PEDOLOGICAL INVESTIGATION AND CHARACTERIZATION IN LITEMBO VILLAGE, MBINGA DISTRICT, TANZANIA

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ABSTRACT

A pedological investigation was carried out in Litembo village, Mbinga district (Tanzania) to identify the various soil types and characterize them in terms of their physical, chemical and mineralogical properties. The soils were classified according to FAO-Unesco and USDA Soil Taxonomy systems. On the basis of soil and other ecological parameters the potentials and constraints of the land resources were assessed.

Standard soil survey methods and laboratory procedures were utilised to generate both field and laboratory data.

Results indicate that Litembo village has four major landforms i.e. plateaux, hills, piedmonts and valleys Most piedmont soils are deep to very deep having dark brown to dark reddish brown sandy clay topsoils and dark red to red clayey subsoils. The hills and plateaux have shallow sandy clay loam soils. All the studied soils are well drained to excessively well drained except those of the valley bottoms which are poorly drained.

Topsoil bulk densities range from 0.99 to 1.2 Mg m^{-3} whereas subsoil values are slightly higher. Total porosity ranges from 56 to 72% in the topsoils and from 40 to 53% in the subsoils. Topsoils have lower penetrometer resistance (PR values 0.1 to 0.28 MPa) than subsoil (PR values 3.97 - 5.52 MPa). Available water capacity (AWC) of most topsoils ranges from 15 to 25% by volume and the values decrease slightly with depth. AWC per meter range from 125 to 177 mm which is medium to high.

General soil fertility status is poor. Soil reaction is very strongly acid to strong acid with pH values between 4.4 and 5.4 in topsoils and 4.4 and 6.0 in subsoils. Total nitrogen ranges from very low to medium (< 0.03 - 0.3); phosphorus, bases, CEC and base saturation are low. OC ranges from low to very high in topsoils and very low in subsoils. The clay mineralogy is dominantly kaolinitic with accessory amounts of gibbsite and goethite. The piedmont soils classified as Ferric Acrisols, Haplic Acrisols and Humic Acrisols; plateau soils classified as Humic Acrisols; soils of the as Dystric Leptosols and Haplic Acrisols and valley bottom soils as Umbric Fluvisols.

From the results of this study it is concluded that Litembo soils developed under intensive leaching environment, facilitated by a mountainous/hilly topography. Fertility status is poor, and due to steep slopes and weak soil structure Litembo soils are prone to erosion. The traditional farming system (ngoro) seems to control soil erosion on steep slopes. It is recommended that steep slopes should be planted with trees that will protect soil from erosion. Use of the traditional farming system (ngoro) should be encouraged. Due to low soil fertility status, use of fertilizers both artificial and organic manures is recommended. Non-acidifying fertilizers should be preferable because of the low soil pH values. The study area lacks climatic data. More research in this line is recommended. Research on different land use alternatives which can sustainably be applicable in the village should be carried out.

DECLARATION

I, JOEL LOITU MELIYO, do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my own original work and that it has never been submitted for a degree in any other university.

Date 26 - 8 - 1997 Signature JMeliyo

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

A	= Angstrom
Al	= Aluminium
AWC	= Available water capacity
FAO	= Food and Agricultural Organization of the United Nations
Fe	= Iron
Fe_d	= dithionite exctractable iron
Fe_o	= oxalate extractable iron
Ca	= Calcium
CEC	= Cations exchange capacity
CEC_{clay}	= Cations exchange capacity clay
CEC_{soil}	= Cation exchange capacity soil
K	= Potassium
LTP	= Litembo profile
Mg	= Magnesium
MPa	= Megapascal
MU	= Mapping units
Na	= Sodium
OC	= organic carbon
PR	= Penetrometer resistance
TEB	= Total exchangeable bases
USDA	= United States Department of Agriculture
Unesco	= United Nations Education and Scientific Organization

CHAPTER ONE

1.0 INTRODUCTION

Land resources data obtained through systematic land and soil characterization are a pre-requisite when sound interpretation towards land use potentials are to be made (Cline, 1949, 1963, 1978; Young, 1976; Dent and Young, 1981; "unpublished, Msanya *et al.*, 1995c;"). Such data are important in the assessment of ecological potentials and constraints for various land uses and permit the development of sound environmental conservation strategies ("unpublished, Msanya *et al.,* 1995a,c" ; Msanya *et al.*, 1995b).

In Tanzania, information on land and soil resources is inadequate (Msanya and Magoggo, 1993). Historical evolution shows that since early times attention has been paid to land and soil assessment based on utility and usefulness for production of specific crops like coffee, tobacco and cotton (Magoggo, 1993). Suitability assessment of soils for crops took into consideration factors such as texture, soil colour, availability of water, slope of the land, soil depth and crop yield. Apparently no detailed pedological investigations were made.

Soil information acquisition for national planning during the colonial era started when Milne (1935) produced a map at a scale of 1:4 million. Several other maps were produced by Calton (1954), Anderson (1967) and Hathout (1972) as an improvement of Milne's work. The documents were all of very small scales, using Milne's *catena* concept and land systems to define mapping units. These works in general lack the basic information necessary to make assessment on the changes that are likely to occur on soils because of different management practices. Information on soil genesis, profile morphological characteristics and mineralogy that are basic for proper soil management are lacking in these works.

The existing national soil inventories by Samki (1983) and De Pauw (1984) inherited similar weaknesses because both do not have enough field data. De Pauw (1984) for example reported that. southern Tanzania could not be surveyed due to fuel problems and time lag, thus the information presented in his work was just an extrapolation from previous works and/or air photographs. The southern part of Tanzania with extrapolated soil information includes Ruvuma region.

More useful information for district and regional planning was generated in 1970s (Magoggo, 1993) as an effort by the government to acquire necessary data for land use planning, management and environmental protection. Several regions were surveyed at reconnaissance scale (1:500,000). However, the available regional and district land and soil resources information cover only a small part of the country and at details that are not sufficient for sound land use planning and management (Msanya and Magoggo, 1993). Most areas that have not been covered have potential for agricultural production and simultaneously face serious land and soil resources degradation due to increasing population (Msanya *et al.,* 1995b). These areas include the named *big four* regions i.e. Iringa, Mbeya, Rukwa and Ruvuma that are known to have high potential for cash and food crop production. However, soil information in the mentioned areas is inadequate or sometimes lacking (De Pauw, 1984) to permit proper evaluation of their potentials.

Ruvuma region (where the current study has been carried out) is a big producer of cash crops like tobacco and coffee which are major foreign exchange earners in the country. The region also produces cereals including maize, wheat and sorghum for local market. However, the region suffers from lots of problems of land

and soil degradation because of land clearing for crop production and other related human activities. The problems of land and soil degradation are more serious in the mountainous and hilly areas of Mbinga district. These areas were originally under diverse natural forest i.e. *Afromontane* rain and *undifferentiated* forest (Mchau, 1993; Mwihomeke *et al.*, 1991) in the highlands and *Miombo woodland* in the low hills. It is currently highly deforested due to wood harvesting for fuel, building poles and shifting cultivation for crop production, particularly in the densely populated mountain areas (Mchau, 1993). Land clearing is a threat to upkeep of agriculture, forestry, public works and the total environment in Mbinga district. Of late, the increasing anthropogenic intervention in the hilly water catchment segments with the ever increasing population, has further aggravated the problem of land degradation. The resultant effects of peasantry practices of shifting cultivation which involve a lot of deforestation of these areas has resulted in serious ecological hazards like gully erosion and other ecological imbalances in natural resources accompanied by sharp decline of soil productivity (Alegre and Cassel, 1986). Similar observations have been reported elsewhere within Ruvuma region and the rest of the Miombo woodland areas (Msanya *et al.*, 1995b).

The current study was initiated in Litembo, one of the villages in Matengo highlands of Mbinga district, in Ruvuma region. Some preliminary studies show that this area is highly prone to both physical and chemical land degradation ("unpublished, Kimaro *et al.*, 1996"). The overall objective of the current study was to carry out a detailed pedological investigation and characterization in Litembo village, to provide the needed land and soil resources information and data for proper land use planning, management and sustainable use of natural resources in general.

It was also envisaged that data emanating from this study could be useful and transferable to areas with similar ecological conditions in Mbinga and elsewhere in the country. The specific objectives were to:

1} identify the various soil types of Litembo village,

2} characterize in detail the different soils in terms of their physical and chemical properties,

3} study the clay mineralogy of soils of the village,

4} classify the soils of Litembo using the two international soil classification systems commonly used in Tanzania i.e. FAO -Unesco and Soil Taxonomy systems, and

5} highlight on the potentials and constraints of the land and soil resources of the village on the basis of soil properties and other ecological properties.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1. PEDOGENESIS

Soil is the product of the interaction of five factors i.e. (1) parent material (2) organisms i.e. vegetation and animals (3) Relief/topography (4) climate, and (5) geological time. These factors were first stipulated by Dokuchaev (1898) and later elaborated by Jenny (1941). The variations between soil forming factors are potential for creating different kinds of soils (Birkeland, 1984).

A study of soil genesis leads to an understanding of how soils developed, why soils differ in their properties and their productivity, and how soils can be managed for various uses. This information is also needed to understand the geographic distribution of soils and their mapping (Foth, 1984; Fitzpatrick, 1984). In studying the influence of variations in each factor on soil properties other factors are assumed constant (Foth and Turk, 1972).

2.1.1. Factors of soil formation

Parent material

In pedology all rocks from which soils are formed are called soil-forming rocks or parent rocks (Zonn, 1986). This concept was introduced by Dokuchaev (1898) to explain the importance of rocks in soil formation. Jenny (1941) defined soil parent material as the "state of the soil system at time zero of soil formation". Soil Survey Staff (1975) defined parent material as "unconsolidated mass from which the solum develops. It includes the C horizon and horizons above." Parent material may develop from weathered rocks, alluvial deposits, aeolian material and organic residues (Foth and Turk, 1972; Soil Survey Staff, 1975; Fitzpatrick, 1984; Buol *et al.*, 1984).

Rocks of different origins, different petrographic and mineralogical composition give rise to different parent materials; and the formation of secondary soil clay minerals and their chemical composition will also differ as function of the kind of parent material (Wilson, 1975; Loveland and Bullock, 1976; Paton, 1978). Properties of rocks are reflected in the morphological and physical properties of soils such as their thickness, consistency and texture (van Wambeke, 1991). Under tropical conditions, rocks of different compositions and properties undergo deep transformation, into a homogeneous kaolinite- enriched products of weathering (Zonn, 1986; Buol *et al.*, 1984). In Tanzania, the most important rocks are unconsolidated marine sediments, strongly weathered terrestrial sediments of Karoo age, sandstone, limestones, dolomites, granites, gneisses of various mineral compositions, schists, ferromagnesian rocks and volcanic ash (Government of Tanzania (GoT), 1976; Samki, 1989).

The composition of parent material especially with regard to the content of weatherable minerals, and their ease of weathering determines the rate of physical and chemical weathering of rocks to form soils (Loughnan, 1969; Fitzpatrick, 1984; van Wambeke, 1991). This means that the composition of parent material will influence the rate of soil maturity (van Wambeke, 1991).

In early stages of soil formation rocks are degraded to saprolite (Calvert *et al.*, 1980; Rice *et al.*, 1985; Rebertus *et al.*, 1986). The saprolite shows some relationship with parent rock but, under tropical conditions, saprolite is subjected to various pedogenic processes such that at advanced stage of soil formation it is very difficult to establish a genetical relationships between rocks and the weathering crust and formed soil (Buol *et al.*, 1984; Zonn, 1986). In general, the younger the soil the greater the influence of parent material to soil properties (Buol, *et al.*, 1984).

Strongly weathered sediments cover the underlying igneous and metamorphic rocks on the continental shield areas of much of South America and Africa. The sediments are characterized by inclusion of one or several layers of pediment gravels, hillwash and stone lines (Foster *et al.*, 1971; Sanchez, 1976). They range in thickness from one metre to several metres. The material has attained a high degree of weathering by passing through one or more weathering and pedogenic cycles (Loughnan, 1969; Buol *et al.*, 1984; Fitzpatrick, 1984). Iron content is relatively high. Many of these sediments have high clay contents and the silicate clays present are usually 1:1 kaolinite type; the gibbsite content may be relatively high.

Sandstones (orthoquartzites or quartzose sandstone) contain over 50 percent sand-size particles mostly quartz, cemented by silica, iron and carbonates, with impurities such as feldspars and mica. The soils formed from these rocks are of coarse texture and highly permeable. They have low base status, low nutrient reserve and acidic pH particularly in the tropics where high precipitation promotes leaching. These soils tend to be deep and red in colour due to presence of iron.

Light coloured rocks include more "acidic" quartzose igneous and metamorphic rocks. They are divided into two broad groups according to their mineralogical composition. *Granite and granite gneiss* consist of approximately 25 % quartz, 65 % or less orthoclase with less amounts of mica and hornblende (Buol *et al.*, 1984). These rocks show differences in weathering pattern due to differences in structure; the gneisses being banded, with mineral segregation in the bands (Loughnan, 1969) and therefore easily weathered.

Basically, both *granite* and *granite gneiss* tend to produce the same kinds of soils. Soils formed from saprolite derived from these rocks by geochemical weathering tend to be coarse loamy, friable and permeable, generally acid and of low base status because of high quartz content in the parent rock and the leaching due to high permeability (Loughnan, 1969; Paton, 1978). Mineral nutrient reserve tends to be low in these soils particularly in the tropics (Sanchez, 1976). Clay minerals in these soils are mostly kaolinite in the warmer and more humid climates, and vermiculite-illite-montmorillonite in the cooler and/or more arid climates (Jackson, 1963, 1965; Sanchez, 1976; Bohn *et al.*, 1984).

Young soils developed from granite and granite gneiss tend to be yellower or yellowish brown in colour because of the low iron content in the parent rock but reddish or reddish brown in old soils due to increase in iron content as result of pedogenic processes (Bohn *et al.*, 1984). The latter is the case in most old landscape of Tanzania as shown by several studies by Msanya *et al.*, (1995a,b, c).

Schists are foliated metamorphic rocks, rich in mica (or chlorite), with varying amounts of quartz, and with very small amounts of other weatherable minerals (Fitzpatrick, 1984). Soils formed from saprolite of mica schists are more silty and finer than those derived from granites. They tend to have high potassium reserve except in highly weathered soils (Buol *et al.*, 1984). The clay minerals in these soils are dominantly illite and vermiculite in young soils and kaolinite in highly weathered soils of the tropics. This phenomenon has been observed by Mgata (1996) when working on clay minerals from different parent rocks/materials in Coast region, Tanzania.

Dark-coloured ferromagnesian rocks are also called *mafic* or *basic* rocks . *Mafic* or *basic* rocks have low contents of silica and high contents of iron and magnesium bearing minerals and calcic plagioclase feldspars. This group include parent rocks like andesites, diorites, basalt and hornblende gneiss. The rocks weather rapidly, yielding large amounts of clay and free iron oxides and hydroxides (Loughnan, 1969; Paton, 1978; Buol *et al.*, 1984).

The mafic minerals keep the base status high in young soils, but as weathering process continues the base status declines to very low values (Eswaran and Bin, 1978a, b) due to leaching of bases. Quartz content in ferromagnesian rocks is very low and upon weathering the rocks releases relatively small amounts of sand in the soils (van Wambeke, 1991). The surface soil textures are generally loamy or clay loam. These soils tend to be dark red or dark brown due to high free iron content (Zonn, 1986). The pH values are relatively high and exchangeable aluminium levels are low (Eswaran and Bin, 1978a), particularly in young soils. The clay minerals are mostly kaolinite and halloysite in well drained soils and montmorillonite in poorly drained and dry areas' soils. The mafic or dark coloured rocks are widespread in Tanzania (GoT, 1976; Samki, 1989).

Living organisms

The influence of living organisms on soil formation may be illustrated by making observations in contrasting biotic communities and certain components in them, such as individual tree species and colonies of insects (Buol, *et al.*, 1984). Plants affect soil genesis through addition of organic matter (leaf litter accumulates on the ground), the cycling of ions, and the movement of water through hydrologic cycle (Foth, 1984). These phenomena are substantiated by the fact that soil loses productivity status few seasons after plants are cleared (Chan *et al.*, 1992).

Roots contribute organic material below the soil surface that dissolves rock particles and therefore cause both biological and chemical weathering (Huang and Keller, 1972). The roots also mechanically break rocks. Coatings of organic matter form on particle surfaces along with clays and chelate metals (Bohn *et al.*, 1984). The formation of organic complexes in the soil, buffers the soil reaction (pH), a characteristic which is important in soils for plant nutrient availability.

Organic matter also has influence on physical properties such as porosity, structure, water holding capacity and bulk density (Seubert *et al.*, 1977; Alegre and Cassel, 1986). The organic carbon rich soils are porous, have high water holding capacity, have granular structure, and have low bulk densities.

Nitrogen, sulphur and calcium cycle are examples of many biocycles within a biota-sola combination (Buol *et al.*, 1984). These biocycles enrich soils with plant nutrients and affect some soil chemical properties such as pH.

Soil animals affect soil genesis as consumers and decomposers of organic matter, and most important as earth movers (Foth, 1984). The organisms therefore affect morphology, physical and chemical properties of soil profiles (Soil Survey Staff, 1975).

Man's influence on soil formation has been on alteration of natural soil drainage class, on vegetation clearing and on application of fertilisers that result in man-made horizons (Bidwell and Hole, 1965). Man's influence on soil formation in Tanzania, has been vegetation clearing which results in severe erosion in steep landscapes and accumulation in valley bottoms and river floors.

Relief/topography

The influence of relief on soil formation depends on the forms of the relief surface, its ruggedness and its absolute heights from sea level (Zonn, 1986). The various types of relief affect the distribution of moisture by the surface run-off, intra-soil run-off and by the groundwater run-off. As the steepness of a slope increases, there is greater run-off, severe erosion, soil creep, less infiltration and less available soil water for chemical and biological activity. The net effect of less available soil water is a retardation in soil genesis (Foth, 1984). At lower heights the groundwater table rises and affects processes of soil formation and development.

Variabilities in heat (soil temperature) and moisture distribution as affected by relief also influences soil formation and soil distribution (Stolt *et al.,* 1993). Soil moisture and soil temperature regimes differ sharply as a function of relief, and the resulting soils vary according to the relief boundaries (Buol *et al.,* 1984; Zonn, 1986).

The spatial distribution of soils is related to the types and forms of relief, the absolute heights of relief and amplitude of their fluctuations (Franzmeier *et al.,* 1969). The resulting soil toposequence has been defined by Milne (1935) as *catena*. Milne defined soil catena as "*a regular repetition of a certain sequence of soil profiles in association with a certain topography, while parent material remains uniform.*"

Relief also affects the rate of removal of soil by erosion, and by directing movement of materials in suspension or solution from one area to another. Water erosion, as well as deflation, is responsible for new stages of soil formation where "old" soils were eroded or blown away. Weathering crust has come to the surface particularly in the tropics and subtropics, as a result of soil erosion (Buol *et al.,* 1984; Fitzpatrick, 1984; Zonn, 1986). Generally, an increase in slope is associated with reduction in leaching, organic matter content, clay translocation, mineral weathering, horizon differentiation and solum thickness.

Climate

Important climatic elements that affect soil development are precipitation and temperature (Loughnan, 1969). The presence of water (from precipitation) in soil enhances soil genesis through its effect on biomass production, mineral weathering, clay formation and translocation of colloids within the soil, and removal of soluble products from the soil (Foth, 1984). In general, an increase in precipitation is associated with an increase in weathering and clay formation. Surplus water is effective in the translocation and removal of soluble weathering products from the solum. Humid region soils, compared to arid region soils, tend to have greater clay content, low pH, low base percent saturation and low fertility level, and have greater biomass productivity (Foth, 1984).

Temperature increase by 10^{0}C, speeds up the rate of chemical reaction by two to three times; and also physical and biological processes are increased which result in an increased rate of weathering and clay formation (Loughnan, 1969; Foth and Turk, 1972; Paton, 1978; Bohn *et al.,* 1984).

The rate at which climate and specifically temperature and precipitation affect soil formation is influenced by relief (Stolt *et al.,* 1993) and by plant distribution with their influence on root growth, exudates and shading effect (Loughnan, 1969). The conditions that result in a minimum degree of weathering are found where the climate is warm and dry and cold and dry or cold and moist (Foth and Turk, 1972).

Geological time

Soils, as products of evolution, are constantly changing as the landscape changes (Foth, 1984). They have a life cycle in the same sense that landscape evolve through a cycle. The life cycle of soils typically includes the stages of parent material, immature soil, mature soil and old age soil (Foth, 1984). The rate at which these stages are accomplished vary with time.

The relationship of soil to time has been discussed in relative terms referring to stages of development. The terms youth, mature and old age soil (senile) have been developed for description and identification of landscape and soils. For example Entisols and some Inceptisols are *young* or *youthful* (FAO/Unesco, 1988). Mature soils are considered "normal" soils while *senile soils* are characterised by pedogenic accumulation of inert sesquioxides and heavy minerals (Zonn, 1986; Buol *et al.*, 1984).

Scharpenseel (1971) determined the absolute age of soil horizons and profiles by ^{14}C dating method. Ruhe (1956) studied soil age in relation to slope and landform associated to weathering complex. Generally speaking soil forming factors need time to take place to form mature soils with well-developed profiles.

2.1.2. Weathering and soil formation

Weathering includes the physical disintegration and chemical decomposition of solid rocks or other earth materials upon exposure to the atmosphere. Rocks are solid aggregates of primary minerals (Fitzpatrick, 1984). The weatherability of rocks is defined by the kinds of minerals they contain (Loughnan, 1969) and their energy of formation (Paton, 1978). The decomposition rates of primary minerals depend on intrinsic and extrinsic factors such as their chemical composition, the thermodynamics of rocks forming minerals, their crystal structure, and the size of the surface area exposed to the air or water as intrinsic factors; and climatic condition as extrinsic factors (Helgeson *et al.*, 1978; Paton, 1978; Fitzpatrick, 1984; van Wambake, 1991). Weatherability of rocks also depends on the kinetics of mass transfer of the weathered product (Helgeson, 1971).

Chemical decomposition of rocks to form soils is brought about by processes of solution, oxidation and reduction, hydration and hydrolysis in the presence of water. The chemical weathering is a slow transformation of the exposed unstable ions to more stable state. Chemical weathering occurs when chemical agents attack the exposed surface of rocks (Mohr and van Baren, 1959; Paton, 1978) simultaneously physical agents of weathering are also at work (Loughnan 1969; Bohn *et al.*, 1984).

