survey Staff, 1996), and into Cambisols in the FAO-Unesco (1988) system. The soils on the middle part of the landscape on gentle slopes are also well drained but deeper and more developed than the soils on the higher landscape positions. They are deep to very deep, red clay soils classified into the order Alfisols in the US Soil Taxonomy (Soil Survey Staff, 1996) and into Lixisols in the FAO-Unesco system. The soils on the lower parts of the landscape and depressions are imperfectly drained dark gray and black cracking clays commonly referred to as 'mbuga' soils. Most of them are classified into soil order Vertisols and the rest into the order Entisols in the US Soil Taxonomy (Soil Survey Staff, 1996). These are correlated with soil units Vertisols and Cambisols in the FAO-Unesco system. An almost similar relationship was observed for the Magadu soil map (Appendix 2.2) where the soils on the higher parts of the landscape are classified into the order Inceptisols in the US Soil Taxonomy (Soil Survey Staff, 1996) and as Cambisols in the FAO-Unesco system. The soils on the middle part of the landscape with gentle slopes are classified into the orders Ultisols, Alfisols and Oxisols in the US Soil Taxonomy (Soil Survey Staff, 1996) and into Acrisols and Lixisols in the FAO-Unesco system. The soils on the lower parts of the landscape in the Magadu area are classified into the orders Entisols and Inceptisols in the US Soil Taxonomy (Soil Survey Staff, 1996) and correlated with the soil unit Fluvisols in the FAO-Unesco (1988) system.

General assessment of natural fertility of the soils and suggestions for different land uses and management practices are discussed. The suggestions or recommendations were based on some morphological and physical properties studied in the field and some selected chemical properties of the studied soil profiles. With exception of soils in topographic depressions, most of the soils of the studied areas are generally of low to moderate agricultural potential. The amount and seasonal distribution of rainfall is one of the major limitations to agricultural production in the district. Low reserves of nutrients, low cation exchange capacity, and high P adsorption are also limitations to agricultural production in the area. Most of the soils in topographic depressions are characterized by high soil pH levels and relatively high levels of macronutrients. These soil properties can possibly lead to nutritional problems, especially the nutrient imbalance and deficiency of some micronutrients which become insoluble with increasing soil pH.

Most of the soils on the lower parts of the landscape, especially on the river plains, are generally deep, with relatively high contents of nutrients, but they have poor water infiltration rates and imperfect drainage conditions. Management practices required for such soils include those aimed at improving infiltration rate of water. The soils in depressions are suitable for rice production during the rainy season. With irrigation, fertilization and good water management two rice crops can be realized per year. Proper drainage of these soils is required for successful cultivation of other field crops.

Soils on the gently undulating to undulating plains are generally well drained and deep with low levels of available nutrients and low nutrient reserves as indicated by low CEC values. With fertilizer application and soil conservation practices they can be used for a wide range of rain-fed crops. Split application of the fertilizers is needed in order to minimize leaching losses of the applied nutrients. Cultivation of tuber crops such as cassava and sweet potatoes or groundnuts enhances destruction of soil structure and consequently increase the danger of soil erosion. Cultivation of theses crops on these soils and those on the ridge tops and relatively steep slopes should therefore be discouraged unless they are cultivated under proper soil conservation practices.

Soils on the ridge tops and relatively steep slopes are relatively shallower than those on the undulating plains and they are generally more vulnerable to erosion. These soils should not be used for crop cultivation but rather as forest land or for wet season grazing of animals. Where arable land is scarce, and cultivation on these slopes is inevitable, then soil conservation practices like terracing, contour cultivation, mulching, and cultivation of cover crops should be part of the management practices in order to minimize soil erosion. The annual bush burning which is a common practice in the northern part of Morogoro District should be discouraged because it accelerates soil degradation and consequently decreases plant productivity of the land. Some of the known effects of bush fires on tropical soils include decrease of soil organic matter content, acceleration of soil erosion and increased crust formation on the soil surface (Møberg, 1974).

Time limitation, nature of the study and the common problems associated with conducting detailed soil surveys in the developing countries (Acres *et al.*, 1993), dictated the techniques employed in mapping of these soils. Consequently, errors associated with filling out the gaps during mapping are very possible. Similarly, the techniques could not allow for estimation of proportions of soil units in different mapping units. Given time and more personnel, such errors and shortcomings could be minimized by carrying out more detailed soil investigations through field checks and traverses. However, the results of this study contribute to more understanding of the characteristics and distribution of the major soil types found on different land (geomorphic) units in the study area. The results will form one of the important inputs in land evaluation of the district and hopefully assist in the land use planning of the Morogoro District.

6. REFERENCES

Acres, B.D., M.A. Green, and L.J. Rackham (1993). A method for identifying soil catenas and determining map unit composition used in a reconnaissance soil survey in Tanzania. *Geoderma*, **57**: 387 - 404

Baize, D. (1993). Soil Science Analysis: A guide to current use. John Wiley & Sons Ltd., West Sussex.

Barnhisel, R. and P.M. Bertsch (1982). Aluminum. In: A.L. Page (Editor) Methods of Soil Analysis, Part 2. Chemical and microbiological properties, 2nd edition. Agronomy Series no. 9, Part 2, ASA, SSSA, Madison, Wisc., USA, p. 275 - 300.

Blake, G.R. and K.H. Hartge (1986). Bulk density. In: A. Klute (Editor) Methods of Soil Analysis, Part 1. Physical and Mineralogical methods, 2nd edition. Agronomy Series no. 9, Part 1, ASA, SSSA, Madison, Wisc., USA, p. 363 - 375.

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

Bremner, J.M. and C.S. Mulvaney (1892). Nitrogen - total. In: A.L. Page (Editor) Methods of Soil Analysis, Part 2. Chemical and microbiological properties, 2nd edition. Agronomy Series no. 9, Part 2, ASA, SSSA, Madison, Wisc., USA, p. 595 - 624.

De Pauw, E. (1984). Soils, physiography and agroecological zones of Tanzania. Ministry of Agriculture and Food and Agriculture Organization (FAO), Dar es Salaam.

Dent, D. and A. Young (1981). Soil survey and land evaluation. George Allen & Unwin (Publishers) Ltd, UK. 278 pp.

Driessen, P.M. and R. Dudal (Eds.) 1991. The Major Soils of the World, Lecture notes on their geography, formation, properties and use. Agricultural University Wageningen and Katholieke Universiteit Leuven. 310 pp.

FAO, (1990). Guidelines for Soil Profile Description, 3rd Edition. FAO, Rome.

FAO, 1988. FAO/Unesco Soil Map of the World, Revised Legend, with corrections. World Resources Report 60, FAO, Rome. Reprinted as Technical Paper 20, ISRIC, Wageningen, 1994.

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

Fozzard, P.M.H. (1965). Geological survey of Tanganyika, Kimamba, Quarter degree sheet 182. Survey Division, Dar es Salaam, Tanzania.

Kaaya, A.K. (1989). Soil survey and land suitability evaluation of the central part of Sokoine University of Agriculture farm (Morogoro) for rainfed crops. Unpublished M.Sc. (Agric.) dissertation, Department of Soil Science, Sokoine University of Agriculture, Morogoro, Tanzania.

Kaaya, A.K. (1996). A geomorphological analysis of two watersheds in Morogoro District, Tanzania. Unpublished report for Dr. Scient course in Tropical Geomorphology, Institute of Soil and Water Sciences, Agricultural University of Norway, Ås, Norway.

Kaaya, A.K. and P. Jørgensen (in prep). Chemical and mineralogical studies of soils of two toposequences in Morogoro District, Tanzania.

Kaaya, A.K., B.M. Msanya and J.P. Mrema (1994). Soil survey and land suitability evaluation of part of the Sokoine University of Agriculture farm (Tanzania) for some crops under rainfed conditions. *African Study Monographs*, **15** (2): 97 - 118.

Kaaya, A.K., T. Krogstad, I. Digernes, P. Jørgensen and B.R. Singh (1996). Chemical and mineralogical studies of some soils from Tanzania. Report no. 7/96 (48). Department of Soil and Water Sciences, Agricultural University of Norway, Ås, Norway.

Kesseba, A., J.R. Pitblado and A.P. Uriyo (1967). Trends of soil classification in Tanzania: 1. The experimental use of the 7th Approximation. J. Soil Science, **23**: 235 - 247

King, R.B. (1976). Land resources of the Northern and Luapula Provinces, Zambia - A reconnaissance assessment, Vol. 6: The land systems. Land Resources Study 19, Land Resources Division, Ministry of Overseas Development, England.

Klute, A. (1986). Water retention: Laboratory methods. In: A. Klute (Editor) Methods of Soil Analysis, Part 1. Physical and Mineralogical methods, 2nd edition. Agronomy Series no. 9, Part 1, ASA, SSSA, Madison, Wisc., USA, p. 635 - 662.

McLean, E.O. (1982). Soil pH and lime requirement. In: A.L. Page (Editor) Methods of Soil Analysis, Part 2. Chemical and microbiological properties, 2nd edition. Agronomy Series no. 9, Part 2, ASA, SSSA, Madison, Wisc., USA, p. 199 - 224.

Møberg, J.P. (1974). Formation, mineralogy and fertility of some tropical highland soils. København. 65 pp.

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

Mpepo, H.L.J. (1986). Soil survey and land evaluation of part of the University farm, Morogoro, for rainfed agriculture. M.Sc. (Agric.) dissertation, Department of Soil Science, Sokoine University of Agriculture, Tanzania.

Msanya B.M. and J.P. Magoggo (1993). Review of soil surveys (Soil Resource Inventories) in Tanzania. Ecology and Development Paper No. 6, The Ecology and Development programme, The Agricultural University of Norway.

Msanya, B.M., A.K. Kaaya and G.I. Nyadzi (1994). Pedological studies and characterization of some Benchmark soils of Morogoro District, Tanzania. Unpublished report, Department of Soil Science, Sokoine University of Agriculture, Morogoro.

Muhongo, S. (1995). Neoproterozoic collision tectonics in the Mozambique Belt of East Africa: Evidence from the Uluguru mountains, Tanzania. *Journal of African Earth Sciences*, **19** (3): 153-168.

Munsell Soil Color Charts, (1992). Revised edition. Munsell Color, Newburgh, New York

Nelson, D.W. and L.E. Sommers (1982). Total carbon, organic carbon, and organic matter. In: A.L. Page (Editor) Methods of Soil Analysis, Part 2. Chemical and microbiological properties, 2nd edition. Agronomy Series no. 9, Part 2, ASA, SSSA, Madison, Wisc., USA, p. 539 - 579.

Olsen, S.R. and L.E. Sommers (1982). Phosphorus. In: A.L. Page (Editor) Methods of Soil Analysis, Part 2. Chemical and microbiological properties, 2nd edition. Agronomy Series no. 9, Part 2, ASA, SSSA, Madison, Wisc., USA, p. 403 - 430.

Pócs, T. (1976). Vegetation mapping in the Uluguru mountains (Tanzania, East Africa). *Boissiera* **24**: 477 - 498 + 1 map

Rapp, A., V. Axelsson, L. Berry and D. H. Murray-Rust (1972). Soil erosion and sediment transport in the Morogoro river catchment, Tanzania. *Geogr. Ann.* A, **54**: 125-155.

Sampson, D.N. and A.E. Wright (1964). *The Geology of the Uluguru Mountains*, Geological Survey of Tanzania, Bulletin No. 37. Dar es Salaam, Tanzania. 69 p.

Sampson, D.N., A.E. Wright, and B.N. Temperley (1961). Geological survey of Tanganyika, -Morogoro, Quarter degree sheet 183. Geological Survey Division, Dodoma.

Soil Survey Staff, (1975). Soil taxonomy: A basic system of soil classification for making and interpreting soil surveys. USDA-SCS Agric. Handb. 436. U.S. Govt. Print. Office, Washington, D.C.

Soil Survey Staff, (1996). Keys to Soil Taxonomy, 7th Edition. USDA-Natural Resources Conservation Service, U.S. Govt. Print. Office, Washington, D.C.

Sørensen, R.S., and A.K. Kaaya (in prep.). Geology, landscape evolution and soil development in Northern Morogoro District, Tanzania.

