ENVIRONMENTAL PROFILE FOR AGRICULTURAL PRODUCTION AND DEVELOPMENT OF CONSERVATION STRATEGIES IN MAHENGE VILLAGE, MBINGA DISTRICT, TANZANIA

Juvent P. Magoggo
Balthazar M. Msanya
Didas N. Kimaro

1996

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

Ministry of Agriculture
National Soil Service
A.R.I. Mlingano
P.O. Box 5088
Tanga, Tanzania

ACKNOWLEDGEMENTS

The authors wish to express their sincere thanks to the Japan International Cooperation Agency (JICA) for providing funds through the Miombo Woodland Research Project (MWRP) at Sokoine University of Agriculture (SUA), which enabled the execution of this particular work. The cooperation given by the JICA resident expert at the Sokoine University of Agriculture, Dr. M. Tsunoda, is highly appreciated.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

EXECUTIVE SUMMARY

Mahenge village is among the villages in Mbinga district selected for study on natural resources. This report describes the study as part of the continuing project on the assessment of the natural resources of Mbinga district. Investigations involved measurements of terrain characteristics, quantitative determinations of pedological properties, inventory of land use systems and the assessment of the ecological potential and constraints based on the analysis of the available resources and land use requirements.

Climatic resources

There are no specific climatic records for Mahenge village. However, the rainfall pattern is monomodal, starting in November and ending in May with an estimated mean annual precipitation of over 1,200 mm. During this period crop production is feasible without irrigation. The rest of the year is virtually dry. The average annual temperatures for Mbinga district are reported to range from about 13°C in the Matengo highlands to about 30°C on the shores of Lake Nyasa. The study area is expected to be in between with mean annual temperature of about 20°C. Seasonal variations in temperature exist whereby the dry season (May to September) is cooler than the rainy season.

Geology and landform

The study area is underlain by gneissic metamorphic rocks rich in ferromagnesian minerals. The area is characterized by highly dissected mountainous landscapes with steep hills and dissected piedmonts with narrow drainage ways. Some of the hill tops have rock outcrops. There are two wide but sloping valleys along the Mngaka and the Luunei rivers which are possibly perpendicular fault lines. The other valleys are narrow and drain utlimately into one of these valleys.

Vegetation and land use

The natural vegetation in Mahenge village has mostly been cleared. On some hill tops and slopes the natural vegetation has been replaced by planted forests of mainly *Eucalyptus spp.* and black wattle. Three major cropping systems are practised viz (a) *Arabica* coffee grown under tree shade; (b) Maize, wheat and beans as monocultures under *Ngoro* cultivation; and (c) vegetables in the valleys. Livestock-based land uses include pigs, goats, cows and chicken. Cows and goats are kept under semi-zero grazing.

Soils

Seven mapping units were distinguished in the area and their distribution and extent are shown on the soil map which is presented at the scale of 1:25,000. The soils of Mahenge area are:

(a) association of rock outcrops, boulders and stones; and shallow and very shallow, somewhat excessively drained, dark brown, sandy clay loam soils in the hilly landscape.

(b) very deep, well to somewhat excessively drained, dark red, sandy clay loams to sandy clays and clays, with very thick, dark brown to reddish brown, sandy clay loam topsoils in the hilly landscape.

(c) deep to very deep, well drained, red to reddish brown, sandy clay loams (in places over gneiss saprolite) with very thick, dark yellowish brown and dark brown to dark reddish brown, sandy clay loam to clay loam topsoils in the piedmonts.

(d) very deep, poorly drained, greyish brown, stratified and mottled sandy clays and clays in the minor river valleys.

The soils of the hillands were classified as **Dystric Leptosols (Lithic Ustorthents), Haplic Acrisols (Acrustoxic Kandiustults), Eutric Regosols (Lithic Ustorthents), Haplic Phaeozems (Pachic Haplustolls)**. The soils of the piedmonts were classified as **Dystric and Ferralic Cambisols (Typic Ustochrepts).**

The bulk densities in the topsoils are generally low, between 0.9 and 1.2 g/cc. Total soil

porosity ranges between 55 and 67% for topsoils, and between 33 and 56% for subsoils. The values suggest that there are no compaction limitations particularly in the topsoils. The subsoil of profile MP-5 may impose compaction stresses to plant rooting system. The available water capacity of most soils is only medium with values ranging between 126 and 160 mm/m of soil.

The soils have overall poor supply of the major nutrients i.e. nitrogen and phosphorus. The C/N ratios range from 10 to 18, which indicates good to moderate quality of organic matter. Most of the basic cations e.g. Ca^{++}, Mg^{++} and K^{+} are low to medium. The overall capacity of the soils to retain nutrients against leaching is low.

Agricultural productivity in Mahenge village is generally limited by the steep slopes and shallow soil depths in the hilly landscape, and the low soil fertility. It is apparent that, currently the land cannot optimally suppost the fast growing population. Recommendations on the improvement of the farming systems have been restricted by lack of climatic data required to advise on various appropriate land utilization types. Research on climate, land conservation techniques and alternative land uses are highly recommended.

1 INTRODUCTION

Mbinga district is among the districts of the big four regions (Ruvuma, Iringa, Mbeya and Rukwa) in Southern Tanzania, potential for both cash and food crop production. The district is potential for coffee and maize production in the mountaneous areas, and fingermillet in the low rolling hills. However, the district is facing tremendous problems of land pressure and decline in yields of most crops. Moreover, Mbinga like many other areas in Tanzania lacks proper land use planning due to inadequate research and lack of information on natural resources.

Land resource information gathered through systematic identification, grouping, delineation and interpretation of various biophysical as well as socio-economic parameters is a pre-requisite when sound land use planning and development of land conservation strategies are to be made. A good data bank on land resources is inevitable for one to be able to advise both current and potential land users on how to use the land in the best possible way. Proper site selection and characterization are also basic to the success of agronomic experiments and to the effectiveness of extending research results to a large number of land users.

The current study is part of the continuing *Miombo* Woodlands Research Project focussing on the assessment of the natural resources of Mbinga district with particular emphasis on terrain, soils, vegetation and land use systems. Information generated by this and other studies in the project will form a base for further development of land information system for Tanzania and its linkage to computerized land evaluation systems and geographic information systems (GIS). This study was aimed mainly at the identification of the natural resources of Mahenge village, their characterization and interpretation of their spatial relationships.

The specific objectives of the study were:

(a) to identify and characterize the soils and terrain elements of Mahenge village;

(b) to map the spatial distribution of the existing pedological entities in the village;

(c) to classify the soils of Mahenge village using the two international systems adopted in Tanzania (i.e. the FAO legend of the soil map of the world and the United States Department of Agriculture [USDA] Soil Taxonomy system) in order to enable correlation with other areas in the country and international transfer of soil technology;

(d) to link the properties of the land resources above to ecological requirements of the existing land use systems in order to provide a basis for quantification of their potential and constraints to the use of land in the village;

(e) to provide a land information system (LIS) to both researchers and land use planners in the area that will guide activities related to management of land resources.

2 MATERIALS AND METHODS

2.1 Pre-field work

The tasks performed during this phase including literature search, collection of available data and preliminary study of the materials listed below:

- Geological map: quarter degree sheet 297 at the scale of 1:125,000. *Geological Survey of Tanganyika, 1957.* Geological Survey Department, Dodoma, Tanzania.
- Topographic map: sheet 297/4 (Mbinga) at the scale of 1:50,000. *Ministry of Lands, 1972.* Dar es Salaam, Tanzania.
- Aerial photographs: frame 5121 to 5125, 5133 to 5136 by *Geosurvey International Limited, 1992* at the scale of 1:10,000 and frame 8425 to 8427 by *Photomap International, 1990* at scale 1:50,000.
- SPOT imagery: False colour composite (FCC)
- A report on the identification of indigenous tree species and shrubs for agroforestry use and suggestion of boundary for the forest reserve in Mpepo Division, Mbinga district, Tanzania. *Mwihomeke, S.T., C.K. Ruffo and C.K. Mabula, 1991.*
- Progress report, Natural Resources Study Team of the *Miombo* Woodlands Research Project. *Msanya, B.M., 1995.*
- Pedological investigations and land resources characterization in Lupilo village, Mbinga district, Tanzania. *Msanya, B.M., D.N. Kimaro and J.P. Magoggo, 1995b.*
- Pedological investigations for slash and burn experiment in Lupilo village and soil erosion studies in Tukuzi village, Mbinga district, Tanzania. *Kimaro D.N., B.M. Msanya and J.P. Magoggo, 1995a.*
- Characteristics of two pedons and their implications for environmental management in parts of Mbinga district, Tanzania. *Msanya, B.M., D.N. Kimaro and J.P. Magoggo, 1995c.*
- Considerations of some land qualities in relation to land management in Lupilo village, Mbinga district, Tanzania. *Kimaro D.N., B.M. Msanya, B.M. and J.P. Magoggo, 1995b.*

In preparation for the field soil mapping, stereoscopic examination of the aerial photographs and interpretation of photo elements (landform, geology, lineaments, drainage patterns, vegetation cover, land use and drainage attributes was carried out. The delineated polygons on the photo interpretation map formed the basis for planning the field mapping.

2.2 Field work

In the field the free survey method was used using the results of the aerial photo interpretation to select observation and sampling points. The soils were examined from hand auger borings. At each observation site data on soil morphological characteristics, landform, elevation, slope gradients, parent material, lithology, vegetation and land use/crops were collected. Soils were studied by description of auger hole borings. At representative sites for each soil unit soil profile pits were excavated. In total seven fully geo-referenced soil profile pits were studied, described and sampled. Geo-referencing was done using the Sony PYXIS portable Global Positioning System Receiver. Description of the soils and landforms was done following standard procedures as outlined in the FAO (1990) guidelines and USDA Soil Taxonomy (Soil Survey Staff, 1990). The data collected were recorded on standard analogue field forms.

Correlation of the described soil augerings enabled soils similar in characteristics and in arrangement of soil horizons to be singled out and mapped. In this way eight soil mapping units (section 3.2.5) were confirmed on the photo interpretation base map.

Soil samples were collected from the field for laboratory analysis as follows:

- disturbed soil samples for physico-chemical analysis
- undisturbed soil samples for bulk density and soil moisture characteristics determination.

2.3 Post-field work

After the field mapping cartographic generalization of the topographic base map was carried out to reduce thematic details and to enlarge the scale to 1:25,000. Information from the small scale aerial photographs was integrated into the interpretation of the larger scale photographs. The delineated polygons were transferred from the photo-interpretation map to the enlarged topographic base map. The field and laboratory analytical data (appendix 1) were digitized using *SISTAN* (Magoggo, 1992). Appendix 2 provides a guide to general evaluation of soil chemical and physical properties.

