PEDOLOGICAL INVESTIGATIONS AND LAND RESOURCES CHARACTERIZATION IN LUPILO VILLAGE, MBINGA DISTRICT, TANZANIA

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EXECUTIVE SUMMARY

Mbinga district (like most of Tanzania) lacks soils information at sufficient detail for proper land use planning and management. The district falls under the *Miombo* woodlands zone of Tanzania which are areas that are or were formerly under *Miombo* woodlands. These areas have been under natural vegetation for a long time but are now being encroached by arable land uses. The resultant changes in land cover are liable to disturb the ecological equilibrium of the natural resources. Studies to assess the land resources have not been done adequately in these areas.

Several villages have been selected for detailed studies in the district. The selected villages will form sample areas and nuclei of technology transfer in the district and the *Miombo* woodland areas of Tanzania in general. The studies which are taking place include socio-economy, technological studies and natural resources.

This report describes the natural resources study of Lupilo village as part of the continuing project on the assessment of the natural resources of Mbinga district. The study involved measurements of terrain characteristics, quantitative investigations of soil properties, inventory of land use systems and an assessment of the ecological potential and constraints as determined from a balance sheet analysis of resources and land use requirements.

Climatic resources

There are no specific climatic records for Lupilo village. However, the rainfall pattern is monomodal, starting in November and ending in May with an estimated mean annual precipitation of slightly less than 1,000 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 temperatures between 20°C and 25°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 mixed intermediate and mafic metamorphic rocks. The higher-lying parts of the village form hilland which is essentially a denudational landscape. Immediately below and adjacent to the hilland are the piedmonts which are primarily colluvial (depositional) sites but are also secondary denudational sites. The lowest-lying parts are the valleys. These form the ultimate sink for all material eroded from the higher-lying land.

Vegetation and land use

In Lupilo village *miombo* woodland still prevails. In general *miombo* woodlands, with grasses as undergrowth, occupy mainly the hillands and middle terrace of the moderately dissected piedmonts. The dominant tree species are *Brachystegia spp.*, *Parinari curatelifolia, Uapaka kirikiana, Pterocarpus angolensis*. Others include *Ntomoni* and *Mtumbitumbi*. The dominant grasses are *Hyparrhenia spp.* and *Brycharia spp*. There are two major categories of land use in Lupilo village: *ngoro* and/or ridge cultivation with maize and beans as the dominant crops and shifting cultivation (known as slash and burn) with finger millet as the main crop.

Soils

Eight 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 Lupilo area are:

(a) mainly shallow and very shallow, well and excessively drained dark reddish brown to dark brown gravelly sandy clay loams to clay loams in the hilly landscape. Here rock outcrops and surface stones are common.

(b) very deep, well drained, dark red clays on the piedmonts. In many places these soils have a moderately thick dark reddish brown, sandy clay to clay topsoils to which the *ngoro* farming practice has contributed a great deal in transforming.

(c) very deep, moderately well to imperfectly drained, brown and dark yellowish brown, sandy clays and clays. In some places the soils are stratified and/or mottled.

The soils of the hillands were classified as Eutric Leptosol (Lithic Ustorthent) and Ferralic Cambisol, lithic phase (Lithic Ustropept) and Chromic Luvisol, lithic phase (Lithic Rhodustalf)

The soils of the piedmonts were classified as Ferric Luvisol (Typic Rhodusltalf), Haplic Acrisol (Typic Rhodustult) and Geric Ferralsol (Rhodic Acrustox).

The soils of the river valleys were classified as Eutric Fluvisol (Tropofluvent) and Dystric Cambisol (Ustic Humitropept).

The bulk densities of most topsoils are relatively lower than those of the subsoils, ranging from 0.7 to 1.3 g/cc (topsoils) and 1.3 to 1.5 g/cc (subsoils). Total porosity ranges from 50 to 62 percent in the topsoils and from 46 to 59 percent in the subsoils. Available water holding capacities of the soils are between 120 and 167 mm per meter 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 (CEC values range between 6 and 12 $Cmol^{(+)}$/kg).

1.INTRODUCTION

Soil information gathering by systematically identifying, grouping and delineating different soils according to their genesis, physico-chemical characteristics and overall ecological conditions is a pre-requisite when sound interpretations towards land use potential are to be made. Socio-economic factors also form an important element in land management (Msanya *et al*, 1995). A good data bank on soil properties and related site characteristics is inevitable for one to be able to advise both current and potential land users on how to use the land in the best possible way. Proper site selection and soil characterization are also basic to the success of agronomic experiments and to the effectiveness of extending research results to a large number of farmers. Fertilizer and other agronomic trials carried out on uncharacterized soils are not very useful because their results are of local value (i.e. they are specific to the trial site) and have low transferability to other areas.

Tanzania in general and Mbinga district specifically have a lack of soils information at sufficient detail for proper land use planning and management. A large part of Tanzania is covered by *Miombo* woodlands or was formerly under *Miombo* woodlands. These areas have been under natural vegetation for a long time but are now being encroached by arable land uses. The resultant changes in land cover are liable to disturb the ecological equilibrium of the natural resources. Studies to assess the land resources have not been done adequately in these areas. In order to provide a starting point the *Miombo* Woodlands Research Project (MWRP) was initiated and Mbinga district was chosen as an area which could represent a large part of *Miombo* woodland areas on Tanzania.

This study is part of the continuing *Miombo* Woodlands Research Project 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 the development of the soil information system for Tanzania (*SISTAN*) and its linkage to computerized land evaluation systems and geographic information systems (GIS).

The Natural Resources Study team of the *Miombo* Woodlands Research Project at the Sokoine University of Agriculture, which carried out the current study, has, as one of its mandates, the responsibility of providing information on natural resources to other research teams of the MWRP working in Mbinga district. This study was aimed mainly at the identification of the soils of Lupilo village, their pedological characterization and the spatial relationships between the identified pedological entities.

The specific objectives of the study were:

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

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

(c) to classify the soils of Lupilo 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 at the scale of 1:125,000 quarter degree sheet 285 (85 N.E.) Mnada. Geological survey of Tanganyika, 1957. Geological Survey Department, Dodoma, Tanzania.
- Topographic map at the scale of 1:50,000, Kigonsera, map sheet 298/3, 1972. Ministry of Lands, Survey and Mapping Division, Dar es Salaam, Tanzania.
- Aerial photographs at the scale of 1:50,000, runs 8403, 8404, 8405, by Geosurvey International Limited, August/September 1990.
- 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. Tanzania Forestry Research Institute (TAFORI).

Before the commencement of the soil mapping, systematic stereoscopic interpretation of static and dynamic photo elements (landform, geology, lineaments, drainage patterns, vegetation, land use and drainage conditions 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 soils were examined from hand auger borings. The free survey method was applied, using the photo interpretation map to select observation and sampling points. At each observation site data on pedological (soil morphological) characteristics, landform, elevation, slope gradients, parent material (lithology), vegetation and land use/crops were collected. Soils were studied by description of mini-pits plus auger hole borings and/or soil profile pits. In total 12 mini-pits and 11 soil profile pits were studied and described. Description of the soils and landforms was done following standard procedures as outlined in the FAO guidelines and USDA Soil Taxonomy. 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
- composite topsoil samples (0-20 cm) for soil fertility characterization.

Appendix 1 presents the soil profile descriptions and their corresponding laboratory data. Appendix 2 provides a guide to general evaluation of soil chemical and physical properties.

2.3. Post-field work

Post-field work activities included cartographic generalization of the topographic base map to reduce thematic details and enlarging the scale to 1:25,000, transfer of the polygons delineated on the photo-

interpretation map onto the enlarged topographic base map and copying of the field and laboratory analytical data recorded on the analogue forms into the national digital soil data base management system (*SISTAN*).

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 Kjeldal 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 Kjeldal distillation method for the estimation of CEC of soil. The bases Ca^{2+}, Mg^{2+}, Na^+, and K^+, displaced by NH_{4+} were measured by atomic absorption spectrophotometer. CEC of clay was calculated using the formula developed by Baize (1993) which corrects for the CEC contributed by organic matter (OM) as follows:

$$CEC_{clay} = \{[CEC_{soil} - (\% \text{ OM} \times 2)]/\% \text{ clay}\} \times 100.$$

Texture was determined by pipette method 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 soil map and legend

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

In the legend and on the map every mapping unit has a code referring to the topography. Further subdivision is based on slope and soil characteristics and is indicated by a number following the capital letter. The column "soil description" in the legend gives the main characteristics of the soil types i.e. soil depth, drainage, color, texture, and other diagnostic characteristics that separate each soil type from all other soil types described.

2.3.3. Soil classification and data processing

Using both field and laboratory data the identified soil types were classified to level-2 of the FAO-Unesco (1989) legend of the soil map of the world and up to subgroup level of the USDA Soil Taxonomy (Soil Survey Staff, 1990). This information is also 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 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. Lupilo village is situated in the Kigonsera low hills and footslopes. The approximate geographical coordinates are 35° 12' E and 10° 52' S. Figure 1 shows the location of the study area

3.1.2. Climate

The rainfall pattern is monomodal, starting in November and ending in May. 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 (Mchau, 1993). The study area is expected to be in between with mean annual temperatures between 20°C and 25°C. Seasonal variations in temperature exist whereby the dry season (May to September) is cooler than the rainy season.

There are no specific climatic records for Lupilo village. The study area falls in a relatively drier part of Mbinga district and is estimated to receive a total annual rainfall of slightly less than 1000 mm compared to the average 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. During this period crop production is feasible without irrigation. The rest of the year is virtually dry.

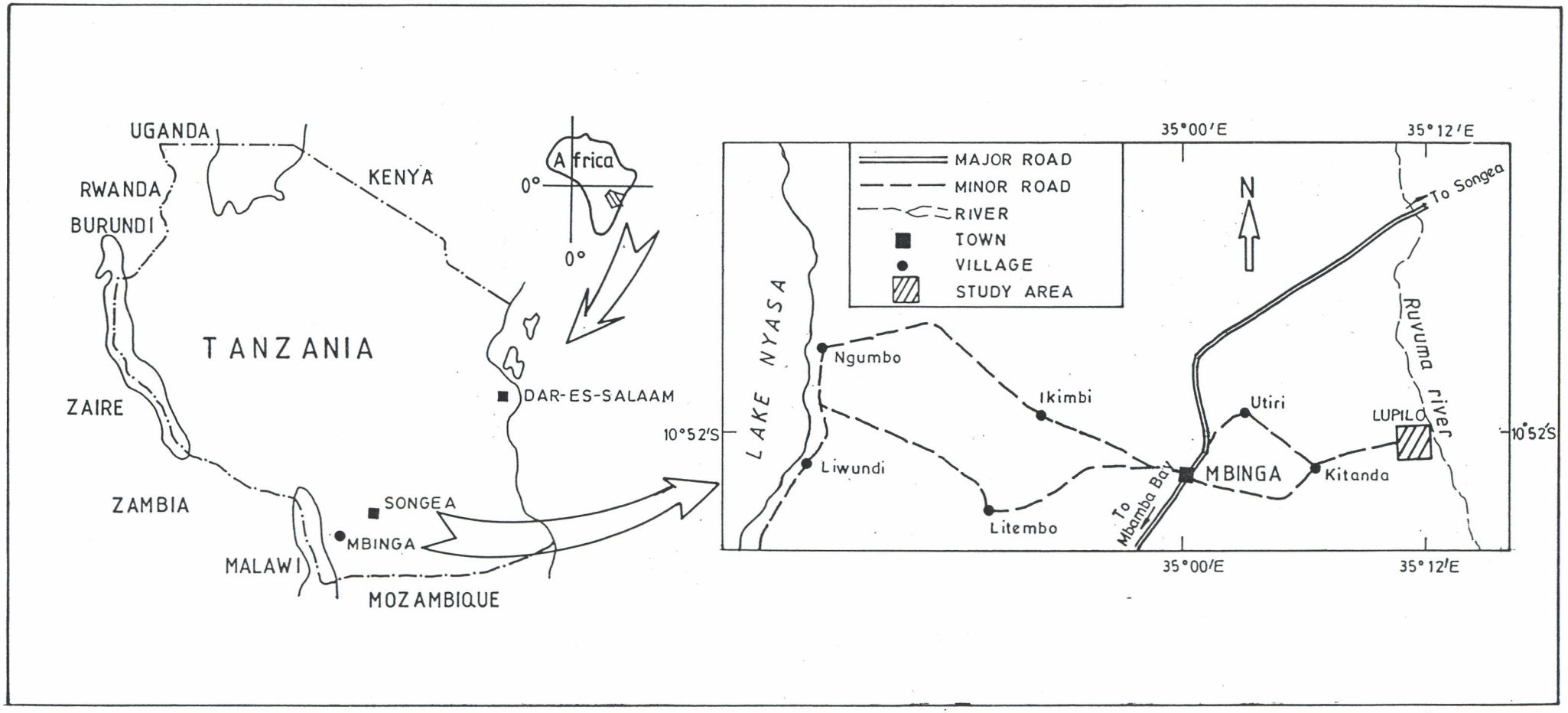

Figure 1: Location of the study area

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

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 Lupilo village comprises two main geological blocks namely migmatized and hornfelsed granulites and amphibolites (Geological Survey Department, 1956).