Thomas, G.W. (1982). Exchangeable cations. In: A.L. Page (Editor) Methods of Soil Analysis, Part 2. Chemical and microbiological properties, 2nd edition. Agronomy Series no. 9, Part 2, ASA, SSSA, Madison, Wisc., USA, p. 159 - 165.

Vinces, A., F. Chalié and R. Bonnefille (1993). Pollen-derived rainfall and temperature estimates from Lake Tanganyika and their implication for Late Pleistocene water levels. *Quaternary Research* **40**: 343-350.

Whittig, L.D. and W.R. Allardice (1986). X-Ray diffraction techniques. In: A. Klute (Editor) Methods of Soil Analysis, Part 1. Physical and Mineralogical methods, 2nd edition. Agronomy Series no. 9, Part 1, ASA, SSSA, Madison, Wisc., USA, p. 331 - 362.

Young, A. (1976). Tropical soils and soil survey. Cambridge University Press, Cambridge. 468 pp.

APPENDICES

Appendix 1.1: DESCRIPTION OF SOIL PROFILE MK 2

1. GENERAL INFORMATION

1.1 Registration and Location

1.1.1 Profile number: MK 2
1.1.2 Date of description: 19.08.94
1.1.3 Author(s): Abel K. Kaaya
1.1.4 Soil unit: Mapping unit I.1a on the Lubungo-Mkata soil map
1.1.5 Location: About 400 metres south of Mkata railway station, on the left of the Melela - Kilosa road in Morogoro district
1.1.6 Elevation: 400 m asl
1.1.7 Grid reference: 37M CC 182528
1.1.8 Coordinates: Longitude 37° 21' 24'' E, Latitude 6° 45' 27'' S

1.2 Soil classification: USDA Soil Taxonomy: Chromic Haplusterts
FAO-Unesco: Eutric Vertisols (VRe)

1.3 Landform and Topography

1.3.1 Topography and landform: Flat to almost flat alluvial/fluvial plain with slopes < 2 %
1.3.2 Position: Intermediate part of the Mkata river plain
1.3.3 Slope: Profile on a nearly level terrain with convex slope of < 0.5 %)
1.3.4 Microtopography: Low gilgai microrelief with height difference of < 20 cm within 10 m

1.4 Land use and Vegetation

1.4.1 Land use: The major land use is extensive grazing of cattle and goats. Rain-fed cultivation of crops like sorghum, maize and pepper is also practiced in small plots. Irrigated rice is cultivated during rainy seasons in plots near the active streams.
1.4.2 Human influence: Grass cover strongly disturbed by extensive grazing and frequent burning. Several fire scars are common during dry season. Clearing of the woody vegetation for fire wood and charcoal burning is also an important human activity in the area.
1.4.3 Vegetation: Acacia wooded savanna. *Acacia nigrescens* is a dominant tree species. Other tree species include *Dalbergia melanoxylon*, *Harrisonia abyssinica* and *Cussonia arborea. Hyperrhenia rufa* dominates the herbaceous species.

1.5 Parent Material

1.5.1 Parent material: Alluvial/fluvial deposits over micaceous gneisses. Amphibolites were also observed near Mkata Ranch (about 2 km from this profile).
1.5.2 Effective soil depth: Class 4 - Deep (100 - 150 cm). Root growth of the dominant grass species extends to slightly below 100 cm.

1.6 Surface characteristics

1.6.1 Rock outcrops: None
1.6.2 Surface coarse fragments: None
1.6.3 Erosion: No evidence
1.6.4 Surface sealing: None
1.6.5 Surface cracks: Closely spaced to moderately widely spaced (0.2 - 1.0 m) wide (2 - 4 cm) cracks

1.7 Soil-Water relationships

1.7.1 Drainage class: Somewhat poorly (imperfectly) drained
1.7.2 Internal drainage: Saturated for short periods in most years. Permeability is slow to very slow
1.7.3 External drainage: Slow run-off
1.7.4 Flooding: None
1.7.5 Groundwater: Not observed but below the profile depth at the time of description
1.7.6 Moisture conditions: Dry throughout at the time of description

2. SOIL HORIZON DESCRIPTION

Horizon	*Depth (cm)*	*Description*
A_h	0 - 12	Dark gray (2.5Y 4/1) moist and dark gray (2.5Y 4/1) dry; clay; moderate to strong fine and medium subangular blocky structure; very sticky and very plastic (wet), firm (moist), very hard (dry); few very fine and fine tubular pores; few fine and medium roots; gradual, smooth boundary.
B_{w1}	12 - 102	Dark gray (2.5Y 4/1) moist and dark gray (2.5Y 4/1) dry; clay; strong medium and coarse prismatic structure; very sticky and very plastic (wet), very firm (moist), extremely hard (dry); few very fine random inped tubular pores; common, distinct, partly intersecting slickensides; very few, very fine roots; gradual, smooth boundary.
B_{w2}	102 - 159+	Light olive brown (2.5Y 5/4) moist, light yellowish brown (2.5Y 6/4) dry; clay; moderate medium subangular blocky structure; very sticky and very plastic (wet), very firm (moist), very hard (dry); few very fine random inped tubular pores; patchy, prominent predominantly intersecting slickensides; very few fine (2 - 5 mm), hard, rounded brownish iron-manganese (sesquioxides) nodules

3. Some physico-chemical properties of soil profile MK 2

Horizon	A_h	B_{w1}	B_{w2}
Depth (cm)	0 - 12	12 - 102	102 - 159+
Texture: % clay (< 0.002 mm)	44.4	48.2	50.8
% fine silt (0.002 - 0.02 mm)	8.2	9.3	7.6
% coarse silt (0.02 - 0.05 mm)	4.3	2.2	5.4
% sand (0.05 - 2.0 mm)	43.1	40.3	36.2
Textural class[1]	C	C	C
pH: in H_2O	7.5	8.0	8.3
in KCl	6.6	7.4	7.8
Organic C (%)	1.89	1.38	0.45
Organic matter (%)	3.26	2.38	0.78
Total N (%)	0.11	0.03	0.02
Olsen P (mg kg^{-1})	1.4	3.5	1.4
Exchangeable bases: Ca^{2+} (cmol(+) kg^{-1})	15.00	17.00	19.00
Mg^{2+} (cmol(+) kg^{-1})	10.02	8.06	8.30
K^+ (cmol(+) kg^{-1})	1.33	1.44	1.46
Na^+ (cmol(+) kg^{-1})	0.97	5.39	5.56
Sum of bases (cmol(+) kg^{-1})	27.32	31.89	34.32
Exchangeable Al^{3+} (cmol(+) kg^{-1})	0.06	0.00	0.00
ECEC by summation (cmol(+) kg^{-1})	27.38	31.89	34.32
CEC by NH_4OAc (cmol(+) kg^{-1})	28.02	31.96	34.92
% Base saturation	97.5	99.8	98.3
ECEC clay (cmol(+) kg^{-1})	46.99	56.29	64.5
CEC clay* (cmol(+) kg^{-1})	48.43	56.44	65.69

[1] Textural classes: C = Clay

* CEC clay = {(CEC soil - (% OM x 2))/% clay} x 100

Appendix 1.2: DESCRIPTION OF SOIL PROFILE LUB 1

1. GENERAL INFORMATION

1.1 Registration and Location

1.1.1 Profile number LUB 1
1.1.2 Date of description: 06.02.95
1.1.3 Author(s): Abel K. Kaaya and R. Sørensen
1.1.4 Soil unit: Mapping unit I.1a on the Lubungo-Mkata soil map
1.1.5 Location: Eastern part of Mkata ranch in Morogoro district, about 12 km west of Lubungo village along the Lubungo - Mkata field road, 3.6 km west of main cattle route junction.
1.1.6 Elevation: 445 masl
1.1.7 Grid reference: 37M CC 260515
1.1.8 Coordinates: Longitude 37° 25' 33'' E and Latitude 6° 46' 16'' S

1.2 Soil classification:

Soil classification:	USDA Soil Taxonomy:	Petrocalcic Calciusterts
	FAO-Unesco:	Calcic Vertisols (VRk)

1.3 Landform and Topography

1.3.1 Topography and landform: Flat to almost flat alluvial/fluvial plain with slopes < 2 %
1.3.2 Position: Intermediate part of an Alluvial/fluvial plain.
1.3.3 Slope: Profile on a level (slope < 0.2%) plain
1.3.4 Microtopography: Low gilgai microrelief with height difference of < 20 cm within 10 m

1.4 Land use and Vegetation

1.4.1 Land use: The major land use is extensive grazing of cattle.
1.4.2 Human influence: Extensive grazing of animals, bush fires and charcoal burning
1.4.3 Vegetation: Hyparrhenia-Combretum wooded grassland. Most of the woody vegetation have been cleared for charcoal burning and firewood supply. The remaining natural vegetation is dominated by herbaceous species notably *Hyperrhenia rufa* and scattered wooded vegetation composed mainly of *Combretum* tree species.

1.5 Parent Material

1.5.1 Parent material: Alluvial/fluvial deposits over micaceous gneisses
1.5.2 Effective soil depth: Class 3 - Moderately deep (40 - 48 cm). Root growth of the dominant grass species extend to 65 cm depth.

1.6 Surface characteristics

1.6.1 Rock outcrops: None
1.6.2 Surface coarse fragments: Few medium and coarse calcrete gravel
1.6.3 Erosion: None
1.6.4 Surface sealing: None
1.6.5 Surface cracks: Closely spaced (0.2 - 0.5 m) medium and wide (1 - 5 cm) cracks

1.7 Soil-Water relationships

1.7.1 Drainage class: Somewhat poorly (imperfectly) drained
1.7.2 Internal drainage: Saturated for short periods in most years. Permeability is generally slow to very slow
1.7.3 External drainage: Slow run-off during the periods of high rainfall intensity
1.7.4 Flooding: None
1.7.5 Groundwater: Below the profile depth (110 cm) at the time of description
1.7.6 Moisture conditions: Dry throughout at the time of description

2. SOIL HORIZON DESCRIPTION:

Horizon	*Depth (cm)*	*Description*
A_{ck}	0 - 25	Black (5Y 2.5/1) moist, very dark gray (5Y 3/1) dry; clay; strong fine angular blocky structure; very sticky, very plastic (wet), firm (moist), very hard (dry); common fine and medium tubular pores; few fine to medium (5 - 15 mm) hard spherical and irregular white carbonates nodules; common very fine to fine and few medium roots; clear, wavy boundary.
B_{ck1}	25 - 65	Black (5Y 2.5/1) moist, black (5Y 2.5/1) dry; clay; strong coarse prismatic structure; very sticky, very plastic (wet), firm (moist), very hard (dry); very few medium tubular pores; common, distinct partly intersecting slickensides; few fine to medium (5 - 15 mm) hard spherical and irregular white carbonates nodules; few medium roots; slightly calcareous; gradual, wavy boundary.
B_{ck2}	65 - 90	Black (5Y 2.5/1) moist, black (5Y 2.5/1) dry; clay; strong coarse prismatic structure; very sticky,.very plastic (wet), firm (moist), very hard (dry); very few medium tubular pores; common, distinct partly intersecting slickensides; many fine to medium (5 - 20 mm) hard spherical and irregular white carbonates nodules; very few very fine roots; strongly calcareous; clear, smooth boundary.
C_{ck}	90 - 110+	Petrocalcic horizon. Discontinuous (about 80%) moderately cemented by platy carbonates

3. Some physico-chemical properties of soil profile LUB 1

Horizon	A_h	B_{ck1}	B_{ck2}	C_{ck}
Depth (cm)	0 - 25	25 - 65	65 - 90	90 - 110+
Texture: % clay (< 0.002 mm)	50.2	55.3	55.2	N.D.
% fine silt (0.002 -0.02 mm)	7.8	5.5	7.8	N.D.
% coarse silt (< 0.02 - 0.05 mm)	4.4	4.4	4.4	N.D.
% sand (< 0.05 - 2.0 mm)	37.6	34.8	32.6	N.D.
Textural class[1]	C	C	C	N.D.
pH: in H_2O	7.6	8.4	8.5	N.D.
in KCl	7.1	7.6	7.9	N.D.
Organic C (%)	1.47	1.05	1.11	N.D.
Organic matter (%)	2.53	1.81	1.91	N.D.
Total N (%)	0.14	0.09	0.09	N.D.
Olsen P (mg kg^{-1})	2.5	4	3.8	N.D.
Exchangeable bases: Ca^{2+} (cmol(+) kg^{-1})	30.46	32.44	35.42	N.D.
Mg^{2+} (cmol(+) kg^{-1})	9.53	10.26	14.16	N.D.
K^+ (cmol(+) kg^{-1})	1.44	0.11	0.12	N.D.
Na^+ (cmol(+) kg^{-1})	1.55	4.58	7.28	N.D.
Sum of bases (cmol(+) kg^{-1})	42.98	47.39	56.98	N.D.
Exchangeable Al^{3+} (cmol(+) kg^{-1})	0	0	0	N.D.
ECEC by summation (cmol(+) kg^{-1})	42.98	47.39	56.98	N.D.
CEC by NH_4OAc (cmol(+) kg^{-1})	47.6	52.4	57.6	N.D.
% Base saturation	90.3	90.4	98.9	N.D.
ECEC clay (cmol(+) kg^{-1})	75.52	79.15	96.29	N.D.
CEC clay* (cmol(+) kg^{-1})	84.72	88.21	97.41	N.D.