2.3.1 Laboratory and office work

Analysis of chemical and physical properties of soils was as follows:
pH was measured potentiometrically in water and in 1M KCl at the ratio of 1/2.5 soil-water and soil-KCl respectively. Organic carbon was determined by the wet oxidation method of Walkley and Black (Nelson and Sommers, 1982) and converted to organic matter by multiplying by a factor of 1.724. Total nitrogen was determined by Kjeldahl method (Bremner and Mulvaney, 1982). Phosphorus was extracted by Bray and Kurtz-1 method (Bray and Kurtz, 1945) and determined spectrophotometrically (Murphy and Riley, 1962; Watanabe and Olsen, 1965). The cation exchange capacity and exchangeable bases were extracted by saturating soil with neutral 1M NH_4OAc (Thomas, 1982) and the absorbed NH_4^+ displaced by K^+ using 1M KCl and then determined by Kjeldahl distillation method for the estimation of CEC of soil. The bases Ca^{2+}, Mg^{2+}, Na^+, and K^+, displaced by NH_4^+ were measured by atomic absorption spectrophotometer. Exchangeable acidity and Aluminium were determined by percolating with 1M KCl and then titrating with NaOH (exchangeable acidity) and with HCl (exchangeable Al. Texture was determined by pipette method (Day, 1965) after dispersing soil with sodium hexametaphosphate (calgon). Bulk density was determined using core sample method (Blake, 1965). Soil moisture characteristics were determined using pressure plate and membrane apparatus (Klute, 1986).

2.3.2 Preparation and presentation of the soil map and legend

The soil map polygons were delineated on the basis of the following hierarchy of elements: landforms, relative position in the landscape, slope classes and soil properties. The soil mapping legend is given in Table 2.

Each mapping unit has a symbol referring to the landform. Further subdivision is based on soil characteristics and is indicated by a number following the capital letter. The "soil description" column in the legend gives the main characteristics of the soil types i.e. soil depth, drainage, color, texture, and other diagnostic characteristics that separate each soil unit from the others identified.

2.3.3 Soil classification and data processing

The identified soil types were classified to the second level of the FAO-Unesco legend of the soil map of the world (FAO, 1988) and up to subgroup level of the USDA Soil Taxonomy (Soil Survey Staff, 1990) on the basis of morphological and analytical data. Information on soil classification is included in the description of map units. Data processing and report writing was done using *SISTAN* and other computer software available at Sokoine University of Agriculture, Morogoro and National Soil Service, Mlingano, Tanga.

3 RESULTS AND DISCUSSION

3.1 Physical environment

3.1.1 Location

Mbinga district in which the study was carried out is located within longitudes 34° 24'E and 35° 28'E and latitudes 10° 15'S and 11° 34'S. Mahenge village is approximately 20 km west of Mbinga town. The approximate geographical coordinates of Mahenge village are 34° 52' E and 10° 59' S. Figure 1 shows the location of the study area.

3.1.2 Climate

There are no specific climatic records for Mahenge village. However, it is estimated that the village receives about 1,300 mm of rainfall per year compared to the average district range of between 1,200 to 1,500 mm as reported by Mchau (1993) for Mbinga district in general. Table 1 shows some rainfall data obtained from District authorities at Mbinga covering a period of 6 years.

The rainfall pattern is monomodal, starting in November and ending in May. The rest of the year is virtually dry. The average annual temperatures for Mbinga district are reported to range from about 13°C in the Matengo highlands (altitude about 1,500 - 2,000 m) to about 30°C on the shores of Lake Nyasa (altitude about 1,100 m) (Mchau, 1993). The study area, with altitudes ranging between approximately 1500 and 1800, is expected to be in the lower range. Seasonal variations in temperature exist whereby the dry season (May to September) is cooler than the rainy season.

The data available for the study area on climate are inadequate for a proper analysis of the climatic resources of the village.

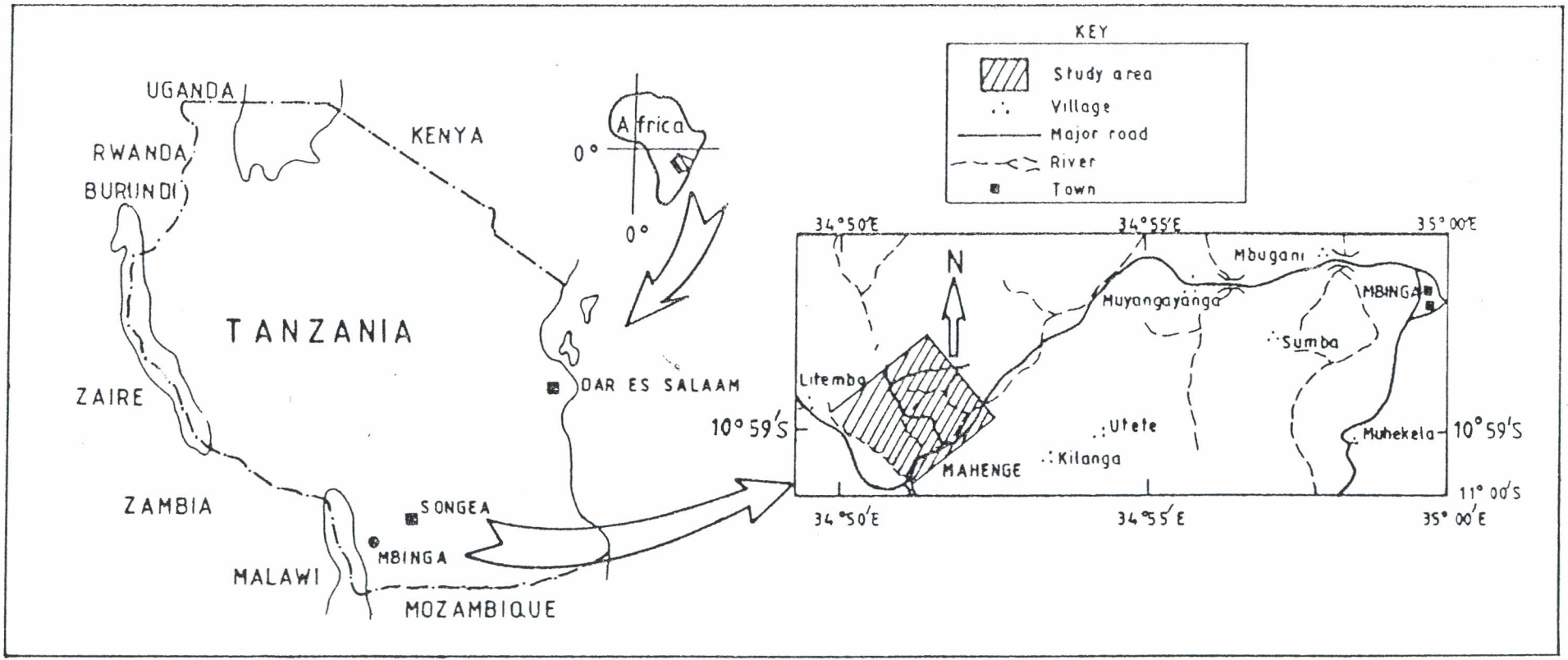

Figure 1 *Location of the study area*

Table 1. ***Rainfall distribution (mm) during the period 1988/89 - 1993/94 at Mbinga***

Month / Year	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Total
1988/89	-	56.0	70.1	179.2	198.3	110.1	253.7	139.9	35.0	-	-	-	1024.3
1989/90	-	-	82.0	200.0	149.9	188.5	166.4	137.3	15.5	-	-	-	939.6
1990/91	4.7	-	18.2	47.5	314.0	126.2	199.0	164.8	2.6	-	-	-	877.0
1991/92	-	-	79.4	182.6	218.5	179.3	151.5	65.5	64.4	-	-	-	941.2
1992/93	-	-	107.9	95.0	266.2	319.1	479.1	154.5	36.1	-	-	-	1457.9
1993/94	-	-	5.2	54.5	21.5	325.0	324.5	300.5	94.6	-	-	-	1125.8

Source: Rutatora *et al.* (1995)

3.1.3 Geology and landforms

The underlying geology of Mbinga district is essentially comprising hornblende-biotite and garnet gneisses, granulites and charnockites of the Ubendian system (Ministry of Commerce and Industries, 1967). The geology of Mahenge village comprises mainly gneissic metamorphic rocks rich in ferromagnesian minerals.

The present landscape in Mahenge village has been shaped by faulting. Two major faults have been identified. To the west, the village boundary follows the Luunei river, which marks a major fault line. This fault more or less follows the boundary between the metamorphic rocks and the granitic basement complex to the west. The faulting has resulted in long piedmonts (footslopes) sloping from the Nalioba hills with renewed mass movement of pellitic colluvial sediments. Another, less prominent fault line, is marked by the course of the Mngaka river. Since this fault runs through rocks of the same lithological composition, the eastern part of the village remains an erosional surface whose drainage is controlled by the eastern fault line.

As a result of the above geomorphic processes, Mahenge village is characterized by a highly dissected mountaineous landscape with many hills, piedmonts and narrow drainage ways. The hill tops, which stand out to an altitude of about 1,800 m, commonly have rock outcrops. The slopes are between 0 and about 40%. The hill slopes lie at altitudes between 1,550 and 1800. Slopes are very steep (between 15 and 45%). Below some hill slopes, especially in the western part of the village are piedmonts, which are less steeply sloping. Most of the low lying lands (streams and tributaries of the Luunei and Mngaka rivers) are found at altitudes between 1,550 and 1,700 m. Slopes on the piedmonts are generally less than 16%.

During the rains water infiltrates into the soil and underlying parent rock and seeps slowly down the hill slopes and into the valleys. This seepage water continues throughout a major part of the dry season and contributes to the perennial streams in the valleys.

3.1.4. Vegetation and land use

The natural vegetation in Mahenge village has mostly been cleared. Cultivation has been going on for many years (over a generation). On some hill tops and slopes the natural vegetation has been replaced by planted forests of mainly *Eucalyptus spp.* and black wattle.

Three major cropping systems were observed in the village:

(a) *Arabica* coffee grown under tree shade. The common shade trees are *Grevillea robusta*. Coffee is harvested in July to October.

(b) Maize, wheat and beans grown under *Ngoro* cultivation system as monocultures. Maize is planted in October to January and harvested in July to September. Wheat is planted in March to April and harvested in September to October while beans are planted in March to April and harvested in July to August. Frequently, beans are planted around the wheat field for the purpose of fooling birds as a biological means of controlling damage to the wheat crop by birds. Off-season maize is planted in the valleys in September and harvested in February.

(c) Vegetables such as spinach, cabbages and tomatoes are planted in the dry season in the valleys.

Other crops grown in the village include sweet potatoes and fruit trees such as peaches and guava.

Livestock-based land uses include pigs, goats, cows and chicken. Cows and goats are kept under semi-zero grazing.

3.2. Soils

3.2.1. Landforms, soils and vegetation/land use associations

The soils have a strong relationship to landforms in Mahenge village. To a great extent, land use is also related to landforms. The relationship between landforms, soils and vegetation/land use is shown in Table 2. The map showing the spatial distribution of the soils of Mahenge village is included in the back cover of this report.