The village lies in three landscapes generally corresponding to altitude levels. The high areas are predominantly hilly, the mid-altitude areas are piedmonts adjacent to the hilly landscape. The river valleys comprise the lowest-lying landscape.

The general topography of the area comprises very steep slopes (dominantly 30 - 50%) in the hilly landscapes, becoming gentler in the piedmont landscapes (mainly less than 10%, rising to about 30% in some parts closer to the hillands). The valleys are generally flat, being river terraces and river floors.

The hilly landscape is dominated by processes of denudation. Due to the high altitudes and steep slopes the materials resulting from weathering of the lithological materials are removed relatively quickly. These materials are deposited as colluvium on the piedmonts. The valley landscape forms the ultimate sink for all material denuded laterally from the higher landscapes as well as longitudinally along the courses of the drainage ways and river courses.

3.1.4. Vegetation and land use

Miombo woodland is the typical vegetation which covers approximately three quarters of the agricultural land in southern Tanzania. Many agricultural lands in this part of the country are influenced by the ecological conditions prevailing under *miombo* woodlands. Human influence in the *miombo* woodland environment e.g. fuel wood harvesting, food production, livestock keeping etc. plays a major role in the ecological balance. This vegetation type contributes little to the soils in terms of fertility. Once disturbed, its contribution disappears quickly and it can not be replenished quickly. For this reason the practice of shifting cultivation (slash and burn) has evolved in these areas.

In this paragraph an inventory on vegetation and land use of Lupilo village is presented. The relationship between landforms, soils, vegetation and land use is given in Table 2. Actually, natural vegetation still exists only in the hillands and some parts of the piedmonts. In the remaining areas, the woodland has been cleared. The lands in Lupilo village have been occupied for agricultural production rather recently i.e. less than 15 years.

Miombo woodlands, with grasses as undergrowth, occupy mainly the hillands and middle terraces of the moderately dissected piedmonts. The dominant tree species are *Brachystegia spp., Parinari curatelifolia, Uapaka kirikiana, Pterocarpus angolensis*. Others include Ntomoni and Mtumbitumbi. The dominant grasses are *Hyparrhenia spp.* and *Brycharia spp.*

A big part of the piedmonts and river valleys in Lupilo village are used for cultivation. There are two major categories of land use in Lupilo village:

(a) *Ngoro and/or ridge cultivation system* with maize and beans as the dominant crops. Maize is planted in November/December and harvested in July/August. Beans are planted in February and harvested in May. In the river valleys maize and beans are planted in August on residual moisture and harvested in February.

(b) *Shifting cultivation (slash and burn)* with finger millet as the main crop. The crop is planted

in November/December and harvested in April/May.

Other minor land use systems are those based on coffee (Arabica), cassava, pigeon peas, bananas, groundnuts and mango.

3.2. Soils

3.2.1. Landforms, soils and vegetation/land use associations

The map showing the spatial distribution of the soils of Lupilo village is included in the back cover of this report. The relationship between landforms, soils and vegetation/land use is shown in table 2.

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

MAP SYMBOL	LANDFORM	DOMINANT SLOPE (%)	AREA		SOIL DESCRIPTION	VEGETATION/LAND USE
			Ha	%		
HILLAND (H), elevation 1000 to 1500 m above sea level						
H1	Hills (summits and shoulder, convex slopes)	0 - 2	597	12.5	Very shallow to shallow, well to somewhat excessively drained, dark reddish brown, gravelly clay loams with very thin dark brown, sandy clay loam topsoils; developed on mixed metamorphic rocks. In places rock outcrops, boulders, stones and gravel appear at or near the surface	Natural forest: mainly *miombo* woodland (*Brachystegia spp., Parinari curatelifolia, Uapaka kirikiana, Pterocarpus angolensis*). Grasses: mainly *Hyparrhenia spp., Brycharia spp.* Farming systems include few ridge cultivation, with mainly maize, sweet potato and finger millet.
H2	Hills (backslopes, linear, very steep slopes)	30 - 50	746	15.7	Association of: Very shallow to shallow, excessively drained, dark brown, extremely gravelly sandy clay loams with very thin, brown, sandy loam topsoils; and Very shallow to moderately deep, well to somewhat excessively drained, dark reddish brown, clay loams with very thin, dark brown, clay loam topsoils; developed on mixed metamorphic rocks. In places occur rock outcrops, boulders and stones up to 1 m high	Natural forest: mainly *miombo* woodland (*Brachystegia spp., Parinari curatelifolia, Uapaka kirikiana, Pterocarpus angolensis*). Grasses: mainly *Hyparrhenia spp., Brycharia spp.*
STRONGLY DISSECTED PIEDMONT (P1), elevation 950 to 1100 m above sea level						
P11	Higher terrace (rolling to hilly)	10 - 30	586	12.3	Very deep, well drained, dark red to dusky, clays, with moderately thick, dark reddish brown to reddish brown, sandy clay to clay loam, man-made horizon (ngoro epipedon) or topsoils; developed on colluvium derived from mixed metamorphic rocks)	Ngoro cultivation system with maize and beans as the main crops. Coffee, few bananas and mango trees are also grown. The unit is also covered with few scattered *miombo* woodland trees such as *Brachystegia spp.* and *Parinari curatelifolia.*
P12	Middle terrace (undulating to rolling)	5 - 15	272	5.7	Very deep, well drained, dark reddish brown, sandy clays to clays, with thin dark brown, sandy clay loam topsoils; developed on colluvium derived from mixed metamorphic rocks	Patches of natural forest mainly *miombo* woodland (*Brachystegia spp., Parinari curatelifolia, Uapaka kirikiana, Pterocarpus angolensis*). Also grasses (*Hyparrhenia spp.*). Farming systems in this unit are ridge cultivation with maize and beans as the main crops. Slash and burn for finger millet cultivation is also practised.

MODERATELY DISSECTED PIEDMONT (P2), elevation 900 to 980 m above sea level

P21	Higher terrace (gently undulating to undulating)	2 - 10	1,243	26.2	Very deep, well drained, red clays, with very thin, yellowish red, clay topsoils; developed on colluvium derived from mixed metamorphic rocks	Ridge and ngoro cultivation system; the main crops grown are maize, beans, cassava. Few bananas, pigeon peas, and pumpkins are also grown. Fallow land about 3 to 5 years is common. Few scattered trees such as *Brachystegia spp.*, Ntomoni and Mtumbitumbi occur in the unit.
P22	Middle terrace (almost flat to gently undulating)	0 - 5	221	4.7	Very deep, well drained, red clays with thick, red sandy clay topsoils; developed on colluvium derived from mixed metamorphic rocks	Natural forest: mainly *miombo* woodland (*Brachystegia spp.*, *Parinari curatelifolia, Uapaka kirikiana, Pterocarpus angolensis*). Grasses: mainly *Hyparrhenia spp.*, *Brycharia spp.* Farming systems include some ridge cultivation with maize, beans and groundnut as the main crops.

RIVER VALLEYS (V), elevation 850 to 950 m above sea level

V1	Almost flat river terrace	0 - 2	863	18.2	Very deep, moderately well to imperfectly drained, brown and dark yellowish brown, stratified, mottled, loams and sandy clay loams with thick, dark yellowish brown; developed on alluvial-colluvium derived from highly weathered mixed metamorphic rocks	Ridge and ngoro cultivation systems; the main crops grown are maize, beans and cassava. Other vegetation include Bamboo trees, Ferns, *Hyparrhenia spp.* and Napia grass.
V2			224	4.7	Very deep, well drained, dark brown to dark yellowish brown, sandy clay loams with very thick, dark brown, clay topsoils; developed on colluvio-alluvium derived from highly weathered mixed metamorphic rocks	Mainly *miombo* wood land trees.

Table 3. *Texture, organic carbon, bulk density, total porosity and available water capacity of selected soils of soils of Lupilo village*

Profile No.	Depth (cm)	Textural class	Organic carbon (%)	Bulk density (g/cc)	Total porosity (%)	Available water capacity (% vol)	Available water capacity (mm/m)
LP-1	0-10	SCL	1.8	1.1	57	13	
	25-60	SC	0.6	1.4	48	8	120
	60-100	C	0.4	1.4	47	15	
LP-2	0-15	SC	1.0	1.3	53	13	
	15-55	C	0.4	1.3	50	15	149
	55-100	C	0.2	1.2	57	16	
LP-3	0-10	C	3.2	1.0	62	13	
	40-50	C	1.0	1.2	58	14	167
	50-100	C	0.3	1.1	59	21	
LP-6	0-20	C	3.4	1.2	55	16	
	40-55	SCL	1.4	1.4	49	17	148
	75-100	SCL	0.4	1.5	46	11	
LP-7	0-15	SC	1.4	1.3	51	18	
	40-85	C	0.2	1.1	60	15	156
	85-120	C	0.2	1.0	63	11	
LP-9	0-15	CL	3.1	0.7	73	16	
	30-55	CL	0.8	1.5	44	16	120
	90-110	SCL	0.4	1.5	44	10	
LP-10	0-18	CL	2.3	1.3	53	11	
	40-80	C	0.4	1.5	48	13	122
	80-120	C	0.2	1.4	51	14	

3.2.2. Physical properties

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

Soil texture, bulk density and total porosity

The dominant texture of the studied soils is sandy clay and clay except for profiles LP-6 and LP-9 in which the texture is predominantly sandy clay loam. The bulk densities of most topsoils are relatively lower than those of the subsoils; ranging from 0.7 to 1.3 g/cc (topsoils) and 1.3 to 1.5 g/cc for the subsoils. Profiles LP-6 and LP-9 have higher bulk densities (1.5 g/cc) in the deeper subsoils while profile LP-7 has the lowest bulk densities (1.0 - 1.1 g/cc). Total porosity ranges from 50 - 62% in the topsoils and from 46 - 59% in the subsoils except for profile LP-7 which has total porosity of 60 - 63% in the subsoils. Bulk density and total porosity of the soils are mainly influenced by texture and to some extent by the organic matter content of the soils.

Water retention and available water capacity

Figure 2 shows the moisture characteristics of three depths (surface horizon, intermediate horizon and subsoil) of the studied profiles. In Lupilo village the soils are mainly clayey in texture. Therefore they have relatively high matric potential throughout the suction ranges which decreases gently with increasing suction. Nonetheless, differences of practical significance exist which are related to topographic position in the landscape.

