

**ESTABLISHMENT OF DIGITAL LAND RESOURCES DATABASE FOR  
LAND USE PLANNING: A CASE STUDY OF EASTERN MOROGORO  
RURAL DISTRICT, TANZANIA**

**BY**

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## ABSTRACT

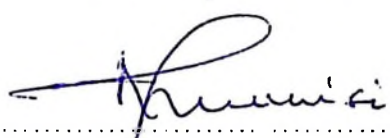
A study was conducted in the eastern part of Morogoro Rural District to establish digital land resources database which could be used when making decision on land use planning. Four Divisions namely; Mkuyuni, Matombo, Mvuha and Bwakira Chini were included in the study. Land resources data for climate (rainfall and temperature), physiography and soils and socio-economic were collected and compiled from field survey and other sources. The data were analysed, characterised and computerized to generate digital land resources database. The generated databases were stored, manipulated and geoprocessed using computer and various softwares to produce digital spatial and non-spatial information which included thematic maps for elevation, climate, length of growing period (LGP), soils and agroecological zones. Tables on land attribute database, descriptive soil legend and reports were other digital products generated. The digital databases were then used to run land evaluation for the area. Automated land evaluation system (ALES) was employed to compute physical land suitability evaluation for specified land utilization types (LUTs) i.e. maize, rice, citrus and sesame. The results of the suitability evaluation showed that 57% of the area could be used to produce maize, 85% to produce citrus, 22% paddy and 78% to produce sesame; with production potentials ranging from moderate to poor for all studied LUTs. The major limitations were erosion hazard, nutrient availability, rooting condition and wetness. Citrus was more suited to the area, followed by sesame, maize and lowland rice. The study has demonstrated that greater capability for storing, displaying spatial and non-spatial data in different forms and scales, data analysis and computation of land evaluations

exist when land resources data are captured in digital format. Basing on this conclusion, it is highly recommended that land resources data at any level should be inventoried and automated to simplify the process of land use planning.

**DECLARATION**

I, **ABBAS IDRIS MAWENYA MUNISI**, do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my own original work and that it has neither been submitted nor currently being submitted for higher degree in any other University.

Date ..... 15/05/2001 .....

Signature .....  .....

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## CHAPTER ONE

### INTRODUCTION

Inadequate and current land resources information is a primary constraint to proper and effective land use planning in most of the developing countries. These countries have characteristic high population growth rate which impose high demand or pressure on existing land resources, and later on results in land resources degradation and environmental destruction (Parry, 1986 and Williams, 1989).

Tanzania, being among the developing countries, requires readily accessible and adequate information on its land resources, plus sound land use policies for proper land use planning and management (King, 1984). However, large amount of information on land resources is required for proper decisions on land use planning to be made. Adequate and up-to-date land resource information is crucial for effective and efficient planning of land resources use in order to avoid land use conflicts, mismanagement and resources degradation. Nevertheless, Tanzania, like many other developing countries lacks readily available, accessible, sufficient and current information on the endowment and status of its land resources. Most of existing information is very old (of more than 30 years), not easily accessible and of a general scale which does not offer enough detail to effect planning at district level and below.

Despite the fact that information on land resources is a pre-requisite for land use planning (to avoid land use conflicts and land resources mismanagement and degradation), it is estimated that nearly 60 percent of Tanzania's land

resources (soil in particular) are still largely unknown (Msanya *et al.*, 1993). This situation calls for increased effort plus adaptation of modern technologies to inventory land resources and establish database necessary for guiding decisions on land resources planning, management and conservation.

Since the amount of information required for land use planning is so large, the only practical way to handle such a situation is through the establishment of digital databases (FAO, 1996a). This simplifies storage and retrieval of information, incorporate new data that are being made available, accommodate future revision and updating. Therefore, the proposed study is intended to establish a computerised or digital land resources database for eastern part of Morogoro Rural District on which decisions on land use planning for the District can be based.

Several donor-supported projects have attempted to bridge this land resources information gap by compiling land resources data for several regions and/or districts at different scales. However, a large portion of the country's land resources including the eastern Morogoro Rural District, does not have current land resources inventory. This area has high potential for agriculture and other uses, and the population is rapidly increasing as consequently increasing pressure on land resources and their degradation. The study intended to supplement these projects effort by establishing digital land resources database for the eastern Morogoro rural District.

Computerised land resources data including social and economic aspects are a prerequisite for understanding the potential of the land and permit proper

decision making for land use planning. Digital databases are becoming important in the assessment of ecological constraints for various land uses, and enable the development of sound environmental conservation strategies (Kimaro *et al.*, 1996).

Availability of land resources information is becoming increasingly possible because of improvement in the techniques of data collection and manipulation such as Remote Sensing and Geographic Information System (GIS) (Parry, 1986 and Williams, 1989). The use of computer techniques in handling land resources information is becoming more useful in land use planning.

The established digital land resources inventory can supply comprehensive information which can be used to improve and strengthen planning, management and evaluation systems for land and land resources, simplify the process of land suitability evaluation and enable land users to respond quickly to the requirements of the rapid changing land use in the area. Moreover, the database will be useful in the development of land evaluation models and guide the development of technologies and policies that are appropriate for sustainable land resources use.

The main objective of study was to establish digital land resources database for eastern part of Morogoro Rural District and use the information to prepare a land use plan for the area. The specific objectives were:

- i. to identify, collect and compile land resources data of the study area including climate, landforms, soils and social economic data.
- ii. to characterize the soils in terms of their physical and chemical properties.

- iii. to classify the soils of the area using internationally recognized systems of soil classification commonly used in Tanzania (i.e. FAO World Resource Base (WRB) (FAO, 1998) and USDA Taxonomy (Soil Survey Staff, 1999).
- iv. to generate digital land resources database for the study area.
- v. to compute automated land suitability evaluation as a part of land use planning for the study area.

## CHAPTER TWO

### LITERATURE REVIEW

#### 2.1 Land resources

According to FAO (1995a), “*land*” is a delineable area of the earth’s surface, encompassing all attributes of the biosphere immediately above or below this surface, including those of the near-surface climate, the soil and terrain forms, the surface hydrology (including shallow lakes, rivers, marshes and swamps), the near-surface sedimentary layers and associated ground water reserves, the plant and animal populations, the human settlement pattern and physical results of past and present human activities (terracing, water storage or drainage structures, roads and buildings). The components of the natural land unit can be termed land resources, including physical, biotic, environmental, infrastructural, social and economic components, in as much as they are fixed to the land unit.

Land resources include all those features of the land which can in some way, be used to fulfil certain human needs. It comprises many elements that can be divided into two main categories: (a) natural land resources (b) artificial land resources. The first category constitutes the largest group and includes sub-groups such as climate, relief/landforms, vegetation, soils, water and wildlife (FAO, 1993a). The second category includes the products of past human activities such as dikes, polders, roads, canals and terraces (Vink, 1975).

### 2.1.1 Climate

Climate covers a range of factors including precipitation, temperature, sunshine, wind, humidity and cloudiness. Climatic elements are measured and quantified by well-established and standardized methods. Meteorological stations are placed at strategic areas with equipment to record precipitation, temperatures, humidity, wind, sunshine, evaporation, cloudiness and day length. Many of the land resources have been, and are, influenced by climate during their formation. Climate is one of the genetic factors in the formation of relief (topography) and soils. It is the main agent in determining water balance in hydrology and geohydrology (Vink, 1975). Temperature and water are the major factors that govern crop distribution (in both space and time). In combination with solar radiation, these factors condition the net photosynthesis and influence the rates at which plants accumulate dry matter and accomplish the successive development stages, according to the rates and patterns which are specific to cultivated plants (FAO, 1993a).

The "*length of growing period*" has been used as a framework for the assessment of climatic resources (FAO, 1979; 1984). It is defined as the period in which temperature and moisture permit crop growth. The inventory of climatic resources allows; a differentiation of an area into reference thermal zones, reflecting the geographical and seasonal distribution of the prevailing temperature regimes; a differentiation of an area or region into reference Length of Growing Period (LGP) and LGP-pattern zones, reflecting the prevailing moisture regimes and including the year-to-year variations; a quantification of potential yields (of

crops, livestock and fuelwood) that can be attained under constraint-free conditions; and an assessment of various agroclimatic constraints in order to take into account agricultural land use possibilities and yield losses likely to occur.

### 2.1.2 Soils

“*Soil*” is a three dimensional body occupying the uppermost part of the earth’s crust and having properties differing from the underlying rock material as a result of interactions between climate, living organisms (including human activity), parent material and relief over periods of time and which is distinguished from other ‘soil’ in terms of differences in internal characteristics and/or in terms of gradient, slope-complexity, microtopography, stoniness and rockiness of its surface (Brinkman and Smith, 1973).

Soil resources are studied in soil survey, which is taken as the most essential part representing all other land resources. Soil maps for land use planning are made with many different scales, varying from very small (1:5 million) to very large (1:5 thousand). The scale is very important as it has direct correlation with the detail with which field investigations are carried out. The maps on different scales are applicable to different kinds of land use planning. The detail and usefulness for planning are most properly expressed by the use of the “basic mapping unit” and the “basic planning unit” (Vink, 1963). These terms respectively indicate the smallest area that can be indicated on the map and the smallest area on this map which is sufficiently reliable to be used as a planning unit.

### **2.1.3 Water**

Next to the soil, “water” is by far most important land resource, which is simultaneously relatively stable, and rather easy for man to manipulate. In the whole world fresh water is a scarce resource (Douglas, 1994). Under natural conditions flowing water carries different quantities of solid materials, depending on the kind of climate, relief, lithology, soils, vegetation in the source areas and on the kind of action present in the different parts of the stream (upper, middle and lower). Plants, animals and men use water as an agricultural resource. Part of this water is temporarily stored in their tissue. A large part is, however, returned to the hydrological cycle through transpiration, which together with direct evaporation from free water and land surfaces, is returned to the atmosphere as “evapotranspiration”.

Ground water is intimately connected with the soils. Excess of ground water leads to insufficient air in the soils and is therefore deleterious to many plants. It may be caused by excess precipitation on soils of poor permeability. Excess surface water is a landscape characteristic which is intimately connected with the periodicity on the flow of rivers as well as with local relief. Intensive drainage may therefore be necessary.

### **2.1.4 Vegetation**

“Vegetation”, to some extent, is considered a land resource. It is a land attribute in so far as it is reasonably permanent or predictably cyclic. It may be

natural or the result of past or present human activity. Vegetation often exerts a great influence on the present and future uses of the land by man (Vink, 1975).

Vegetation, which is important component of land resource includes: (a) natural forests, which produce timber, fuel wood and other forest products. (b) natural grazing lands in semi-arid areas (c) natural and semi-natural forests, and grazing lands which have obtained a degree of permanency and with nearly stable position in the ecosystem of an area (d) natural or semi-natural vegetation which conserves important species and acts or may act as “gene-centers” for future plant breeding. (e) natural or semi-natural vegetation which in some way or other, fulfills a specially useful ecological function for example areas of enhanced stability and variability in an otherwise monotonous areas of intensive agriculture (f) vegetation which serves several roles in different kinds of recreation sheltering and aesthetic/visual roles.

#### **2.1.5 Geology and relief**

The nature and structures of geological formation have many indirect influences on agricultural land use. Geological formations provide the basic materials and structures for the parent materials of soils. Furthermore, geological formations have a strong impact on climate and hydrology.

The influence of relief on agricultural land is multifaceted. Relief is the expression of the interaction of several different phenomena and processes within the earth’s crust and on its surface (Zink, 1989). Its forms and dimensions are

primarily related to geological formations and to the climate, both past and present, which have either directly or indirectly acted upon these formations.

The indirect action of climates and the effect produced by the nature of geological formations on the relief occurs through the processes of weathering and soil formation and through the influence of living organisms including plants, animals and man. Relief is therefore typically connected with many other land resources. It influences climate, hydrology and is one of the most important factors in soil formation, including its negative aspect of soil degradation: both natural and accelerated processes of soil erosion are largely dependant on the nature of the relief.

Agricultural land use is strongly influenced by the size and shape of the relief forms. With regard to size, a division into three categories is often useful (Douglas, 1994). (a) macorelief: relief forms with height differences of more than 50 m, (b) mesorelief: all relief forms with height differences between approximately 10 m and 50 m, (c) microrelief: relief forms with height differences of less than approximately 10 m. It should be noted that these categories are often superimposed on each other. Relief may further be divided into positive and negative forms, the former is elevation above a more or less arbitrary chosen reference plane, whereas the latter are depressions below this plane: for example hills, hummocks, etc., and valley, watercourses, etc., respectively.

Relief shows many differences in shape, which in general has both a horizontal and a vertical component. Relief patterns include both hill patterns and

drainage patterns, the dimensions of which may belong to any of the preceding size categories. According to Douglas (1994), hill and slope forms may be generalized as: (a) straight, flat, convex, concave, (b) long, short (slopes), (c) regular, irregular (slope forms surfaces) (d) narrow, wide (depressions, valleys). All of these factors have a direct impact on land management and may have a considerable significance for land improvement. They may to a great extent determine whether certain land utilization types are feasible in certain area or not.

#### **2.1.6 Artificial land resources**

Artificial land resources are found in nearly all parts of the world. They are often of very old and very specialized construction, completely adapted to the natural land conditions of an area by the age-old artisanship of the local peoples. These resources have been constructed by mankind through the ages and are still being constructed. Most of these must as well be carefully maintained by human efforts and organizations, the fact which constitute an essential difference between artificial and natural land resources (Vink, 1975).

Some examples of artificial land resources include: the paddy terraces in Asia (Ceylon and Indonesia); "khanats" or "khareez" subterranean irrigation canals of arid countries in Iran and Iraq; river embankments; man made canals and waterways which have become essential for both transport and drainage functions, and polders (in Netherlands, Belgium, etc.). Other examples are dams and barrages in rivers which serve both as a method of flood prevention and supply water for irrigation and for urban and industrial uses; and roads and rail

roads for transportation of products and materials. All these are essential land resources for agricultural land use and for land development in general.

## **2.2 Compilation of land resources data (data capturing)**

Information on available land resources is an essential input to efficient use of resources to mutual agreement and to sustainable management of the environment. A land use planning team, for example, requires information in order to make rational decisions to support policies and objectives. Good decisions at whatever level can not be made without adequate information.

There are three major sources from which land resources information can be compiled or captured. FAO (1996b) indicated these sources as presented here below:-

### **2.2.1 Data from existing publications**

A great deal of information can be availed from the existing literatures and different forms of publications. Land resources information can be extracted from books, maps and statistical reports. This type of information may be fairly easy to access and use.

### **2.2.2 Data from field surveys**

This method of information acquisition requires people to go to the field to collect physical and/or socio-economic data. During field survey/ground

survey, in most cases information collectors have clear idea of the basic development process and collect only the specific information which is needed.

### **2.2.3 Data from remote sensing**

In remote sensing, generally information is gathered through aerial photography or satellite and radar imagery. Depending on sensor system and its ground resolution, much information on the ground can be recorded. Aerial photography, which is the most common, versatile and economical, is taken with frame cameras mounted on a platform (airplane). Photographs are taken with overlaps at a vertical or slanting position. Depending on the scale, almost all features viewed on the ground are recorded (Lillesand and Kiefer, 1994). On the other hand imagery are taken by scanners {for example multispectral scanner (MSS), thematic mapper (TM) and return beam vidicon (RBV)} on board platforms orbiting at high altitudes. The data are recorded in digital form and then processed to produce multispectral images (Sabins, 1987).

The compiled land resources information provides important database that can be used to identify present and future needs for land, water, grazing, fuelwood and many other requirements; and this allows proper land use decisions to be made.

### **2.3 Forms of land resources database**

A database system is essentially a record keeping system i.e. a system whose overall purpose is to maintain data and to make that data available on

demand (Date, 1986 and Martin, 1988). It is a collection of maps, written reports, tables, charts and associated information in analogue or digital form. Data/information in analogue form can manually be digitized or scanned or typed through the computer keyboard to establish computerised or digital database (FAO, 1993b). Digitizing, which is the task of creating an acceptable, correct, machine-readable data file from a variety of sources (maps, field observation, digital products etc.) is one of the most time-consuming and costly tasks in the creation of databases (Aronoff, 1989 and Eastman, 1997). This form of database can be regarded as a kind of electronic filing cabinet.

#### **2.4 Advantages of digital database**

The demand for storage, analysis and display of complex and voluminous land resources data has lead, in recent years, to the use of computers for data handling and creation of sophisticated information systems (Tomlison, 1990). The advantages of digital database as pointed out by Valenzuela (1991) include among others the ability of computer to store, process, analyse and display large volumes of data and data updating make computerised data superior over other forms. Sharing data by different applications instead of each having independent database result in reduction of data redundancy and as a result maintain data integrity and quality. GIS can also link spatial and descriptive information and maintain spatial relationship between map features (ESRI, 1995). Moreover, a database includes security tool to control access to the data. This is important particularly for inserting and deleting data. Only authorized users can have access

to the database. Data output provides products required by the user and analyst, to guide decision on evaluation and land use planning. These products include maps, graphs, tables, photographs and magnetic devices.

## **2.5 Review on existing digital databases**

Several attempts have been made by different individuals and organizations/institutions to establish land resources databases for assessment, evaluation and guide decisions on land use planning in Tanzania and in other developing countries. The International Soil Reference and Information Centre (ISRIC) has prepared a number of national, continental and global soil profile database and spatially georeferenced soil and terrain database for a wide range of application and users (Batjes *et al.*, 1994). These databases include ISRIC Soil Information System (ISIS), World Inventory of Soil Emission Potentials (WISE) and World Soils and Terrain Digital Database (SOTER).

FAO through Agro-ecological Zone Project in Kenya assessed production potential and land resources and provided the physical database necessary for planning future agricultural development (FAO, 1993b). It has also developed a multilingual soil database (SDBm) to facilitate the organization, storage and retrieval of basic soil data on a micro computer in a quick, efficient and systematic way (FAO, 1995b). SDBm can enhance the exploitation of soil survey data for various purposes. It can ease the flow of such data into computerized land evaluation systems, land resource based geographic information systems (GIS) and simulation models.

More useful information for regional and district planning was generated in 1970s (Msanya and Magogo, 1993) as an effort by the government to acquire necessary data for land use planning, management and environmental protection. Parts of several regions were surveyed at reconnaissance scale (1:5000).

Soil information system for Tanzania (SISTAN) has been developed, with the facility for inputting of either full soil profile description (site characteristics and analytical data) or site characteristics and soil characteristics separately depending on user preference (Magoggo, 1992). Kimaro (1997) compiled a land resources database for Morogoro District and developed a computerised land information system for natural resources management and land use planning. SISTAN is still currently being used by some institutions in Tanzania as a data capture, storage and retrieval facility (Msanya *et al.*, 1996; 1998). A digital land resources data set for a part of Southern highlands of Tanzania has been generated by National Environmental Management Council in collaboration with National Soil Service (Mbogoni, 1999).

The land resources data discussed/mentioned above are not in a format which can easily be linked to automated land evaluation systems and they cover only a small part of the country and at details that are not sufficient for sound land use planning and management (Msanya and Magogo, 1993). More emphasis has been put on soil resources while other land resources such as landform, climate, socio-economic, etc. have not well been covered. Also most areas that have not been covered have potential for agricultural production and simultaneously face serious land resources degradation due to increasing population (Msanya *et al.*,

1996). The prospect is such that the effort will continue to establish comprehensive land resources information for all deficient areas for effective and sound land use planning, management and conservation of the valuable land resources.

## **2.6 Land use planning**

*“Land use planning”* is the systematic assessment of land and water potential alternatives for land use and economic and social conditions in order to select and adopt the best land use options (FAO, 1993a). Resources and land use assessment and planning are basis for efficient agricultural systems and sustainable land resources and management (Eden, 1986). As population and aspirations increase, so do the demand for land resources and land becomes increasingly a scarce resource. There is bound to be conflict over land use. The demand for arable land, grazing, forestry, wildlife, tourism and urban development are greater than the land resources available. Even where land is still plentiful, many people may have inadequate access to land or to the benefits from its use.

Knowledge of land resources and their potentials is a prerequisite to the assessment and planning for optimal land use and subsequent sound agricultural and economic development that is sustainable in the long term (FAO, 1993a). In land use planning, physical data (e.g. land cover, soil and relief) are combined with social and economic data for identification of possible interventions (e.g. policies, projects, programs) and for the prediction of the effects of such

interventions (Kaoneka, 1993)

Land use planning helps decision-makers to improve land use by reducing current land use problems and creating conditions in which specific social, economic or environmental goals can be met (Anaman and Krishnamra, 1994). The purpose is to select and put into practice those land uses that will best meet the needs of the people while safeguarding resources for the future. The driving force in planning is the need for change, the need for improved management or the need for a quite different pattern of land use dictated by changing circumstances (FAO, 1993a).

## **2.7 Land evaluation**

*“Land suitability evaluation”* or *“land evaluation”* is part of land use planning. It is the process of assessment of land performance when used for specific purposes, and involves the execution and interpretation of surveys and studies of landforms, soils, vegetation, climate and other aspects of land in order to identify and make a comparison of promising kinds of land use. These land uses include arable farming, livestock production, forestry, water catchment, recreation, tourism and wildlife conservation (Sharma, 1987).

Inappropriate land use leads to inefficient exploitation of natural resources, destruction of the land resource, poverty and other problems. The land is known to be an ultimate source of wealth and the foundation on which many civilizations are constructed. The society must ensure that land is not degraded and that it is used according to its capacity so that it can satisfy human needs for

present and future generations while also maintaining the earth's ecosystems. Land evaluation provide solution for part of the land use problems in support of rational land-use planning and appropriate and sustainable use of natural and human resources (Rossiter, 1996).

Land evaluation provides a rational basis for taking land use decisions based on analysis of relations between land use and land. The basic feature is the comparison of the requirements of land use with the resources offered by the land. Fundamental to the evaluation is the fact that different land uses have different requirements. For example crop production, livestock keeping or forestry requires land with different qualities.

Land evaluation deals with two major aspects: (i) physical resources such as soil, relief and climate (ii) socio-economic resources such as farm size, management level, availability of manpower, markets etc. Therefore evaluation needs information from land, land use, and economics (FAO, 1976). Data are obtained from natural resource survey, agronomy, forestry and other relevant disciplines.

Land evaluation may be given in quantitative, qualitative physical, or economic terms. In quantitative studies, economic analysis plays an important part. However, the nature of the analysis varies according to the land utilization type under consideration, and whether the study is at the semi-detailed or detailed level of intensity. In qualitative evaluation the suitability of land for alternative uses is expressed in qualitative terms only, such as highly, moderately or marginally suitable, or not suitable for a specified use. Socio-economic analysis is

only considered in generalized terms, and there are no calculations based on specific costs and prices. It covers general information on the present agricultural and other rural economy, an inventory of the technical and institutional infrastructure, information on population, land tenure systems, labour potential, education levels, etc. This evaluation is employed mainly in surveys at a reconnaissance scale, or as a preliminary to more detailed investigation.

Some terminologies and definitions which are commonly used in land evaluation that must clearly get apprehended include: land (already defined in 2.1 above), land mapping unit, land characteristic, land utilization type (LUT), land use requirement, land quality (LQ), severity level or factor level, yield, and land suitability.

*“Land mapping unit”* (LMU) is a specific area of land that can be delineated on a map, and whose land characteristic can be determined. It is the evaluation unit about which statements will be made regarding its land suitability. The LMU can be a grid cell, a single map delineation (polygon), or a set of map delineation with common characteristics.

*“Land characteristics”* (LC) is a simple attribute of the land that can be directly measured or estimated in routine survey, including remote sensing and census as well as natural resource inventory. The LC can be measure at different points or areas within the LMU. But for the purpose of land evaluation, these individual observations are usually aggregated or summarized to a single value or parameterized distribution (Bouma *et al.*, 1996).

*“Land utilization type”* (LUT) is a specific land-use system with specified

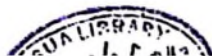
management methods in a defined technical and socio-economic setting, and with a specific duration or planning horizon. The description of LUT may include a time-series of activities and outputs. The definition includes only those attributes that serve to differentiate the suitability of land areas, for example, those that can be expressed as land use requirements with critical values in the study area. It also includes attributes that limit the land use options by discarding those that are a priori unfeasible over the entire evaluation area.

*“Land use requirement”* (LUR) is a condition of land necessary for successful and sustained implementation of a specific land utilization type. A LUT may be defined by a set of LURs. A LUR expresses the ‘demand’ side of the land use-land area matching procedure.

*“Severity level”* or *“factor level”* is a ranking or classification of the LQ of a particular area. Severity levels are conventionally numbered from level 1 indicating “no limitation” upwards to some maximum meaning “completely limiting” in the context of a specific LUT.

*“Yield”* is the amount of an output produced in a given area, either normalized to a unit of land area (e.g. per hectare) or not (i.e. the amount over the entire evaluation unit).

*“Land suitability”* is the fitness of a given LMU for a LUT, or the degree to which it satisfies the land user. Suitability expresses how well the LMU matches the requirements of the LUT. It may be expressed on a continuous scale of “goodness” (e.g. 0 to 100) or, as a set of discrete classes numbered from class 1 “highly suitable” to “not suitable”.



### **2.7.1 Automated land evaluation**

Computers have been applied to compute land evaluations at different levels of detail, together with or to replace manual land evaluations. Land Evaluation Computer Systems (LECS) was the first to implement the FAO Framework for Land Evaluation and it was tested and used in Indonesia (Wood and Dent, 1983). LECS has recently been incorporated into the FAO's Agricultural Planning Toolkit (APT) to execute land evaluation at the regional level based on small scale soil surveys (Elbersen *et al.*, 1988).

Automated Land Evaluation System (ALES) is another computer program which has been used to carry out land evaluation at different levels (provincial, country and regional levels). ALES is map-unit based, expert-systems approach which also implement the FAO framework for land evaluation (Rossiter and Van Wambeke, 1995). It is a specialized program for physical and economic land evaluation based on *in situ* land characteristics, using land qualities (Rossiter, 1995). Another computer program for land evaluation is MicroLEIS designed for land evaluation in Mediterranean climates (De la Rosa *et al.*, 1992). Integrated Land and Water information System (ILWIS) is a Geographical Information System (GIS) which is also designed for land evaluation (Meijerink *et al.*, 1988).

### **2.7.2 Application of automated land evaluation in Tanzania**

Computerised land evaluation systems have been applied at several places and in different scales in the country. Kimaro and Kips (1991) carried out physical and economic land suitability assessment for smallholder low-input

maize in Kilosa District using ALES and concluded that ALES could fairly be adapted for physical as well as economic evaluation especially when a multidisciplinary approach is employed.

Magoggo and Meliyo (1994) performed land suitability for Mbulu District using ALES. Kimaro and Msanya (1999) have done a study to assess the applicability of ALES and LECS to Tanzanian condition in Kilosa District and reached conclusion similar to those obtained by Kimaro and Kips (1991). Kileo (2000) carried out physical and economic land suitability assessment for smallholder low-input maize, rice and extensive grazing in the Wami Plains in Morogoro District using ALES and concluded that ALES is fairly capable for computing both physical and economic evaluation.

The advantages of automated land evaluation over the manual one is that many reports can easily be generated on the land use or land utilization type in question. For example reports on physical land suitability, economic suitability, yield prediction etc. Also it can interchange result files to be read by spreadsheets, databases and other GIS softwares; and when the need arise, changes can easily be made to the input physical land attributes or economic parameters and compute new evaluations. However some expertise is needed in handling computers, both the computer hardware and software are expensive in securing and maintenance costs and data entry and its manipulation takes quite some time and is cumbersome.

## **CHAPTER THREE**

### **MATERIALS AND METHODS**

#### **3.1 Physical environment of the study area**

##### **3.1.1 Location**

The research was conducted in the Eastern part of Morogoro Rural District covering four Divisions, i.e, Mkuyuni, Matombo, Mvuha and Dutumi with a total area of 503,101 ha. The centre of the area is Matombo, which is about 60 km south-east of Morogoro Municipality. The area is located between latitudes 6°45'S and 7°30'S and between longitudes 37°40'E and 38°15'E. It is bounded by Uluguru mountain ranges in the south-west, TAZARA railway in the east and Dar es Salaam – Mwanza/Kigoma central line in the north. Most of the eastern part comprises a peneplain lying between 200 and 450 meters above sea level, with an abrupt rise to more than 2400 meters in the west to form the peaks of Uluguru mountain complex.

##### **3.1.2 Climate**

The climate of the study area is of sub-humid tropical type (Sharma, 1987). The annual rainfall varies between 900 mm and 2500 mm. The area experiences bimodal rainfall characterized by two rainfall peaks in a year. The short and lighter rains usually last from October to January with its peak in December; and the long and heavier ones start from February to May with their peak period in April. The distribution pattern of both long and short rains is irregular and therefore rainfall is to some degree unreliable.

The mean monthly maximum temperature ranges from 27.4°C during the coldest month (July) to 32.3°C during the hottest months. The mean monthly minimum temperature ranges from 15.2°C to 21.1°C. The mean annual air temperature is 24.4°C. The average soil temperature is estimated as 25°C after adding 1°C to the mean annual air temperature (Soil Survey Staff, 1975) and therefore the soil temperature regime is isohyperthermic.

The relative humidity is medium. Early morning values may be in the range of 76 – 89% with a mean of 81%, but in the afternoon it decreases to a range of 42 – 67% with its mean at 52%. The number of sunshine hours amount to around 2500 per year in Morogoro. The area experiences an annual mean of 7.0 hours of sun shine per day. A maximum of almost 10 hours per day occurs during the months of November and January. Wind speed is lowest in May. From June it starts to increase and reaches the highest value in December (235 km per day).

### 3.1.3 Geology

The Uluguru mountains and the surrounding plains belong to the Usagaran system of the Mozambican belt (Saggerson, 1962). The rocks are metasediments of precambrian age and mainly composed of pyroxene granulites and neogene containing plagioclase, mica, and quartz minerals (Westerberg, 1999). In some areas, there are pockets underlain by crystalline limestone and dolomite; and a complex of sandstones, siltstones and calcareous sediments of Karroo epoch (Sampson and Wright, 1964).

### **3.1.4 Vegetation**

The mountainous parts are dominated by tropical rain forest and grassland (Msanya, 1980). The major land use in this area is bean, rice, cassava, citrus and maize cultivation. The plains are dominated with bushed shrubland and grassland, but some crops such as maize, millet, sorghum and cassava are also cultivated.

### **3.1.5 Physiography, soils and hydrology**

The eastern part of Morogoro Rural District is highly dissected with complex steep slopes and narrow valleys in between (National Soil Service, 1989; Kimaro, 1997). The undulating to rolling plains cover the eastern portion. The soils of the area are a complex of Eutric Cambisol, Haplic Luvisol and Dystric Leptosol. The area is drained by a complex system of rivers like Ngerengere, Kiziwa, Mvuha and Mgeta. The area forms the bigger portion of the watershed for the Great Ruvu river which drains to the Indian ocean.

## **3.2 Pre-field work**

### **3.2.1 Collection of materials and relevant data**

The following materials and data were collected for the study:

- i. topographical maps of 1: 50 000 scale, sheet no. 183/3 (Morogoro), sheet no. 183/4 (Kingolwira), sheet no. 184/3 (Ngerengere), sheet no. 201/1 (Mgeta), sheet no. 201/2 (Matombo), sheet no. 202/1 (Mkulazi), sheet no. 201/3 (Kisaki), sheet no. 201/4 (Dutumi) and sheet no. 202/3 (Kinyanguru).

- ii. Standard vertical aerial photographs, black and white, 23 cm square with sixty percent stereoscopic overlap and scale between 1: 20 000 and 1: 50 000, photos no. 60-64, 71-75, 34-39, 106-110, 63-66, 58-62, 99-105 and 165-171 produced in 1969, 1974, 1979 and 1980s by Fairy Air Survey Company and Airborne Profile Recording Co. Ltd, were used.
- iii. Satellite imagery print-out (false colour composite) of Landsat Thematic Mapper with ground resolution 185 km<sup>2</sup>, acquired in July 1995 and March 1996. Two scenes covering the study area with runs 166/65, 166/66 and 167/65 (path/row), produced by Eosat Company were employed.
- iv. Geological map for Morogoro region at 250 000 scale of 1980, produced by DHV Consulting Engineers, Netherlands, was used.
- v. Mirror stereoscope with 3x binocular.
- vi. Personal computer with GIS software (IDRISI, ARC INFO, ARC VIEW, SISTAN and ALES)
- vii. Digitizing table and printing facilities.
- viii. Global Positioning Systems (GPS 12XL).
- ix. Published historical data on climate (mainly rainfall) for Morogoro Region.  
  
The data were obtained from the Meteorological department data bank, Ministry of communication and works Dar es Salaam. Some other data on rainfall and temperature were extracted from FAO (1984) Agroclimatological data volume II covering countries south of equator.
- x. Guidelines for soil profile description, by FAO (1990).

- xi. Guidelines for soil classification, FAO World Reference Base (WRB) (FAO, 1998) and USDA Soil Taxonomy (Soil Survey Staff, 1999).
- xii. Munsell colour charts (Munsell Color Co, 1992).
- xiii. Cartographic equipment and materials.