Table 2. Landforms, soils, vegetation and land use of Mahenge village

MAP SYMBOL	LANDFORM CHARACTERISTICS	DOMINANT SLOPE (%)	AREA		SOIL DESCRIPTION	LAND USE
			Ha	%		
HILLAND (H), elevation 1,700 to 1,850 m above sea level						
H1	Rocky hill summits and shoulders	0 - 45	151	13	Mainly rock outcrops, boulders and stones with pockets of very shallow (skeletal) and moderately deep dark brown sandy clay loams. The soils classify as **Dystric Leptosols (Lithic Ustorthents)**	Planted forest, mainly *Eucalyptus* trees and black wattle
H2	Hill summits, shoulders and saddles	0 - 16	13	1	Very deep, well drained, red, sandy clays to clays with thick reddish brown, sandy clay loam man-made topsoils (*ngoro* horizon); developed on gneiss colluvium. The soils classify as **Haplic Acrisols (Acrustoxic Kandiustults)**	Coffee under *Grevillea* trees on bench terraces
H31	Hill slopes with many rock outcrops, boulders and stones	30 - 45	119	10	Very shallow and shallow (in places moderately deep), somewhat excessively drained, dark brown sandy clay loams over stones, boulders and bedrock; developed on gneiss colluvium. The soils classify as **Eutric Regosols (Lithic Ustorthents)**	Coffee under *Grevillea* trees on bench terraces. In places some maize is grown under *ngoro* cultivation
H32	Hill slopes with scattered rock outcrops, narrow interfluves and very steep slopes towards the drainage ways	45 - 60	69	6	Very deep, well to somewhat excessively drained, red sandy clay loams to sandy clays with thick dark brown to reddish brown sandy clay loam man-made topsoils (*ngoro* horizon); developed on gneiss colluvium; with inclusions of very deep, poorly drained, stratified greyish brown clays with a high water table in the minor river valleys. The soils classify as **Haplic Acrisols (Acrustoxic Kandiustults)**	Wheat and maize under *ngoro* cultivation. In places sweet potatoes are grown on down-slope ridges. In the valleys, off-season maize, beans and vegetables are grown.

H33	Hill slopes with broad interfluves	30 - 45	313	27	Very deep, well to somewhat excessively drained, red sandy clay loams to sandy clays with very thick dark brown to reddish brown, sandy clay loam man-made topsoils (*ngoro* horizon); developed on gneiss colluvium; with inclusions of very deep, poorly drained, stratified greyish brown clays with a high water table in the minor river valleys. The soils classify as **Haplic Acrisols (Acrustoxic Kandiustults)**	Maize and wheat under *ngoro* cultivation. In the valleys, off-season maize, beans and vegetables are grown.

DISSECTED PIEDMONT (P), elevation 1,600 to 1,750 m above sea level

P1	Highly dissected glacis with few rock outcrops and very steep slopes (>45%) towards drainage ways	8 - 16	226	20	Deep to very deep, well drained, red sandy clay loams over gneiss saprolite, having a very thick dark yellowish brown sandy clay loam topsoils; developed on gneiss colluvium; with inclusions of very deep, poorly drained, stratified greyish brown clays with a high water table in the minor river valleys The soils classify as **Dystric Cambisols (Typc Ustochrepts)**	Mainly coffee under *Grevillea* trees. Maize and wheat are also grown. Fallowing is common. Scattered *Eucalyptus* trees
P2	Moderately dissected glacis and steep slopes (<40%) towards drainage ways	4 - 12	269	23	Very deep, well drained, reddish brown sandy clay loams with boulders and pockets of weathered rock mass in the subsoil, having a very thick dark brown to dark reddish brown, clay loam to sandy clay loam man-made topsoils (*ngoro* horizon); developed on gneiss colluvium; with inclusions of very deep, poorly drained, stratified greyish brown clays with a high water table in the minor river valleys. The soils classify as **Ferrallic Cambisols (Typic Ustochrepts)**	Maize, wheat and beans under *ngoro* cultivation

3.2.2 *Physical properties*

Seven main soil physical properties, i.e. texture, 3-phase distribution, bulk density, particle density, porosity and available water capacity (Table 3) and water retention characteristics (Figure 2) are presented and discussed.

Soil texture, bulk density and total porosity

The soils of Mahenge village are dominantly sandy clay loams, occasionaly grading to sandy clays and clays in the subsoils. They are fairly uniform in texture except in the valleys where stratification is a common feature. The bulk densities in the topsoils are generally low, between 0.9 and 1.2 g/cc. Profile MP-5, located in old cultivation land (currently under *Grevillea* forest), has relatively high bulk densities, reaching values as high as 1.8 g/cc in the subsoil. Generally the BD values increase with depth. The *Ngoro* cultivation practices lead to accumulation of organic matter which is responsible for low topsoil bulk densities. The phase distribution, i.e. the relative ratios between solid, liquid and gaseous matter in the soil, is highly variable. Total soil porosity ranges between 55 and 67% for topsoils and between 33 and 56% for subsoils. These values suggest there are no compaction limitations particularly in the topsoils. The subsoil of profile MP-5 may impose compaction stresses to plant rooting system.

Water retention and available water capacity

Figure 2 and table 3 present data on moisture retention characteristics and available water capacity based on three soil depths i.e. surface horizon, intermediate horizon and subsoil. Most of the studied soils are medium textured, texture being dominantly sandy clay loam. The curves show variable total porosity values as indicated by the saturation moisture contents. Pofiles MP-2, MP-5, MP-7 and MP-6 have the highest total porosity (43, 37-42, 36-44 and 36-41% rsepectively), followed closely by profile MP-4 (37-40%) although the total porosity of its topsoil is relatively low (25%) suggesting compaction. As shown in table 3, the absolute values of available water capacity of most topsoils is low to medium (ranging from about 9 to 14%). Only profile MP-6 has high topsoil AWC. The overall profile AWC for most soils is medium (values ranging between 126 and about 150 mm/m of soil).

3.2.3 *Chemical properties*

The analytical data of the studied soil profiles are given in Appendix 1. Tables 4 and 5 present the chemical analytical data of topsoils and subsoils of Mahenge soils. The following chemical properties are presented and discussed:

Soil reaction

The soils of Mahenge village are quite variable in terms of their soil reaction, generally with pH below 6. They range from extremely acid soils (e.g. profile MP-1) to medium acid soils (e.g. profiles MP-2, MP-3 and MP-7). The pH values are fairly constant within the profile whereby even the topsoil values do not differ much from the subsoil ones. Aluminium saturation is generally low to very low, but on account of low pH, reaches high levels (up to 73% in profile MP-5). Since most plants thrive well in soils of pH 6.5 to 7.5 (Baize, 1993), the pH conditions of soils of Mahenge are not optimal for crop growth.

Organic matter and nitrogen

The soils of the village commonly have medium to high amounts of organic matter in the top-soils (2.3 to 2.4 organic carbon). Some parts of the hilland very high amounts of organic matter, reaching over 3.5% organic carbon (profile MP-4). The subsoil organic matter content is very low

Table 3. Some selected physical properties of soils of Mahenge village

PROFILE	DEPTH (cm)	TEXTURE	3-phase distribution			BULK DENSITY (g/cc)	PARTICLE DENSITY (g/cc)	POROSITY %	AVAIL. WATER CAPACITY	
			% VOL AIR	% VOL LIQUID	% VOL SOLID				% vol	mm/m
MP-2	topsoil	CL	59.5	4.1	36.4	1.0	2.7	63	8.5	
	intermediate	SCL	31.5	18.0	50.5	1.4	2.7	48	20	142
	subsoil	SCL	29.5	23.1	47.4	1.3	2.7	52	16	
MP-3	topsoil	SCL	54.5	13.1	32.4	0.9	2.7	67	11.4	
	intermediate	SCL	42.0	20.7	37.3	1.0	2.7	63	10.7	126
	subsoil	SCL	33.1	24.5	42.4	1.2	2.7	56	16	
MP-4	topsoil	SCL	51.7	12.9	35.4	0.9	2.6	65	12.8	
	intermediate	SC	20.6	22.9	56.5	1.5	2.7	44	15.7	139
	subsoil	C	22.1	24.8	53.1	1.5	2.7	44	13.7	
MP-5	topsoil	SCL	36.6	16.3	47.1	1.2	2.7	55	13.5	
	intermediate	SL	19.8	18.4	61.8	1.7	2.7	37	16.4	135
	subsoil	L	18.8	16.8	64.3	1.8	2.7	33	11.5	
MP-6	topsoil	SCL	52.5	9.8	37.7	1.0	2.7	63	17.4	
	intermediate	SCL	34.6	18.5	46.9	1.3	2.7	52	22.7	152
	subsoil	SC	24.2	24.8	51.0	1.4	2.7	48	10.1	
MP-7	topsoil	SCL	52.9	5.4	41.7	1.1	2.7	59	4.4	
	intermediate	SCL	51.3	9.8	38.9	1.1	2.7	59	10.6	nd

C=clay L=loam CL=clay loam SC=sandy clay SL=sandy loam SCL=sandy clay loam nd=not determined