In the alluvial landscape, at any given water potential, the volume fraction of water in the surface layer was higher than that in the intermediate layer and subsoil. This can be explained by the relatively higher organic matter in topsoils (see Table 3). In the piedmont this trend is reversed. This can be explained by the fact that organic matter levels in the topsoils of the piedmont are in general not much higher than in the subsoil, but there is a general increase of clay content with depth. Thus texture is the controlling factor for water retention. Profile LP-3 is exceptional for piedmont soils due to its high organic matter levels in the topsoil and high porosity. Available water capacity per meter of soil ranges from 120 to 167 mm (Table 3).

3.2.3. Chemical properties

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

Soil reaction

Soil pH values are medium acid in most topsoils ranging from 5.7 to 6.0. The subsoils are strongly acid to medium acid with pH values ranging from 5.0 to 5.8. The pH values of profile LP-3 (map unit P21) are strongly acid in the topsoil and very strongly acid in the subsoil. In general nearly all topsoils have higher pH values than subsoils. Soils with very low pH values (less than 5.5) and high aluminum saturation levels require very high doses of fertilizers as well as heavy liming to obtain acceptable yields. Soils of mapping unit P21 (profile LP-3) have medium percent aluminum saturation (41 to 54%) in the subsoils.

Organic matter and nitrogen

Organic matter contents are generally medium to high corresponding to organic carbon levels between 1.4 to 3.5 percent in topsoils. The levels of organic matter in the subsoils are very low (less than 0.6 percent organic carbon). The soils of profile LP-2 (map unit P11) are low in organic matter (less than 1.2 percent organic carbon). In most soils absolute nitrogen levels are generally low (less than 0.2 percent). However, the topsoils of these soils have moderate to good quality organic matter contents (C/N ratios between 10 and 18).

Available phosphorus

All soils have low levels of available phosphorus in the subsoils (about 1 mg P/kg). An average phosphorus levels of more than 7 mg P/kg are considered to be optimum below which P-deficiency symptoms are likely to occur in many crops. The topsoils of profile LP-1, LP-3, LP-4, LP-6, LP-7 and LP-10 have high levels (ranging from 20 to 31 mg P/kg) of available phosphorus. The topsoils of remaining soils have very low levels of available phosphorus (less than 6 mgP/kg).

Cation exchange capacity (CEC)

The CEC reflect the capacity of the soil to retain nutrients against leaching. CEC values of most soils are low ranging from 6 to 12 me/100g soil. The soils of profile LP-5, LP-6, LP-9 and LP-10 have high CEC values (ranging from 15 to 30 Cmol(+)/kg).

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

Table 5 presents the topsoil and subsoil exchangeable cations (Ca, Mg, and K) levels of Lupilo soils. It appears that the levels of exchangeable Ca and Mg are very low to low for most soils and medium to high for profiles LP-5, LP-6, LP-9 and LP-10. Exchangeable K levels are low to medium in most topsoils.

Nutrient balance

The availability of nutrients for uptake by the plant depends not only upon absolute levels but also on nutrient balances. It is important to consider the nutrient ratios Ca/Mg, Mg/K and K/total exchangeable bases Ca, Mg, K and Na (TEB). The general trends for Lupilo soils are as follows: In most soils calcium, magnesium and potassium are well balanced with calcium higher than magnesium and magnesium higher than potassium. Ca/Mg ratios are 2 and 3 which is considered to be an optimal range. The Mg/K ratios for most soils are in the range of 1 to 4. Because of overall higher K levels this ratio is reported as unfavourable for most tropical crops. The K levels are medium for most of the soils. The overall K/TEB (total exchangeable bases) ratios are above 2 percent which is said to be favourable for most tropical crops.

3.2.4. Soil classification

Table 6 gives a summary of the salient soil morphological and diagnostic features used in classifying the soils. Table 7 gives the soil names according to the two systems of classification used. The soils were categorized into five soil orders of the USDA Soil Taxonomy namely Ultisol (LP-1), Oxisol (LP-2, LP-3, LP-7), Entisol (LP-4 and LP-9), Alfisol (LP-5 and LP-10) and Inceptisol (LP-6 and LP-8) which respectively correspond to Acrisol, Ferralsol, Leptosol/Fluvisol, Luvisol and Cambisol in the FAO-Unesco Classification.

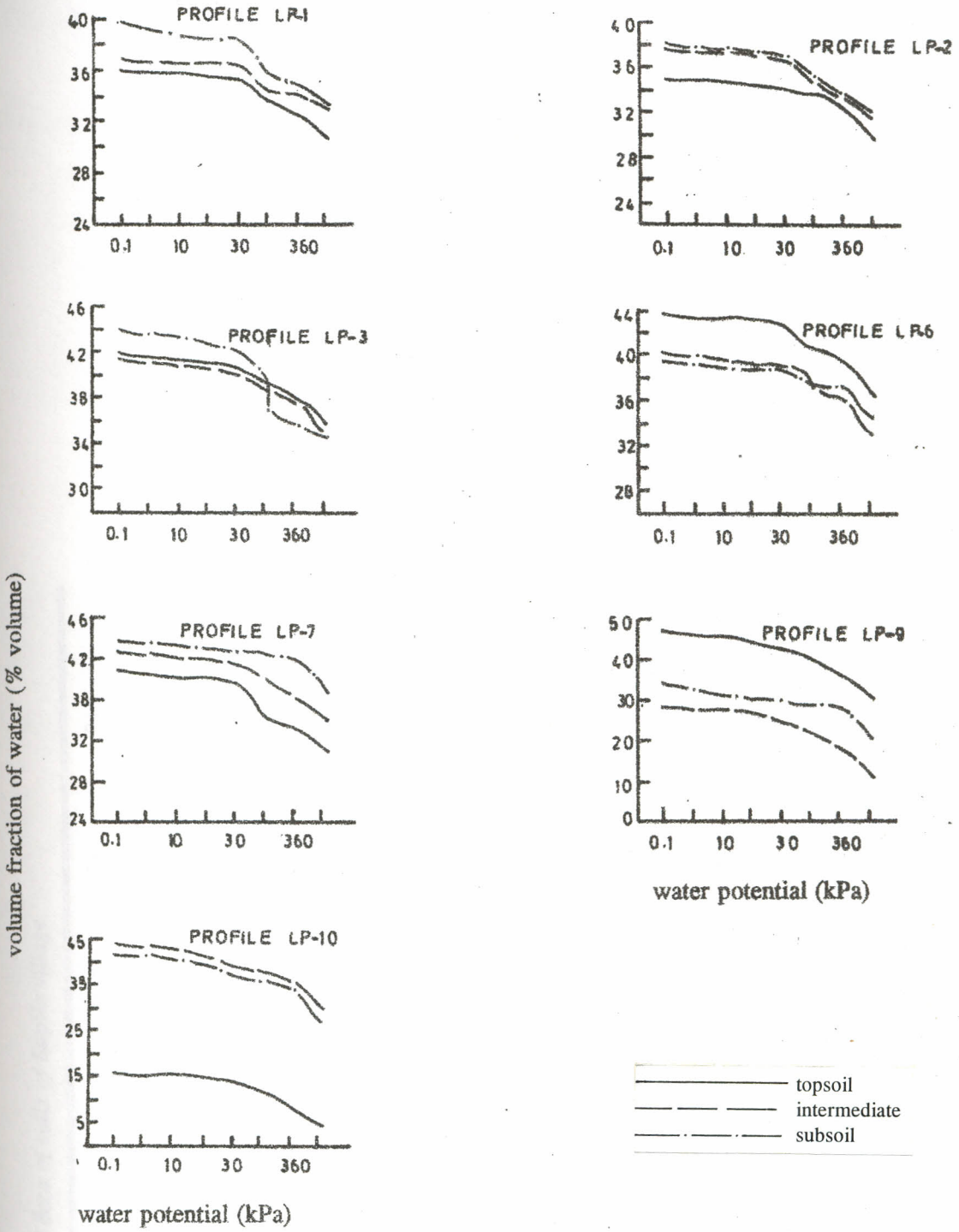

Figure 2: Moisture release characteristics of some soil profiles of Lupilo

Table 4. Chemical analytical data of soils of Lupilo village

Profile No.	Depth	pH (H2O)	Org. C (%)	Total N (%)	C/N	Available P (mg/kg)	CEC (Cmol(+)/kg)	Base saturation (%)
LP-1	Topsoil	6.0	1.8	0.12	15	28	7.0	61
	subsoil	5.3	0.4	0.03	12	12	8.8	39
LP-2	Topsoil	5.9	1.0	0.09	11	6	6.1	63
	Subsoil	5.4	0.2	0.02	10	1	5.8	48
LP-3	Topsoil	5.3	3.2	0.20	16	31	11.9	39
	Subsoil	4.7	0.3	0.03	10	1	8.5	9
LP-4	Topsoil	5.7	1.8	0.11	16	31	11.7	55
LP-5	Topsoil	6.1	3.1	0.18	17	2	18.3	64
	Subsoil	6.1	0.6	0.06	10	1	29.7	70
LP-6	Topsoil	5.5	3.4	0.19	18	20	27.8	47
	Subsoil	5.7	0.4	0.04	10	1	17.3	52
LP-7	Topsoil	5.7	1.4	0.08	18	25	6.7	52
	Subsoil	5.4	0.2	0.02	10	1	7.3	46
LP-8	Topsoil	5.8	2.4	0.13	18	5	7.3	62
	Subsoil	5.8	0.5	0.05	10	1	7.0	62
LP-9	Topsoil	5.7	3.1	0.24	13	1	23.5	53
	Subsoil	5.0	0.5	0.04	13	1	15.0	28
LP-10	Topsoil	6.1	2.3	0.17	14	26	15.0	69
	Subsoil	5.7	0.4	0.04	10	1	20.5	56

Table 5. Interpretation ratings for exchangeable cations of Lupilo soils

Profile No.	Map Unit	Exchangeable Calcium (Cmol(+)/kg)		Exchangeable Magnesium (me/100g soil)		Exchangeable Potassium (me/100g soil)		Percent Aluminum saturation	
		Topsoil (0-20cm)	Subsoil (30-150cm)	Topsoil (0-20cm)	Subsoil (30-150cm)	Topsoil (0-20cm)	Subsoil (30-150cm)	Topsoil (0-20cm)	Subsoil (30-150cm)
LP-1	P12	Low (2.4)	Very low (1.3-1.8)	Low (0.7-1.4)	Low to medium (0.6-1.2)	Medium (0.42)	Low to medium (0.33-0.67)	Nil	Low (5)
LP-2	P11	Low (2.0-4.1)	Very low (1.6-1.7)	Medium (1.3-1.8)	Low (0.5-0.8)	Medium (0.54)	Low (0.33-0.37)	Nil	Nil
LP-3	P21	Low (2.3)	Very low (0.4-0.8)	Medium (1.9)	Very low to low (0.1-0.5)	Medium (0.42)	Low to medium (0.10-0.50)	Low (2)	Medium (41-54)
LP-4	H1	Low to medium (4.6-5.8)	Nil	Low to medium (1.4-2.7)	Nil	Low to medium (0.33-66)	Nil	Nil	Nil
LP-5	H2	Medium (7.2)	High (9.2-13.7)	High (3.5)	High (6.4)	Medium (0.91)	Medium (0.64)	Nil	Nil
LP-6	V2	Medium to high (8.0-10.7)	Medium (3.4-5.3)	Medium (1.8)	Medium to high (2.1-3.6)	Medium (0.42)	Low to medium (0.26-0.53)	Nil	Low (1-2)
LP-7	P22	Low (2.5)	Very low (1.5-1.9)	Low (0.5-1.0)	Low to medium (0.8-1.3)	Low to medium (0.31-0.50)	Low to medium (0.29-0.54)	Nil	Nil
LP-8	H2	Very low (2.0-2.5)	Very low (1.8)	Low (0.8-1.3)	Medium (1.2)	Medium (0.40)	Medium (0.41)	Nil	Nil
LP-9	V1	Medium (8.3-8.8)	Low (2.1-2.9)	Medium (2.4-2.8)	Medium (1.2-1.7)	Low to Medium (0.32-0.71)	Very low (0.05-0.21)	Nil	Low (8-16)
LP-10	P11	Medium (7.8-8.5)	Medium (6.8-8.0)	Medium to high (1.1-4.9)	High (2.6-4.6)	Medium (0.48-0.78)	Medium (0.49-0.65)	Nil	Nil