Rock surfaces are vulnerable to attack by water, oxygen and carbon dioxide. Water penetrates through the pores, cleavages and other micro-openings (Loughnan, 1969; Helgeson, 1971) and attack the weakest bonds in the structure, which are oxygen-common cation bonds and dissolves the soluble constituents (Paton, 1978; van Wambeke, 1991). As rock decomposition intensifies, only the more resistant components of the rock remain. Chemical weathering follows the law of chemical equilibria and therefore mineral weathering can proceed beyond the state of equilibria if the components are added and/or removed from the system (De Vore, 1959; Loughnan, 1969). In tropical situations, leaching washes out the previous product of weathering, therefore a forward reaction continues (van Wambeke, 1991).

The chemistry of weathering has been studied by many authors using feldspar. Garels and Christ (1965), Uehara and Gillman (1982) while studying weathering found that feldspar can progressively weather to mica, kaolinite and gibbsite as a last weathering product. Warm and humid conditions in the tropics facilitate removal of potassium and dissolved silica so that feldspar and mica quickly turn into kaolinite and gibbsite (Loughnan, 1969; Eswaran and Bin, 1978a,b; Bohn *et al.,* 1984). Minerals are synthesized from the product of rock weathering (Fitzpatrick, 1984). The rate at which minerals are synthesized depends on the concentration and composition of the equilibrium solution (Loughnan, 1969). For a given rock, the solution concentration and composition will vary with temperature and water supply and therefore the climate.

Drainage which depends on precipitation, relief and rock properties such as texture and crystallinity influences markedly the mineralogical differences among neighbouring soils (Zonn, 1986).

Accumulation of weathering rock products results into parent material for soil formation (Eswaran and Bin, 1978a,b; Rice *et al.,* 1986). The parent material undergoes pedogenic processes i.e. translocation, addition, removal and transformation of matter and energy in the system which result horizon differentiation of soil profile (Fitzpatrick, 1984).

2.1.3. Formation of secondary minerals

There are several mechanisms by which minerals enter the clay fraction. Residual clays have been altered by isomorphous substitution or loss of some but not all of their original constituents. This process is called alteration (Brady, 1984). A second mechanism involves complete crystallization of minerals from electrolytes dissolved in the soil solution water and is called clay synthesis or neoformation (van Wambeke, 1991). The kinds of minerals that form depend on the conditions prevailing in the soil solution, with particular reference to drainage and soil reaction environment; and the rate at which clay grows are a function of the kinetics of crystal formation (Loughnan, 1969; van Wambeke, 1991).

Formation of silicate minerals

There are many theories put forward to account for the synthesis of 1:1 layer clay minerals such as kaolinite and halloysite, 2:1 layer clay minerals e.g. the smectite group of clay minerals (montmorillonite, beidellite and nontronite) and the illite group of 2:1 layer clay minerals during weathering under humid conditions in the tropics. Mohr and van Baren (1959) suggested that kaolinite is formed under acid conditions by a natural process; and montmorillonite in neutral or slightly alkaline environment. The synthesis may be attributed to simple reactions between aluminium and silica, while monovalent and divalent cations at varying concentrations may also be involved in the reaction (Loughnan, 1969; van Wambeke, 1991). It has been observed that kaolinite form when the ratio of Al_2O_3:SiO_2 equals 1:2 at adequate pressure of about 41 to 168 atmospheres (Paton, 1978; van Wambeke, 1991) and temperature ranging from 250 to 350°C. Under these conditions all the initial components crystallize into kaolinite. A given excess Al_2O_3 remaining after the reaction to form kaolinite, crystallizes as boehmite ($Al_2O_3.H_2O$) whereas excess of $Si0_2$ forms amorphous silicon dioxide. At high temperatures, the formation of pyrophyllite occurs at ratios of Al_2O_3:SiO_2 equal 1:1 and 1:4.

When the monovalent and multi-valent cations are present in a sufficient concentration, then smectite minerals particularly montmorillonite is formed. When the ratio of M_2O or MO (where M_2O and MO represent monovalent and divalent respectively e.g K^+ and Mg^{2+}) to Al_2O_3 are as low as 0.02:1, kaolinite is synthesized but at a ratio of 0.2:1 montmorillonite is formed (Mohr and van Baren, 1959). In dilute solution containing alkali and alkaline earths; kaolinite and montmorillonite could be formed simultaneously. As the concentration of sodium and potassium increases, so montmorillonite correspondingly becomes the dominant product of crystallization. This means, montmorillonite forms in high pH values whereas kaolinite forms in low pH values (Loughnan, 1969; Paton, 1978; van Wambeke, 1991).

Formation of aluminium oxide and hydroxides

The crystalline mineral gibbsite $Al(OH)_3$ or $((Al_2O_3.3H_2O)$ is the most abundant free hydrous oxides of aluminium in soils, occurring primarily in soils of tropical and subtropical regions which have undergone intensive leaching of silica during weathering processes. Gibbsite consists of paired sheets of hydroxyl held together dioctahedrally by aluminium ions. The series of paired sheets are held together by hydrogen bonding between adjacent hydroxyls arranged directly above and below one another.

Amorphous hydrous oxides of aluminium are rare except when they occur in gels involving other ions such as iron (Bear, 1965). The hydroxyl aluminium oxide, boehmite (Al-OOH), in which the aluminium ions are octahedrally coordinated by oxygen and hydroxyl ions occurs in the intensively leached, highly weathered soils frequently in association with gibbsite.

Formation of iron oxides and hydroxides

Iron oxides and hydroxides in permanently well-aerated and oxidizing conditions usually occur as coating (films) on clay, silt and/or sand particles (Zonn, 1986). The kind of iron oxide and hydroxide that form depends on the rate at which their concentration products in the soil solution increase beyond their solubility

(Blume and Schwertmann, 1969). The most common iron oxides in soils are hematite F_2O_3, which gives the pink to bright red colour of soils, and goethite (Fe-OOH or $F_2O_3.H_2O$) which gives the brown and dark reddish brown colour to soils. Goethite is abundant (20 to 80% of the soils) in concretions in certain Oxisols; and in ironstone. Cool temperatures, high moisture and high organic matter contents favour the formation of goethite (Bear, 1965; Loughnan, 1969; Zonn, 1986).

Iron oxides of soils are usually products of weathering of iron-bearing minerals. Hematite may also be inherited from the parent rocks including sedimentary, metamorphic and certain igneous rocks (Bear, 1965). Iron oxides tend to occur as amorphous coating gradually transforming to crystalline form as the amount present increases. Iron oxides provide important reflection of chemical properties of the soils and the genetic processes that have governed soil formation.

2.1.4. Soil forming processes

Since many processes act together to form any one soil profile, it is difficult to discuss soil formation as a function of a specific process (Birkeland, 1984). The formation of a soil profile results from a combined effect of additions to the ground surface, transformation within the soil, vertical transfer (up and down) within the soil and removal from the soil (Simonson, 1978).

The main *additions* to most soils are organic matter from the surface vegetation and their contained elements, ions and solid particles introduced with rainfall and particles carried by the wind (Birkeland, 1984). *Transformation* includes the multitude of organic compounds that form during organic matter decomposition, the weathering of primary minerals and the formation of secondary minerals and other products. Another group of pedogenic processes involves movement within the profile and is referred to as *translocation*. Soluble and suspended substances move with percolating water from one point to another within the profile, unless changing chemical conditions or dehydration causes them to precipitate out of solution (Birkeland, 1984) and/or get deposited. Removal of materials out of the soils also shapes soil profiles. The removal of soil materials are in terms of soil erosion and leaching of soluble materials. The processes form the various horizons diagnostic of soil profiles and therefore diagnostic to soil types.

It should be pointed out that it is very difficult to determine soil processes because few actual measurements can or have been made (Birkeland, 1984). For example, clay translocation from horizon A to horizon B is so slow that measurements taken over one year or two may not be an adequate indicator of how soil forming processes are efficient in soil formation.

2.2. TECHNIQUES USED IN PEDOLOGICAL STUDIES

2.2.1. Soil survey

Standard techniques used to gather information in soil survey are field work and interpretation of remote sensing materials by which all sorts of land resource surveys except detail surveys use normal airborne photos (Cline, 1978; Young, 1976; Dent and Young, 1981). Radar and satellite scanning images are also used particularly on small scale reconnaissance surveys to delineate different mapping units.

More different survey methods have been developed in the tropics compared to those used in temperate areas (Acres *et al.,* 1993). The most important ones are

(1) the use of traverse (transect) cuts on bearings to give access in forested areas and to provide a means of accurately locating ground positions, and (2) the combination of photo interpretation with field observations (Vink, 1963 cited by Acres *et al.,* 1993). Large areas of the tropics have been surveyed by stratifying the survey areas into physiographic units or their equivalents i.e. land systems, divided into land facets (Acres *et al.*, 1993); landforms units (Rackham *et al.*, 1982) by means of photo interpretation, and by subjectively siting sample areas, traverses in representative units as access permits (Acres *et al.*, 1993). The established mapping units are used to develop a map legend which lists the mapping units and records the profile classes occurring in each, with their definitive characters (Bie and Beckett, 1971). Mapping during the field work phase is done according to the predetermined mapping units, transects and specified intensity (Dent and Young, 1981). These are then sampled by free survey or systematically at fixed intervals (grid survey).

A grid survey where observations are regularly spaced over the survey area is used in detail surveys and in complex areas. The observations are patterned by traverses, auger-holes and planned profile sites according to a working scale. Free survey method is mostly used by experienced surveyors who make their own judgement on where to locate auger-holes and profile sites using the objectives of the survey and the ground and air photographs (Dent and Young, 1981). A combination of grid and free survey may be used according to the intricacies of the survey area and the accuracy of the data needed to be collected.

Data recorded will have information on the site identification and location (Dent and Young, 1981; FAO, 1990) and soil profile description and field tests. A soil map is drawn after soil profiles and sites have been described, sample tested and analyzed for their physical and chemical properties (Bie and Beckett, 1971). Basing on analytical data the soils are classified according to widely used international classification systems e.g. FAO-Unesco classification system (FAO, 1988) and Soil Taxonomy USDA (Soil Survey Staff, 1990).

2.2.2. Soil classification

Essentially, soils like other objects are classified in order to organise knowledge thus reduce complexity; aid remembering soil properties and understanding relationships among soils. It also provides means of transferring information about soils (Isbell, 1992). Classification aims to group soils in a manner useful for practical applied purposes in predicting their behaviour, identifying their best use and estimating their productivity (Bie and Beckett, 1971; Isbell, 1992). The latter practical objective is usually the concern of soil surveys and field research. Soil classification is a necessary part of the language of science that coordinates scientists and links between scientists with soil users. Soils are grouped according to their similarities and differences in their properties into segments, classes or taxa that can be identified by use of well-defined criteria (Young, 1976; Cline, 1978; Dent and Young, 1981).

FAO-Unesco Classification system (FAO, 1988) and USDA Soil Taxonomy (Soil Survey Staff, 1990) have been adopted as major classification systems particularly in english-speaking countries and in three East African countries. In East Africa FAO-Unesco system is used as a primary classification system while the Soil Taxonomy is used as secondary soil classification system. Both systems have been tested worldwide and frequently revised for improvement to current editions.

FAO-Unesco legend system started as an attempt to developing a universal soil classification system. It is a bicategorical system in which 28 units are recognized and are divided into 106 subunits using connotative names such as *Luvic, Dystric* and *Eutric* (Dent and Young, 1981; FAO, 1988). The system also provides 16 phases, textural classes and slope classes for mapping and soil classification purposes.

The FAO-Unesco legend use popular and traditional names in assigning names to the soil units. In cases where popular and traditional names create confusion due to various uses in different classification systems, new names are coined using formative elements that point out the properties of the soil in the style of the Soil Taxonomy (FAO, 1988).

Soil Taxonomy (Soil Survey Staff, 1990) is a comprehensive system developed in 1950s by the *Soil Conservation Service* of the United State Department of Agriculture. From the beginning the system stress the principles of classification based on properties of the objects that could be seen or measured quantitatively in preference to qualitative determinations.

The *Soil Taxonomy* classification system is a multicategorical one. The system has orders, suborders, great groups, subgroups, families and series in that decreasing order.

Eleven soil orders are recognized in the classification system and these are subdivided into 47 suborders. The orders are basically differentiated by the horizon or horizon combinations that occur in the soil profile. These usually can be recognized in the field. Classification into suborders requires an increasingly quantitative knowledge of soil properties and soil moisture and soil temperature regimes. Suborders can be subdivided into greatgroups with much additional information to that available in suborder level. Greatgroups are subdivided into subgroups which are further subdivided into families. Soil families are finally subdivided into series. Information needed to assign a soil in certain category increases from the order to the series. The series which is the lowest taxonomic level demands a lot of information including climate, landforms, drainage; and chemical, physical and mineralogical properties of soil.

The presence or absence of diagnostic horizons and soil properties are used to differentiate orders, suborders and great groups. The diagnostic criteria used are often related to the pedogenetic processes that operated in the soil. The system uses Latin and Greeks roots to coin soil names such as Cryqueptic Haplaquoll, and Aquic Ustochrept.

2.3. PEDOLOGICAL STUDIES IN TANZANIA

Pedological studies in the country date back to colonial era. The first mapping and characterization of soils of Tanzania was done at a scale of 1:4 million, by Milne (1935). This work was improved by Calton (1954) and later by Anderson (1967).

Basing on previous works and few field observations Samki (1983) and De Pauw (1984) produced national soil maps at scale of 1:2 million. The two maps have more information than the former works as they involved better use airphotos, airphoto mosaics and other soil related studies.

The reliability of the small scale maps is limited as they depended very much on the accessibility, particularly the first pioneer works. Areas with good roads and railway lines were better surveyed whereas the remote areas remained with guess work. Furthermore these small scale works did not involve systematic and detailed study of soil genesis and morphology, characterization of physico-chemical properties and mineralogical studies but rather concentrated on some soil parameters especially those related to use and crop production like texture, depth, drainability and fertility parameters (Msanya and Magoggo, 1993; Magoggo, 1993). The utility of these maps in terms of the accuracy of the message they carry is thus low. The best these documents can do is to provide impressions about soil distribution in the country, also provide a starting point for detailed studies that can be used in planning, management and conservation of land and soil resources. These maps can be improved to serve as national planning documents by additional field observations and correlation studies to fill gaps of areas that were not accessed during their preparation.

Towards alleviating the mentioned gaps several regional surveys have been undertaken since 1970s. The major studies were undertaken at scales between 1:50,000 and 1:500,000 for project planning and for planning at regional and/or district level. This exercise of mapping of land and soil resources was still tuned for general purpose agricultural planning. The regional surveys cover half of the country (Magoggo, 1993; Msanya and Magoggo, 1993). The scale of coverage is between 1:250,000 and 1:500,000. The 1:250,000 scale is mostly used for district surveys but few regions have been covered under this scale. The scale adopted for regional surveys is 1:500,000. Mbeya and Rukwa regions were studied with the aid of satellite imagery interpretation using the land systems (broad physiographic units) approach to map soils (King, 1982; Rombulow-Pearse and Kamasho, 1982). These reconnaissance surveys do not provide adequate information about soil genesis and have limited predictive value for different uses. A study conducted by Brinns (1993) to assess the use of land system as basic unit in soil survey has shown that three out of four cases did not conform even to the defined characteristics of landforms, rock type or altitude. This shows that the basic unit used in reconnaissance may not provide correct information in these surveys and therefore may not be reliable in land use planning and in particular project planning.

A wide range of areas have been covered in terms of detailed soil surveys in the country. The detailed soil surveys cover plantation estates, farms, irrigation schemes and villages (Msanya and Magoggo, 1993). These project areas are scattered throughout the country and they total about 10 square km (Magoggo,1993) which is a negligible area considering the size of the country. The detailed surveys are for project planning and are particularly problem solving in nature. There are prospects that many of such surveys will be undertaken because of their value in solving clients/farmers problems.

CHAPTER THREE

3. 0 MATERIALS AND METHODS

3.1. PHYSICAL ENVIRONMENT

3.1.1. Location

Mbinga district is located between longitudes 34° 24'E and 35° 28'E and latitudes 10° 15'S and 11° 34'S. Litembo village is in the western part of Mbinga district on the Matengo highlands at an average elevation of about 1800 meters a.s.l. The centre of the village is approximately at longitude 34^0 50' E and latitude 10^0 59' S. The areal extent of the village is about 760 ha. Figure 1 shows the location of the study area.

3.1.2. Climate

There is no meteorological station in Litembo village. The nearest station is in Mbinga town about 27 km east of Litembo village. Annual rainfall in Mbinga town and surrounding areas is about 1000 mm; evenly distributed from November to May. The study area falls in a relatively higher altitude and wetter part of the district and is estimated to receive a total annual rainfall of over 1200 mm (Mchau, 1993). The rainfall pattern is monomodal, starting in November and ending in May. The rest of the year is essentially dry. Table 1 shows some rainfall data obtained from Mbinga district authorities. The average annual temperatures range from 13°C in the Matengo highlands at an altitude of about 1500 - 2000 m a.s.l. to about 30°C on the shores of Lake Nyasa at an altitude of about 500 m a.s.l. (Mchau, 1993). The study area, with an altitude between 1500 and 2000 m a.s.l. is expected to have a lower temperature range. The dry season from May to September is cooler than the rainy season.

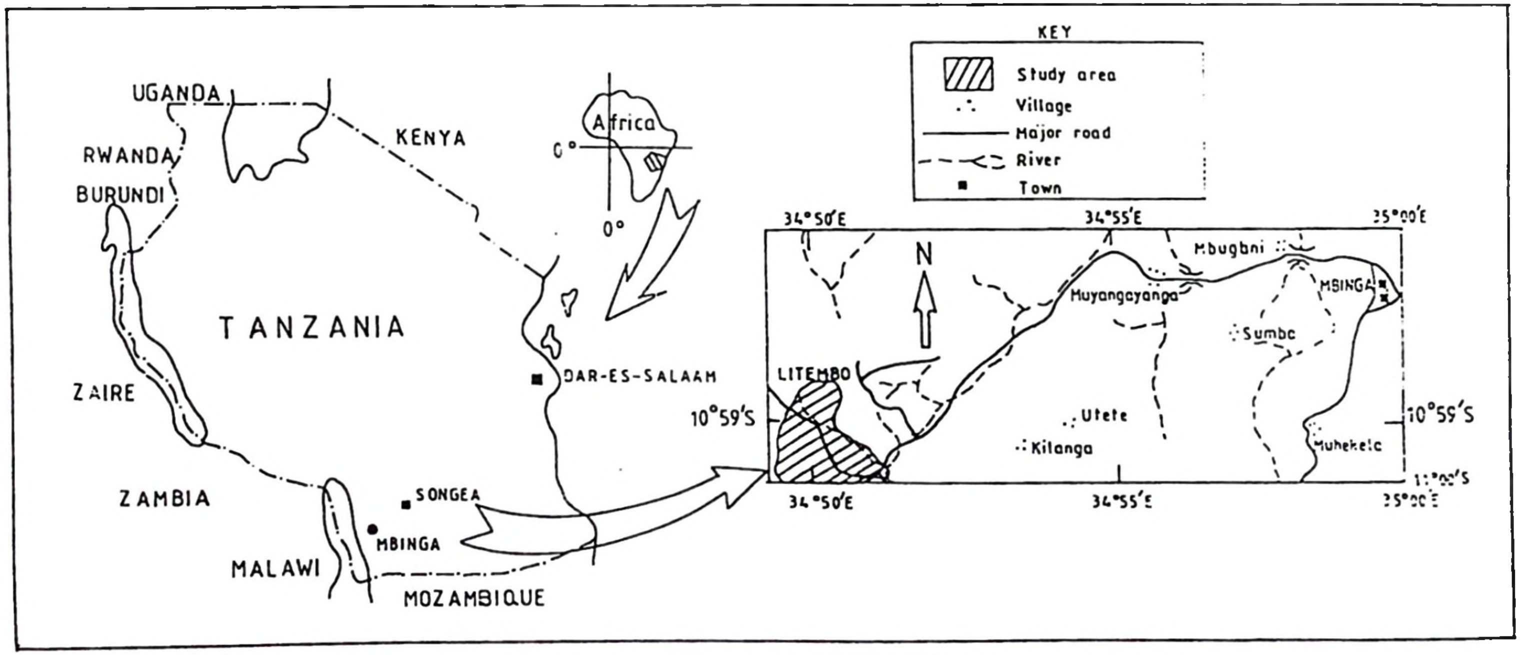

Figure 1. *Location of the study area*

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

Geology

The underlying geology of Mbinga district is essentially comprised of *hornblende-biotite* and *garnet gneisses, granulites* and *charnockites* of the Ubendian system (Ministry of Commerce and Industries, 1967). The study area is underlain by igneous granitic rocks with *hornblende* and/or *biotite* in the western part and gneissic metamorphic rocks rich in ferromagnesian minerals (*migmatised* and *hornfelsed granulite, charnockite* and *amphibolite)* in the eastern part of the village (Geological Survey Department, 1956).

Landforms

There are four major landscapes in Litembo village generally corresponding to altitude levels. These are (i) plateau (ii) hills (iii) piedmonts and (iv) valley bottoms. Figure 2 shows a cross-section of the village from west to east. Litembo village is generally mountainous. The western part with an altitude of over 2000 m a.s.l. is dominantly composed of a granitic parent rock. The eastern part rises from 500 m a.s.l. to 1900 m a.s.l. and is dominated by a gneissic parent rock. A fault line separates the two major parent rocks. River Luunei runs through the fault line (Figure 2).

The plateau occupies the highest elevation in the area while the hills occupy the mid-altitude areas. The piedmonts are primarily colluvial and depositional landscapes, and are also secondary denudational sites. The river valleys form the lowest lying landscape. These form the sink sites for materials eroded from the higher landscapes.