### **3.2.2 Interpretation of maps, satellite imagery and photographs**

This phase included preparation of topographical base map of the study area and other thematic maps for the geology and physiography.

The study area was identified in the topographical maps covering Morogoro District. Nine topographic sheets of 1:50,000 scale were used. Coordinates (latitudes/longitudes and UTM) were used to identify the area and as control points. The maps were attached to a digitizing tablet/board connected to PC, and the main features (contours, drainage lines, roads, settlement and area boundary) were traced with stylus. This way, the features were recorded into the ARC VIEW GIS software and stored as a digital spatial data with several layers (rivers, roads, village centers, contours and area boundary). This provides a base map upon which other thematic map layers were based.

Geology map of the study area was extracted from geological map of Morogoro. Some amendments and modification of minor geological units was made to suit the scale and objectives of the study.

Physiographic information (landscapes and relief) for the study area were derived by interpretation of Landsat TM (FCC) in conjunction with 44 aerial photographs and 9 topographical maps. Hierarchical and systematic

physiographic analysis of Landsat TM and Aerial photos was adopted as a standard procedure for photomorphologic analysis. Systematic interpretation of image/photo elements i.e. static elements (landform, drainage pattern, geology and lineaments) and dynamic elements (vegetation, land use and drainage condition) facilitated delineation of mapping units. Elements of image/photo interpretation such as colour, tone, pattern, texture, shape, size and shadows were used to interpret Landsat TM. Landforms were based upon the morphological expression of the relief obtained from aerial photos and supported by drainage pattern and parameters of geological structures. Contoured topographical maps provided additional relief information. A systematic integration of the individual elements was done to obtain an optimum physiographic map at 1: 250 000 scale, which indicate the major land units and their corresponding landform characteristics. This base map was used in the field to establish relationship between landform setting, soil development and land use.

### **3.2.3 Questionnaire development**

The semi-structured questionnaires were developed for agricultural and farm survey to collect information related to farmers produce, farm management practice, farmers education (level of technology), farm labour, farm power, land tenure systems, yield and marketing systems. Other information deduced were availability of farm services such as credits, extension services and economic infrastructures (water, fuel wood, rural roads, etc.).

### **3.3 Field work**

#### **3.3.1 Collection of climatic data**

Two important components of climate namely rainfall and temperature data were collected, analyzed and used in the production of the climate and Length of Growing Period (LGP) maps for the area.

#### **Rainfall**

The historical rainfall data of about forty years, recorded from meteorological stations which once existed in the area were documented. The location of these stations were identified in the base map by using coordinates. Their monthly and annual average rainfall (in millimeter) was computed. Areas with the same rainfall were joined by isolines which formed the rainfall map of the study area.

#### **Temperature**

Temperature records were not available. This is because almost all weather stations in the area did not record temperature data. Information about temperature was extrapolated from Morogoro weather station by relating temperature and altitude. By applying the concept of temperature gradient and lapse rate (i.e. for every 1km altitude change, temperature change by  $6.5^{\circ}\text{C}$ ), it was found that for every 154 m change in altitude, temperature change by  $1^{\circ}\text{C}$  on average (Reddy and Sankara, 1992). Therefore, since the altitude change in the area was known, the Morogoro average year temperature of  $24.3^{\circ}\text{C}$  at altitude of

526 m a.s.l was taken as a reference base. Temperatures above or below 526 m altitude throughout the area were extrapolated accordingly and places with the same temperatures were joined to produce isotherms that present a temperature map of the area.

### **Length of growing period**

Length of growing period (LGP) for the study area was computed based on calculations made from the mean annual rainfall and extrapolated mean annual temperatures at Morogoro meteorological station. Reference evapotranspiration (ET<sub>o</sub> mm/day) was calculated by using temperature method based on Blaney-Criddle equation (FAO, 1991). The equation estimate ET<sub>o</sub> as:-

$$f = P (0.46T + 8)$$

P is the value related to the latitudes where the area falls and is given as constants in a table. For latitudes 5° to 10° south (where the study area lies), P value is 0.27. T is the temperature.

All months with rainfall greater than half ET<sub>o</sub> were taken to have growing season and length of growing period (LGP) was given in days. Areas with the same LGPs were grouped together. The groups were (a) areas with short LGP (150-180 days); (b) areas with very long LGP (210-240 days); (c) areas with extremely long LGP (240-300 days) and (d) areas with almost continuous LGP (over 300 days) (FAO, 1991). These LGP zones were later plotted to form LGP map for the study area.

### 3.3.2 Collection of soil data

Free soil survey procedure was adopted (Dent and Young, 1981). Soil survey was done at reconnaissance scale (1: 250 000) using the base map prepared at the same scale whereby main soils of the area and other land characteristics such as landform, slope, surface stoniness, drainage class, parent material, elevation, land use and human influence were used to confirm mapping units. The survey was carried out at an observation intensity of four observations per km<sup>2</sup> and according to procedures outlined by Dent and Young (1981). At the beginning of the survey, reconnaissance of the whole study area was done followed by selection of representative transects to allocate observation sites and sampling points. In each transect, soils were described and measured at two levels of detail: (a) soil description at each transect by augering (to 120 cm depth), (b) soil profile pit (to 2 m or to lithic or paralithic contact, whichever was shallowest). Soils and landforms were described according to standard procedures as outlined in the FAO guidelines (FAO, 1990) and USDA Soil Taxonomy (Soil Survey Staff, 1999). The data collected were recorded on the standard analogue field forms.

Soil sampling was done as follows: from each profile pit, bulk samples were taken from every horizon for physical and chemical analyses. In addition, composite top soil samples (0 - 20) and (25 - 50) cm were collected for general soil fertility characterization.

### **3.3.3 Collection of socio-economic data**

The semi structured questionnaires were administered, together with simple PRA, to collect socio-economic data. Information related to the land utilization types as practiced in the study area were compiled. These information included type of produce, management practice, farmers education (level of technology), farm labour, land tenure systems, yield and marketing systems. Also information about existence of other farm services such as credits, extension services and economic infrastructures were documented. A total of forty farmers (male and female) were interviewed.

## **3.4 Post fieldwork**

### **3.4.1 Laboratory methods**

Soil samples were analysed at SUA soil science laboratory as follows:

The pH was measured potentiometrically in water and in 1M KCl at the ratio of 1/2.5 soil-water and soil-KCl respectively (McLean, 1982). Organic carbon was determined by wet oxidation method of Walkley and Black (Nelson and Sommers, 1982). Total nitrogen was determined by Kjeldahl method (Bremner and Mulvaney, 1982). Phosphorus was extracted by Bray and Kurtz-1 method (Bray and Kurtz, 1945) and determined spectrophotometrically (Murphy and Riley, 1962; Watanabe and Olsen, 1965). The cation exchange capacity and exchangeable bases were extracted by saturating soil with neutral 1M  $\text{NH}_4\text{OAc}$  (Thomas, 1982) and the absorbed  $\text{NH}_4^+$  displaced  $\text{K}^+$  using 1M KCl and then determined by Kjeldahl distillation method for the estimation of CEC of soil. The

bases  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Na}^+$ , and  $\text{K}^+$ , displaced by  $\text{NH}_4^+$  were measured by atomic absorption spectrophotometer.

Texture was determined by hydrometer method after dispersing soil with sodium hexametaphosphate (calgon) (National Soil Service, 1990).

### **3.4.2 Soil classification**

Soil properties identified in the field as well as those determined in the laboratory were used to classify soils. FAO WRB (FAO, 1998) up to third level soil unit names and USDA Soil Taxonomy (Soil Survey Staff, 1999) to subgroup level names were used.

### **3.4.3 Cartographic work and digitization of maps**

#### **Physiography and soil map**

The soil map polygons were delineated basing on landforms, relative position in the landscape, slope classes, geology and soil properties. Mapping units were given a symbol referring to the topography. Further subdivision indicated by arbitrary numbers following the capital letter, was based on slope and soil characteristics. The legend was made to present main characteristics of the soil types and its classification i.e. soil depth, drainage, colour, texture and other diagnostic characteristics that distinguish each soil type from another.

#### **Digitisation of thematic maps**

Thematic maps were digitized into ARC-INFO software to generate digital layers for rainfall, temperature, LGP, elevation and physiography/soil. The following digital map layers were produced and coded as indicated below:-

- a) contour layer (cr) – as a line feature
- b) road layer (rd) – as a line feature
- c) river layer (vr) – as a line feature
- d) land use/land cover (lu) – as a polygon feature
- e) village centre (vc) – as a point feature
- f) soil profile pit location (pp) – as a point feature
- g) meteorological station location (ms) – as a point feature
- h) rainfall isohyets (ri) – as a polygon feature
- i) temperature isotherms (ti) – as a polygon feature
- j) length of growing period isolines (lg) – as a polygon feature
- k) physiography/soil map (su) – as a polygon feature, and
- l) boundary map (ba) – as a polygon feature

The above different map layers were combined digitally to produce various thematic maps for the study area as presented in a summary form below:-

**Digital elevation map:-**  $\sum E_i \dots E_{i n}$

Where  $i = 1, n = 4$  and  $E_1 - 4$  are the digital layers (cr, rd, vr, ba) combined to form the elevation map.

**Digital rainfall map:-**  $\sum R_i \dots R_{i n}$

Where  $i = 1, n = 3$  and  $R_1 - 3$  are the digital layers (ri, ms, ba) which are combined to form the rainfall map.

**Digital temperature map:-**  $\sum T_i \dots T_{i n}$

Where  $i = 1, n = 3$  and  $T_1 - 3$  are the digital layers (ti, ms, ba) combined to form the temperature map.

***Digital LGP zones map:-***  $\sum GP i \dots GP i n$

Where  $i = 1, n = 5$  and GP 1-5 are the digital layers (lg, ri, ti, ms, ba) combined to form the LGP zones map (map 4)

***Digital physiography/soil map:-***  $\sum S i \dots S i n$

Where  $i = 1, n = 7$  and S 1 – 7 are the digital layers (su, vr, gu, pp, rd, vc, ba) combined to form the physiography/soil map.

***Agroecological Zones (AEZs) map***

The digital thematic maps for elevation, temperature, rainfall and LGP were combined by intersection to produce agroclimatic zones for the study area. Elevation, temperature, rainfall and LGP layers were first intersected and produce agroclimatic zones for the area. This product was intersected with physiography/soil layer to form agroecological zones for the study area.

**3.4.4 Land suitability evaluation.**

Qualitative land evaluation was done for the smallholder low-input rainfed agriculture in the study area. Four major land utilization types were taken into account; these were smallholder low input rainfed maize, smallholder low input rainfed rice, smallholder low input rainfed citrus and smallholder low input rainfed sesame. Physical land suitability for agricultural use was ascertained by correlating land qualities of each mapping unit with land use requirements relevant for that land utilization type. In this way an overview was obtained of the limitations of each land unit for the land use being under consideration.

Soil information from the field and laboratory analysis of soil samples were used to compile the soil database for input into ALES. The questionnaire information were used to define the land utilization types (LUTs) for screening by ALES, i.e. smallholder low-input rainfed maize, smallholder low-input rainfed rice, smallholder low-input rainfed citrus and smallholder low-input rainfed sesame.

The suitability of the land was assessed on the basis of those land use requirements (LURs) that were considered diagnostic for the identified LUT (Sys, *et al.*, 1991). In the study area the diagnostic LURs taken into account were moisture availability, plant nutrients, temperature regime, rooting condition, soil fertility, erosion hazard, topography, flooding, oxygen availability to root zones and wetness. Rating of the LURs was done using severity levels as follows: (1) no limitation, (2) moderate limitation, (3) severe limitation, and (4) very severe limitation (Appendix 6a-d). At the level of the LURs the final physical suitability of the mapping unit was arrived at by using the "law of minimum" (most limiting LUR determines the suitability class). Four physical suitability classes were defined to carry out land suitability ratings. These were: 1. Good potential, 2. Moderate potential, 3. Poor potential and 4. Very poor potential (i.e. physically not suitable). Since in ALES the interrelations of LCs to rate LURs are accounted for in the form of decision tree, a severity level decision tree model for the four LUTs was built into the ALES (Appendix 7a-d). The class limits were set in the decision trees by basing mainly on literature sources and data from meteorological stations in the study area.

## CHAPTER FOUR

### RESULTS AND DISCUSSION

#### 4.1 Climatic resources database

Table 1 presents rainfall (mean monthly and mean annual), mean annual temperatures, evapotranspiration (ET<sub>o</sub>) and length of growing period (LGP) for 12 meteorological stations in the study area. Table 2 presents mean monthly rainfall, mean monthly temperatures, ET<sub>o</sub> and LGP for three representative meteorological stations in the study area. Table 3 presents the reference temperature zones.

##### 4.1.1 Rainfall

Figure 1 shows the climatic regimes of three representative meteorological stations in the study area. The area experiences bimodal rainfall type i.e short and long rains (*vuli* and *masika*). Short rains occur in October through December and long rains starts in February to the end of May. The mean annual rainfall in the area vary from around 900 mm in penepains to about 2500 mm in the mountains. This amount of rainfall is sufficient for production of different types of field crops, hence the area is good for rainfed agriculture. Figure 2 presents rainfall map for the whole study area.

Knowledge on rainfall and its distribution over the area is useful because all agricultural activities are rainfall dependant. Generally speaking, rainfall determines the kind of land utilization types (LUTs) that can be practiced in the area for optimum production. For example different crops (i.e. different LUTs).

Table 1. Rainfall, reference evapotranspiration and LGP for eastern part of Morogoro Rural District

Station	Mean monthly rainfall (mm)												Temp(°C)	ETo	1/2ETo	LGP(mon)	
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec					Annual
Mkuyuni Primary Sc.	184	153	244	325	154	45	39	33	45	86	132	196	1615	24	155	78	8
Athina S Estate	96	85	137	193	97	22	11	18	34	60	93	95	941	26	163	81	7
Dutumi	126	122	200	271	1112	28	13	10	22	33	84	100	1119	26	163	81	7
Singiza Mision	153	147	279	431	193	38	25	16	33	47	117	140	1600	22	148	74	7
Matombo Primary Sc.	215	177	306	326	158	66	64	62	68	93	170	220	1954	24	155	78	8
Mvuha	143	122	196	221	104	22	21	27	39	56	89	118	1195	25	159	80	7
Bwakira Juu	128	147	241	355	138	40	30	23	23	48	102	127	1368	22	148	74	7
Kibungo Mission	279	194	319	377	144	44	58	78	132	245	336	394	2581	19	137	68	10
Kibungo Maji	214	171	257	320	129	53	37	34	48	101	139	224	1712	24	155	78	8
Bwakira S. Estate	114	112	165	226	102	30	27	13	20	38	94	78	1006	25	159	80	7
Tawa Hi. Centre	165	163	282	367	176	72	68	87	87	132	205	191	1884	24	155	78	10
Mikula	81	67	141	225	83	18	9	11	24	31	98	127	947	26	163	81	5

**Table 2. Rainfall, temperature, ET<sub>o</sub> and LGP for three representative meteorological stations in the study area**

Station	Climate	Months											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Mkuyuni	Rainfall	184	153	244	325	154	44	39	32	45	86	132	196
	Temp.(Avg)	27.2	27.2	27	25.9	24.4	22.5	22	23	24.1	25.5	26.6	27.2
	ET <sub>o</sub>	142	128	137	107	96	89	96	110	128	154	148	147
	0.5ET <sub>o</sub>	71	64	68.5	53.5	48	44.5	48	55	64	77	74	73.5
Mikula	LGP	1	1	1	1	1	0	0	0	0	1	1	1
	Rainfall	81	65	141	225	83	18	9	11	24	31	98	127
	Temp.(Avg)	27.9	27.9	27.7	26.6	25.1	23.2	22.7	23.7	24.8	26.2	27.3	28.1
	ET <sub>o</sub>	145	132	140	110	98	91	99	114	131	159	152	152
Kibungo	0.5ET <sub>o</sub>	72.5	66	70	55	49	40.5	49.5	57	65.5	79.5	76	76
	LGP	1	0	1	1	1	0	0	0	0	0	1	1
	Rainfall	279	195	319	377	144	44	58	78	132	245	338	394
	Temp.(Avg)	23.3	23.3	23.1	22	20.5	18.6	18.1	19.1	20.2	21.6	22.7	23.5
Kibungo	ET <sub>o</sub>	121	110	117	91	80	73	79	92	107	131	126	127
	0.5ET <sub>o</sub>	60.5	55	58.5	45.5	40	36.5	39.5	46	53.5	65.5	63	63.5
	LGP	1	1	1	1	1	1	1	1	1	1	1	1

**Table 3. Reference temperature zones in the study area**

Thermal zone code	Mean annual temperature range (°C)	Altitude range
1	13.3 – 16.3	1600 – 2400
2	16.3 – 19.3	800 – 1600
3	19.3 – 22.3	600 – 800
4	22.3 – 24.3	400 – 600
5	24.3 – 25.3	200 – 400
6	>25	<200

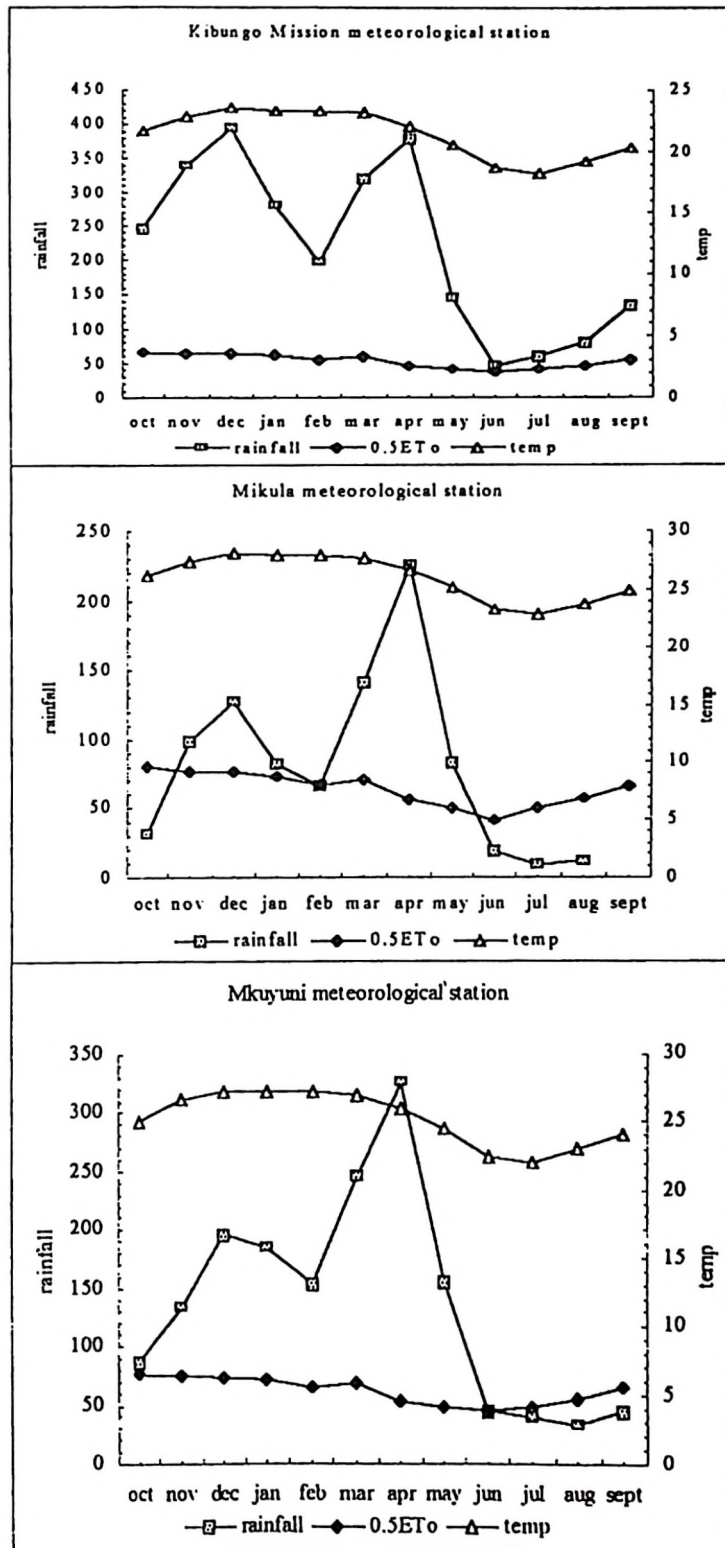


Figure 1. Climatic regime in the study area

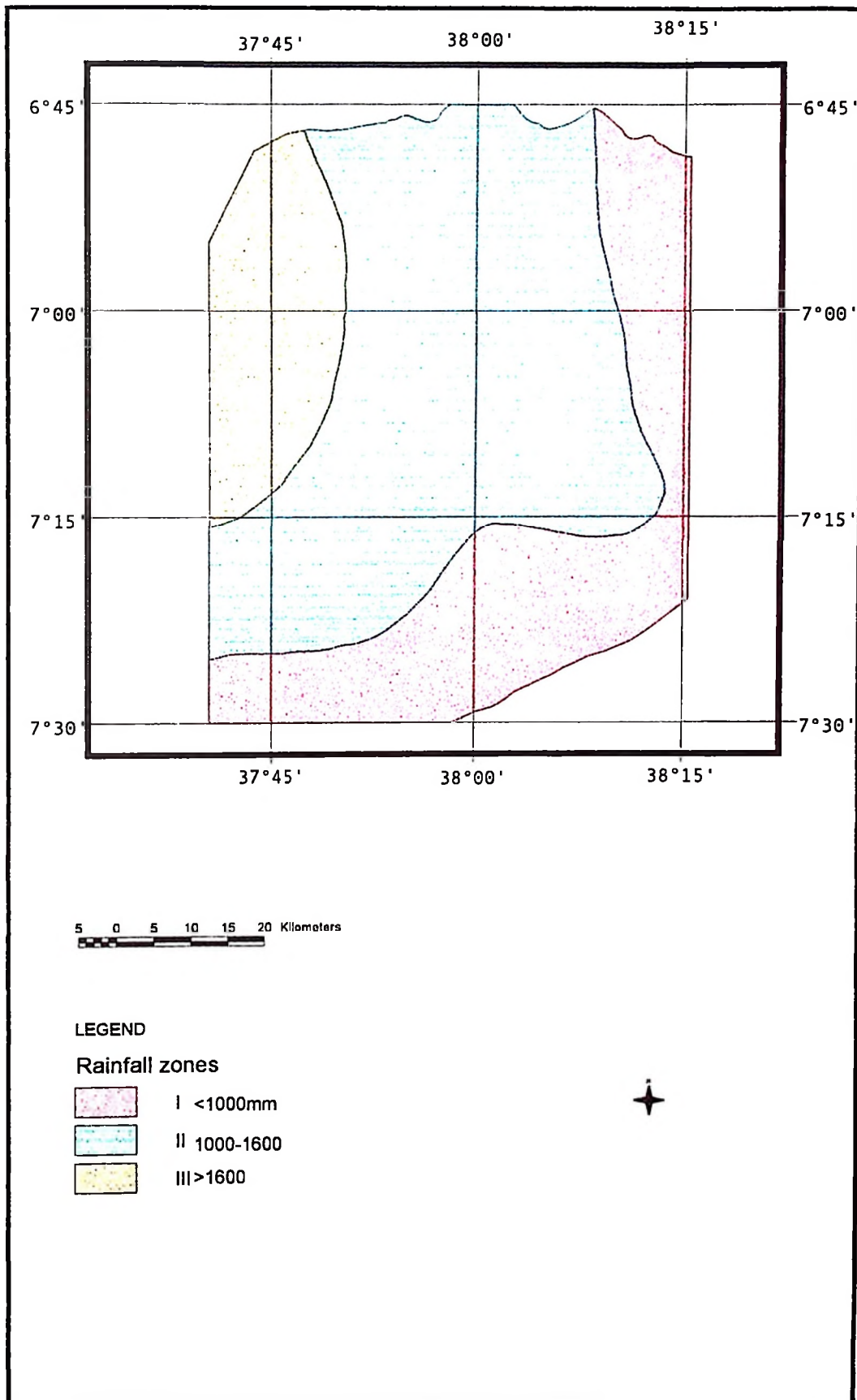


Figure 2: Rainfall Map of the Eastern part of Morogoro Rural District, Tanzania

have different moisture requirements for their growth and production.

#### 4.1.2 Temperature

Temperature of the study area is presented in a map form indicating the thermal zones (Figure 3). The lowest temperatures are found within the highest elevations where mean annual temperature is between 13.3<sup>0</sup>C and 16.3<sup>0</sup>C. The highest temperatures (above 25.3<sup>0</sup>C) are found in the peneplains. The spatial variation in temperature is expressed through the concept of “thermal zones”. Within the study area, six thermal zones were identified and their temperature and altitude ranges are elaborated in Table 3. The distribution of temperature over the study area shows a clear trend that temperatures change with altitude. Temperature decreased with increase in altitude, which makes the mountainous areas cooler than the plains. Evapotranspiration (water loss from soil and plants due to heating) increases during the dry season. Areas with higher temperatures such as plains recorded higher evapotranspiration than the mountainous areas. For example in Table 2, Athina and Mikula meteorological stations in the plains recorded the highest mean annual temperatures of 26<sup>0</sup>C while Kibungo Mission station in the mountains recorded the lowest mean annual temperature of 19<sup>0</sup>C.

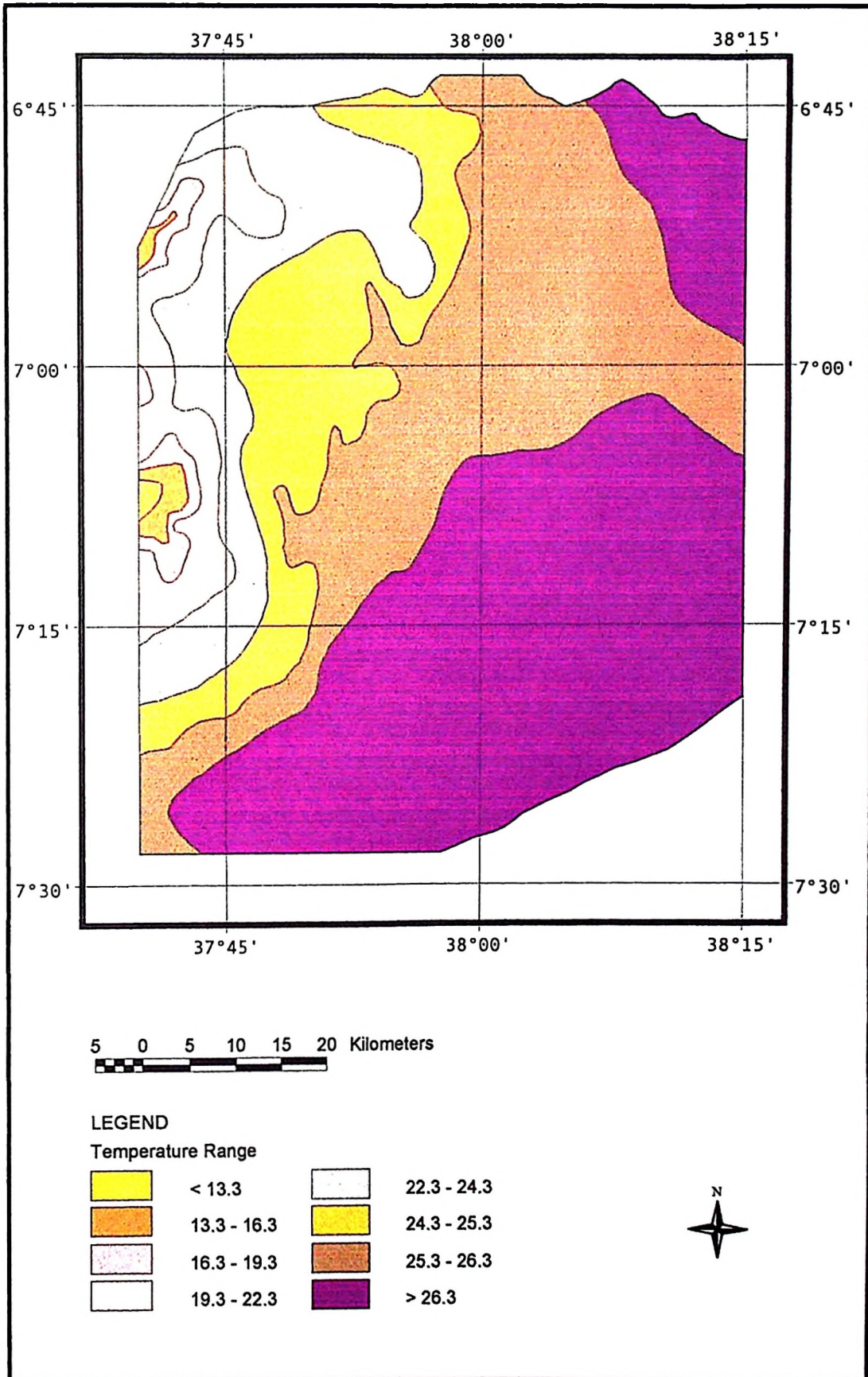


Figure 3: Temperature Map of the Eastern part of Morogoro Rural District, Tanzania

#### 4.1.3 Length of growing period (LGP)

LGP zones for the study area are presented in the form of map (Figure 4). During this period moisture supply exceeds half-potential evapotranspiration. LGP compares rainfall with potential evapotranspiration to know for how long moisture will last and be sufficient for growth of a particular crop. The reference LGP is therefore the period of the year when moisture supply and temperature permit crop growth.

The study area can be divided into four LGP zones. Zone I has the longest LGP of 300 days and above, and is found in the mountains between 800 m a.s.l and 2400 m.a.s.l. and is covered mainly with forests and perennial crops. Zone II has very long LGP that ranges between 240 to 300 days, and extends from the mountains to the piedmonts, between 400 m to 800 m a.s.l. This zone is used mainly for cultivation of annual crops during the wet months (8 to 10 months). Zones III and IV are found in the plains and valleys between less than 200 m to 400 m a.s.l. Zone III is slightly longer (LGP of 180 to 240 days) than zone IV (LGP of 150 to 180 days). This is because zone III has higher rainfall (greater than 1000 mm) than zone IV (less than 1000 mm). Cultivation of annual crops is possible in both zones.

The LGP zones show the relationship between rainfall and evapotranspiration, which is an indication of onset date, duration and quality of growing season. Knowledge on the LGP zones for the area is important to know which land utilization types can be practised and where.

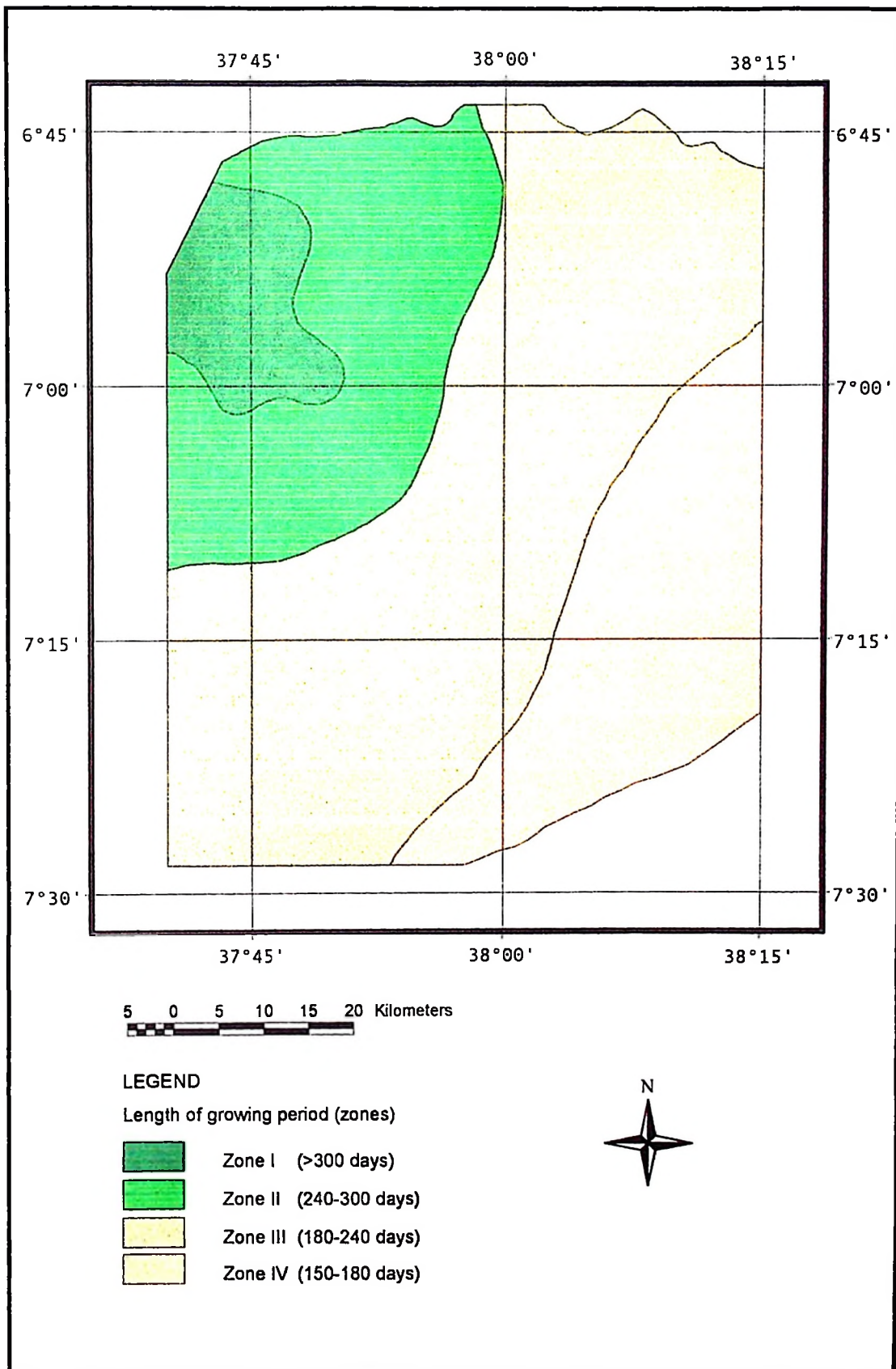


Figure 4: Length of Growing Period Map of the Eastern part of Morogoro Rural District, Tanzania

## **4.2 Physiography and soil resources database**

### **4.2.1 Elevation**

Elevation of the study area is presented as a map (Figure 5). It shows the relationship between the altitude and terrain. The area is divided into four elevation segments. These are areas with elevation below 200 m.a.s.l which comprise mainly valleys, 200 m to 400 m.a.s.l (plains), 400 m to 600 m.a.s.l (piedmonts) while elevation above 600 m.a.s.l are mainly mountains. The elevation map provided useful information on physiography of the study area. Crops and other vegetation (trees, shrubs, etc.) are distributed with respect to elevation. For example maize and sesame are mostly grown in higher elevation while rice is grown in lower elevation. Likewise, trees species are on higher elevation and shrubs dominate low-lying areas.