[1] Textural classes: C = Clay

* CEC clay = {(CEC soil - (% OM x 2))/% clay} x 100

Appendix 1.3: DESCRIPTION OF SOIL PROFILE LUB 2

1. GENERAL INFORMATION

1.1 Registration and Location

1.1.1 Profile number LUB 2
1.1.2 Date of description: 02.02.95
1.1.3 Author(s): Abel K. Kaaya and R. Sørensen
1.1.4 Soil unit: Mapping unit I.1b on the Lubungo-Mkata soil map
1.1.5 Location: Morogoro district, about 4 km west of Lubungo village along the Lubungo - Mkata field road, 1.5 km west of the river.
1.1.6 Elevation: 470 masl
1.1.7 Grid reference: 37M CC 318466
1.1.8 Coordinates: Longitude 37° 29' 45" E and Latitude 6° 49' 05" S

1.2 Soil Classification:

	USDA Soil Taxonomy:	Fluventic Ustropepts
	FAO-Unesco:	Eutric Cambisols (CMe)

1.3 Landform and Topography

1.3.1 Topography and lanform: Flat to almost flat alluvial/fluvial plains with slopes of < 2 %
1.3.2 Position: Intermediate part of the Mbesegera river Alluvial/fluvial plain.
1.3.3 Slope: Profile on a level (slope < 0.2%) plain
1.3.4 Microtopography: None

1.4 Land use and Vegetation

1.4.1 Land use: The major land use extensive grazing of cattle and charcoal.
1.4.2 Human influence: Grazing and bushfires has disturbed the natural vegetation affecting mostly the grass species and herbaceous shrubs. Clearing of trees vegetation.
1.4.3 Vegetation: Medium grassland (grass cover ranging from 20 to 50%) with shrubs and scattered trees. This complex woodland is mainly composed of Hyphaene palm, various species of Combretum, *Acacia xanthoghloea, Annona senegalensis, Flacourtia indica* and grasses dominated by *Hyparrhenia species.* River valleys are characterised by relatively taller and are more densely vegetated.

1.5 Parent Material

1.5.1 Parent material: Fluvial deposits over micaceous gneisses
1.5.2 Effective soil depth: Class 4 - Deep (100 - 150 cm).

1.6 Surface characteristics

1.6.1 Rock outcrops: None
1.6.2 Surface coarse fragments: None
1.6.3 Erosion: Water erosion on the surface. Thin layer (about 2 cm) of the surface soil depleted of fine soil particles.
1.6.4 Surface sealing: None
1.6.5 Surface cracks: None
1.6.6 Other surface characteristics: presence of thin sand layer on the surface (covers between 40 and 70% of the surface)

1.7 Soil-Water relationships

1.7.1 Drainage class: Somewhat poorly (imperfectly) drained.
1.7.2 Internal drainage: Saturated for short periods in most years due to seasonal fluctuations of groundwater table. Slow to very slow permeability.
1.7.3 External drainage: Moderately rapid run-off during the periods of high rainfall intensity
1.7.4 Flooding: Rare
1.7.5 Groundwater: Below the profile depth (200 cm) at the time of description but fluctuates with seasons up to 40/48 cm depth.
1.7.6 Moisture conditions: Dry throughout at the time of description

2. SOIL HORIZON DESCRIPTION:

Horizon	*Depth (cm)*	*Description*
A_h	0 - 28/30	Black (10YR 2/1) moist, very dark grayish brown (10YR 3/2) dry; sandy clay, with very thin (2 cm) sandy layer on the surface; strong fine and medium angular blocky structure; sticky, plastic (wet), firm (moist), very hard (dry); common fine and medium tubular pores; common fine and few medium and coarse roots; gradual, wavy boundary.
B_w	28/30 - 40/48	Very dark grayish brown (10YR 3/2) moist, brown (10YR 4/3) dry; clay; strong medium angular blocky structure; very sticky, very plastic (wet), firm (moist), very hard (dry); common fine and medium tubular pores; few medium roots; slightly calcareous; clear, wavy boundary.
B_{ck}	40/48 - 83	Dark yellowish brown (10YR 4/4) moist, yellowish brown (10YR 5/4) dry; common, medium, faint, clear reddish brown mottles; clay; moderate, medium subangular blocky structure; very sticky, very plastic (wet), firm (moist), hard (dry); few fine and medium tubular pores; common fine and medium (4 - 12 mm) hard and soft irregular calcareous nodules in strongly calcareous soil matrix; very few very fine roots; clear, smooth boundary.
BC_{ck}	83 - 130	Light olive brown (2.5Y 5/4) moist, light yellowish brown (2.5Y 6/4) dry; few, medium, faint, clear reddish brown mottles; sandy clay; moderate fine and medium subangular blocky structure; very sticky, very plastic (wet), firm (moist), hard (dry); few fine and medium tubular pores; many medium (10 - 20 mm) hard and soft irregular calcareous nodules, and few fine (2 - 5 mm) hard spherical black manganiferous concretions in strongly calcareous soil matrix; gradual, smooth boundary.
C_{ck}	130 - 200 +	Light olive brown (2.5Y 5/4) moist, light yellowish brown (2.5Y 6/4) dry; sandy clay; few fresh and slightly weathered coarse (3 - 5 cm) quartz gravel; massive structure; sticky, plastic (wet), firm (moist), hard (dry); many medium and coarse (10 - 30 mm) hard and soft irregular calcareous nodules, and very few fine (2 - 5 mm) hard spherical black manganiferous concretions in moderately calcareous matrix.

3. **Some physico-chemical properties of soil profile LUB 2**

Horizon	A_h	B_w	B_{ck}	BC_{ck}	C_{ck}
Depth (cm)	0 - 28/30	28/30 - 40/48	40/48 - 83	83 - 130	130 - 200 +
Texture: % clay (< 0.002 mm)	35.8	41.1	42.2	38.2	36.8
% fine silt (< 0.002 - 0.02 mm)	5.3	7.2	6.8	5.6	5.2
% coarse silt (< 0.02 - 0.05 mm)	6.3	8.8	7.3	6.3	6.4
% sand (< 0.05 - 2.0 mm)	52.6	42.9	43.7	49.9	51.6
Textural class[1]	SC	C	C	SC	SC
pH: in H_2O	7.4	8.1	8.4	8.2	8.5
in KCl	7.1	7.5	7.9	7.8	7.9
Organic C (%)	1.15	0.31	0.14	0.18	0.10
Organic matter (%)	1.98	0.53	0.24	0.31	0.17
Total N (%)	0.13	0.05	0.04	0.04	0.03
Olsen P (mg kg^{-1})	8.5	0.8	2.2	2.0	1.3
Exchangeable bases: Ca^{2+} (cmol(+) kg^{-1})	4.86	5.67	10.76	5.41	6.41
Mg^{2+} (cmol(+) kg^{-1})	8.88	8.69	9.11	9.24	9.03
K^+ (cmol(+) kg^{-1})	0.45	0.32	0.36	0.33	0.32
Na^+ (cmol(+) kg^{-1})	3.63	5.94	6.77	11.82	10.05
Sum of bases (cmol(+) kg^{-1})	17.82	20.62	27.00	26.80	25.81
Exchangeable Al^{3+} (cmol(+) kg^{-1})	0.00	0.00	0.00	0.00	0.00
ECEC by summation (cmol(+) kg^{-1})	17.82	20.62	27.00	26.80	25.81
CEC by NH_4OAc (cmol(+) kg^{-1})	19.20	20.80	27.20	28.00	26.40
% Base saturation	92.8	99.1	99.3	95.7	97.8
ECEC clay (cmol(+) kg^{-1})	38.70	47.57	62.84	68.53	69.20
CEC clay* (cmol(+) kg^{-1})	42.56	48.01	63.31	71.67	70.80

[1] Textural classes: SC = Sandy clay; C = Clay

* CEC clay = {(CEC soil - (% OM x 2))/% clay} x 100

Appendix 1.4: DESCRIPTION OF SOIL PROFILE LUB 3

1. GENERAL INFORMATION

1.1 Registration and Location

1.1.1 Profile number LUB 3
1.1.2 Date of description: 02.02.95
1.1.3 Author(s): Abel K. Kaaya and R. Sørensen
1.1.4 Soil unit: Mapping unit I.2a on the Lubungo-Mkata soil map
1.1.5 Location: At one of the cultivated fields in Lubungo village about 1 km west of the Lubungo Primary School, Morogoro district.
1.1.6 Elevation: 495 masl
1.1.7 Grid reference: 37M CC 346453
1.1.8 Coordinates: Longitude 37° 30' 14'' E and Latitude 6° 49' 38'' S.

1.2 Soil Classification:

USDA Soil Taxonomy: Kandic Paleustalfs
FAO-Unesco: Haplic Lixisols (LXh)

1.3 Landform and Topography

1.3.1 Topography and landform: Undulating plain formed by wide interfluves with slopes of 2 - 5%
1.3.2 Position: Lower part of the a relatively wide interfluve
1.3.3 Slope: Profile on a convex very gently sloping (slope = 1.5%) topography
1.3.4 Microtopography: None

1.4 Land use and Vegetation

1.4.1 Land use: The major land use is cultivation of food crops under rainfed conditions. The crops include pigeon peas, maize, sorghum and cassava.
1.4.2 Human influence: Land tillage by hand for agricultural crops.
1.4.3 Vegetation: Most of the woody vegetation had been cleared for charcoal burning and for the purpose.of expanding agricultural land. The natural vegetation is Combretum woodland composed of *Combretum spp, Acacia spp., Stercularia spp.* and *Markhamia platycalyx.*The herbaceous species is mainly *Hyparrhenia rufa.*

1.5 Parent Material

1.5.1 Parent material: Fluvial/colluvial deposits over micaceous gneisses
1.5.2 Effective soil depth: Class 4 - Deep (150 cm), limited by a plinthite layer below 150 cm depth.