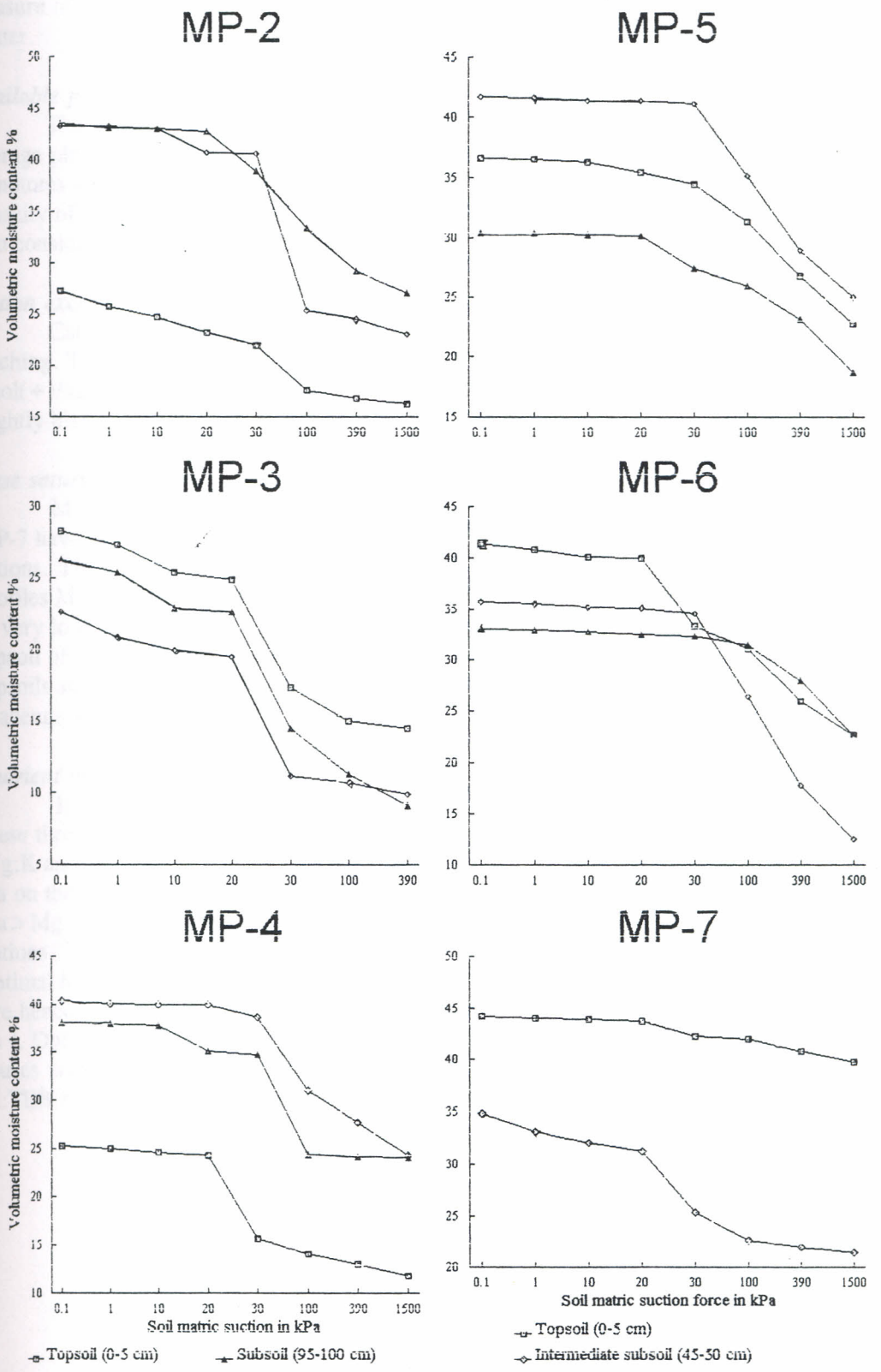

Figure 2. Soil moisture release curves for selected profiles of Mahenge village

to medium, ranging from 0.2 to 1.8% organic carbon. The high content of organic matter in the topsoils can be attributed to the ngoro farming practices. Contents of total nitrogen in the topsoils are generally low (less than about 0.2%); in places medium (between 0.2 and 0.3%). The carbon to nitrogen ratio, a measure of nitrogen availability, varies between 9 and 16, indicating good to moderate quality of organic matter.

Available phosphorus

The available phosphorus of almost all soils of Mahenge village is low (less than 7 mg/kg). An average phosphorus level of more than 7mg P/kg is considered to be optimal below which P-deficiency symptoms are likely to occur in many crops. The low pH may be responsible for high phosphate fixation capacity of Mahenge soils. Future phosphatic fertilizer recommendations in the study area must put this into consideration.

Cation exchange capacity (CEC)

Cation exchange capacity is a measure of the capacity of the soil to retain nutrients against leaching. The CEC of most topsoils of Mahenge is medium, with values generally slighly more than 12 cmol(+)/kg. Most subsoils are low in CEC with values generally much smaller than 12 cmol(+)/kg. The slightly higher CEC values in topsoils can be attributed to their higher organic carbon contents.

Base saturation (BS), exchangeable calcium (Ca), magnesium (Mg) and potassium (K)

Most of Mahenge soils have low % BS with values less than 50. Only profiles MP-2, MP-3 and MP-7 have BS values slightly more than 50%. Table 5 presents the topsoil and subsoil exchangeable basic cations. The topsoil levels of Ca are low to very low in profiles MP-1, MP-5 and MP-6; medium in profiles MP-2, MP-3 and MP-7; and high only in profile MP-4. The subsoil levels of Ca are mostly low to very low. The levels of Mg in Mahenge soils are generally low to very low. They are only high in the topsoil of profile MP-1. In the case of exchangeable K, the levels are generally low to very low in both topsoils and subsoils. The low values of the basic cations could be an indication of strong leaching in the Mahenge soils.

Nutrient balance

In addition to the absolute amounts of Ca, Mg and K in the soil, the relative amounts between these three elements is a measure of the general availability of nutrients. In particular the ratio Ca:Mg, Mg:K and K:TEB (where TEB is the total exchangeable bases) are important. All soils are dominated by Ca on the exchange complex, with the exception of profile MP-1 which is dominated by Mg. The trend Ca>Mg>K which prevails in all profiles except MP-1, indicates a good balance among the basic cations. The ratio between Ca and Mg for most of the soils varies between 2 and 4 which is considered optimal for most crops. The Ca:Mg ratios for profiles MP-1 and MP-7 are outside the optimal range and are hence unfavourable. The Mg:K ratios of the studied soils are quite variable. The optimal range is 1 to 4. Only profiles MP-4 and MP-6 have favourable Mg/K ratios. The K:TEB ratio, expressed as percent, varies widely but is generally above 2%, which is said to be favourable for most tropical crops. The K:TEB ratios of profiles MP-1 and MP-7 are unfavourable.

Table 4. Chemical analytical data of soils of Mahenge village

Profile No.	Depth	pH (H_2O)	Org. C (%)	Total N (%)	C/N	Avail.P (mg/kg)	CEC (cmol(+)/kg)	Exchangeable acidity Al^{3+} (cmol(+)/kg)	Exchangeable acidity H^+ (cmol(+)/kg)	Aluminum sat. (%)	Base sat. (%)
MP-1	Topsoil	4.4	2.3	0.16	14	2	13.4	1.2	0.01	23	7
	Subsoil	4.4	1.3	0.10	13	3	13.7	0.9	0.04	18	29
MP-2	Topsoil	5.6	2.8	0.29	10	8	6.3	-	-	-	53
	Subsoil	5.6	0.6	0.07	9	1	3.8	-	-	-	55
MP-3	Topsoil	5.7	3.4	0.30	11	3	8.1	-	-	-	58
	Subsoil	5.6	0.7	0.07	10	0.1	2.4	-	-	-	55
MP-4	Topsoil	5.4	4.2	0.30	14	3	16.4	-	0.06	-	45
	Subsoil	5.1	0.3	0.03	10	0.2	4.5	-	0.02	-	16
MP-5	Topsoil	4.5	2.4	0.15	16	0.1	12.5	1.7	-	71	5
	Subsoil	4.7	0.2	0.02	10	1	6.2	1.1	-	73	6
MP-6	Topsoil	4.9	2.8	0.14	20	1	13.5	0.7	0.05	26	15
	Subsoil	4.9	0.4	0.03	13	0.3	3.1	0.2	0.10	18	29
MP-7	Topsoil	5.6	2.3	0.17	14	3	5.9	-	-	-	55
	Subsoil	5.7	1.8	0.13	14	0.2	5.1	-	-	-	54

Table 5. ***Interpretation ratings for exchangeable cations for soils of Mahenge village***

Profile No.	Exchangeable calcium (cmol(+)/kg)		Exchangeable magnesium (cmol(+)/kg soil)		Exchangeable potassium (cmol(+)/kg soil)	
	Topsoil (0-20cm)	Subsoil (30-150cm)	Topsoil (0-20cm)	Subsoil (30-150cm)	Topsoil (0-20cm)	Subsoil (30-150cm)
MP-1	low (1.6)	low (1.4)	high (2.3)	high (2.6)	very low (0.06)	very low (0.02)
MP-2	medium (2.5)	low to medium (1.5-2.1)	low (0.7)	low (0.3-0.5)	very low (0.12)	very low to medium (0.05-0.41)
MP-3	medium (3.4)	low to medium (1.0-3.3)	medium (1.0)	low to medium (0.3-0.9)	medium (0.26)	low (0.01-0.13)
MP-4	high (5.2)	medium (1.6)	medium (1.6)	very low to low (0.2-0.5)	medium (0.49)	very low (0.10-0.17)
MP-5	very low (0.3)	very low (0.1)	very low (0.1)	very low (0.1)	low (0.23)	very low (0.02-0.04)
MP-6	low (1.3)	low (0.5)	low (0.5)	very low to low (0.1-0.4)	low (0.17)	very low (0.05-0.07)
MP-7	medium (2.7)	low (0.5)	low (0.5)	low (0.3)	very low (0.03)	very low (0.05)

3.2.4 Soil classification

Table 6 gives a summary of the salient soil morphological and diagnostic features used in classifying the soils. All the profiles except MP-3 have **ochric** horizons as diagnostic epipedons. The epipedon of profile MP-3 qualifies to be a **mollic** horizon. It is very thick and has a BS >50 %. Profiles MP-2, MP-3 and MP-5 have subsurface horizons which are pedogenically moderately developed and qualify as **cambic** horizons. Profiles MP-4 and MP-6 have strongly weathered subsurface horizons which qualify to be **kandic** horizons. Profiles MP-1 and MP-7 are shallow soils characterized by having no diagnostic subsurface horizons. Table 7 gives the soil names according to the two systems of classification used. The soils were categorized into five soil units according to the FAO legend of the soil map of the world namely **Leptosol, Cambisol, Phaeozem, Acrisol and Regosol.** These translate into four orders of the USDA Soil Taxonomy namely **Entisol, Inceptisol, Mollisol and Ultisol.**

Table 6. Summary of salient morphological and other diagnostic features of the studied representative soils

Profile	Diagnostic horizons	Other diagnostic features
MP-1	*ochric A (ochric epipedon)	BS <50%; ustic SMR; thermic STR; soil depth <30 cm
MP-2	*ochric A (ochric epipedon); *cambic B (cambic horizon)	*ferrallic properties, ustic SMR; thermic STR
MP-3	*mollic A (mollic epipedon); *cambic B (cambic horizon)	ustic SMR; thermic STR; BS >50% throughout
MP-4	*ochric A (ochric epipedon); *argic B (kandic horizon)	ustic SMR; thermic STR
MP-5	*ochric A (ochric epipedon); *cambic B (cambic horizon)	*low BS throughout (< 50%); ustic SMR; thermic STR
MP-6	*ochric A (ochric epipedon); argic B (kandic horizon)	ustic SMR); thermic STR
MP-7	*ochric A (ochric epipedon)	ustic SMR; thermic STR

NB. * terminology used particularly in the FAO-Unesco Classification; those without * are mostly used in USDA System.

Table 7. Classification of the studied representative soils

Profile	FAO-Unesco legend classification		USDA Soil Taxonomy			
	level 1	*level 2*	*order*	*suborder*	*greatgroup*	*subgroup*
MP-1	Leptosol (LP)	Dystric Leptosol (LPd)	Entisol	Orthent	Ustorthent	Lithic Ustorthent
MP-2	Cambisol (CM)	Ferralic Cambisol (CMo)	Inceptisol	Ochrept	Ustochrept	Typic Ustochrept
MP-3	Phaeozem (PH)	Haplic Phaeozem (PHh)	Mollisol	Ustoll	Haplustoll	Pachic Haplustoll
MP-4	Acrisol (AC)	Haplic Acrisol (ACh)	Ultisol	Ustult	Kandiustult	Acrustoxic Kandiustult
MP-5	Cambisol (CM)	Dystric Cambisol (CMd)	Inceptisol	Ochrept	Ustochrept	Typic Ustochrept
MP-6	Acrisol (AC)	Haplic Acrisol (ACh)	Ultisol	Ustult	Kandiustult	Acrustoxic Kandiustult
MP-7	Regosol (RG)	Eutric Regosol (RGe)	Entisol	Orthent	Ustorthent	Lithic Ustorthent

3.2.5 Description of soil mapping units

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

Mapping unit H1

Mainly rock outcrops, boulders and stones with pockets of very shallow (skeletal) and moderately deep, dark brown sandy, clay loams

Setting:
Rocky hill summits and shoulders at an average elevation of about 1,800 m above sea level. Slopes range from 0% on the summits to about 45% on the hill shoulders. This unit is mainly used for planted forest, with *Eucalyptus* trees and black wattle as the main trees.