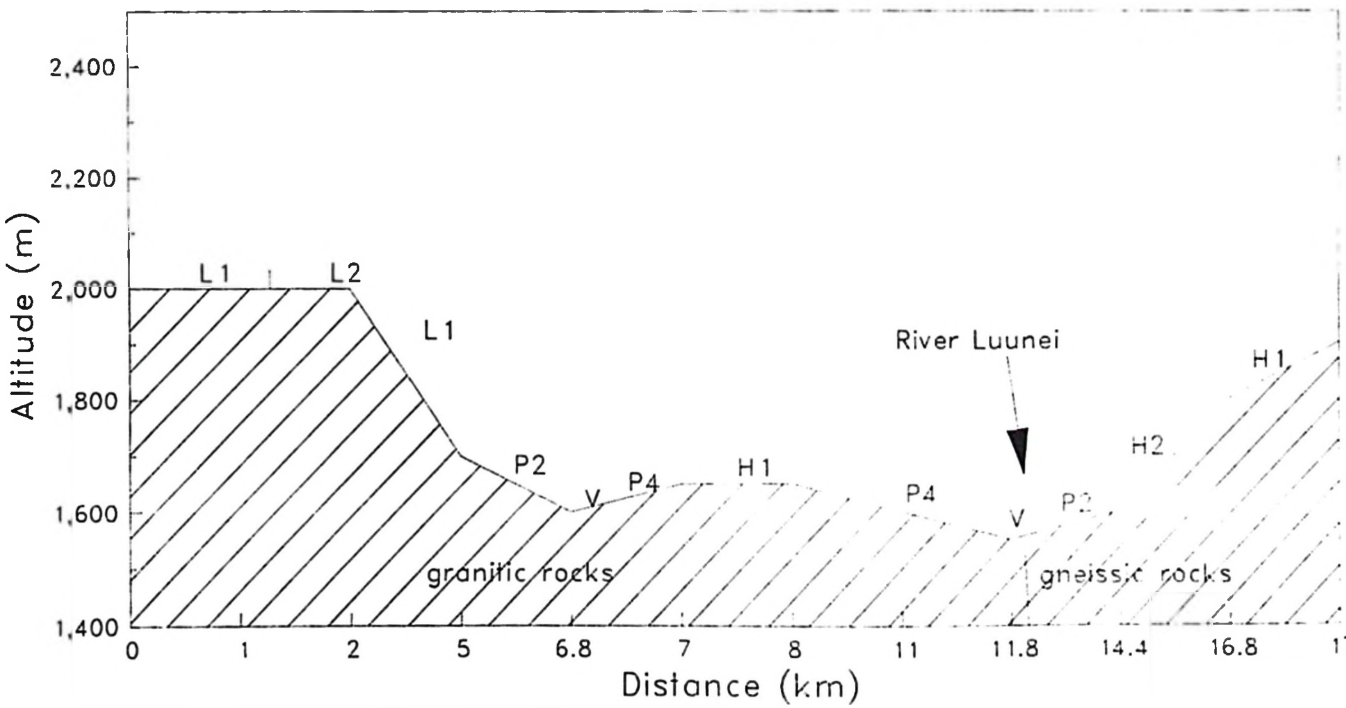

Figure 2. Cross-section of Litembo village from west to east

L1, L2, H1, H2, P1–P4, V = mapping units

The present topography in Litembo village is closely associated with the formation of the East African Great Rift Valley. This is evident from the numerous fault lines that traverse the study area (Quennell *et al.*, 1956). The uplifted blocks have been acted upon by geomorphological processes both endogenetic (internal) i.e. chemical decomposition; and exogenetic (external) i.e. erosion, landslides etc. resulting in the present topography. As a result of the above geomorphic processes, Litembo village is characterized by highly dissected and denudated plateaux (mean elevation 1900 m a.s.l.) and piedmonts (mean elevation 1500 - 1600 m a.s.l.), land-scapes with many rock outcrops and inselbergs and narrow drainage ways and river valleys. The hill tops, which stand out to an altitude of about 1900 m a.s.l. commonly have rock outcrops.

3.1.4. Hydrology

Litembo village has a *dendritic* type of drainage system. Several river tributaries collect run-off and seepage from steep slopes of the western part of the village. These drain north-western part of the village to the south at the boundary with Lituru village and drain out of the village through Luunei river. The north-eastern part of the village drain southwards to Luunei river. The village has two permanent rivers i.e. Luunei and Luhali. These rivers traverse following the fault lines. The two rivers meet at the boundary between Litembo and Mahenge villages.

During the rainy season run-off drains from higher landscapes and empty into the valley bottoms. Some water infiltrates into the soil and underlying parent rock and seeps slowly down the hillslopes and into the valleys, making the rivers to flow throughout all seasons of the year. This seepage water contributes to the perennial streams in the valleys which allow off-season farming of grains and vegetables.

3.1.5. Vegetation and land use

In Litembo village most of the natural vegetation has been cleared. The remnants in some catchment areas comprise *Afromontane rain* and *undifferentiated* forest. Dominant grass species include *Imperata cylindrica, Tegetes minuta, Hyparrhenia spp.* and *Coryza spp.*

There are two major kinds of land use in Litembo village i.e. improved traditional agriculture and fallow/grazing land use systems. These land use systems are mostly practised in the piedmonts and river valleys. The main production systems are *ngoro* (traditional tie ridge) and/or *ridge* cultivation systems, with annual crops such as maize, beans and wheat. 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. Coffee/Grevillea agroforestry is practised on bench terraces on the steep slopes (hills). In some areas intercropping with crops such as bananas and maize is done. Fallowing and grazing are mainly practised on the plateaux and other areas, waiting for crop rotation cycles. Few trees (eucalypts, cypress and black wattle) are planted as a source of firewood and for soil and water conservation. Another minor land use is cultivation of sweet potatoes and vegetables during the dry season in the valley bottoms. *Ngoro* drainage ditches are used in poorly drained areas.

3.2. PRE-FIELD WORK

Literature search and collection of available data on the study area were done. Documents consulted include geological map at the scale of 1:125,000 (Geological Survey Department, 1956), topographic map at scale of 1:50,000 (Ministry of Lands, 1972), aerial photographs at scales of 1:10 000 and 1:50 000, SPOT satellite imagery and natural resources technical report (Mwihomeke *et al.*, 1991); "unpublished" reports by Msanya *et al.* (1995a,c), Kimaro *et al.* (1995) and Magoggo *et al.* (1996).

Stereoscopic interpretation of aerial photographs was carried out on the basis of landforms, geology, lineaments, drainage patterns, vegetation, land use and drainage conditions. Aerial photo-interpretation (API) map at a scale of 1:50,000 was then produced and used subsequently as a basemap for the field survey.

3.3. FIELD WORK

Free survey method was used to execute the work. The API map was used to select transects which were used to plan observation sites and sampling points in the field (Bie and Beckett, 1971; Beckett and Bie, 1976; Young, 1976; Dent and Young, 1981). At each observation site data on soil morphological characteristics, landform, elevation, slope gradient, parent material (lithology), vegetation and land use/crops were studied and recorded following the FAO (1990) guidelines for soil profile description. Soil colours were determined using Munsell Color Charts (Munsell Color Co., 1992). Field soil description involved use of auger hole borings, mini-pits and soil profile pits. In total 12 mini-pits and 9 representative soil profile pits were studied and described. Both disturbed and undisturbed soil samples were collected for laboratory routine and special analyses.

3.4. POST-FIELD WORK

3.4.1. Cartographic work

The field activities were followed by cartographic generalization of the topographic base map to reduce thematic details and enlargement of the map scale to 1:25,000. The polygons delineated on the API map were transferred onto the enlarged topographic base map. The field and laboratory analytical data recorded on analogue forms were copied into the national digital soil data base management system, *Soil Information System for Tanzania (SISTAN*) ("unpublished, Magoggo, 1992).

3.4.2. Laboratory work

The disturbed soil samples were air dried, ground to pass through 2 mm sieve to obtain the fine earth fractions which were used for most laboratory analyses.

Bulk density was determined using the undisturbed samples according to core sample method (Blake and Hartage, 1986). Penetrability was determined by cone head penetrometer method (Bradford, 1980, 1986). Texture was determined by Hydrometer method (Gee and Bauder, 1986) after destroying soil organic matter to obtain sand, silt and clay fractions. Sand fractionation was done by wet sieving method. Soil moisture retention characteristics were studied using pressure membrane and pressure plate extractor method (Klute, 1986). Water dispersible clay (using water alone as dispersing agent) was also determined.

pH was determined potentiometrically in a 1:2.5 soil:water and soil:KCl suspensions (McLean, 1986). Determination of electrical conductivity (EC) was done by conductivity meter in a 1:2.5 soil:water ratio. Organic carbon was determined by the Walkley and Black wet digestion method as outlined by Nelson and Sommers (1982). Total nitrogen was determined by Kjeldahl method (Bremner and Mulvaney, 1982). Available phosphorus was extracted by Bray and Kurtz-1 method (Bray and Kurtz, 1945) and determined spectrophotometrically (Olsen and Sommers, 1982). Cation exchange capacity (CEC) and exchangeable cations were extracted by leaching soils with 1M NH_4OAc at pH 7.0. The adsorbed NH_4^+ displaced with K^+ using 1M KCl were 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 (Thomas, 1982). Exchangeable acidity (Al^{3+} and H^+ ions) was extracted with 1M KCl and determined titrimetrically (McLean, 1986). Determination of oxides of Al, Fe and Mn was according to Mehra and Jackson (1960) and McKeague (1978) methods.

Samples for mineralogical analysis were prepared following the method outlined by Msanya *et al.* (1995b). About 25 g of fine-earth subsoil (well-developed B-horizon) were first treated with 30% H_2O_2 in glass beakers to remove organic matter and the excess H_2O_2 evaporated on hot plate. To each sample 10 ml of 1N NaOH (dispersing agent) and then 300 ml of deionized water were added. The samples were then shaken overnight in an end-over-end shaker to allow thorough dispersion. The suspensions were transferred to 1000 ml glass cylinders, their volumes made up to the mark then allowed to settle. At appropriate intervals and depth, clay samples were siphoned out of the cylinders into 250 ml glass beakers. Five treatments were applied, namely Mg saturation, Mg + glycerol saturation, K saturation, K saturation + 350^{0}C and K saturation + 550^{0}C. The Mg treated samples were scanned between 3^0 - 30^0 for air dried samples and between 3^0 - 15^0 for Mg +

and for the K+ 350^{0}C and K+ 550^{0}C treatments. Shimadzu X-ray diffractometer model XD-D1 equipped with a Cu-Kα goniometer was used for the analysis and the x-ray diffractograms interpreted manually using information registered on the x-ray diffraction charts. Identification of clay minerals species was done using standard guidelines and books (Brindley and Brown, 1980; Dixon and Weed, 1989). Relative abundances of clay minerals were estimated by a formula based on the areas under the curve of diffractograms.

3.4.3. Soil classification, data processing and interpretation

Using both field and laboratory data the identified soil types were classified up to level-2 soil unit names according to the FAO-Unesco classification system (FAO, 1988) and up to family level according to the USDA Soil Taxonomy (Soil Survey Staff, 1990). This information is also included in the description of map units. Data processing, interpretation and report writing was done using computer softwares available at the Sokoine University of Agriculture.

CHAPTER FOUR

4. RESULTS AND DISCUSSION

4.1. SOILS

4.1.1. Soil morphology

Detailed information on the sites and representative soil profile morphological data together with physico-chemical properties of Litembo soils are given in appendix 1. The mapping units characteristics are summarized in Table 2. The general soil morphology is summarized in Table 3 and the important morphological features of the various mapping units are given below. The soil map of Litembo village is presented as appendix 3.

Mapping units H1 & H2

Profile LTP-8 represents mapping unit (MU) H1 which has over 80% surface rock outcrops. The soils are shallow (less than 60 cm) and are somewhat excessively drained. They are dark brown (7.5YR3/4, moist) in colour, and have sandy clay loam topsoil texture and clay loam subsoil texture. Profile LTP-9 represents mapping unit H2, with very deep (> 200 cm) well drained soils. The topsoil is very thick (40 cm thick), dark brown (7.5YR3/4, moist) and has sand clay loam texture; the subsoil is reddish brown to red (2.5YR4/4 to 10R4/8, moist) and has clayey texture. Both units are located in the partially metamorphosed gneissic rocks on a hilly landform.

Table 2: Characteristics of the various mapping units in Litembo village

MAP SYMBOL	LANDFORM CHARACTERISTICS	SLOPE (%)	AREA ha	SOIL DESCRIPTION	LAND USE
DISSECTED PLATEAU (L), elevation 1,900 m above sea level					
L1	Rock outcrops and inselbergs		97	Bare rocky land without soil	Bare
L2	Undulating to rolling slopes	2 - 15	54	Very deep, well drained to somewhat excessively drained, red, extremely gravelly, clays; developed on granitic rocks.	Improved traditional agriculture (*ngoro* cultivation) with wheat and maize as the main crops; sunflower is grown with maize as an intercrop.
HILLS (H), elevation 1,600 to 1,800 m above sea level					
Hi	Hill summits and upper slopes	2 - 45	38	Mainly rock outcrops with pockets of shallow to moderately deep excessively drained soil with sandy clay loams texture.	Planted forest with mainly Eucalyptus and black wattle
H2	Steeply dissected hill slopes	15 - 35	72	Very deep, well drained, red, sandy clay loams to sandy clays; developed on colluvium derived from mixed metamorphic rocks, mainly gneisses.	Coffee/Grevillea agroforestry and maize cultivation.
DISSECTED PIEDMONT (P), elevation 1,550 - 1,650 m above sea level					
P1	Undulating to rolling piedmonts	10 - 20	41	Very deep, well drained, clays; developed on colluvium derived from mixed metamorphic rocks, mainly gneisses.	Improved traditional agriculture (*ngoro* cultivation system). Main crops are maize, wheat and beans on *ngoro* and Coffee/Grevillea agroforestry on bench terraces.

Table 2. continued

P2	Moderately to steeply dissected piedmont slopes	10 - 45	132	Association of rock outcrops (40 to 50 %) and very deep, well drained, clays; developed on colluvium derived from granitic rocks.	Natural forest has been cleared Coffee/Grevillea agroforestry. Grevillea covers about 20% of the land surface
P3	Undulating to rolling piedmonts	5 - 20	131	Very deep, well drained, clays, developed on colluvium derived from granitic rocks; in the profile there is a layer of gravels mixed with angular rocks at variable depth (stone-line) ranging from 50 to 150 cm., few scattered rock outcrops.	*ngoro* and ridge cultivation systems; fallow and Coffee/Grevillea agroforestry and grazing are common land uses
P4	Undulating piedmont plain	5-14	50	Very deep, well drained, clays; developed on colluvium derived from granitic rocks. Few scattered rock outcrops.	Fallow and *ngoro* cultivation, with maize, wheat and beans on *ngoro* and few Coffee/Grevillea agroforestry.
RIVER VALLEY (V), elevation 1,550 to 1,600 m above sea level					
V	Gently undulating to undulating river slopes	0 - 8	146	Very deep, very poorly drained, stratified and mottled, gravelly, sandy clay loams, developed on mixed alluvial-colluvium of diverse origin.	Maize, beans, sweet potatoes and vegetables grown on improved drainage conditions

Mapping unit L1 & L2

Mapping unit L1 is composed of rock outcrops and inselbergs, without soil. Mapping unit L2 is represented by profile LTP-1. The unit has 50% surface rock outcrops. There are deep to very deep (100 to > 150 cm) pockets of soil between rock outcrops with gravelly sand clay topsoils and extremely gravelly clay subsoils. Gravel content increases with increasing depth. The soils are well to somewhat excessively drained most probably because of the high gravel content throughout the profile. The colour ranges from brown (7.5YR3/4, moist) in topsoil to red (2.5YR4/3, moist) in subsoils.

Mapping units P1 - P4

The mapping units are represented by profiles LTP-2 (MU- P1), LTP-3 (MU-P4), LTP-4 and LTP-5 (MU-P3) and LTP-7 (MU-P2). The piedmont soils are very deep (> 150 cm), well drained and very friable having dark reddish brown topsoils (with hues 7.5YR and 5YR) and red to dark red subsoils (with hues 2.5YR or redder). The topsoils are clay loams and sandy clays whereas the subsoils are clays. In general these soils have weak, medium, subangular blocky structure, small spherical and angular fresh and weathered granite and quartz fragments. There are also small spherical hard clay and iron nodules, which signify in-situ hydromorphism (Zonn, 1986). Clay cutans are evident in profiles LTP-1, LTP-4 and LTP-5 which is an indication of clay illuviation.

Table 3. Morphological characteristics of Litembo soils

Profile/ Horizons	Depth (cm)	Colour	Texture	Consistence	Structure	Rock and mineral fragments	Cutans / Nodules	Pores / roots	Boundary
					Description				
LTP-1									
Ap	0-35	dr (7 5YR3/4)	gr CL	sd, vfr, ss&sp	mo,me,fn,grn	a qt	no no	co,me,my fn&vfn	ab wavy
Bt1	35-50	br (7 5YR4/6)	gr C	shd,fr, s&p	w,mo sbk	a qt & gra	cl no	my,fn vfn	di smooth
Bt2	50-90	r (2 5YR4/3)	ex gr C	hd,fr, s&p	w,mo,ca sbk	a qt & gra	cl no	my fn vfn	di smooth
Bt3	90-140	r (2.5YR4/3)	ex gr C	hd,fr, s&p	w,mo,ca,sbk	a qt & gra	cl no	fn vfn	di smooth
LTP-2									
Ap	0-25	dr (7 5YR3/4)	CL	sd, vfr, ss&sp	w,fn,sbk	no	no, no	me,fn,fn,vfn	ab wavy
Bt1	25-50	rb (5YR4/4)	C	hd,fr, s&p	mo,a, sbk	no	no, a,i,s,cl&Fe	me fn, ca fn	di smooth
Bt2	50-100	dr(2 5YR3/6)	C	hd,fr, s&p	mo,a, sbk	no	no, a i,s,cl&Fe	fn vfn,me ca	di smooth
Bt3	100-140	dr(2 5YR3/6)	C	hd,fr, s&p	mo a, sbk	no	no, a,i,s cl&Fe	fn vfn,vfn	di smooth
Bt4	140-190	dr(2 5YR3/6)	C	hd,fr, s&p	mo,a sbk	no	no, a,i,s cl&Fe	fn,vfn,vfn	
LTP-3									
Ap	0-30	drb(5YR3/2)	sgr SC	sd, vfr, ss&sp,	w, fn, sbk	a, qt	no s,cl&Fe	me fn, ca me fn	ab wavy
Bt1	30-60	rb (5YR4/4)	C	sd, fr, ss&sp	mo fn, sbk	a, qt	no, s,cl&Fe	me fn ca me fn	grad smooth
Bt2	60-95	yr (5YR5/6)	C	shd, fr, s&p	mo,fn, sbk	a, qt	no s,i,cl&Fe	me fn,ca me fn	di smooth
BT3	95-160	yr (5YR5/6)	C	hd, fr, s&p	mo,fn, sbk	a qt	no s,i,cl&Fe	me,fn,ca me,fn	
LTP-4									
Ap	0-40	drb (5YR3/4)	SC	sd, vfr, ss&sp,	me fn, sbk	a, qt	no s,cl	co me fn ca,me fn	cla wavy
Bt1	40-60	r (2.5YR4/6)	C	shd, fr, s&p	mo, fn,sbk	a, qt	no, s,cl	fn&vfn ca fn	grad smooth
Bt2	60-100	r (2 5YR4/8)	C	shd, fr, s&p	mo&st, sbk	a, qt & gra	no, s,i cl&Fe	fn&vfn vfn	ab smooth
2CB	100-130	r (10R4/8)	ex gr C	hd, fr, s&p	w, me, sbk	rocks, qt & gra	no no	fn&vfn vfn	ab smooth
2Bt	130-180	r (2 5YR5/6)	SC	hd, fr, s&p	mo,ca, sbk	gravel qt & gra	cl&Fe cl&Fe	fn&vfn vfn	

Table 3 continued

LTP-5									
Ap	0-30	rb (5YR4/4)	CL	sd, vfr, ss&sp	w,me sbk	-	no,cl	fn&vfn me fn&vfn	ab wavy
Bt1	30-50	r (2 5YR4/6)	C	sd, fr, s&p	mo,me, sbk	a qt	cl cl	fn&vfn fn&vfn	grad smooth
Bt2	50-90	r (2 5YR4/6)	C	shd, fr s&p	mo,me, sbk	a, qt & gra	cl cl	fn&vfn vfn	di smooth
Bt3	90-160	r (2 5YR4/6)	C	hd, fr, s&p	mo,me, sbk	a qt & gra	cl,cl&Fe	fn&vfn vfn	
LTP-6									
Apg	0-35	rb (5YR3/2)	gr SCL	fr, ss&sp	w, me, sbk	a, qt	no no	fn&vfn cr,vfn	ab wavy
2Cg	35-60	yr (5YR5/6)	vgr SCL	ss&sp	massive	a qt & gra	no, no	fn&vfn vfn&fn	grad wavy
3Cg	60-90	so (7 5YR5/8)	sgr SCL	ss&sp	massive	a, qt & gra	no, no	fn&vfn vfn	cle wavy
4Cg	90-130	pi (7 5YR8/4)	sgr SCL	s&p	massive	a, qt & gra	no cl&Fe	fn&vfn vfn	
LTP-7			SC	sd,fr,ss&sp	vw,me sbk	a,qt & gra	no, cl&Fe	fn&vfn fn&vfn	ab smooth
Ap1	0-30	drb (5YR3/3)	C	fr,s&p	mo,me sbk	a,qt & gra	no cl&Fe	fn&vfn fn&vfn	grad smooth
Ap2	30-80	drb (2 5YR3/4)	C	fr,s&p	mo,me,sbk	a qt & gra	no cl&Fe	fn&vfn fn&vfn	grad smooth
Bt1	80-120	drb (2 5YR3/4)	C	fr,s&p	mo,me sbk	a qt & gra	no, cl&Fe	fn,fn,fn fn	
Bt2	120-160	r (10R4/8)							
LTP-8									
Ah	0-20	db (7 5YR3/4)	SCL	nd	nd	nd	nd	nd	
Bw	20-60	db (7 5YR4/4)	SCL	nd	nd	nd	nd	nd	
LTP-9									
Ap1	0-20	db (7 5YR3/4)	SCL	sd, vfr,ss&sp	w me sbk	-	no no	fn&vfn,fn&vfn	cle smooth
Ap2	20-45	rb (5YR4/4)	SCL	vfr,s&p	mo,me,sbk	-	cl cl	fn&vfn,fn&vfn	grad smooth
Bw	45-60	r (2 5YR4/6)	SCL	vfr, s&p	mo,me sbk	-	cl cl	fn&vfn fn&vfn	grad smooth
Bt1	60-120	r (2 5YR4/6)	SC	vfr, s&p	mo,me. sbk	-	cl cl	fn fn fn,fn	a smooth
Bt2	120-200	r (10R4/8)	SC	vfr, s&p	mo me, sbk	-	cl cl		

Key

Colour
db = dark brown
dr = dark red
drb = dark reddish brown
rb = reddish brown
r = red
pi = pink
sb = strong brown
yr = yellowish

Textural class
C = clay
CL = clay loam
SC = sandy clay
SCL = sandy clay loam
gr.C = gravelly clay
gr. CL = gravelly clay loam
sgr SC = slightly gravelly SC
ex.gr C = extremely gravelly clay
V gr SCL = very gravelly SCL

Consistence
sd = soft dry
fr = friable moist
hd = hard dry
shd = slightly hard dry
vfr - very friable moist
s&p = sticky and plastic
ss&sp = slightly sticky and slightly plastic

Structure
me = medium
mo = moderate
w = weak
fn = fine
grn = granular
cr = coarse
a = angular
st = strong
sbk = subangular blocky

Rock and minerals
a = angular
qt = quartz
gra = granite
i = irregular
s = spherical

Cutans and nodules
cl - = clay cutans
cl,cl = clay cutans and nodules
-, cl&fe clay and iron nodules

Pores/roots
cr = coarse
co = common
fn = fine
vfn = very fine
me = medium
my = many

Boundary
ab = abrupt
di = diffuse
cle = clear
grad = gradual

Others
nd = not determined
no = not observed

Mapping unit V

This unit represents valley bottoms and river floors, which receive sediments from the high altitude areas. Soils are very deep, poorly to very poorly drained. Topsoils are dark reddish brown (5YR3/2). Subsoil matrix colours are yellowish red (5YR4/6, moist), strong brown (7.5YR5/8) and pink (7.5YR8/8, moist). The mottled colours show the oxidation/reduction reactions of Fe and/or Mn with alternate drying and wetting as water levels/water table change with seasons (Bohn *et al.*, 1984). The soil profile is also stratified. The texture of soils in this mapping unit is gravelly, sandy clay loam. Profile LTP-6 represents this unit.