1.6 Surface characteristics

1.6.1 Rock outcrops: None
1.6.2 Surface coarse fragments: None
1.6.3 Erosion: Slight sheet erosion, still active
1.6.4 Surface sealing: None
1.6.5 Surface cracks: None

1.7 Soil-Water relationships

1.7.1 Drainage class: Well drained
1.7.2 Internal drainage: The profile is never saturated
1.7.3 External drainage: Slow to moderately rapid run-off depending on the rainfall intensity
1.7.4 Flooding: None
1.7.5 Groundwater: Not observed but below the profile depth (200 cm) at the time of description.
1.7.6 Moisture conditions: Dry throughout at the time of description

2. SOIL HORIZON DESCRIPTION:

Horizon	*Depth (cm)*	*Description*
A_p	0 - 20	Dark reddish brown (5YR 3/3) moist, dark reddish brown (5YR 3.5/4) dry; sandy clay loam; weak to moderate fine and medium granular structure; slightly sticky, slightly plastic (wet), friable (moist), hard (dry); common very fine and fine, and few medium tubular pores; common very fine and fine, and few medium roots, few termite and ant channels and nests; clear, smooth boundary.
B_{t1}	20 - 39	Dark red (2.5YR 3/6) moist, red (2.5YR 4/6) dry; clay; strong fine and medium subangular blocky structure; sticky, plastic (wet), very friable (moist), hard (dry); common very fine and fine, and few medium tubular pores; few faint clay cutans on ped faces; few very fine and fine roots, common termite and ant channels and nests; clear, smooth boundary.
B_{t2}	39 - 101	Dark red (2.5YR 3/6) moist, red (2.5YR 4/8) dry; clay; weak fine and medium subangular blocky structure; sticky, plastic (wet), very friable (moist), slightly hard (dry); very fine and few fine tubular pores; common distinct clay cutans on ped faces; few fine (2 - 5 mm) moderately hard spherical brownish and black iron-manganese (sesquioxides) concretions; many very fine to fine and few medium roots; common termite and ant channels and nests; gradual, wavy boundary.
B_{tcs}	101 - 150	Dark red (2.5YR 3/6) moist, red (2.5YR 4/8) dry; clay; few fine and medium (3 - 20 mm) slightly weathered angular quartz gravel; moderate fine and medium subangular blocky structure; very sticky, very plastic (wet), friable (moist), slightly hard (dry); few very fine and medium tubular pores; common distinct clay cutans on ped faces; common fine (2 - 5 mm) moderately hard, spherical brownish and black iron-manganese (sesquioxides) concretions; few termite and ant channels and nests; abrupt, smooth boundary.
B_{ms}	150 - 200+	Plinthite layer with very frequent fine and medium (2 - 10 mm) very hard predominantly spherical brownish iron-manganese(sesquioxides) concretions.

3. Some physico-chemical properties of soil profile LUB 3

Horizon	A_p	B_{t1}	B_{t2}	B_{tcs}	B_{ms}
Depth (cm)	0 - 20	20 - 39	39 - 101	101 - 150	150 - 200+
Texture: % clay (< 0.002 mm)	30.7	55.6	60.6	56.2	N.D.
% fine silt (< 0.002 - 0.02 mm)	11.8	3.2	5.3	7.5	N.D.
% coarse silt (< 0.02 - 0.05 mm)	1.1	2.1	2.2	4.3	N.D.
% sand (< 0.05 - 2.0 mm)	56.4	39.1	31.9	32	N.D.
Textural class[1]	SCL	C	C	C	N.D.
Bulk density (Mg m^{-3})	1.18	1.27	1.35	N.D.	N.D.
Water between 33 and 1500 kPa (vol. %)	10.05	13.35	16.46	N.D.	N.D.
pH: in H_2O	7.6	6.4	6.3	6.5	N.D.
in KCl	7.1	5.7	5.7	6.1	N.D.
Organic C (%)	1.37	0.75	0.50	0.54	N.D.
Organic matter (%)	2.36	1.29	0.86	0.93	N.D.
Total N (%)	0.14	0.09	0.07	0.04	N.D.
Bray P (mg kg^{-1})	N.D.	3.7	0.7	0.9	N.D.
Olsen P (mg kg^{-1})	12.5	N.D.	N.D.	N.D.	N.D.
Exchangeable bases: Ca^{2+} (cmol(+) kg^{-1})	8.32	5.90	7.19	2.94	N.D.
Mg^{2+} (cmol(+) kg^{-1})	2.97	2.90	3.36	4.08	N.D.
K^+ (cmol(+) kg^{-1})	1.72	1.90	0.81	0.53	N.D.
Na^+ (cmol(+) kg^{-1})	0.83	0.80	1.03	1.26	N.D.
Sum of bases (cmol(+) kg^{-1})	13.84	11.50	12.39	8.81	N.D.
Exchangeable Al^{3+} (cmol(+) kg^{-1})	0.30	0.20	0.40	0.60	N.D.
ECEC by summation (cmol(+) kg^{-1})	14.14	11.70	12.79	9.41	N.D.
CEC by NH_4OAc (cmol(+) kg^{-1})	15.60	15.20	16.02	13.60	N.D.
% Base saturation	88.7	75.7	77.3	64.8	N.D.
ECEC clay (cmol(+) kg^{-1})	30.67	16.39	18.26	13.43	N.D.
CEC clay* (cmol(+) kg^{-1})	35.43	22.69	23.59	20.89	N.D.

[1] Textural classes: SCL = Sandy clay loam; C = Clay

* CEC clay = {(CEC soil - (% OM x 2))/% clay} x 100

Appendix 1.5: DESCRIPTION OF SOIL PROFILE LUB 4

1. GENERAL INFORMATION

1.1 Registration and Location

1.1.1 Profile number LUB 4
1.1.2 Date of description: 03.02.95
1.1.3 Author(s): Abel K. Kaaya and R. Sørensen
1.1.4 Soil unit: Mapping unit I.2a on the Lubungo-Mkata soil map
1.1.5 Location: About 15 m on the left of the Sangasanga - Lubungo field road at about 6.7 km from the Morogoro - Iringa highway in Morogoro district.
1.1.6 Elevation: 535 masl
1.1.7 Grid reference: 37M CC 360430
1.1.8 Coordinates: Longitude 37° 31' 02'' E and Latitude 6° 50' 54'' S.

1.2 Soil Classification: USDA Soil Taxonomy: Kandic Paleustalfs
FAO-Unesco: Haplic Lixisols (LXh)

1.3 Landform and Topography

1.3.1 Topography and landform: Moderately dissected undulating plain with slopes 2 - 5 %
1.3.2 Position: Intermediate part of the a relatively wide interfluve
1.3.3 Slope: Profile on a convex gently sloping (slope = 3%) topography
1.3.4 Microtopography: None

1.4 Land use and Vegetation

1.4.1 Land use: The major land use is extensive grazing of cattle and goats. Rainfed cultivation of crops like sorghum, maize and cassava.
1.4.2 Human influence: Grass cover strongly disturbed by extensive grazing and frequent burning. Several fire scars characterise the area during dry season. Clearing of the woody vegetation for fire wood and charcoal burning is also an important human activity in the area.
1.4.3 Vegetation: Most of the woody vegetation cleared for charcoal burning and the grass cover highly disturbed by grazing animals and bush fire. The natural vegetation is Combretum woodland with *Combretum, Acacia spp., Stercularia spp.* and *Markhamia platycalyx* and grass species dominated by *Hyparrhenia rufa*

1.5 Parent Material

1.5.1 Parent material: Fluvial/colluvial deposits over micaceous gneisses
1.5.2 Effective soil depth: Class 5 - Very deep (100 - 150 cm). Root growth of the dominant grass species extends to >120 cm.

1.6 Surface characteristics

1.6.1 Rock outcrops: None
1.6.2 Surface coarse fragments: None
1.6.3 Erosion: Slight sheet erosion, still active
1.6.4 Surface sealing: None
1.6.5 Surface cracks: None

1.7 Soil-Water relationships

1.7.1 Drainage class: Well drained
1.7.2 Internal drainage: The profile is never saturated
1.7.3 External drainage: Slow to moderately rapid run-off depending on the rainfall intensity
1.7.4 Flooding: None
1.7.5 Groundwater: Not observed but below the profile depth (200 cm) at the time of description.
1.7.6 Moisture conditions: Dry throughout at the time of description

2. SOIL HORIZON DESCRIPTION:

Horizon	*Depth (cm)*	*Description*
A_h	0 - 19	Dark reddish brown (5YR 3/3) moist, dark reddish brown (5YR 3/3) dry; clay; moderate fine subangular blocky structure; sticky, plastic (wet), friable (moist), hard (dry); common very fine to fine and few medium tubular pores; common very fine to fine and few medium; clear, smooth boundary.
BA	19 - 33	Dark reddish brown (2.5YR 2.5/4) moist, dark red (2.5YR 3/6) dry; clay; moderate fine subangular blocky structure; sticky, plastic (wet), friable (moist), slightly hard (dry); common very fine to fine tubular pores; many very fine to fine and few medium roots; few termite and ant channels and nests; gradual, wavy boundary.
B_{t1}	33 - 90	Dark red (10R 3/6) moist, red (10R 4/8) dry; clay; moderate medium subangular blocky.structure; slightly sticky, slightly plastic (wet), friable (moist), hard (dry); common very fine and few fine tubular pores; few faint clay cutans on some ped faces; very few fine (2 - 5 mm) slightly hard spherical brownish iron-manganese (sesquioxides) nodules; many very fine to fine and few medium roots; few termite and ant channels and nests; gradual, wavy boundary.
B_{t2}	90 - 200+	Dark red (10R 3/6) moist, red (10R 4/8) dry; clay; moderate medium subangular blocky structure; slightly sticky, slightly plastic (wet), firm (moist), hard (dry); common very fine and few fine tubular pores; common faint clay cutans on some ped faces; very few fine (2 - 5 mm) slightly hard spherical reddish brown iron nodules; few very fine to fine and few medium roots; few termite and ant channels and nests.

3. Some physico-chemical properties of soil profile LUB 4

Horizon	A_h	B_{t1}	B_{t2}	B_{t3}
Depth (cm)	0 - 19	19 - 33	33 - 90	90 - 200+
Texture: % clay (< 0.002 mm)	45.6	68.4	57.9	57.9
% fine silt (< 0.002 - 0.02 mm)	8.4	6.5	8.2	11.3
% coarse silt (< 0.02 - 0.05 mm)	4.4	1.6	3.4	7.4
% sand (< 0.05 - 2.0 mm)	41.6	23.5	30.5	23.4
Textural class[1]	C	C	C	C
Bulk density ($Mg\ m^{-3}$)	1.43	1.30	N.D.	1.43
Water between 33 and 1500 kPa (vol. %)	20.51	16.38	N.D.	18.13
pH: in H_2O	6.2	6.1	5.6	6.4
in KCl	5.3	5.3	5.0	5.8
Organic C (%)	1.54	1.01	0.47	0.25
Organic matter (%)	2.65	1.74	0.81	0.43
Total N (%)	0.14	0.1	0.07	0.07
Bray P ($mg\ kg^{-1}$)	2.6	5.2	1.8	1.8
Exchangeable bases: Ca^{2+} (cmol(+) kg^{-1})	4.71	3.12	2.06	3.63
Mg^{2+} (cmol(+) kg^{-1})	3.81	3.15	4.04	3.55
K^+ (cmol(+) kg^{-1})	0.76	0.59	0.24	0.75
Na^+ (cmol(+) kg^{-1})	0.97	1.03	0.99	1.12
Sum of bases (cmol(+) kg^{-1})	10.25	7.89	7.33	9.05
Exchangeable Al^{3+} (cmol(+) kg^{-1})	0.70	2.20	0.20	0.00
ECEC by summation (cmol(+) kg^{-1})	10.95	10.09	7.53	9.05
CEC by NH_4OAc (cmol(+) kg^{-1})	13.60	15.20	12.80	14.40
% Base saturation	75.4	51.9	57.3	62.8
ECEC clay (cmol(+) kg^{-1})	12.37	9.66	10.21	14.14
CEC clay* (cmol(+) kg^{-1})	18.18	17.13	19.31	23.38

[1] Textural classes: C = Clay

* CEC clay = {(CEC soil - (% OM x 2))/% clay} x 100

Appendix 1.6: DESCRIPTION OF SOIL PROFILE LUB 5

1. GENERAL INFORMATION

1.1 Registration and Location

1.1.1 Profile number LUB 5
1.1.2 Date of description: 04.02.95
1.1.3 Author(s): Abel K. Kaaya and R. Sørensen
1.1.4 Soil unit: Mapping unit I.2a on the Lubungo-Mkata soil map
1.1.5 Location: About 15 m on the left of the Sangasanga - Lubungo field road at 4.7 km from the Morogoro - Iringa highway in Morogoro district.
1.1.6 Elevation: 580 masl
1.1.7 Grid reference: 37M CC 385407
1.1.8 Coordinates: Longitude 37° 32' 17'' E and Latitude 6° 52' 02'' S

1.2 Soil Classification: USDA Soil Taxonomy: Rhodic Kandiustalfs
FAO-Unesco: Haplic Lixisols (LXh)

1.3 Landform and Topography

1.3.1 Topography and landform: Undulating plain with slopes of 2 - 5 %
1.3.2 Position: Near the top of a relatively wide interfluve
1.3.3 Slope: Profile on a convex gently sloping (slope = 4%) topography
1.3.4 Microtopography: None

1.4 Land use and Vegetation

1.4.1 Land use: The major land use is extensive grazing of cattle and goats. Rainfed cultivation of crops like sorghum, maize and cassava.
1.4.2 Human influence: Grass cover strongly disturbed by extensive grazing and frequent burning. Several fire scars are common during dry season. Wooded vegetation is also cleared for fire wood supply and charcoal production.
1.4.3 Vegetation: Most of the trees have been cleared for charcoal burning. The natural vegetation is Combretum woodland with *Combretum, Acacia spp.,Stercularia spp.* and *Markhamia platycalyx* and grass species dominated by *Hyparrhenia rufa*

1.5 Parent Material

1.5.1 Parent material: Fluvial/colluvial deposits over micaceous gneisses
1.5.2 Effective soil depth: Class 5 - Very deep (> 150 cm). Roots of grass species extends to >200 cm.