Soil profile characteristics:
Mainly rock outcrops, boulders and stones. The soil is dark brown, sandy clay loam and is weakly structured. The soil classifies as **Dystric Leptosol** (*Lithic Ustorthent*) and profile **MP-1** is representative.

Soil physical properties:
The soil is well to somewhat excessively drained and the root zone extends to a depth of 50 cm. The soil water holding capacity is limited by restricted soil volume due to rockiness.

Soil chemical properties:
The soil reaction is extremely acid with low levels of available phosphorus and total nitrogen. It has medium levels of organic matter. Generally these soils have low capacity to retain nutrients against leaching.

Mapping unit H2

Very deep, well drained, red sandy clays to clays with a thick reddish brown, sandy clay loam man-made topsoils (Ngoro *horizon); developed on gneiss colluvium*

Setting:
This unit occopies the hill summits, shoulders and saddles at an average elevation between 1,700 and 1,750 m above sea level. Slopes range between 0 and 16%. The unit is used for cultivation and afforestation. The common crops are intercropped coffee, banana and *Grevillea* trees on flat cultivation without *ngoro*.

Soil profile characteristics:
The topsoil is 20 cm thick. It is very friable, reddish brown, sandy clay loam and weakly structured. The subsoil below a depth of 50 cm is very friable, red, sandy clay to clay and moderately structured. The

soil classifies as **Haplic Acrisol** (*Acrustoxic Kandiustult*) and profile **Mp-4** is representative.

Soil physical properties:
The soil is well drained with a rooting depth of more than 120 cm. The available water capacity is medium (139 mm/m). Bulk desity for topsoil is 0.9 g/cc and that of subsoil is 1.5 g/cc. Total porosity is decreasing from topsoil (65%) to subsoil (44%).

Soil chemical properties:
The soil is strongly to very strongly acid. Organic matter content is very high in the topsoil and very low in the subsoil. Nitrogen is medium and available phosphorus is low. The soil has medium levels of CEC in the topsoil, decreasing sharply to very low levels in the subsoil.

Mapping unit H31

Very shallow and shallow (in places moderately deep), somewhat excessively drained, dark brown sandy clay loams over stones, boulders and bedrock; developed on gneiss colluvium

Setting:
The unit occupies the hill slopes with many rock outcrops, boulders and stones at an average elevation between 1,700 to 1,750 m above sea level. The slopes are between 30 and 45%. Coffee is grown under *Grevillea* trees on bench terraces. In places some maize is grown under *ngoro* cultivation system.

Soil profile characteristics:
The soil to a depth of 40 cm is dark brown, very friable, sandy clay loam over stones, boulders and bedrockm. The soil classifies as **Eutric Regosol (Lithic Ustothent)** and profile **MP-7** is representative.

Soil physical properties:
The soils are somewhat excessively drained, very rocky and fairly stony. Overall water holding capacity of the soil is restricted by the limited soil depth and a relatively high percentage of rocks and stones.

Soil chemical properties:
The soil reaction is medium acid with medium levels of organic matter. Levels of total nitrogen and available phosphorus are very low. The bases (Ca, Mg, K) are very low (Table 5). Nutrient balance is unfavourable for most crops i.e. Ca/Mg and Mg/K ratios have very wide range suppressing Mg and/or K uptake by plants. The overall capacity of the soils to retain nutrient is very low.

Mapping unit H32

Very deep, well to somewhat excessively drained, red, sandy clay loams to sandy clays with thick, dark brown to reddish brown, sandy clay loam man-made topsoils (Ngoro *horizon); developed on gneiss colluvium; with inclusions of very deep, poorly drained, stratified, greyish brown clays with a high water table in the minor river valleys*

Setting:
The unit occupies the hill slopes with scattered rock outcrops, narrow interfluves and very steep slopes towards the drainage ways. It is at an elevation of 1,600 to 1,700 m above sea level. Slopes are between 45 and 60%. Wheat and maize are grown on the patches of soil between rocks under *ngoro* cultivation system. In places sweet potatoes are grown on down-slope ridges. In the valleys, off-season maize, beans

and vegetables are grown.

Soil profile characteristics:
The topsoil to a depth of 45 cm is very thick, dark brown to reddish brown, very friable, sandy clay loam man-made horizon. The subsoil below a depth of 50 cm is very friable, red, sandy clay loam to sandy clay and moderately structured. The soil classifies as **Haplic Acrisol (Acrustoxic Kandiustult)** and profile **MP - 6** is representative.

Soil physical properties:
The soils are well to somewhat excessively drained, with a slight degree of rock outcrops. Overall water holding capacity of the unit (152 mm/m) is limited slightly by the presence of rocks. The rooting depth is deeper than 180 cm.

Soil chemical properties:
The soil reacton is very strongly acid. Ntrogen and phosphorus levels are very low. The exchangeable bases are very low (Table 5). Generally these soils have low capacity to retain nutrients against leaching.

Mapping unit H33

Very deep, well to somewhat excessively drained, red, sandy clay loams to sandy clays with very thick, dark brown to reddish brown, sandy clay loam man-made topsoils (Ngoro *horizon); developed on gneiss colluvium; with inclusions of very deep, poorly drained, stratified, greyish brown clays with a high water table in the minor river valleys*

Setting:
The unit occupies mainly the hill slopes with broad interfluves and associated valleys at an elevation of about 1,600 to 1,700 m above sea level. Slopes are between 30 and 45%. The major land use is cropland where maize and wheat are grown under *Ngoro* cultivation system; in places coffee/*Grevillea* agroforestry system is practised. In the valleys, off-season maize, beans and vegetables are grown.

Soil profile characteristics:
The topsoil is very thick (45 and 60 cm thick) and it is dark brown to a depth 20 cm. Below a depth of 20 cm to 45 and 60 cm it is reddish brown to dark reddish brown. It is very friable, sandy clay loam and weakly to moderately structured. The subsoil below a depth of 60 cm it is red, very friable, moderately structured, sandy clay loam to sandy clay. The soil classifies as **Haplic Acrisol (Acrustoxic Kandiustult)** and profile **MP-6** is represntative.

Soil physical properties:
The soil is well to somewhat excessively drained with a high potential for erosion and run-off due to the steep slopes. Under conditions of controlled run-off (e.g. the present *ngoro* cultivation system) soil erosion has been checked. The available water capacity of the soil is high (152 mm/m). Bulk density for the topsoil ranges between 0.9 and 1.0 g/cc decreasing with depth to 1.4 g/cc in the subsoil. Total porosity is 63 % in the topsoil and 48 % in the subsoil.

Soil chemical properties:
The soil is medium acid. In the topsoil organic matter content is high, nitrogen is medium and available phosphorus is low. Exchangeable bases are very low (Table 5). The soil has medium levels of CEC, decreasing to very low in the subsoil. Generally the soil has low capacity to retain nutrients against

leaching.

Mapping unit P1

Deep to very deep, well drained, red, sandy clay loams over gneiss saprolite, having a very thick, dark yellowish brown, sandy clay loam topsoils; developed on gneiss colluvium; with inclusions of very deep, poorly drained, stratified, greyish brown clays with a high water table in the minor river valleys

Setting:
The unit occupies the highly dissected piedmont glacis with a few rock outcrops at an elevation of 1700 to 1750 m above sea level. Slopes range between 8 and 16%. The land is used mainly for coffee under *Grevillea* trees. Maize and wheat are also grown. Fallowing is common. Afforestation with *Eucalyptus* trees is a common practice on this unit.

Soil profile characteristics:
The topsoil (35 cm thick) is very friable, sandy clay loam and is moderately structured. The subsoil to a depth of 90 cm is very friable, red, sandy clay loam and moderately structured over gneiss saprolite. The soil classifies as **Dystric Cambisol** (*Typic Ustochrept*) and is typified by profile **MP-5**.

Soil physical properties:
The soil is well drained, in places with highly weathered gneiss saprolite at shallow depth. Effective rooting depth, however, is deep since the saprolite is easily penetrable. The has medium available water capacity (135 mm/m). Total porosity is 55% in the topsoil and 33% in the subsoil. Bulk density is low in the topsoil (1.2 g/cc) and very high in the subsoil (1.7 to 1.8 g/cc).

Soil chemical properties:
The soil is very strongly acid. The soil has high amounts of organic matter in the topsoils, low amounts of nitrogen, and very low levels of available phosphorus (Table 4). Exchangeable cations are very low (Table 5). The soil has low CEC in the topsoil, decreasing to very low in the subsoil. Generally the soil has very low capacity to retain ntrients.

Mapping unit P2

Very deep, well drained, reddish brown, sandy clay loams with boulders and pockets of weathered rock mass in the subsoil, having a very thick, dark brown to dark reddish brown, clay loam to sandy clay loam man-made topsoils (Ngoro *horizon); developed on gneiss colluvium; with inclusions of very deep, poorly drained, stratified, greyish brown clays with a high water table in the minor river valleys*

Setting:
The unit occupies the moderately dissected piedmont glacis. The slopes are generally long and straight with gradients between 4 and 12% at an elevation 1,600 to 1750 m above sea level. The land is largely used for agriculture with mono-culture maize, wheat and beans as the main crops under *Ngoro* cultivation system. Some parts of this unit have been planted with Coffee under *grevillea* trees.

Soil profile characteristics:
The topsoil to a depth of 20 cm is loose, brown to dark brown, clay loam and very eakly structured. Below to a depth of 40 cm it is very friable, dark reddish brown, sandy clay loam, weak and moderately structured. The subsoil below a depth of 50 cm is very friable, red, sandy clay loam to clay loam and

moderately structured. In the deeper subsoil small and soft clay and Fe/Mn nodules are common. The soil classifies as **Ferralic Cambisol** (*Typic Ustochrept*) and is typified by profile **MP-2**.

Soil physical properties:
The soil is well drained with medium available water capacity (142 mm/m). Total porosity is high in the topsoil (63%) and slightly lower in the subsoil (52%).

Soil chemical properties:
The soil is medium to strongly acid with high amounts of organic matter in the topsoil, medium amounts of nitrogen and very low levels of available phosphorus (table 4). The exchangeable bases (Ca, Mg and K) are generally low (Table 5). The soil has overall low to very low CEC.