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

Profile	Diagnostic horizons	Other diagnostic features
LP-1	*Ochric A (*ochric epipedon); *argic B (argillic horizon)	Ustic SMR; Isohyperthemic STR
LP-2	*Ochric A (ochric epipedon); *ferrallic B (oxic horizon)	Ustic SMR; isohyperthermic STR; *ferric properties; gerric properties (small textural gradient in the B-horizon)
LP-3	*Ochric A (ochric epipedon); *ferrallic B (oxic horizon)	Ustic SMR; isohyperthermic STR; *gerric properties (small textural gradient in the B-horizon)
LP-4	*Ochric A (ochric epipedon)	Ustic SMR; isohyperthermic STR
LP-5	*Ochric A (ochric epipedon); *argic B (argillic horizon)	Ustic SMR; isohyperthermic STR; lithic phase
LP-6	*Ochric A (ochric epipedon); *cambic B (cambic horizon)	Ustic SMR; isohyperthermic STR
LP-7	*Ochric A (ochric epipedon); *ferrallic B (oxic horizon)	Ustic SMR; isohyperthermic STR; *gerric properties (small textural gradient in the B_horizon)
LP-8	*Ochric A (ochric epipedon); *cambic B (cambic horizon)	Ustic SMR; isohyperthermic STR; ferralic properties
LP-9	*Ochric A (ochric epipedon)	*Fluvic properties; *gleyic properties (aquic SMR); isohyperthermic STR
LP-10	*Ochric A (ochric epipedon); *argic B (argillic horizon)	Ustic SMR; isohyperthermic STR; *ferric properties; gerric properties (small textural gradient in the B-horizon)

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

Table 7. *Classification of the studied representative soils*

PROFILE	FAO-Unesco legend classification		USDA soil taxonomy			
	level 1	**level 2**	*order*	*suborder*	*great group*	*sub-group*
LP-1	Acrisol	Haplic Acrisol (ACh)	Ultisol	Ustult	Rhodustult	Typic Rhodustult
LP-2	Ferralsol	Geric Ferralsol (FRg)	Oxisol	Ustox	Haplustox	Rhodic Haplustox
LP-3	Ferralsol	Geric Ferralsol (FRg)	Oxisol	Ustox	Acrustox	Rhodic Acrustox
LP-4	Leptosol	Eutric Leptosol (FPe)	Entisol	Orthent	Ustorthent	Lithic Ustorthent
LP-5	Luvisol	Chromic Luvisol (LVx), lithic phase	Alfisol	Ustalf	Rhodustalf	Lithic Rhodustalf
LP-6	Cambisol	Dystric Cambisol (CMd)	Inceptisol	Tropept	Humitropept	Ustic Humitropept
LP-7	Ferralsol	Geric Ferralsol (FRg)	Oxisol	Ustox	Haplustox	Rhodic Haplustox
LP-8	Cambisol	Ferralic Cambisol (FRo)	Inceptisol	Tropept	Ustropept	Lithic Ustropept
LP-9	Fluvisol	Eutric Fluvisol (FLe)	Entisol	Fluvent	Tropofluvent	*
LP-10	Luvisol	Ferric Luvisol (LVf)	Alfisol	Ustalf	Rhodustalf	Typic Rhodustalf

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

Very shallow to shallow, well to somewhat excessively drained, dark reddish brown, gravelly clay loams with very thin dark brown, sandy clay loam topsoils; developed on mixed metamorphic rocks. In places rock outcrops, boulders, stones and gravel appear at or near the surface.

Setting:
This unit is on the summits (convex slopes) of Lupilo hills. It occupies the highest positions in the hilland landscape. The slopes are between 0 and 2 percent at mean elevation of about 1500 m asl. The lands are occupied with natural forest mainly *miombo* woodland (*Brachystegia, Parinari curatelifolia, Pterocarpus angolensis*) with less dense grass vegetation (*Hyparrhenia, Brycharia*) as undergrowth. Farming systems include few ridge cultivation with mainly maize, sweet potato and finger millet.

Soil profile characteristics:
The topsoil (about 10 cm thick) is dark brown, friable, sandy clay loam and it is moderately structured. The subsoil to a depth of 30 cm is friable, dark reddish brown, gravelly clay loam and it is moderately structured. The soil classifies as **Eutric Leptosol (Lithic Ustorthent)** and profile **LP-4** is representative.

Soil physical properties:
The soil is well to somewhat excessively drained and the rooting depth is limited at 30 cm. The available water capacity is low. The surface conditions are limited by rock outcrops, boulders, stones and gravels.

Soil chemical properties:
Organic matter contents are medium. Nitrogen levels are low in the topsoils. The available phosphorus is generally high. The soil is medium acid and has low to medium levels of exchangeable

bases. The overall capacity of the soil to retain nutrient is low.

Mapping unit H2

Association of: Very shallow to shallow, excessively drained, dark brown, extremely gravelly sandy clay loams with very thin, brown, sandy loam topsoils; and Very shallow to moderately deep, well to somewhat excessively drained, dark reddish brown, clay loams with very thin, dark brown, clay loam topsoils; developed on mixed metamorphic rocks. In places occur rock outcrops, boulders and stones up to 1 m high.

Setting:

The unit occupies the backslopes (very steep linear slopes) of Lupilo hills. The dominant slopes are between 30 and 50 percent and the mean elevation is at about 1100 m asl. Typically the soil surface is rocky, bouldery and stony. The lands are occupied with natural forest mainly *miombo* woodlands (*Brachystegia, Parinari curatelifolia, Pterocarpus angolensis*) with less dense grass vegetation (*Hyparrhenia, Brycharia*) as undergrowth.

Soil profile characteristics:

The topsoils less than 10 cm thick, are brown and dark brown, sandy loam and clay loam and weakly to moderately structured. The subsoils to a depth of 50 cm are friable and firm, dark brown and dark reddish brown sandy clay loam and clay loam and it is moderately strongly structured. The soils classifies as **Ferrallic Cambisols - Lithic phase (Lithic Ustropept)** and **Chromic Luvisol - Lithic phase (Lithic Rodustalfs)** and profiles **LP-8** and **LP-5** are representative respectively.

Soil physical properties:

The soil are well to excessively drained and the rooting depth is less than 50 cm. The available water capacity is low. In places surface rock outcrops, boulders and stones are common.

Soil chemical properties:

In these soils phosphorus and nitrogen are clearly deficient with levels varying from very low to low. Topsoils have medium to high amounts of moderate quality organic matter. The soils are medium and slightly acid. The soils have low to medium levels of exchangeable bases. The capacity of the soil to retain nutrient is very low for profiles LP-8 and high for profiles LP-5.

Mapping unit P11

Very deep, well drained, dark red to dusky red, clays, with moderately thick, dark reddish brown to reddish brown, sandy clay to clay loam, man-made horizon (ngoro epipedon) or topsoils; developed on colluvium derived from mixed metamorphic rocks.

Setting:

The unit occupies the higher terrace of the strongly dissected piedmont slopes. The dominant slopes are generally between 10 and 30 percent with rolling to hilly topography and the mean elevation is at about 1000 m asl. In this unit Ngoro is the main cultivation system with maize and beans as the main crops. Coffee, few bananas and mango trees are also grown. The unit is also covered with few *miombo* woodland trees such as *Brachystegia* and *parinari curatelifolia.*

Soil profile characteristics:

The topsoil (15 to 20 cm thick) is reddish brown to dark reddish brown, friable, sandy clay to clay loam and moderately structured. The subsoil to a depth of 180 cm and more is friable, dark red to dusky red, clay and it is moderately structured. The subsoils show diffuse textural and colour gradient with many Mn-Fe-Clay nodules increasing with depth. The soil classifies as **Geric FerraLsol (Rhodic Haplustox)** and **Ferric Luvisol (Typic Rhodustalf)** and profile **LP-2** and **LP-10** are representative respectively.

Soil physical properties:

The soil is well drained, the root zone extends to a depth of 180 cm and deeper. Available water capacity is medium (120 to 150 mm/m). Bulk density is medium around 1.3 g/cc in the topsoil and 1.4 g/cc in the subsoil. Total porosity is high (more than 50%) both in the topsoil and subsoil.

Soil chemical properties:

The soil has overall poor supply of major nutrients i.e. nitrogen and phosphorus. Potassium levels are medium in the topsoil and low to medium in the subsoil. The soil reaction is medium slightly acid in the topsoil and strongly to medium acid in the subsoil. The soil has overall good amounts of organic matter. Calcium and magnesium levels are low to medium. The soil has very low to medium capacity to retain nutrients.

Mapping unit P12

Very deep, well drained, dark reddish brown, sandy clays to clays, with thin dark brown, sandy clay loam topsoils; developed on colluvium derived from mixed metamorphic rocks.

Setting:

The unit occupies the middle terrace of the strongly dissected piedmont slopes. The slopes are between 5 and 15 percent with undulating to rolling topography. The mean elevation is at about 950 m asl. The lands are covered with patches of natural forest mainly *miombo* woodland (*Brachystegia, Parinari curatelifolia* and *Pterocarpus angolensis*) and grasses mainly *Hyparrhenia* as undergrowth. Farming systems in this unit are ridge cultivation with maize and beans as the main crops. Slash and burn for finger millet cultivation is also practised.

Soil profile characteristics:

The topsoil (about 10 cm thick) is dark brown, sandy clay loam. The consistence is friable and it is moderately structured. The subsoil to depth of 150 cm and deeper is dark reddish brown, friable sandy clay to clay with moderate structure. Small and hard irregular feldspar nodules are common. This soil classifies as **Haplic Acrisol (Typic Rhodustult)** and profile **LP-1** is representative.

Soil physical properties:

The soil is well drained. The rooting depth is more than 150 cm. The available water capacity is medium (119 mm/m). Bulk densities are medium with values ranging between 1.1 g/cc in the topsoil to 1.4 g/cc in the subsoil. The soil has high porosity in the topsoil (57%) and about 48% in the subsoil.

Soil chemical properties:

The soil has overall poor supply of nitrogen. Phosphorus levels are high in the topsoil. Exchangeable bases are generally low. The soil reaction is medium acid in the topsoil and strongly acid in the subsoil. The soil has overall moderate quality organic matter. The soil has very low capacity to retain nutrients.

Mapping unit P21

Very deep, well drained, red clays, with very thin, yellowish red, clay topsoils; developed on colluvium derived from mixed metamorphic rocks.

Setting:

The unit occupies the higher terrace of the moderately dissected piedmont slopes of Lupilo hills. The slopes are between 2 and 10 percent and the mean elevation is at about 980 m asl. The lands are mainly agricultural land with ridge and *ngoro* cultivation as the main cultivation system. The main crops grown are maize, beans and cassava. Few bananas, pigeon peas, and pumpkins are also grown. Fallow land about 3 to 5 years is common. Few scattered trees such as *Brachystegia*, *Ntomoni* and *Mtumbitumbi* are also found in the area.

Soil profile characteristics:

The topsoil is 10 cm thick and the colour is yellowish red. The soil is friable and texture is clay throughout. The structure is moderate in the topsoil and weak in the subsoil. The soil classifies as **Gerric Ferralsol (Rhodic Acrustox)** and the profile **LP-3** is representative.