1.6 Surface characteristics

1.6.1 Rock outcrops: None
1.6.2 Surface coarse fragments: None
1.6.3 Erosion: Slight sheet erosion, still active
1.6.4 Surface sealing: None
1.6.5 Surface cracks: Widely spaced (2 - 5 m) fine cracks

1.7 Soil-Water relationships

1.7.1 Drainage class: Well drained
1.7.2 Internal drainage: The profile is never saturated
1.7.3 External drainage: Slow to moderately rapid run-off depending on the rainfall intensity
1.7.4 Flooding: None
1.7.5 Groundwater: Not observed but below the profile depth (200 cm) at the time of description.
1.7.6 Moisture conditions: Dry throughout at the time of description

2. SOIL HORIZON DESCRIPTION:

Horizon	*Depth (cm)*	*Description*
A_h	0 - 20	Dark reddish brown (5YR 2.5/2) moist, dark reddish brown (5YR 3/3) dry; clay; moderately strong fine crumb structure; sticky, plastic (wet), friable (moist), hard (dry); common very fine to fine and few medium tubular pores; common very fine to fine and few medium roots; clear, smooth boundary.
BA	20 - 38	Dark reddish brown (2.5YR 2.5/4) moist, dark red (2.5YR 3/6) dry; clay; moderately strong fine subangular blocky structure; sticky, plastic (wet), friable (moist), slightly hard (dry); many very fine to fine and few medium tubular pores; common fine and few medium roots, few termite and ant channels and nests; clear, smooth boundary.
B_{t1}	38 - 134/138	Dark red (10R 3/6) moist, red (10R 4/8) dry; clay; few fine (2 - 6 mm) fresh angular quartz gravel; moderate fine subangular blocky structure; slightly sticky, slightly plastic (wet), friable (moist), slightly hard (dry); many very fine and common fine tubular pores; common faint clay cutans on some ped faces; few fine and medium (4 - 10 mm) soft irregular reddish brown iron nodules and very few fine (3- 6 mm) hard spherical dark brown iron-manganese (sesquioxides) nodules; many very fine to fine and few medium roots; few termite and ant channels and nests; gradual, wavy boundary.
B_{t2}	134/138-200+	Dark red (10R 3/6) moist, red (10R 4/8) dry; clay; few fine (2 - 6 mm) fresh angular quartz gravel; moderate fine subangular blocky structure; slightly sticky, slightly plastic (wet), very friable (moist), slightly hard (dry); many very fine and common fine tubular pores; common faint clay cutans on some ped faces; few medium (6 - 12 mm) soft irregular reddish brown iron nodules and very few fine (3 - 6 mm) hard spherical dark brown iron-manganese (sesquioxides) nodules; few very fine and fine roots; few termite and ant channels and nests.

3. Some physico-chemical properties of LUB 5

Horizon	A_h	BA	B_{t1}	B_{t2}
Depth (cm)	0 -20	20 - 38	38 - 134/138	134/138 - 200+
Texture: % clay (< 0.002 mm)	47.8	69.1	76.4	73.4
% fine silt (< 0.002 - 0.02 mm)	4.5	2.4	3.2	5.0
% coarse silt (< 0.02 - 0.05 mm)	6.3	1.8	1.6	2.0
% sand (< 0.05 - 2.0 mm)	41.4	26.7	18.8	19.6
Textural class[1]	C	C	C	C
Bulk density ($Mg\ m^{-3}$)	1.55	N.D.	1.23	1.40
Water between 33 and 1500 kPa (vol. %)	8.87		15.71	12.79
pH: in H_2O	5.9	5.8	5.4	5.6
in KCl	5.4	5.1	4.5	4.7
Organic C (%)	1.60	0.92	0.31	0.23
Organic matter (%)	2.76	1.59	0.53	0.40
Total N (%)	0.13	0.10	0.06	0.06
Bray P ($mg\ kg^{-1}$)	2.9	1.5	1.8	1.2
Exchangeable bases: Ca^{2+} (cmol(+) kg^{-1})	4.62	2.72	1.55	1.31
Mg^{2+} (cmol(+) kg^{-1})	2.84	2.52	3.04	2.72
K^+ (cmol(+) kg^{-1})	0.73	0.38	0.12	0.11
Na^+ (cmol(+) kg^{-1})	1.02	1.20	1.02	1.23
Sum of bases (cmol(+) kg^{-1})	9.21	6.82	5.73	5.37
Exchangeable Al^{3+} (cmol(+) kg^{-1})	1.2	2.1	3.0	3.2
ECEC by summation (cmol(+) kg^{-1})	10.41	8.92	8.73	8.57
CEC by NH_4OAc (cmol(+) kg^{-1})	13.2	11.2	9.8	8.62
% Base saturation	69.8	60.9	58.5	62.3
ECEC clay (cmol(+) kg^{-1})	10.24	8.32	10.03	10.60
CEC clay* (cmol(+) kg^{-1})	16.07	11.62	11.43	10.66

[1] C = Textural classes: C = Clay

* CEC clay = {(CEC soil - (% OM x 2))/% clay} x 100

Appendix 1.7: DESCRIPTION OF SOIL PROFILE MAG 1

1. GENERAL INFORMATION

1.1 Registration and Location

1.1.1 Profile number MAG 1
1.1.2 Date of description: 09.02.95
1.1.3 Author(s): Abel K. Kaaya and Rolf Sørensen
1.1.4 Soil unit: Mapping unit II.1b on the Magadu soil map
1.1.5 Location: South western part of the Sokoine University of Agriculture farm, about 0.4 km east of Ngerengere River in Morogoro District
1.1.6 Elevation: 500 masl
1.1.7 Grid reference: 37M CC 479431.
1.1.8 Coordinates: Longitude 37° 37' 35'' E and 6° 50' 55'' S

1.2 Soil Classification:

USDA Soil Taxonomy: Fluventic Ustropepts
FAO-Unesco: Chromic Cambisols (CMx)

1.3 Landform and Topography

1.3.1 Topography and landform: Flat Ngerengere River Plain with slopes < 0.5 %.
1.3.2 Position: Intermediate part of the almost flat terrain.
1.3.3 Slope: Profile on almost flat plain (slope = 0.5 %)
1.3.4 Microtopography: Cultivation ridges and furrows.

1.4 Land use and Vegetation

1.4.1 Land use: Currently under cultivation of maize during the normal growing season. Tomatoes are the off-season crop. Lowland rice, sugarcane and elephant grass are grown on the Ngerengere River plain.
1.4.2 Human influence: The area is an agricultural land with hand cultivation of crops being the main activity.
1.4.3 Vegetation: Most of the natural woody vegetation has been cleared. Cultivated land has gradually replaced the valley grassland which occupied the area previously. Natural vegetation is mainly valley grasslands composed of *Cyclosorus interruptus* and sedges (*Cyperus exaltatus*) replaced by cultivated land (swamp rice, sugar cane, etc.)

1.5 Parent Material

1.5.1 Parent material: Alluvial/fluvial materials deposited by the Ngerengere river.from the Uluguru mountains.
1.5.2 Effective soil depth: Class 5 - Very deep (100 - 150 cm).

1.6 Surface characteristics

1.6.1 Rock outcrops: None
1.6.2 Surface coarse fragments: None
1.6.3 Erosion: None
1.6.4 Surface sealing: None
1.6.5 Surface cracks: Fine (< 1 cm) moderately widely spaced (0.5 - 1 m) surface cracks

1.7 Soil-Water relationships

1.7.1 Drainage class: Somewhat poorly (imperfectly) drained
1.7.2 Internal drainage: Rarely saturated (may be saturated for few days in some years
1.7.3 External drainage: Slow run-off
1.7.4 Flooding: Rare
1.7.5 Groundwater: Not observed but below the profile depth (140 cm) at the time of description.
1.7.6 Moisture conditions: Dry throughout at the time of description

2. SOIL HORIZON DESCRIPTION:

Horizon	*Depth (cm)*	*Description*
A_p	0 - 12	Very dark brown (7.5YR 2.5/2) moist, brown (7.5YR 4/3) dry; clay; moderate fine crumb structure; sticky, plastic (wet), firm (moist), slightly hard (dry); many very fine and fine medium tubular pores; common very fine to fine and few medium roots; abrupt, smooth boundary.
BA	12 - 30	Dark brown (7.5YR 3/2) moist, brown (7.5YR 4/3) dry; sandy clay; strong medium and coarse angular blocky structure; sticky, plastic (wet), firm (moist), hard (dry); many fine and few medium tubular pores; common fine and few medium roots; clear, smooth boundary.
B_w	30 - 48	Dark reddish brown (5YR 3/3) moist, reddish brown (5YR 4/3) dry; sandy clay loam; weak fine subangular blocky structure; non sticky, non plastic (wet), soft (moist), slightly hard (dry); common fine and few medium tubular pores; few fine roots; clear, smooth boundary.
B_{cs1}	48 - 95	Dark reddish brown (2.5YR 3/4) moist, red (2.5YR 4/6) dry; clay; strong medium to coarse angular blocky structure; very sticky, very plastic (wet), firm (moist), hard (dry); common fine and few medium tubular pores; few fine (2 - 6 mm) hard spherical black and brownish iron-manganese (sesquioxides) nodules; few fine roots; clear, smooth boundary.
B_h	95 - 110	Dark brown (7.5YR 3/2) moist, brown (7.5YR 4/2) dry; clay; strong medium to coarse angular blocky structure; sticky, plastic (wet), firm (moist), hard (dry); common fine and few medium tubular pores; very few fine roots; clear, smooth boundary.
B_{cs2}	110 - 140 +	Dark reddish brown (5YR 3/3) moist, reddish brown (5YR 4/3) dry; clay; strong fine angular blocky structure; very sticky, very plastic (wet), very firm (moist), very hard (dry); few fine and very few medium tubular pores; few fine (2 - 6 mm) hard spherical black and brownish iron-manganese (sesquioxides) nodules.