4 CONCLUDING REMARKS AND RECOMMENDATIONS

Although land use systems in Mahenge village have been adapted to the terrain, landform characteristics form a serious present and potential limitation to agriculture. The limitations are due to the generally steep slopes in most parts of the village. This has a potential hazard of losses of water supply from rainfall due to run-off and consequently soil erosion. The water holding capacity of most Mahenge soils is only medium. This coupled with the potential runoff and excessive drainage, could contribute significantly to yield reduction of most crops. These factors together with long term climatic profile should be researched on. The severity of the limitations due to topography is highest on lands used for cultivation of annual crops and for grazing. The present land husbandry practice of the *ngoro* cultivation system has controlled this constraint to a great extent.

Soil depth is the most limiting land quality in the summits and upper slopes of the hills. Most of these areas are bare with rock outcrops, boulders and stones which are signs of serious soil erosion.

In terms of chemical characteristics, most Mahenge soils have overall poor fertility. They are generally low in the major plant nutrients including nitrogen, phosphorus, potassium, calcium and magnesium. Moreover, most soils have low capacity to retain nutrients and the soil reaction is unfavourable for availability of certain nutrients such as phosphorus. The low pH of most soils may render the management of phosphate fertilizers difficult. Due to the acid reaction of the soils, non-acidifying fertilizers should be used in order to prevent further acidification of the soils.

In addition to the limitations due to chemical attributes and terrain characteristics, climatic conditions prevailing in Mahenge may also be limiting to some extent, at least in some years. However, the data available do not permit a detailed analysis of the land qualities related to climatic resources. This is therefore an area which should be studied in more detail beginning with the collection of meteorological data at appropriate time intervals.

All lands in Mahenge village are intensively used for cultivation of annual and perennial crops and for livestock keeping. The intensive land use is attributed to the high population density (about 120/sq. km). The effects of continous land cultivation for long periods without proper land management leads to both physical and chemical land degradation. In order to protect lands from further degradation and to protect catchment areas, afforestation should be encouraged in the steeply sloping areas. Although the *ngoro* cultivation system is labour intensive, it should still be encouraged until alternative systems are adequately researched on and elaborated. Possible alternative land conservation techniques which may be considered for further research include *use of grass strips* and *agroforestry*.

The high population pressure in Mahenge village calls for research on alternative land uses such as zero-grazing. This type of land use will promote introduction of improved pastures for feeding animals and will also protect the land from erosion. The animals will produce manures that can be used to ameliorate soil physical and chemical properties.

Due to poor fertility of most Mahenge soils, these soils are likely to respond to application of mineral and organic fertilizers. Research to determine rates and types of fertilizers should be carried out. However, the economics and social implications of using the fertilizers should also be investigated.

5. REFERENCES

Baize, D. 1993. Soil science analyses. A guide to current use. John Wiley & Sons Ltd. West Sussex.

Blake, G.R. 1964. Bulk density. In: Methods of Soil Analysis, part 1 (eds. C.A Black, D.D. Evans, J.L. White, L.E. Ensminger and F.E. Clark), pp. 374-390. ASA, Madison, Wisconsin.

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

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

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

FAO, 1988. FAO-Unesco soil map of the World, revised legend. World Soil Resources report 60, FAO, Rome. Reprinted as Technical Paper 20, ISRIC, Wageningen, 1989.

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

Geological Survey of Tanganyika, 1957. Geology of Tanganyika, Quarter Degree Sheet 297. Geological Survey Department, Dodoma, Tanzania.

Geosurvey International Limited, 1992. Aerial photographs frames 5121 to 5125, 5133 to 5136 (scale 1:10,000).

Kimaro, D.N., B.M. Msanya and J.P. Magoggo, 1995a. Pedological investigations of sites for slash and burn experiment in Lupilo village and soil erosion studies in Tukuzi village, Mbinga District, Tanzania. Miombo Woodland Research Project, Natural Resources Study Team, Technical Report 2. National Soil Service, Agricultural Research Institute, Mlingano, Tanga and Sokoine University of Agriculture, Morogoro, Tanzania.

Kimaro, D.N., B.M. Msanya and J.P. Magoggo, 1995b. Considerations of some land qualities in relation to land Management in Lupilo village, Mbinga District, Tanzania. Paper presented at the First Annual Faculty of Agriculture Research Conference. August 28-30th, 1995. Sokoine University of Agriculture, Morogoro, Tanzania.

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

Landon, J.R., 1984 (ed.). Booker Tropical Soil Manual. A handbook for soil survey and agricultural land evaluation in the tropics and subtropics. Longman Inc., New York.

Landon, J.R., 1991 (ed.). Booker Tropical Soil Manual. A handbook for soil survey and agricultural land evaluation in the tropics and subtropics. Longman Scientific & Technical Publishers, Essex.

Magoggo, J.P., 1992. SISTAN: The soil information system for Tanzania. Version 2. National Soil Service, A.R.I. Mlingano, Tanga, Tanzania.

Mchau, J.M.J., 1993. Evaluation of agroforestry adoption in Mbinga district, Tanzania. M.Sc. thesis. University College of North Wales, Bangor.

Ministry of Commerce and Industries, 1967. Geology of Tanzania. Mining and Geology Division. Government of United Republic of Tanzania.

Miombo Woodland Research Project (SUA), 1995. Annual Progress Report (draft) 1994/1995. Faculty of Agriculture, Sokoine University of Agriculture. Morogoro. Tanzania.

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

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

Msanya, B.M., D.N. Kimaro, and J.P. Magoggo, 1995b. Pedological investigations and land resources characterization in Lupilo village, Mbinga District, Tanzania. Miombo Woodland Research Project, Natural Resources Study Team, Technical Report 1. Department of Soil Science, Faculty of Agriculture, Sokoine University of Agriculture, Morogoro and Ministry of Agriculture, National Soil Service, Agricultural Research Institute, Mlingano, Tanga, Tanzania.

Msanya, B.M., D.N. Kimaro and J.P. Magoggo, 1995c. Characteristics of two pedons and their implication for environmental management in parts of Mbinga District, Tanzania. Paper presented at the First Annual Faculty of Agriculture Research Conference. August 28-30th 1995. Sokoine University of Agriculture, Morogoro, Tanzania.

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

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

Mwihomeke, S.T., C.K. Ruffo and C.K. Mabula, 1991. A report on the identification of indigeneous tree species and shrubs for agroforestry use and suggestion of boundary for the forest reserve in Mpepo Division, Mbinga District, Tanzania. TAFORI.

Nelson, D.W. and L.E. Sommers, 1982. Total carbon, organic carbon and organic matter. In: Methods of Soil Analysis, part 2, 2nd edit. (eds. A.L. Page, R.H. Miller and D.R. Keeney), pp. 539-579. ASA,

SSSA Monograph no. 9, Madison, Wisconsin.

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

Olsen, S.R. and L.E. Sommers, 1982. Phosphorus. In: Methods of Soil Analysis, part 2. Agronomy monograph No. 9 (Edited by A.L. Page, R.H. Miller, and D.R. Keeney). American Society of Agronomy. Madison, Wisconsin. pp. 403-430.

Peech, M., 1965. Hydrogen-ion activity. In: Methods of Soil Analysis, part 2. Edited by C.A. Black. Agronomy Monograph No. 9, 1st edition. Soil Science Society of America. Madison, Wisconsin. pp. 914-925.

Peters, D.B., 1965. Determination of field capacity. In: Methods of Soil Analysis, part 1. Edited by C.A Black. Agronomy Monograph No.9. American Society of Agronomy. Madison, Wisconsin. pp. 281.

Photomap International, 1990. Aerial photographs frames 8425 to 8427 (scale 1:50,000).

Rutatora, D.F., J. Rugambisa and D. Mwaseba, 1995. Report on participatory rural appraisal (PRA) activities carried out by the Socio-economic Studies Team (SEST) of the Miombo Woodland Research Project for the period between 20/10/94 and 18/10/94 in some selected villages of Mbinga District-Ruvuma Region. Sokoine University of Agriculture, Morogoro, Tanzania.

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

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

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

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

Appendix 1 Profile description and analytical data of the soils of Mahenge

Profile : MP-1 Mapping unit: H1
Survey project : Mahenge village
Region : Ruvuma
District : Mbinga
Map sheet no. : 297/4
Coordinates : 34° 50' 56.8" E/10° 58' 25.7" S
Location : Nalioba hill
Elevation : 1770 m asl. Parent material: weathered gneiss. Landform: hill; hilly.
Slope: 2 %; convex
Surface characteristics : Outcrops: 80 %. Erosion: none or slight. Deposition: none.
Natural drainage class : somewhat excessively drained

Described by D.N. Kimaro, J.P. Magoggo and B.M. Msanya on 09/08/95

Soil: Mainly rock outcrops with pockets of very shallow and moderately deep dark brown sandy clay loam soil.

Ah 0 - 20 cm: brown (7.5YR4/2) dry, dark brown (7.5YR3/4) moist; sandy clay loam

Bw 20 - 60 cm: brown to dark brown (7.5Y4/4) moist; sandy clay loam

SOIL CLASSIFICATION: FAO legend (1988): Dystric Leptosol
USDA (1990) : Lithic Ustorthent

ANALYTICAL DATA FOR PROFILE MP-1

Horizon		Ah	Bw
Depth (cm)		0 - 20	30 - 50
Clay	%	25	24
Silt	%	13	11
Very fine sand	%	12	13
Fine sand	%	30	33
Medium sand	%	15	15
Coarse sand	%	3	3
Very coarse sand	%	2	1
Texture class		SCL	SCL
pH H2O	1:2.5	4.4	4.4
pH KCl	1:2.5	3.9	4.0
EC mS/cm	1:2.5	0.04	0.02
Organic C	%	2.3	1.3
Total N	%	0.16	0.10
C/N		14	13
Available P	mg/kg	2	3
CEC NH4OAc	cmol/kg	13.4	13.7
Exch. Ca	cmol/kg	1.6	1.4
Exch. Mg	cmol/kg	2.3	2.6
Exch. K	cmol/kg	0.06	0.02
Exch. Na	cmol/kg	0.03	0.02
Exch. H	cmol/kg	0.01	0.04
Exch. Al	cmol/kg	1.2	0.9
TEB	cmol/kg	4.0	4.0
Base saturation	%	7	29
CECclay	cmol/kg	54	57
Al saturation	%	23	18

Profile : MP-2 Mapping unit: P2
Survey project : Mahenge village
Region : Ruvuma
District : Mbinga
Map sheet no. : 297/4
Coordinates : 34° 51' 13.0" E/10° 59' 25.1" S
Location : Ndololela
Elevation : 1600 m asl. Parent material: weathered gneisses. Landform: piedmont plain; hilly.
Slope: 10 %; straight
Surface characteristics : Erosion: none or slight. Deposition: none.
Natural drainage class : well drained

Described by J.P. Magoggo, D.N. Kimaro and B.M. Msanya on 10/08/95

Soil: Very deep, well drained, redddish brown, sandy clay loam, with a very thick, dark brown to dark reddish brown clay loam to sandy clay loam man-made topsoils.