Soil physical properties:

The soil is well drained. The rooting depth extends to a depth of 150 cm and deeper. Available water capacity is high (167 mm/m). Bulk density is low (1.0 g/cc) in the topsoil and medium (1.1 to 1.2 g/cc) in the subsoil.

Soil chemical properties:

The soil has overall low supply of nitrogen. Phosphorus is high in the topsoil and very low in the subsoil. Potassium levels are medium. Topsoils have moderate quality of organic matter. The soil reaction is strongly acid in the topsoil and very strongly acid in the subsoil associated in some profiles with medium levels of aluminum saturation (aluminum saturation between 40 and 50 percent). Calcium and magnesium levels are very low to low. This soil has low capacity to retain nutrients.

Mapping unit P22

Very deep, well drained, red clays with thick, red sandy clay topsoils ; developed on colluvium derived from mixed metamorphic rocks.

Setting:

The unit occupies the middle terrace of the moderately dissected piedmont slopes of Lupilo hills. The dominant slopes are between 0 and 5 percent and the mean elevation is at about 920 m asl with almost flat to gently undulating topography. The lands are covered with natural forest mainly *miombo* woodland (*Brachystegia, Pterocarpus angolensis, Parinari curatelifolia, Uapaka kirikiana*) with grasses (*Hyparrhenia, Brycharia*) as undergrowth. Farming systems including some ridge cultivation of maize. Beans and groundnut are also grown.

Soil profile characteristics:

The topsoil (15 cm thick) is red, friable, moderately structured sandy clay. The subsoil to a depth of 170 cm and deeper is red, friable, clay and weakly structured. Spherical and hard feldspar fragments are common in the subsoil. The soil classifies as **Gerric Ferralsol (Rhodic Acrustox)** and profile **LP-7** is representative.

Soil physical properties:

The soil is well drained. The rooting depth extends to a depth of 170 cm and deeper. Available water capacity is high (156 mm/m). Bulk density is medium (1.3 g/cc) in the topsoil and low (1.0 g/cc) in the subsoil. Total porosity is around 50% in the topsoil and more than 60% in the subsoil.

Soil chemical properties:

The soil has overall very low supply of nitrogen. Phosphorus is high in the topsoil and very low in the subsoil. Potassium levels are low to medium. Topsoils have moderate quality of organic matter. The soil reaction is medium acid in the topsoil and strongly acid in the subsoil. Calcium and magnesium levels are very low to low. This soil has low capacity to retain nutrients.

Mapping unit V1

Very deep, moderately well to imperfectly drained, brown and dark yellowish brown, stratified, mottled, loams and sandy clay loams with thick, dark yellowish brown; developed on alluvial-colluvium derived from highly weathered mixed metamorphic rocks.

Setting:
The unit represents the almost flat river terrace of the low lying drainage ways and river courses in Lupilo village. The slopes are between 0 and 2 percent. The lands are covered with dense mixed vegetation including few, scattered *miombo* woodland, *bamboo* trees, ferns, and grasses (*Hyparrhenia* and *Napia* grass). Ridge and *ngoro* cultivation systems are also practised with maize, beans and cassava as main crops.

Soil profile characteristics:
The topsoil (15 cm thick) is dark yellowish brown, friable, clay loam. The subsoil is dark yellowish brown and brown, firm, clay loam to sandy loam and sandy clay loam with common angular fresh mica fragments and massive structure. This soil classifies as **Eutric Fluvisol (Tropofluvent)** and profile **LP-9** is representative.

Soil physical properties:
The soil is moderately well to imperfectly drained. The rooting depth extends to a depth of 160 cm and deeper. Available water capacity is medium (120 mm/m). Bulk density is low (< 1.0 g/cc) in the topsoil and high (> 1.5 g/cc) in the subsoil. Total porosity is high (around 70%) in the topsoil and less than 45% in the subsoil.

Soil chemical properties:
The soil has overall very low supply of phosphorus. Nitrogen is medium in the topsoil and very low in the subsoil. Potassium levels are low. Topsoils have good quality amounts of organic matter. The soil reaction is medium acid in the topsoil and very strongly acid in the subsoil associated in some profiles with low levels of aluminum saturation (aluminum saturation between 10 and 20 percent). Calcium and magnesium levels are medium. This soil has medium capacity to retain nutrients.

Mapping unit V2

Very deep, well drained, dark brown to dark yellowish brown, sandy clay loams with very thick, dark brown, clay topsoils; developed on colluvio-alluvium derived from highly weathered mixed metamorphic rocks.

Setting:

The setting of this unit is similar to those of unit V2.

Soil profile characteristics:

The topsoil is very thick (about 20 cm thick), dark brown, friable, clay with moderate structure. The subsoil is dark brown to dark yellowish brown, friable, sandy clay loam, with weak structure. Weathered fragments and small and hard irregular feldspar nodules are common. The soil classifies as **Dystric Cambisol (Ustic Humitropept)** and profile **LP-6** is representative.

Soil physical properties:

The soil is well drained and the rooting depth is deeper than 145 cm. The available water capacity is medium (148 mm/m). Bulk density is medium (1.2 g/cc) in the topsoil and relatively higher (1.4 to 1.5 g/cc) in the subsoil. Total porosity decreases with depth i.e. 55 % in the topsoil to about 45 % in the subsoil.

Soil chemical properties:

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

4. CONCLUDING REMARKS

The climatic conditions prevailing in Lupilo are not limiting for the production of adapted crops. The amount of rainfall is sufficient to support most crops. The soil physical characteristics are also favorable for rooting and aeration. However, in most parts of the village slopes are steep, which results in losses of water supply from rainfall and soil erosion. The hazard of soil erosion is mainly due to the clearing of vegetation which has been done after introduction of agricultural production. The area was originally covered by *miombo* woodland until the late 1970s; this vegetation still exists in many parts of the village.

In order to protect the lands of the village from further erosion, the steep parts and hills should be protected from clearing, and where possible trees should be replanted. In areas where lands are already under arable agriculture, studies to determine the effectiveness of the established *ngoro* farming technology in land conservation should be undertaken. Research on agroforestry should also be taken into consideration.

Most of the soils in the area have low to medium exchangeable potassium, available phosphorus, and low nitrogen and organic matter content. The low soil fertility in Lupilo village is to a large extent due to the high degree of weathering of the soils which are relatively old. In Lupilo village, as in other parts of the *miombo* ecosystem, organic matter (from the natural vegetation) is the dominant contributing factor to soil fertility. The mineral exchange complex has less contribution. Once the woodland is cleared and annual crops established, replenishment of organic matter is reduced drastically and soil productivity declines very quickly. Therefore, apart from mineral fertilizers, trials on the application of organic matter and its economics and well as the social implications should be carried out. Due to the low pH levels in most of the soils, there may be a P-fixation problem. All P-fertilizer experimentation should take this factor into account in order to come out with proper fertilizer recommendations for the village.

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Appendix 1 Soil profile descriptions and analytical data

Profile number : LP-1 Mapping unit: P12
Region : Ruvuma
District : Mbinga
Map sheet no. : 298/3
Coordinates : 35° 8' 48.1" E/10° 52' 39.0" S
Location : 27 km from Mbinga to Kitanda ward (1.5 km east of village office)
Elevation : 930 m asl. **Parent material**: colluvium derived from mixed metamorphic rocks.
Landform : piedmont plain; rolling. **Slope**: 11 %; straight
Surface characteristics: **Outcrops**: 0 % **Erosion**: none or slight. **Deposition**: none.
Drainage class: well drained
Described by: B.M. Msanya, D.N. Kimaro, J.P. Magoggo and A.E. Kiwelu on 25/10/94

Soils: Very deep, well drained, dark reddish brown, sandy clays to clays with thin dark brown sandy clay loam topsoil

Ah 0 - 10 cm: dark brown (7.5YR4/4) dry, dark brown (7.5YR3/2) moist; sandy clay loam; soft dry, friable moist, slightly sticky and slightly plastic wet; moderate fine and medium subangular blocks; many fine and very fine pores; few small irregular hard feldspar nodules; common fine and few medium roots; pieces of charcoal, clay + Fe nodules throughout; gradual smooth boundary to

BA 10 - 25 cm: yellowish red (5YR4/6) dry, dark reddish brown (5YR3/4) moist; sandy clay loam; soft dry, friable moist, slightly sticky and plastic wet; moderate fine and medium subangular blocks; many fine and very fine pores; few medium irregular hard feldspar nodules; few coarse and common fine roots; clear smooth boundary to

Bt1 25 - 60 cm: dark red (2.5YR3/6) dry, dark reddish brown (2.5YR3/4) moist; sandy clay; hard dry, friable moist, sticky and plastic wet; moderate medium subangular blocks and moderate coarse angular blocks; patchy thin clay + iron (hydr)oxide cutans; many fine and very fine pores; frequent small irregular hard feldspar nodules; few coarse and common medium roots; krotovina; diffuse smooth boundary to

Bt2 60 - 100 cm: dark red (2.5YR3/6) dry, dark reddish brown (2.5YR3/4) moist; clay; friable moist, sticky and plastic wet; moderate fine subangular blocks and moderate medium angular blocks; patchy thin clay + iron (hydr)oxide cutans; many fine and very fine pores; few medium angular fresh quartz fragments; frequent small irregular hard feldspar nodules; few coarse and medium roots; clear smooth boundary to

Bt3 100 - 155 cm: red (2.5YR4/8) dry, red (2.5YR4/6) moist; clay; friable moist, sticky and plastic wet; moderate fine angular blocks and moderate medium subangular blocks; patchy thin clay + iron (hydr)oxide cutans; many fine and very fine pores; frequent small irregular hard feldspar nodules; few fine and very fine roots

SOIL CLASSIFICATION: FAO legend : 1989: Haplic Alisol
USDA taxonomy: Haplic Rhodustult

ANALYTICAL DATA FOR PROFILE LP-1

Horizon		Ah	BA	Bt1	Bt2	Bt3
Depth (cm)		0 - 10	10 - 25	35 - 55	65 - 85	120 - 140
Clay	%	22	29	36	45	49
Silt	%	15	14	13	12	9
Very fine sand	%	8	7	6	1	4
Fine sand	%	20	16	12	12	8
Medium sand	%	22	20	18	16	13
Coarse sand	%	11	12	12	11	12
Very coarse sand	%	2	2	3	3	5
Total sand	%	63	57	51	43	42
Texture class		SCL	SCL	SC	C	C
pH H2O	1:2.5	6.0	5.2	5.4	5.3	5.2
pH KCl	1:2.5	5.6	4.5	4.2	4.5	4.9
EC mS/cm	1:2.5	0.07	0.03	0.23	0.02	0.01
Organic C	%	1.8	0.9	0.6	0.4	0.2
Total N	%	0.12	0.07	0.04	0.03	0.02
C/N		15	13	15	13	10
Available P	mg/kg	28	20	24	12	1
CEC NH4OAc	cmol(+)/kg	7.0	7.0	7.6	8.8	9.6
Exch. Ca	cmol(+)/kg	2.4	1.3	1.6	1.8	1.5
Exch. Mg	cmol(+)/kg	1.4	0.7	0.6	1.2	1.2
Exch. K	cmol(+)/kg	0.42	0.33	0.49	0.33	0.67
Exch. Na	cmol(+)/kg	0.06	0.04	0.07	0.08	0.06
Exch. H	cmol(+)/kg	-	0.06	0.09	0.08	0.02
TEB	cmol(+)/kg	4.3	2.4	2.8	3.4	3.4
Base saturation	%	61	34	37	39	35
CECclay	cmol(+)/kg	32	24	21	20	20

Profile number : LP-2 Mapping unit: P11
Region : Ruvuma
District : Mbinga
Map sheet no. : 298/3
Coordinates : 35° 8' 41.3" E/10° 52' 39.7" S
Location : 27 km from Mbinga town, 1.5 km east of Lupilo village office
Elevation : 950 m asl. **Parent material**: felsic metamorphic rocks.
Landform : piedmont plain; rolling. **Slope**: 12 %; straight
Surface characteristics: Cracks: none **Erosion**: moderate. **Deposition**: none.
Drainage class: well drained
Described by: D.N. Kimaro, B.M. Msanya, J.P. Magoggo and A.E. Kiwelu on 26/10/94

Soil: Very deep, well drained, dark red clays with moderately thick dark reddish brown sandy clay topsoils.