3. **Some physico-chemical properties of MAG 1**

Horizon	A_p	BA	B_w	B_{cs1}	B_h	B_{cs2}
Depth (cm)	0 - 12	12 - 30	30 - 48	48 - 95	95 - 110	110 - 140+
Texture: % clay (< 0.002 mm)	47.4	39.2	20.6	52.8	57.6	70.7
% fine silt (< 0.002 - 0.02 mm)	9.3	7.2	1.0	5.1	11.1	6.1
% coarse silt (< 0.02 - 0.05 mm)	6.2	4.1	4.1	8.1	6.1	4.1
% sand (< 0.05 - 2.0 mm)	37.1	49.5	74.3	34	25.2	19.1
Textural class[1]	C	SC	SCL	C	C	C
Bulk density (Mg m^{-3})	1.26	N.D.	1.61	1.60	N.D.	N.D.
Water between 33 and 1500 kPa (vol. %)	5.28	N.D.	8.17	5.59	N.D.	N.D.
pH: in H_2O	6.9	6.9	6.4	6.7	6.7	6.6
in KCl	6.4	6.3	6.1	6.1	5.9	5.9
Organic C (%)	2.10	1.12	0.44	0.88	1.55	0.92
Organic matter (%)	3.62	1.93	0.76	1.52	2.67	1.59
Total N (%)	0.19	0.11	0.05	0.09	0.11	0.10
Bray P (mg kg^{-1})	30.8	5.6	6.3	11.2	11.4	1.0
Exchangeable bases: Ca^{2+} (cmol(+) kg^{-1})	13.00	10.00	5.00	7.00	13.70	11.56
Mg^{2+} (cmol(+) kg^{-1})	3.46	3.08	1.84	3.57	5.39	4.77
K^+ (cmol(+) kg^{-1})	2.21	0.59	1.87	1.18	0.45	0.31
Na^+ (cmol(+) kg^{-1})	0.23	0.22	0.17	0.51	0.36	0.38
Sum of bases (cmol(+) kg^{-1})	18.9	13.89	8.88	12.26	19.90	17.02
Exchangeable Al^{3+} (cmol(+) kg^{-1})	0.58	0.28	0.28	0.64	0.20	0.60
ECEC by summation (cmol(+) kg^{-1})	19.48	14.17	9.16	12.90	20.10	17.62
CEC by NH_4OAc (cmol(+) kg^{-1})	25.48	15.77	10.76	17.70	24.00	22.80
% Base saturation	74.2	88.1	82.5	69.3	82.9	74.6
ECEC clay (cmol(+) kg^{-1})	25.82	26.30	37.10	18.69	25.62	20.44
CEC clay* (cmol(+) kg^{-1})	38.48	30.38	44.87	27.78	32.39	27.76

[1] Textural classes: SCL = Sandy clay loam; SC = Sandy clay; C = Clay

* CEC clay = {(CEC soil - (% OM x 2))/% clay} x 100

Appendix 1.8: DESCRIPTION OF SOIL PROFILE MAG 2

1. GENERAL INFORMATION

1.1 Registration and Location

1.1.1 Profile number MAG 2
1.1.2 Date of description: 21.02.95
1.1.3 Author(s): Abel K. Kaaya
1.1.4 Soil unit: Mapping unit II.2 on the Magadu soil map
1.1.5 Location: About 2 km South West of Sokoine University of Agriculture main campus on Morogoro - Mzinga road, 100 m to the west of the road in SUA farm, Morogoro District.
1.1.6 Elevation: 530 masl
1.1.7 Grid reference: 37M CC 497424.
1.1.8 Coordinates: Longitude 37° 38' 24'' E and Latitude 6° 51' 15'' S

1.2 Soil Classification: USDA Soil Taxonomy: Typic Paleustults
FAO-Unesco: Haplic Acrisols (ACh)

1.3 Landform and Topography

1.3.1 Topography and Landform: Gently undulating plain composed of wide interfluves with slope ranging from 2% to 5%
1.3.2 Position: Profile on the middle of a straight gently sloping plain
1.3.3 Slope: Profile on a slope gradient of 3%
1.3.4 Microtopography: None

1.4 Land use and Vegetation

1.4.1 Land use: Rainfed arable cultivation. The area is currently under rotational cultivation of annual food crops including maize, groundnuts and beans at subsistence level. Previously the area was under sisal production farm i.e. Tanke Sisal Estate
1.4.2 Human influence: Increased rate of replacement of the natural vegetation with agricultural crops
1.4.3 Vegetation: Most of the natural vegetation in this plain has been cleared, resulting in a complex of secondary savanna patches and cultivated land. Remnants of te the tree species include *Acacia spp.*, *Adansonia digitata* and *Cassia spp.* Grass species are dominated by *Hyparrhenia rufa*

1.5 Parent Material

1.5.1 Parent material: Colluvial deposits from the Uluguru mountains. The Uluguru mountains are composed of hornblende pyroxene granulites and micaceous gneisses.
1.5.2 Effective soil depth: Class 5 - Very deep (> 150 cm).

1.6 Surface characteristics

1.6.1 Rock outcrops: None
1.6.2 Surface coarse fragments: None
1.6.3 Erosion: moderate sheet erosion
1.6.4 Surface sealing: None
1.6.5 Surface cracks: none

1.7 Soil-Water relationships

1.7.1 Drainage class: Well drained
1.7.2 Internal drainage: The profile is never saturated
1.7.3 External drainage: Slow run-off
1.7.4 Flooding: None
1.7.5 Groundwater: Not observed but below the profile depth (200 cm) at the time of description.
1.7.6 Moisture conditions: Dry throughout at the time of description

2. SOIL HORIZON DESCRIPTION:

Horizon	*Depth (cm)*	*Description*
A_p	0 - 13	Dark brown (7.5YR 3/4) moist, brown (7.5YR 4/6) dry; sandy clay; moderate fine and medium crumb structure; sticky, plastic (wet), friable (moist), hard (dry); common very fine to fine and few medium tubular pores; many very fine to fine roots; abrupt, smooth boundary.
BA	13 - 28	Reddish brown (5YR 4/4) moist, yellowish red (5YR 5/6) dry; sandy clay; moderately strong fine to medium subangular blocky structure; sticky, plastic (wet), friable (moist), hard (dry); common very fine to fine and few medium tubular pores; common very fine to fine roots; clear, smooth boundary.
B_{t1}	28 - 74	Yellowish red (5YR 4/6) moist, yellowish red (5YR 5/6) dry; clay; moderate fine subangular blocky structure; very sticky, very plastic (wet), friable (moist), hard (dry); common very fine to fine tubular pores; few faint clay and sesquioxides cutans; very few, fine (1 - 2 mm), hard, black, spherical manganiferous nodules; common very fine to fine roots, few termite channels; diffuse, smooth boundary.
B_{t2}	74 - 152	Yellowish red (5YR 4/6) moist, yellowish red (5YR 5/6) dry; clay; moderate fine to medium subangular blocky structure; very sticky, very plastic (wet), friable (moist), hard (dry); common very fine to fine tubular pores; common faint clay and sesquioxides cutans; few, fine (2 - 4 mm), hard, black and brownish, spherical iron-manganese nodules and few fine to medium (5 - 12 mm) irregular soft aggregations of clay; few very fine to fine roots, few termite channels; gradual, smooth boundary.
B_{t3}	152 - 200+	Strong brown (7.5YR 4/6) moist, strong brown (7.5YR 5/6) dry; clay; moderate fine to medium subangular blocky structure; very sticky, very plastic (wet), friable (moist), hard (dry); common very fine to fine tubular pores; common faint clay and sesquioxides cutans; few, fine (2 - 4 mm), hard, black and brownish, spherical iron-manganese nodules and few fine to medium (5 - 12 mm) irregular soft aggregations of clay; few very fine to fine roots, few termite channels.

3. **Some physico-chemical properties of soil profile MAG 2**

Horizon	A_p	BA	B_{t1}	B_{t2}	B_{t3}
Depth (cm)	0 - 13	13 - 28	28 - 74	74 - 152	152 - 200+
Texture: % clay (< 0.002 mm)	46.8	49.8	59.2	63	65
% fine silt (< 0.002 - 0.02 mm)	1.6	1.6	3.2	4.2	4.2
% coarse silt (< 0.02 - 0.05 mm)	3.2	3.2	1.4	2.6	2.6
% sand (< 0.05 - 2.0 mm)	48.4	45.4	36.2	30.2	28.2
Textural class[1]	SC	SC	C	C	C
Bulk density (Mg m^{-3})	1.35	N.D.	1.26	1.28	N.D.
Water between 33 and 1500 kPa (vol. %)	14.62	N.D.	9.18	13.84	N.D.
pH: in H_2O	4.8	4.6	4.8	5.2	5.0
in KCl	3.8	3.7	3.9	4.1	3.9
Organic C (%)	1.12	0.98	0.66	0.53	0.30
Organic matter (%)	1.93	1.69	1.14	0.91	0.52
Total N (%)	0.12	0.07	0.05	0.05	0.05
Bray P (mg kg^{-1})	3.6	1.3	1.2	1.4	1.8
Exchangeable bases: Ca^{2+} (cmol(+) kg^{-1})	0.45	1.41	1.03	1.18	0.92
Mg^{2+} (cmol(+) kg^{-1})	4.20	1.04	1.06	1.14	1.23
K^+ (cmol(+) kg^{-1})	0.82	0.44	0.51	0.12	0.16
Na^+ (cmol(+) kg^{-1})	1.10	1.02	1.12	1.14	1.21
Sum of bases (cmol(+) kg^{-1})	6.57	3.91	3.72	3.58	3.52
Exchangeable Al^{3+} (cmol(+) kg^{-1})	3.90	5.90	5.90	6.40	7.40
ECEC by summation (cmol(+) kg^{-1})	10.47	9.81	9.62	9.98	10.92
CEC by NH_4OAc (cmol(+) kg^{-1})	13.80	12.20	12.00	12.40	13.40
% Base saturation	47.6	32.0	31.0	28.9	26.3
ECEC clay (cmol(+) kg^{-1})	14.12	12.91	12.41	12.94	15.21
CEC clay* (cmol(+) kg^{-1})	21.24	17.71	16.43	16.78	19.02

[1] Textural classes: SC = Sandy clay; C = Clay

* CEC clay = {(CEC soil - (% OM x 2))/% clay} x 100

Appendix 1.9: DESCRIPTION OF SOIL PROFILE MAG 3

1. GENERAL INFORMATION

1.1 Registration and Location

1.1.1 Profile number MAG 3
1.1.2 Date of description: 06.02.95
1.1.3 Author(s): Abel K. Kaaya and R. Sørensen
1.1.4 Soil unit: Mapping unit II.2 on the Magadu soil map
1.1.5 Location: About 200 m West of Magadu Primary School in Morogoro District
1.1.6 Elevation: 600 masl
1.1.7 Grid reference: 37M CC 506414.
1.1.8 Coordinates: Longitude 37° 38' 55'' E and Latitude 6° 51' 41'' S

1.2 Soil Classification: USDA Soil Taxonomy: Kandic Paleustalfs
FAO-Unesco: Haplic Lixisols (LXh)

1.3 Landform and Topography

1.3.1 Topography and Landform: Undulating to rolling plain composed of interfluves with slope range of 8 - 15%
1.3.2 Position: Profile on the middle of a concave slope
1.3.3 Slope: Profile on a slope gradient of 12%
1.3.4 Microtopography: None

1.4 Land use and Vegetation

1.4.1 Land use: Rainfed arable cultivation. The area is currently under cultivation of food crops including maize, cassava, pigeon peas, beans, papaw and bananas at subsistence level. Also present are mango fruit trees.
1.4.2 Human influence: Increased rate of replacement of the natural vegetation with agricultural crops
1.4.3 Vegetation: Most of the natural vegetation in this plain has been cleared, resulting in a complex of secondary savanna patches and cultivated land. Remnants of the tree species include *Acacia spp.*, *Adansonia digitata* and *Cassia spp.* Grass species are dominated by *Hyparrhenia rufa*

1.5 Parent Material

1.5.1 Parent material: Colluvial deposits from the Uluguru mountains. The Uluguru mountains are formed mainly by hornblende pyroxene granulites and micaceous gneisses. The exposed rock fragments on some stream channels are dominated by quartz, feldspars.and some micaceous gneiss.
1.5.2 Effective soil depth: Class 5 - Very deep (> 200 cm).

1.6 Surface characteristics

1.6.1 Rock outcrops: None
1.6.2 Surface coarse fragments: None
1.6.3 Erosion: moderate sheet erosion
1.6.4 Surface sealing: None
1.6.5 Surface cracks: none

1.7 Soil-Water relationships

1.7.1 Drainage class: Well drained
1.7.2 Internal drainage: The profile is never saturated
1.7.3 External drainage: Slow run-off
1.7.4 Flooding: None
1.7.5 Groundwater: Below the profile depth (200 cm) at the time of description.
1.7.6 Moisture conditions: Dry throughout at the time of description

2. SOIL HORIZON DESCRIPTION:

Horizon	*Depth (cm)*	*Description*
A_p	0 - 13	Dark reddish brown (2.5YR 2.5/4) moist, Dark reddish brown (2.5YR 2.5/4) dry; clay; strong fine and medium crumb structure; sticky, plastic (wet), friable (moist), slightly hard (dry); common very fine, few medium and very few coarse tubular pores; common very fine to fine and very few medium roots; abrupt, smooth boundary.
B_{t1}	13 - 71	Dark red (10R 3/6) moist, Dark red (10R 3/6) dry; clay; moderately strong fine to medium subangular blocky structure; very sticky, very plastic (wet), firm (moist), hard (dry); many very fine and common fine tubular pores; few faint clay and sesquioxides cutans; very few, fine (2 - 5 mm), slightly hard, reddish brown, irregular iron nodules; few very fine to fine and few medium roots, few termite nests and channels; gradual, smooth boundary.
B_{t2}	71 - 122	Dark red (10R 3/6) moist, red (10R 4/6) dry; clay; very few angular slightly weathered fine (0.2 - 0.3 cm) quartz and feldspar gravel; moderate fine subangular blocky structure; very sticky, very plastic (wet), friable (moist), hard (dry); common very fine to fine and few medium tubular pores; common distinct clay cutans; very few, fine to medium (2 - 10 mm), slightly hard, reddish brown, irregular iron nodules; few very fine to fine and few medium roots, few termite nests and channels; gradual, smooth boundary.
B_{t3}	122 - 200+	Dusky red to dark red (10R 3/5) moist, dark red to red (10R 3.5/6) dry; clay; few angular slightly weathered fine (0.2 - 0.5 cm) quartz and feldspar gravel; moderate fine subangular blocky structure; very sticky, very plastic (wet), friable (moist), hard (dry); common very fine to fine and few medium tubular pores; common distinct clay cutans; very few, fine to medium (2 - 10 mm), slightly hard, reddish brown, irregular iron nodules; very few very fine and few medium to coarse roots, few termite nests and channels.