Ap1 0 - 20 cm: pinkish grey (7.5YR6/2) dry, brown to dark brown (7.5YR4/2) moist; clay loam; loose dry, loose moist, slightly sticky slightly plastic wet; weak fine and medium granular; many pores; many fine roots; clear smooth boundary to

Ap2 20 - 40 cm: dark reddish brown (5YR3/4) dry, dark reddish brown (5YR3/3/3) moist; sandy clay loam; soft dry, very friable moist, slightly sticky and plastic wet; weak fine crumbs and moderate medium subangular blocks; many pores; many fine and common medium roots; abrupt smooth boundary to

Bw1 40 - 55 cm: yellowish red (5YR4/6) dry, reddish brown (5YR4/4) moist; sandy clay loam; soft dry, very friable moist, sticky and plastic wet; moderate medium subangular blocks; many pores; few small irregular slightly weathered quartz fragments; few fine and medium roots; clear smooth boundary to

Bw2 55 - 140 cm: red (2.5YR4/6) dry, reddish brown (2.5YR4/4) moist; sandy clay loam to clay loam; very friable moist, sticky and plastic wet; moderate medium and coarse subangular blocks; patchy thin clay + iron (hydr)oxide cutans; many pores; few small irregular slightly weathered quartz fragments; few small spherical soft nodules; few fine and medium roots; clear smooth boundary to

Bw3 140 - 150 cm: red (2.5YR4/8) moist; clay loam; friable moist, sticky and plastic wet; moderate medium subangular blocks; broken thin clay + iron (hydr)oxide cutans; many pores; few small spherical soft nodules

SOIL CLASSIFICATION: FAO legend (1988) : Ferralic Cambisol
USDA (1990) : Typic Ustochrept

ANALYTICAL DATA FOR PROFILE MP-2

Horizon		Ap1	Ap2	Bw1	Bw2	Bw2	Bw3
Depth (cm)		0 - 20	20 - 40	40 - 55	70 - 90	110 - 130	140 - 150
Clay	%	30	30	30	32	32	33
Silt	%	25	24	24	21	25	23
Very fine sand	%	11	9	10	11	11	10
Fine sand	%	12	15	16	16	15	12
Medium sand	%	14	13	11	11	10	10
Coarse sand	%	6	7	6	6	6	9
Very coarse sand	%	2	2	3	3	1	3
Texture class		CL	SCL	SCL	SCL	SCL - CL	CL
pH H2O	1:2.5	5.6	5.4	5.5	5.6	5.8	6.0
pH KCl	1:2.5	4.9	4.6	4.7	4.9	4.9	5.2
EC mS/cm	1:2.5	0.08	0.03	0.03	0.02	0.03	0.02
Organic C	%	2.8	2.6	1.6	0.6	0.7	0.2
Total N	%	0.29	0.21	0.14	0.07	0.08	0.02
C/N		10	12	11	9	9	10
Available P	mg/kg	8	3	1	1	0.4	0.1
CEC NH4OAc	cmol/kg	6.3	6.5	5.7	3.8	4.2	2.9
Exch. Ca	cmol/kg	2.5	2.1	1.9	1.5	2.1	1.6
Exch. Mg	cmol/kg	0.7	0.5	0.5	0.5	0.4	0.3
Exch. K	cmol/kg	0.12	0.31	0.41	0.06	0.05	0.05
Exch. Na	cmol/kg	0.02	0.02	0.02	0.04	0.02	0.03
Exch. H	cmol/kg	-	0.03	-	-	-	-
Exch. Al	cmol/kg	-	0.1	-	-	-	-
TEB	cmol/kg	3.3	2.9	2.8	2.1	2.6	2.0
Base saturation	%	53	45	50	55	61	68
CECclay	cmol/kg	21	22	19	12	13	9
Al saturation	%		3				

Profile : MP-3 Mapping unit: H33
Survey project : Mahenge village
Region : Ruvuma
District : Mbinga
Map sheet no. : 297/4
Coordinates : 34° 51' 33.8" E/10° 58' 5.9" S
Elevation : 1690 m asl. Parent material: mixed colluvial material. Landform: hill; hilly; straight
Surface characteristics : Erosion: moderate. Deposition: none.
Natural drainage class : somewhat excessively drained

Described by J.P. Magoggo, B.M. Msanya and D.N. Kimaro on 10/08/95

Soil: Very deep, well to somewhat excessively drained, dark reddish brown sandy clay loam with a very thick dark brown sandy clay loam to sandy loam man-made topsoil. The surface run-off and present erosion has been altered by the ngoro cultivation system.

Ap1 0 - 20 cm: dark yellowish brown (10YR4/4) dry, dark brown (10YR3/3) moist; sandy clay loam; loose dry, loose moist, slightly sticky and slightly plastic wet; very weak fine and medium granular; many fine pores; many fine and medium roots; gradual smooth boundary to

Ap2 20 - 38 cm: dark reddish brown (5YR3/4) dry, dark reddish brown (5YR3/3) moist; sandy loam; loose dry, loose moist, slightly sticky and slightly plastic wet; weak fine and medium subangular blocks; many fine pores; many fine and medium roots; gradual smooth boundary to

Ap3 38 - 80 cm: dark reddish brown (5YR3/4) dry, dark reddish brown (5YR3/3) moist; sandy clay loam; soft dry, very friable moist, slightly sticky and plastic wet; moderate medium and fine subangular blocks; many fine pores; many fine roots; clear wavy boundary to

Bw 80 - 170 cm: red (10YR4/6) moist; sandy clay loam; very friable moist, sticky and plastic wet; moderate medium subangular blocks; patchy thin clay cutans; many fine pores; few small irregular fresh quartz fragments; frequent small nodules; very few fine roots

SOIL CLASSIFICATION: FAO legend (1988): Haplic Phaeozem
USDA (1990) : Pachic Haplustoll

ANALYTICAL DATA FOR PROFILE MP-3

Horizon		Ap1	Ap2	Ap3	Bw
Depth (cm)		0 - 20	20 - 37	38 - 70	100 - 120
Clay	%	24	20	26	24
Silt	%	23	26	24	22
Very fine sand	%	7	9	7	8
Fine sand	%	20	20	20	19
Medium sand	%	16	16	15	15
Coarse sand	%	6	7	6	9
Very coarse sand	%	3	2	2	3
Texture class		SCL	SL	SCL	SCL
pH H2O	1:2.5	5.7	5.7	5.8	5.6
pH KCl	1:2.5	5.0	5.0	5.0	5.2
EC mS/cm	1:2.5	0.04	0.03	0.03	0.01
Organic C	%	3.4	3.7	2.2	0.7
Total N	%	0.30	0.25	0.23	0.07
C/N		11	15	10	10
Available P	mg/kg	3	0.3	0.1	0.1
CEC NH4OAc	cmol/kg	8.1	7.4	7.4	2.4
Exch. Ca	cmol/kg	3.4	3.3	3.3	1.0
Exch. Mg	cmol/kg	1.0	0.7	0.9	0.3
Exch. K	cmol/kg	0.26	0.11	0.13	0.01
Exch. Na	cmol/kg	0.02	0.03	0.03	0.02
Exch. H	cmol/kg	-	-	-	-
Exch. Al	cmol/kg	-	-	-	-
TEB	cmol/kg	4.7	4.1	4.4	1.3
Base saturation	%	58	56	59	55
CECclay	cmol/kg	34	37	28	10
ESP	%				

Profile : MP-4 Mapping unit: H2
Survey project : Mahenge village
Region : Ruvuma
District : Mbinga
Map sheet no. : 297/4
Coordinates : 34° 51' 27.0" E/10° 58' 0.8" S
Location : Mazenge locality
Elevation : 1730 m asl. Parent material: mixed colluvial material. Landform: piedmont; gently undulating; convex
Surface characteristics : Erosion: none or slight. Deposition: none.
Natural drainage class : well drained

Described by D.N. Kimaro, B.M. Msanya and J.P. Magoggo on 10/08/95

Soil: Very deep, well drained, red sandy clay to clay with very thick sandy clay loam topsoil.

Ap 0 - 20 cm: reddish brown (5YR5/3) dry, reddish brown (5YR4/4) moist; sandy clay loam; soft dry, very friable moist, sticky and plastic wet; weak fine subangular blocks; clear smooth boundary to

Bt1 20 - 45 cm: reddish brown (5YR4/4) moist; sandy clay; very friable moist, sticky and plastic wet; moderate medium and fine subangular blocks; gradual smooth boundary to

Bt2 45 - 80 cm: red (2.5YR4/6) moist; sandy clay; very friable moist, sticky and plastic wet; moderate medium and fine subangular blocks; broken thin clay cutans; many fine pores; few quartz fragments; diffuse smooth boundary to

Bt3 80 - 170 cm: red (2.5YR4/6) moist; clay; very friable moist, sticky and plastic wet; moderate medium and fine subangular blocks; broken thin clay cutans; many fine pores; few quartz fragments; frequent nodules

SOIL CLASSIFICATION: FAO legend (1988): Haplic Acrisol
USDA (1990) : Acrustoxic Kandiustult

ANALYTICAL DATA FOR PROFILE MP-4

Horizon		Ap	Bt1	Bt2	Bt3
Depth (cm)		0 - 20	20 - 40	50 - 70	100 - 120
Clay	%	22	36	38	49
Silt	%	27	16	13	8
Very fine sand	%	10	9	8	9
Fine sand	%	20	20	22	18
Medium sand	%	12	11	12	9
Coarse sand	%	6	5	4	4
Very coarse sand	%	3	3	3	3
Texture class		SCL	SC	SC	C
pH H2O	1:2.5	5.4	5.4	4.9	5.1
pH KCl	1:2.5	4.8	4.7	4.3	5.1
EC mS/cm	1:2.5	0.09	0.03	0.02	0.01
Organic C	%	4.2	1.7	0.8	0.3
Total N	%	0.30	0.13	0.07	0.03
C/N		14	13	11	10
Available P	mg/kg	3	3	1	0.2
CEC NH4OAc	cmol/kg	16.4	5.7	3.3	4.5
Exch. Ca	cmol/kg	5.2	1.7	0.4	0.4
Exch. Mg	cmol/kg	1.6	0.5	0.2	0.2
Exch. K	cmol/kg	0.49	0.17	0.13	0.10
Exch. Na	cmol/kg	0.05	0.01	0.04	0.01
Exch. H	cmol/kg	0.06	0.23	0.08	0.02
Exch. Al	cmol/kg	-	0.1	0.3	-
TEB	cmol/kg	7.4	2.4	0.8	0.7
Base saturation	%	45	42	23	16
CECclay	cmol/kg	75	16	9	9
Al saturation	%		4	27	

Profile : MP-5 Mapping unit: P1
Survey project : Mahenge village
Region : Ruvuma
District : Mbinga
Map sheet no. : 297/4
Coordinates : 34° 51' 24.5" E/10° 58' 40.8" S
Elevation : 1720 m asl. Parent material: alluvium. Landform: piedmont; undulating. Slope: 5 %; convex
Surface characteristics : Outcrops: 2 % Erosion: none or slight. Deposition: none.
Natural drainage class : well drained

Described by B.M. Msanya, J.P. Magoggo and D.N. Kimaro on 11/08/95

Soil: Very deep, well drained, red sandy clay loam over gneiss saprolite, having a very thick dark yellowish brown topsoil.