### **4.2.2 Landform and soils**

Table 4 summarises important site features, landform, vegetation/land use and soil description. Appendix 8 present the physiography and soils of the study area. Four major landscapes were identified, namely: mountains, piedmonts, peneplains and valleys. On the basis of these landscapes, relief units comprised strongly dissected ridges having complex steep slopes and moderately dissected ridges with deep V-shaped valleys (susceptible to landslides and high soil erosion), MO1, MO21 and MO22; dissected piedmonts with gentle to moderate slopes, Pi1 and Pi2; undulating to rolling peneplains with isolated hills, Pe1, Pe2, Pe3 and Pe4; and floodplains and watershed valleys, Va1 and Va2. Piedmonts and peneplains are a result of colluviation and severe erosion while valleys resulted from deposition of material of diverse origin (Westerberg, 1999).

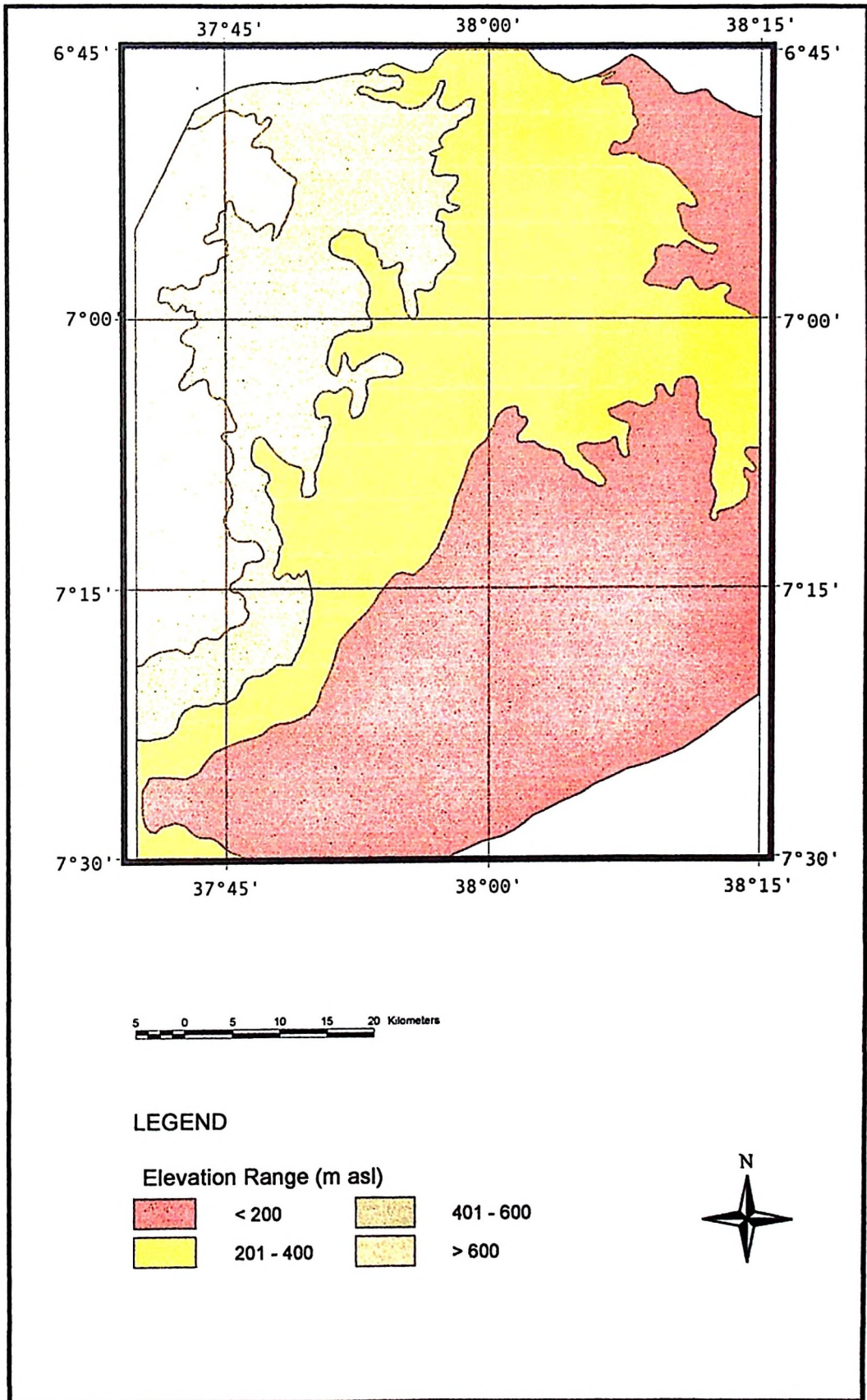


Figure 5: Elevation Map of the Eastern part of Morogoro Rural District, Tanzania

Table 4. Salient site features, landform, vegetation/land use and soils of the study area

MAP UNIT SYMBOL	LANDFORM	SLOPE (%)	PARENT MATERIAL	VEGETATION/LAND-USE	SOIL DESCRIPTION	AREAL EXTENT ha (%)
MOUNTAINS (MO) ELEVATION 500 – 800 m ASL						
MO 1	Strongly dissected ridges with complex steep slopes	>60	Hornblende-pyroxene granulites and biotite granulites	Wooded grassland with mixed cultivation of banana, maize, citrus and spices	Complex of: Rock outcrops; <u>and</u> deep, well drained, dusky red clays, with thin dark reddish brown sandy clay loam topsoils; and deep, well drained, dark reddish brown sand clay loams, with thick brown sandy clay loam topsoils; <u>and</u> very deep, well drained, reddish brown sandy clay soils; <u>and</u> very deep, well drained, dusky red sand clays, with thick brown sand clay loam topsoils. Soils classify as <i>Rhodi-Profondic Lixisols (Rhodic Kandustals)</i> , <i>Hapli-Rhodic Lixisols (Typic Rhodustals)</i> , <i>Humi-Acric Ferralsols (Humic Haplustox) and Rhodi-Profondic Lixisols (Kanhaplic Rhodustals)</i> . Profiles MTP 18, MTP 20, MTP 1, and MTP 5.	83 563 (16.6%)

Table 4. continued

MAP UNIT SYMBOL	LANDFORM	SLOPE (%)	PARENT MATERIAL	VEGETATION/LAND-USE	SOIL DESCRIPTION	AREAL EXTENT ha (%)
MO 21	Moderately dissected ridges with V-shaped valleys	30-60	Banded pyroxene granulites	Wooded grassland with mixed cultivation of banana, maize, citrus and cassava	Complex of: Rock outcrops and moderately deep, well drained, dark reddish brown sandy loams, with thick very dark brown sandy loam topsoils; and deep, well drained, dark reddish brown clays, with thin dark reddish brown sandy clay topsoils. Soils classify as <i>Rhodi-Profondaic Livisols</i> ( <i>Kanhaplic Rhodustalfs</i> ) and <i>Hapli-Rhodic Livisols</i> ( <i>Typic Rhodustalfs</i> ). Profiles MTP 16, MTP 38.	21 313 (4.2%)
MO 22	Moderately dissected ridges with V-shaped valleys	30-60	Crystalline limestones and dolomites	Wooded grassland with mixed cultivation of banana, maize, citrus, cassava, rice and sorghum	Complex of: moderately deep, well drained, dark reddish brown clays, with thick dark reddish brown sandy clay topsoils; and deep, well drained, dark reddish brown sandy clay loams, with thick very dark grey sandy clay loam topsoils. Soils classify as <i>Rhodi-Profondaic Livisols</i> ( <i>Kanhaplic Rhodustalfs</i> ) and <i>Hapli-Chromic Phaeozems</i> ( <i>Typic Argiustolls</i> ). Profiles MTP 30, MTP 27.	24 719 (4.9%)

Table 4. continued

MAP UNIT SYMBOL	LANDFORM	SLOPE (%)	PARENT MATERIAL	VEGETATION/LAND-USE	SOIL DESCRIPTION	AREAL EXTENT ha (%)
PIEDMONTS (Pi) ELEVATION 400 – 500 m ASL						
Pi 1	Dissected foothills with gentle slopes	10-15	Colluvium derived from hornblende-pyroxene granulites overlying mainly gneiss and gabbroic rocks	Wooded grassland with mixed cultivation of banana, maize, citrus, cassava, rice and sorghum	Complex of: deep, well drained, dark reddish brown clays; and very deep, well drained, dark reddish brown clays, with thick dark brown sandy clay loam topsoils; Soils classify as <i>Hapli-Rhodic Ferrasols (Inceptic Haplustox)</i> and <i>Orthidystri-Profondic Acrisols (Kanhaplic Haplustults)</i> . Profiles MTP 8, MTP 6.	31 000 (6.2%)
Pi 2	Level to gently sloping non-dissected foothills	5-10	Colluvium derived from crystalline limestones overlying sandstones and shales	Wooded grassland with mixed cultivation of banana, maize, citrus, cassava, rice and sorghum	Complex of: deep, imperitctly drained, very dark greyish brown sandy clay loams, with thick brown sandy loam topsoils; and very deep, somewhat excessively drained, dark brown loamy sands, with thick very darkish brown sands topsoils. Soils classify as <i>Calcart-Sodic Cambisols (Vertic Haplustepts)</i> and <i>Hapli-Orthidistic Cambisols (Dystric Haplustepts)</i> . Profiles MTP 31, MTP 12.	22 688 (4.3%)

Table 4. continued

MAP UNIT SYMBOL	LANDFORM	SLOPE (%)	PARENT MATERIAL	VEGETATION/LAND-USE	SOIL DESCRIPTION	AREAL EXTENT ha (%)
PENEPLAINS (Pe) ELEVATION 200 -- 400 m ASL						
Pe 1	Undulating to rolling with many dissected hills	10-15	Migmatite and gneisses	Wooded shrubland use mainly for grazing and firewood collection	Association of: shallow, excessively drained, strong brown loamy sands, with thin dark yellowish brown loamy sand topsoils; and deep, somewhat excessively drained, dark brown sandy loams, with thick very dark greyish brown loamy sand topsoils. Soils classify as <i>Chromi-Ferralic Cambisols (Oxic Haplustepts)</i> and <i>Orthientri-ferralic Cambisols (Typic Haplustepts)</i> . Profiles MTP 32, MTP 3.	39 688 (8.0%)
Pe 2	Undulating to rolling with isolated hills	5-10	Muscovite-biotite migmatite gneisses	Shrubbed grassland Mixed cultivation of maize, sorghum, rice and sugarcane	Association of: deep, well drained, very dark greyish brown sandy clay loams, with thick very dark grey sandy clay loam topsoils; and very deep, excessively drained, dark brown sandy loams, with thin very dark grey sandy loam topsoils. Soils classify as <i>Hapli-Profondic Lixisols (Typic Haplustalfs)</i> and <i>Eutri-Fluvic Cambisols (Fluventic Haplustepts)</i> . Profiles MTP 24, MTP 13.	71 063 (14.1%)

Table 4. continued

MAP UNIT SYMBOL	LANDFORM	SLOPE (%)	PARENT MATERIAL	VEGETATION/LAND-USE	SOIL DESCRIPTION	AREAL EXTENT ha (%)
Pe 3	Undulating to rolling with isolated hills	5-10	Various: siltstones, sandstones, limestones	Wooded shrubland used mainly for grazing and firewood collection	Association of: shallow, excessively drained, reddish brown sandy clay loams, with thick dark reddish brown sandy loam topsoils; and deep, well drained, dark greyish brown clays, with thick very dark grey clay loam topsoils; Soils classify as <i>Hapli-Chromic Plaeozems (Lithic Haplustolls)</i> , and <i>Eutri-Mollic Cambisols (Fluventic Haplustolls)</i> Profiles MTP 11, MTP 28.	23 875 (4.7%)
Pe 4	Nearly level to gently sloping	2-10	Sandstones, siltstones and calcareous, and undifferentiated Karroo sediments	Shrubbed grassland Mixed cultivation of maize, sorghum, rice and sugarcane	Association of: deep, imperfectly drained, very dark grey clays, with thick, very dark grey clay loam topsoils; and deep, imperfectly drained, black sandy clays, with thin very dark grey sandy clay loam topsoils. Soils classify as <i>Eutri-Gleyic Cambisols (Humic Endoaquepts)</i> and <i>Hapli-Eutric Regosols (Typic Ustorthenis)</i> . Profiles MTP 23, MTP 36.	36 063 (7.2%)



The major parent materials in the mountains are hornblende-pyroxene and biotite granulites, and crystalline limestones (Sampson and Wright, 1964). The colluvial material in the piedmonts are overlying gneisses, sandstones, shales and gabbroic rocks. Peneplains are formed from Karroo sediments, gneisses and gravels while valleys have mixture of alluvial-colluvial materials and sandstones, shales, calcareous and gneisses. Vegetation and land use pattern is closely related to the physiographic units (Table 4). Combination of landforms, parent materials and soils form the land mapping units. A total of 11 land mapping units and 24 soil units were identified in the study area.

The mountains have complex of rock outcrops and shallow to moderately deep, well drained soils. The piedmonts have complex of moderate to deep, well to imperfectly drained soils. The peneplains have association of deep to very deep, imperfectly drained to well drained soils whereas the valleys have a complex of deep to very deep, moderately well drained to imperfectly drained soils.

#### **4.2.3 Soil properties**

##### **(a) Soil physical properties**

Table 5 summarises some important physical properties of soils of the study area. A guide to rate some physical and chemical properties of soils is presented in Appendix 8.

Table 5. Selected important soil physical properties of eastern part of Morogoro Rural District.

Profile/ Horizon	Depth (cm)	% Particle size distribution			Textural class	Soil color (moist)
		Sand	Silt	Clay		
<b>MTP1</b>						
Ah	0 - 20	52	9.8	38.2	SC	Dark reddish brown (5YR3/4)
BA	20 - 35	45	9.8	45.2	SC	Reddish brown (5YR4/4)
Bt1	35 - 60	45	7.4	47.2	C	Yellowish red (5YR4/6)
Bt2	60 - 110	40	8.4	51.6	C	Yellowish red (5YR5/8)
Bt3	110 - 140	41	7.4	51.6	C	Red (2.5YR4/8)
<b>MTP5</b>						
Ah	0 - 15	63.8	14.4	21.8	SCL	Black (5YR2.5/1)
Bt1	15 - 35	49.2	12	38.8	SC	Dark red (2.5YR2.5/2)
Bt2	35 - 75	52.6	5.8	41.6	SC	Dark reddish brown (2.5YR2.5/4)
Bts1	75 - 100	55	5.8	39.2	SC	Dark red (2.5YR3/2)
Bts2	100 - 140	57	5.8	37.2	SC	Dark red (2.5YR3/2)
<b>MTP18</b>						
Ap	0 - 7	47.8	13.2	39	SCL	Dark reddish brown (5YR3/3)
Bt1	7 - 38	24.2	7.2	68.6	C	Dusky red (10R3/4)
Bt2	38 - 66	27.8	11.8	60.4	C	Dark red (10R3/3)
Bt3	66 - 100	23.3	8.2	68.4	C	Dark red (10YR3/4)
<b>MTP20</b>						
Ap	0 - 15	64.2	13.2	22.9	SCL	Brown (10YR2/1)
Bt	15 - 35	49.2	9.2	41.6	SC	Dark reddish brown (2.5YR3/4)
BC	35 - 85	64.2	8.2	27.6	SCL	Dark reddish brown (2.5YR2.5/4)
<b>MTP16</b>						
Ah	0 - 7	12	12	41.8	SC	Dark reddish brown (5YR3/2)
AB	7 - 22	7.6	7.6	47.2	SC	Dark reddish brown (2.5YR3/4)
Bt1	22 - 52	7	7	54.8	C	Dark reddish brown (2.5YR3/4)
Bt2	52 - 87	6.2	6.2	51.2	C	Dark red (2.5YR3/6)
BCt	87 - 100	6	6	42.8	SC	Dark reddish brown (2.5YR3/4)
<b>MTP8</b>						
Ah	0 - 15	28	8.4	63.6	C	Dark reddish brown (5YR3/4)
Bw1	15 - 48	35.6	12.4	52	C	Dark reddish brown (2.5YR3/4)
Bw2	- 90	38	14.4	47.6	C	Dark red (2.5YR3/6)
<b>MTP27</b>						
Ap	0 - 10	66.4	13.4	20.2	SCL	Dark grey (5YR3/1)
BA	10 - 26	65.4	9.4	25.2	SCL	Dark reddish brown (5YR3/2)
Bt1	26 - 47	59.6	8.2	32.2	SCL	Dark reddish brown (5YR3/3)
Bt2	47 - 70	53	7.8	39.2	SC	Dark reddish brown (5YR3/4)
BCt	70 - 110	53.2	13	38.8	SC	Dark red (2.5YR3/6)
<b>MTP30</b>						
Ah	0 - 13	50	7.8	42.2	CL	Dark reddish brown (5YR3/4)
Bt1	13 - 22	39	48.2	32.8	SC	Dark reddish brown (2.5YR3/4)
Bt2	22 - 45	36	17.2	45.8	C	Dark red (2.5YR3/6)
BC	45 - 80	40	18.8	41.2	C	Red (2.5YR4/6)

Table 5. continued

Profile/ Horizon	Depth (cm)	% Particle size distribution			Textural class	Soil color (moist)
		Sand	Silt	Clay		
MTP6						
Ah	0 - 10	57.2	10.4	32.4	SCL	Dark brown (7.5YR3/2)
BA	10 - 19	46.2	8.4	45.4	SC	Dark reddish brown (5YR3/3)
Bt1	19 - 38	31.2	7.4	61.4	C	Dark reddish brown (5YR4/4)
Bt2	38 - 85	35.2	8.4	56.4	C	Dark red (2.5YR3/6)
Bt3	85 - 125	34.8	5.4	59.8	C	Red (2.5YR4/6)
Bt4	125 - 150	33.4	8.2	58.4	C	Red (2.5YR4/8)
MTP11						
Ap	0 - 13/17	73	9.8	17.2	SL	Dark reddish brown (5YR2.5/2)
BA	13/17-25	67.2	5.4	27.4	SCL	Dark reddish brown (5YR3/2)
MTP12						
Ah	0 - 18	87.6	3.2	9.2	S	Dark grey (10YR3/1)
Bw1	18 - 40	86	4.8	9.2	LS	Dark brown (10YR3/3)
Bw2	40 - 112	88	2.8	9.2	S	Dark yellowish brown (10YR4/6)
BC	112 - 150	87	3.8	9.2	S	Yellowish brown (10YR5/6)
MTP31						
Ah	0 - 10	60	23.8	16.2	SL	Brown (7.5YR2/0)
Bw	10 - 45	48.2	24	27.8	SCL	Dark greyish brown (10YR3/2)
BC	45 - 75	50	20.8	29.2	SCL	Dark grey (10YR4/1)
BC/CK	75 - 100	49.4	20.4	30.2	SCL	Dark greyish brown (10YR4/2)
MTP24						
Ap	0 - 16	78	11.6	10.4	SL	Dark reddish brown (10YR3/1)
BA	16 - 37	77.6	8	14.4	SL	Dark greyish brown (10YR3/2)
Bt1	37 - 60	73.6	4.4	22	SCL	Dark yellowish brown (10YR3/4)
Bt2	60 - 83	62.4	5.2	32.4	SCL	Dark yellowish brown (10YR4/4)
Bt3	83 - 110	60.2	5	34.8	SC	Dark yellowish brown (10YR4/6)
MTP28						
Ah	0 - 17	31	29.8	39.2	CL	Dark grey (10YR3/1)
AB	17 - 44	34	22.8	43.2	C	Dark greyish brown (2.5YR3/2)
Bw	44-65/72	27	24.8	48.2	C	Dark greyish brown (2.5YR4/2)
CR	65/72-17	20	36.8	43.2	C	Olive brown (2.5YR4/4)
MTP3						
Ah	0 - 10	82.2	7.2	10.4	LS	Dark greyish brown (10YR3/2)
Bw	10 - 25	80.4	9.2	10.4	SL	Dark brown (10YR3/3)
BC	40 - 55	80.6	6	13.4	SL	Brown (7.5YR4/4)
C	55 - 90	73.4	4.2	22.4	SCL	Dark brown (7.5YR3/4)
MTP32						
Ah	0-8/10	87.2	5	7.8	LS	Dark yellowish brown (10YR4/4)
Bw	8/10-31/38	84.8	3.8	11.4	LS	Brown (7.5YR4/4)
CR	31/38-					

Table 5. continued

Profile/ Horizon	Depth (cm)	% Particle size distribution			Textural class	Soil color (moist)
		Sand	Silt	Clay		
MTP13						
Ap	0-7	73.4	16.8	9.8	SL	Dark grey (10YR3/2)
Bw	7 - 30	68.4	19.4	12.2	SL	Dark brown (10YR3/3)
2C	30-35	81	9.6	9.4	LS	Dark greyish brown (10YR3/2)
3C	35-50	87	3.8	9.2	LS	Dark greyish brown (10YR3/2)
4C	50-85/87	50	30.4	19.6	L	Dark greyish brown (10YR3/2)
5C	85/87-100	31.2	58.6	10.2	Sil.	Dark yellowish brown (10YR3/6)
6C	100-114	54.4	25.4	20.2	SCL	Dark brown (10YR2/2)
7C	114-133	69	17	14	SL	Dark brown (10YR3/5)
8C	133-150	14.4	51.8	29.8	SiCL	Dark greyish brown (10YR3/2)
MTP19						
Ap	0-24	36.2	36	27.8	CL	Dark grey (10YR3/1)
2C	24-34/45	72.2	12	15.8	SL	Dark greyish brown (10YR3/2)
3C	34/35-60	21.2	43.8	35	CL	Dark brown (10YR3/3)
4Cg	60-88	37.8	35.8	26.4	L	Dark yellowish brown (10YR3/4)
5Cg	88-100	30.2	30.6	39.2	CL	Dark yellowish brown (10YR3/6)
6Cg	100-134	59.8	21.2	19	SL	Dark greyish brown (10YR4/2)
MTP35						
Ah	0-7	56.2	15	28.8	SCL	Dark brown (10YR3/1)
AB	7 - 23	55.2	15.6	29.2	SCL	Dark greyish brown (10YR3/2)
2C	23-68	46.8	12.4	40.8	SC	Black (5Y2.5/1)
3C	68-90	47.2	11.6	41.2	SC	Dark grey (5Y3/1)
4C	90-120	47.6	11.6	40.8	SC	Dark olive grey (5Y3/2)
MTP36						
Ap	0-8	76.6	8.8	44.6	SL	Dark grey (5Y3/1)
2C	8 - 25	34.2	30.8	35	CL	Black (5Y2.5/2)
3C	25-70	47.2	12.2	40.6	SC	Dark grey (5Y3/1)
4C	70-103	46.2	12.8	41	SC	Dark olive grey (5Y3/2)
MTP10						
Ah	0-20/24	28	29	42.8	SC	Black (10YR2/1)
AC1	20/24-50	20	21	49	C	Dark grey (2.5Y3/1)
AC2	50-90	20	21.6	58.4	C	Black (2.5Y2.5/1)
C	90-135	7	14.6	56.4	C	Dark olive grey (5Y3/2)
MTP22						
Ap	0-18/20	19	26.6	22.4	SCL	Dark reddish brown (5YR3/2)
Bt1	18/20-30	52	13.6	34.4	SCL	Dark reddish brown (5YR3/3)
Bt2	30-53	49.4	12.2	33.4	SCL	Dark reddish brown (5YR3/4)
BC	53-98	49	11.6	39.4	SC	Reddish brown (5YR4/4)
MTP23						
Ap	0-20	41.2	23	35.8	CL	Dark grey (10YR3/1)
Bwg1	20-46	40.8	17.8	41.4	C	Dark grey (10YR3/1)
Bwg2	46-70	45.2	13.8	41.4	C	Dark brown (10YR2/2)
BC	70-105	49.2	15	35.8	SCL	brown (10YR2/1)

*Soil texture (particle size distribution)*

Textural data are presented in Table 5 and Figure 6. The soils have mostly sandy clay loam topsoils and clayey subsoils. Sand contents are high in topsoils, ranging from 88% to 46%, and generally sand content decreases with soil depth to a range of 23% to 33% in subsoil. Higher sand contents in the topsoils compared to subsoils can be attributed to finer particles migrating in suspension down the profiles and/or washing out of the surface soil.

The clay content of the studied soils range from 20% to 47% in the topsoils. Subsoil clay content ranges from 48% to 68% but in some other soil profiles, for example MTP 12, MTP 36 and MTP 13 do not show any particular trend. Subsoils have relatively higher clay content (Figure 6). Soil materials in the valley have coarser texture. This is due to seasonal washing of valley bottoms by run-off which normally carries away finer soil materials. Therefore, coarser textures dominate river valley soils (Birkeland, 1984). This situation was observed in Va2 unit in the study area.

Silt content of the studied soils are low compared to sand and clay contents. However, there is no clear trend of the changing of silt content with soil depth in almost all profiles.

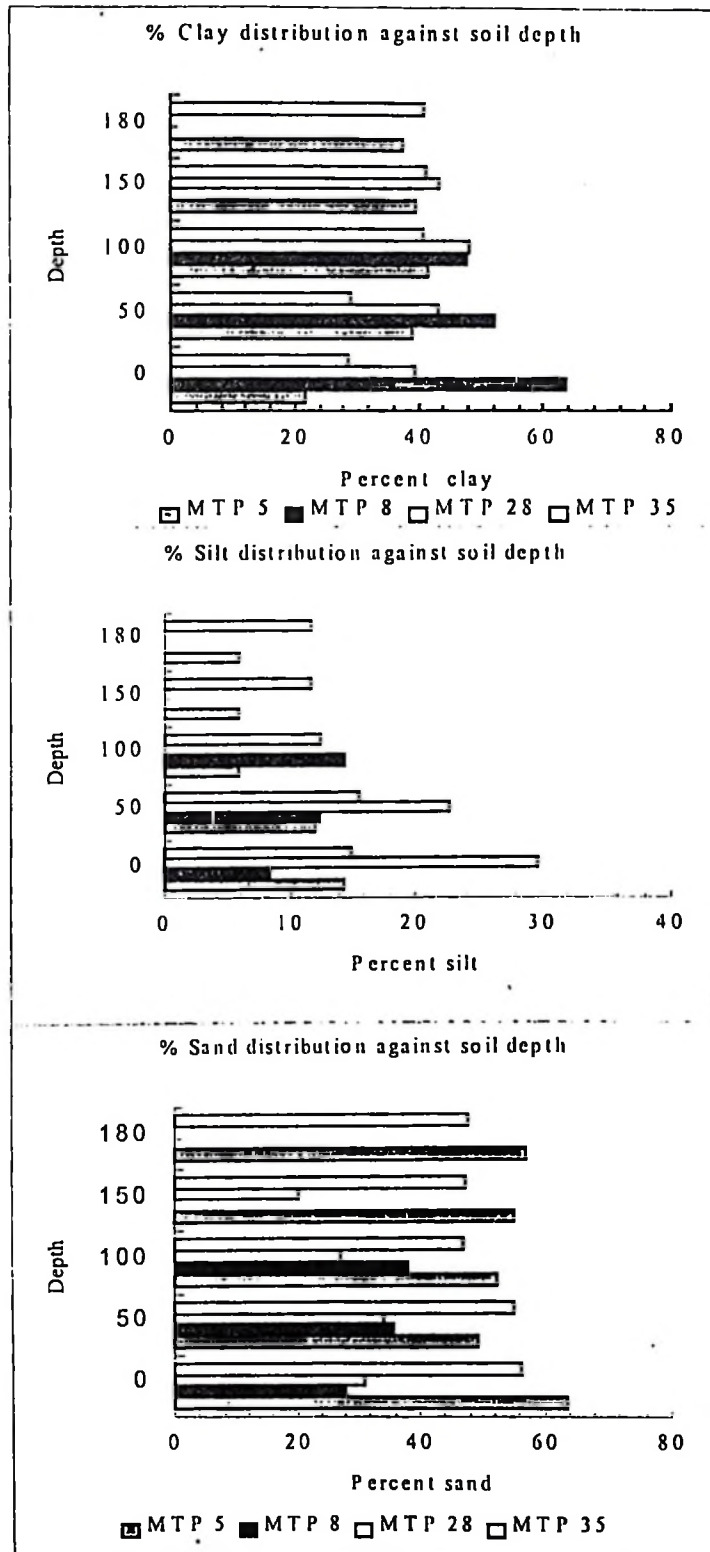


Figure 6. Percent particle size distribution of some selected soils in the study area

### *Structure and consistence*

The structure of the soils of the study area was found to be generally weak to moderate, fine and medium, granular, angular blocky and sub-angular blocky. Soil consistence is soft to slightly hard when dry, friable when moist and slightly sticky to sticky when wet.

### **(b) Soil chemical properties**

Some important soil chemical data are presented in Table 6 while Figure 7 shows relationship between some chemical properties with soil depth for selected soils in the study area.

### *Soil reaction*

Generally the studied soils have pH values ranging between strongly acid (pH 5.1-5.5) and moderately alkaline (pH 7.9-8.4). The lowest pH values are observed in profile MTP 6 on the piedmont, with surface pH of 4.3 and subsurface pH of 5.5. The pH of the soils varies to some degree between profiles. In some profiles pH generally increase with soil depth. This trend could be due to leaching of most of the exchangeable bases down the profile.

### *Soil organic carbon and nitrogen*

Organic carbon content in the topsoils is low to medium ranging from 0.6% to 2.5%. The cause of low to medium organic carbon content of these soils may be due to clearing of vegetation to give land for cultivation and erosion especially on mountainous lands. According to Landon (1991) total nitrogen (N) content in topsoils of the study area is low to medium ranging from 0.1 to 0.5% and it generally decreases with soil depth. The low nitrogen levels observed may be attributed to erosion and continued nutrient mining by plants.

Table 6. Selected Important Soil Chemical Properties of the eastern part of Morogoro Rural District.