Ap 0 - 15 cm: yellowish red (5YR4/5) dry, reddish brown (5YR4/4) moist; sandy clay; slightly hard dry, very friable moist, sticky and plastic wet; moderate medium and coarse subangular blocks; common medium and many fine pores; many fine and very fine roots; clear wavy boundary to

Bts1 15 - 55 cm: red (2.5YR4/8) dry, red (2.5YR4/6) moist; clay; hard dry, friable moist, sticky and plastic wet; moderate coarse subangular blocks and moderate medium angular blocks; patchy thin clay + iron (hydr)oxide cutans; common medium and many fine pores; frequent medium irregular hard Fe & Mn nodules; common fine and very fine roots; gradual smooth boundary to

Bts2 55 - 100 cm: red (2.5YR4/6) dry, dark red (2.5YR3/6) moist; clay; hard dry, friable moist, sticky and plastic wet; moderate coarse subangular blocks and moderate medium angular blocks; patchy thin clay + iron (hydr)oxide cutans; many medium and fine pores; few small angular fresh quartz fragments; frequent medium irregular hard Fe & Mn nodules; few fine and very fine roots; diffuse smooth boundary to

Bts3 100 - 180 cm: red (2.5YR4/6) dry, dark red (2.5YR3/6) moist; clay; hard dry, friable moist, sticky and plastic wet; moderate coarse subangular blocks and moderate medium angular blocks; patchy thin clay + iron (hydr)oxide cutans; many medium and fine pores; few small angular fresh quartz fragments; frequent medium irregular hard Fe & Mn nodules; few fine and very fine roots

SOIL CLASSIFICATION: FAO legend : 1989 :Ferric Acrisol

ANALYTICAL DATA FOR PROFILE LP-2

Horizon			Ap	Bts1	Bts2	Bts3
Depth (cm)			0 - 15	25 - 45	70 - 90	130 - 150
Clay	%		40	64	58	59
Silt	%		12	5	10	8
Very fine sand	%		5	4	4	4
Fine sand	%		14	9	9	9
Medium sand	%		15	10	10	10
Coarse sand	%		7	6	6	7
Very coarse sand	%		7	2	3	3
Total sand	%		48	31	32	33
Texture class			SC	C	C	C
pH H2O		1:2.5	5.9	5.8	5.4	5.5
pH KCl		1:2.5	5.3	5.2	5.4	4.6
EC	mS/cm	1:2.5	0.05	0.03	0.02	0.01
Organic C	%		1.0	0.4	0.2	0.2
Total N	%		0.09	0.03	0.02	0.01
C/N			11	13	10	20
Available P	mg/kg		6	1	1	1
CEC NH4OAc	cmol(+)/kg		7.2	7.2	5.8	5.8
Exch. Ca	cmol(+)/kg		2.1	2.0	1.6	1.7
Exch. Mg	cmol(+)/kg		1.8	1.3	0.8	0.5
Exch. K	cmol(+)/kg		0.54	0.37	0.34	0.33
Exch. Na	cmol(+)/kg		0.10	0.06	0.09	0.10
Exch. H	cmol(+)/kg		-	-	-	-
TEB	cmol(+)/kg		4.5	3.7	2.8	2.6
Base saturation	%		63	51	48	45
CECclay	cmol(+)/kg		18	11	10	10

Profile number : LP-3 Mapping unit: P21
Region : Ruvuma
District : Mbinga
Map sheet no. : 298/3
Coordinates : 35° 9' 24.5" E/10° 52' 48.0" S
Location : 1 km south of Lupilo P/School, along the road to Chipole
Elevation : 980 m asl. **Parent material**: colluvium derived from mixed metamorphic rocks.
Landform : piedmont plain; gently undulating. **Slope**: 4 %; straight
Surface characteristics: **Outcrops**: 0 % **Erosion**: none or slight. **Deposition**: none.
Drainage class: well drained
Described by: J.P. Magoggo, D.N. Kimaro, B.M. Msanya and A.E. Kiwelu on 29/10/94

Soil: Very deep, well drained, red clays with very thin dark reddish brown clay topsoils.

Ah 0 - 10 cm: dark reddish brown (5YR3/4) dry, yellowish red (5YR3/3) moist; clay; soft dry, friable moist, slightly sticky and slightly plastic wet; moderate medium and fine subangular blocks; common medium and many fine pores; many medium and fine roots; clear smooth boundary to

Bts1 10 - 40 cm: red (2.5YR4/6) dry, dark red (2.5YR3/6) moist; clay; soft dry, friable moist, sticky and slightly plastic wet; weak medium subangular blocks; many fine and very fine pores; common coarse and many fine roots; diffuse smooth boundary to

Bts2 40 - 100 cm: red (10R4/8) dry, red (10R4/6) moist; clay; soft dry, friable moist, sticky and slightly plastic wet; weak medium subangular blocks; many fine and very fine pores; few medium and common fine roots; diffuse smooth boundary to

Bts3 100 - 160 cm: red (10R4/6) dry, dark red (10R3/6) moist; clay; soft dry, friable moist, sticky and slightly plastic wet; weak medium subangular blocks; many fine and very fine pores; common fine and very fine roots

SOIL CLASSIFICATION: FAO legend :

ANALYTICAL DATA FOR PROFILE LP-3

Horizon		Ah	Bts1	Bts2	Bts3
Depth (cm)		0 - 10	15 - 35	60 - 80	100 - 140
Clay	%	48	54	57	57
Silt	%	10	9	7	7
Very fine sand	%	9	10	9	8
Fine sand	%	10	12	10	14
Medium sand	%	14	11	10	8
Coarse sand	%	7	6	5	4
Very coarse sand	%	2	2	2	2
Total sand	%	42	41	36	36
Texture class		C	C	C	C
pH H2O	1:2.5	5.3	4.8	4.7	4.9
pH KCl	1:2.5	4.6	4.0	4.1	4.2
EC mS/cm	1:2.5	0.05	0.01	0.01	0.04
Organic C	%	3.2	1.0	0.3	0.2
Total N	%	0.20	0.06	0.03	0.02
C/N		16	17	10	10
Available P	mg/kg	31	6	1	1
CEC NH4OAc	cmol(+)/kg	11.9	9.2	8.5	9.2
Exch. Ca	cmol(+)/kg	2.3	0.6	0.4	0.8
Exch. Mg	cmol(+)/kg	1.9	0.1	0.2	0.5
Exch. K	cmol(+)/kg	0.42	0.10	0.20	0.50
Exch. Na	cmol(+)/kg	0.06	0.06	0.04	0.81
Exch. H	cmol(+)/kg	0.04	0.10	0.20	0.03
TEB	cmol(+)/kg	4.7	0.9	0.8	1.9
Base saturation	%	39	10	9	21
CECclay	cmol(+)/kg	25	17	15	16

Profile number : LP-4 Mapping unit: H1
Region : Ruvuma
District : Mbinga
Map sheet no. : 298/3
Coordinates : 35° 9' 18.7" E/10° 55' 8.0" S
Location : Matengo hill, 3 km from Lupilo P/School
Elevation : 1140 m asl. **Parent material**: mixed metamorphic rocks.
Landform : hill; hilly. **Slope**: 1 %; convex
Surface characteristics: **Outcrops**: 5 % Stones: 5 % **Erosion**: moderate.
Deposition: none.
Drainage class: somewhat excessively drained
Described by: D.N. Kimaro and A.E. Kiwelu on 28/10/94

Soil: Very shallow to shallow, well to somewhat excessively drained, dark reddish brown, gravelly clay loams with very thin dark brown sandy clay loam topsoils.

Ah 0 - 10 cm: strong brown (7.5YR4/6) dry, dark brown (7.5YR4/4) moist; sandy clay loam; slightly hard dry, friable moist, slightly sticky and slightly plastic wet; moderate coarse and medium subangular blocks; many fine and very fine pores; many fine and few medium roots; clear smooth boundary to

Bt 10 - 30 cm: dark red (2.5YR3/6) dry, dark reddish brown (2.5YR3/4) moist; gravelly clay loam; hard dry, friable moist, sticky and plastic wet; moderate medium angular blocks and moderate fine subangular blocks; patchy thin clay + iron (hydr)oxide cutans; many fine and very fine pores; few small angular fresh quartz fragments; few fine and very fine roots; abrupt wavy boundary to

SOIL CLASSIFICATION: FAO legend :

ANALYTICAL DATA FOR PROFILE LP-4

Horizon			Ah	Bt
Depth (cm)			0 - 10	10 - 30
Clay	%		22	39
Silt	%		19	17
Very fine sand	%		9	7
Fine sand	%		16	11
Medium sand	%		14	10
Coarse sand	%		13	10
Very coarse sand	%		7	6
Total sand	%		59	44
Texture class			SCL	CL
pH H2O		1:2.5	5.7	5.8
pH KCl		1:2.5	5.0	4.9
EC mS/cm		1:2.5	0.05	0.03
Organic C	%		1.8	0.5
Total N	%		0.11	0.05
C/N			16	10
Available P	mg/kg		3	1
CEC NH4OAc	cmol(+)/kg		11.7	16.6
Exch. Ca	cmol(+)/kg		4.6	5.8
Exch. Mg	cmol(+)/kg		1.4	2.7
Exch. K	cmol(+)/kg		0.30	0.66
Exch. Na	cmol(+)/kg		0.05	0.06
Exch. H	cmol(+)/kg		-	-
TEB	cmol(+)/kg		6.4	9.2
Base saturation	%		55	55
CECclay	cmol(+)/kg		53	43
ESP	%		4	

Profile number : LP-5 Mapping unit: H2
Region : Ruvuma
District : Mbinga
Map sheet no. : 298/3
Coordinates : 35° 9' 24.5" E/10° 54' 5.8" S
Location : Matengo hill, about 2.5 km from Lupilo P/School
Elevation : 1080 m asl. **Parent material**: mixed metamorphic rocks.
Landform : hill; hilly. **Slope**: 45 %; straight
Surface characteristics: **Outcrops**: 50 % **Erosion**: moderate. **Deposition**: none.
Drainage class: well drained
Described by: B.M. Msanya, D.N. Kimaro, D.N. Kimaro and A.E. Kiwelu on 20/10/94

Soil: Very shallow, well to somewhat excessively drained dark reddish brown clays with very thin brown clay loam topsoils.