Ah 0 - 35 cm: dark yellowish brown (10YR4/4) moist; sandy clay loam; slightly hard dry, very friable moist, slightly sticky and slightly plastic wet; moderate medium subangular blocks; common medium and few coarse roots; clear smooth boundary to

Bw1 35 - 58 cm: yellowish red (5YR5/6) moist; sandy loam; slightly hard dry, very friable moist, sticky and plastic wet; moderate medium and medium subangular blocks; patchy thin clay cutans; few medium roots; gradual smooth boundary to

Bw2 58 - 90 cm: red (2.5YR4/6) moist; sandy clay loam ; very friable moist, sticky and plastic wet; moderate medium and fine subangular blocks; broken thin clay cutans; frequent nodules; clear broken boundary to

2BC 90 - 135 cm: red (2.5YR4/6) moist; loam; very friable moist, sticky and plastic wet; moderate medium and fine subangular blocks; broken thin clay cutans; frequent large irregular weathered gneiss fragments; frequent nodules; abrupt broken boundary to

2CR 135 - 170 cm: gneiss saprolyte, strongly weathered, with original rock structure.

SOIL CLASSIFICATION: FAO legend (1988): Dystric Cambisol
USDA (1990) : Typic Ustochrept

ANALYTICAL DATA FOR PROFILE MP-5

Horizon		Ap	Bw1	Bw2	2BC	CR
Depth (cm)		0 - 35	35 - 58	65 - 85	100 - 120	150 - 170
Clay	%	24	18	25	18	15
Silt	%	23	27	28	36	33
Very fine sand	%	10	10	9	8	9
Fine sand	%	21	22	17	16	14
Medium sand	%	16	17	15	12	18
Coarse sand	%	5	5	5	7	10
Very coarse sand	%	1	1	1	3	1
Texture class		SCL	SL	SCL	L	L
pH H2O	1:2.5	4.5	4.6	4.7	4.7	4.8
pH KCl	1:2.5	4.0	4.0	3.9	4.0	4.1
EC mS/cm	1:2.5	0.03	0.02	0.01	0.01	0.07
Organic C	%	2.4	0.6	0.4	0.2	0.1
Total N	%	0.15	0.06	0.03	0.02	0.01
C/N		16	10	13	10	10
Available P	mg/kg	0.1	0.1	1	1	0.4
CEC NH4OAc	cmol/kg	12.5	6.0	5.2	6.2	5.1
Exch. Ca	cmol/kg	0.3	0.2	0.1	0.2	0.3
Exch. Mg	cmol/kg	0.1	0.1	0.1	0.1	0.1
Exch. K	cmol/kg	0.23	0.04	0.02	0.03	0.04
Exch. Na	cmol/kg	0.05	0.01	0.04	0.02	0.05
Exch. H	cmol/kg	-	0.04	-	-	-
Exch. Al	cmol/kg	1.7	1.0	1.1	1.1	0.8
TEB	cmol/kg	0.7	0.4	0.3	0.4	0.5
Base saturation	%	5	6	5	6	10
CECclay	cmol/kg	52	33	21	34	34
Al saturation		71	71	79	73	62

Profile : MP-6 Mapping unit: H33
Survey project : Mahenge village
Region : Ruvuma
District : Mbinga
Map sheet no. : 297/4
Coordinates : 34° 51' 31.7" E/10° 58' 54.1" S
Location : About 100 m north of village office
Elevation : 1650 m asl. Parent material: mixed colluvial material. Landform: hill; hilly.
Slope: 17 %; straight
Surface characteristics : Erosion: none or slight. Deposition: none.
Natural drainage class : well drained

Described by B.M. Msanya, D.N. Kimaro and J.P. Magoggo on 11/08/95

Soil: Very deep, well drained to somewhat excessively drained red sandy clay loam to sandy clay with very thick dark brown to reddish brown sandy clay loam man-made topsoil.

Ap1 0 - 20 cm: dark brown (7.5YR4/4) dry, dark brown (7.5YR3/4) moist; sandy clay loam; soft dry, very friable moist, slightly sticky and slightly plastic wet; weak medium subangular blocks; many fine pores; many fine roots; clear smooth boundary to

Ap2 20 - 45 cm: reddish brown (5YR4/4) moist; sandy clay loam; very friable moist, sticky and plastic wet; moderate medium subangular blocks; many fine pores; many fine and medium roots; gradual smooth boundary to

Bw 45 - 60 cm: red (2.5YR4/6) moist; sandy clay loam ; very friable moist, sticky and plastic wet; moderate medium subangular blocks; patchy thin clay cutans; many fine pores; few nodules; few fine and common medium roots; gradual smooth boundary to

Bt1 60 - 120 cm: red (2.5YR4/6) moist; sandy clay; very friable moist, sticky and plastic wet; moderate medium and fine subangular blocks; broken thin clay cutans; many fine pores; frequent nodules; few fine roots; diffuse smooth boundary to

Bt2 120 - 200 cm: red (10R4/8) moist; sandy clay; very friable moist, sticky and plastic wet; moderate medium and fine subangular blocks; broken thin clay cutans; many fine pores; frequent nodules; few fine roots

SOIL CLASSIFICATION: FAO legend (1988): Haplic Acrisol
USDA (1990) : Acrustoxic Kandiustult

ANALYTICAL DATA FOR PROFILE MP-6

Horizon		Ap1	Ap2	Bw	Bt1	Bt2
Depth (cm)		0 - 20	20 - 45	45 - 60	80 - 100	160 - 180
Clay	%	25	31	26	40	46
Silt	%	17	13	10	14	8
Very fine sand	%	10	9	12	9	9
Fine sand	%	29	26	31	22	21
Medium sand	%	14	17	16	11	12
Coarse sand	%	4	3	4	3	3
Very coarse sand	%	1	1	1	1	1
Texture class		SCL	SCL	SCL	SC	SC
pH H2O	1:2.5	4.9	5.2	4.8	4.9	5.0
pH KCl	1:2.5	4.1	4.4	4.1	4.3	4.3
EC mS/cm	1:2.5	0.01	0.03	0.02	0.01	0.01
Organic C	%	2.8	1.4	0.6	0.4	0.2
Total N	%	0.14	0.10	0.05	0.03	0.02
C/N		20	14	12	13	10
Available P	mg/kg	1	7	1	0.3	-
CEC NH4OAc	cmol/kg	13.5	5.0	5.9	3.1	3.1
Exch. Ca	cmol/kg	1.3	1.3	0.7	0.6	0.7
Exch. Mg	cmol/kg	0.5	0.4	0.1	0.2	0.3
Exch. K	cmol/kg	0.17	0.06	0.05	0.06	0.07
Exch. Na	cmol/kg	0.02	0.04	0.01	0.04	0.01
Exch. H	cmol/kg	0.05	0.06	0.05	0.10	0.02
Exch. Al	cmol/kg	0.7	0.3	0.6	0.2	-
TEB	cmol/kg	2.0	1.8	0.9	0.9	1.1
Base saturation	%	15	36	15	29	35
CECclay	cmol/kg	54	16	23	8	7
Al saturation	%	26	14	46	18	

Profile : MP-7 Mapping unit: H31
Survey project : Mahenge village
Region : Ruvuma
District : Mbinga
Map sheet no. : 297/4
Coordinates : 34° 51' 56.2" E/10° 59' 19.7" S
Location : About 200 m from office along Mahenge - Kilangajuu road.
Elevation : 1680 m asl. Parent material: mixed colluvial material. Landform: hill; hilly; convex
Surface characteristics : Erosion: none or slight. Deposition: none.
Natural drainage class : excessively drained

Described by D.N. Kimaro, B.M. Msanya and J.P. Magoggo on 11/08/95

Soil: Shallow to moderately deep, excessively drained, dark brown sandy clay loams over stones and boulders.

Ap1 0 - 15 cm: pinkish grey (7.5YR6/2) dry, dark brown (7.5YR3/4) moist; sandy clay loam; soft dry, very friable moist, slightly sticky and slightly plastic wet; weak medium granular and subangular blocks; many fine pores; many fine roots; gradual smooth boundary to

Ap2 15 - 40 cm: brown (7.5YR5/2) dry, dark brown (7.5YR3/4) moist; sandy clay loam; soft dry, very friable moist, slightly sticky and slightly plastic wet; moderate medium subangular blocks; many fine pores; many fine roots; clear smooth boundary to

CR 40 cm+: mainly boulders and rocks

SOIL CLASSIFICATION: FAO legend (1988): Eutric Regosol
USDA (1990) : Lithic Ustorthent

ANALYTICAL DATA FOR PROFILE MP-7

Horizon		Ap1	Ap2
Depth (cm)		0 - 15	15 - 40
Clay	%	23	23
Silt	%	15	14
Very fine sand	%	10	11
Fine sand	%	26	26
Medium sand	%	19	16
Coarse sand	%	6	7
Very coarse sand	%	1	3
Texture class		SCL	SCL
pH H2O	1:2.5	5.6	5.7
pH KCl	1:2.5	4.9	4.9
EC mS/cm	1:2.5	0.03	0.02
Organic C	%	2.3	1.8
Total N	%	0.17	0.13
C/N		14	14
Available P	mg/kg	3	0.2
CEC NH4OAc	cmol/kg	5.9	5.1
Exch. Ca	cmol/kg	2.7	2.4
Exch. Mg	cmol/kg	0.5	0.3
Exch. K	cmol/kg	0.03	0.05
Exch. Na	cmol/kg	0.03	0.02
Exch. H	cmol/kg	-	-
Exch. Al	cmol/kg	-	-
TEB	cmol/kg	3.3	2.8
Base saturation	%	55	54
CECclay	cmol/kg	26	22

Appendix 2. Guide to general evaluation of some soil chemical and physical properties

Compiled from Baize (1993), EUROCONSULT (1989) and Landon (1984; 1991)

1. Organic matter and total nitrogen

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

C/N ratios give an indication of the quality of the organic matter:
C/N 8 - 13 : good quality
C/N 14 - 20: moderate quality
C/N > 20 : poor quality

2. Soil reaction

Soil reaction (pH H_2O) is classified as follows:

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

3. Available phosphorus

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

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

4. Cation exchange capacity (CEC)

cmol(+)/kg	Very low	Low	Medium	High	Very high
CEC	<6.0	6.0-12.0	12.1-25.0	25.0-40.0	>40.0

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

5. Exchangeable calcium

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

6. Exchangeable magnesium

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

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

7. Exchangeable K

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

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

8. Exchangeable sodium

cmol(+)/kg	Very low	Low	Medium	High	Very high
Na	<0.10	0.10-0.30	0.31-0.70	0.71-2.00	>2.00

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

9. Soil sodicity

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

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

10. Basic infiltration rate (IR)

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

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

11. Available water capacity (AWC)

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

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

12. Aluminium saturation

	very low	low	medium	high	very high
Al saturation %	< 10	10 - 30	31 - 50	51 - 80	> 80

Aluminium saturation as a measure of toxicity is calculated by dividing exchangeable Al by the sum of exchangeable bases and exchangeable Al.