Profile/ Horizon	Depth (cm)	pH		OC %	N %	C:N	P mg/kg	CEC (soil)	Exchangable cations cmol(+)/kg				BS %	ESP %
		H <sub>2</sub> O	KCl						Ca	Mg	K	Na		
MTP1														
Ah	0-20	5.8	5.1	2.5	0.3	8.1	33.5	13.4	0.3	0.3	0.1	0.2	6.6	1.4
BA	20-35	4.8	3.9	2.3	0.2	11.6	5.1	9.3	0.3	0.1	0.06	0.2	7.5	5.6
B1	35-60	4.8	3.8	1.1	0.1	9	2.5	76.1	0.3	0.1	0.04	0.5	10.7	0.6
B2	60-110	4.8	3.9	1.5	0.2	9.7	2.5	4	0.3	0.1	0.02	0.1	12.3	1.8
B3	110-140	6.9	6.1	1	0.1	9.8	2.5	4.2	0.2	0.1	0	0.1	10.2	3.1
MTP5														
Ah	0-15	6.3	4.9	1.1	0.1	8.5	10.6	25	13.3	6.3	0.8	0.3	82.7	1.2
B1	15-35	6.6	5.9	1.2	0.2	8.2	7.8	19.5	8.2	7.1	0.2	0.3	82	1.3
B2	35-75	6.5	5.8	0.9	0.1	7.5	4.7	15.2	5.9	5.6	0.1	0.2	77.6	1
Bts1	75-100	6.6	5.8	0.7	0.1	6.3	2.6	15.3	6.6	6.1	0.1	0.2	87.8	1.4
Bts2	100-140	6.9	6.1	0.4	0.07	6.9	2.6	16	7	7	7	0.3	90	1.6
MTP18														
Ap	0-7	5.9	5.1	2.4	0.3	9.5	6.1	25	3.2	2.8	0.2	0.1	25.2	0.4
B1	7-38	5.7	5.1	1	0.1	8.1	8.4	17	3.9	3.8	0.1	0.1	46.5	0.5
B2	38-66	5.8	5.2	0.7	0.1	6.6	9.8	10.6	3.5	3.1	0.04	0.1	63.2	0.6
B3	66-100	6.2	5.9	0.7	0.1	6.8	10.8	8.7	3.1	2.9	0.03	0.1	71.3	1.5
MTP20														
Ap	0-15	6.5	5.9	2.4	0.2	12	7.3	19.5	9.7	6.3	0.1	0.1	82.9	0.3
Bt	15-35	6.8	6.1	1	0.1	10	9.2	21.5	9.3	8.2	0.02	0.1	82.1	0.5
BC	35-85	6.6	5.9	0.7	0.1	7	6	17.9	6.5	5.9	0.01	0.1	69.9	0.4
MTP16														
Ah	0-7	7.5	6.8	2.2	0.2	9.2	13.4	12.7	18.7	6	0.7	0.1	101.2	0.6
AB	7-22	6.6	5.4	1	0.2	6.1	13.4	15.7	12	1.5	0.4	0.1	88.2	0.3
B1	22-52	5.7	4.6	0.5	0.1	4.2	14.3	18.6	9.9	3.1	0.1	0.1	70.5	0.3
B2	52-87	6	4.8	0.3	0.04	8.3	14	15.7	8.6	5.5	0.1	0.1	90.8	0.4
BC1	87-100	6.2	4.8	0.3	0.03	11	14	15.9	7.2	6.8	0.07	0.1	92.9	0.4

Table 6. continued

Profile/ Horizon	Depth (cm)	pH		OC %	N %	C:N	P mg/kg	CEC (soil)	Exchangeable cations cmol(+)/kg					BS %	ESP %
		H <sub>2</sub> O	KCl						Ca	Mg	K	Na			
<b>MTP8</b>															
Ah	0-15	6.1	5.4	1.3	0.1	10.8	7.5	5.6	5.9	4.1	0.1	0.3	185.2	5.4	
Bw1	15-48	5.6	4.9	1	0.1	9.1	8	7.6	4	2.1	0.5	0.4	91.2	5.3	
Bw2	48-90	5.5	5	0.7	0.1	7	8.9	11.4	1.8	1.6	0.2	0.4	33.6	3.6	
<b>C</b>															
<b>MTP27</b>															
Ap	0-10	5.6	4.6	2.1	0.2	9.1	32.4	7.6	3.9	1.2	0.2	0.2	72	2.8	
BA	10-26	6.1	5.1	1	0.1	7.9	14.2	6.5	5.2	0.8	0.1	0.2	95.8	3.1	
Bt1	26-47	6.3	5.2	0.8	0.1	6.7	16.4	3.8	3.6	1.4	0.1	0.4	149.3	10	
Bt2	47-70	6	4.9	0.5	0.1	5	16.4	2.3	2.7	0.9	0.03	0.2	166	9.1	
BCt	70-110	6	5	0.5	0.1	5	10.8	11	6.9	5.9	0.04	0.3	119.8	2.3	
<b>MTP30</b>															
Ah	0-13	6.2	5.9	1.2	0.1	20	14.4	14.8	2.4	4.9	0.03	0.2	51.0	7.3	
Bt1	13-22	6	5.5	0.4	0.1	3.1	7.5	15.5	6.4	6.2	0.1	0.2	83.3	1.4	
Bt2	22-45	6.3	5.8	0.7	0.1	7	8.5	12.3	6	5.1	0.03	0.2	92.8	1.7	
BC	45-80	6.4	5.9	0.5	0.1	10	8.5	11.4	5.4	4.9	0.02	0.2	93.1	1.8	
<b>MTP6</b>															
Ah	0-10	6.0	nd	2.1	0.21	10.0	4.3	17.8	6.6	4.4	1.6	0.1	70.7	0.4	
BA	10-19	6.5	nd	1.4	0.13	10.5	7.2	15.4	3.9	3.4	1.3	0.1	55.8	0.5	
Bt1	19-38	5.8	nd	1.1	0.1	10.6	7.3	16.3	2	2.3	0.5	0.1	30.7	0.4	
Bt2	38-85	4.9	nd	0.5	0.1	4.9	4.8	12.3	0.2	2.4	0.1	0.1	22.0	0.6	
Bt3	85-125	5.1	nd	0.3	0.06	4.7	2.7	11	0.8	2.8	0.1	0.1	33.6	5.1	
Bt4	125-150	5.7	nd	0.2	0.04	5.8	7.4	8.4	1.3	2.3	0.1	0.4	48.8	4.2	
<b>MTP11</b>															
Ap	0-13/17	6.6	5.5	1.5	0.2	7.7	13.2	13.4	10	4.7	0.7	0.1	115.7	0.7	
BA	13/17-25	5	3.7	0.6	0.1	7.7	7.2	10.4	6	2.2	0.1	81.2	81.2	0.9	



Table 6. continued

Profile/ Horizon	Depth (cm)	pH		OC %	N %	C:N	P mg/kg	CEC (soil)	Exchangeable cations cmol(+)/kg				BS %	ESP %
		H <sub>2</sub> O	KCl						Ca	Mg	K	Na		
MTP13														
Ap	0-7	7	6.4	1.1	0.1	8.5	23	11.5	7.8	3.9	1.2	0.2	11.4	1.9
Bw	7-30	7.2	6.1	0.8	0.1	7.3	33.6	10.4	7.5	2.9	0.8	0.2	109	2
2C	30-35	7.1	6	0.5	0.1	7	11.6	6.9	5.5	2.5	0.2	0.2	123	23.3
3C	35-50	7.3	6.2	0.2	0.04	6	43	6.7	3.5	1.8	0.1	0.2	85	2.7
4C	50-85/87	7	6.4	0.9	0.1	7.8	12.7	16.5	9.9	4.3	0.1	0.2	88	1.3
5C	85/87-100	6.4	5.9	0.5	0.1	5.6	12.8	8.8	7.9	3.7	0.1	0.3	136	2.8
6C	100-114	7.1	6.4	0.9	0.1	7.1	13	15.4	7.4	4.1	0.01	0.2	95	1.4
7C	114-133	7	6.3	0.5	0.1	5.2	11.6	7.8	7.4	3.4	0.02	0.3	141	3.5
8C	133-150	6.8	5.5	1.2	0.2	7.6	12.2	24.9	6.8	3.2	0.01	0.3	85	1.2
MTP19														
Ap	0-24	6.8	6.7	1.5	0.1	11.7	26.7	25.3	14.8	8.1	0.7	0.1	93.6	0.5
2C	24-34/45	6.9	6.1	0.7	0.2	4.1	20.5	14.3	8.8	5.3	0.2	0.2	101.2	1.1
3C	34/35-60	8.1	7.5	2.4	0.2	9.8	nd	18.4	18.9	11.5	0.3	0.4	108.5	2.1
4Cg	60-88	6	5.6	0.7	0.1	6	23.3	22.2	14	8	0.2	0.3	101.2	1.3
5Cg	88-100	5.8	4.9	0.9	0.1	6.7	23.9	35.7	19.2	11.7	0.3	0.4	88.2	1
6Cg	100-134	7.8	6.9	2.5	0.3	9.5	nd	10	11.5	5.5	0.1	0.3	124.7	2.9
MTP35														
Ah	0-7	6.1	4.8	1.5	0.3	5.5	15	20.7	8.3	7.9	0.7	0.3	82.8	1.4
AB	7-23	6.1	4.8	1.6	0.3	4.7	13	20.6	8.1	7.5	0.2	0.3	78.6	1.7
2C	23-68	6.3	5.6	1	1.4	0.7	14.7	26.5	10.9	9.8	0.2	1.4	84.3	5.3
3C	68-90	8.4	7.9	0.8	0.4	2.3	22.3	16.9	12.9	12.1	0.2	0.4	150.9	2.4
4C	90-120	8.5	8.4	0.7	1.9	0.6	23.9	17.2	17.2	7.4	0.1	1.2	160	7
MTP36														
Ap	0-8	6.8	5.3	1.2	0.1	9.2	2.7	16.2	5.5	2.4	0.5	0.1	52.4	0.5
2C	8-25	7.1	6.5	1	0.1	8.3	5.2	15.9	12.5	8.9	0.1	0.4	137.4	2.6
3C	25-70	7.6	7	0.7	0.1	7	2.1	28.2	13.9	10.6	0.1	0.8	90.1	3
4C	70-103	8.8	8.2	0.7	0.1	7	2.1	27.8	19.8	15.2	0.1	0.3	127.3	12.9

Table 6. continued

Profile/ Horizon	Depth (cm)	pH		OC %	N %	C:N	P mg/kg	CEC (soil)	Exchangeable cations cmol(+)/kg				BS %	ESP %
		H <sub>2</sub> O	KCl						Ca	Mg	K	Na		
MTP12														
Ah	0-18	6.7	5.5	0.6	0.1	4.6	8.4	5.3	1	1	0.2	0.3	49.0	6.3
Bw1	18-40	5.2	4.8	0.3	0.1	5	7.6	5.9	0.4	0.3	0.1	0.2	16.9	3.9
Bw2	40-112	6.1	5.8	0.1	0.01	8	4	3.9	0.1	0.1	0.1	0.3	12.8	6.9
BC	112-150	6.4	5.7	nd	nd	nd	3.8	2.9	0.1	0.1	0.1	0.3	20.7	10.1
MTP22														
Ap	0-18/20	7.7	6.6	0.6	0.1	5	2.6	12.3	9.9	8.8	1.1	0.1	161.0	0.4
Bt1	18/20-30	6.7	5.2	2.3	0.2	10.5	14.5	16.2	6.9	3.9	0.5	0.1	70.3	0.4
Bt2	30-53	6.4	4.9	1.4	0.2	8.8	2.6	14.1	6.1	2.6	0.2	0.1	64.0	0.6
BC	53-98	6.3	4.9	1.1	0.1	8.5	4.8	16.7	7	4.2	0.2	0.1	69.0	0.4
MTP23														
Ap	0-20	6.5	5.4	2.1	0.2	9.5	37.8	20.1	18.1	6.6	1.7	0.1	136.0	0.7
Bwg1	20-46	6.5	5.2	1.8	0.2	9	38	27.7	18.1	5.9	1.1	0.1	109.0	0.5
Bwg2	46-70	6.6	4.9	0.9	0.1	7	50	25.8	16.8	4	0.8	0.1	84.5	0.5
BC	70-105	6.7	4.9	0.5	0.1	6.5	41.8	23.7	14	3.5	0.5	0.1	76.5	0.5
MTP38														
Ah	0-15	6.2	5.2	2.5	0.3	8.3	8.8	17.2	10.1	7.8	0.3	0.2	107.0	1.4
Bt	15-45	6.5	5.3	0.7	0.13	5.4	11.4	16.5	9.8	6.7	0.04	0.4	102.0	2.2
BC	45-70	5.3	5.0	1.7	0.21	8.1	12.3	12.0	3.3	3.0	0.9	0.2	61.0	1.8

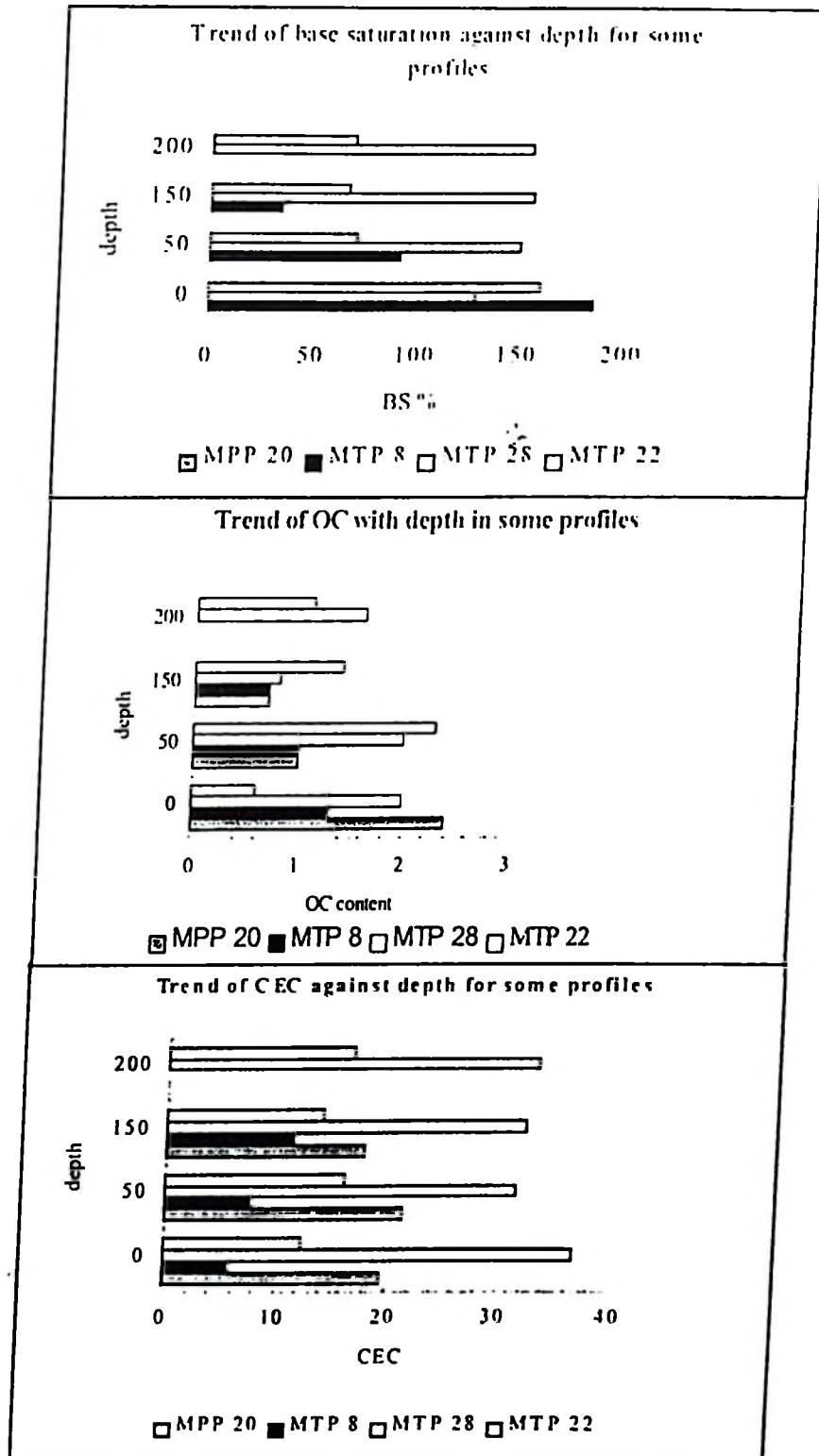


Figure 7. R relationship between some soil chemical properties with soil depth

The C:N ratio of the studied soils range between 8-11.7 which is an indication that most soils have good quality organic matter content.

#### *Available phosphorus*

The soils in the study area have medium to high available phosphorus. Its values range between 7 to above 20 mg/kg. According to ILACO (1991), available P of 7 mg/kg in the topsoil is considered optimal below which P-deficiency symptoms are likely to occur in most crops. Of the studied area, only some few soil units were found to have topsoil P of less than 7 mg/kg (MTP 6, MTP 18, MTP 24, MTP 28 and MTP 36), which are found in the piedmont and in the plains.

#### *Cation Exchange Capacity (CEC)*

CEC reflects the capacity of the soil to retain nutrients against leaching. The CEC in topsoils are comparably higher than those of the subsoils. This can be caused by the fact that soil organic matter content on the topsoils is higher than in subsoils (Alegre and Cassel, 1986). Generally the soils of the study area have medium CEC ranging between 12.1 to 25.0 cmol(+)/kg (Landon, 1991).

#### *Exchangeable bases ( $Ca^{++}$ , $Mg^{++}$ , $K^+$ and $Na^+$ )*

Exchangeable calcium levels vary among profiles and with soil depth. It ranges between medium to very high (2.1 to more than 20 cmol(+)/kg soil) (Landon, 1991). Exchangeable magnesium levels in topsoils are high to very high ranging from 1.1 to over 6 cmol(+)/kg. The levels show no clear trend with soil depth.

The topsoil exchangeable potassium levels range from 0.05 to about 2.0 cmol(+)/kg, which is low to high and show no particular trend with increasing soil depth. Exchangeable sodium levels range from 0.1 cmol(+) to 1.7 cmol(+)/kg throughout

the study area. According to Landon (1991) these values are low to high, and do not show much variation with the soil depth.

#### ***Base saturation (BS)***

The studied soils have generally high to very high (above 80%) base saturation both in the surface and subsurface soils except in soil units MTP 2, MTP 6, MTP 12, MTP 24, MTP 32 and MTP 36 which have low to medium (30.7-52%) BS on both the surface and subsurface soils. Soil unit MTP 1 has very low (6.6-10.2%) BS. The high soil BS indicates that the area has moderate to high fertility. The high BS could be attributed to the dolomitic rocks which are found in the study area.

#### ***Soil sodicity***

Most of the soils in the study area are non-sodic (ESP less than 6%) except MTP 12, MTP 27, MP 30 and MTP 31 which are slightly to moderately sodic in the subsoil (6-15% ESP). Only MTP 28 is strongly sodic (16-25% ESP). In the area represented by this unit crops that are tolerant and semi-tolerant to sodicity can be grown, for example sorghum, rice and sugarcane.

#### **4.2.4 Soil classification**

Tables 7 and 8 present a summary of the soil morphological and other diagnostic features used in classifying the soils. Table 9 presents the classification of the studied soils according to the two commonly used systems of soil classification i.e. FAO-WRB (World Reference Base) (FAO, 1998) and USDA Soil Taxonomy (Soil Survey Staff, 1999). By using FAO WRB system of classification, eight level-I soil units were identified namely; Ferralsols, Luvisols, Regosols, Cambisols,

Lixisols, Phaeozems, Acrisols and Fluvisols. Ferralsols, Luvisols, Lixisols and Acrisols are found in the mountains and in the piedmonts. Cambisols and Phaeozems are dominant in the peneplains, while Fluvisols and Regosols are found in the valleys.

**Table 7. Diagnostic features of representative soil profiles (FAO WRB)**

Profile code	Horizons	Other diagnostic properties
MTP 8	Ochric horizon, Ferralic horizon,	Rhodic, Haplic,
MTP 5	Ochric horizon, Argic horizon,	Profondic, Rhodic, Cutanic,
MTP 16	Ochric horizon, Argic horizon,	Profondic, Rhodic, Cutanic,
MTP 10	Ochric horizon,	Humic, Eutric, Haplic,
MTP 12	Ochric horizon, Cambic horizon,	Orthidystic, Haplic,
MTP 1	Ochric horizon Ferralic horizon	Acric, Humic, Hyperdystic,
MTP 18	Ochric horizon, Argic horizon,	Profondic, Rhodic, Haplic,
MTP 27	Mollic horizon, Argic horizon,	Chromic, Haplic,
MTP 30	Ochric, Argic horizon,	Profondic, Rhodic, Haplic,
MTP 6	Ochric horizon, Argic horizon,	Profondic, Orthidystic, Rhodic, Haplic,
MTP 19	Mollic horizon,	Hypereutric, Fluvic, Gleyic,
MTP 31	Ochric horizon, Cambic horizon,	Sodic, Calcaric, Eutric,
MTP 24	Ochric horizon, Argic horizon,	Profondic, Haplic,
MTP 28	Mollic horizon, Cambic horizon,	Haplic,
MTP 3	Ochric horizon, Cambic horizon,	Ferralic, Orthieutric
MTP 35	Mollic horizon,	Hypereutric, Pachic, Haplic,
MTP 36	Ochric horizon,	Hypereutric, Duric
MTP 13	Ochric horizon, Cambic horizon,	Fluvic, Eutric, Haplic,
MTP 23	Ochric horizon, Cambic horizon,	Cutanic, Eutric, Gleyic,
MTP 22	Mollic horizon, Argic horizon,	Luvic, Chromic, Haplic,
MTP 32	Ochric horizon, Cambic horizon,	Ferralic, Chromic, Eutric,
MTP 11	Mollic horizon,	Chromic, Haplic,
MTP 20	Ochric horizon, Argic horizon,	Rhodic, Haplic,
MTP 38	Ochric horizon, Argic horizon,	Rhodic, Haplic,

Table 8. Diagnostic features of representative soil profiles (USDA Soil Taxonomy)

Profile code	Diagnostic horizons		Other diagnostic properties
	Surface	Subsurface	
MTP 8	Ochric epipedon	Oxic horizon	Ustic SMR, Isohyperthermic STR
MTP 5	Ochric epipedon	Argillic horizon	Ustic SMR, Isohyperthermic STR
MTP 16	Ochric epipedon	Argillic horizon	Ustic SMR, Isohyperthermic STR
MTP 10	Ochric epipedon	-- --	Ustic SMR, Isohyperthermic STR
MTP 12	Ochric epipedon	Cambic horizon	Ustic SMR, Isohyperthermic STR
MTP 1	Ochric epipedon	Cambic horizon	Ustic SMR, Isohyperthermic STR
MTP 18	Ochric epipedon	Argillic horizon	Ustic SMR, Isohyperthermic STR
MTP 27	Mollic epipedon	Kandic horizon	Ustic SMR, Isohyperthermic STR
MTP 30	Ochric epipedon	Argillic horizon	Ustic SMR, Isohyperthermic STR
MTP 6	Ochric epipedon	Argillic horizon	Ustic SMR, Isohyperthermic STR
MTP 19	Mollic epipedon	-- --	Ustic SMR, Isohyperthermic STR, Stratification
MTP 31	Ochric epipedon	Cambic horizon	Ustic SMR, Isohyperthermic STR, Vertic, Wide cracks
MTP 24	Mollic epipedon	Argillic horizon	Ustic SMR, Isohyperthermic STR
MTP 28	Mollic epipedon	Cambic horizon	Ustic SMR, Isohyperthermic STR
MTP 3	Ochric epipedon	Cambic horizon	Ustic SMR, Isohyperthermic STR
MTP 35	Mollic epipedon	-- --	Ustic SMR, Isohyperthermic STR, Cumulic
MTP 36	Ochric epipedon	-- --	Ustic SMR, Isohyperthermic STR
MTP 13	Ochric epipedon	Cambic horizon	Ustic SMR, Isohyperthermic STR, Stratification
MTP 23	Ochric epipedon	Cambic horizon	Aquic SMR, Isohyperthermic STR
MTP 22	Mollic epipedon	Argillic horizon	Ustic SMR, Isohyperthermic STR
MTP 32	Ochric epipedon	Cambic horizon	Ustic SMR, Isohyperthermic STR
MTP 11	Mollic epipedon	-- --	Ustic SMR, Isohyperthermic STR
MTP 20	Ochric epipedon	Argillic horizon	Ustic SMR, Isohyperthermic STR
MTP 38	Ochric epipedon	Argillic horizon	Ustic SMR, Isohyperthermic STR

Table 9. Classification of the soils of the study area

Profile	FAO WRB			USDA Soil Taxonomy			
	Level 1	Level 2	Level 3	Order	Sub-order	Great group	Sub-group
MTP 8	Ferralsols (FR)	Rhodic Ferralsols	Hapli-Rhodic Ferralsols	Oxisols	Ustox	Haplustox	Inceptic Haplustox
MTP 5	Luvissols (LV)	Profondic Luvissols	Rhodi-Profondic Luvissols (Cutanic)	Alfisol	Ustalf	Rhodustalfs	Kanhaplic Rhodustalfs
MTP 16	Luvissols (LV)	Profondic Luvissols	Rhodi-Profondic Luvissols (Cutanic)	Alfisol	Ustalf	Rhodustalfs	Kanhaplic Rhodustalfs
MTP 10	Regosols (RG)	Eutric Regosols	Humi-Eutric Regosols (Haplic)	Entisol	Fluvent	Ustofluvent	Mollic Ustofluvent
MTP 12	Cambisols (CM)	Orthidystric Cambisols	Hapli-Orthidystric Cambisols	Inceptisol	Ustcept	Haplustepts	Dystric Haplustepts
MTP 1	Ferralsols (FR)	Acric Ferralsols	Humi-Acric Ferralsols (Orthidystric)	Oxisol	Ustox	Haplustox	Humic Haplustox
MTP 18	Lixisols (LX)	Profondic Lixisols	Rhodi-Profondic Lixisols (Haplic)	Alfisol	Ustalf	Kandiustalfs	Rhodic Kandiustalfs
MTP 27	Phaeozems (PH)	Chromic Phaeozems	Hapli-Chromic Phaeozems	Mollisol	Ustolls	Argiustolls	Typic Argiustolls
MTP 30	Lixisols (LX)	Profondic Lixisols	Rhodi-Profondic Lixisols (Haplic)	Alfisol	Ustalf	Rhodustalfs	Kanhaplic Rhodustalfs
MTP 6	Acrisols (AC)	Profondic Acrisols	Orthidystri-Profondic Acrisols (Rhodic)	Ultisol	Ustalf	Haplustults	Kanhaplic Haplustults
MTP 19	Fluvisols (FL)	Gleyic Fluvisols	Molli-Gleyic Fluvisols (Eutric)	Entisol	Aquepts	Fluvaquepts	Mollic Fluvaquepts
MTP 31	Cambisols (CM)	Sodi Cambisols	Calcari-Sodic Cambisols (Eutric)	Inceptisol	Ustcept	Haplustepts	Verti Haplustepts
MTP 24	Lixisols (LX)	Profondic Lixisols	Hapli-Profondic Lixisols	Alfisol	Ustalf	Haplustalfs	Typic Haplustalfs
MTP 28	Phaeozems (PH)	Haplic Phaeozems	Orthieutri-Ferralic Cambisols	Mollisol	Ustolls	Haplustolls	Fluventic Haplustolls
MTP 3	Cambisols (CM)	Ferralic Phaeozems	Hapli-Pachic Phaeozems	Inceptisol	Ustcept	Haplustepts	Typic Haplustepts
MTP 35	Phaeozems (PH)	Pachic Phaeozems	Hapli-Pachic Phaeozems	Mollisol	Ustolls	Haplustolls	Cumulic Haplustolls
MTP 36	Regosols (RG)	Eutric Regosols	Hapli-Eutric Regosols (Duric)	Entisol	Ustolls	Ustorthents	Typic Ustorthents
MTP 13	Cambisols (CM)	Fluvic Cambisols	Eutri-Fluvic Cambisols	Inceptisol	Ustcept	Haplustepts	Fluventic Haplustepts
MTP 23	Cambisols (CM)	Gleyic Cambisols	Eutri-Gleyic Cambisols (Haplic)	Inceptisol	Aquepts	Endoaquepts	Humic Endoaquepts
MTP 22	Phaeozems (PH)	Luvic Phaeozems	Chromi-Luvic Phaeozems (Haplic)	Mollisol	Ustolls	Argiustolls	Typic Argiustolls
MTP 32	Cambisols (CM)	Ferralic Cambisols	Chromi-Ferralic Cambisols (Eutric)	Inceptisol	Ustcept	Haplustepts	Oxic Haplustepts
MTP 11	Phaeozems (PH)	Chromic Phaeozems	Hapli-Chromic Phaeozems	Mollisol	Ustolls	Haplustolls	Lithic Haplustolls
MTP 20	Luvissols (LV)	Rhodic Luvissols	Hapli-Rhodic Luvissols	Alfisol	Ustalf	Rhodustalfs	Typic Rhodustalfs
MTP 38	Luvissols (LV)	Rhodic Luvissols	Hapli-Rhodic Luvissols	Alfisol	Ustalf	Rhodustalfs	Typic Rhodustalfs

soil units were identified namely; Ferralsols, Luvisols, Regosols, Cambisols, Lixisols, Phaeozems, Acrisols and Fluvisols. Ferralsols, Luvisols, Lixisols and Acrisols are found in the mountains and in the piedmonts. Cambisols and Phaeozems are dominant in the peneplains, while Fluvisols and Regosols are found in the valleys.

#### **4.3 Agro-Ecological Zones (AEZ)**

Appendix 9 presents an AEZs map for the study area. The area was divided into nine agro-ecological zones (AEZs) based on landscape/landform, elevation, length of growing period and soils as discussed below:-

##### **AEZ I**

This zone constitutes mountainous area with altitudes 800 m.a.s.l and above. The growing period is very long to almost continuous (240 to >300 days). The soils are mostly clayey with low to moderate fertility.

##### **AEZ II**

This is mountainous with altitude ranging between 500 to 800 m.a.s.l. The growing period in this area is long (210 to 240 days) and soils are clayey having low to moderate fertility.

##### **AEZ III**

This zone occupy mostly the piedmonts (foothills) with altitude ranging between 400 to 500 m.a.s.l. The growing period is long (210 to 240 days) and soils are mostly mixture of clayey and loamy with low to moderate fertility.

**AEZs IV and V**

These zones have the same temperatures and LGP but differ substantially in landform and soils. AEZ IV is a river valley with altitudes ranging between 100 to 200 m.a.s.l and has a long growing period (210 to 240 days). Soils are mostly loamy with moderate to high fertility. AEZ V constitute the penclains with altitudes ranging from 200 to 400 m asl. Soils are mostly a mixture of loamy and sandy with low to moderate fertility.

**AEZ VI**

This zone constitutes the penclains with altitude ranging between 100 to 200 m.a.s.l. The LGP is short (150 to 180 days) and soils are mainly loamy with low to moderate fertility.

**AEZ VII**

This covers mostly the watershed valleys with altitude ranging between 100 to 200 m.a.s.l. The LGP is long (210 to 240 days) and soils are mostly loamy with low to moderate fertility.

**AEZs VIII and IX**

These zones have the same LGP and dominant soils but they differ in elevation. They have short LGP ranging from 150 to 180 days and loamy soils with low to moderate fertility. AEZ VIII has an altitude ranging between 200 and 400 m.a.s.l while AEZ IX has an altitude below 200 m.a.s.l.

De Pauw (1984) produced an ecological zones map of Tanzania at 1 to 2 million scale. The country was divided into 64 AEZs from which the study area had 3 AEZs. The difference of these two maps is the number of zones resulted. De Pauws' scale was smaller and hence fewer AEZs units.

#### 4.4 Social economic data

Table 10 summarises the description of four land utilisation types which were used in land evaluation. Land holdings are small and sometimes fragmented with very low capital intensity. Production is mainly subsistence and labour intensity is high which are mainly non-costed manual family labour using hand tools which include hoe, machete (panga), bush axe, sickle and knife. The level of know-how and technology employed is low. Local cultivars are commonly used with no fertilizers, chemical pests and/or diseases control and no conservation measures. Also there is inadequate advisory services, for example Division with thirty two villages is served by three Agricultural Extension personnel only. This makes timely delivery of technical advisory services to farmers somehow impractical.

Both annual and perennial crops are produced with annual crops dominant. Management practices depend on traditional knowledge and experience of the environment. The average farm size ranges from 0.25 to 3 ha and land tenure system is customary. In some places land is cleared by burning, bigger trees and stumps not being removed. The type of land use is mostly permanent. Four crops that are found almost throughout the area were considered. Their choice were based on their importance as food and/or cash crop and farmers preferences. These crops were maize (*Zea mays*), paddy/rice (*Oryza sativa*), citrus (*Citrus spp.*) (orange and

Table 10. Description of land utilization types (LUTs) for Eastern part of Morogoro Rural District

LUTs	Produce	Management	Labour	Level of technology	Farm size (ha)	Land tenure	Yield (kg/ha)
1. Smallholder low input rainfed maize	Maize, Kito, Staha and other local varieties	Single and sequential cropping systems. Production is in small farms with limited use of fertilizers and chemicals	High, family, 65-70 manday/ha	Low	0.5-3.0	Customary	500-1200
2. Smallholder low input rainfed rice	Lowland rice, selected various local seed varieties used	Single crop grown per year. Hand tools used and no fertilizers or chemicals used	High, mainly family 70-240 mandays/ha	Low	0.25-2.0	Customary	900-1200
3. Smallholder low input rainfed citrus	Citrus is perennial tree crop. Local varieties of oranges and mandarins	Mixed cropping system. Production in smallholder farms and no fertilizer or chemical use	Low, family 30-45 mandays/ha	Low	0.5-3.0	Customary	15 000
4. Smallholder low input rainfed sesame	Single sesame crop grown in a growing season. Selected local seed varieties are used	Single and mixed farming cropping system applied. Production is in small farms without fertilizer or chemical use	High, family 65-70 manday/ha	Low	0.5-3.0	Customary	500-600

mandarin) and sesame (*Sesamum indicum*). Sesame is newly introduced crop to the area to replace cotton, which is no longer grown due to erratic marketing systems.