3. Some physico-chemical properties of soil profile MAG 3

Horizon	A_p	B_{t1}	B_{t2}	B_{t3}
Depth (cm)	0 - 13	13 - 71	71 - 122	122 - 200+
Texture: % clay (< 0.002 mm)	56.7	72.4	73.4	68.9
% fine silt (< 0.002 - 0.02 mm)	7.8	3.4	4.5	6.7
% coarse silt (< 0.02 - 0.05 mm)	3.4	1.2	1.8	1.8
% sand (< 0.05 - 2.0 mm)	32.1	23.0	20.3	22.6
Textural class[1]	C	C	C	C
Bulk density (Mg m^{-3})	1.21	1.35	1.31	N.D.
Water between 33 and 1500 kPa (vol. %)	14.96	11.63	9.77	N.D.
pH: in H_2O	6.7	6.6	6.4	6.2
in KCl	6.3	6.4	6.3	6.0
Organic C (%)	2.14	0.67	0.50	0.29
Organic matter (%)	3.69	1.16	0.86	0.50
Total N (%)	0.20	0.10	0.07	0.08
Bray P (mg kg^{-1})	11.9	1.0	0.7	0.3
Exchangeable bases: Ca^{2+} (cmol(+) kg^{-1})	9.73	6.36	4.41	6.68
Mg^{2+} (cmol(+) kg^{-1})	5.02	4.12	2.39	1.41
K^+ (cmol(+) kg^{-1})	0.24	0.26	1.81	1.57
Na^+ (cmol(+) kg^{-1})	1.72	1.10	1.06	1.09
Sum of bases (cmol(+) kg^{-1})	16.71	11.84	9.67	10.75
Exchangeable Al^{3+} (cmol(+) kg^{-1})	0.2	0.2	0.2	0.0
ECEC by summation (cmol(+) kg^{-1})	16.91	12.04	9.87	10.75
CEC by NH_4OAc (cmol(+) kg^{-1})	21.62	15.82	13.60	14.00
% Base saturation	77.3	74.8	71.1	76.8
ECEC clay (cmol(+) kg^{-1})	16.81	13.44	11.10	14.15
CEC clay* (cmol(+) kg^{-1})	25.12	18.66	16.18	18.87

[1] Textural classes: C = Clay

* CEC clay = {(CEC soil - (% OM x 2))/% clay} x 100

Appendix 1.10: DESCRIPTION OF SOIL PROFILE MAG 5

1. GENERAL INFORMATION

1.1 Registration and Location

1.1.1 Profile number MAG 5
1.1.2 Date of description: 21.02.95
1.1.3 Author(s): Abel K. Kaaya and R. Sørensen
1.1.4 Soil unit: Mapping unit II.3 on the Magadu soil map
1.1.5 Location: Near the top of the ridge in Vilengwe village in Magadu area, about 0.5 km SE of Magadu Primary School in Morogoro District
1.1.6 Elevation: 780 masl
1.1.7 Grid reference: 37M CC 512408.
1.1.8 Coordinates: Longitude 37° 39' 08'' E and Latitude 6° 51' 57'' S

1.2 Soil Classification: USDA Soil Taxonomy: Ultic Paleustalfs
FAO-Unesco: Chromic Luvisols (Lvx)

1.3 Landform and Topography

1.3.1 Topography and Landform: Hilly to steeply dissected landform
1.3.2 Position: Profile on the upper part of a convex slope
1.3.3 Slope: Profile on an average slope gradient of 15%
1.3.4 Microtopography: None

1.4 Land use and Vegetation

1.4.1 Land use: Rainfed arable cultivation. The area is currently under traditional cultivation of food crops including maize, cassava, pigeon peas, groundnuts, beans at subsistence level.
1.4.2 Human influence: Expansion of agricultural land by clearing of the natural vegetation
1.4.3 Vegetation: Patches of cultivated land replacing sub-montane Pterocarpus-Combretum woodland composed mainly of *Pterocarpus angolensis, Julbernardia globiflora, Combretum spp., Brachystegia spp.* and herbaceous species including *Hyparrhenia rufa, Sporobolus pyramidalis*, etc. Crops include cassava, maize, groundnuts, bananas, mango and sweet potatoes.

1.5 Parent Material

1.5.1 Parent material: Colluvial deposits from the Uluguru mountains. The Uluguru mountains are formed mainly by hornblende pyroxene granulites and micaceous gneisses. The rock fragments observed in the C horizon were mainly micaceous gneisses with quartz and feldspars.
1.5.2 Effective soil depth: Class 4 - Deep (soil depth = 100 cm).

1.6 Surface characteristics

1.6.1 Rock outcrops: Few at an average distance of 30 m
1.6.2 Surface coarse fragments: Few fine to coarse gravel
1.6.3 Erosion: moderate rill erosion
1.6.4 Surface sealing: None
1.6.5 Surface cracks: none

1.7 Soil-Water relationships

1.7.1 Drainage class: Well drained
1.7.2 Internal drainage: The profile is never saturated
1.7.3 External drainage: Moderately rapid run-off
1.7.4 Flooding: None
1.7.5 Groundwater: Below the profile depth (200 cm) at the time of description.
1.7.6 Moisture conditions: Dry throughout at the time of description

2. SOIL HORIZON DESCRIPTION:

Horizon	*Depth (cm)*	*Description*
A_p	0 - 5	Dark brown (7.5YR 3/3) moist, brown (7.5YR 4/3) dry; sandy clay; moderate fine and medium granular structure; non sticky, non plastic (wet), friable (moist), slightly hard (dry); many very fine to fine tubular pores; many fine roots; abrupt, smooth boundary.
B_{t1}	5 - 31	Dark red (2.5YR 3/6) moist, red (2.5YR 4/6) dry; clay; strong medium angular blocky structure; sticky, plastic (wet), friable (moist), very hard (dry); common fine to medium tubular pores; few faint clay cutans; common fine roots; abrupt, wavy boundary.
Stone line	31 - 39	Stone line composed mainly of fresh angular quartz gravel and stones (1 - 10 cm) ; abrupt, wavy boundary.
B_{t2}	39 - 92/116	Red (2.5YR 4/8) moist, red (2.5YR 4/8) dry; sandy clay; few, slightly weathered, angular, fine (0.2 - 0.5 cm) quartz and feldspar gravel; strong medium angular blocky structure; sticky, plastic (wet), friable (moist), very hard (dry); common fine and few medium tubular pores; few faint clay cutans; few fine roots; clear, wavy boundary.
BC	92/116 - 145	Red (2.5YR 4/6) moist, red (2.5YR 5/8) dry; sandy loam; many, slightly weathered, fine to medium (0.2 - 1.2 cm) quartz and feldspar gravel; strong fine angular blocky structure; slightly sticky, slightly plastic (wet), friable (moist), slightly hard (dry); common fine tubular pores; few very fine roots; clear, wavy boundary.
C	145 - 200+	Weathered micaceous gneiss with quartz and feldspars

3. Some physico-chemical properties of soil profile MAG 5

Horizon	A_p	B_{t1}	Stone line	B_{t2}	BC	C
Depth (cm)	0 - 5	5 - 31	31 - 39	39 - 92/116	92/116 - 145	145 - 200+
Texture: % clay (< 0.002 mm)	36.5	52.4	N.D.	47.6	24.4	N.D.
% fine silt (< 0.002 - 0.02 mm)	7.4	1.2	N.D.	4.2	5.2	N.D.
% coarse silt (< 0.02 - 0.05 mm)	5.6	3.5	N.D.	2.4	9.5	N.D.
% sand (< 0.05 - 2.0 mm)	50.5	42.9	N.D.	45.8	60.9	N.D.
Textural class[1]	SC	C	gravel	SC	SL	N.D.
Bulk density (Mg m^{-3})	1.37	1.46	N.D.	1.42	N.D.	N.D.
Water between 33 and 1500 kPa (vol. %)	6.03	9.54	N.D.	6.36	N.D.	N.D.
pH: in H_2O	5.8	6.0	N.D.	6.8	6.9	N.D.
in KCl	5.1	5.6	N.D.	6.1	6.0	N.D.
Organic C (%)	1.38	0.47	N.D.	0.23	0.07	N.D.
Organic matter (%)	2.38	0.81	N.D.	0.40	0.12	N.D.
Total N (%)	0.13	0.08	N.D.	0.05	0.03	N.D.
Bray P (mg kg^{-1})	10.5	10.5	N.D.	0.2	1.4	N.D.
Exchangeable bases: Ca^{2+} (cmol(+) kg^{-1})	4.42	5.00	N.D.	3.20	2.18	N.D.
Mg^{2+} (cmol(+) kg^{-1})	2.72	1.60	N.D.	1.76	1.64	N.D.
K^+ (cmol(+) kg^{-1})	0.97	2.40	N.D.	2.03	1.24	N.D.
Na^+ (cmol(+) kg^{-1})	0.49	0.26	N.D.	0.17	0.16	N.D.
Sum of bases (cmol(+) kg^{-1})	8.60	9.26	N.D.	7.16	5.22	N.D.
Exchangeable Al^{3+} (cmol(+) kg^{-1})	0.64	2.70	N.D.	1.94	0.74	N.D.
ECEC by summation (cmol(+) kg^{-1})	9.24	11.96	N.D.	9.10	5.96	N.D.
CEC by NH_4OAc (cmol(+) kg^{-1})	14.60	15.20	N.D.	13.80	10.28	N.D.
% Base saturation	58.9	60.9	N.D.	51.9	50.8	N.D.
ECEC clay (cmol(+) kg^{-1})	12.28	19.73	N.D.	17.45	23.44	N.D.
CEC clay* (cmol(+) kg^{-1})	26.96	25.91		27.33	41.14	N.D.

[1] Textural classes: SL = Sandy loam; SC = Sandy clay; C = Clay

* CEC clay = {(CEC soil - (% OM x 2))/% clay} x 100

Appendix 1.11: DESCRIPTION OF SOIL PROFILE KIP 1

1. GENERAL INFORMATION

1.1 Registration and Location

1.1.1 Profile number KIP 1
1.1.2 Date of description: 08.02.95
1.1.3 Author(s): Abel K. Kaaya and R. Sørensen
1.1.4 Soil unit: Mapping unit I.4 on the Lubungo-Mkata soil map
1.1.5 Location: Near TAZAMA pipeline about 1 km west of the Sangasanga hill top to the NW of the Sangasanga Dairy Farm in Morogoro District
1.1.6 Elevation: 610 masl
1.1.7 Grid reference: 37M CC 374382
1.1.8 Coordinates: Longitude 37° 31' 38'' E and Latitude 6° 53' 23'' S

1.2 Soil Classification: USDA Soil Taxonomy: Typic Eutropepts
FAO-Unesco: Eutric Cambisols (CMe)

1.3 Landform and Topography

1.3.1 Topography and Landform: Undulating peneplane with close interfluves.
1.3.2 Position: Profile on the middle part of a convex slope
1.3.3 Slope: Profile on an average slope gradient of 6%
1.3.4 Microtopography: None

1.4 Land use and Vegetation

1.4.1 Land use: Extensive grazing and exploitation of wooden vegetation to provide charcoal and firewood
1.4.2 Human influence: Strongly disturbed vegetation due to continuous burning and clearing of trees for firewood and charcoal production.
1.4.3 Vegetation: Savanna woodland with tree and shrub layers dominated by *Cassia* species, *Acacia spp.* and *Combretum* species. The herbaceous layer is dominated by *Heteropogon contortus.* These savanna like vegetation seem to be fire-products rather than climatic climaxes.