4.1.2. Soil physical properties

Table 4 presents some important physical properties of the soils of Litembo village.

Texture (particle size distribution)

The studied soils have sandy clay topsoils and clayey subsoils. Sand contents are high in topsoils ranging from 45 to 62%. Generally sand content decreases with soil depth to a range of 23 to 37% in subsoils. Profiles LTP-6 (MU-V) and LTP-8 (MU-H1) have high sand contents in the subsoils with values of 61 and 65% respectively. Higher sand contents in topsoils compared to subsoils can be attributed to finer particles migrating in suspension down the profiles and/or washing out of the soil.

Table 4. Selected physical properties of Litembo soils

Profile no.	Depth (cm)	Particle size distribution percentage (%)			Textural Class	Bulk density (Mg m-3)	Particle density (Mg m-3)	Total porosity (%)	Penetrometer Resistance (MPa)	Available water capacity	
		Sand	Silt	Clay						% vol/vol	(mm/m)
LTP-1	0-35	45	16	39	CL	1.0	2.7	61.5	0.28	18	
	35-50	38	13	49	C	1.5	2.6	44.3	1.44	16	137
	50-90	29	10	61	C	1.6	2.6	40.2	5.52	10	
	90-100	27	18	55	C	1.6	2.6	40.2	3.7	10	
LTP-2	0-25	47	18	35	CL	1.0	2.7	63.1	0.1	16	
	25-50	22	19	59	C	1.4	2.8	50.8	3.97	14	125
	50-100	23	14	63	C	1.4	2.8	50.8	3.7	10	
LTP-3	0-30	50	11	39	SC	1.2	2.7	56.9	0.22	17	
	30-60	42	9	49	SC	1.2	2.7	55.4	2.3	18	176
	60-95	38	9	53	C	1.3	2.7	53.2	1.8	15	
	95-100	30	7	63	C	nd	nd	nd	4.2	-	
LTP-4	0-40	50	10	40	SC	1.2	2.7	57.0	1.3	16	
	40-60	46	9	44	C	1.2	2.8	55.4	1.7	15	146
	60-100	29	10	61	C	1.4	2.7	47.6	4.3	13	
LTP-5	0-30	45	14	39	CL	1.0	2.7	60.5	nd	nd	nd
	30-50	40	13	47	C	1.2	2.8	51.4	nd	nd	nd
	50-90	33	12	55	C	1.2	2.8	45.0	nd	nd	nd
	90-100	29	8	63	C	1.3	2.8	43.0	nd	nd	nd

Table 4 continued

LTP-6	0-35	53	16	31	SCL	nd	nd	nd	nd	nd	nd
	35-60	55	17	28	SCL	nd	nd	nd	nd	nd	nd
	60-90	53	15	32	SCL	nd	nd	nd	nd	nd	nd
	90-130	61	13	26	SCL	nd	nd	nd	nd	nd	nd
LTP-7	0-30	48	14	38	SC	0.98	2.7	72.2	0.2	24	
	30-80	23	12	65	C	1.0	2.7	61.6	2.6	15	177
	80-120	23	12	65	C	1.3	2.7	51.6	3.9	15	
LTP-8	0-20	62	13	25	SCL	1.1	2.7	59.0	nd	4.4	nd
	30-50	65	11	24	SCL	1.1	2.7	59.0	nd	10.6	
LTP-9	0-20	58	17	25	SCL	1.0	2.7	63.0	nd	17.4	
	20-45	56	13	31	SCL	nd	nd	nd	nd	nd	152
	45-60	64	10	26	SCL	1.3	2.7	52.0	nd	22.7	
	80-100	46	14	40	SC	1.3	2.7	48	nd	10.1	

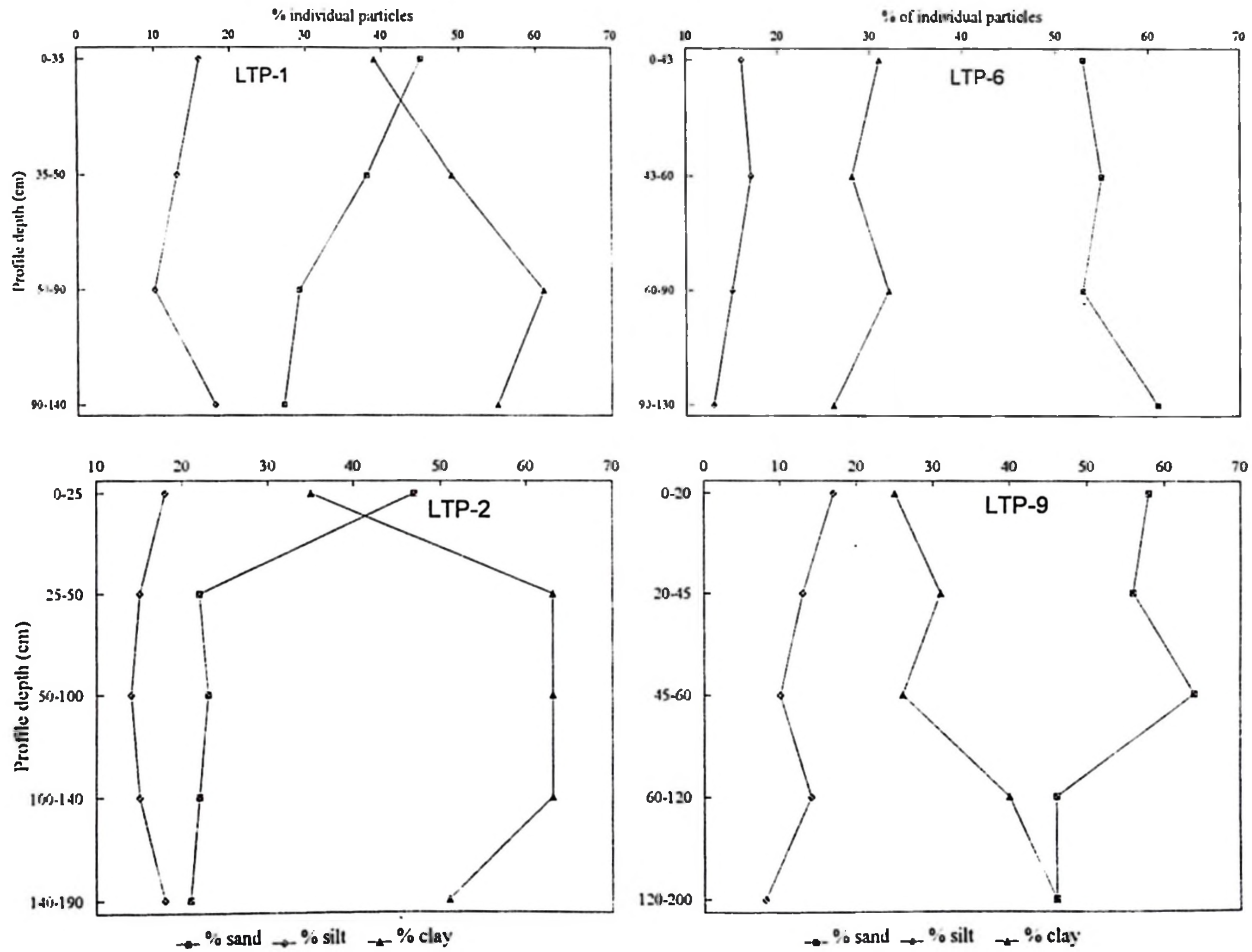

Figure 3. Particle size distribution versus soil depth for some Litembo soils

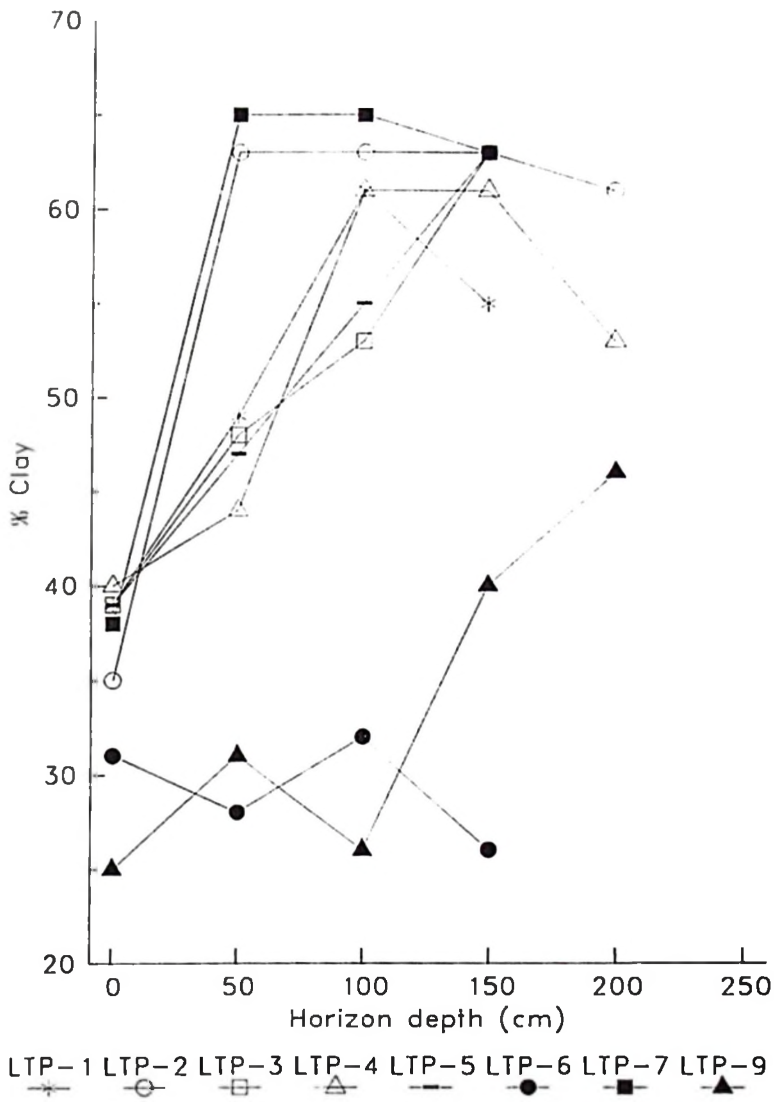

Figure 4. Distribution of clay with soil depth for some Litembo soils

The clay content of studied soils range from 35% to 40% in topsoils and increases with soil depth (see also figure 4) except for LTP-6 where the variation in clay content does not show any particular trend. Subsoil clay content ranges from 55 to 65% . Clay cutans were observed in profiles LTP-1, LTP-4, LTP-5 and LTP-9. This is probably due to clay illuviation down the profiles. Low clay content in profiles LTP-6 (MU-V), LTP-8 (MU-H1) and LTP-9 (MU-H2) compared to profiles in other mapping units (MUs) is probably due to erosion and/or deposition processes. In profile LTP-8 the underlying weathering rock is observable and is probably due to steep slopes, and washing away of finer materials down the slope which is attributed to the position on the landscape (hilly). In profile LTP-6 (MU-V) deposition is more pronounced due to its position (valley bottoms). Soil materials in the valley bottoms are of coarser texture; deposited by run-off from the higher landscape. Seasonal washing of valley bottoms by floods normally carries away finer soil materials therefore coarser textures dominate river valley soils (Birkeland, 1984). This is the case for the soil in mapping unit V of Litembo village.

Silt contents of the studied soils are low compared to sand and clay content. The topsoil silt content ranges from 10 to 18% while in the subsoils it ranges from 7 to 18%. The silt contents do not follow a clear trend with soils depth (figure 3).

Bulk density, particle density and porosity

The topsoil bulk density ranges from 0.99 to 1.2 Mg m^{-3}. Subsoil bulk density ranges from 1.3 to 1.4 Mg m^{-3}, for most profiles. According to Zonn (1986) these values are within the common range for tropical soils. Profile LTP-1 has bulk density values in the subsoils ranging from 1.5 to 1.6 Mg m^{-3} which may indicate compaction. Generally, bulk densities of the studied soils increase with soil depth, which is possibly due to increase in clay content and free oxides of iron, aluminium and manganese which act as cementing agents that strongly bind together the soil particles (Mullins *et al.*, 1992). Low values of bulk density in topsoils compared to subsoils can be attributed to higher levels of organic carbon (Alegre and Cassell, 1986; Dalal and Mayer, 1986). In the study area the traditional tie-ridge cultivation system (*ngoro)* is practised (Msanya *et al.,* 1995 a,b; Kimaro *et al.,* 1995). In this system, plant materials (grasses, crop residues, etc.) are incorporated into the soil and upon decomposition, they increase the soil organic matter content particularly of the topsoils. Soil organic matter has been reported to improve soil structure and consequently lowers bulk density (Alegre and Cassel, 1986; Dalal and Mayer, 1986; Chan *et al.,* 1992).

The observed bulk densities in the studied soils do not pose any serious limitation for agricultural purposes except for profile LTP-1 whose relatively higher values in subsoil bulk density may inhibit root growth of many crops. It has been demonstrated that high soil bulk density imposes many stresses such as mechanical resistance, poor aeration and reduced permeability to plant rooting system (Bowen, 1981; Marschner, 1990).

All the studied soils have the same particle density (2.7 Mg m^{-3}) in the topsoils. Profile LTP-1 shows a slight decrease of particle density with soil depth from 2.7 Mg m^{-3} in the surface to 2.6 Mg m^{-3} in subsoils. In profiles LTP3, LTP-4, LTP-7, LTP-8 and LTP-9 the particle density is 2.7 Mg m^{-3} throughout; whereas for profiles LTP-2 and LTP-5 the particle density slightly increases with soil depth from 2.7 to 2.8 Mg m^{-3}. According to Hillel (1982), normal mineral soils have particle density of 2.6 Mg m^{-3}. This means that with the exception of profile LTP-1, Litembo village soils have slightly higher particle densities than the above figure. This may be due to relatively large amounts of sand particles, dominated mostly by quartz. According to Landon (1991) the particle density values observed in this study suggest that the soils are more of the ferruginous (sesquioxide-rich) than the humose type.

The total porosity of the studied soils ranges from 56 to 72% in the topsoils and from 40 to 53% in the subsoils. The higher values in the topsoils suggest the influence of soil organic matter. The lower values in the subsoils are probably due to higher clay contents responsible for increase in compaction. Differences in total porosity in topsoils among profiles is small. Profile LTP-7 has the highest value (72%) and LTP-3 the least (56%) in topsoils. The subsoil total porosity ranges from highest (59%) in LTP-8 to lowest (40%) in LTP-1. According to Harrold (1975), the observed total porosity values are acceptable for most crops.

Penetrometer resistance (PR)

Figure 5 shows the relationship between PR, bulk density and soil depth. Most soils have topsoils PR values ranging from 0.1 to 0.28 MPa and the values increase with soil depth. In subsoils of profiles LTP-1 (MU-L2) and LTP-2 (MU-P1), PR values of 5.52 and 3.97 MPa respectively are encountered. Profiles LTP-3 (MU-P4), LTP-4 (MU-P3) and LTP-7 (MU-P2) have PR values between 4.2 and 4.3 MPa in subsoils. The lower PR values in topsoils may be attributed to plough layer and the ngoro cultivation system.

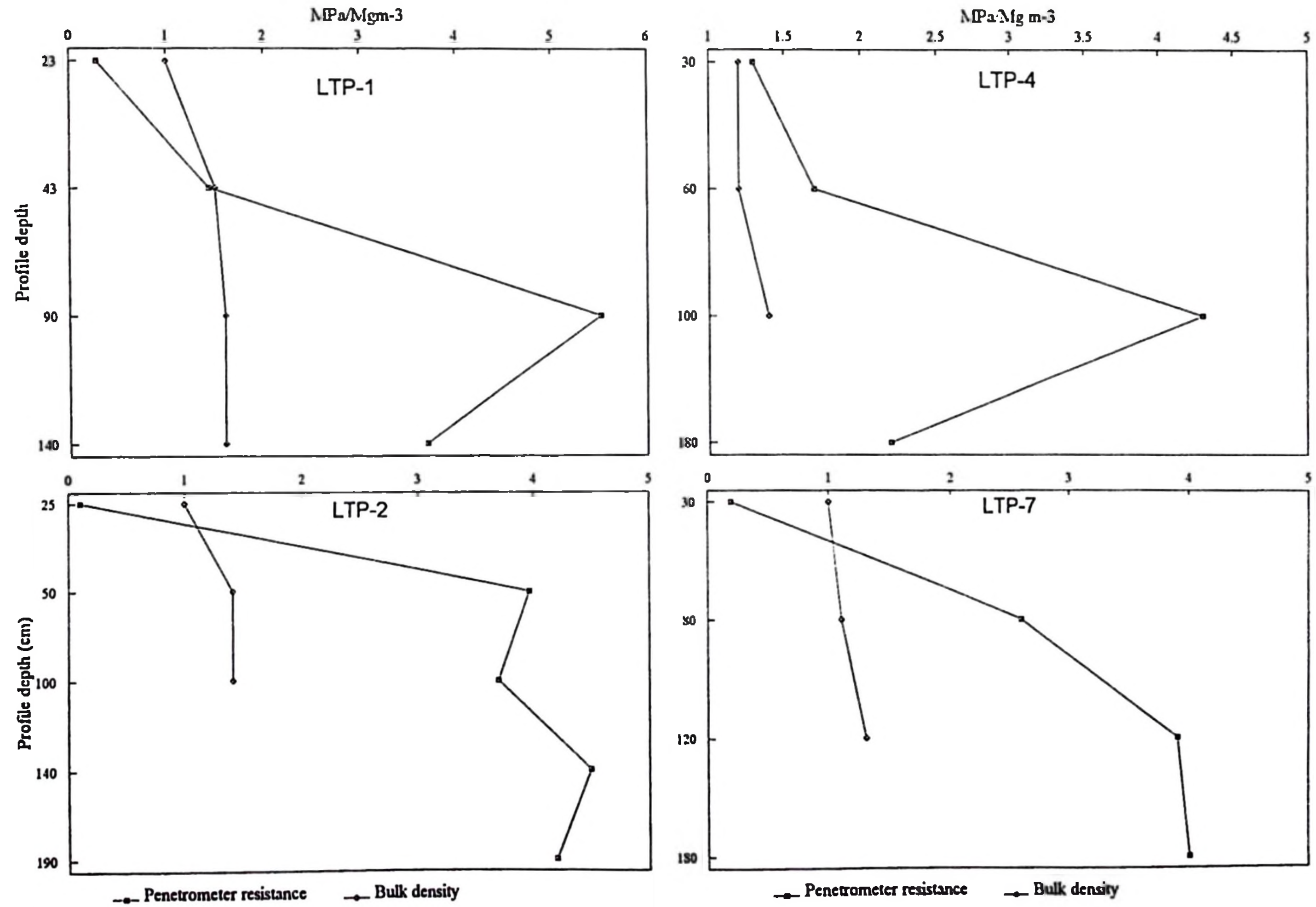

Figure 5. Penetrometer resistance and bulk density versus soil depth for selected soils of Litembo

The increase of PR with soil depth for most soils may be due to clay increase down the profiles (Figure 4). It may also be related to the advanced stage of soil weathering which has resulted into high concentration of free oxides that cement the aggregates together.

According to Bengough and Mullins (1990), PR values of between 3 and 6 are limiting for crop establishment. Tsegaye and Mullins (1993) cited by Mtakwa (1993) further reported that PR values of 1 MPa or more cause serious reduction in crop growth.

The PR values observed in this study for topsoils do not pose any limitation to crop growth. However, the observed PR values for subsoils may pose some limitations especially if the topsoils are eroded and the subsoils are exposed.

Available water capacity

Results show moisture release characteristics at three depths i.e. surface, intermediate horizon and subsoil. Available water capacity (AWC) of most topsoils range from 15 to 25% by volume (see Table 4). The AWC of intermediate horizons and subsoils range between 10 to 18% by volume. The observed data indicate no clear variations of AWC between profiles. The volume fraction of water in the surface layer is generally higher than that in the intermediate horizon and subsoils. Organic matter has been reported to influence water holding capacity of soils (Klute, 1986) and this can probably explain the relatively higher available water capacity values in the topsoils which had relatively higher levels of organic matter than the subsoils. AWC per meter range from 125 to 177 mm which is medium to high (Landon, 1991). Profiles LTP-3, LTP-7 and LTP-9 have high AWC (values > 170 mm/m) while the remaining profiles have medium AWC (values 100 - 150 mm/M). According to Hillel

(1982) and Landon (1991) clayey soils like those of Litembo hold more water than coarse textured soils.

4.1.3. Soil chemical properties

Some chemical data are presented in Tables 5 and appendix 1.

Soil reaction and exchangeable acidity

The pH-water of the studied soils vary slightly between profiles. Generally pH increases slightly with soil depth. The lowest pH values are observed in profiles LTP-8 (MU-H1) and LTP-9 (MU-H2) with values of 4.4 to 4.9 for topsoils and 4.4 to 5.0 in subsoils respectively. The other mapping units have topsoil pH values of 5.0 to 5.4 and subsoil values of 5.0 to 6.0. The trend where pH increases with increasing depth may be due to the greater concentration of organic matter which has a tendency of accumulating acid (low pH) dependent cations on the exchange sites (McLean, 1986). The relatively lower pH values in topsoils may also be due to acidification resulting from continuous application of ammonium fertilizers which have acidifying effects. A tendency where pH increases with soil depth has also been observed by Mishra and Ghosh (1995) in some Indian soils.