#### **4.5 Land suitability evaluation**

##### **4.5.1 Analysis of soil and socio-economic data by ALES**

Input land attribute database as presented in Appendix 2 include important climatic, physical and chemical properties of soils of the study area. Appendix 6a through d show LURs for the identified LUTs in the study area. The LURs include moisture availability, soil moisture retention, temperature regime, oxygen availability to rooting zone, rooting condition, nutrient availability, nutrient retention capacity, wetness and erosion hazard.

The severity level decision trees model for the LUTs i.e. maize, rice, citrus and sesame are presented in appendix 7a through d.

##### **4.5.2. ALES suitability classification results**

Table 11 presents summary results of the ALES land suitability classification for the area. About 17% of the area is moderately suitable for maize production. These areas include land mapping unit (LMU) Pe2 and some part of LMUs MO22 aPe3. Land mapping units Pe1, Va1 and parts of Pi1 and Va2 (about 38% of the area) are physically not suitable for maize production. The rest of the area (45% of the area) has poor potential for this LUT. The major limiting LURs are nutrient availability, nutrient retention, erosion hazard, oxygen availability to root zones, rooting condition and flooding.

Table 11. Summary of ALES land suitability classification for the study area

Mapping unit	Soil unit	Land suitability rating				Area (ha)
		Maize	rice	citrus	Sesame	
MO 11	Humi-Acric Ferralsols	3e/nr	4tg/wt	3nr/tg	4e	12 535
MO 12	Rhodi-Profondic Luvisols	3e/m	4m/tg/wt	3na/tg	3e/m	20 891
MO 13	Rhodi-Profondic Lixisols	3e/r	4tg/wt	3r/tg	3e/na	25 069
MO 14	Hapli-Rhodic Luvisols	3m	4m/o/tg/wt	2na/r/tg	3m	25 069
MO 211	Hapli-Rhodic Luvisols	3m	4o/tg/wt	3na/r/tg	4e	8 525
MO 212	Rhodi-Profondic Luvisols	3e/r	4tg/wt	3na/r/tg	4e	12 788
MO 221	Hapli-Chromic Phaeozems	2m/na/hr/r	4wt	3r	2m/na/nr	8 652
MO 222	Rhodi-Profondic Lixisols	3e/na/nr/r	4tg/wt	3na/r/tg	4e	16 067
Pi 11	Orthidystri-Profondic Acrisols	3na	4na/wt	3na	4na	15 500
Pi 12	Hapli-Rhodic Ferralsols	4e/nr	4nr/tg/wt	4nr	4nr	15 500
Pi 21	Calcar-Sodic Cambisols	3r	4o/tg/t	4r	2m/na/r	13 613
Pi 22	Hapli-Orthidystic Cambisols	3nr	4o/wt	3na/nr	3na/nr	9 075
Pe 11	Eutri-Gleyic Cambisols	4fl	3wt	3r	3o	19 835
Pe 12	Hapli-Eutric Regosols	4fl	3na/nr	3na/nr	3na/nr/o	16 228
Pe 21	Hapli-Profondic Lixisols	2m/na/hr/r	4wt	3na	3na	35 532
Pe 22	Eutri-Fluvic Cambisols	2na/nr	4o/wt	2m/na/nr	2na/nr	35 532
Pe 31	Eutri-Mollic Cambisols	4fl	4o	3na/r	3na	16 713
Pe 32	Hapli-Chromic Phaeozems	2na/r	4o/wt	2m/na/r	2na	7 163
Pe 41	Chromi-Ferralic Cambisols	3na	4na/tg/wt	3na	3na	13 891
Pe 42	Orthieutri-Ferralic Cambisols	3na	4o/r/wt	4r	3na/nr/r	25 797
Va 11	Molli-Gleyic Fluvisols	4fl	2o	2m/na	2na	45 813
Va 12	Hapli-Pachic Phaeozems	4fl	3wt	3r	3o	45 813
Va 21	Humi-Eutric Regosols	4o	3m/wt	3o	4o	28 750
Va 22	Chromi-Luvic Phaeozems	3na	4na/wt	3na/r	3na	28 750
Total area						503 101

na = nutrient availability, e = erosion hazard, nr = nutrient etension, t = temperature regime, m = moisture availability, r = rooting condition, wt = wetness, fl = flooding, o = oxygen availability to root zone, tg = topography.

Only some parts of LMU Va1 (9% of the area) is moderately suitable for paddy while LMU Pe1 and some parts of mapping units Va1 and Va2 (22% of the area) is marginally suitable for this LUT. The remaining 69% in MO1, MO21, MO22, Pi1, Pi2, Pe2, Pc3, Pc4 and parts of Va2 are not suitable for paddy farming. The main limiting LURs are topography, wetness, nutrient availability, oxygen availability to root zones and nutrient retention.

Citrus production is moderately suitable in parts of LMUs MO1, Pe2, Pe3 and Va1 occupying about 23% of the study area. Parts of LMUs Pi1, Pi2 and Pe4 (10% of the area) are not suitable for this LUT while the remaining area (67%) is marginally suitable. The limiting LURs are nutrient retention, topography, nutrient availability, rooting condition and oxygen availability to root zone.

Some parts of LMUs MO22, Pi2, Pe2, Pe3, and Va1 which occupy 22% of the area are moderately suitable for sesame production. LMUs MO21, Pi1 and some parts of MO1, MO22 and Va2 (22%) are not suitable for this LUT. The remaining LMUs (56% of the area) is marginally suitable for sesame production. The limitations include erosion hazard, moisture availability, nutrient retention and oxygen availability to root zones.

There was no any mapping unit classified as having good potential (highly suitable) for any of the four LUTs. This is because its natural fertility has been depleted over time through leaching, erosion and nutrient mining through continuous cropping.

Among the four LUTs, citrus was more suited to the area for it can be grown to about 90% of the area. This is because most of the area has enough rainfall to supply moisture, which is among the critical factors for citrus

production. Also the crop (citrus) can even grow to soils with relatively poor fertility (Kips *et.al.*, 1989). For citrus soil physical condition is more important than its chemical properties. Sesame rank the second (about 78% of the total area). Maize, although most popular to the area, can be grown profitably to only 57% of the total area. This is because the LUT prefer high and well balanced nutrient availability as well as good aerated soils. But these conditions rarely exist naturally without some modifications or improvements.

## CHAPTER FIVE

### CONCLUSIONS AND RECOMMENDATIONS

#### 5.1 Conclusions

Four main land resources database namely climate, landform, soils and land utilisation types were established in the study area. Four major landforms are dominant. These are mountains ranging between 600 m to over 2000 m.a.s.l, piedmonts ranging between 400 m to 600 m.a.s.l, peneplains ranging between 200 m to 400 m.a.s.l and valleys lying below 200 m.a.s.l. The major parent rocks are hornblende-pyroxene granulites, limestones and dolomites in the mountainous areas; colluvial materials in the piedmonts; sandstones, siltstones, limestones, gneisses and Karroo sediments in the peneplains; and mixture of alluvial-colluvial materials in the valleys.

The climatic regime of the study area showed that rainfall is bimodal and fairly high. The annual average rainfall ranges between 900 mm and 2500 mm, and increase with altitude i.e. the higher the altitude the higher the rainfall. Annual average temperatures range between 19<sup>0</sup>C to 26<sup>0</sup>C and vary with elevation. The highest elevation areas (mountainous) are cooler than the plains. The length of growing period (LGP) ranges from short (152 days) to almost continuous (above 300 days).

The soils in the study area are mostly sandy clays to sandy clay loams and are well drained except on the valleys where they are poorly drained. Soil structure is weak to moderate and soil reaction range between slightly acid to moderately alkaline with generally low to medium chemical fertility. These soils

classify into eight soil units which are Ferralsols, Luvisols, Regosols, Cambisols, Lixisols, Phaeozems, Acrisols and Fluvisols. Four land utilisation types (LUTs) namely maize, rice, citrus and sesame were identified as being dominant in the study area.

Computerisation of climate, landforms, soils and socio-economic data implemented in this study showed that digital land resources database are quick in generating information such as Agro-ecological zones and automated land suitability classification which are prerequisite in land use planning.

Through digital manipulation and analysis of land resources database established in this study, nine agroecological zones were generated. Automated land evaluation of various soils in the study area showed that soils on the mountains and piedmonts have moderate to marginal suitability for maize, citrus and sesame production, but not suitable for rice farming. Peneplains have soils mostly with moderate to marginal suitability for maize, citrus and sesame production but not suitable (in greater parts) for rice farming. The valleys have moderate to marginal suitability for rice, citrus and sesame production but are mostly not suitable for maize farming. The most unfavourable conditions for the production of maize, rice, citrus and sesame are nutrient availability, nutrient retention capacity, moisture availability, rooting condition, topography, oxygen availability to root zone and erosion hazards.

The study showed that digital land resources database together with automated land evaluation form the basis for future agricultural land use planning in Morogoro Rural District, Tanzania.

## 5.2. Recommendations

The following recommendations are made with respect to established digital land resources database and automated land evaluation in the study area:

- a) Climatic information available in the study area is inadequate. The meteorological department should make effort to improve the present meteorological stations and install new ones in strategic areas.
- b) Effort should be made to generate digital land resources database from village up to the national level to facilitate the land use planning process.
- c) Agroecological zones (AEZs) should be used for land suitability evaluation and hence for land use planning instead of land mapping units.
- d) The possibility of conducting detailed socio-economic survey should be looked upon. This will supplement the physical suitability evaluation to obtain economic land evaluation for the area.
- e) The extension staff in the area should access the evaluation results so that they can make a rational land use planning for the area. They should also be provided with adequate working gears and training on how to interpret automated databases.
- f) Further research on the establishment of digital land resources database and automated land evaluation for the development of appropriate soil conservation strategies in the area is highly recommended.

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## APPENDICES

### Appendix 1. Soil profile description sheets

Profile number: MTP-1 Mapping unit: MO 1 Agro-eco. zone: I

Region : Morogoro

District : Morogoro

Map sheet no. : 183/4

Coordinates : 6° 55'E / 37° 46'S

Location : About 1 km from Kinole village along road to Kibwaya

Elevation : 480 m asl. Landform: mountain; mountainous. Slope: 47 %

Surface characteristics : Erosion: none or slight. Deposition: cm.

Natural drainage class : well drained

Described by B.M. Msanya, D.N. Kimaro and A.I.M. Munisi on 08/12/99

Soils are very deep, well drained reddish brown sandy clays, with dark reddish brown sandy clay top soils.

Ah 0-20cm: dark reddish brown (5YR3/4) moist; sandy clay; very friable moist, sticky and plastic wet; weak fine granular and medium subangular blocks; many fine pores; many fine roots; clear smooth boundary to

BA 20 - 35 cm: reddish brown (5YR4/4) moist; sandy clay; very friable moist, sticky and plastic wet; moderate fine and medium subangular blocks; many fine pores; many fine and few medium roots; gradual smooth boundary to

Bt1 35-60cm: yellowish red (5YR4/6) moist; clay; very friable moist, sticky and plastic wet; strong fine and medium subangular blocks; many fine pores; many fine and few medium roots; gradual smooth boundary to

Bt2 60 - 110 cm: yellowish red (5YR5/8) moist; clay; very friable moist, sticky and plastic wet; strong fine and medium subangular blocks; continuous thin clay cutans; many fine pores; many fine and few medium roots; diffuse smooth boundary to

Bt3 110 - 140 cm: red (2.5YR4/8) moist; clay; very friable moist, sticky and plastic wet; moderate fine and medium subangular blocks; few medium spherical fresh quartz fragments; clear smooth boundary to

SOIL CLASSIFICATION: FAO legend: Humi-Acric Ferralsols

USDA Soil Taxonomy: Humic Haplustox

Profile number : MTP-11 Mapping unit: Pi 2 Agro-ecol. zone: III

Region : Morogoro

District : Morogoro

Map sheet no. : 184/3

Coordinates : 38° 12'E/ 6° 46'S

Location: About 200 m north of Kidugalo dam along the road to Station

Elevation : 230 m asl. Landform: plain; undulating

Surface characteristics: Erosion:none or slight. Deposition: cm.

Natural drainage class : excessively drained

Described by A.I.M. Munisi, B.M. Msanya and D.N. Kimaro on 10/12/99

Soils are shallow, excessively drained dark reddish brown sandy clay loams, with thick dark reddish brown sandy loam topsoils.

Ap 0-17cm: dark reddish brown (5YR3/2) dry, dark reddish brown (5YR2.5/2) moist; sandy loam; soft dry, friable moist, slightly sticky and slightly plastic wet; moderate fine and medium subangular blocks; many fine pores; many fine roots; clear wavy boundary to

BA 17 - 25 cm: dark reddish brown (5YR3/3) dry, dark reddish brown (5YR3/2) moist; sandy clay loam; slightly hard dry, friable moist, sticky and plastic wet; moderate fine and medium subangular blocks; frequent small spherical quartz fragments; common fine roots

CR Saprolite

SOIL CLASSIFICATION: FAO WRB: Hapli-Chromic Phaeozem

USDA Soil Taxonomy: Lithic Haplustolls

Profile number : MTP-12      Mapping unit: Pi 2      Agro-ecol. zone: III

Region      : Morogoro

District     : Morogoro

Map sheet no. : 201/2

Coordinates : 37° 55'E/ 7° 13' S

Location     : About 8 km east of Mvuha, 80 m south of road to Magogoni

Elevation    : 140 m asl. Landform: plain; gently undulating. Slope: 2.5 %

Surface characteristics : Erosion: none or slight. Deposition: cm.

Natural drainage class : excessively drained

Described by D.N. Kimaro, B.M. Msanya and A.I.M. Munisi on 10/12/99

Soils are very deep, excessively drained darkish brown loamy sands with thick very darkish brown sand top soils.

Ah    0 - 18 cm: very dark greyish brown (10YR3/2) dry, very dark grey (10YR3/1) moist; sand; soft dry, friable moist, non-sticky and non-plastic wet; weak fine subangular blocks; clear smooth boundary to

Bw1   18 - 40 cm: light brownish grey (10YR6/2) dry, dark brown (10YR3/3) moist; loamy sand; soft dry, friable moist, non-sticky and non-plastic wet; weak; clear smooth boundary to

Bw2   40 - 112 cm: light brownish grey (10YR6/2) dry, dark yellowish brown (10YR4/6) moist; sand; soft dry, friable moist, non-sticky and non-plastic wet; moderately weak; clear smooth boundary to

BC    112 - 150 cm: very pale brownish red (10YR7/3) dry, yellowish brown (10YR5/6) moist; sand; soft dry, friable moist, non-sticky and non-plastic wet; moderately weak

SOIL CLASSIFICATION:FAO WRB:Hapli-Orthidystic Cambisols

USDA Soil taxonomy:Dystric Haplustepts

Profile number : MTP-13 Mapping unit: Va 1 Agro-ecol zone: IV

Region : Morogoro District : Morogoro

Map sheet no. : 201/2 Coordinates : 37° 58'E/ 7° 13' S

Location : About 125m east of Magogoni village close to Pamba store Elevation: 100 m asl. Landform: plain; flat or almost flat. Slope: 1% Surface characteristics: Erosion: none or slight. Deposition: none.

Natural drainage class : excessively drained Described by D.N. Kimaro, B.M. Msanya and A I M Munisi on 10/12/99

Soils are excessively drained darkish brown sandy loams, with thin very darkish grey sandy loam top soils.

Ap 0 - 7 cm: brown (10YR4/3) dry, very dark grey (10YR3/2) moist; sandy clay loam; soft dry, friable moist, non-sticky and non-plastic wet; weak fine subangular blocks; few mica fragments; abrupt wavy boundary to

Bw 7 - 30 cm: dark yellowish brown (10YR4/4) dry, dark brown (10YR3/3) moist; sandy clay loam; soft dry, friable moist, non-sticky and non-plastic wet; weak fine subangular blocks; few mica fragments; abrupt wavy boundary to

2C 30 - 35 cm: dark brown (10YR3/3) dry, very dark greyish brown (10YR3/2) moist; loamy sand, soft dry, friable moist, non-sticky and non-plastic wet; strong; few mica fragments; abrupt wavy boundary to

3C 35 - 50 cm: dark brown (10YR3/3) dry, very dark greyish brown (10YR3/2) moist; sand, soft dry, friable moist, non-sticky and non-plastic wet; strong; few mica fragments; abrupt wavy boundary to

4C 50 - 87 cm: dark brown (10YR3/3) dry, very dark greyish brown (10YR3/2) moist; clay loam; soft dry, friable moist, slightly sticky and slightly plastic wet; weak fine subangular blocks; few mica fragments; abrupt wavy boundary to

5C 87 - 100 cm: dark yellowish brown (10YR3/6) moist; sandy clay loam; friable moist, non-sticky and non-plastic wet; weak fine subangular blocks; few mica fragments; abrupt wavy boundary to

6C 100 - 114 cm: very dark brown (10YR2/2) moist; clay loam; friable moist, slightly sticky and slightly plastic wet; weak fine subangular blocks; few mica fragments; abrupt wavy boundary to

7C 114 - 133 cm: dark brown (10YR3/5) moist; clay loam; friable moist, slightly sticky and slightly plastic wet;; abrupt wavy boundary to

8C 133 - 150 cm: very dark greyish brown (10YR3/2) moist; clay loam; friable moist, slightly sticky and slightly plastic wet; weak fine subangular blocks; few mica fragments

SOIL CLASSIFICATION: FAO WRB : Eutri- Fluvic Cambisols

USDA Soil Taxonomy: Fluventic Haplustepts

Profile number : MTP-16    Mapping unit: MO 21    Agro-ecol. zone: II  
 Region        : Morogoro  
 District      : Morogoro  
 Map sheet no. : 201/4  
 Coordinates   : 37° 47' E/ 7° 19' S  
 Location      : About 2 km north-east of Mbwade village  
 Elevation     : 430 m asl. Landform: mountain; hilly. Slope: 45 %  
 Surface characteristics : Erosion: none or slight. Deposition: none.  
 Natural drainage class : well drained  
 Described by B.M. Msanya, D.N. Kimaro and A.I.M. Munisi on 11/12/99

Soils are deep, well drained dark reddish brown sandy clays with thin dark reddish brown sandy clay top soils.

Ah        0 - 7 cm: dark reddish brown (5YR3/3) dry, dark reddish brown (5YR3/2) moist; sandy clay; slightly hard dry, friable moist, sticky and plastic wet; strong fine and medium subangular blocks; many fine pores; many very fine and common medium roots; clear smooth boundary to

AB        7 - 22 cm: dark red (2.5YR3/6) dry, dark reddish brown (2.5YR3/4) moist; clay; slightly hard dry, friable moist, sticky and plastic wet; strong fine and medium subangular blocks; many fine and common medium pores; many very fine and common medium roots; clear smooth boundary to

Bt1       22 - 52 cm: reddish brown (2.5YR4/4) dry, dark reddish brown (2.5YR3/4) moist; clay; slightly hard dry, friable moist, sticky and plastic wet; moderate fine and medium subangular blocks; many fine pores; few fine and common medium roots; gradual smooth boundary to

Bt2       52 - 87 cm: red (2.5YR4/6) dry, dark red (2.5YR3/6) moist; clay; slightly hard dry, friable moist, sticky and plastic wet; moderate fine and medium subangular blocks; patchy clay cutans; many fine pores; few spherical weathered quartz fragments; few fine and common medium roots; gradual smooth boundary to

BCt       87 - 100 cm: dark red (2.5YR3/6) dry, dark reddish brown (2.5YR3/4) moist; sandy clay; slightly hard dry, friable moist, sticky and plastic wet; weak fine and medium subangular blocks; few spherical weathered quartz fragments

**SOIL CLASSIFICATION: FAO WRB: Rhodi-Profondi Luvisols**  
**USDA Soil Taxonomy: Kanhaplic Rhodustalfs**

Profile number : MTP-18    Mapping unit: MO 1    Agro-ecological zone: I  
 Region        : Morogoro  
 District      : Morogoro  
 Map sheet no. : 201/3  
 Coordinates   : 37° 40' E/ 7° 16' S  
 Location      : About 800 m north of Singiza village  
 Elevation     : 500 m asl. Landform: mountain; hilly. Slope: 36 %  
 Surface characteristics : Erosion: none or slight. Deposition: cm.  
 Natural drainage class : well drained  
 Described by D.N. Kimaro, B.M. Msanya and A.I.M. Munisi on 12/12/99

Soils are deep, well drained, dusk red clays, with thin red darkish brown sandy clay loam topsoils. Surface very stony.

Ap    0 - 7 cm: dark reddish brown (5YR3/4) dry, red dark brown (5YR3/3) moist; sandy clay loam; soft dry, friable moist, sticky and plastic wet; moderate fine granular; many fine pores; many fine and few medium roots; abrupt smooth boundary to

Bt1    7 - 38 cm: dark red (10R3/6) dry, duskyred (10R3/4) moist; clay; hard dry, friable moist, sticky and plastic wet; strong fine and medium subangular blocks; clay cutans; common very fine and medium roots; clear smooth boundary to

Bt2    38 - 66 cm: dark red (10R3/4) dry, dark red (10R3/3) moist; clay; hard dry, friable moist, sticky and plastic wet; strong fine and medium subangular blocks; clay cutans; few very fine and many medium roots; clear smooth boundary to

Bt3    66 - 100 cm: dark red (10YR3/4) moist; clay; hard dry, friable moist, sticky and plastic wet; moderate fine and medium subangular blocks; few very fine and many medium roots; clear smooth boundary to

C    Saprolite

SOIL CLASSIFICATION: FAO legend: Rhodi-Profondic Lixisols

USDA Soil Taxonomy: Rhodic Kandustalfs

Profile number : MTP-19 Mapping unit: Va 1 Agro-ccol. zone: IV  
 Region : Morogoro District : Morogoro  
 Map sheet no. :201/4Coordinates : 37° 49' E/ 7° 24' S  
 Location : About 2 km from Dutumi market centre along the road to Kisaki Elevation:  
 130 m asl. Landform: plain; flat or almost flat. Slope: 1 %  
 Surface characteristics : Erosion: none or slight.  
 Natural drainage class: moderately well drained Described by D.N. Kimaro, B.M. Msanya  
 and A.I.M. Munisi on 12/12/99

Soils are very deep, moderately well drained very dark greyish brown sandy loams, with very thick very darkish grey clay loam topsoils.

Ap 0 - 24 cm: very dark greyish brown (10YR3/2) dry, very dark grey (10YR3/1) moist; clay loam; hard dry, friable moist, sticky and plastic wet; moderate fine granular and medium subangular blocks; common medium pores; many very fine and few medium roots; abrupt smooth boundary to

2C 24 - 45 cm: dark brown (10YR3/3) dry, very dark greyish brown (10YR3/2) moist; sandy clay loam; very hard dry, friable moist, sticky and plastic wet; weak fine and medium subangular blocks; common medium pores; frequent medium irregular quartz fragments; many fine and few medium roots; abrupt wavy boundary to

3C 45 - 60 cm: dark yellowish brown (10YR3/4) dry, dark brown (10YR3/3) moist; clay loam; common fine faint clear 5YR3/3 mottles; very hard dry, friable moist, sticky and plastic wet; weak fine and medium angular blocks; common medium pores; many fine and few medium roots; abrupt smooth boundary to

4Cg 60 - 88 cm: dark yellowish brown (10YR3/6) dry, dark yellowish brown (10YR3/4) moist; loam; hard dry, friable moist, sticky and plastic wet; weak fine subangular blocks and medium angular blocks; many very fine and common medium pores; few medium irregular quartz fragments; common fine and few medium roots; abrupt smooth boundary to

5Cg 88 - 100 cm: brownish red (10YR4/3) dry, dark yellowish brown (10YR3/6) moist; clay loam; common fine faint clear 5YR3/4 mottles; slightly hard dry, friable moist, sticky and plastic wet; weak fine and medium subangular blocks; many fine and common medium pores; few fine and medium roots; abrupt smooth boundary to

6Cg 100 - 134 cm: dark yellowish brown (10YR4/4) dry, dark greyish brown (10YR4/2) moist; sandy loam; slightly hard dry, friable moist, slightly sticky and slightly plastic wet; moderate fine and medium subangular blocks; many fine pores; few fine and medium roots

SOIL CLASSIFICATION: FAO legend: Molli-Gleyic Fluvisols  
 USDA Soil Taxonomy: Mollic Fluvaquents

Profile number : MTP-22    Mapping unit: Va 2    Agro-ecological zone: VII  
 Region        : Morogoro  
 District      : Morogoro  
 Map sheet no. : 184/3  
 Coordinates   : 38° 8' E/ 6° 49' S  
 Location      : About 8 km south of Ngerengere village 20 m west along old Dar road  
 Elevation     : 198 m asl. Landform: plain; undulating. Slope: 2 %  
 Surface characteristics : Erosion: none or slight. Deposition: cm.  
 Natural drainage class : well drained  
 Described by D.N. Kimaro, B.M. Msanya and A.I.M. Munisi on 13/12/99

Soils are deep, well drained dark reddish brown sandy clay loams, with thick dark reddish brown sandy clay loam top soils. Rock outcrop covering less than 20%.

**Ap**    0 - 20 cm: dark reddish brown (5YR3/3) dry, dark reddish brown (5YR3/2) moist; sandy clay loam; soft dry, friable moist, sticky and plastic wet; moderate fine and medium subangular blocks; many fine and common medium pores; many fine roots; clear wavy boundary to

**Bt1**    20 - 30 cm: dark reddish brown (5YR3/4) dry, dark reddish brown (5YR3/3) moist; sandy clay loam; hard dry, friable moist, sticky and plastic wet; moderate fine and medium subangular blocks; clay cutans; many fine and common medium pores; many fine roots; gradual smooth boundary to

**Bt2**    30 - 53 cm: reddish brown (5YR4/4) dry, dark reddish brown (5YR3/4) moist; sandy clay loam; soft dry, friable moist, sticky and plastic wet; moderate fine and medium subangular blocks; many fine and few medium pores; few medium spherical quartz fragments; common fine and few medium roots; gradual smooth boundary to

**BC**    53 - 98 cm: yellowish red (5YR4/6) dry, reddish brown (5YR4/4) moist; sandy clay; soft dry, friable moist, sticky and plastic wet; weak fine and medium subangular blocks; many fine and few medium pores; frequent medium spherical weathered quartz fragments; few fine and medium roots

**SOIL CLASSIFICATION: FAO legend: : Chromi-Luvic Phaeozems**

**USDA Soil Taxonomy: Typic Argiustolls**

Profile number: MTP-23 Mapping unit: Va 2 Agro-ecological zone: VII

Region : Morogoro

District : Morogoro

Map sheet no. : 184/3

Coordinates : 38° 8' E/ 6° 46' S

Location : About 1.5 km east of Ngerengere village, 50m south of Sangasanga road

Elevation : 170 m asl. Landform: plain; flat or almost flat. Slope: 0.5 %

Surface characteristics : Erosion: none or slight. Deposition: cm.

Natural drainage class : imperfectly drained

Described by B.M. Msanya, D.N. Kimaro and A.I.M. Munisi on 14/12/99

Soils are deep, imperfectly drained very dark grey clays, with thick very darkish grey clay loam topsoils.

**Ap** 0 - 20 cm: dark grey (10YR4/1) dry, very dark grey (10YR3/1) moist; clay loam; very hard dry, firm moist, sticky and plastic wet; moderate fine and medium subangular blocks; common medium pores; many fine roots; clear smooth boundary to

**Bwg1** 20 - 46 cm: very dark grey (10YR3/1) moist; clay; very hard dry, firm moist, sticky and plastic wet; weak fine and medium subangular blocks; many fine pores; many fine and common medium roots; gradual smooth boundary to

**Bwg2** 46 - 70 cm: very dark brown (10YR2/2) moist; clay; slightly hard dry, firm moist, sticky and plastic wet; weak fine and medium subangular blocks; many fine pores; few fine and medium roots; gradual smooth boundary to

**BC** 70 - 105 cm: brown (10YR2/1) moist; sandy clay loam; hard dry, firm moist, sticky and plastic wet; weak fine and medium subangular blocks; many fine pores; few fine and medium roots

**SOIL CLASSIFICATION: FAO legend :** Eutri-Gleyic Cambisols

**USDA Soil Taxonomy:** Humic Endoaquepts

Profile number: MTP-24 Mapping unit: Pc 3 Agro-ecological zone: V

Region : Morogoro

District : Morogoro

Map sheet no. : 184/3

Coordinates : 38° 2' E/ 6° 56' S

Location : About 19 km from Tununguoa village along Ngerengere road

Elevation : 274 m asl. Landform: plain; gently undulating. Slope: 2 %

Surface characteristics : Erosion: none or slight. Deposition: none.

Natural drainage class : well drained

Described by B.M. Msanya, D.N. Kimaro and A.I.M. Munisi on 13/12/99

Soils are deep, well drained very dark greyish brown sandy clay loams, with thick very darkish grey sandy loam topsoils. Discontinuous iron stone at 110cm deep.

**Ap 0 - 16 cm:** dark grey (10YR4/1) dry, red dark grey (10TR3/1) moist; sandy loam; soft dry, friable moist, non-sticky and non-plastic wet; weak fine granular; many fine pores; many fine roots; clear smooth boundary to

**BA 16 - 37 cm:** dark greyish brown (10YR4/2) dry, very dark greyish brown (10YR3/2) moist; sandy loam; soft dry, friable moist, non-sticky and non-plastic wet; moderate fine and medium subangular blocks; many fine pores; many fine roots; gradual smooth boundary to

**Bt1 37 - 60 cm:** dark yellowish brown (10YR4/4) dry, dark yellowish brown (10YR3/4) moist; sandy clay loam; soft dry, friable moist, sticky and plastic wet; moderate fine and medium subangular blocks; many fine pores; few medium and coarse roots; gradual smooth boundary to

**Bt2 60 - 83 cm:** yellowish brown (10YR5/8) dry, dark yellowish brown (10YR4/4) moist; sandy clay loam; soft dry, friable moist, sticky and plastic wet; weak fine and medium subangular blocks; many fine pores; few medium and coarse roots; gradual smooth boundary to

**Bt3 83 - 110 cm:** yellowish brown (10YR5/6) dry, dark yellowish brown (10YR4/6) moist; sandy clay; slightly hard dry, friable moist, sticky and plastic wet; weak fine and medium subangular blocks; many fine pores; few fine roots

**SOIL CLASSIFICATION:** FAO legend: Hapli-Profondic Lixisols

USDA Soil Taxonomy: Typic Haplustalfs

Profile number : MTP - 8    Mapping unit: Pi 1    Agro-ecol. zone: III

Region        : Morogoro

District      : Morogoro

Map sheet no. : 201/2

Coordinates   : 37° 51' E/ 7° 4' S

Location      : Along the rd to Ngongoro village about 2.5 km east of Lundi vilge

Elevation     : 300 m asl. Landform: mountain; hilly. Slope: 21 %

Surface characteristics : Erosion: none or slight. Deposition: cm.

Natural drainage class : well drained

Described by A.I.M. Munisi, B.M. Msanya and D.N. Kimaro on 15/12/99

Soils are deep, well drained, dark reddish brown clays, with thick darkish red clay topsoils. Profile slightly gravelly.

Ah        0 - 15 cm: yellowish red (5YR4/8) dry, dark reddish brown (5YR3/4) moist; clay; slightly hard dry, friable moist, sticky and plastic wet; moderate fine granular and medium angular blocks; medium angular weathered quartz fragments; clear smooth boundary to

Bt1       15 - 48 cm: dark reddish brown (2.5YR3/4) dry, dark reddish brown (2.5YR3/4) moist; clay; slightly hard dry, friable moist, sticky and plastic wet; strong fine and medium subangular blocks; thin clay cutans; medium angular weathered quartz fragments; gradual smooth boundary to

Bt2       48 - 90 cm: dark red (2.5YR3/6) dry, dark red (2.5YR3/6) moist; clay; slightly hard dry, friable moist, sticky and plastic wet; strong fine and medium subangular blocks; thin clay cutans; medium angular weathered quartz fragments; abrupt wavy boundary to

SOIL CLASSIFICATION: FAO WRB: Hapli-Rhodic Ferralsols

USDA Soil Taxonomy: Inceptic Haplustox

Profile number : MTP-27    Mapping unit: MO 22    Agro-ecological zone: II  
 Region        : Morogoro  
 District      : Morogoro  
 Map sheet no. : 201/2  
 Coordinates   : 37° 49' E/ 7° 6' S  
 Location      : At Tambuu village about 2.4 km Matombo-Mvuha road junction  
 Elevation     : 420 m asl. Landform: mountain; undulating. Slope: 2 %  
 Surface characteristics : Erosion: none or slight. Deposition: cm.  
 Natural drainage class : well drained  
 Described by B.M. Msanya, D.N. Kimaro and A.I.M. Munisi on 15/12/99

Soils are deep, well drained dark reddish brown sandy clay loams, with thick very darkish grey sandy clay loam topsoil. Deeper subsoil gravelly.