Ah 0 - 10 cm: brown (7.5YR4/4) dry, dark brown (7.5YR3/4) moist; clay loam; hard dry, friable moist, slightly sticky and slightly plastic wet; moderate medium and fine subangular blocks; many very fine and fine pores; many medium and fine roots; gradual smooth boundary to

Bt1 10 - 25 cm: dark red (2.5YR3/6) dry, dark reddish brown (2.5YR3/4) moist; clay loam; hard dry, firm moist, sticky and plastic wet; strong coarse and medium angular blocks; many fine and very fine pores; few medium angular fresh quartz fragments; frequent small irregular hard Fe & Mn nodules; few very fine and fine roots; diffuse smooth boundary to

Bt2 25 - 40 cm: dark red (2.5YR3/6) dry, dark reddish brown (2.5YR3/4) moist; clay; hard dry, firm moist, sticky and plastic wet; strong medium and fine angular blocks; many fine and very fine pores; few medium angular weathered granite fragments; frequent small spherical hard feldspar nodules; few very fine roots

SOIL CLASSIFICATION: FAO legend :

ANALYTICAL DATA FOR PROFILE LP-5

Horizon		Ah	Bt1	Bt2
Depth (cm)		0 - 10	10 - 25	25 - 40
Clay	%	29	40	64
Silt	%	31	27	19
Very fine sand	%	11	10	5
Fine sand	%	15	12	6
Medium sand	%	7	5	3
Coarse sand	%	5	4	2
Very coarse sand	%	2	2	1
Total sand	%	40	33	17
Texture class		CL	CL	C
pH H2O	1:2.5	6.1	6.0	6.1
pH KCl	1:2.5	5.2	5.0	4.9
EC mS/cm	1:2.5	0.07	0.06	0.03
Organic C	%	3.1	1.1	0.6
Total N	%	0.18	0.12	0.06
C/N		17	9	10
Available P	mg/kg	2	1	1
CEC NH4OAc	cmol(+)/kg	18.3	20.2	29.7
Exch. Ca	cmol(+)/kg	7.2	9.2	13.7
Exch. Mg	cmol(+)/kg	3.5	3.2	6.4
Exch. K	cmol(+)/kg	0.91	0.62	0.64
Exch. Na	cmol(+)/kg	0.08	0.07	0.06
Exch. H	cmol(+)/kg	-	-	-
TEB	cmol(+)/kg	11.7	13.1	20.8
Base saturation	%	64	65	70
CECclay	cmol(+)/kg	63	51	46

Profile number : LP-6 Mapping unit: V2
Region : Ruvuma
District : Mbinga
Map sheet no. : 298/3
Coordinates : 35° 12' 1.1" E/10° 52' 18.1" S
Location : Kiyogawali. RC Sisters' farm
Elevation : 850 m asl. **Parent material**: colluvio-alluvium derived from mixed metamorphic rocks.
Landform : (closed) depression; gently undulating. **Slope**: 1 %; straight
Surface characteristics: **Outcrops**: 0 % **Erosion**: none or slight. **Deposition**: none.
Drainage class: well drained
Described by: D.N. Kimaro and A.E. Kiwelu on 31/10/94

Soil: Very deep, well drained, dark brown to dark yellowish brown sandy clay loams with dark brown clay topsoils

Ah 0 - 20 cm: brown (7.5YR4/2) dry, dark brown (7.5YR3/2) moist; clay; hard dry, friable moist, sticky and plastic wet; moderate medium and fine subangular blocks; common medium and many fine pores; many fine and medium roots; gradual smooth boundary to

Bw 20 - 40 cm: dark reddish brown (5YR3/4) dry, dark reddish brown (5YR3/3) moist; clay; hard dry, friable moist, sticky and plastic wet; moderate medium and fine subangular blocks; common medium and many fine pores; common coarse and many medium roots; abrupt smooth boundary to

2ABb 40 - 55 cm: reddish brown (5YR4/3) dry, dark reddish brown (5YR3/3) moist; sandy clay loam; hard dry, friable moist, sticky and plastic wet; weak coarse and medium subangular blocks; many fine and very fine pores; few small irregular weathered fragments; few coarse and many medium roots; abrupt smooth boundary to

2Bt1 55 - 75 cm: strong brown (7.5YR4/6) dry, dark brown (7.5YR4/4) moist; sandy clay loam; hard dry, friable moist, sticky and plastic wet; weak coarse and medium subangular blocks; many fine and very fine pores; few small irregular weathered fragments; few small irregular hard feldspar nodules; common fine and very fine roots; gradual smooth boundary to

2Bt2 75 - 100 cm: dark yellowish brown (10YR4/6) dry, dark yellowish brown (10YR4/4) moist; sandy clay loam; hard dry, friable moist, sticky and plastic wet; weak coarse and medium subangular blocks; many fine and very fine pores; frequent large irregular slightly weathered granite fragments; frequent medium irregular hard Fe & Mn nodules; few fine and very fine roots; diffuse smooth boundary to

2Bt3 100 - 145 cm: dark yellowish brown (10YR4/6) dry, dark yellowish brown (10YR3/6) moist; sandy clay loam; hard dry, friable moist, sticky and plastic wet; weak coarse and medium subangular blocks; many fine and very fine pores; frequent large irregular slightly weathered fragments; frequent medium irregular hard Fe & Mn nodules; few fine and very fine roots

SOIL CLASSIFICATION: FAO legend :

ANALYTICAL DATA FOR PROFILE LP-6

Horizon		Ah	Bw	2ABb	2Bt1	2Bt2	2Bt3
Depth (cm)		0 - 20	20 - 40	40 - 55	55 - 75	80 - 100	120 - 140
Clay	%	45	48	28	29	34	25
Silt	%	16	15	12	12	9	11
Very fine sand	%	-	8	10	11	10	10
Fine sand	%	22	14	23	24	22	24
Medium sand	%	10	10	17	17	17	20
Coarse sand	%	4	4	8	6	6	8
Very coarse sand	%	3	1	2	1	2	2
Total sand	%	39	37	60	59	57	64
Texture class		C	C	SCL	SCL	SCL	SCL
pH H2O	1:2.5	5.5	5.4	5.4	5.4	5.7	6.0
pH KCl	1:2.5	4.5	4.7	4.4	4.3	4.6	4.8
EC mS/cm	1:2.5	0.05	0.04	0.02	0.02	0.01	0.02
Organic C	%	3.4	1.6	1.4	0.8	0.4	0.3
Total N	%	0.19	0.11	0.08	0.06	0.04	0.02
C/N		18	15	18	13	10	15
Available P	mg/kg	20	3	1	1	1	17
CEC NH4OAc	cmol(+)/kg	27.8	26.5	16.3	15.8	17.3	12.7
Exch. Ca	cmol(+)/kg	10.7	8.0	3.6	4.1	5.3	3.4
Exch. Mg	cmol(+)/kg	1.8	3.6	3.0	2.1	3.4	0.5
Exch. K	cmol(+)/kg	0.42	0.50	0.26	0.53	0.32	0.10
Exch. Na	cmol(+)/kg	0.04	0.06	0.05	0.08	0.07	0.05
Exch. H	cmol(+)/kg	-	0.07	0.05	0.05	-	-
TEB	cmol(+)/kg	13.0	12.2	6.9	6.8	9.1	4.1
Base saturation	%	47	46	42	48	52	32
CECclay	cmol(+)/kg	62	55	58	54	51	51

Profile number : LP-7 Mapping unit: P22
Region : Ruvuma
District : Mbinga
Map sheet no. : 298/3
Coordinates : 35° 11' 19.7" E/10° 52' 8.0" S
Location : Kiyogawali, RC Kilimo/Mifugo farm, 1 km from the camps
Elevation : 920 m asl. **Parent material**: mixed metamorphic rocks.
Landform : piedmont plain; gently undulating. **Slope**: 3 %; straight
Surface characteristics: **Erosion**: none or slight. **Deposition**: none.
Drainage class: well drained
Described by: J.P. Magoggo, D.N. Kimaro, B.M. Msanya and A.E. Kiwelu on 31/10/94

Soil: Very deep, well drained red clays with very thin red sandy clay topsoil

Ap 0 - 15 cm: red (10R4/6) dry, red (10R4/6) moist; sandy clay; hard dry, friable moist, sticky and plastic wet; moderate medium and fine subangular blocks; common medium and many fine pores; common fine and very fine roots; gradual smooth boundary to

Bts1 15 - 40 cm: red (10R4/6) dry, red (10R4/6) moist; clay; hard dry, friable moist, sticky and plastic wet; moderate fine and medium subangular blocks; many fine and very fine pores; few small spherical hard feldspar nodules; few coarse and common fine roots; gradual smooth boundary to

Bts2 40 - 85 cm: red (10R4/8) dry, red (10R4/6) moist; clay; slightly hard dry, friable moist, sticky and plastic wet; weak medium and fine subangular blocks; many fine and very fine pores; frequent medium irregular hard feldspar nodules; few fine and very fine roots; diffuse smooth boundary to

Bts3 85 - 120 cm: red (10R4/8) dry, red (10R4/6) moist; clay; soft dry, very friable moist, slightly sticky and plastic wet; weak medium subangular blocks; many fine and very fine pores; frequent medium spherical hard feldspar nodules; few fine and very fine roots; diffuse smooth boundary to

Bts4 120 - 170 cm: red (10R4/8) dry, red (10R4/6) moist; clay; soft dry, very friable moist, slightly sticky and plastic wet; weak medium subangular blocks; many fine and very fine pores; frequent medium spherical hard feldspar nodules; few fine and very fine roots

SOIL CLASSIFICATION: FAO legend :

ANALYTICAL DATA FOR PROFILE LP-7

Horizon		Ap	Bts1	Bts2	Bts3	Bts4
Depth (cm)		0 - 10	20 - 35	45 - 80	90 - 110	130 - 160
Clay	%	37	60	63	58	61
Silt	%	10	9	6	9	9
Very fine sand	%	11	8	8	9	9
Fine sand	%	26	14	14	15	12
Medium sand	%	13	7	6	6	5
Coarse sand	%	3	2	2	2	2
Very coarse sand	%	-	-	1	1	2
Total sand	%	53	31	31	33	30
Texture class		SC	C	C	C	C
pH H2O	1:2.5	5.7	5.3	5.5	5.4	5.4
pH KCl	1:2.5	4.9	4.7	5.2	5.0	5.0
EC mS/cm	1:2.5	0.07	0.02	0.01	0.01	0.01
Organic C	%	1.4	0.4	0.2	0.2	0.2
Total N	%	0.08	0.03	0.02	0.01	0.01
C/N		18	13	10	20	20
Available P	mg/kg	25	1	1	1	1
CEC NH4OAc	cmol(+)/kg	6.7	7.6	7.6	7.3	7.6
Exch. Ca	cmol(+)/kg	2.5	1.5	1.9	1.7	2.5
Exch. Mg	cmol(+)/kg	0.5	1.0	1.3	0.8	0.4
Exch. K	cmol(+)/kg	0.50	0.31	0.29	0.54	0.19
Exch. Na	cmol(+)/kg	0.04	0.05	0.05	0.06	0.04
Exch. H	cmol(+)/kg	-	0.09	-	0.05	0.05
TEB	cmol(+)/kg	3.5	2.9	3.5	3.1	3.1
Base saturation	%	52	38	46	42	41
CECclay	cmol(+)/kg	18	13	12	13	12

Profile number : LP-8 Mapping unit: H2
Region : Ruvuma
District : Mbinga
Map sheet no. : 298/3
Coordinates : 35° 8' 20.4" E/10° 53' 46.0" S
Location : 1.5 km north of village office, along the road to Kitanda.
Elevation : 1140 m asl. **Parent material**: mixed metamorphic rocks.
Landform : hill; hilly. **Slope**: 52 %; straight
Surface characteristics: **Outcrops**: 2 % Stones: 10 % **Erosion**: moderate.
Deposition: none.
Drainage class: somewhat excessively drained
Described by: B.M. Msanya, J.P. Magoggo, D.N. Kimaro and A.E. Kiwelu on 31/10/94

Soil: Very shallow to shallow, excessively drained drk brown, extremely gravelly clays. In places rock outcrops, stones and gravel appear at or near the surface.