All profiles in Litembo village have positive delta pH ($pH_{water} - pH_{KCl}$) values, an indication that the exchange complex of the colloidal fractions of the soils are mostly negatively charged (Bear, 1965; Uehara and Gillman, 1981; Bohn *et al.*, 1984). Most plants thrive well in soils of pH 6.5 to 7.5 (Baize, 1993). This means most soils of the study area may present limitations to crop growth because of

Table 5. Some chemical properties of Litembo soils

Profile no.	Depth (cm)	Horizon	pH H_2O	pH 1NKCl	EC (mS/cm) (1:2.5)	OC (%)	Tot N (%)	C/N	Avai P (Bray 1) (mg P/kg)	CEC cmol(+)/kg soil	% BS	Exch. bases cmol(+)/kg soil Ca^{2+}	Mg^{2+}	K^+	Na^+	Exch.Acidity cmol (+)/kg soil H^+	Al^{3+}
LTP-1	0-35	Ap	5.4	5.3	0.04	3.1	0.3	10	6	19.5	39	5.9	1.5	0.1	0.08	0.2	tr
	35-50	BA	5.4	4.7	0.02	1.1	0.2	5.5	2	11.5	21	2.1	0.2	0.05	0.07	0.1	tr
	50-90	Bt1	5.3	4.8	0.01	0.4	0.1	-	7	10.0	31	2.5	0.5	0.04	0.07	0.1	tr
	90-140	Bt2	5.3	4.8	0.01	0.2	0.07	-	10	9.5	31	2.3	0.5	0.04	0.07	0.1	0.3
LTP-2	0-25	Ap	5.2	5.0	0.05	1.3	0.26	5	9	15.0	23	2.1	0.4	0.25	0.7	0.2	tr
	25-50	Bt1	5.8	5.6	0.02	0.8	0.11	7	1	10.0	28	2.1	0.5	0.15	0.07	0.1	tr
	50-100	Bt2	5.9	5.6	0.02	0.4	0.08	5	1	10.0	30	2.1	0.7	0.1	0.08	0.1	tr
	100-140	Bt3	5.9	5.6	0.01	0.3	0.05	-	1	7.5	60	3.3	1.0	0.1	0.1	0.1	tr
	140-190	Bt4	6.0	5.6	0.02	0.1	0.04	-	1	5.0	54	2.1	0.4	0.1	0.08	0.1	tr
LTP-3	0-30	Ap	5.1	4.6	0.02	2.1	0.19	11	7	13.0	19	1.9	0.3	0.2	0.07	0.1	0.2
	30-60	Bt1	5.2	4.7	0.01	0.8	0.12	7	3	10.0	26	2.0	0.4	0.1	0.07	0.2	tr
	60-95	Bt2	5.4	5.0	0.01	0.5	0.08	-	2	10.0	23	1.6	0.4	0.2	0.07	0.1	tr
	95-160	Bt3	6.0	5.4	0.01	0.4	0.07	-	1	10.0	20	1.5	0.3	0.1	0.08	0.1	tr
LTP-4	0-40	Ap	5.0	4.7	0.3	1.7	0.17	10	4	14.5	14	1.4	0.4	0.14	0.07	0.1	0.3
	40-60	Bt1	5.2	4.9	0.01	0.7	0.09	8	2	10.0	21	1.6	0.4	0.05	0.08	0.1	tr
	60-100	Bt2	5.4	5.0	nd	0.5	0.06	-	1	5.0	52	1.9	0.6	0.04	0.07	0.1	tr
	100-130	2CB	5.7	5.3	nd	0.3	0.05	-	1	5.5	37	1.4	0.3	0.05	0.08	0.1	tr
	130-180	2Bt	5.7	5.4	nd	0.2	0.03	-	1	5.0	50	2.0	0.4	0.05	0.07		
LTP-5	0-30	Ap	5.4	4.7	0.01	2.2	0.18	12	11	17.5	16	2.1	0.4	0.21	0.07	0.1	0.1
	30-50	Bt1	5.5	4.9	0.01	0.9	0.13	7	4	14.5	49	5.5	1.4	0.15	0.07	0.1	tr
	50-90	Bt2	5.8	5.4	0.03	0.3	0.07	-	3	9.5	27	1.8	0.5	0.16	0.07	0.1	tr
	90-160	Bt3	5.9	5.4	0.01	0.3	-	-	2	9.5	23	1.6	0.4	0.10	0.07	0.1	tr

Table5. continued

LTP-6	0-35	Apg	5.4	4.7	0.01	1.8	0.17	11	7	19.5	15	2.2	0.3	0.26	0.11	0.1	0.1
	35-60	2Cg	5.4	5.0	0.01	0.4	0.08	5	5	14.5	18	2.1	0.3	0.15	0.10	0.1	tr
	60-90	3Cg	5.8	5.0	0.01	0.3	0.06	-	5	9.5	30	2.2	0.4	0.14	0.10	0.1	tr
	90-130	4Cg	5.7	5.5	0.07	0.2	0.05	-	2	9.5	20	1.5	0.2	0.10	0.10	0.1	tr
LTP-7	0-30	Ap1	5.4	4.9	0.05	3.7	0.3	12	32	29.5	32	7.0	1.9	0.33	0.10	0.1	tr
	30-80	Ap2	5.9	4.9	0.02	0.9	0.14	6	7	19.5	30	4.7	0.8	0.29	0.10	0.1	tr
	80-120	Bt1	5.6	4.9	0.02	0.6	0.11	-	5	14.5	42	5.0	0.7	0.23	0.10	0.1	tr
	120-180	Bt2	5.9	5.5	0.01	0.3	0.05	-	3	9.5	49	3.9	0.6	0.10	0.10	0.05	tr
LTP-8	0-20	Ah	4.4	3.9	0.04	2.3	0.16	14	2	13.4	7	0.6	0.3	0.06	0.03	0.04	tr
	20-60	Bw	4.4	4.0	0.02	1.3	0.10	13	3	13.7	29	1.4	2.6	0.02	0.02	0.02	tr
LTP-9	0-20	Ap1	4.9	4.1	0.01	2.8	0.14	20	1	13.5	15	1.3	0.5	0.17	0.02	0.01	tr
	20-45	Ap2	5.2	4.4	0.03	1.4	0.10	14	7	5.0	36	1.3	0.4	0.06	0.04	0.03	tr
	45-60	Bw	4.8	4.1	0.02	0.6	0.50	12	1	5.9	15	0.7	0.1	0.05	0.01	0.02	tr
	80-100	Bt1	4.9	4.3	0.01	0.4	0.03	13	-	3.1	29	0.6	0.2	0.06	0.04	0.01	tr
	160-180	Bt2	5.0	4.3	0.01	0.2	0.02	10	-	3.1	35	0.7	0.3	0.07	0.01	0.01	

nd = not determined
tr = trace less than 0.05 cmo (+) kg/soil

their low pH values which may adversely affect availability of various plant nutrients such as phosphorus and bases (Marschner, 1990). Liming may be necessary to raise the pH to favourable levels. However, it has been reported by ILACO (1991) that plant species and even varieties differ in the degree to which they tolerate pH values outside that range. Hence crops that are tolerant to acidity are recommended for this area.

The exchangeable hydrogen values range from 0.1 to 0.2 cmol(+)/kg soil. Exchangeable aluminium is observed in profiles LTP-1, with value of 0.3 cmol(+)Al/kg in subsoil. Profiles LTP-3, LTP-4, LTP-5 and LTP-6 have exchangeable aluminium in topsoils ranging from 0.1 to 0.3 cmol(+)Al/kg soil. According to Landon (1991) the exchangeable acidity for the studied soils in general is low and are likely not to limit soil productivity.

Soil organic matter and nitrogen

Organic matter contents in the topsoils are mostly medium to very high ranging from 2.2 to 6.4 % OM corresponding to 1.3 and 3.7% OC. Profile LTP-7 has very high OM content (6.4%) while the rest have medium to high values. The levels of OM decrease with soil depth to low levels in subsoils (about 0.2% OC) (see also figure 6).

The high levels of organic matter in the topsoil may be attributed to the traditional farming system *(ngoro* cultivation) which involves incorporation of large quantities of grasses, shrubs and crop remains into the soil every season.

According to Landon (1991) total nitrogen (N) content in topsoils of the studied area is high ranging from 0.17 to 0.3%. Profiles LTP-1 (MU-L2), LTP-2 (MU-P1) and LTP-7 (MU-P2) have N content values of about 0.3% N in topsoils, whereas in subsoils values are very low (< 0.1% N). The remaining profiles have less than 0.2% N in topsoils and the values decline with depth to about 0.05% N in subsoils which is very low (see Figure 7). The relatively higher levels of nitrogen observed in topsoils may be due to the traditional *ngoro* farming system. Nitrogen, however, is a dynamic plant nutrient, which frequently needs replenishment, either as an organic manure or as mineral fertilizer.

The topsoil C/N ratios of the studied soils are optimal (values 10 - 12) except for profile LTP-2 which has a ratio of 5. In the subsoils the ratios decline to values between 5 and 8. According to the rating by Landon (1991) and ILACO (1991) C/N ratios of between 10 and 12 indicate satisfactory mineralization of organic nitrogen into nitrates. The C/N ratios greater than 12 and/or less than 10 indicate that nitrification is inhibited.

Available phosphorus

Available phosphorus in the studied soils range from 1 to 32.3 mg P/kg soil and from 1 to 10 mg P/kg soil for topsoils and subsoils respectively. According to ILACO (1991) these values range from very low to high in topsoils and very low to medium in subsoils. Profiles LTP-2 (MU-P1), LTP-3 (MU-P3), LTP-5 (MU-P3), LTP-6 (MU-V), and LTP-7 (MU-P2) have phosphorus values above 7 mg P/kg) in topsoils. The remaining profiles have phosphorus values which are less than 7 mg P/kg soil. Available P of 7 mg/kg soil is considered optimum below which P-deficiency symptoms are likely to occur in most crops (ILACO, 1991; Landon, 1991). The phosphorus values decrease irregularly with depth. In profiles LTP-2 (MU-P1), phosphorus values decreased abruptly in the first 26 cm from 9 mg P/kg soil to 1 mg P/kg soil throughout the profiles. The relatively high topsoil values (LTP-2) may be attributed to the residual effect of P-fertilizers, which is normally restricted to the surface soils. Most of the remaining profiles show a more gentle decrease of available phosphorus with depth to low or very low values.

The general low P contents in the soils may be attributed to low pH values, probably due to fixation of P by oxides and hydroxides of iron, aluminium and manganese (Bohn *et al*. 1984; Marschner, 1990; Sanchez, 1976; Mekaru and Uehara, 1971), which increases considerably when pH goes below 5.5 the case of Litembo soils. The observed phosphorus levels in this study suggest that most of the Litembo soils require P-fertilization for optimal crop production.

Cation exchange capacity (CEC)

The CEC reflects the capacity of the soil to retain nutrients against leaching. According to ILACO (1991) profile LTP-7 (MU-P2) has high topsoil CEC (about 30 cmol(+)/kg soil). Profiles LTP-1 (MU-L2), LTP-5 (MU-P3) and LTP-6 (MU-V) have CEC values between 15 and 19.5 cmol(+)/kg soil in topsoils. The rest of the profiles have values between 13 and 14.5 cmol(+)kg soil in topsoils. The CEC values in topsoils are comparably higher than those in subsoils and this can be attributed to higher contents of soil organic matter (Seubert *et al.,* 1977; Alegre and Cassel, 1986). There is a general trend that CEC decreases with soil depth (see figure 8). Profile LTP-9 (MU-H2) shows an abrupt decrease of CEC with depth whereas the remaining profiles variably show a gentle decline to very low CEC values (5 - 14 cmol(+)/kg soil) in the subsoils. Generally Litembo soils have low CEC levels that may be attributed to strong leaching and low ion exchange capacity of kaolinite which is the dominant clay mineral in the soils.

Exchangeable bases (Ca^{2+}, Mg^{2+}, K^{+} and Na^{+})

Exchangeable calcium levels vary among profiles and with soil depth. Profiles LTP-1 (MU-L2) and LTP-7 (MU-P2) have comparable exchangeable Ca^{2+} with values of 5.9 and 7.0 cmol(+)/kg soil in the topsoils respectively. The exchangeable calcium values of the same profiles decline with depth to 2.3 and 3.9 cmol(+)/kg soil in subsoil respectively. These two profiles have relatively higher exchangeable calcium levels compared to the rest, particularly in topsoils. According to Landon (1991) exchangeable calcium levels of LTP-1 and LTP-7 are very high in topsoils and medium in subsoils.The remaining profiles have topsoil exchangeable calcium values between 1.3 to 2.2 cmol(+)/kg soil except for LTP-8 (MU-H1) which has 0.6 cmol(+)/kg soil. Profiles LTP-2 (MU-P1), LTP-3 (MU-P4) and LTP-6 (MU-V) have exchangeable calcium uniformly distributed with soil depth with a value of about 2 cmol(+)/kg soil throughout, and profile LTP-9 (MU-H2) show a decline with soil depth. Profiles LTP-4 and LTP-5 show irregular changes of exchangeable Ca^{2+} with soil depth. According to Landon (1991) the calcium levels of Litembo soils are medium to very high.

Exchangeable magnesium levels in topsoil are low (about 0.4 cmol(+)/kg soil) except for profiles LTP-1 and LTP-7 which have 1.5 and 1.9 cmol(+)/kg soil respectively. The levels show no clear trend with soil depth and with clay contents, except for profile LTP-8 in which Mg^{2+} is ten times the value in topsoil. This is possibly because the profile is shallow and the weathering rock could be contributing to Mg^{2+}. The low Mg^{2+} values may be attributed to leaching, washing by run-off, lateral movement and mining by cropping systems. Sanchez (1976) however, reported that 0.2 to 0.64 cmol(+)/kg levels of exchangeable Mg^{2+} are sufficient for

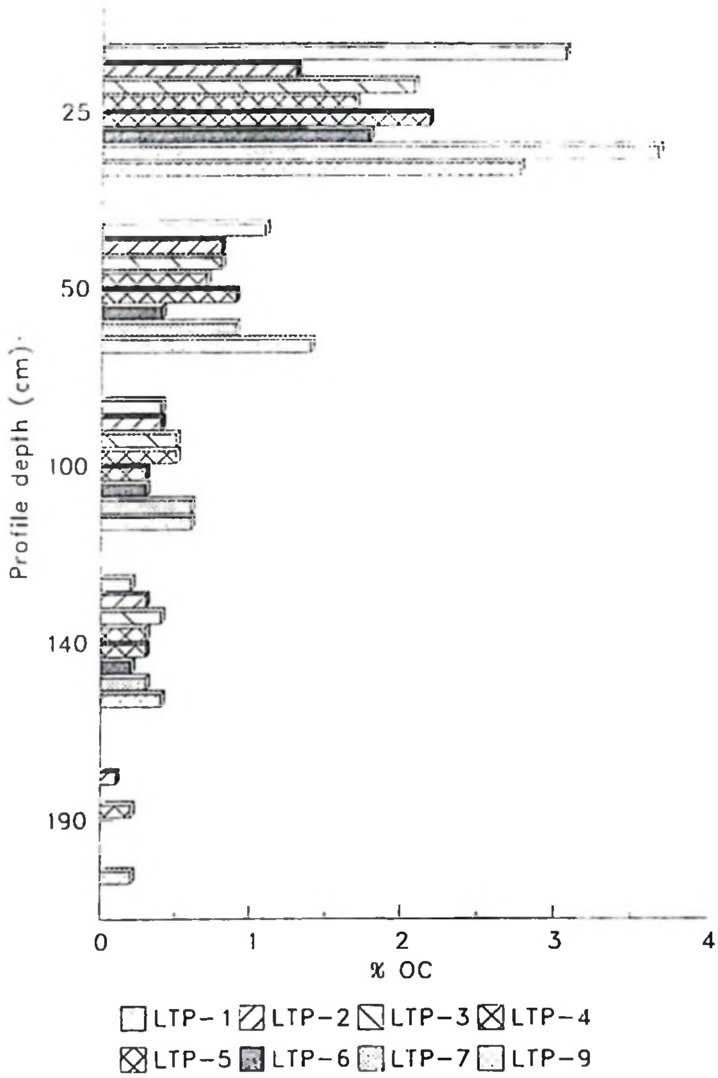

Figure 6. Distribution of soil organic matter with soil depth for Litembo soils

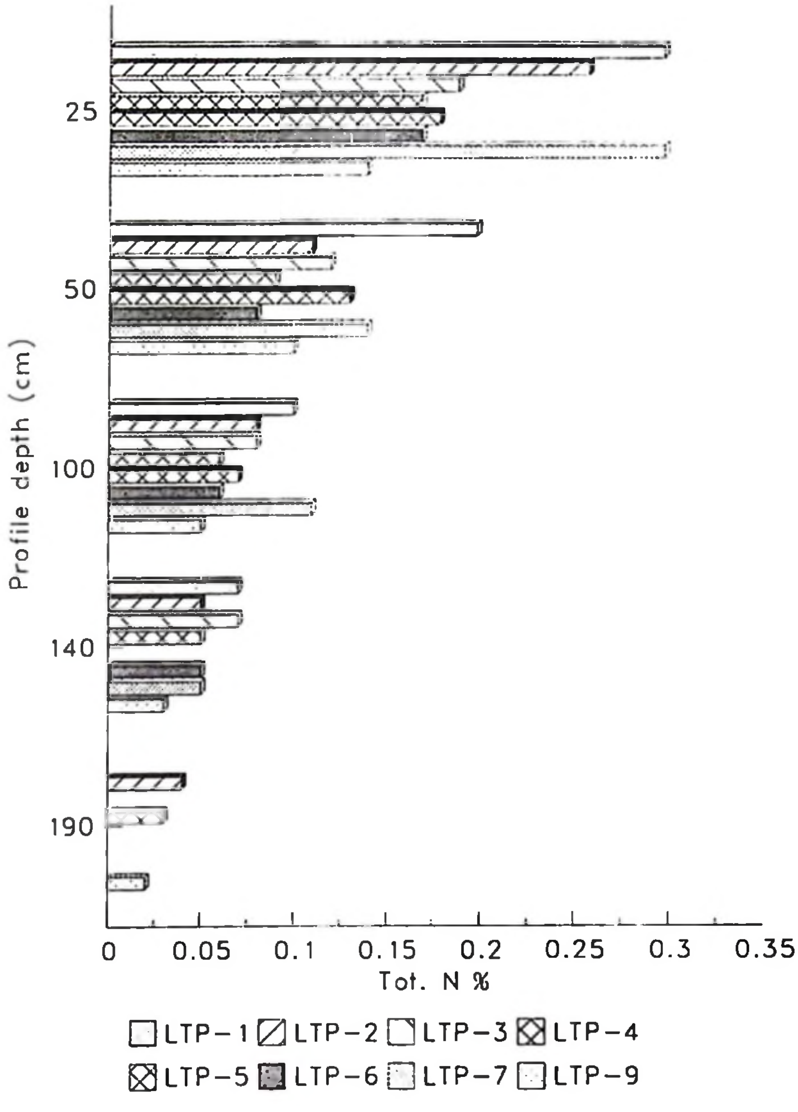

Figure 7. Distribution of total nitrogen with soil depth for Litembo soils

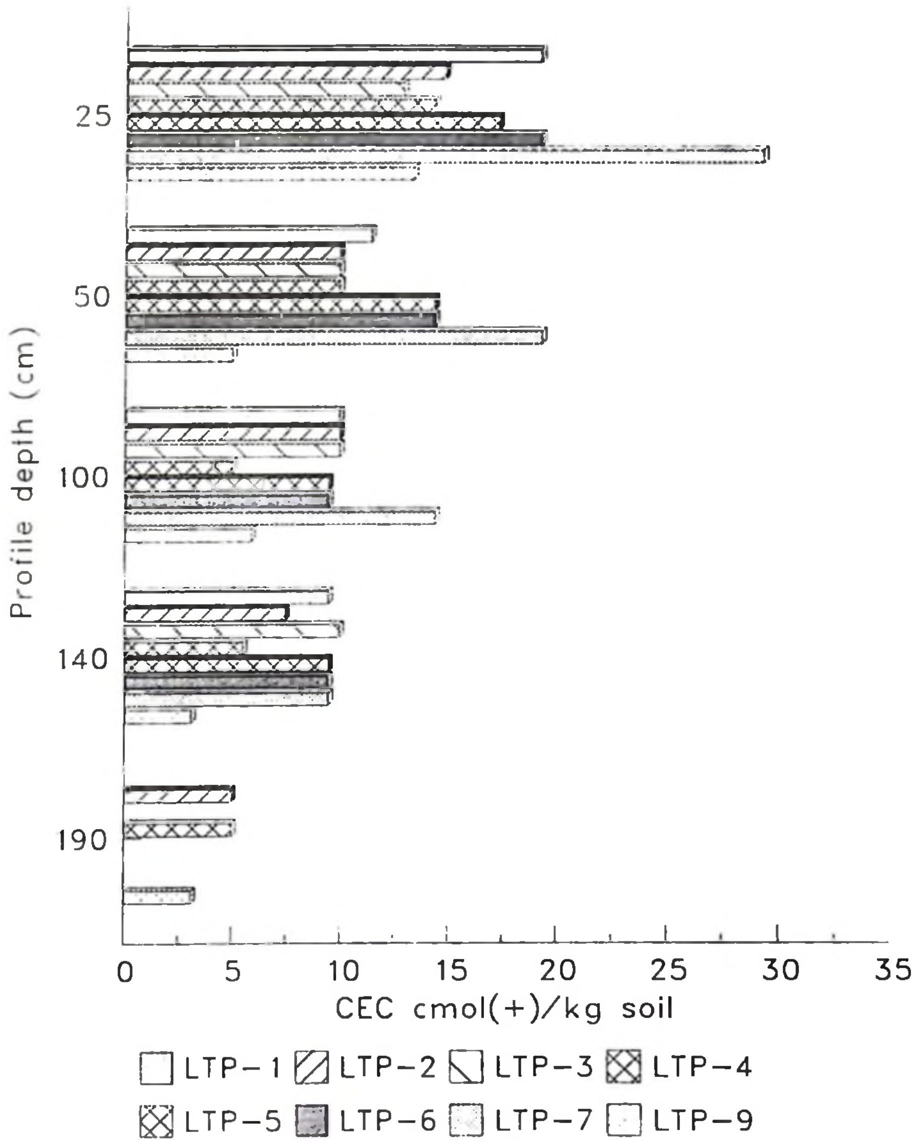

Figure 8. Distribution of CECsoil with soil depth for Litemb soils

most crops, which suggest that if the present Mg^{2+} levels are maintained they are still optimal for production of most crops.

The topsoil exchangeable K^+ levels range from 0.10 to 0.20 cmol(+)/kg soil which is very low; and the values show no trend with increasing soil depth. Exchangeable sodium ranges from 0.07 to 0.11 cmol(+)/kg soil for almost all studied profiles. According to Landon (1991) the values are very low. The levels do not vary with soil depth. Low levels of sodium can be attributed to its solubility and mobility when soils are sufficiently moist which leads to removal of sodium out of soils (Zonn, 1986). The data on exchangeable K^+ and Na^+ indicate that these nutrients are very low and this may probably affect nutrient ratios and nutrient availability.

Base saturation

Base saturation of studied soils range from 7 to 39% in topsoils and 20 to 60% in subsoils. Most of topsoils have base saturation below 20%. There is no clear trend of base saturation with soil depth. Differences among profiles are small. Low base saturation is attributed to intensive leaching of bases and it indicates poor fertility status of the soils.

Nutrient balance

Results on nutrients ratios are given in Table 6. In most of the studied soils Ca levels are greater than Mg levels and Mg levels greater than K. This trend has been observed in other soils of Mbinga (Msanya *et al.*, 1995b). However, individual nutrient ratios such as Ca/Mg, Mg/K and K/total exchangeable bases (TEB) and Ca/TEB have shown nutrient imbalances that will probably affect crop performance in the study area.