**Ap**    0 - 10 cm: very dark grey (5YR3/1) moist; sandy clay loamy sand; friable moist, slightly sticky and slightly plastic wet; weak fine and medium granular; many fine pores; many fine roots; gradual smooth boundary to

**BA**    10 - 26 cm: dark reddish brown (5YR3/3) dry, dark reddish brown (5YR3/2) moist; sandy clay loam; soft dry, friable moist, sticky and plastic wet; moderate fine and medium subangular blocks; common medium pores; many fine roots; clear smooth boundary to

**Bt1**    26 - 47 cm: dark reddish brown (5YR3/4) dry, dark reddish brown (5YR3/3) moist; sandy clay loam; slightly hard dry, friable moist, sticky and plastic wet; strong fine and medium subangular blocks; many fine and common medium pores; few fine roots; gradual smooth boundary to

**Bt2**    47 - 70 cm: reddish brown (5YR4/4) dry, dark reddish brown (5YR3/4) moist; sandy clay; slightly hard dry, friable moist, sticky and plastic wet; strong fine and fine subangular blocks; few medium pores; few fine roots; gradual smooth boundary to

**BCt**    70 - 110 cm: dark red (2.5YR4/6) dry, dark red (2.5YR3/6) moist; sandy clay; slightly hard dry, friable moist, sticky and plastic wet; moderate fine and medium subangular blocks; few medium pores; few fine roots; clear smooth boundary to

**C**    110+

**SOIL CLASSIFICATION: FAO legend: Hapli-Chromic Phaeozems**  
**USDA Soil Taxonomy: Typic Argiustolls**

Profile number : MTP-28    Mapping unit: Pc 4    Agro-ecological zone: IX

Region        : Morogoro

District      : Morogoro

Map sheet no. : 184/4

Coordinates   : 38° 16' E/ 7° 0' S

Location      : 25 m south-east of Kwaba village and 5 m east of road to Kidunda

Elevation     : 145 m asl. Landform: plain; flat or almost flat. Slope: 0.5 %

Surface characteristics : Erosion: none or slight. Deposition: cm.

Described by B.M. Msanya, D.N. Kimaro and A.I.M. Munisi on 16/12/99

Soils are deep, well drained dark greyish brown clays, with thick very darkish grey clay loam topsoils. Calcareous rock.

**Ah    0 - 17 cm:** dark grey (10YR4/1) dry, very dark grey (10YR3/1) moist; clay loam; hard dry, friable moist, sticky and plastic wet; moderate fine and medium subangular blocks; many fine pores; many very fine and few medium roots; clear smooth boundary to

**AB    17 - 44 cm:** dark greyish brown (2.5Y4/2) dry, dark greyish brown (2.5Y3/2) moist; clay; very hard dry, firm moist, sticky and plastic wet; moderate medium and coarse angular blocks; common fine pores; common fine and few medium roots; gradual smooth boundary to

**Bw    44 - 72 cm:** dark greyish brown (2.5Y4/2) moist; clay; friable moist, sticky and plastic wet; weak fine and medium angular blocks; clay cutans; few fine pores; few fine roots; gradual wavy boundary to

**CR    72 - 117 cm:** olive brown (2.5Y4/4) moist; clay; friable moist, sticky and plastic wet; weak fine and medium angular blocks; few very fine roots

**SOIL CLASSIFICATION: FAO legend: Eutri- Mollic Cambisols**

**USDA Soil Taxonomy: Fluventic Haplustolls**

Profile number : MTP-3 Mapping unit: Pe 4 Agro-ecol. zone: IX

Region : Morogoro

District : Morogoro

Map sheet no. : 183/4

Coordinates : 37° 57' E/ 6° 47' S

Location : About 2.5 km east of Msemakweli village & 20 m north of Ngerengere road

Elevation : 400 m asl. Parent material: igneous rocks. Landform: plain; undulating.  
Slope: 6 %

Surface characteristics : Erosion: none or slight. Deposition: cm.

Natural drainage class : well drained

Described by D.N. Kimaro, B.M. Msanya and A.I.M. Munisi on 08/12/99

Soils are deep, somewhat excessively drained dark brown sandy loams, with thick very dark greyish brown loamy sand topsoils.

**Ah** 0 - 10 cm: dark greyish brown (10YR4/2) dry, very dark greyish brown (10YR3/2) moist; loamy sand; slightly hard dry, friable moist, non-sticky and non-plastic wet; weak fine granular; and many fine roots; clear smooth boundary to

**Bw** 10 - 25 cm: dark greyish brown (10YR3/4) dry, dark brown (10YR3/3) moist; sandy loam; friable moist, non-sticky and non-plastic wet; moderate fine subangular blocks; many fine and common medium pores; gradual smooth boundary to

**BC** 25 - 55 cm: brown (7.5YR5/4) dry, brown (7.5YR4/4) moist; sandy loam; friable moist, slightly sticky and slightly plastic wet; moderate fine subangular blocks; few fine roots; abrupt irregular boundary to

**C** 55 - 90 cm: brown (7.5YR4/4) dry, dark brown (7.5YR3/4) moist; sandy clay loam; friable moist, slightly sticky and slightly plastic wet; weak fine subangular blocks; few fine roots

**SOIL CLASSIFICATION: FAO legend: Orthieutri-Ferralsic Cambisols**

**USDA Soil Taxonomy: Typic Haplustepts**

Profile number : MTP-30 Mapping unit: Mo12 Agro-ecological zone: II

Region : Morogoro

District : Morogoro

Map sheet no. : 201/2

Coordinates : 37° 48' E/ 7° 4' S

Location : Along the road to Gozo village at about 2.5 km west of Lundi villg

Elevation : 360 m asl. Landform: mountain; hilly. Slope: 24 %

Surface characteristics : Erosion: none or slight. Deposition: cm.

Natural drainage class : well drained

Described by B.M. Msanya, D.N. Kimaro and A.I.M. Munisi on 03/01/00

Soils are moderately deep, well drained dark reddish brown clays, with thick dark reddish brown clay loam topsoils. Profile slightly gravelly.

Ah 0 - 13 cm: yellowish red (5YR4/6) dry, dark reddish brown (5YR3/4) moist; clay loam; soft dry, friable moist, sticky and plastic wet; moderate fine subangular blocks and medium granular; clear smooth boundary to

Bt1 13 - 22 cm: dark reddish brown (2.5YR3/4) dry, dark reddish brown (2.5YR3/4) moist; sandy clay; slightly hard dry, friable moist, sticky and plastic wet; strong fine and medium subangular blocks; many fine and common medium pores; few quartz fragments; common fine roots; gradual smooth boundary to

Bt2 22 - 45 cm: dark red (2.5YR3/6) moist; clay; friable moist, sticky and plastic wet; strong fine and fine subangular blocks; clay cutans; many fine and common medium pores; few fine roots; gradual smooth boundary to

Bt3 45 - 80 cm: red (2.5YR4/6) moist; clay; friable moist, sticky and plastic wet; moderate fine and medium subangular blocks; clay cutans; many fine and common medium pores; few fine roots; clear smooth boundary to

C 80+

SOIL CLASSIFICATION: FAO legend: Rhodi-Profondic Lixisols

USDA Soil Taxonomy: Kanhaplic Rhodustalfs

Profile number : MTP-31    Mapping unit: Pi 2    Agro-ecol. zone: III

Region        : Morogoro

District     : Morogoro

Map sheet no. : 201/2

Coordinates  : 37° 57' E/ 7° 14' S

Location     : About 13 km from Mvuha, 50m east of the road to Magogoni

Elevation    : 110 m asl. Landform: plain; flat or almost flat

Surface characteristics : Erosion: none or slight. Deposition: cm.

Described by B.M. Msanya, A.I.M. Munisi and D.N. Kimaro on 03/01/00

Soils are deep, imperfectly drained dark greyish brown sandy clay loams, with thick brown sandy loam topsoils. Surface cracks about 3cm wide and up to 30cm deep.

Ah        0 - 10 cm: brown (7.5YR2/0) moist; sandy loam; friable moist, slightly sticky and slightly plastic wet; weak fine and medium subangular blocks; clear smooth boundary to

Bw       10 - 45 cm: very dark greyish brown (10YR3/2) moist; sandy clay loam; friable moist, sticky and plastic wet; weak fine and medium subangular blocks; clear smooth boundary to

Bck      45 - 75 cm: dark grey (10YR4/1) moist; sandy clay loam; friable moist, slightly sticky and slightly plastic wet; weak fine and medium subangular blocks; spherical Fe and Mn nodules; clear smooth boundary to

BC/Ck    75 - 100 cm: dark greyish brown (2.5YR4/2) moist; sandy clay loam; friable moist, sticky and plastic wet; weak fine and medium subangular blocks; spherical Fe and Mn nodules; clear smooth boundary to

SOIL CLASSIFICATION: FAO legend: Calcari-Sodic Cambisols

USDA Soil Taxonomy: Vertic Haplustepts

Profile number : MTP-32    Mapping unit: Pc 4    Agro-ecological. zone: EX

Region        : Morogoro

District      : Morogoro

Map sheet no. : 184/3

Coordinates   : 38° 5' E/ 6° 49' S

Location      : 7.5 km from Ngerengere village along the road to Tununguo, 15 m east of Mr

Elevation     : 274 m asl. Landform: plain; flat or almost flat. Slope: 2 %

Surface characteristics : Erosion: none or slight. Deposition: cm.

Natural drainage class : excessively drained

Described by B.M. Msanya, D.N. Kimaro and A.I.M. Munisi on 06/01/00

Soils are shallow, excessively drained strongly brown loamy sands, with thin dark yellowish brown loamy sand topsoil.

Ah    0 - 10 cm: yellowish brown (10YR5/4) dry, dark yellowish brown (10YR4/4) moist; loamy sand; soft dry, friable moist, non-sticky and non-plastic wet; weak very fine granular; many fine pores; few medium roots; clear wavy boundary to

AB    10 - 38 cm: strong brown (7.5YR5/6) dry, brown (7.5YR4/4) moist; loamy sand; soft dry, friable moist, non-sticky and non-plastic wet; weak medium granular; many fine pores; few medium angular weathered quartz fragments; few fine roots

CR Saprolite

SOIL CLASSIFICATION: FAO legend: Chromi-Ferralic Cambisols

USDA Soil Taxonomy: Oxic Haplustepts

Profile number : MTP-35 Mapping unit: Va 1 Agro-ecological zone: IV

Region : Morogoro

District : Morogoro

Map sheet no. : 201/4

Coordinates : 37° 51' E/ 7° 22' S

Location : About 7 km from Dutumi market centre and 3 km south of the rd to Moro

Elevation : 110 m asl. Landform: plain; flat or almost flat. Slope: 1.5 %

Surface characteristics : Erosion: none or slight. Deposition: cm.

Described by B.M. Msanya, D.N. Kimaro and A.I.M. Munisi on 09/01/00

Soils are very deep, imperfectly drained very dark greyish brown sandy clay loams, with thin very darkish grey sandy clay loam topsoils.

Ah 0 - 7 cm: very dark greyish brown (10YR3/2) dry, dark brown (10YR3/1) moist; sandy clay loam; weak fine granular and medium subangular blocks; few medium pores; many fine roots; abrupt smooth boundary to

AB 7 - 23 cm: dark brown (10YR3/3) dry, very dark greyish brown (10YR3/2) moist; sandy clay loam; weak fine subangular blocks and medium angular blocks; many fine and common medium pores; few medium spherical hard manganese nodules; many fine roots; abrupt smooth boundary to

2C 23 - 68 cm: black (5Y2.5/2) dry, black (5Y2.5/1) moist; sandy clay; moderate fine subangular blocks and medium angular blocks; common medium pores; few medium spherical hard Fe and Mn nodules; many fine roots; abrupt smooth boundary to

3C 68 - 90 cm: very dark grey (5Y3/1) moist; sandy clay; common medium pores; few medium spherical hard Fe and Mn nodules; many fine roots; abrupt smooth boundary to

4C 90 - 120 cm: dark olive grey (5Y3/2) moist; sandy clay; common medium pores; few medium spherical hard Fe and Mn nodules; many fine roots; abrupt smooth boundary to

SOIL CLASSIFICATION: FAO legend: Hapli-Pachic Phaeozems

USDA Soil Taxonomy: Cumulic Haplustolls

Profile number : MTP-36 Mapping unit: Va 1 Agro-ecological zone: IV

Region : Morogoro

District : Morogoro

Map sheet no. : 201/4

Coordinates : 37° 50' E/ 7° 24' S

Location : About 4 km south-east of Mbwade village

Elevation : 120 m asl. Landform: plain; flat or almost flat. Slope: 0.5 %

Surface characteristics : Erosion: none or slight. Deposition: cm.

Natural drainage class : imperfectly drained

Described by D.N. Kimaro, B.M. Msanya and A.I.M. Munisi on 11/01/99

Soils are deep imperfectly drained black loamy sand clays, with thin very darkish grey sandy loam topsoils. Surface with cracks up to 6cm wide and 110cm deep.

Ap 0 - 8 cm: very dark greyish brown (10YR3/2) dry, very dark grey (10YR3/1) moist; sandy loam; very hard dry, friable moist, sticky and plastic wet; moderate fine granular and fine subangular blocks; many fine pores; many fine roots; abrupt smooth boundary to

2C 8 - 25 cm: black (5Y2.5/2) moist; clay loam; very hard dry, friable moist, sticky and plastic wet; weak fine and medium subangular blocks; common fine pores; spherical soft Fe and Mn nodules; many fine roots; clear smooth boundary to

3C 25 - 70 cm: very dark grey (5Y3/1) moist; sand clay; friable moist, sticky and plastic wet; weak fine and medium angular blocks; common fine pores; spherical soft Fe and Mn nodules; few fine roots; gradual smooth boundary to

4C 70 - 103 cm: dark olive grey (5Y3/2) moist; sandy clay; friable moist, sticky and plastic wet; weak fine angular blocks and moderate; common fine pores; spherical soft Fe and Mn nodules; few fine roots

SOIL CLASSIFICATION: FAO legend: Hapli-Eutric Regosols

USDA Soil Taxonomy: Typic Ustorthents

Profile number : MAT P-38    Mapping unit: MO 21    Agro-ecological zone: II

Region        : Morogoro

District      : Morogoro

Map sheet no. : 201/3

Coordinates   : 37° 42' E/ 7° 22' S

Location      : About 1.5 km south-west of Bwakira Juu

Elevation     : 380 m asl. Landform: mountain; hilly. Slope: 40 %

Surface characteristics : Erosion: none or slight. Deposition: cm.

Natural drainage class : well drained

Described by B.M. Msanya, D.N. Kimaro and A.I.M. Munisi on 15/01/00

Moderately deep, well drained, very dark brown loamy topsoil over dark reddish brown and dark red clayey profile. Sight slightly rocky.

Ah    0 - 15 cm: brownish red (10YR4/3) dry, very dark brown (10YR2/2) moist; sandy loam; slightly hard dry, friable moist, slightly sticky and slightly plastic wet; weak fine and medium subangular blocks; clear smooth boundary to

Bt    15 - 45 cm: dark red (2.5YR3/6) dry, dark reddish brown (2.5YR3/4) moist; sandy clay; slightly hard dry, friable moist, sticky and plastic wet; moderate fine and medium subangular blocks; clear smooth boundary to

BC    45 - 70 cm: red (2.5YR4/6) dry, dark red (2.5YR3/6) moist; sandy clay loam; slightly hard dry, friable moist, sticky and plastic wet; moderate fine and medium subangular blocks; clear smooth boundary to

SOIL CLASSIFICATION: FAO legend: Hapli-Rhodic Luvisols

USDA Soil Taxonomy: Typic Rhodustalfs

Profile number : MTP-5 Mapping unit: MO 1 Agro-ecological zone: I

Region : Morogoro

District : Morogoro

Map sheet no. : 183/4

Coordinates : 37° 47' E/ 6° 49' S

Location : About 2 km north of Kiroka village along the road to Morogoro

Elevation : 600 m asl. Landform: mountain; mountaineous. Slope: 38 %

Surface characteristics : Erosion: none or slight. Deposition: none.

Natural drainage class : well drained

Described by D.N. Kimaro, B.M. Msanya and A.I.M. Munisi on 09/12/99

Soils are very deep, well drained dusky red sandy clays, with thick brown sandy clay loam topsoils.

Ah 0 - 15 cm: black (5YR 3/1) dry, black (5YR2.5/1) moist; sandy clay loam; soft dry, friable moist, non-sticky and non-plastic wet; moderate fine granular and medium subangular blocks; many fine pores; many fine and few medium roots; clear smooth boundary to

Bt1 15 - 35 cm: very dark red (2.5YR2.5/4) dry, very dark red (2.5YR2.5/2) moist; sandy clay; hard dry, friable moist, sticky and plastic wet; moderately weak medium subangular blocks; clay cutans; many fine pores; many fine and common medium roots; gradual smooth boundary to

Bt2 35 - 75 cm: dark reddish brown (2.5YR3/2) dry, dark reddish brown (2.5YR2.5/4) moist; sandy clay; hard dry, friable moist, sticky and plastic wet; moderate medium subangular blocks; clay cutans; many fine pores; few quartz fragments; common medium roots; gradual smooth boundary to

Bts1 75 - 100 cm: dark red (2.5YR3/4) dry, dark red (2.5YR3/2) moist; sandy clay; hard dry, friable moist, sticky and plastic wet; moderate medium subangular blocks; many fine pores; few quartz fragments; common medium roots; gradual smooth boundary to

Bts2 100 - 140 cm: dark red (2.5YR3/4) dry, dark red (2.5YR3/2) moist; sandy clay; hard dry, friable moist, sticky and plastic wet; strong medium subangular blocks; many fine pores; few quartz fragments; common medium roots; gradual smooth boundary to

SOIL CLASSIFICATION: FAO legend: Rhodi-Profondic Luvisols

USDA Soil Taxonomy: Kanhaplic Rhodustalfs

Profile number : MTP-6 Mapping unit: P1 1 Agro-ccological zone: III

Region : Morogoro

District : Morogoro

Map sheet no. : 183/4

Coordinates : 37° 55' E/ 6° 47' S

Location : Mikescko village about 1.2 km north-west of Msemakweli village

Elevation : 400 m asl. Landform: plain; undulating. Slope: 5 %

Surface characteristics : Erosion: none or slight. Deposition: cm.

Natural drainage class : well drained

Described by B.M. Msanya, D.N. Kimaro and A.I.M. Munisi on 09/12/99

Soils are very deep well drained dark reddish brown clays, with thick darkish brown sandy clay loam topsoils.

Ah 0 - 10 cm: dark brown (7.5YR3/4) dry, dark brown (7.5YR3/2) moist; sandy clay loam; slightly hard dry, friable moist, sticky and plastic wet; moderate fine and medium subangular blocks; few medium pores; common medium roots; clear smooth boundary to

BA 10 - 19 cm: dark reddish brown (5YR3/4) dry, dark reddish brown (5YR3/3) moist; sandy clay; slightly hard dry, friable moist, sticky and plastic wet; moderate fine and medium subangular blocks; common medium pores; many fine and common medium roots; gradual smooth boundary to

Bt1 19 - 38 cm: dark reddish brown (5YR4/4) dry, dark reddish brown (5YR4/4) moist; clay; slightly hard dry, friable moist, sticky and plastic wet; moderate fine and medium subangular blocks; thin clay cutans; common medium pores; common medium roots; gradual smooth boundary to

Bt2 38 - 85 cm: dark red (2.5YR4/6) dry, dark red (2.5YR3/6) moist; clay; soft dry, friable moist, sticky and plastic wet; moderately strong fine and medium subangular blocks; thin clay cutans; common medium pores; common fine and few medium roots; diffuse smooth boundary to

Bt3 85 - 125 cm: red (2.5YR4/8) dry, red (2.5YR4/6) moist; clay; soft dry, friable moist, sticky and plastic wet; strong fine and medium subangular blocks; many fine and common medium pores; many fine and common medium roots; diffuse smooth boundary to

Bt4 125 - 150 cm: red (2.5YR5/8) dry, red (2.5YR4/8) moist; clay; soft dry, friable moist, sticky and plastic wet; moderate fine subangular blocks; many fine pores; few fine roots

SOIL CLASSIFICATION: FAO legend: Orthidystri-Profondic Acrisols

USDA Soil Taxonomy: Kanhaplic Haplustults

Profile number : MTP- 10    Mapping unit: Va 2    Agro-ecological zone: VII

Region        : Morogoro

District      : Morogoro

Map sheet no. : 184/4

Coordinates   : 37° 50' E/ 6° 59' S

Location      : Mwarazi Primary school farm

Elevation     :    m asl. Landform: plain: undulating. Slope: 4 %

Surface characteristics : Stones: 10 % Erosion: none or slight. Deposition: none.

Natural drainage class : poorly drained

Described by D.N. Kimaro, B.M. Msanya and A.I.M. Munisi on 10/12/99

Soils are moderately deep, poorly drained very darkish brown clays, with thin brown sandy clay topsoils.

Ah    0 - 5 cm: very dark grey (10YR3/1) dry, brown (10YR2/1) moist; slightly stony sandy clay; soft dry, friable moist, sticky and plastic wet; weak fine crumbs; many fine pores; many fine roots; clear smooth boundary to

AC1    5 - 13 cm: very dark greyish brown (10YR3/2) dry, very dark brown (10YR2/2) moist; slightly stony clay; many fine distinct clear 7.5YR4/4 mottles; hard dry, friable moist, sticky and plastic wet; weak fine subangular blocks; many fine and few medium pores; many fine roots; clear smooth boundary to

AC2    13 - 26 cm: dark grey (2.5YR4/1) dry, dark grey (2.5YR4/1) moist; slightly stony clay; few fine distinct clear 7.5YR4/4 mottles; hard dry, friable moist, sticky and plastic wet; moderate medium subangular blocks; many fine pores; many fine roots; gradual smooth boundary to

AC3    26 - 40 cm: dark red (2.5YR3/2) moist; slightly stony clay; friable moist, sticky and plastic wet; moderate medium subangular blocks; many pores; clear smooth boundary to

AC4    40 - 72 cm: red (2.5YR4/2) moist; slightly stony clay; friable moist, sticky and plastic wet; weak medium subangular blocks; many fine pores; few small irregular soft manganese nodules; many fine roots

SOIL CLASSIFICATION: FAO legend: Humi-Eutric Regosols

USDA Soil Taxonomy: Mollic Ustofluvents

Profile number : MTP-20 Mapping unit: MO1 Agro-ecological zone: I

Region : Morogoro

District : Morogoro

Map sheet no. : 201/3

Coordinates : 37° 41' E/ 7° 17' S

Location : About 4 km from Singiza along the road to Dutumi

Elevation : 420 m asl. Landform: mountain; hilly. Slope: 18 %

Surface characteristics : Erosion: none or slight. Deposition: cm.

Natural drainage class : well drained

Described by D.N. Kimaro, B.M. Msanya and AIM. Munisi on 13/12/99

**Ap 0 - 15 cm: very dark greyish brown (10YR3/2) dry, brown (10YR2/1) moist; sandy clay loam; slightly hard dry, friable moist, slightly sticky and slightly plastic wet; weak fine and medium granular; many fine pores; many fine and few medium roots; clear smooth boundary to**

**Bt 15 - 35 cm: dark red (2.5YR3/6) dry, dark reddish brown (2.5YR3/4) moist; sandy clay; slightly hard dry, friable moist, sticky and plastic wet; strong fine and medium subangular blocks; many fine pores; common fine and few coarse roots; abrupt smooth boundary to**

**BC 35 - 85 cm: 2.5YR3/4 dry, dark reddish brown (2.5YR2.5/4) moist; sand clay loam; slightly hard dry, friable moist, sticky and plastic wet; moderate fine and medium subangular blocks; few medium pores; common fine and few coarse roots; abrupt smooth boundary to**

**SOIL CLASSIFICATION: FAO legend: Hapli-Rhodic Luvisols**

**USDA Taxonomy: Typic Rhodustalfs**

Appendix 2. Land attribute database for Eastern part of Morogoro Rural District

LC	Alt (m)	Temp (°C)	GPR mm	MAR mm	LGP days	Slope %	Surface text.	Sub- surface texture	Flood- ing days	Soil Depth cm	Drain- age (class)	Soil pH	CBC cmol- (+)/kg	OC %	N %	P mg/ kg	Avl K cmol- (+)/kg	BS %	ESP %
MO1	P1 480	22	876	1650	244	47	SC	C	<1	>140	WD	5.4	13.4	2.5	0.3	33.6	0.1	7	1.4
	P5 600	19	1050	1600	213	38	SCL	SC	<1	140	WD	6.6	25	1.1	0.1	10.6	0.8	83	1.2
	P18 500	19	877	1712	244	36	SCL	C	<1	>100	WD	5.8	25	2.4	0.3	6.1	0.2	25	0.4
	P20 490	19	1032	2581	304	18	SCL	SCL	<1	85	SED	6.6	19.5	2.4	0.24	7.3	0.1	83	0.3
MO21	P38 460	22	881	1368	213	40	SC	SCL	<1	70	SED	6.3	17.2	2.5	0.3	8.8	0.3	107	1.8
	P16 430	22	705	1119	213	42	SC	C	<1	100	WD	6.4	12.7	2.2	0.2	13.4	0.7	201	0.6
MO22	P27 420	22	967	1954	244	2	SCL	SC	<1	>110	WD	6.0	7.6	2.1	0.2	32.4	0.2	72	2.8
	P30 360	24	967	1954	244	24	CL	C	<1	>80	WD	6.2	14.8	1.2	0.06	14.4	0.03	51	7.3
PI1	P6 400	22	605	1006	213	5	SCL	C	<1	150	WD	5.6	17.8	2.1	0.21	4.3	1.6	71	0.4
	P8 370	25	967	1954	244	21	C	C	<1	90	WD	6.1	5.6	1.3	0.12	7.5	0.1	185	5.4
PI2	P31 230	26	449	947	152	6	SL	SCL	<1	25	SED	5.8	13.4	1.5	0.2	13.2	0.7	115	0.7
	P12 140	26.5	743	1195	213	2.5	S	LS	<1	150	SED	6.1	5.3	0.6	0.1	8.4	0.2	49	6.3
Pe1	P23 170	26.5	705	1119	213	0.5	CL	C	<15	105	ID	6.6	20.1	2.1	0.22	37.8	1.7	132	0.7
	P36 120	27.0	705	1119	213	0.5	SL	SCL	<15	103	ID	7.6	16.2	1.2	0.13	2.7	0.5	52	0.5
Pe2	P24 274	26	512	941	213	2	SL	SCL	<1	110	WD	6.2	12.7	1.5	0.2	2.5	0.4	76	0.6
	P13 100	27.5	743	1195	213	1	SL	L	<1	150	SED	7.0	11.5	1.1	0.13	2.3	0.3	114	1.9

## Appendix 2. continued.

LC	Alt (m)	Temp (°C)	GPR mm	MAR mm	LGP days	Slope %	Surface texture	Sub- surface texture	Flood- ing days	Soil Depth cm	Drain- age (class)	Soil pH	CEC cmol- (+)/kg	OC %	N %	Avl P mg/ kg	Avl K cmol- (+)/kg	BS %	ESP %
Pe 3	P28 145	27	512	941	213	0.5	CL	C	<5	117	WD	7.6	36.5	2.0	0.2	2.6	1.4	129	16.7
	P11 230	26.5	743	1195	213	5	SL	SCL	<1	25	ED	5.8	13.4	1.5	0.2	13.2	0.7	115	0.7
Pe 4	P3 400	26	512	941	213	6	LS	LS	<1	90	WD	6.5	6.4	0.4	0.04	2.5	0.6	91	0.3
	P32 274	26.5	512	941	213	2	LS	SCL	<1	>38	ED	5.5	2.2	0.7	0.07	32.2	0.3	46	3.6
Va 1	P19 130	27.0	705	1119	213	1	CL	L	<15	134	PD	6.9	25.3	1.5	0.13	26.7	0.7	94	0.5
	P35 110	28.	705	1119	213	1.5	SCL	SC	<15	120	ID	7.1	20.7	1.5	0.3	15.0	0.7	83	1.4
Va 2	P10 130	27	876	1615	244	0.5	SC	C	<15	135	PD	7.1	44.9	2.8	0.3	39.6	1.6	107	3.8
	P22 198	26.5	512	941	213	2	SCL	SC	<5	98	WD	6.8	12.3	0.6	0.1	2.6	1.1	161	0.4

Note: Mean annual temperature calculated from equation  $T_{mean} = 30.2 - 0.0065h$ ,  $h$  = altitude (m); developed by meteorology Department, Nairobi (1970).

GPR = growing period rainfall, MAR = mean annual rainfall, LGP = length of growing period, WD = well drained, SED = somewhat excessively drained, ID = imperfectly drained, PD = poorly drained

**Appendix 3. Land attribute table dictionary for the study area**

**Rfcrop-t (Rainfed cropping- traditional management) Land Characteristics**

LC Id	LC Name	Classes Units (Upper Limit)	Unit
Code	class	Class Name	
<b>sl</b>		<b>Dominant slope classes</b>	<b>%</b>
1	1	Flat to nearly level	0-10
2	2	Very gently slopping	10-20
3	3	Gently slopping	20-50
4	4	Slopping	50-10
5	5	Strongly slopping	10-15
6	6	Moderately steep	15-30
7	7	Steep	30-60
8	8	Very steep	>60
<b>T-GP</b>		<b>Mean annual temperature</b>	
1	1	Very cool	10-15
2	2	Cool	15-17.5
3	3	Moderately cool	17.5-20
4	4	Moderately warm	20-22.5
5	5	Warm	22.5-25
6	6	Very warm	25-27.5
7	7	Extremely warm	>27.5
<b>Tex-p</b>		<b>Average soil texture throughout profile</b>	<b>Class</b>
1	1	Clay (C)	
2	2	Sandy clay (SC)	
3	3	Silty clay (SiC)	
4	4	Clay loam (CL)	
5	5	Sandy clay loam (SCL)	
6	6	Silty loam (SiL)	
7	7	Silty clay loam (SiCL)	
8	8	Sandy loam (SL)	
9	9	Sand (S)	
10	10	Loamy sand (LS)	
11	11	Loam (L)	
12	12	Silt (Si)	
<b>Tex-t</b>		<b>Average soil texture within 0-30 cm</b>	<b>class</b>
1	1	Clay (C)	
2	2	Sandy clay (SC)	
3	3	Silty clay (SiC)	
4	4	Clay loam (CL)	
5	5	Sandy clay loam (SCL)	
6	6	Silty loam (SiL)	
7	7	Silty clay loam (SiCL)	
8	8	Sandy loam (SL)	

9	9	Sand (S)		
10	10	Loamy sand (L.S)		
11	11	Loam (L)		
12	12	Silt (Si)		
<b>Dr</b>		<b>Soil drainage class</b>		
1	1	Excessively drained		
2	2	Somewhat excessively drained		
3	3	Well drained		
4	4	Somewhat poorly (imperfectly) drained		
5	5	Poorly drained		
6	6	Very poorly drained		
<b>FL</b>		<b>Duration of flooding</b>		
1	1	Less than 1 day		
2	2	1 – 5 days		
3	3	5 – 15 days		
4	4	15 – 30 days		
5	5	30 – 90 days		
6	6	90 – 180 days		
7	7	180 – 365 days		
<b>LGP</b>		<b>Reference length of growing period</b>		<b>Days</b>
1	1	Short	150-180	
2	2	Medium	180-210	
3	3	Long	210-240	
4	4	Very long	240-270	
5	5	Extremely long	270-300	
6	6	Almost continuous	300-365	
<b>Sd</b>		<b>Effective soil depth</b>		<b>cm</b>
1	1	Very shallow	<20	
2	2	Shallow	20-40	
3	3	Moderately deep	40-80	
4	4	Deep	80-120	
5	5	Very deep	>120	
<b>Sd-T</b>		<b>Topsoil thickness</b>		<b>cm</b>
1	1	Thin	<10	
2	2	Thick	10-20	
3	3	Very thick	>20	
<b>P-gp</b>		<b>Rainfall 4 months before end of growing period.</b>		<b>mm/m</b>
1	1	Very low	0-200	
2	2	Low	200-400	
3	3	Moderate	400-600	
4	4	High	600-800	

5	5	Very high	800-1000	
6	6	Extremely high	1000-1100	
<b>P-an</b>		<b>Mean annual precipitation</b>		<b>mm</b>
1	1	Very low	100-250	
2	2	Low	250-500	
3	3	Moderate	500-750	
4	4	High	700-1500	
5	5	Very high	1500-2000	
6	6	Extremely high	>2000	
<b>pH-t</b>		<b>Soil reaction pH (H<sub>2</sub>O) within 0-30 cm</b>		
1	1	Very strongly acid	0-5.0	
2	2	Strongly acid	5.1-5.5	
3	3	Moderately acid	5.6-6.0	
4	4	Slightly acid	6.1-6.5	
5	5	Neutral	6.6-7.5	
6	6	Mildly alkaline	7.6-8.0	
7	7	Moderate alkaline	>8	
<b>pH-s</b>		<b>Soil reaction pH (H<sub>2</sub>O)</b>		
1	1	Very strongly acid	0-5.0	
2	2	Strongly acid	5.1-5.5	
3	3	Medium	5.6-6.0	
4	4	Slightly acid	6.1-6.5	
5	5	Neutral	6.6-7.3	
6	6	Mildly alkaline	7.4-7.8	
7	7	Moderate alkaline	7.9-8.4	
<b>CEC</b>		<b>Cation exchange capacity within 0-30 cm</b>		
1	1	Very low	<6.0	
2	2	Low	6.0-12.0	
3	3	Medium	12.1-25.0	
4	4	High	25.0-40.0	
5	5	Very high	>40.0	
<b>N</b>		<b>Nitrogen content within 0-30 cm</b>		<b>cmol(+)/kg</b>
1	1	Very low	<0.10	
2	2	Low	0.10-0.20	
3	3	Medium	0.21-0.50	
4	4	High	>0.50	
<b>P-Av.</b>		<b>Available Phosphorus within 0-30 cm</b>		<b>%</b>
1	1	Low	<7.0	
2	2	Medium	7-20	
3	3	High	>20	

<b>K-cl</b>		<b>Potassium within 0-30 cm (clay soils)</b>		
1	1	Very low	<0.2	mgP/kg soil
2	2	Low	0.2-0.4	
3	3	Medium	0.41-1.2	
4	4	High	1.21-2.0	
5	5	Very high	>2.0	
<b>K-loa</b>		<b>Potassium within 0-30 cm (loam soils)</b>		
1	1	Very low	<0.13	
2	2	Low	0.13-0.25	
3	3	Medium	0.26-0.8	
4	4	High	0.81-1.35	
5	5	Very high	>1.35	
<b>K-sa</b>		<b>Potassium within 0-30 cm (sandy soils)</b>		
1	1	Very low	<0.05	
2	2	Low	0.05-0.10	
3	3	Medium	0.11-0.40	
4	4	High	0.41-0.70	
5	5	Very high	>0.7	
<b>OC</b>		<b>Organic carbon content within 0-30 cm.</b>		%
1	1	Very low	<0.6	
2	2	Low	0.6-1.25	
3	3	Medium	1.26-2.50	
4	4	High	2.51-3.50	
5	5	Very high	>3.50	
<b>ESP</b>		<b>Soil sodicity</b>		%
1	1	Non-sodic	<6	
2	2	Slightly sodic	6-10	
3	3	Moderately sodic	11-15	
4	4	Strongly sodic	16-25	
5	5	Very strongly sodic	26-35	
6	6	Extremely sodic	>35	
<b>BS</b>		<b>Base saturation</b>		%
	1		<20	
1	2	Very low	20-40	
	3	Low	41-60	
2	4	Medium	61-80	
	5	High	>80	
3		Very high		
4				
5				



## Appendix 5. Questionnaire for digital land resources database

### A. General information

Questionnaire number:- .....  
 Name of interviewer :- .....  
 Date :- .....  
 Name of respondent:- .....  
 Tribe :- .....  
 Religion:- .....  
 Agroecological zone (De Pauw, 1984):- .....  
 Landscape :-..... Soil type:-.....  
 Village:-.....  
 Ward:-.....  
 Division:-.....  
 District:-.....  
 Region:-.....