Ah 0 - 12 cm: light brown (7.5YR6/4) dry, brown (7.5YR5/4) moist; gravelly sandy loam; soft dry, very friable moist, slightly sticky and plastic wet; weak medium subangular blocks; common medium and many fine pores; frequent small irregular fresh fragments; few medium and many fine roots; abrupt smooth boundary to

Bw1 12 - 33 cm: strong brown (7.5YR5/6) dry, dark brown (7.5YR4/4) moist; very gravelly sandy clay loam; hard dry, friable moist, sticky and plastic wet; weak medium subangular blocks; many fine and very fine pores; frequent medium irregular fresh fragments; common fine and very fine roots; gradual smooth boundary to

Bw2 33 - 50 cm: strong brown (7.5YR5/6) dry, dark brown (7.5YR4/4) moist; very gravelly sandy clay loam; hard dry, friable moist, sticky and plastic wet; weak medium subangular blocks; many fine and very fine pores; frequent small irregular fresh quartz fragments; common fine and very fine roots; abrupt smooth boundary to

SOIL CLASSIFICATION: FAO legend :

ANALYTICAL DATA FOR PROFILE LP-8

Horizon			Ah	Bw1	Bw2
Depth (cm)			0 - 12	12 - 33	33 - 50
Clay	%		18	25	32
Silt	%		20	19	17
Very fine sand	%		10	8	7
Fine sand	%		14	12	10
Medium sand	%		13	11	10
Coarse sand	%		13	13	12
Very coarse sand	%		12	12	12
Total sand	%		62	56	51
Texture class			SL	SCL	SCL
pH H2O		1:2.5	5.8	5.6	5.8
pH KCl		1:2.5	5.2	4.5	4.5
EC mS/cm		1:2.5	0.07	0.03	0.02
Organic C	%		2.4	0.7	0.5
Total N	%		0.13	0.04	0.05
C/N			18	18	10
Available P	mg/kg		5	1	1
CEC NH4OAc	cmol(+)/kg		7.3	6.4	7.0
Exch. Ca	cmol(+)/kg		2.5	2.0	1.8
Exch. Mg	cmol(+)/kg		1.3	0.8	1.2
Exch. K	cmol(+)/kg		0.40	0.41	0.41
Exch. Na	cmol(+)/kg		0.30	0.31	0.91
Exch. H	cmol(+)/kg		-	-	-
TEB	cmol(+)/kg		4.5	3.5	4.3
Base saturation	%		62	55	62
CECclay	cmol(+)/kg		41	26	22
ESP	%		4	5	13

Profile number : LP-9 Mapping unit: V1
Region : Ruvuma
District : Mbinga
Map sheet no. : 298/3
Coordinates : 35° 9' 28.8" E/10° 53' 17.2" S
Location : Namangwina. 1 km east of Lupilo P/School.
Elevation : 900 m asl. **Parent material**: alluvio-colluvium derived from mixed metamorphic rocks.
Landform : alluvial/flood plain; flat or almost flat. **Slope**: 1 %; straight
Surface characteristics: **Erosion**: none or slight. **Deposition**: none.
Drainage class: imperfectly drained
Described by: B.M. Msanya, J.P. Magoggo, D.N. Kimaro on 01/11/94

Soil: Very deep, moderately well to imperfectly drained brown and dark yellowish brown, stratified mottled loams

Ah 0 - 15 cm: yellowish brown (10YR5/4) dry, dark yellowish brown (10YR4/4) moist; clay loam; slightly hard dry, weak coarse and medium subangular blocks; many fine and very fine pores; frequent small angular fresh mica fragments; many medium and fine roots; abrupt smooth boundary to

2Cg 15 - 30 cm: dark brown (7.5YR3/4) dry, dark brown (7.5YR3/2) moist; loam; common medium distinct clear mottles; slightly hard dry, porous massive; few medium and many fine pores; frequent small angular fresh mica fragments; common medium and many fine roots; abrupt smooth boundary to

3Cg 30 - 55 cm: dark brown (10YR4/3) moist; clay loam; many coarse prominent sharp mottles; firm moist, porous massive; many fine and very fine pores; frequent small angular fresh mica fragments; common medium and many fine roots; clear smooth boundary to

4Cg 55 - 70 cm: brown (10YR5/3) moist; sandy loam; common coarse distinct clear mottles; firm moist, porous massive; many fine and very fine pores; frequent small angular fresh mica fragments; common fine and very fine roots; clear smooth boundary to

5Cg 70 - 90 cm: dark yellowish brown (10YR4/4) moist; sandy clay loam; common medium distinct clear mottles; firm moist, porous massive; many fine and very fine pores; frequent small angular fresh mica fragments; common fine and very fine roots; clear smooth boundary to

6Cg 90 - 110 cm: brown (10YR4/3) moist; sandy clay loam; many medium distinct clear mottles; firm moist, porous massive; common fine and very fine pores; frequent small angular fresh mica fragments; few fine and medium roots; gradual smooth boundary to

7Cg 110 - 160 cm: brown (7.5YR5/4) moist; clay loam; many coarse prominent sharp mottles; firm moist, porous massive; common fine and very fine pores; frequent small angular fresh mica fragments; few fine and very fine roots

SOIL CLASSIFICATION: FAO legend :

ANALYTICAL DATA FOR PROFILE LP-9

Horizon		Ah	2Cg1	3Cg1	4Cg3	5Cg4	6Cg5	7Cg6
Depth (cm)		0 - 15	15 - 30	35 - 55	55 - 70	70 - 90	90 - 110	120 - 140
Clay	%	30	26	35	18	23	29	38
Silt	%	41	34	31	16	17	24	23
Very fine sand	%	10	11	12	15	16	15	12
Fine sand	%	10	12	15	32	28	20	17
Medium sand	%	5	7	1	15	13	8	8
Coarse sand	%	3	4	6	3	3	3	2
Very coarse sand	%	1	6	-	1	-	1	-
Total sand	%	29	40	34	66	60	47	39
Texture class		CL	L	CL	SL	SCL	SCL	CL
pH H2O	1:2.5	5.7	5.8	5.7	5.4	5.0	4.8	5.0
pH KCl	1:2.5	5.0	5.0	4.7	4.3	3.8	3.6	3.6
EC mS/cm	1:2.5	0.10	0.06	0.03	0.01	0.01	0.01	0.01
Organic C	%	3.1	1.8	0.8	0.5	0.5	0.4	0.3
Total N	%	0.24	0.13	0.06	0.03	0.04	0.03	0.02
C/N		13	14	13	17	13	13	15
Available P	mg/kg	1	1	1	1	1	1	1
CEC NH4OAc	cmol(+)/kg	23.5	18.7	22.8	11.9	15.0	18.4	23.7
Exch. Ca	cmol(+)/kg	8.8	8.3	8.3	2.9	2.6	2.1	4.2
Exch. Mg	cmol(+)/kg	2.8	2.4	3.7	1.7	1.3	1.2	2.6
Exch. K	cmol(+)/kg	0.71	0.32	0.19	0.09	0.19	0.20	0.16
Exch. Na	cmol(+)/kg	0.08	0.04	0.06	0.05	0.06	0.05	0.07
Exch. H	cmol(+)/kg	-	-	-	0.05	0.20	0.21	0.31
TEB	cmol(+)/kg	12.4	11.1	12.3	4.7	4.2	3.6	7.0
Base saturation	%	53	59	54	39	28	20	30
CECclay	cmol(+)/kg	78	72	65	66	65	63	62

Profile number : LP-10 Mapping unit: P11
Region : Ruvuma
District : Mbinga
Map sheet no. : 298/3
Coordinates : 35° 8' 1.0" E/10° 53' 27.6" S
Location : Makambako. 1 km west of the road to Kitanda - Chopole road
Elevation : 1020 m asl. **Parent material**: colluvium derived from mixed metamorphic rocks.
Landform : piedmont plain; rolling. **Slope**: 12 %; straight
Surface characteristics: **Erosion**: none or slight. **Deposition**: none.
Drainage class: well drained
Described by: J.P. Magoggo, B.M. Msanya, D.N. Kimaro and A.E. Kiwelu on 01/11/94

Soil: Very deep, well drained, dark red clays with moderately thick man-made dark reddish brown clay loam topsoils ("Ngoro horizon"). The "ngoro horizon" is comparatively young. It is thin and less dark.

Ap 0 - 18 cm: reddish brown (5YR3/4) dry, dark reddish brown (5YR3/3) moist; clay loam; hard dry, friable moist, sticky and plastic wet; moderate fine and medium subangular blocks; few coarse and many fine pores; common fine and very fine roots; clear wavy boundary to

Bt1 18 - 40 cm: dark red (2.5YR3/6) dry, dark reddish brown (2.5YR3/4) moist; clay; hard dry, friable moist, sticky and plastic wet; moderate medium angular blocks and moderate fine subangular blocks; patchy thin clay + iron (hydr)oxide cutans; many fine and very fine pores; frequent small irregular hard Fe & Mn nodules; few fine and very fine roots; gradual smooth boundary to

Bt2 40 - 80 cm: red (10R4/6) dry, dark red (10R3/6) moist; clay; hard dry, friable moist, sticky and plastic wet; moderate medium angular blocks and moderate fine subangular blocks; patchy thin clay + iron (hydr)oxide cutans; many fine and very fine pores; few medium angular fresh quartz fragments; frequent medium irregular hard Fe & Mn nodules; few fine and very fine roots; diffuse smooth boundary to

Bt3 80 - 120 cm: dark red (10R4/6) dry, duskyred (10R3/4) moist; clay; hard dry, friable moist, sticky and plastic wet; moderate medium angular blocks and moderate fine subangular blocks; patchy thin clay + iron (hydr)oxide cutans; many fine and very fine pores; frequent small irregular weathered fragments; frequent small irregular hard Fe & Mn nodules; few very fine roots; diffuse smooth boundary to

Bt4 120 - 160 cm: dusky red (10R3/4) moist; clay; slightly hard dry, friable moist, sticky and plastic wet; moderate medium angular blocks and moderate fine subangular blocks; patchy thin clay + iron (hydr)oxide cutans; common fine and very fine pores; frequent small irregular weathered fragments; frequent small irregular hard Fe & Mn nodules; few very fine roots

SOIL CLASSIFICATION: FAO legend :

ANALYTICAL DATA FOR PROFILE LP-10

Horizon		Ap	Bt1	Bt2	Bt3	Bt4
Depth (cm)		0 - 20	20 - 40	50 - 70	90 - 110	130 - 150
Clay	%	38	62	71	69	67
Silt	%	18	12	7	9	11
Very fine sand	%	20	5	4	4	5
Fine sand	%	5	8	6	7	7
Medium sand	%	11	6	5	5	5
Coarse sand	%	6	5	4	4	3
Very coarse sand	%	2	2	3	2	2
Total sand	%	44	26	22	22	22
Texture class		CL	C	C	C	C
pH H2O	1:2.5	6.1	6.0	5.7	5.7	5.6
pH KCl	1:2.5	5.3	5.0	5.3	5.4	5.4
EC mS/cm	1:2.5	0.10	0.05	0.03	0.02	0.01
Organic C	%	2.3	1.1	0.4	0.2	0.2
Total N	%	0.17	0.08	0.04	0.02	0.02
C/N		14	14	10	10	10
Available P	mg/kg	26	2	1	1	1
CEC NH4OAc	cmol(+)/kg	15.0	20.8	21.4	20.5	19.8
Exch. Ca	cmol(+)/kg	8.5	7.8	6.7	8.0	7.5
Exch. Mg	cmol(+)/kg	1.1	4.9	4.6	2.7	2.6
Exch. K	cmol(+)/kg	0.78	0.48	0.49	0.65	0.54
Exch. Na	cmol(+)/kg	0.04	0.09	0.08	0.05	0.05
Exch. H	cmol(+)/kg	-	-	-	-	-
TEB	cmol(+)/kg	10.4	13.3	11.9	11.4	10.7
Base saturation	%	69	64	56	56	54
CECclay	cmol(+)/kg	39	34	30	30	30
ESP	%		5			

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

(Compiled from Baize (1993), EUROCONSULT (1989) and Landon (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 acid	pH 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_20 of the soil is less than 7.0. In soils with a pH H_20 of more than 7.0 the Olsen method is used.

4. Cation exchange capacity (CEC)

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

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

5. Exchangeable calcium

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

6. Exchangeable magnesium

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

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

7. Exchangeable K

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

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

8. Exchangeable sodium

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

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

9. Soil sodicity

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

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

10. Basic infiltration rate (IR)

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

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

11. Available water capacity (AWC)

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

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

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.