The Ca/TEB ratio for the studied soils range between 0.6 and 0.8. This ratios indicate that calcium is higher than other bases. The high Ca/TEB ratios may affect uptake of other bases particularly Mg and/or K as Ca induced deficiency of Mg and/or K.

The Ca/Mg ratios in Litembo soils are mostly optimal (see Table 6). Profiles LTP-2 (MU-P1), LTP-3 (MU-P4), LTP-5 (MU-P3) and LTP-6 (MU-P3) however have relatively higher ratios. The optimum range for Ca/Mg ratios are between 2 and 4 which is considered favourable for most crops (Landon, 1991). When this ratio is greater or equal to 5:1, availability of Mg and P is reduced.

Mg/K ratios in LTP-2, LTP-3, LTP-5, LTP-6 and LTP-7 range from 1.2 to 2.9 which is within the recommended range between 1 and 4 for optimal nutrient uptake by plants (Landon, 1991). Profiles LTP-1, LTP-7 and LTP-8 have Mg/K ratios between 5 and 15 which are likely to inhibit magnesium uptake by most crops.

The K^+/TEB saturation for Litembo village soils is above 2% except for LTP-1 which has K^+/TEB of 1%. Landon (1991) reported that the favourable K/TEB saturation for most tropical crops is 2% or more, which is common in most soils of the study area.

In general, nutrient ratios show that plant nutrients are well balanced, except in few cases which shows imbalances.

4.1.4. Mineralogy of clay fractions

The mineralogy of subsoil clay fractions of Litembo soils is presented on Figure 9 and Table 7. The diagnostic x-ray diffraction (XRD) peaks are used to identify the mineral species. The x-ray diffractograms for Mg-saturated air dried samples show strong peaks at 7.19Å, 4.85Å and 3.59A. These peaks are common

Table 6. Nutrient ratios for topsoils (0-50 cm) of Litembo soils

Profile no.	Ca/TEB	Ca/Mg	Mg/K	K/TEB
LTP-1	0.8	3.9	15	0.01
LTP-2	0.6	5.3	1.6	0.07
LTP-3	0.8	6.3	1.5	0.08
LTP-4	0.7	2.9	0.07	0.07
LTP-5	0.8	5.3	1.9	0.08
LTP-6	0.8	7.3	1.2	0.09
LTP-7	0.8	3.6	5.8	0.04
LTP-8	0.6	2	5	0.06
LTP-9	0.7	2.6	2.9	0.09

for all the studied profiles. Profiles LTP-1 and LTP-6 in addition have also a diffraction peak at 4.18Å. A strong peak at 7.19Å reappeared in Mg-glycol treatment also in all profiles. K-air treatments show strong peaks at 7.19Å and 4.85Å observed in all profiles and peak 3.59Å in LTP-1 (MU-L2), peaks 4.37Å in profiles LTP-5 (MU-P3) and LTP-7 (MU-P2). Upon heating K-treated samples to 350^{0}C, all studied soils remained with a strong peak 7.19Å. Heating the K -treated samples to 550^{0}C resulted in the collapse of all peaks in all studied soils. The peaks at 7.19Å and 3.59Å which disappeared after heating at 550^{0}C are diagnostic for kaolinite. The peaks at 4.85Å and 3.37Å are diagnostic for gibbsite, whereas the peaks at 4.18Å represents goethite.

The XRD patterns also confirm absence of expanding clay minerals in the studied soils. The reflection patterns of Litembo soils do not show differences which suggests that the soils have similar mineralogy.

Relative abundance of clay minerals

The relative abundances of clay minerals for each profile are summarized in Table 8. Kaolinite dominates in all profiles of studied soils with accessory amounts of gibbsite and goethite. The presence of these minerals in the clay fraction indicates an advanced stage of soil weathering (van Wambeke, 1991). The absence of expanding clay minerals is due to the pedogenic processes that have formed the soils that are characterized by intensive leaching, and low pH that do not favour the

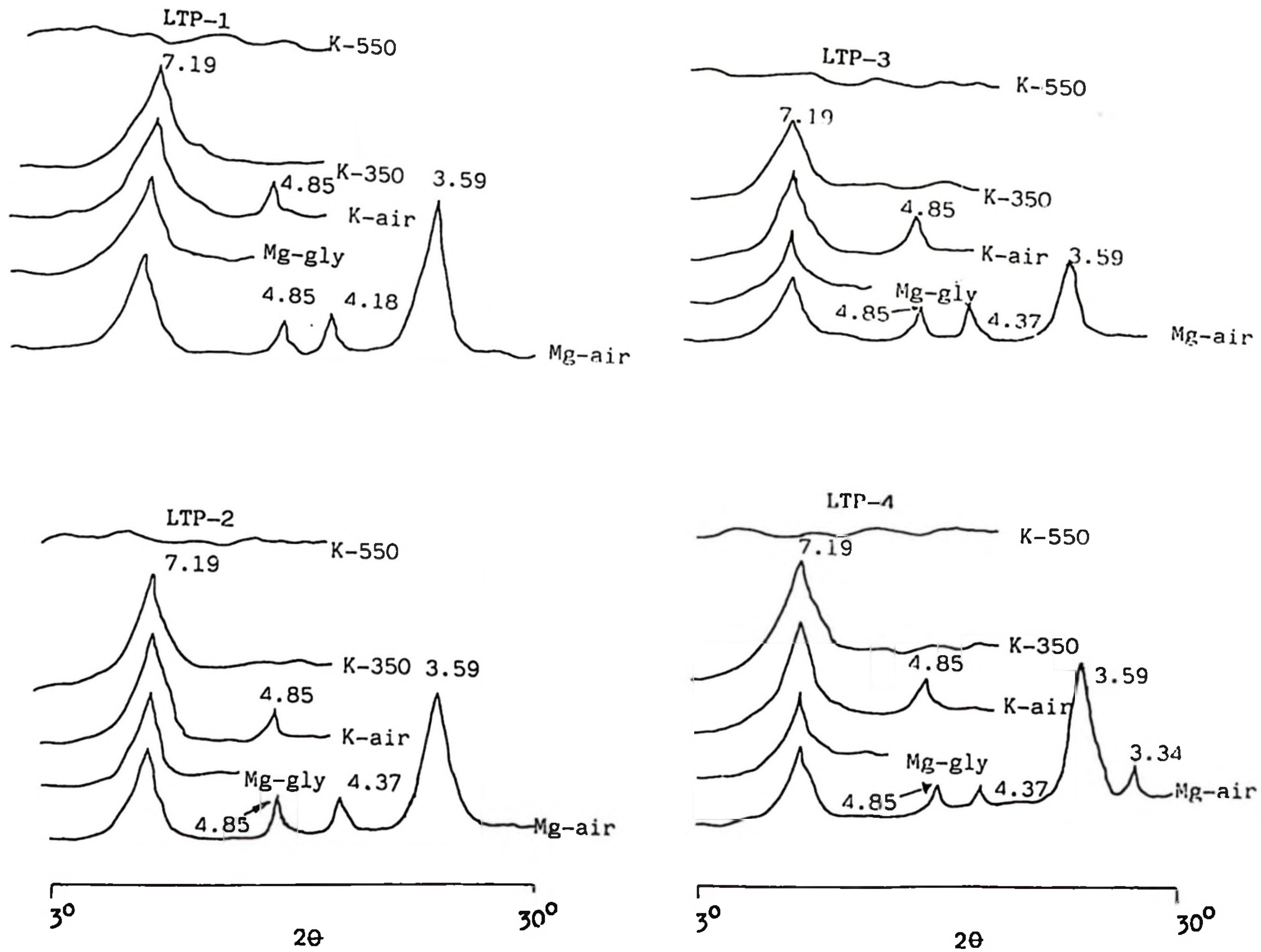

Figure 9. X-ray diffractograms of subsoil clay fractions of selected Litembo soils, peaks in Angstroms (A)

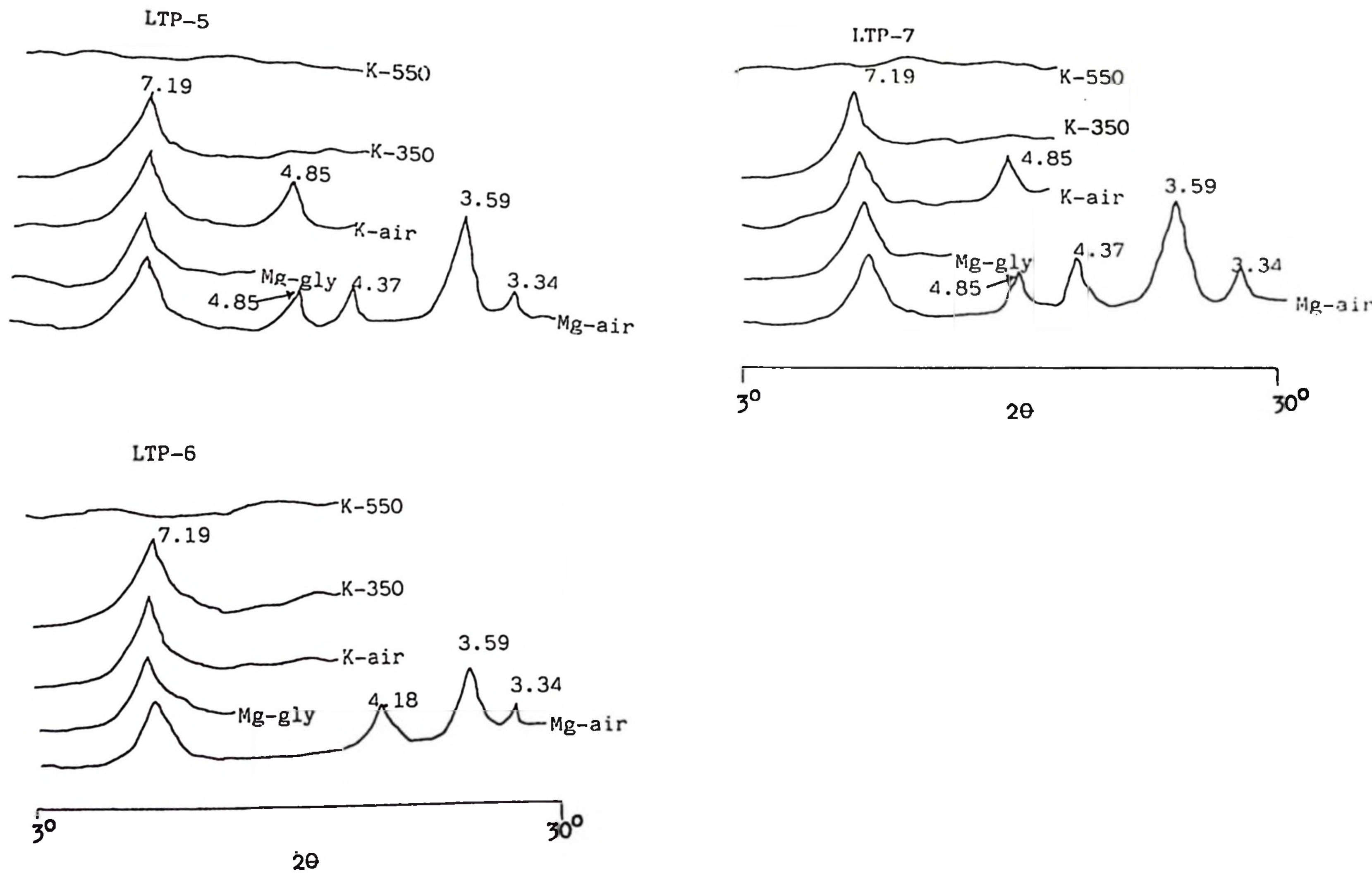

Figure 9. cont.

Table 7. X-ray diffraction data of subsoil clay fractions of some Litembo soils

Profile	Treatment					Mineral species
	Mg-aturated air dried	Mg-glycerol solvated	K-saturated air dried	K+ 350°C	K+ 550°C	
LTP-1	7 19Å,3.59Å,4.85Å, 4.18Å	7.19Å	7.19Å,4.85Å	7.19A	NP	Kaolinite, gibbsite, goethite
LTP-2	7.19Å, 4.85Å, 3.59Å,4.37Å	7.19Å	7 19Å, 4.85Å	7 19A	NP	Kaolinite, gibbsite, goethite
LTP-3	7.19Å, 4.85Å, 3.37Å,3.59Å	7.19Å	7.19Å,4 85Å	7.19A	NP[1]	Kaolinite, gibbsite
LTP-4	7.19A, 4.85A, 3 59A,4.37A 3.34A	7.19A	7.19A, 4 85A	7 19A	NP	Kaolinite, gibbsite
LTP-5	7.19A,4.85A,4.37A, 3.59A, 3.34Å	7.19A	7.19A,4 85A, 4 37A	7.19A	NP	Kaolinite, gibbsite
LTP-6	7.19A, 4.18A, 3.59A,3.34Å	7.37Å	7.19Å, 4.85A	7.19A	NP	Kaolinite, gibbsite, goethite
LTP-7	7.19Å,4.85Å,4.37Å, 3 59Å, 3.34Å	7.19Å	7.19Å,4.85Å, 4 37A	7.19Å	NP	Kaolinite, gibbsite

[1] NP = no peaks

formation of expanding clay minerals right from the beginning of soil formation (Jackson, 1965; Carroll, 1970; van Wambeke, 1991). The kaolinitic clay mineralogy of the studied soils is reflected in the physical properties such as plasticity, whereby most soils are slightly plastic, structure which is weak, and chemical properties such as cation exchange capacity which is low to very low.

Table 8. Relative amounts of clay minerals in some selected soil profiles of Litembo

Profile depth (cm)	Mineral species		
	Kaolinite	Gibbsite	Goethite
LTP-1	****	*	*
LTP-2	****	*	*
LTP-3	****	**	**
LTP-4	****	*	*
LTP-5	****	**	**
LTP-6	****	***	
LTP-7	****	**	**

* 1- 10%   **** 31 - 70%
** 11 - 20%   ***** 71 - 99%
*** 21 - 30%

4.1.5. Oxides/hydroxides of Mn, Al and Fe

Table 9 gives the results on oxides and hydroxides of manganese, aluminum and iron.

The ammonium oxalate extractable oxides represent amorphous (poorly crystalline) hydrous oxides of Mn, Al and Fe of soils (McKeague, 1978). Generally the oxalate extractable oxides of the studied soils decrease with depth. This may probably be due to the fact that amorphous inorganic oxides of Al, Fe and Mn are bound by organic matter. There is no significant difference between profiles in terms of the content of the different oxides.

Manganese oxide content ranges from 0.03 to 0.10% in topsoils and decline to 0.01% in subsoil except for profile LTP-2 with manganese oxide content of 0.04% in subsoil.

Values of amorphous aluminum oxides are relatively higher than those of manganese oxides. The topsoil values range from 0.27 to 0.83%. Profiles LTP-4 and LTP-6 have amorphous aluminum of 0.27 and 0.48% respectively. The remaining profiles have topsoil values above 0.50% which decrease with soil depth.

Values of oxalate extractable iron oxides range from 0.3 to 1.19% in topsoils. Profiles LTP-4 and LTP-5 have relatively higher values (1.19% and 0.72%) than the others. Most profiles have higher iron oxide values in subsoils than in topsoils and this indicates the effect of illuviation of poorly crystalline iron into the B horizons.

The sodium pyrophosphate extractable Mn, Al and Fe represent the organically bound Mn, Al and Fe (McKeague, 1978). The values of pyrophosphate extractable Mn, Al and Fe are higher in topsoils than in the subsoils. The values decrease with depth. The observed trend corresponds with the distribution of soil organic matter. Profiles LTP-3 and LTP-5 have higher values in Bt horizons than the other profiles which suggests high contents of organically bound Fe translocated to the Bt horizons. Manganese oxide content is generally lower than the other oxides.

The sodium citrate bicarbonate dithionite (CBD) extractable Mn, Al and Fe constitute the amorphous, organic, inorganic and crystalline forms of Mn, Al and Fe and finely divided hematite and goethite (McKeague, 1978). The CBD extractable Fe generally increases with depth while CBD extractable Al and Mn decrease with depth. This can be explained by the fact that Fe correlates with clay contents and that clay increase with depth. There is much higher dithionite extractable Fe compared to Al and Mn oxides in the soil (Table 9). Wilson and Bown (1976) reported elsewhere that the amounts of Fe tend to be larger than the amounts of Al in most soils. In the easily erodible parent materials the Al amounts exceed those of Fe. Profiles LTP-5, LTP-2 and LTP-6 have high contents of CBD extractable Fe in their subsoils suggesting presence of crystalline forms of iron in the subsoils.

4.1.6. Pedogenesis

Pedochemical weathering is evident in all studied soils. Oxidation-reduction cycles i.e. alteration between reducing and oxidizing condition is responsible for release of free oxides of iron, aluminium and manganese from primary minerals and their localization into mottles in LTP-6 (MU-V), and concretions in the soil sola of profiles LTP-2 (MU-P1) and LTP-3 (MU-P4).

The dominant soil forming processes in the study area include addition or enrichment of organic and mineral materials. *Melanization* and *humification* take place in all soils in the study area as indicated by dark coloured thick surface

Table 9. Oxides and hydroxides of Mn, Al and Fe in Litembo soils extracted by different extractants

Profile/horizon (cm)	NH_4-Oxalate extractable (%)			Sodium pyrophosphate extractable (%)			Sodium citrate bicarbonate dithionite extractable (CBD) (%)		
	Mn	Al	Fe	Mn	Al	Fe	Mn	Al	Fe
LTP-1									
0-35	0.03	0.57	0.65	0.04	0.35	0.46	0.13	0.39	2.00
35-50	0.05	0.55	0.66	0.01	0.27	0.76	0.05	0.32	2.32
50-90	trace	0.57	0.53	0.01	0.06	0.07	0.01	0.22	2.34
90-140	trace	0.32	0.42	0.01	0.07	0.04	0.01	0.18	2.41
LTP-2									
0-25	0.06	0.66	0.44	0.03	0.34	0.16	0.05	0.25	3.17
25-50	0.05	0.40	0.70	0.01	0.10	0.12	0.06	0.23	3.72
50-100	0.03	0.42	0.33	0.01	0.16	0.34	0.04	0.21	1.73
100-140	0.04	0.25	0.89	0.01	0.08	0.08	0.02	0.12	6.28
140-190	0.04	0.23	1.29	0.01	0.29	0.15	0.03	0.15	4.91
LTP-3									
0-30	0.05	0.71	0.36	0.02	0.36	0.30	0.60	0.28	1.63
30-60	0.04	1.10	0.76	0.01	0.04	0.05	0.04	0.16	3.50
60-95	0.02	0.40	0.37	0.03	0.21	2.33	0.02	0.17	1.91
95-160	0.01	0.39	0.38	0.01	0.06	0.06	0.01	0.14	2.67

Table 9 continued

LTP-4									
0-40	0.05	0 27	1.19	0.02	0.21	0.26	0.09	0 28	2.31
40-60	0 04	0.22	1 08	0.01	0.15	0.30	0.08	0.44	3.57
60-100	0.03	0.32	0 67	0.01	0.04	0.05	0.03	0.16	3.83
100-130	0 01	0.33	0.61	0 01	0.03	0.05	0.01	0 16	2 41
130-180	0 01	0 17	0.58	0.01	0.21	0.22	0.01	0 20	3.54
LTP-5									
0-30	0.06	0 65	0.72	0 02	0 24	0.20	0.07	0.27	1.66
30-50	0.05	0.46	0.34	0.08	0.33	2.34	0.07	0 25	2.16
50-90	0.01	0.32	0.41	0 01	0.04	0.05	0.02	0.26	8.69
90-160	0.01	0.39	0.91	0.01	0.03	0.05	0.01	0.22	2.84
LTP-6									
0-35	0.03	0.48	0.36	0.02	0.31	0.54	0.04	0 30	1.187
35-60	0.02	0.24	0.85	0.01	0 10	0.34	0.03	0.17	1.89
60-90	0.06	0.33	0 42	0 01	0.08	0 24	0 05	0.18	5.93
90-130	0.01	0.03	0.93	0 01	0.80	0.48	0.01	0.14	3.15
LTP-7									
0-30	0.10	0.83	0.30	0.04	0 29	0.19	0.14	0.40	3.29
30-80	0.07	0.63	1.16	0.01	0.20	0 21	0.11	0.34	2.83
80-120	0.05	0.62	1.54	0.01	0.19	0.21	0.09	0.45	3.31
120-180	0.01	0.29	0.94	0.01	0.25	0.16	0.02	0 22	2.90

horizons.

Translocation of materials from one point to another within the soil, is another dominant process. Eluviation/illuviation of clay is evident in all profiles as manifested by clay increase with depth and the presence of clay cutans in most studied soils. *Leaching* which is analogous to eluviation by solution is evident in all soils as shown by low bases and low pH which are indications of loss of bases by intensive leaching.

Transformation of the mineral and organic substances within the soil has also been observed in these soils. Formation of iron concretions/nodules and mineralization of organic material to release mineral elements are evident. Braunification, rubification and ferrugination which represent development of brown, reddish brown and reddish colours respectively are also evident in most studied soils.

4.1.7. Indices of degree of weathering

Several indices are used in this study to assess the degree of weathering (Table 10). The indices discussed are silt/clay ratio, fine sand/coarse sand ratio, water dispersible clay, and CEC_{clay}. Other indices are percent aluminum/iron ratio and iron oxide crystallinity.