### B. Specific information concerning respondent

Question	Value	Response
Gender	Male / Female	
Marital status	Married/Single/divorced/Widow	
Age	Years	
Time lived at this place	Years	
Occupation	Agriculture/Business/Others (specify)	
Ownership (land)	Bought, Inherited, Rented, Shared, others	
Education	Level of education	

#### Family composition:

	Members (number)	How many contribute to the work on the farm	Off-farm work
Adults			

Children			
Elderly people			

**C. Farm characteristics:**

Plot No.	Size (ha)	Crops	Soil constraints	Yield per plot	Topography	Distance to the residence	This LUT permanent	Remarks (interviewer)
1.								
2.								
3.								
4.								
5.								

**Other farm characteristics**

Distance of farm to the market (km):-.....

Do you keep any livestock ?

If yes; Type.....

Quantity .....

Function/products .....

Do you have credit ? Yes / No

If Yes; Purpose:.....

Conditions: .....

Sources: Bank / Cooperatives / Family / Money-lenders

Do you access any extension services ?.....

How many times do you have contact with estate / agriculture / livestock extension services ?

Where do you get firewood from ?..... Cost ? .....

Where do you get water from ?..... Cost ?.....

**E. Crop information**

Crop	Area per crop	Crop production system	Land preparation	Fertilizers & chemical use	Yield (Kg/h)	Amount used for subsistence (%)	Amount sold (%)	Price (sh /kg)
1.								
2.								
3.								
4.								
5.								

Total benefit accrued: (T.shilling).....

Sales done at: The field / farm house / local markets

What is the most important crop(s) to you ?.....

Why ?.....

What area the main crop requirements or soil constraints ?

.....  
 .....  
 .....

**F. Soil conservation**

Do you experience soil erosion on your land / farm ?

What kind of erosion ?

water, wind, others (specify)

Do you practice land husbandry ? Yes / No

Which type of soil conservation measure do you practice ?

contour tillage, terracing, strip cropping, others (specify)

What kind of labour is used ?

family labour, communal labour, hired labour, other (specify)

Is there any constraints to soil conservation ? Explain briefly.

**G. Future prospects**

Is your land / farm area adequate? If not what are your plans ?

Are you planning to change the present land use ?

If yes, what kind of change do you envisage and why ?

Appendix 6a. Land use requirements (LURs) for rainfed maize (*Zea mays*) production

Land quality	Diagnostic factor	Unit	Factor rating			
			Highly suitable (S1)	Moderately suitable (S2)	Marginally suitable (S3)	Not suitable (N)
Moisture availability	Total rainfall in growing period	mm	800-600	600-400	400-250	<250
Temperature regime	Mean temp in growing period	°C	24-18 24-32	18-16 32-35	16-14 35-40	<14 >40
Oxygen availability to roots	Soil drainage	Drainage class	Well	Moderately well	Imperfect	Poor, very poor
Rooting condition	Flooding	days	<1	1-5	15-30	>30
	Effective depth	cm	>120	75-120	30-75	<30
Nutrient availability	Profile texture	class	SiC, SiCL, Si, CL, SC, L, SCL	SL, LfS, LS	fS, S, LcS	Cm, Si, CM, cS
	Soil reaction	pH	6.6-5.8 6.6-7.8	5.8-5.5 7.8-8.2	5.5-5.2 8.2-8.5	5.2 8.5
	Top soil organic C	%	>2.0	1.0-2.0	0.5-1.0	0.5
	Top soil N content	%	>0.2	0.1-0.2	0.02-0.1	0.02
Nutrient retention capacity	Top soil available P	mg/kg	>40	40-10	10-5	5
	Base saturation	%	>80	40-80	20-40	20
	Top soil CEC	cmol(+)/kg	>25	25-13	13-6	6
Erosion hazard	Slope angle	%	0-5	5-10	10-15	15
	Surface texture	class	SiC, SiCL, Si, CL, SC, L, SCL	SL, LfS, LS	fS, S, LcS	Cm, Si, CM, cS

Appendix 6b. Land use requirements (LURs) for rainfed rice (*Oryza sativa*) production

Land quality	Diagnostic factor	Unit	Factor rating			
			Highly suitable (S1)	Moderately suitable (S2)	Marginally suitable (S3)	Not suitable (N)
Moisture availability	Total rainfall in growing period	mm	700-600	600-300	300-200	<200
	Length of growing period (LGP)	days	180-210	700-800	800-900	<900
Moisture retention	Top soil texture	Textural class	C, SiC, CL	240-270 SC, SiCL, SiL	270-300 SL, L, SCL	>300 S, LS
	Mean temp in growing period	°C	34-24	24-18	18-10	<18
Oxygen availability to roots	Soil drainage	Drainage class	31-36	>36	Moderate	Well
	Rooting condition	Effective depth	cm	75-50	50-25	<25
Nutrient availability	Profile texture	Class	C, SiC, CL	SC, SiCL, SiL	SL, L, SCL	S, LS
	Soil reaction	pH	6.5-5.5	5.5-5.0	5.0-4.5	<4.5
	Top soil organic C	%	6.5-8.2	8.2-8.5	8.5-8.8	>8.8
	Top soil N content	%	2.0-4.0	1.0-2.0	0.5-1.0	<0.5
	Top soil available P	mg/kg	>0.2	0.1-0.2	0.05-0.1	<0.05
Nutrient retention capacity	Base saturation	%	>40	40-20	20-10	<10
	Top soil CEC	cmol(+) / kg	>75	75-50	50-30	<30
Wetness	Flooding	days	>25	25-13	13-6	<6
	Slope angle	%	<1	1-2	2-4	>4

Appendix 6c. Land use requirements (LURs) for rainfed citrus (*Citrus spp*) production

Land quality	Diagnostic factor	Unit	Factor rating			
			Highly suitable (S1)	Moderately suitable (S2)	Marginally suitable (S3)	Not suitable (N)
Moisture availability	Total rainfall in growing period	mm	2300-1200	1200-1000	1000-800	<800
Temperature regime	Mean temp in growing period	°C	26-33	33-36	36-39	>39
Oxygen availability to roots	Soil drainage	Drainage class	26-19 well	19-16 Moderately well	16-13 imperfect	<13 Poor/very poor
	Flooding	days	<1	1-15	15-30	>30
Rooting condition	Effective depth	cm	>150	150-100	100-75	<75
Nutrient availability	Profile texture	Textural class	SL, SiL, L, SiCl, Si, CL, LS, SCL, Lfs	SC, S, fS, SiCs	C<60v, C<60s	Cm, SiCm, C<60v
	Soil reaction	pH	6.5-5.5	5.5-5.2	5.2-5.0	<5.0
	Top soil organic C	%	6.5-7.6	7.6-8.0	8.0-8.2	>8.2
	Top soil N content	%	>0.8	0.8-0.6	0.6	<0.6
Nutrient retention capacity	Top soil N content	%	>0.2	0.2-0.1	0.1-0.02	<0.02
	Top soil available P	mg/kg	>25	25-10	10-5	<5
	Base saturation	%	>35	35-20	20-10	<10
Topography	Top soil CEC	cmol(+)/kg	>16	16-9	9-5	<5
	Slope angle	%	0-15	15-30	30-60	>60

Appendix 6d. Land use requirements (LURs) for rainfed sesame (*Sesamum indicum*) production

Land quality	Diagnostic factor	Unit	Factor rating			
			Highly suitable (S1)	Moderately suitable (S2)	Marginally suitable (S3)	Not suitable (N)
Moisture availability	Total rainfall in growing period	mm	800-600	600-400	400-200	<200
Temperature regime	Mean temp in growing period	°C	25-28	800-900	900-100	>1000
Oxygen availability to roots	Soil drainage	Drainage class	25-20	28-30	30-38	<38
	Effective depth	cm	Well/excessively/ Somewhat well drain. >100-75	20-18	18-16	<16
Nutrient availability	Profile texture	Textural class	L, SL, SiCs, SCL, SiCL, CL, SiL, SC	Moderately well	imperfect	Poor/very poor
	Soil reaction	pH	6.3-5.8	75-50	50-30	<30
	Top soil organic C	%	6.3-7.0	Cs, LS	C, S	Cm, SiCm
	Top soil N content	%	>1.2	5.8-5.5	5.5-5.2	5.2
Nutrient retention capacity	Top soil available P	mg/kg	>0.2	7.0-7.5	7.5-8.2	>8.2
	Base saturation	%	>40	1.2-0.8	0.8-0.6	>0.6
	Top soil CEC	cmol(+)/kg	>80	0.2-0.1	0.1-0.02	<0.02
Erosion hazard	Slope angle	%	>24	40-20	20-10	<10
	Surface texture	Textural class	0-10	80-50	50-35	35
				24-16	16-9	9
				10-15	15-30	30
				Cs, LS	C, S	Cm, SiCm
				L, SL, SiCs, SCL, SiCL, CL, SiL, SC		

Appendix 7a. ALIES decision trees for smallholder low-input rainfed maize

Matombo (Matombo automated land evaluation)		Decision Trees	
Soil Type	Where Used	Where Used	Soil Type
1 > Severity Level			
1 (flat to nearly level) : 1 (good)			
2 (very gently sloping) : 1 (good)			
3 (gently sloping) [2-5] : 1 (good)			
4 (sloping) [5-10 %] > st (surface soil texture)			
1 (clay) : 2 (moderate)			
2 (sandy clay) : 2 (moderate)			
3 (silty clay) : 2 (moderate)			
4 (clay loam) : 2 (moderate)			
5 (sandy clay loam) : 2 (moderate)			
6 (silty clay loam) : 2 (moderate)			
7 (silty clay loam) : 2 (moderate)			
8 (sandy loam) : 2 (moderate)			
9 (sand) : 1 (good)			
10 (loamy sand) : 1 (good)			
7 : 1			
5 (strongly sloping) [10-15 %] > st (surface soil texture)			
1 (clay) : 1 (poor)			
2 (sandy clay) : 2 (moderate)			
3 (silty clay) : 2 (moderate)			
4 (clay loam) : 2 (moderate)			
5 (sandy clay loam) : 2 (moderate)			
6 (silty clay loam) : 2 (moderate)			
7 (silty clay loam) : 2 (poor)			
8 (sandy loam) : 2 (moderate)			
9 (sand) : 2 (moderate)			
10 (loamy sand) : 2 (moderate)			
7 : 2			
7 : 2			
6 (moderately steep) [15-30 %] > st (surface soil texture)			
1 (clay) : 1 (poor)			
2 (sandy clay) : 3 (poor)			
3 (silty clay) : 3 (poor)			
4 (clay loam) : 3 (poor)			
5 (sandy clay loam) : 2 (moderate)			
6 (silty clay loam) : 3 (poor)			
7 (silty clay loam) : 3 (poor)			
8 (sandy loam) : 2 (moderate)			
9 (sand) : 2 (moderate)			
10 (loamy sand) : 2 (moderate)			
7 : 2			
7 : 2			
7 (steep) [30-60 %] > st (surface soil texture)			
1 (clay) : 1 (poor)			
2 (sandy clay) : 3 (poor)			
3 (silty clay) : 3 (poor)			
4 (clay loam) : 4 (very poor)			
5 (sandy clay loam) : 3 (poor)			
6 (silty clay loam) : 4 (very poor)			
7 (silty clay loam) : 4 (very poor)			
8 (sandy loam) : 3 (poor)			
9 (sand) : 3 (poor)			
10 (loamy sand) : 3 (poor)			
7 : 3			
7 : 3			
2 > Severity Level			
1 (duration of flooding) (0-1) : 1			
2 (extremely short) (0-1) : 1			
3 (very short) (1-5 days) : 2			
4 (short) (5-15 days) : 3			
5 (moderately long) (15-30) : 4			
6 (long) (30-90 days) : 4			
7 (very long) (90-180 da) : 4			
8 (extremely long) (180-360) : 7			
9 : 7			
3 > Severity Level			
1 (duration of flooding) (0-1) : 1			
2 (extremely short) (0-1) : 1			
3 (very short) (1-5 days) : 2			
4 (short) (5-15 days) : 3			
5 (moderately long) (15-30) : 4			
6 (long) (30-90 days) : 4			
7 (very long) (90-180 da) : 4			
8 (extremely long) (180-360) : 7			
9 : 7			
4 > pr pH (profile pH)			
1 (very strongly acid) (0-5 no dimension) > n (nitrogen content)			
1 (very low) (0-6 %) : 4			
2 (low) (6-1.25 %) : 4			
3 (medium) [1.25-2.5 %] > n (nitrogen content)			
1 (very low) (0-1 %) : 1			
2 (low) (1-2 %) : 1			
3 (medium) [2-5 %] : 3			
4 (high) [2.5-5 %] : 3			
5 (very high) [3.5-5 %] : 3			
6 : 3			
7 : 3			
2 (strongly acid) (5-5.5 no dimension) > n (nitrogen content)			
1 (very low) (0-6 %) : 4			
2 (low) [6-1.25 %] > n (nitrogen content)			
1 (very low) (0-1 %) : 1			
2 (low) (1-2 %) : 1			
3 (medium) [2-5 %] : 3			
4 (high) [2.5-5 %] : 3			
5 (very high) [3.5-5 %] : 3			
6 : 3			
7 : 3			
3 (medium) [2-5 %] > p (available phosphorus)			
1 (very low) (0-5 mg P/kg) : 1			
2 (low) [5-10 mg P/kg] : 3			
3 (medium) [10-20 mg P/kg] : 3			
4 (high) [20-45 mg P/kg] : 3			
5 (very high) [45-90 mg P/kg] : 3			
6 : 3			
7 : 3			
4 (high) [3-1 %] : 3			
5 : 3			
6 : 3			
7 : 3			
8 : 3			
9 : 3			
10 : 3			
11 : 3			
12 : 3			
13 : 3			
14 : 3			
15 : 3			
16 : 3			
17 : 3			
18 : 3			
19 : 3			
20 : 3			
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58 : 3			
59 : 3			
60 : 3			
61 : 3			
62 : 3			
63 : 3			
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222 : 3</			

Appendix 7a. ALES decision trees for smallholder low-input rainfed maize

Macombo (Macombo automated land evaluation)		Macombo (Macombo automated land evaluation)	
Soil Type	Where Used	Soil Type	Where Used
1	SLIRM,c	2	SLIRM,fl
>	Severity Level	>	Severity Level
1	(flat to nearly slope) : 1 (good)	1	(duration of flooding) (0-1) : 1
2	(very gently sloping) : 1 (good)	2	(extremely short) (1-5 days) : 2
3	(gently sloping) [2-5] : 1 (good)	3	(very short) (5-15 days) : 3
4	(sloping) [5-10 %] > st (surface soil texture)	4	(moderately long) [15- : 4
1	(clay) : 2 (moderate)	5	(long) (30-90 days) : 4
2	(sandy clay) : 2 (moderate)	6	(very long) (90-180 da : 4
3	(silty clay) : 2 (moderate)	7	(extremely long) (180- : 4
4	(clay loam) : 2 (moderate)	?	?
5	(sandy clay loam) : 2 (moderate)	3	Severity Level
6	(silty loam) : 2 (moderate)	1	SLIRM,m
7	(silty clay loam) : 2 (moderate)	>	Severity Level
8	(sandy loam) : 2 (moderate)	1	(very low) (0-200 mm) : 4
9	(sand) : 2 (moderate)	2	(low) (200-400 mm) : 3
10	(loamy sand) : 1 (good)	3	(moderate) (400-600 mm) : 2
?	?	4	(high) (600-800 mm) : 1
5	(strongly sloping) [10-15 %] > st (surface soil texture)	5	(very high) (800-1000 : 2
1	(clay) : 3 (poor)	6	(extremely high) (1000 : 3
2	(sandy clay) : 3 (moderate)	7	?
3	(silty clay) : 3 (poor)	4	Severity Level
4	(clay loam) : 3 (moderate)	1	SLIRM,na
5	(sandy clay loam) : 3 (moderate)	>	Severity Level
6	(silty loam) : 3 (moderate)	1	(very strongly acid) (0-5 no dimension) > oc (organic carbon content)
7	(sandy loam) : 3 (poor)	2	(very low) (0-.6 %) : 4
8	(silty clay loam) : 3 (poor)	3	(low) (.6-1.25 %) : 4
9	(sandy loam) : 3 (poor)	1	(medium) (1.25-2.5 %) > n (nitrogen content)
10	(loamy sand) : 2 (moderate)	2	(very low) (0-.1 %) : 4
?	?	3	(low) (.1-.2 %) : 4
6	(moderately steep) [15-30 %] > st (surface soil texture)	4	(high) (2.5-3.5 %) : 3
1	(clay) : 4 (very poor)	5	(very high) (3.5-5 %) : 3
2	(sandy clay) : 3 (poor)	7	?
3	(silty clay) : 3 (poor)	2	(strongly acid) [5-5.5 no dimension] > oc (organic carbon content)
4	(clay loam) : 3 (poor)	1	(very low) (0-.6 %) : 4
5	(sandy clay loam) : 3 (poor)	2	(low) (.6-1.25 %) > n (nitrogen content)
6	(silty loam) : 3 (poor)	3	(very low) (0-.1 %) : 4
7	(sandy loam) : 3 (poor)	4	(low) (.1-.2 %) : 4
8	(silty clay loam) : 3 (poor)	5	(medium) (.2-.5 %) > p (available phosphorus)
9	(sandy loam) : 3 (moderate)	1	(very low) (0-5 mg P/kg) : 1
10	(loamy sand) : 2 (moderate)	2	(low) (5-10 mg P/kg) : 3
?	?	3	(medium) (10-20 mg P/k : 2
7	(steep) [30-60 %] > st (surface soil texture)	4	(high) (20-45 mg P/kg) : 2
1	(clay) : 4 (very poor)	5	(very high) (45-80 mg : 2
2	(sandy clay) : 3 (poor)	7	?
3	(silty clay) : 3 (poor)	4	(high) (.5-1 %) : 3
4	(clay loam) : 4 (very poor)	?	?
5	(sandy clay loam) : 3 (poor)	3	(medium) (1.25-2.5 %) > n (nitrogen content)
6	(silty loam) : 4 (very poor)	1	(very low) (0-.1 %) : 4
7	(silty clay loam) : 4 (very poor)	2	(low) (.1-.2 %) : 4
8	(sandy loam) : 3 (poor)	3	(medium) (.2-.5 %) > p (available phosphorus)
9	(sand) : 3 (poor)	1	(very low) (0-5 mg P/kg) : 1
10	(loamy sand) : 3 (poor)	2	(low) (5-10 mg P/kg) : 2
?	?	3	(medium) (10-20 mg P/k : 2
?	?	4	(high) (20-45 mg P/kg) : 2
?	?	5	(very high) (45-80 mg : 2
?	?	7	?
?	?	4	(high) (.5-1 %) : 3
?	?	?	?
?	?	3	(medium) (1.25-2.5 %) > n (nitrogen content)
?	?	1	(very low) (0-.1 %) : 4
?	?	2	(low) (.1-.2 %) : 4
?	?	3	(medium) (.2-.5 %) > p (available phosphorus)
?	?	1	(very low) (0-5 mg P/kg) : 1
?	?	2	(low) (5-10 mg P/kg) : 2
?	?	3	(medium) (10-20 mg P/k : 2
?	?	4	(high) (20-45 mg P/kg) : 2
?	?	5	(very high) (45-80 mg : 2
?	?	7	?
?	?	4	(high) (.5-1 %) : 3
?	?	?	?
?	?	4	(high) (2.5-3.5 %) : 3
?	?	?	?
?	?	?	?

Matombo (Matombo automated land evaluation)		Decision Trees		Matombo (Matombo automated land evaluation)	
Dtid Type	Where Used			Dtid Type	Where Used
SLIRM,na				SLIRM,na	
4 (continued)				5	Severity Level
	5 (very high) [3.5-5 %] : =3			1	(very low) [0-20 %] : =4
	7			2	(low) [20-40 %] : =3
	1 (moderately acid) [5.5-6 no dimension] > oc (organic carbon content)			3	(medium) [40-60 %] : =3
	1 (very low) [0-6 %] > n (nitrogen content)			4	(high) [60-80 %] : =2
	2 (low) [6-12 %] > p (available phosphorus)			5	(very high) [80-200 %] : =2
	1 (very low) [0-5 mg P/k] : =3			7	
	2 (low) [5-10 mg P/kg] : =3			2	(low) [6-12 cmol(+) /kg] > bs (base saturation)
	3 (medium) [10-20 mg P/k] : =2			1	(very low) [0-20 %] : =4
	4 (high) [20-45 mg P/kg] : =2			2	(low) [20-40 %] : =3
	5 (very high) [45-80 mg] : =2			3	(medium) [40-60 %] : =3
	7			4	(high) [60-80 %] : =2
	3 (medium) [1.2-2.5 %] : =2			5	(very high) [80-200 %] : =2
	4 (high) [1.5-1 %] : =2			7	
	7			3	(medium) [12-25 cmol(+) /kg] > bs (base saturation)
	1 (very low) [0-1 %] > n (nitrogen content)			1	(very low) [0-20 %] : =3
	2 (low) [1-2 %] : =2			2	(low) [20-40 %] : =3
	3 (medium) [1.2-2.5 %] : =2			3	(medium) [40-60 %] : =2
	4 (high) [1.5-1 %] : =2			4	(high) [60-80 %] : =2
	7			5	(very high) [80-200 %] : =2
	3 (medium) [1.25-2.5 %] : =2			7	
	4 (high) [2.5-3.5 %] : =2			4	(high) [25-40 cmol(+) /kg] > bs (base saturation)
	5 (very high) [3.5-5 %] : =2			1	(very low) [0-20 %] : =3
	7			2	(low) [20-40 %] : =3
	4 (slightly acid) [6-6.5 no dimension] > oc (organic carbon content)			3	(medium) [40-60 %] : =1
	1 (very low) [0-6 %] > n (nitrogen content)			4	(high) [60-80 %] : =1
	2 (low) [1-2 %] : =2			5	(very high) [80-200 %] : =1
	3 (medium) [1.2-2.5 %] : =2			7	
	4 (high) [1.5-1 %] : =2			5	(very high) [40-60 cmol(+) /kg] > bs (base saturation)
	7			1	(very low) [0-20 %] : =3
	1 (very low) [0-1 %] > n (nitrogen content)			2	(low) [20-40 %] : =3
	2 (low) [1-2 %] : =2			3	(medium) [40-60 %] : =1
	3 (medium) [1.2-2.5 %] : =2			4	(high) [60-80 %] : =1
	4 (high) [1.5-1 %] : =2			5	(very high) [80-200 %] : =1
	7			7	
	2 (low) [1.2-2.5 %] : =1			3	(medium) [12-25 cmol(+) /kg] > bs (base saturation)
	3 (medium) [1.25-2.5 %] > n (nitrogen content)			1	(very low) [0-20 %] : =3
	1 (very low) [0-1 %] : =1			2	(low) [20-40 %] : =3
	2 (low) [1-2 %] : =2			3	(medium) [40-60 %] : =1
	3 (medium) [1.2-2.5 %] : =2			4	(high) [60-80 %] : =1
	4 (high) [1.5-1 %] : =2			5	(very high) [80-200 %] : =1
	7			7	
	4 (high) [1.5-1 %] : =3			5	(very high) [40-60 cmol(+) /kg] > bs (base saturation)
	7			1	(very low) [0-20 %] : =3
	3 (very high) [3.5-5 %] : =3			2	(low) [20-40 %] : =3
	7			3	(medium) [40-60 %] : =3
	5 (neutral) [6.5-7.5 no] : =4			4	(high) [60-80 %] : =1
	6 (mildly alkaline) [7.5] : =3			5	(very high) [80-200 %] : =1
	7 (moderately alkaline) : =2			7	
	7			3	Severity Level
				1	dr (soil drainage) : =1
				2	(excessively drained) : =1
				3	(somewhat excessively) : =1
				4	(well drained) : =1
				5	(imperfectly drained) : =3
				6	(poorly drained) : =4
				7	(very poorly drained) : =4
				7	
				SLIRM,na	

Macombo (Macombo automated land evaluation) Dcid Type	Decision Trees	Macombo (Macombo automated land evaluation) Dcid Type
Where Used	Where Used	Where Used
SLIRM,na	SLIRM,na	SLIRM,nt
4 Severity Level		5 Severity Level
(continued)		> cec (cation exchange capacity)
5 (very high) [3.5-5 %] : =3		1 (very low) [0-5 cmol(+) /kg] > bs (base saturation)
7..... : ?		1 (very low) [0-20 %] : 4
1 (moderately acid) [5.5-6 no dimension] > oc (organic carbon content)		3 (medium) [20-40 %] : 3
1 (very low) [0-.6 %] > n (nitrogen content)		4 (high) [60-80 %] : 3
1 (very low) [0-1 %] : 1		5 (very high) [80-200 %] : 3
2 (low) [1.1-2 %] > p (available phosphorus)		7..... : ?
1 (very low) [0-5 mg P/k] : 3		2 (low) [6-12 cmol(+) /kg] > bs (base saturation)
3 (medium) [5-10 mg P/kg] : 3		1 (very low) [0-20 %] : 4
4 (high) [20-45 mg P/kg] : 2		3 (medium) [20-40 %] : 3
5 (very high) [45-80 mg P/kg] : 2		4 (high) [60-80 %] : 2
7..... : ?		5 (very high) [80-200 %] : 2
3 (medium) [1.2-5 %] : 2		7..... : ?
4 (high) [5-1 %] : 2		3 (medium) [12-25 cmol(+) /kg] > bs (base saturation)
7..... : ?		1 (very low) [0-20 %] : 1
2 (low) [1.6-1.25 %] > n (nitrogen content)		2 (low) [20-40 %] : 2
1 (very low) [0-1 %] : 3		3 (medium) [40-60 %] : 2
2 (low) [1.1-2 %] : 2		4 (high) [60-80 %] : 1
3 (medium) [1.2-5 %] : 2		5 (very high) [80-200 %] : 1
4 (high) [1.5-1 %] : 2		7..... : ?
7..... : ?		4 (high) [25-40 cmol(+) /kg] > bs (base saturation)
3 (medium) [1.25-2.5 %] : =2		1 (very low) [0-20 %] : 3
4 (high) [2.5-1.5 %] : =2		2 (low) [20-40 %] : 2
5 (very high) [3.5-5 %] : =2		3 (medium) [40-60 %] : 1
7..... : ?		4 (high) [60-80 %] : 1
4 (slightly acid) [6-6.5 no dimension] > oc (organic carbon content)		5 (very high) [80-200 %] : 1
1 (very low) [0-.6 %] > n (nitrogen content)		7..... : ?
1 (very low) [0-1 %] : 3		5 (very high) [10-60 cmv] : =4
2 (low) [1.1-2 %] : 2		7..... : ?
3 (medium) [1.2-5 %] : 2		
4 (high) [1.5-1 %] : 2		3 Severity Level
7..... : ?		> dr (soil drainage)
2 (low) [1.6-1.25 %] : =1		1 (excessively drained) : 1
3 (medium) [1.25-2.5 %] > n (nitrogen content)		2 (somewhat excessively) : 1
1 (very low) [0-1 %] : 3		3 (well drained) : 1
2 (low) [1.1-2 %] : 2		4 (imperfect drained) : 3
3 (medium) [1.2-5 %] > p (available phosphorus)		5 (poorly drained) : 4
1 (very low) [0-5 mg P/k] : 2		6 (very poorly drained) : 4
2 (low) [5-10 mg P/kg] : 2		7..... : ?
3 (medium) [10-20 mg P/k] : 2		
4 (high) [20-45 mg P/kg] : 1		
5 (very high) [45-80 mg P/kg] : 1		
7..... : ?		
4 (high) [1.5-1 %] : =3		
7..... : ?		
4 (high) [2.5-1.5 %] : =3		
5 (very high) [3.5-5 %] : =3		
7..... : ?		
5 (neutral) [6.5-7.5 no : =4		
6 (mildly alkaline) [7.5 : =3		
7 (moderately alkaline) : =2		
7..... : ?		