1.5 Parent Material

1.5.1 Parent material: Colluvial deposits. The underlying bedrock mainly banded muscovite-biotite migmatites
1.5.2 Effective soil depth: Class 3 - Moderately deep (average soil depth = 90 cm).

1.6 Surface characteristics

1.6.1 Rock outcrops: None
1.6.2 Surface coarse fragments: None
1.6.3 Erosion: moderate sheet erosion
1.6.4 Surface sealing: None
1.6.5 Surface cracks: None

1.7 Soil-Water relationships

1.7.1 Drainage class: Moderately well drained
1.7.2 Internal drainage: The profile is never saturated
1.7.3 External drainage: Moderately rapid run-off
1.7.4 Flooding: None
1.7.5 Groundwater: Below the profile depth (134 cm) at the time of description.
1.7.6 Moisture conditions: Dry throughout at the time of description

2. SOIL HORIZON DESCRIPTION:

Horizon	*Depth (cm)*	*Description*
A_h	0 - 19	Very dark grayish brown (10YR 3/2) moist, dark grayish brown (10YR 4/2) dry; sandy loam; moderate fine granular structure; non sticky, non plastic (wet), friable (moist), hard (dry); common very fine to fine tubular pores; few very fine and fine roots; clear, smooth boundary.
B_{w1}	19 - 42	Yellowish red (5YR 4/6) moist, yellowish red (5YR 5/8) dry; sandy clay loam; moderate fine subangular blocky structure; sticky, plastic (wet), friable (moist), very hard (dry); common fine to medium tubular pores; few fine to medium roots; gradual, smooth boundary.
B_{w2}	42 - 71	Yellowish red (5YR 4/6) moist, yellowish red (5YR 5/6) dry; sandy clay loam; few, fine to coarse (0.2 - 3.0 cm), angular, fresh quartz and slightly weathered feldspar gravel; moderate fine to medium angular blocky structure; sticky, plastic (wet), friable (moist), very hard (dry); common fine to medium tubular pores; few very fine to fine roots; clear, wavy boundary.
B_{gw}	71 - 80/98	Yellowish brown (10YR 5/8) moist, yellowish brown (10YR 5/8) dry; common, medium, faint, reddish mottles; sandy clay loam; few, fine to coarse (0.2 - 3.0 cm), angular, fresh quartz and slightly weathered feldspar gravel; moderate, medium, angular blocky structure; sticky, plastic (wet), firm (moist), very hard (dry); common fine to medium tubular pores; very few, fine (2 - 6 mm), spherical and irregular, hard, reddish black iron-manganese (sesquioxide or laterite) nodules; few very fine to fine roots; clear, wavy boundary.
B_{cs}	80/98 - 134+	Yellow (2.5YR 7/6) moist, yellow (2.5YR 7/6) dry; common, medium, faint, reddish mottles; sandy loam; few, fine to medium (0.2 - 2.0 cm), angular, fresh quartz and slightly weathered feldspar gravel; massive structure; slightly sticky, slightly plastic (wet), friable (moist), very hard (dry); few medium tubular pores; weakly cemented by broken nodular sesquioxides (iron-manganese); many very fine to coarse (< 2 - 25 mm) irregular, hard and slightly hard, reddish black iron-manganese (sesquioxide or laterite) nodules.

3. **Some physico-chemical properties of soil profile KIP 1**

Horizon	A_h	B_{w1}	B_{w2}	B_{gw}	B_{cs}
Depth (cm)	0 - 19	19 - 42	42 - 71	71 - 80/98	80/98 - 134+
Texture: % clay (< 0.002 mm)	16.2	28.3	26.3	33.3	N.D.
% fine silt (< 0.002 - 0.02 mm)	2.1	2.1	2.1	1.1	N.D.
% coarse silt (< 0.02 - 0.05 mm)	2.1	2.1	4.1	2.1	N.D.
% sand (< 0.05 - 2.0 mm)	79.6	67.5	67.5	63.5	N.D.
Textural class[1]	SL	SCL	SCL	SCL	N.D.
Bulk density ($Mg\ m^{-3}$)	1.63	1.69	1.77	N.D.	N.D.
Water between 33 and 1500 kPa (vol. %)	19.07	17.68	9.01	N.D.	N.D.
pH: in H_2O	6.4	6.2	6.2	6.6	N.D.
in KCl	5.8	5.3	5.1	5.4	N.D.
Organic C (%)	1.16	0.22	0.05	0.17	N.D.
Organic matter (%)	2.00	0.38	0.09	0.29	N.D.
Total N (%)	0.09	0.03	0.03	0.03	N.D.
Bray P ($mg\ kg^{-1}$)	5.6	1.4	1.4	0.7	N.D.
Exchangeable bases: Ca^{2+} (cmol(+) kg^{-1})	4.24	4.09	4.24	4.39	N.D.
Mg^{2+} (cmol(+) kg^{-1})	1.36	2.63	3.66	4.24	N.D.
K^+ (cmol(+) kg^{-1})	1.85	1.20	0.89	0.97	N.D.
Na^+ (cmol(+) kg^{-1})	0.15	0.19	0.24	0.56	N.D.
Sum of bases (cmol(+) kg^{-1})	7.60	8.11	9.03	10.16	N.D.
Exchangeable Al^{3+} (cmol(+) kg^{-1})	1.88	1.88	1.96	1.58	N.D.
ECEC by summation (cmol(+) kg^{-1})	9.48	9.99	10.99	11.74	N.D.
CEC by NH_4OAc (cmol(+) kg^{-1})	10.68	12.86	13.62	14.00	N.D.
% Base saturation	71.2	63.1	66.3	72.6	N.D.
ECEC clay (cmol(+) kg^{-1})	33.83	32.62	41.13	33.5	N.D.
CEC clay* (cmol(+) kg^{-1})	41.24	42.76	51.13	40.28	N.D.

[1] Textural classes: SL = Sandy loam; SCL = Sandy clay loam; ND = Not determined

* CEC clay = {(CEC soil - (% OM x 2))/% clay} x 100

Appendix 1.12: DESCRIPTION OF SOIL PROFILE KIP 3

1. GENERAL INFORMATION

1.1 Registration and Location

1.1.1 Profile number: KIP 3
1.1.2 Date of description: 08.02.95
1.1.3 Author(s): Abel K. Kaaya
1.1.4 Soil unit: Mapping unit I.4 on the Lubungo-Mkata soil map
1.1.5 Location: Near the top of the Sangasanga hill, about 2 km NW of Sangasanga Dairy Farm in Morogoro District
1.1.6 Elevation: 640 masl
1.1.7 Grid reference: 37M CC 382383
1.1.8 Coordinates: Longitude 37° 32' 05'' E and Latitude 6° 53' 18'' S

1.2 Soil Classification:

USDA Soil Taxonomy: Typic Ustropepts
FAO-Unesco: Eutric Leptosols (LPe)

1.3 Landform and Topography

1.3.1 Topography and Landform: Undulating peneplane with close interfluves
1.3.2 Position: Profile on the top of an interfluve close to the top a hill
1.3.3 Slope: Profile on an average slope gradient of 1%
1.3.4 Microtopography: None

1.4 Land use and Vegetation

1.4.1 Land use: Extensive grazing and clearing of wooded vegetation to provide charcoal and firewood
1.4.2 Human influence: Strongly disturbed vegetation due to continuous burning and clearing of trees for firewood and charcoal production.
1.4.3 Vegetation: Savanna woodland with tree and shrub layers dominated by *Cassia* species, *Acacia spp.*, and *Combretum* species. The herbaceous layer is dominated by *Heteropogon contortus.* These savanna-like vegetation are fire products rather than climatic climaxes.

1.5 Parent Material

1.5.1 Parent material: Colluvial deposits. The underlying bedrock is composed of banded muscovite biotite migmatites The rock fragments in the C-horizon are mostly quartz and feldspars with some muscovite.
1.5.2 Effective soil depth: Class 1 - Very shallow (soil depth = 18 cm).

1.6 Surface characteristics

1.6.1 Rock outcrops: Few at an average distance of 35 m
1.6.2 Surface coarse fragments: Common medium to coarse gravel
1.6.3 Erosion: moderate to severe sheet erosion
1.6.4 Surface sealing: None
1.6.5 Surface cracks: None

1.7 Soil-Water relationships

1.7.1 Drainage class: Well drained
1.7.2 Internal drainage: The profile is never saturated
1.7.3 External drainage: Moderately rapid run-off
1.7.4 Flooding: None
1.7.5 Groundwater: Below the profile depth (92 cm) at the time of description.
1.7.6 Moisture conditions: Dry throughout at the time of description

2. SOIL HORIZON DESCRIPTION:

Horizon	*Depth (cm)*	*Description*
A_h	0 - 8	Very dark grayish brown (10YR 3/2) moist, yellowish brown (10YR 5/4) dry; sandy loam; very few, fine and medium (0.2 - 2 cm), angular, slightly weathered quartz and feldspar gravel; moderate fine to medium granular structure; non sticky, non plastic (wet), friable (moist), slightly hard (dry); common very fine and fine tubular pores; common very fine to fine and few medium roots; clear, smooth boundary.
B_w	8 - 18	Dark reddish brown (2.5YR 3/4) moist, red (2.5YR 4/6) dry; sandy clay loam; few, fine and medium (0.2 - 2 cm), angular, slightly weathered quartz and feldspar gravel; moderate medium angular blocky structure; sticky, plastic (wet), firm (moist), hard (dry); common fine and medium tubular pores; few fine and medium and very few medium and coarse roots; clear, smooth boundary.
BC	18 - 55/65	Dark reddish brown (2.5YR 3/4) moist, reddish brown (2.5YR 4/4) dry; gravelly sandy clay loam; common, fine and medium (0.2 - 2 cm), angular, slightly weathered, quartz and feldspar gravel; moderate fine to medium angular blocky structure; sticky, plastic (wet), friable (moist), hard (dry); few fine medium tubular pores; clear, wavy boundary.
C	55/65 - 92+	Slightly weathered quartz and feldspar gravel and stones with muscovite particles.

3. Some physico-chemical properties of soil profile KIP 3

Horizon	A_h	B_w	BC
Depth (cm)	0 - 8	8 - 18	18 - 55/92
Texture: % clay (< 0.002 mm)	18.2	33.6	34.2
% fine silt (< 0.002 - 0.02 mm)	7.8	2.8	8.8
% coarse silt (< 0.02 - 0.05 mm)	5.4	5.4	6.9
% sand (< 0.05 - 2.0 mm)	68.6	58.2	50.1
Textural class[1]	SL	SCL	SCL
pH: in H_2O	6.5	5.9	6.2
in KCl	5.8	4.9	5.5
Organic C (%)	1.00	0.83	0.26
Organic matter (%)	1.72	1.43	0.45
Total N (%)	0.10	0.06	0.03
Bray P (mg kg^{-1})	4.1	2.9	2.3
Exchangeable bases: Ca^{2+} (cmol(+) kg^{-1})	3.23	2.77	2.74
Mg^{2+} (cmol(+) kg^{-1})	1.54	2.07	1.22
K^+ (cmol(+) kg^{-1})	0.39	0.29	0.43
Na^+ (cmol(+) kg^{-1})	1.04	1.14	0.93
Sum of bases (cmol(+) kg^{-1})	6.20	6.27	5.32
Exchangeable Al^{3+} (cmol(+) kg^{-1})	0.60	0.40	0.50
ECEC by summation (cmol(+) kg^{-1})	6.80	6.67	5.82
CEC by NH_4OAc (cmol(+) kg^{-1})	7.86	10.80	7.22
% Base saturation	78.9	58.1	73.7
ECEC clay (cmol(+) kg^{-1})	18.42	11.33	14.40
CEC clay* (cmol(+) kg^{-1})	24.24	23.63	18.49

[1] Textural classes: SL = Sandy loam; SCL = Sandy clay loam

* CEC clay = {(CEC soil - (% OM x 2))/% clay} x 100