Silt/clay ratio

Most subsoils in the study area have silt/clay ratios that range from 0.16 to 0.22. Profile LTP-6 (MU-V), however has silt/clay ratio of 0.46 in subsoil, most probably because it receives fresh soil materials annually by floods. Profiles LTP-1 (MU-L2), LTP-3 (MU-P4), LTP-5 (MU-P3) and LTP-7 (MU-P2) have silt/clay ratios of

Table 10. Weathering indices for Litembo soils

profile/horizon	silt/clay ratio	fine sand / coarse sand	water dispersible clay	CEC_{clay} cmol(+)/kg	dithionite extractable Al_2O_3%/Fe_2O_3%	iron oxide crystallinity Fe_d-Fe_o	Fe_o/Fe_d
LTP_1							
Ap	0.41	0.13	9.0	50	0.19	1.35	0.33
Bt1	0.27	nd	9.5	23	0.13	1.66	0.28
Bt2	0.16	0.14	9.0	16	0.09	1.81	0.23
Bt3	0.33	nd	1.0	17	0.07	2.01	0.17
LTP_2							
Ap	0.51	1.70	7.0	43	0.07	2.73	0.14
Bt1	0.32	nd	5.0	16	0.06	3.02	0.19
Bt2	0.22	2.23	3.0	16	0.12	1.40	0.19
Bt3	0.20	nd	1.0	12	0.01	4.99	0.21
Bt4	0.23	nd	1.0	8	0.03	3.50	0.19
LTP_3							
Ap	0.28	1.70	5.0	33	0.20	1.27	0.22
Bt1	0.18	nd	9.0	21	0.04	2.74	0.22
Bt2	0.16	1.15	9.0	19	0.09	1.54	0.19
Bt3	0.11	nd	1.0	16	0.05	2.29	0.14

Table 10. continued

LTP_4							
Ap	0.25	0.75	15.0	36	0.12	1.12	0.52
Bt1	0.20	nd	13.0	23	0.12	2.49	0.30
Bt2	0.16	0.87	1.0	8	0.04	3.16	0.17
2CB	0.15	nd	1.0	8	0.06	1.81	0.25
2Bt	0.33	nd	1.0	9	0.05	2.96	0.16
LTP_5							
Ap	0.36	1.22	7.0	45	0.16	0.94	0.43
Bt1	0.27	nd	9.0	32	0.11	1.82	0.16
Bt2	0.21	1.43	1.0	17	0.03	8.28	0.05
Bt3	0.13	nd	1.0	15	0.07	1.94	0.32
LTP-6							
Apg	0.52	0.18	11.0	63	0.16	1.51	0.19
2Cg	0.61	nd	11.0	52	0.08	1.04	0.45
3Cg	0.46	0.30	11.0	30	0.03	5.51	0.07
4Cg	0.50	nd	5.0	37	0.04	2.22	0.30
LTP-7							
Ap1	0.37	0.50	7.0	78	0.12	2.99	0.09
Ap2	0.18	nd	13.0	30	0.12	1.67	0.40
Bt1	0.18	0.62	15.0	22	0.13	1.77	0.47
Bt2	0.20	nd	1.0	15	0.07	1.95	0.33

Fe, = dithionite extractable iron; Fe_oo = oxalate extractable iron less than 0.2. According to van Wambeke (1962) and Barshad (1965) soils having silt/clay ratio of less than 0.2 are considered highly weathered. Hence most soils in the study area are highly weathered. Relatively higher silt/clay ratios in topsoils than in subsoils can be explained by the phenomenon of lessivage of clay down the profile resulting to lower proportion of clay in topsoils compared to the subsoils. The translocation of clay is also a good index for soil development (Zonn, 1986).

Fine sand/coarse sand ratio

Fine sand/coarse sand ratios for Litembo soils range between 0.13 and 1.70 in topsoils and 0.14 to 2.2 in subsoils. Profiles LTP-2 (MU-P1), LTP-3 (MU-P4) and LTP-5 (MU-P3) have fine sand/coarse sand ratios >1. This indicates that these profiles are more highly weathered than the others. Soils in mapping unit L2 and V have low fine sand/coarse sand ratios which is an indication of less soil development compared to the rest. This observation is supported by presence of unweathered quartz, gravels and rock fragments in profiles (LTP-1) and LTP-6) (appendix 1). Oertel and Giles (1966) evaluated profile development using fine sand/coarse sand ratio and concluded that the greater the ratio, the more developed the soil profile is.

Water dispersible clay

Water dispersible clay content in Litembo soils are low. Profiles LTP-1 through LTP-5 have water dispersible clay of less than 10%. Profiles LTP-6 and LTP-7 have 11 and 14% water dispersible clay contents respectively. In general, water dispersible clay is mostly less than 10% which indicates immobility of clay, a manifestation of advanced stage of soil weathering. Immobility of clay increases with increase in soil age or advanced weathering (FAO, 1988). The values of water dispersible clay agree very well with the other indicators that these soils are highly weathered.

CEC_{clay}

CEC_{clay} is generally higher in topsoils than in subsoils. Profiles LTP-2 (MU-P1), LTP-3 (MU-P4), LTP-4 (MU-P3) and LTP-5 (MU-P3) have CEC_{clay} that ranges from 33 to 45 cmol(+)/kg in topsoils. The CEC_{clay} of the same profiles ranges from 8 to 16 cmol(+)/kg in subsoils. Generally CEC_{clay} decreases with soil depth (Figure 10). Profile LTP-7 (MU-P2) although located on piedmonts like the previous profiles, has CEC_{clay} of 78 and 15 cmol(+)/kg in topsoil and subsoil respectively. The CEC_{clay} values in subsoils of piedmont profiles is comparable but topsoil values are variable in function of the organic matter content.

The hills profiles LTP-1, LTP-8 and LTP-9 have CEC_{clay} that ranges from 50 to 54 cmol(+)/kg in topsoils. The values decline with soil depth to 8 and 17 cmol(+)/kg in subsoils of profiles LTP-9 and LTP-1 respectively. Profile LTP-8 is a shallow one with a uniform CEC_{clay} value of 54 cmol(+)/kg. Profile LTP-6 (MU-V) has CEC_{clay} of 63 cmol(+)/kg clay in topsoils. The values decrease with soil depth to about 30 cmol (+)/kg clay in subsoils.

Generally Litembo soils have both low CEC_{soil} and low CEC_{clay} which according to Bear (1965) suggests that the soils are in advanced stage of soil formation. According to van Wambeke (1991) the observed CEC_{clay} values particularly those of subsoils correspond with the CEC of 1:1 silicate clay minerals, which characterize highly weathered soils. Studies on the clay mineral fractions of these soils indicated kaolinite to be the dominant clay mineral (Table 7).

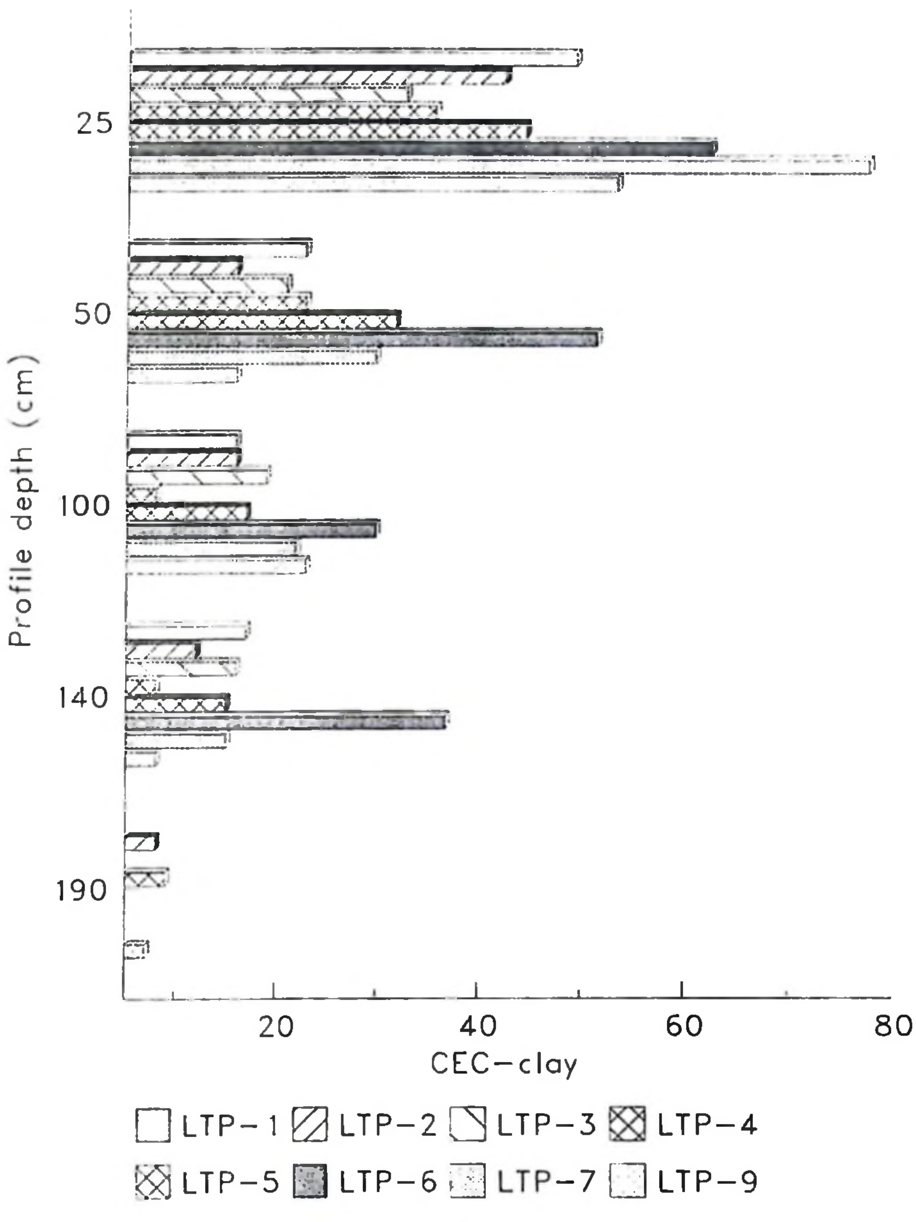

Figure 10. CECclay versus soil depth for Litembo soils

Aluminum/iron ratio

$Al_2O_3\%/Fe_2O_3\%$ ratios are low. The proportion of aluminum is also low compared to that of iron extracted by the same extractant. The ratios are comparable among profiles but profile LTP-2 has a ratio of about 0.07 in topsoils. Other profiles have values between 0.12 to 0.2 in topsoils which decrease with depth to a range of 0.03 to 0.07. Smaller $Al_2O_3\%/Fe_2O_3\%$ ratios show that Al_2O_3 in soils is less than Fe_2O_3. The ratios indicate that the soils are in an advanced stage of weathering.

Iron oxide crystallinity index

Difference in amounts of dithionite extractable iron (Fe_d) and oxalate extractable iron (Fe_o) indicates the distribution of amorphous and crystalline forms of iron in soils. The (Fe_d - Fe_o) values in the studied soils indicate relatively higher figures in profiles LTP-5 (MU-P2) and LTP-6 (MU-V) than in the other profiles with values of 8.28 and 5.51% respectively. Profiles LTP-2 (MU-P1) and LTP-4 (MU-P3) have (Fe_d - Fe_o) values of about 3% whereas profile LTP-3 (MU-P4) has values of 2%. Profiles LTP-1 (MU-L2) and LTP-7 (MU-P2) have (Fe_d - Fe_o) values less than 2%. The profiles with high (Fe_d - Fe_o) values have higher amounts of crystalline iron than amorphous iron. High amounts of crystalline Fe are an indication of high degree of soil weathering (Jackson, 1965; Schulze, 1989).

Loveland and Bullock (1976) used a ratio of Fe_o/Fe_d (activity ratio) to assess the degree of crystallization and the mobilization of free iron within the profiles. Profiles LTP-1 to LTP-4 have Fe_o /Fe_d values of between 0.14 and 0.17. These low values indicate that most iron oxides are in a crystalline form, suggesting high degree of soil weathering. Profiles LTP-5 to LTP-7 have Fe_o/Fe_d values of about 0.3 which suggest that these profiles have less crystalline iron and therefore relatively less weathered than profiles LTP-1 to LTP-4.

4.2. SOIL CLASSIFICATION

Table 11 presents a summary of the soil morphological and other diagnostic features used in classifying the soils. Table 12 shows the soil names according to the two systems of classification i.e. FAO-Unesco classification system (FAO, 1988) and USDA Soil Taxonomy (Soil Survey Staff, 1990).

Table 11. Morphological and diagnostic features of Litembo soils

Profile	Diagnostic horizons	Other diagnostic features
LTP-1	*ochric A (ochric epipedon); *argic B (argillic horizon)	*strongly humic, ustic SMR; thermic STR
LTP-2	*ochric A (ochric epipedon); *argic B (argillic horizon)	*ferric properties, ustic SMR; thermic STR; (*small textural gradient in the B horizon)
LTP-3	*ochric A (ochric epipedon); *argic B (argillic horizon)	*ferric properties, ustic SMR; thermic STR
LTP-4	*ochric A (ochric epipedon); *argic B (argillic horizon)	ustic SMR; thermic STR
LTP-5	*ochric A (ochric epipedon); *argic B (argillic horizon)	*ferric properties, ustic SMR; thermic STR
LTP-6	*umbric A (umbric epipedon)	*gleyic and stagnic properties (aquic SMR); thermic STR, fluvic properties, ferric properties
LTP-7	*umbric A (umbric epipedon); *argic B (argillic horizon)	ustic SMR; thermic STR; *ferric properties, *strongly humic, (abrupt textural gradient in the B horizon)
LTP-8	*ochric A (ochric epipedon)	ustic SMR; thermic STR
LTP-9	*ochric A (ochric epipedon); *argic B (kandic horizon)	ustic SMR; thermic STR

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

Table 12. Classification of the soils of Litembo village

Profile	FAO Unesco classification system		USDA Soil Taxonomy classification system				
	Level 1	Level 2	Order	Suborder	Greatgroup	Subgroup	Family
LTP-1	Acrisol (AC)	Humic Acrisol (ACh)	Ultisol	Humult	Kanhaplohumult	Ustic Kanhaplohumult	very deep, kaolinitic fine clayey thermic Ustic Kanhaplohumult
LTP-2	Acrisol (AC)	Ferric Acrisol (ACf)	Ultisol	Ustult	Kandiustult	Typic Kandiustult	very deep, kaolinitic very fine clayey, thermic, Typic Kandiustult
LTP-3	Acrisol (AC)	Ferric Acrisol (ACf)	Ultisol	Ustult	Kandiustult	Typic Kandiustult	very deep, kaolinitic very fine clayey, thermic, Typic Kandiustult
LTP-4	Acrisol (AC)	Ferric Acrisol (ACf)	Ultisol	Ustult	Kandiustult	Typic Kandiustult	very deep, kaolinitic very fine clayey, thermic, Typic Kandiustult
LTP-5	Acrisol (AC)	Haplic Acrisol (ACh)	Ultisol	Humult	Haplohumult	Ustic Haplohumult	kaolinitic fine clayey, thermic, Ustic Haplohumult
LTP-6	Fluvisol (FL)	Umbric Fluvisol (FLu)	Entisol	Aquent	Fluvaquent	Aeric Fluvaquent	kaolinitic fine loamy, thermic, Aeric Fluvaquent
LTP-7	Acrisol (AC)	Humic Acrisol (ACu)	Ultisol	Humult	Haplohumult	Ustic Haplohumult	very deep, kaolinitic very fine clayey, thermic, Ustic Haplohumult
LTP-8	Leptosol (LP)	Dystric Leptosol (LPd)	Entisol	Orthent	Ustorthent	Lithic Ustorthent	shallow, kaolinitic fine loamy, thermic, Lithic Ustorthent
LTP-9	Acrisol (AC)	Haplic Acrisol (ACh)	Ultisol	Ustult	Kandiustult	Typic Kandiustult	very deep, kaolinitic fine clayey, thermic, Typic Kandiustult

CHAPTER 5

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1. CONCLUSIONS

Litembo soils developed under intensive weathering conditions. Weatherable minerals have been altered to secondary clay minerals mostly kaolinite, oxides and hydroxides of aluminum and iron. The piedmont soils classified as Ferric Acrisols, Haplic Acrisols and Humic Acrisols; plateau soils classified as Humic Acrisols; soils of the hills as Dystric Leptosols and Haplic Acrisols and valley bottom soils as Umbric Fluvisols.

Topography and climate have influenced intensity of weathering whereby piedmont soils are very deep and well drained, with well developed profiles. Hill summit and plateau (H1, L1 and L2) soils are shallow with only AC profiles, and are excessively drained. Most of the summits are bare rock outcrops and stony surfaces which show remnants of past soil erosion. Valley bottom soils are very deep, sandy, poorly to very poorly drained.

On the basis of topography (deep dissections and steep slopes) and weak soil structures, Litembo soils are prone to soil erosion. Deforestation in the area has increased erosion hazards and general land degradation. The traditional ngoro (tie-ridge) farming system has to a great extent reduced the seriousness of soil erosion.

Subsoil penetrometer resistance values are relatively higher (> 3 MPa) than those of topsoils (< 0.4 MPa). Subsoil bulk densities are also relatively higher than those of the topsoils. The topsoils should thus be protected so that erosion does not expose the compacted subsoils.

Litembo soils have low pH, low levels of bases, low CEC and low base saturation. These chemical parameters show that Litembo soils have poor fertility status. The bases are also in unfavourable proportions for nutrient uptake by plants in some profiles (LTP-2, LTP-3, LTP-5 and LTP-7). The Ca/Mg ratios are above optimal level which negatively affects Mg availability to plants.

Phosphorus levels are low. Low pH values may magnify the P unavailability considering the fact that pH values below 5.5 are associated with free Al and Fe which fix phosphorus.

5.2. RECOMMENDATIONS

The following recommendations are made with respect to land use in the study area. The areas that are susceptible to soil erosion should be planted with permanent crops such as coffee and trees. Forest is a suitable land use alternative on steep slopes with deep soils; and grasses and short rooted plants on the steep slopes with shallow soils.

Catchment areas should be protected from water erosion by planting suitable tree species to sustain water supply for the growing population and protect land and soil from erosion. Afforestation should be encouraged in sloping lands and hilly areas. Agroforestry systems are recommended particularly to protect the lands from further degradation, facilitate nutrient cycling and to provide wood for household uses.

The traditional farming system of *ngoro* (tie-ridge) has proved to be useful and efficient in erosion control in high altitude areas by building up soil organic matter and improving soil water conservation. This practice should be emphasized and encouraged, but researchers should work to find easier ways of making the tie-ridges.

Further research on different land use alternatives that will sustain and create a balanced ecosystem is also recommended.

In view of the observed poor soil fertility of the studied soils, there is a clear need of fertilization to improve the plant nutrient status of the soils. Research to determine rates and types of mineral fertilizers and organic manures should be carried out. This should consider also liming to raise pH to desirable levels. The economics and social implications of using both types of fertilizers should be investigated.

The study area has a serious lack of basic climatic records useful in advising farmers on planting schedules. Research is required on rainfall elements such as onset, pattern and distribution, intensity and effective rainfall. Research should also consider the planting dates, growing periods and water balance for various crops grown in the area.

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Appendix 1. Soil profile description and analytical data

Profile number : LTP-1 Mapping unit: L 2 Agro-ecol. zone:
Region : Ruvuma
District : Mbinga
Map sheet no. : 297/4
Coordinates : 34°49.456'E /11°00.2990' S
Location : Mandekendeke, 3 km West of Litembo village head office
Elevation : 1920 m asl. Parent material: Granite (felsic igneous) rocks Landform: plateau, undulating. Slope: 4 %; straight
Surface characteristics : Outcrops boulders: 50 % Erosion: None or slight (checked by ngoro)
Deposition: none. Natural drainage class : well drained to somewhat excessive
Described by D.N. Kimaro, G.J. Nkondola, J.L. Meliyo and B.M. Msanya on 22/11/15

Ap 0 - 35 cm: brown (7.5YR5/2) dry, dark brown (7.5YR3/4) moist; gravelly clay loam; soft dry, very friable moist, slightly sticky and slightly plastic wet; moderate medium and fine granular; common medium and many fine pores; frequent small angular fresh and weathered quartz fragments; many fine and very fine roots; abrupt wavy boundary to

Bt1 35 - 50 cm: brown (7.5YR5/4) dry, brown (7.5YR4/6) moist; gravelly clay; slightly hard dry, friable moist, sticky and plastic wet; weak to moderate subangular blocks; patchy moderately thick clay cutans;medium and many fine pores; frequent small angular fresh and weathered quartz fragments; very fine roots; diffuse smooth boundary to

Bt2 50 - 90 cm: red (2.5YR4/3) dry, red (2.5YR4/3) moist; extremely gravelly clay; hard dry, friable moist, sticky and plastic wet; weak to moderate coarse and medium subangular blocks; patchy moderately thick clay cutans; many fine and very fine pores; frequent small and medium angular, round fresh and weathered quartz and granite fragments; diffuse smooth boundary to

Bt3 90 - 140 cm: red (2.5YR4/8) dry, red (2.5YR4/3) moist; extremely gravelly clay; hard dry, friable moist, sticky and plastic wet; weak to moderate coarse and medium subangular blocks; patchy moderately thick clay cutans; many fine and very fine pores; frequent small, medium angular, round , fresh weathered quartz and granite fragments; diffuse smooth boundary to

SOIL CLASSIFICATION: FAO legend: 1988: Humic Acrisol (ACh)
USDA Soil Taxonomy: 1990: Ustic Kanhaplohumult

ANALYTICAL DATA FOR PROFILE LTP-1

Horizon		Ap	Bt1	Bt2	Bt3
Depth (cm)		0-35	35-50	50-90	90 - 140
Clay	%	39	49	61	55
Silt	%	16	13	10	18
sand	%	45	38	29	27
Texture class		CL	C	C	C
pH H_2O	1:2.5	5.4	5.4	5.3	5.3
pH KCl	1:2.5	5.3	4.7	4.8	4.8
EC mS/cm	1:2.5	0.04	0.02	0.01	0.01
Organic C	%	3.1	1.1	0.4	0.2
Total N	%	0.30	0.20	0.10	0.07
C/N		10	6	4	3
Available P	mg/kg	6	2	7	10
CEC NH4OAc and Exch. cations /bases (cmol (+)/kg					
CEC		19.5	11 5	10.0	9.5
CECclay		50	23	16	17
Ca		5.9	2.1	2.5	2.3
Mg		1.5	0.2	0.5	0.5
K		0.10	0.05	0.04	0.04
Na		0.08	0.07	0.07	0.07
H		0.20	0.10	0.10	0.10
TEB		7.6	2.4	3.1	2.9
Base saturation	%	39	21	31	31

Profile number : LTP-2 Mapping unit: P 1 Agro-ecol. zone:
Region : Ruvuma
District : Mbinga
Map sheet no. : 297/4
Coordinates : 10° 58.904.9' S / 34° 50.118'E
Location : Nang'ombe, 2 km East of Litembo mission Hospital
Elevation : 1570 m a.s.l. Parent material: colluvium derived from gneissic rocks. Landform: piedmont plain; undulating to rolling slopes.
Slope: 14 %; straight
Surface characteristics : Erosion: none or slight. Deposition: none.
Natural drainage class : well drained
Described by B.M. Msanya, D.N. Kimaro, G.J. Nkondola and J.L. Meliyo on 24/11/95

Ap 0 - 25 cm: brown (7.5YR4/4) dry, dark brown (7.5YR3/4) moist; clay loam; soft dry, very friable moist, slightly sticky and slightly plastic wet; weak fine subangular blocks; few medium and many very fine pores; many fine and very fine roots; abrupt wavy boundary to

Bt1 25 - 50 cm: yellowish (5YR4/6) dry, reddish brown (5YR4/4) moist; clay; hard dry, friable moist, sticky and plastic wet; moderate medium and fine angular and subangular blocks; few medium and many fine pores; frequent medium and small angular, irregular and spherical hard clay and iron nodules; few coarse and many fine roots; diffuse smooth boundary to

Bt2 50 - 100 cm: red (2.5YR4/6) dry, dark red (2.5YR3/6) moist; clay; hard dry, friable moist, sticky and plastic wet; moderate medium and fine angular and subangular blocks; many fine and very fine pores; very frequent large, medium and small angular, irregular and spherical hard clay and iron nodules; few medium and common very fine roots, diffuse smooth boundary to

Bt3 100 - 140 cm: red (2.5YR4/6) dry, dark red (2.5YR3/6) moist; clay; hard dry, friable moist, sticky and plastic wet; moderate medium and fine angular and subangular blocks; many fine and very fine pores; very frequent large, medium and small angular, irregular and spherical hard clay and iron nodules; very fine roots; diffuse smooth boundary to

Bt4 140 - 190 cm: red (2.5YR4/6) dry, dark red (2.5YR3/6) moist; clay; hard dry, friable moist, sticky and plastic wet; moderate medium and fine angular and subangular blocks; many fine and very fine pores; very frequent large, medium and small angular, irregular and spherical hard clay and iron nodules; very fine roots

SOIL CLASSIFICATION: FAO legend: 1988 : Ferric Acrisol (ACf)
USDA Soil Taxonomy: 1990 : Typic Kandiustult

ANALYTICAL DATA FOR PROFILE LTP-2

Horizon	Ap	Bt1	Bt2	Bt3	Bt4
Depth (cm)	0-25	25- 50	50 - 100	100 - 140	140 - 190
Clay %	35	63	63	63	61
Silt %	18	15	14	15	18
Sand %	47	22	23	22	21
Texture class	CL	C	C	C	C
pH H_2O 1:2.5	5.2	5.8	5.9	5.9	6.0
pH KCl 1:2.5	5.0	5.6	5.6	5.6	5.6
EC mS/cm 1:2.5	0.05	0.02	0.02	0.01	0.02
Organic C %	1.3	0.8	0.4	0.3	0.1
Total N %	0.26	0.11	0.08	0.05	0.04
C/N	5	7	5	6	3
Available P mg/kg	9	1	1	1	1
CEC NH4OAc and Exch cations/bases cmol(+)/kg					
CEC	15.0	10.0	10.0	7.5	5.0
CECclay 43	16	16	12	8	
Ca	2.1	2.1	2.1	3.3	2.1
Mg	0.4	0.5	0.7	1.0	0.4
K	0.25	0.15	0.10	0.10	0.10
Na	0.70	0.07	0.08	0.10	0.08
H	0.20	0.10	0.10	0.10	tr
TEB	3.5	2.8	3.0	4.5	2.7
Base saturation %	23	28	30	60	54

Profile number : LTP-3 Mapping unit: P4 Agro-ecol. zone:
Region : Ruvuma
District : Mbinga
Map sheet no. : 297/4
Coordinates : 10° 59.380' S / 34° 50.208' E
Location : Kitupi - 1.5 km North of the village head office; 100m west of road
Elevation : 1600 m asl. Parent material: colluvium derived from granite (felsic igneous rocks).
Landform: piedmont plain; undulating. Slope: 14 %; straight
Surface characteristics : Outcrops: 5 % Erosion: none or slight. Deposition: none.
Natural drainage class : well drained
Described by J.L. Meliyo, D.N. Kimaro, B.M. Msanya and G.J. Nkondola on 24/11/95

Ap 0 - 30 cm: dark reddish grey (5YR4/2) dry, dark reddish brown (5YR3/2) moist; slightly gravelly sandy clay; soft dry, very friable moist, slightly sticky and slightly plastic wet; weak medium subangular blocks; few medium and many very fine pores; frequent medium and small angular fresh quartz fragments; few small spherical hard clay and iron nodules; common medium and many fine roots; abrupt wavy boundary to

Bt1 30 - 60 cm: yellowish red (5YR4/6) dry, reddish brown (5YR4/4) moist; clay; soft dry, friable moist, sticky and plastic wet; moderate medium and fine subangular blocks; few medium and many fine pores; few small angular fresh quartz fragments; few small irregular and spherical hard clay and iron nodules; common medium and many fine roots; crotovinas filled with topsoil material; gradual smooth boundary to

Bt1 60 - 95 cm: yellowish red (5YR5/8) dry, yellowish red (5YR5/6) moist; clay; slightly hard dry, friable moist, sticky and plastic wet; moderate medium and fine subangular blocks; many fine and very fine pores; few small angular fresh quartz fragments; frequent large, medium and small spherical and irregular hard clay and iron nodules; common fine and very fine roots; crotovinas filled with topsoil material; diffuse smooth boundary to

Bt2 95 - 160 cm: yellowish red (5YR5/8) dry, yellowish red (5YR5/6) moist; clay; hard dry, friable moist, sticky and plastic wet; moderate medium and fine subangular blocks; many fine and very fine pores; frequent small angular fresh quartz fragments mixed in the nodules; frequent large, medium and small angular hard clay and iron nodules; few fine and very fine roots; crotovina filled in by topsoil materials

SOIL CLASSIFICATION: FAO legend: 1988 : Ferric Acrisol (ACf)
USDA Soil Taxonomy: 1990 : Typic Kandiustult

ANALYTICAL DATA FOR PROFILE LTP-3

Horizon		Ap	Bt1	Bt2	Bt3
Depth (cm)		0-30	30-60	60 - 95	95 - 160
Clay	%	39	48	53	63
Silt	%	12	9	9	7
Sand	%	49	43	38	30
Texture class		SC	C	C	C
pH H_2O	1:2.5	5.1	5.2	5.4	6.0
pH KCl	1:2.5	4.6	4.7	5.0	5.4
EC mS/cm	1:2.5	0.02	0.01	0.01	0.01
Organic C	%	2.1	0.8	0.5	0.4
Total N	%	0.19	0.12	0.08	0.07
C/N		11	7	6	6
Available P	mg/kg	7	3	2	1
CEC NH4OAc and exch. cations/bases cmol(+)/kg					
CEC		13.0	10.0	10.0	10.0
CECclay		33	21	19	16
Ca		1.9	2.0	1.6	1.5
Mg		0.3	0.4	0.4	0.3
K		0.20	0.10	0.20	0.10
Na		0.07	0.07	0.07	0.08
H		0.10	0.20	-	-
TEB		2.5	2.6	2.3	2.0
Base saturation	%	19	26	23	20

Profile number : LTP-4 Mapping unit: P3 Agro-ecol. zone:
Region : Ruvuma
District : Mbinga
Map sheet no. : 297/4
Coordinates : 10° 59.643' S / 34° 50.621' E
Location : Kigangi, 1km NE of Kigangi Pr. School
Elevation : 1570 m asl. Parent material: felsic igneous rocks. Landform: piedmont plain, (rolling towards the valley).
Slope : 7 %; straight
Surface characteristics : Outcrops: 10 % Erosion: none or slight. Deposition: none.
Natural drainage class : well drained
Described by D.N. Kimaro, B.M. Msanya, G.J. Nkondola and J.L. Meliyo on 25/11/95

Ap 0 - 40 cm: reddish brown (5YR5/4) dry, dark reddish brown (5YR3/4) moist; sandy clay; soft dry, very friable moist, slightly sticky and slightly plastic wet; weak medium and fine subangular blocks; common medium and many fine and very fine pores; very few small angular fresh quartz fragments; few small spherical soft clay nodules; few coarse and many medium, fine and very roots; clear wavy boundary to

AB 40 - 60 cm: red (2.5YR5/6) dry, red (2.5YR4/6) moist; clay; slightly hard dry, friable moist, sticky and plastic wet. moderate medium and fine subangular blocks, many fine and very fine pores; few small and medium angular fresh and weathered quartz fragments, few small spherical soft clay nodules; few coarse and many fine and very roots; gradual smooth boundary to

Bt 60 - 100 cm: red (2.5YR4/6) dry, red (2.5YR4/8) moist; clay; slightly hard dry, friable moist, sticky and plastic wet; moderate and strong fine angular and subangular blocks; many fine and very fine pores; frequent small and medium angular weathered and fresh quartz and granite fragments; frequent small and medium spherical, angular and irregular hard clay and iron nodules; few fine and very fine roots; abrupt smooth boundary to

2CB 100 - 130 cm: red (10R5/8) dry, red (10R4/8) moist; extremely gravelly clay; hard dry, friable moist, sticky and plastic wet; weak medium subangular blocks; common fine and very fine pores; angular rocks (weathered granite and fresh quartz) angular fresh quartz and weathered granite gavels; very few medium and fine roots; abrupt smooth boundary to

2Bt 130 - 180 cm: red (2.5YR5/6) dry, red (2.5YR5/6) moist; sandy clay (clay); hard dry, friable moist, sticky and plastic wet; moderate coarse and medium subangular blocks; continuous moderately thick clay and iron cutans; many fine and very fine pores; frequent small and medium angular weathered and fresh quartz and granite fragments; frequent small and medium spherical, angular and irregular hard clay and iron nodules; very few very fine roots

SOIL CLASSIFICATION: FAO legend: 1988 : Ferric Acrisol (ACf)
USDA Soil Taxonomy: 1990 : Typic Kandiustult

ANALYTICAL DATA FOR PROFILE LTP-4

Horizon		Ap	AB	Bt1	2CB	2Bt
Depth (cm)		0 - 40	40 - 60	60 - 100	100 - 130	130 - 180
Clay	%	40	44	61	61	53
Silt	%	10	9	10	9	18
Sand	%	50	47	29	30	29
Texture class		SC	C	C	C	C
pH H_2O	1:2.5	5.0	5.2	5.4	5.7	5.7
pH KCl	1:2.5	4.7	4.9	5.0	5.3	5.4
EC mS/cm	1:2.5	0.30	0.01	-	-	-
Organic C	%	1.7	0.7	0.5	0.3	0.2
Total N	%	0.17	0.09	0.06	0.05	0.03
C/N		10	8	8	6	7
Available P	mg/kg	4	2	1	1	1
CEC NH4OAc and exch.cations/bases cmol(+)/kg						
CEC		14.5	10.0	5.0	5.0	5.0
CECclay		36	23	8	8	9
Ca		1.4	1.6	1.9	1.4	2.0
Mg		0.4	0.4	0.6	0.3	0.4
K		0.14	0.05	0.04	0.05	0.05
Na		0.07	0.08	0.07	0.08	0.07
H		0.10	0.10	0.10	0.10	0.10
TEB		2.0	2.1	2.6	1.8	2.5
Base saturation	%	14	21	52	37	50

Profile number : LTP-5 Mapping unit: P3 Agro-ecol. zone:
Region : Ruvuma
District : Mbinga
Map sheet no. : 297/4
Coordinates : 10° 59.824' S / 34° 50.536' E
Location : Kiganngi Pr. School
Elevation : 1590 m asl. Parent material: colluvium from granite rocks. Landform: piedmont plain; undulating-rolling towards the valleys.
Slope: 10 %; straight
Surface characteristics : Outcrops: 4 % Erosion: none or slight. Deposition: none.
Natural drainage class : well drained
Described by D.N. Kimaro, G.J. Nkondola, J.L. Meliyo and B.M. Msanya on 25/11/95

Ap 0 - 30 cm: reddish brown (5YR5/4) dry, reddish brown (5YR4/4) moist; clay loam; soft dry, very friable moist, slightly sticky and slightly plastic wet; weak medium subangular blocks; many fine and very fine pores; frequent small spherical hard clay nodules; many medium, fine and very fine roots; abrupt wavy boundary to

Bt1 30 - 50 cm: red (2.5YR4/6) dry, red (2.5YR4/6) moist;clay; soft dry, friable moist, sticky and plastic wet; moderate medium and fine subangular blocks; patchy thin clay cutans; many fine and very fine pores; few small angular fresh quartz fragments; frequent small spherical hard clay nodules; common fine and very fine roots; gradual wavy boundary to

Bt2 50 - 90 cm: red (2.5YR4/8) dry, red (2.5YR4/6) moist; clay; slightly hard dry, friable moist, sticky and plastic wet; moderate medium and fine subangular blocks; patchy thin clay cutans; many fine and very fine pores; few small angular fresh quartz fragments, (angular rocks and weathered granite); frequent large and small spherical hard clay nodules; very fine roots; diffuse smooth boundary to

Bt3 90 - 160 cm: red (2.5YR5/6) dry, red (2.5YR4/6) moist; clay; hard dry, friable moist, sticky and plastic wet; moderate to strong medium and fine subangular blocks; patchy thin clay cutans; many fine and very fine pores; few small angular fresh quartz fragments; frequent large spherical hard clay and iron nodules; very fine roots; angular rocks, weathered granite, quartz and granite gavels below a depth of 150 cm.

SOIL CLASSIFICATION: FAO legend: 1988: Halpic Acrisol (ACh)
USDA Soil Taxonomy: 1990: Ustic Haplohumult

ANALYTICAL DATA FOR PROFILE LTP-5

Horizon		Ap	Bt1		Bt2	Bt3
Depth (cm)		0 - 30	30-50	50-90	90 - 160	
Clay	%	39	47		55	63
Silt	%	14	13		12	8
Sand	%	45	40		33	29
Texture class		CL	C		C	C
pH H2O	1:2.5	5.4	5.5		5.8	5.9
pH KCl	1:2.5	4.7	4.9		5.4	5.4
EC mS/cm	1:2.5	0.01	0.01		0.03	0.01
Organic C	%	2.2	0.9		0.3	0.3
Total N	%	0.18	0.13		0.07	0.50
C/N		12	7		4	1
Available P	mg/kg	11	4		3	2
CEC NH4OAc and exch cations/bases cmol(+)/kg						
CEC		17.5	14.5		9.5	9.5
CECclay		45	32		17	15
Ca		2.1	5.5		1.8	1.6
Mg		0.4	1.4		0.5	0.4
K		0.21	0.15		0.16	0.10
Na		0.07	0.07		0.07	0.07
H		0.10	0.10		0.10	0.10
TEB		2.8	7.1		2.5	2.2
Base saturation	%	16	49		27	23

Profile number : LTP-6 Mapping unit: V Agro-ecol. zone:
Region : Ruvuma
District : Mbinga
Map sheet no. : 297/4
Coordinates : 10° 59.811' S / 34° 50.244' E
Location : Mbugani along river Luhali, 500 m south of Litembo village office.
Elevation : 1570 m asl. Parent material: alluvium from granite rocks. Landform: alluvial/flood plain; flat or almost flat. Slope: 2 %
Surface characteristics : Erosion: none or slight. Deposition: none.
Natural drainage class : poorly drained
Described by B.M. Msanya, D.N. Kimaro, J.L. Meliyo and G J. Nkondola on 27/11/95

Apg 0 - 35 cm: dark reddish brown (5YR3/2) moist; slightly gravelly sandy clay loam; common medium faint diffuse mottles; friable moist, slightly sticky and plastic wet; weak medium and fine subangular blocks; common very fine and fine pores; few small angular fresh quartz fragments; few coarse and many very fine roots; abrupt wavy boundary to

2Cg 35 - 60 cm: yellowish red (5YR4/6) moist; very gravelly sandy clay loam; common coarse distinct clear (7.5YR3/2) mottles; slightly sticky and slightly plastic wet, massive, common very fine and fine pores; frequent medium and small angular and spherical fresh and weathered granite and quartz fragments, common very fine and fine roots; gradual wavy boundary to

3Cg 60 - 90 cm: strong brown (7.5YR5/8) moist; slightly gravelly sandy clay loam; many coarse prominent sharp (2.5YR2.5/2) mottles; slightly sticky and slightly plastic wet; massive: many very fine and fine pores; few small angular weathered and fresh granite and quartz fragments, few medium and small spherical soft clay and iron nodules; common very fine and fine roots; the structure of 2cg - 4cg is massive; clear wavy boundary to

4Cg 90 - 130 cm: pink (7.5YR8/4) moist; slightly gravelly sandy clay loam; many medium distinct clear (10R3/6) mottles; sticky and plastic wet; massive; frequent medium and small irregular weathered granite and quartz fragments; frequent medium and small spherical soft clay and iron nodules; few very fine and fine roots.

SOIL CLASSIFICATION: FAO legend: 1988 : Umbric Fluvisol (FLu)
USDA Soil Taxonomy: 1 990 : Aeric Tropic Fluvaquent

ANALYTICAL DATA FOR PROFILE LTP-6

Horizon	Apg	2Cg	3Cg	4Cg
Depth (cm)	0 - 43	43 - 60	60 - 90	90 - 130
Clay %	31	26	32	26
Silt %	16	17	15	13
Sand %	53	55	53	61
Texture class	SCL	SCL	SCL	SCL
pH H2O 1:2.5	5 4	5.4	5.8	5.7
pH KCl 1:2.5	4.7	50.0	50.0	5.5
EC mS/cm 1:2.5	0.01	0.01	0.01	0.07
Organic C %	1.8	0.4	0.3	0.2
Total N %	0.17	0 08	0.06	0.05
C/N	11	5	5	4
Available P mg/kg	7	5	5	2
CEC NH4OAc and exch. cations/bases cmol(+)/kg				
CEC	19.5	14.5	9.5	9.5
CECclay	63	52	30	37
Ca	2.2	2.1	2.2	1.5
Mg	0.3	0.3	0.4	0.2
K	0.26	0.15	0.14	0.10
Na	0.11	0.10	0 10	0.10
H	0.20	0.10	0 10	0.10
TEB	2.9	2 7	2.8	1.9
Base saturation %	15	18	30	20

Profile number : LTP-7 Mapping unit: P2 Agro-ecol. zone:
Region : Ruvuma
District : Mbinga
Map sheet no. : 297/4
Coordinates : 10° 59.841' S / 34° 49.874' E
Location : Ugenini, 1.5 km west of Litembo village head office along the truck road
Elevation : 1630 m asl. Parent material: colluvium from granite (felsic igneous) rocks. Landform: piedmont plain; rolling. Slope: 15 %, straight
Surface characteristics : Outcrops: 50 % Erosion: none or slight. Deposition: none
Natural drainage class : well drained
Described by D.N. Kimaro, G.J. Nkondola, J.L. Meliyo and B.M. Msanya on 27/11/95

Ap1 0 - 30 cm: reddish grey (5YR5/2) dry, dark reddish brown (5YR3/3) moist; sandy clay loam; soft dry, very friable moist, slightly sticky and slightly plastic wet; very weak medium subangular blocks; many fine and very fine pores; frequent medium and small spherical and angular weathered granite and quartz fragments; frequent small spherical hard clay and iron nodules; few coarse and many fine and very fine roots; abrupt smooth boundary to

Ap2 30 - 80 cm: dark reddish brown (2.5YR3/4) moist; sandy clay; friable moist, sticky and plastic wet; moderate medium and fine subangular blocks; many fine and very fine pores; frequent medium and small angular weathered granite and quartz fragments; frequent large, medium and small spherical and irregular hard clay and iron nodules; few coarse and common very fine roots; a piece of angular granite rock seen; gradual smooth boundary to

Bt1 80 - 120 cm: dark reddish brown (2.5YR3/4) moist; clay; friable moist, sticky and plastic wet; moderate medium and fine subangular blocks; many fine and very fine pores; frequent medium and small angular and irregular weathered granite and quartz fragments; frequent large, medium and small spherical and irregular hard clay and iron nodules; few fine and very fine roots; gradual smooth boundary to

Bt2 120 - 180 cm: red (10R4/8) moist; clay; friable moist, sticky and plastic wet; moderate medium and fine subangular blocks; many fine and very fine pores; frequent medium and small angular and irregular weathered granite and quartz fragments; frequent large, medium and small spherical and irregular hard clay and iron nodules; very few very fine roots

SOIL CLASSIFICATION: FAO legend: 1988:Haplic Acrisol (ACu)
USDA Soil Taxonomy: 1990:Ustic Haplohumult

ANALYTICAL DATA FOR PROFILE LTP-7

Horizon		Ap1	Ap2	Bt1	Bt2
Depth (cm)		0 - 30	30 - 80	80 - 120	120 - 180
Clay	%	38	65	65	63
Silt	%	14	11	12	13
Sand	%	48	24	23	24
Texture class		SC	C	C	C
pH H2O	1:2.5	5.4	5.9	5.6	5.9
pH KCl	1:2.5	4.9	4.9	4.9	5.5
EC mS/cm	1:2.5	0.05	0.02	0.02	0.01
Organic C	%	3.7	0.9	0.6	0.3
Total N	%	0.30	0.14	0.11	0.05
C/N		12	6	5	6
Available P	mg/kg	32	7	5	3
CEC NH4OAc and exch. cations/bases cmol(+)/kg					
CEC		29.5	19.5	14.5	9.5
CECclay		78	30	22	15
Ca		7.0	4.7	5.0	3.9
Mg		1.9	0.8	0.7	0.6
K		0.33	0.29	0.23	0.10
Na		0.10	0.10	0.10	0.10
H		0.10	0.10	0.10	0.05
TEB		9.3	5.9	6.0	4.7
Base saturation	%	32	30	42	49

Profile : LTP-8 Mapping unit: H1
Survey project : Litembo 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 mafic metamorphic rock. 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 soils. Minor pockets of moderately deep 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; clay loam

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

ANALYTICAL DATA FOR PROFILE LTP-8

Horizon		Ah	Bw
Depth (cm)		0 - 20	30 - 50
Clay	%	25	24
Silt	%	13	11
Snd	%	62	65
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		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 and exch. cations/bases cmol/kg

CEC	13.4	13.7
CECclay	54	57
Ca	0.6	1.4
Mg	0.3	2.6
K	0.06	0.02
Na	0.03	0.02
H	0.01	0.04
TEB	1.0	4.0
Base saturation %	7	29

Profile : LTP-9 Mapping unit. H2
Survey project : Litembo 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 red clays.

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

BA 45 - 60 cm: red (2.5YR4/6) moist; clay; 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; 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; 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 (ACh)
USDA Soil Taxonomy: 1990: Typic Kandiustult

ANALYTICAL DATA FOR PROFILE LTP-9

Horizon	Ap1	Ap2	BA	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
Sand %	58	56	64	46	46
Texture class	SCL	SCL	SCL	SC	SC
pH H2O 1:2.5	4.9	5.2	4.8	4.9	5.0
pH KCl	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	-	-
CEC NH4OAc and exch. cations/bases cmol/kg					
CEC	13.5	5.0	5.9	3.1	3.1
CECclay	54	16	23	8	7
Ca	1.3	1.3	0.7	0.6	0.7
Mg	0.5	0.4	0.1	0.2	0.3
K	0.17	0.06	0.05	0.06	0.07
Na	0.02	0.04	0.01	0.04	0.01
H	0.05	0.06	0.05	0.10	0.02
TEB	2.0	1.8	0.9	0.9	1.1
Base saturation %	15	36	15	29	35

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

Compiled from Baize (1993), ILACO (1991) 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	> 3.5
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 6.6to 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	pH above 9.0

3. Available phosphorus

mg P/kg soil	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)

cmol (+)/kg soil	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 soil	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 soil	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

cmol (+)/kg soil	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

cmol (+)/kg soil	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 millimetres 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.