Matombo (Matombo automated land evaluation)		Decision Trees		Matombo (Matombo automated land evaluation)	
Dcid Type		Where Used		Where Used	
4		SLIRM,na		SLIRM,nc	
4	Severity Level				
5	(continued)				
5	(very high) [3.5-5 %] : : *3				
7	..... : ?				
1	(moderately acid) [5.5-6 no dimension] > oc (organic carbon content)				
1	(very low) [0-.6 %] > n (nitrogen content)				
1	(very low) [0-.1 %] : : 3				
2	(low) [1-.3 %] > p (available phosphorus)				
1	(very low) [0-.5 mg P/kg] : : 3				
3	(medium) [10-20 mg P/kg] : : 2				
4	(high) [20-45 mg P/kg] : : 2				
5	(very high) [45-80 mg : : 2				
7	..... : ?				
3	(medium) [1.2-.5 %] : : 2				
4	(high) [1.5-1 %] : : 2				
7	..... : ?				
2	(low) [1.6-1.25 %] > n (nitrogen content)				
1	(very low) [0-.1 %] : : 3				
2	(low) [1.1-2 %] : : 2				
3	(medium) [1.3-.5 %] : : 2				
4	(high) [1.5-1 %] : : 2				
7	..... : ?				
3	(medium) [1.25-2.5 %] : : =2				
4	(high) [2.5-3.5 %] : : =2				
5	(very high) [3.5-5 %] : : =2				
7	..... : ?				
4	(slightly acid) [6-6.5 no dimension] > oc (organic carbon content)				
1	(very low) [0-.6 %] > n (nitrogen content)				
1	(very low) [0-.1 %] : : 3				
2	(low) [1.1-2 %] : : 2				
3	(medium) [1.2-.5 %] : : 2				
4	(high) [1.5-1 %] : : 2				
7	..... : ?				
2	(low) [1.6-1.25 %] : : =1				
3	(medium) [1.25-2.5 %] > n (nitrogen content)				
1	(very low) [0-.1 %] : : 3				
2	(low) [1.1-2 %] : : 2				
3	(medium) [1.2-.5 %] > p (available phosphorus)				
1	(very low) [0-5 mg P/kg] : : 2				
3	(medium) [10-20 mg P/kg] : : 2				
4	(high) [20-45 mg P/kg] : : 1				
5	(very high) [45-80 mg : : 1				
7	..... : ?				
4	(high) [1.5-1 %] : : =3				
7	..... : ?				
4	(high) [2.5-3.5 %] : : =3				
5	(very high) [3.5-5 %] : : =3				
7	..... : ?				
5	(neutral) [6.5-7.5 no : : =4				
6	(mildly alkaline) [7.5 : : =3				
7	(moderately alkaline) : : =2				
7	..... : ?				
5	Severity Level				
>	cec (cation exchange capacity)				
1	(very low) [0-6 cmol(+) /kg]				
1	(very low) [0-20 %] : : 4				
2	(low) [20-40 %] : : 3				
3	(medium) [40-60 %] : : 3				
4	(high) [60-80 %] : : 3				
5	(very high) [80-200 %] : : 3				
7	..... : ?				
2	(low) [6-12 cmol(+) /kg]				
1	(very low) [0-20 %] : : 4				
2	(low) [20-40 %] : : 3				
3	(medium) [40-60 %] : : 3				
4	(high) [60-80 %] : : 2				
5	(very high) [80-200 %] : : 2				
7	..... : ?				
3	(medium) [12-25 cmol(+) /kg]				
1	(very low) [0-20 %] : : 3				
2	(low) [20-40 %] : : 2				
3	(medium) [40-60 %] : : 2				
4	(high) [60-80 %] : : 2				
5	(very high) [80-200 %] : : 1				
7	..... : ?				
4	(high) [25-40 cmol(+) /kg]				
1	(very low) [0-20 %] : : 3				
2	(low) [20-40 %] : : 2				
3	(medium) [40-60 %] : : 1				
4	(high) [60-80 %] : : 1				
7	..... : ?				
5	(very high) [40-60 cmo : : =4				
7	..... : ?				
5	Severity Level				
>	dr (soil drainage)				
1	(excessively drained) : : 1				
2	(somewhat excessively : : 1				
3	(well drained) : : 1				
4	(imperfect drained) : : 3				
5	(poorly drained) : : 4				
6	(very poorly drained) : : 4				
7	..... : ?				

Matombo (Matombo automated land evaluation) Decision Trees  
 DcId Type Where Used

```

7 -----
  Severity Level SLIRM,r
  > sd (effective soil depth)
    1 (very shallow) [0-20 cm] : 4
    2 (shallow) [20-40 cm] : 3
    3 (moderately deep) [40-80 cm] > prt (profile soil texture)
      1 (clay) : 3
      2 (sandy clay) : 2
      3 (silty clay) : 2
      4 (clay loam) : 2
      5 (sandy clay loam) : 2
      6 (silty loam) : 2
      7 (silty clay loam) : 2
      8 (sandy loam) : 2
      9 (sand) : 3
      10 (loamy sand) : 2
      11 (loam) : 2
      12 (silt) : 2
      ? : ?
    4 (deep) [80-120 cm] : -3
    5 (very deep) [120-200 cm] > prt (profile soil texture)
      1 (clay) : 2
      2 (sandy clay) : 1
      3 (silty clay) : 1
      4 (clay loam) : 1
      5 (sandy clay loam) : 1
      6 (silty loam) : 1
      7 (silty clay loam) : 1
      8 (sandy loam) : 1
      9 (sand) : 2
      10 (loamy sand) : 2
      11 (loam) : 1
      12 (silt) : 1
      ? : ?
  
```

```

8 -----
  Severity Level SLIRM,tr
  > tgp (temperature in growing period)
    1 (very cool) [10-15 deg] : 4
    2 (cool) [15-17.5 degree] : 3
    3 (moderately cool) [17.5 : 20] : 2
    4 (moderately warm) [20- : 22.5] : 1
    5 (warm) [22.5-25 degree] : 1
    6 (very warm) [25-27.7 d] : 1
    7 (extremely warm) [27.7 : 30] : 2
    ? : ?
  
```

Appendix 7b. ALES decision trees for smallholder low-input rainfed rice

Matombo (Matombo automated land evaluation) Where Used  
 i Type Decision Tree

Severity Level SHLIRR,m  
 1 (very low) [0-200 mm] : 4 (very poor)  
 2 (low) [200-400 mm] : 3 (poor)  
 3 (moderate) [400-600 mm] : 2 (moderate)  
 4 (high) [600-800 mm] : 1 (good)  
 5 (very high) [800-1000 mm] : 0 (extremely poor)  
 6 (extremely high) [1000-1200 mm] : -1 (very poor)  
 7 (high) [1200-1400 mm] : -2 (moderate)  
 8 (very high) [1400-1600 mm] : -3 (poor)  
 9 (extremely high) [1600-1800 mm] : -4 (very poor)  
 10 (high) [1800-2000 mm] : -5 (moderate)  
 11 (very high) [2000-2200 mm] : -6 (poor)  
 12 (extremely high) [2200-2400 mm] : -7 (very poor)

Matombo (Matombo automated land evaluation) Where Used  
 i Type Decision Tree

Severity Level SHLIRR,na  
 1 (very low) [0-10 mg P/kg] : 3 (poor)  
 2 (low) [10-20 mg P/kg] : 2 (moderate)  
 3 (moderate) [20-45 mg P/kg] : 1 (good)  
 4 (high) [45-80 mg P/kg] : 0 (extremely poor)  
 5 (very high) [80-100 mg P/kg] : -1 (very poor)  
 6 (extremely high) [100-120 mg P/kg] : -2 (moderate)  
 7 (high) [120-140 mg P/kg] : -3 (poor)  
 8 (very high) [140-160 mg P/kg] : -4 (very poor)  
 9 (extremely high) [160-180 mg P/kg] : -5 (moderate)  
 10 (high) [180-200 mg P/kg] : -6 (poor)  
 11 (very high) [200-220 mg P/kg] : -7 (very poor)

Severity Level SHLIRR,na  
 1 (very low) [0-10 mg P/kg] : 3 (poor)  
 2 (low) [10-20 mg P/kg] : 2 (moderate)  
 3 (moderate) [20-45 mg P/kg] : 1 (good)  
 4 (high) [45-80 mg P/kg] : 0 (extremely poor)  
 5 (very high) [80-100 mg P/kg] : -1 (very poor)  
 6 (extremely high) [100-120 mg P/kg] : -2 (moderate)  
 7 (high) [120-140 mg P/kg] : -3 (poor)  
 8 (very high) [140-160 mg P/kg] : -4 (very poor)  
 9 (extremely high) [160-180 mg P/kg] : -5 (moderate)  
 10 (high) [180-200 mg P/kg] : -6 (poor)  
 11 (very high) [200-220 mg P/kg] : -7 (very poor)

Severity Level SHLIRR,na  
 1 (very low) [0-10 mg P/kg] : 3 (poor)  
 2 (low) [10-20 mg P/kg] : 2 (moderate)  
 3 (moderate) [20-45 mg P/kg] : 1 (good)  
 4 (high) [45-80 mg P/kg] : 0 (extremely poor)  
 5 (very high) [80-100 mg P/kg] : -1 (very poor)  
 6 (extremely high) [100-120 mg P/kg] : -2 (moderate)  
 7 (high) [120-140 mg P/kg] : -3 (poor)  
 8 (very high) [140-160 mg P/kg] : -4 (very poor)  
 9 (extremely high) [160-180 mg P/kg] : -5 (moderate)  
 10 (high) [180-200 mg P/kg] : -6 (poor)  
 11 (very high) [200-220 mg P/kg] : -7 (very poor)

1 (very low) [0-10 mg P/kg] : 3 (poor)  
 2 (low) [10-20 mg P/kg] : 2 (moderate)  
 3 (moderate) [20-45 mg P/kg] : 1 (good)  
 4 (high) [45-80 mg P/kg] : 0 (extremely poor)  
 5 (very high) [80-100 mg P/kg] : -1 (very poor)  
 6 (extremely high) [100-120 mg P/kg] : -2 (moderate)  
 7 (high) [120-140 mg P/kg] : -3 (poor)  
 8 (very high) [140-160 mg P/kg] : -4 (very poor)  
 9 (extremely high) [160-180 mg P/kg] : -5 (moderate)  
 10 (high) [180-200 mg P/kg] : -6 (poor)  
 11 (very high) [200-220 mg P/kg] : -7 (very poor)

1 (very low) [0-10 mg P/kg] : 3 (poor)  
 2 (low) [10-20 mg P/kg] : 2 (moderate)  
 3 (moderate) [20-45 mg P/kg] : 1 (good)  
 4 (high) [45-80 mg P/kg] : 0 (extremely poor)  
 5 (very high) [80-100 mg P/kg] : -1 (very poor)  
 6 (extremely high) [100-120 mg P/kg] : -2 (moderate)  
 7 (high) [120-140 mg P/kg] : -3 (poor)  
 8 (very high) [140-160 mg P/kg] : -4 (very poor)  
 9 (extremely high) [160-180 mg P/kg] : -5 (moderate)  
 10 (high) [180-200 mg P/kg] : -6 (poor)  
 11 (very high) [200-220 mg P/kg] : -7 (very poor)

1 (very low) [0-10 mg P/kg] : 3 (poor)  
 2 (low) [10-20 mg P/kg] : 2 (moderate)  
 3 (moderate) [20-45 mg P/kg] : 1 (good)  
 4 (high) [45-80 mg P/kg] : 0 (extremely poor)  
 5 (very high) [80-100 mg P/kg] : -1 (very poor)  
 6 (extremely high) [100-120 mg P/kg] : -2 (moderate)  
 7 (high) [120-140 mg P/kg] : -3 (poor)  
 8 (very high) [140-160 mg P/kg] : -4 (very poor)  
 9 (extremely high) [160-180 mg P/kg] : -5 (moderate)  
 10 (high) [180-200 mg P/kg] : -6 (poor)  
 11 (very high) [200-220 mg P/kg] : -7 (very poor)

1 (very low) [0-10 mg P/kg] : 3 (poor)  
 2 (low) [10-20 mg P/kg] : 2 (moderate)  
 3 (moderate) [20-45 mg P/kg] : 1 (good)  
 4 (high) [45-80 mg P/kg] : 0 (extremely poor)  
 5 (very high) [80-100 mg P/kg] : -1 (very poor)  
 6 (extremely high) [100-120 mg P/kg] : -2 (moderate)  
 7 (high) [120-140 mg P/kg] : -3 (poor)  
 8 (very high) [140-160 mg P/kg] : -4 (very poor)  
 9 (extremely high) [160-180 mg P/kg] : -5 (moderate)  
 10 (high) [180-200 mg P/kg] : -6 (poor)  
 11 (very high) [200-220 mg P/kg] : -7 (very poor)

Matombo (Matombo automated land evaluation) Decision Trees  
 Dtid Type Where Used

10 Severity Level SHLIRR.na

- (continued)
- 1 (very low) [0-5 mg P/k : 3 (poor)
  - 2 (low) [5-10 mg P/kg] .. : 3 (poor)
  - 3 (medium) [10-20 mg P/k : 3 (poor)
  - 4 (high) [20-45 mg P/kg] : 2 (moderate)
  - 5 (very high) [45-80 mg : 2 (moderate)
  - 7 .....
  - 3 (medium) [1.2-5 %] .. : =2
  - 4 (high) [5-1 %] .. : =2
  - 7 .....
  - 3 (medium) [1.25-2.5 %] > n (nitrogen content)
  - 1 (very low) [0-1 %] > p (available phosphorus)
  - 2 (low) [5-10 mg P/k : 4 (very poor)
  - 3 (medium) [10-20 mg P/k] .. : 3 (poor)
  - 4 (high) [20-45 mg P/kg] : 3 (poor)
  - 5 (very high) [45-80 mg : 3 (poor)
  - 7 .....
  - 2 (low) [1.1-2 %] > p (available phosphorus)
  - 1 (very low) [0-5 mg P/k : 3 (poor)
  - 2 (low) [5-10 mg P/kg] .. : 3 (poor)
  - 3 (medium) [10-20 mg P/k] .. : 3 (poor)
  - 4 (high) [20-45 mg P/kg] : 2 (moderate)
  - 5 (very high) [45-80 mg : 2 (moderate)
  - 7 .....
  - 3 (medium) [1.2-5 %] > p (available phosphorus)
  - 1 (very low) [0-5 mg P/k : 3 (poor)
  - 2 (low) [5-10 mg P/kg] .. : 3 (poor)
  - 3 (medium) [10-20 mg P/k] .. : 2 (moderate)
  - 4 (high) [20-45 mg P/kg] : 2 (moderate)
  - 5 (very high) [45-80 mg : 2 (moderate)
  - 7 .....
  - 4 (high) [1.5-1 %] .. : =3
  - 7 .....
  - 4 (high) [2.5-3.5 %] .. : =3
  - 5 (very high) [3.5-5 %] .. : =3
  - 7 .....
  - 2 (strongly acid) [5-5.5 no dimension] > oc (organic carbon content)
  - 1 (very low) [0-6 %] > n (nitrogen content)
  - 1 (very low) [0-5 mg P/k : 4 (very poor)
  - 2 (low) [5-10 mg P/kg] .. : 3 (poor)
  - 3 (medium) [10-20 mg P/k : 3 (poor)
  - 4 (high) [20-45 mg P/kg] : 3 (poor)
  - 5 (very high) [45-80 mg : 2 (moderate)
  - 7 .....
  - 2 (low) [1.1-2 %] > p (available phosphorus)
  - 1 (very low) [0-5 mg P/k : 3 (poor)
  - 2 (low) [5-10 mg P/kg] .. : 3 (poor)
  - 3 (medium) [10-20 mg P/k] .. : 3 (poor)
  - 4 (high) [20-45 mg P/kg] : 2 (moderate)
  - 5 (very high) [45-80 mg : 2 (moderate)
  - 7 .....
  - 3 (medium) [1.2-5 %] > p (available phosphorus)
  - 1 (very low) [0-5 mg P/k : 3 (poor)
  - 2 (low) [5-10 mg P/kg] .. : 3 (poor)
  - 3 (medium) [10-20 mg P/k] .. : 2 (moderate)
  - 4 (high) [20-45 mg P/kg] : 2 (moderate)
  - 5 (very high) [45-80 mg : 2 (moderate)
  - 7 .....
  - 4 (high) [1.5-1 %] .. : =3
  - 7 .....

Matombo (Matombo automated land evaluation) Decision Trees  
 Dtid Type Where Used

10 Severity Level SHLIRR.na

- (continued)
- 4 (high) [20-45 mg P/kg] : 2 (moderate)
  - 5 (very high) [45-80 mg : 2 (moderate)
  - 7 .....
  - 2 (low) [1.1-2 %] > p (available phosphorus)
  - 1 (very low) [0-5 mg P/k : 3 (poor)
  - 2 (low) [5-10 mg P/kg] .. : 2 (moderate)
  - 3 (medium) [10-20 mg P/k] .. : 2 (moderate)
  - 4 (high) [20-45 mg P/kg] : 2 (moderate)
  - 5 (very high) [45-80 mg : 2 (moderate)
  - 7 .....
  - 3 (medium) [1.2-5 %] > p (available phosphorus)
  - 1 (very low) [0-5 mg P/k : 3 (poor)
  - 2 (low) [5-10 mg P/kg] .. : 2 (moderate)
  - 3 (medium) [10-20 mg P/k] .. : 2 (moderate)
  - 4 (high) [20-45 mg P/kg] : 1 (good)
  - 5 (very high) [45-80 mg : 1 (good)
  - 7 .....
  - 4 (high) [1.5-1 %] .. : =3
  - 7 .....
  - 4 (high) [2.5-3.5 %] .. : =3
  - 5 (very high) [3.5-5 %] .. : =3
  - 7 .....
  - 4 (slightly acid) [6-6.5 : =3
  - 5 (neutral) [6.5-7.5 no : =3
  - 6 (mildly alkaline) [7.5 : =2
  - 7 (moderately alkaline) : =2
  - 7 .....

Matombo (Matombo automated land evaluation)  
 Dtd Type Where Used  
 -----  
 SHLIRR, f

Decision Trees

Matombo (Matombo automated land evaluation)  
 Dtd Type Where Used  
 -----  
 SHLIRR, nr

- 11 Severity Level
  - > sed (effective soil depth)
    - 1 (very shallow) [0-20 cm] : 4 (very poor)
    - 2 (shallow) [20-40 cm] > prt (profile soil texture)
      - 1 (clay) : 3 (poor)
      - 2 (sandy clay) : 3 (poor)
      - 3 (silty clay) : 3 (poor)
      - 4 (clay loam) : 3 (poor)
      - 5 (sandy clay loam) : 3 (poor)
      - 6 (silty loam) : 3 (poor)
      - 7 (silty clay loam) : 3 (poor)
      - 8 (sandy loam) : 4 (very poor)
      - 9 (sand) : 4 (very poor)
      - 10 (loamy sand) : 4 (very poor)
      - 11 (loam) : 3 (poor)
      - 12 (silt) : 4 (very poor)
  - > 3 (moderately deep) [40-80 cm] > prt (profile soil texture)
    - 1 (clay) : 1 (good)
    - 2 (sandy clay) : 1 (good)
    - 3 (silty clay) : 1 (good)
    - 4 (clay loam) : 1 (good)
    - 5 (sandy clay loam) : 1 (good)
    - 6 (silty loam) : 1 (good)
    - 7 (silty clay loam) : 1 (good)
    - 8 (sandy loam) : 2 (moderate)
    - 9 (sand) : 2 (moderate)
    - 10 (loamy sand) : 3 (poor)
    - 11 (loam) : 3 (poor)
    - 12 (silt) : 3 (poor)

- 12 Severity Level
  - > cec (cation exchange capacity)
    - 1 (very low) [0-6 cmol(+) /kg] > bs (base saturation)
      - 1 (very low) [0-20 %] : 4 (very poor)
      - 2 (low) [20-40 %] : 4 (very poor)
      - 3 (medium) [40-60 %] : 3 (poor)
      - 4 (high) [60-80 %] : 3 (poor)
      - 5 (very high) [80-200 %] : 2 (moderate)
    - 2 (low) [6-12 cmol(+) /kg] > bs (base saturation)
      - 1 (very low) [0-20 %] : 4 (very poor)
      - 2 (low) [20-40 %] : 3 (poor)
      - 3 (medium) [40-60 %] : 3 (poor)
      - 4 (high) [60-80 %] : 2 (moderate)
      - 5 (very high) [80-200 %] : 2 (moderate)
    - 3 (medium) [12-25 cmol(+) /kg] > bs (base saturation)
      - 1 (very low) [0-20 %] : 3 (poor)
      - 2 (low) [20-40 %] : 2 (moderate)
      - 3 (medium) [40-60 %] : 2 (moderate)
      - 4 (high) [60-80 %] : 2 (moderate)
      - 5 (very high) [80-200 %] : 2 (moderate)
    - 4 (high) [25-40 cmol(+) /kg] > bs (base saturation)
      - 1 (very low) [0-20 %] : 2 (moderate)
      - 2 (low) [20-40 %] : 1 (good)
      - 3 (medium) [40-60 %] : 1 (good)
      - 4 (high) [60-80 %] : 1 (good)
      - 5 (very high) [80-200 %] : 1 (good)
      - 7 : ?
    - 5 (very high) [40-60 cmol(+) /kg] : -4
    - 7 : ?
  - > dr (soil drainage)
    - 1 (excessively drained) : 4 (very poor)
    - 2 (somewhat excessively drained) : 4 (very poor)
    - 3 (well drained) : 3 (poor)
    - 4 (imperfectly drained) : 2 (moderate)
    - 5 (poorly drained) : 1 (good)
    - 6 (very poorly drained) : 1 (good)
    - 7 : ?

- 13 Severity Level
  - > tgp (temperature in growing period)
    - 1 (very cool) [10-15 deg] : 4 (very poor)
    - 2 (cool) [15-17.5 degree] : 4 (very poor)
    - 3 (moderately cool) [17.5 : 20] : 3 (poor)
    - 4 (moderately warm) [20 : 22.5] : 2 (moderate)
    - 5 (warm) [22.5-25 degree] : 2 (moderate)
    - 6 (very warm) [25-27.5] : 1 (good)
    - 7 (extremely warm) [27.5 : 30] : 2 (moderate)
  - > s1 (dominant slope)
    - 1 (flat to nearly sloping) : 1
    - 2 (very gently sloping) : 2
    - 3 (gently sloping) [2-5] : 3
    - 4 (steep) [5-10 %] : 4
    - 5 (strongly sloping) [10 : 15] : 4
    - 6 (moderately steep) [15 : 20] : 4
    - 7 (steep) [20-60 %] : 4

- 14 Severity Level
  - > tgp (temperature in growing period)
    - 1 (very cool) [10-15 deg] : 4 (very poor)
    - 2 (cool) [15-17.5 degree] : 4 (very poor)
    - 3 (moderately cool) [17.5 : 20] : 3 (poor)
    - 4 (moderately warm) [20 : 22.5] : 2 (moderate)
    - 5 (warm) [22.5-25 degree] : 2 (moderate)
    - 6 (very warm) [25-27.5] : 1 (good)
    - 7 (extremely warm) [27.5 : 30] : 2 (moderate)
  - > s1 (dominant slope)
    - 1 (flat to nearly sloping) : 1
    - 2 (very gently sloping) : 2
    - 3 (gently sloping) [2-5] : 3
    - 4 (steep) [5-10 %] : 4
    - 5 (strongly sloping) [10 : 15] : 4
    - 6 (moderately steep) [15 : 20] : 4
    - 7 (steep) [20-60 %] : 4

SHLIRR, nr

SHLIRR, o

Matombo (Matombo automated land evaluation) Decision Trees  
 Dtd Type Where Used  
 -----  
 SLIRR, WC

16 Severity Level  
 > df (duration of flooding)  
 1 (extremely short) [0-1] : 4  
 2 (very short) [1-5 days] : 4  
 3 (short) [5-15 days] : 3  
 4 (moderately long) [15-30] : 3  
 5 (long) [30-90 days] : 1  
 6 (very long) [90-180 da] : 2  
 7 (extremely long) [180-360] : 4  
 ? : ?

17 Severity Level SLIRC, na  
 > pr pH (profile pH)  
 1 (very strongly acid) [0-5 no dimension] > oc (organic carbon content)  
 1 (very low) [0-.6 %] > n (nitrogen content)  
 1 (very low) [0-.1 %] > p (available phosphorus)  
 1 (very low) [0-5 mg P/k] : 4  
 2 (low) [5-10 mg P/kg] : 4  
 3 (medium) [10-20 mg P/k] : 3  
 4 (high) [20-45 mg P/kg] : 1  
 5 (very high) [45-80 mg] : 1  
 ? : ?  
 2 (low) [1-2 %] > p (available phosphorus)  
 1 (very low) [0-5 mg P/k] : 1  
 2 (low) [5-10 mg P/kg] : 3  
 3 (medium) [10-20 mg P/k] : 2  
 4 (high) [20-45 mg P/kg] : 2  
 5 (very high) [45-80 mg] : 2  
 ? : ?  
 3 (medium) [1.2-5 %] > p (available phosphorus)  
 1 (very low) [0-5 mg P/k] : 1  
 2 (low) [5-10 mg P/kg] : 1  
 3 (medium) [10-20 mg P/k] : 2  
 4 (high) [20-45 mg P/kg] : 2  
 5 (very high) [45-80 mg] : 2  
 ? : ?  
 4 (high) [1.5-1 %] : ?  
 7 : ?

2 (low) [1.6-1.25 %] > n (nitrogen content)  
 1 (very low) [0-.1 %] > p (available phosphorus)  
 1 (very low) [0-5 mg P/k] : 4  
 2 (low) [5-10 mg P/kg] : 1  
 3 (medium) [10-20 mg P/k] : 1  
 4 (high) [20-45 mg P/kg] : 1  
 5 (very high) [45-80 mg] : 1  
 ? : ?  
 2 (low) [1-2 %] > p (available phosphorus)  
 1 (very low) [0-5 mg P/k] : 1  
 2 (low) [5-10 mg P/kg] : 1  
 3 (medium) [10-20 mg P/k] : 2  
 4 (high) [20-45 mg P/kg] : 2  
 5 (very high) [45-80 mg] : 2  
 ? : ?  
 3 (medium) [1.2-5 %] > p (available phosphorus)  
 1 (very low) [0-5 mg P/k] : 1  
 2 (low) [5-10 mg P/kg] : 1  
 3 (medium) [10-20 mg P/k] : 2  
 4 (high) [20-45 mg P/kg] : 2  
 5 (very high) [45-80 mg] : 2  
 ? : ?  
 4 (high) [1.5-1 %] : ?  
 7 : ?

Appendix 7c. ALES decision trees for smallholder low-input rainfed citrus

Decision Trees	Where Used	Where Used
Matombo (Matombo automated land evaluation)	Matombo (Matombo automated land evaluation)	Matombo (Matombo automated land evaluation)
DrId Type	DrId Type	DrId Type
17 Severity Level	17 Severity Level	17 Severity Level
(continued)	(continued)	(continued)
<p>3 (medium) [1.25-2.5 %] : -2</p> <p>4 (high) [2.5-3.5 %] : -2</p> <p>5 (very high) [3.5-5 %] : -2</p> <p>7..... : -2</p> <p>2 (strongly acid) [5-5.5 no dimension] &gt; oc (organic carbon content)</p> <p>1 (very low) [0-.6 %] &gt; n (nitrogen content)</p> <p>1 (very low) [0-.1 %] &gt; p (available phosphorus)</p> <p>2 (low) [0-5 mg P/K] : 1</p> <p>3 (medium) [5-10 mg P/K] : 2</p> <p>4 (high) [10-20 mg P/K] : 3</p> <p>5 (very high) [20-45 mg P/K] : 4</p> <p>7..... : 7</p> <p>2 (low) [1-.2 %] &gt; p (available phosphorus)</p> <p>1 (very low) [0-5 mg P/K] : 1</p> <p>2 (low) [5-10 mg P/K] : 2</p> <p>3 (medium) [10-20 mg P/K] : 3</p> <p>4 (high) [20-45 mg P/K] : 4</p> <p>5 (very high) [45-80 mg P/K] : 5</p> <p>7..... : 7</p> <p>3 (medium) [1.2-5 %] &gt; p (available phosphorus)</p> <p>1 (very low) [0-5 mg P/K] : 1</p> <p>2 (low) [5-10 mg P/K] : 2</p> <p>3 (medium) [10-20 mg P/K] : 3</p> <p>4 (high) [20-45 mg P/K] : 4</p> <p>5 (very high) [45-80 mg P/K] : 5</p> <p>7..... : 7</p> <p>4 (high) [1.5-1 %] : -3</p> <p>7..... : -3</p> <p>2 (low) [1.6-1.25 %] &gt; n (nitrogen content)</p> <p>1 (very low) [0-.1 %] &gt; p (available phosphorus)</p> <p>2 (low) [0-5 mg P/K] : 1</p> <p>3 (medium) [5-10 mg P/K] : 2</p> <p>4 (high) [10-20 mg P/K] : 3</p> <p>5 (very high) [20-45 mg P/K] : 4</p> <p>7..... : 7</p> <p>2 (low) [1.1-2 %] &gt; p (available phosphorus)</p> <p>1 (very low) [0-5 mg P/K] : 1</p> <p>2 (low) [5-10 mg P/K] : 2</p> <p>3 (medium) [10-20 mg P/K] : 3</p> <p>4 (high) [20-45 mg P/K] : 4</p> <p>5 (very high) [45-80 mg P/K] : 5</p> <p>7..... : 7</p> <p>3 (medium) [1.2-5 %] &gt; p (available phosphorus)</p> <p>1 (very low) [0-5 mg P/K] : 1</p> <p>2 (low) [5-10 mg P/K] : 2</p> <p>3 (medium) [10-20 mg P/K] : 3</p> <p>4 (high) [20-45 mg P/K] : 4</p> <p>5 (very high) [45-80 mg P/K] : 5</p> <p>7..... : 7</p> <p>4 (high) [1.5-1 %] : -3</p> <p>7..... : -3</p> <p>3 (moderately acid) [5.5-6 no dimension] &gt; oc (organic carbon content)</p> <p>1 (very low) [0-.6 %] &gt; n (nitrogen content)</p> <p>1 (very low) [0-.1 %] &gt; p (available phosphorus)</p>	<p>3 (medium) [1.25-2.5 %] : -2</p> <p>4 (high) [2.5-3.5 %] : -2</p> <p>5 (very high) [3.5-5 %] : -2</p> <p>7..... : -2</p> <p>2 (low) [0-5 mg P/K] : 1</p> <p>3 (medium) [5-10 mg P/K] : 2</p> <p>4 (high) [10-20 mg P/K] : 3</p> <p>5 (very high) [20-45 mg P/K] : 4</p> <p>7..... : 7</p> <p>2 (low) [1-.2 %] &gt; p (available phosphorus)</p> <p>1 (very low) [0-5 mg P/K] : 1</p> <p>2 (low) [5-10 mg P/K] : 2</p> <p>3 (medium) [10-20 mg P/K] : 3</p> <p>4 (high) [20-45 mg P/K] : 4</p> <p>5 (very high) [45-80 mg P/K] : 5</p> <p>7..... : 7</p> <p>3 (medium) [1.2-5 %] &gt; p (available phosphorus)</p> <p>1 (very low) [0-5 mg P/K] : 1</p> <p>2 (low) [5-10 mg P/K] : 2</p> <p>3 (medium) [10-20 mg P/K] : 3</p> <p>4 (high) [20-45 mg P/K] : 4</p> <p>5 (very high) [45-80 mg P/K] : 5</p> <p>7..... : 7</p> <p>4 (high) [1.5-1 %] : -3</p> <p>7..... : -3</p> <p>2 (low) [1.6-1.25 %] &gt; n (nitrogen content)</p> <p>1 (very low) [0-.1 %] &gt; p (available phosphorus)</p> <p>2 (low) [0-5 mg P/K] : 1</p> <p>3 (medium) [5-10 mg P/K] : 2</p> <p>4 (high) [10-20 mg P/K] : 3</p> <p>5 (very high) [20-45 mg P/K] : 4</p> <p>7..... : 7</p> <p>2 (low) [1.1-2 %] &gt; p (available phosphorus)</p> <p>1 (very low) [0-5 mg P/K] : 1</p> <p>2 (low) [5-10 mg P/K] : 2</p> <p>3 (medium) [10-20 mg P/K] : 3</p> <p>4 (high) [20-45 mg P/K] : 4</p> <p>5 (very high) [45-80 mg P/K] : 5</p> <p>7..... : 7</p> <p>3 (medium) [1.2-5 %] &gt; p (available phosphorus)</p> <p>1 (very low) [0-5 mg P/K] : 1</p> <p>2 (low) [5-10 mg P/K] : 2</p> <p>3 (medium) [10-20 mg P/K] : 3</p> <p>4 (high) [20-45 mg P/K] : 4</p> <p>5 (very high) [45-80 mg P/K] : 5</p> <p>7..... : 7</p> <p>4 (high) [1.5-1 %] : -3</p> <p>7..... : -3</p> <p>3 (moderately acid) [5.5-6 no dimension] &gt; oc (organic carbon content)</p> <p>1 (very low) [0-.6 %] &gt; n (nitrogen content)</p> <p>1 (very low) [0-.1 %] &gt; p (available phosphorus)</p>	<p>3 (medium) [1.25-2.5 %] : -2</p> <p>4 (high) [2.5-3.5 %] : -2</p> <p>5 (very high) [3.5-5 %] : -2</p> <p>7..... : -2</p> <p>2 (low) [0-5 mg P/K] : 1</p> <p>3 (medium) [5-10 mg P/K] : 2</p> <p>4 (high) [10-20 mg P/K] : 3</p> <p>5 (very high) [20-45 mg P/K] : 4</p> <p>7..... : 7</p> <p>2 (low) [1-.2 %] &gt; p (available phosphorus)</p> <p>1 (very low) [0-5 mg P/K] : 1</p> <p>2 (low) [5-10 mg P/K] : 2</p> <p>3 (medium) [10-20 mg P/K] : 3</p> <p>4 (high) [20-45 mg P/K] : 4</p> <p>5 (very high) [45-80 mg P/K] : 5</p> <p>7..... : 7</p> <p>3 (medium) [1.2-5 %] &gt; p (available phosphorus)</p> <p>1 (very low) [0-5 mg P/K] : 1</p> <p>2 (low) [5-10 mg P/K] : 2</p> <p>3 (medium) [10-20 mg P/K] : 3</p> <p>4 (high) [20-45 mg P/K] : 4</p> <p>5 (very high) [45-80 mg P/K] : 5</p> <p>7..... : 7</p> <p>4 (high) [1.5-1 %] : -3</p> <p>7..... : -3</p> <p>2 (low) [1.6-1.25 %] &gt; n (nitrogen content)</p> <p>1 (very low) [0-.1 %] &gt; p (available phosphorus)</p> <p>2 (low) [0-5 mg P/K] : 1</p> <p>3 (medium) [5-10 mg P/K] : 2</p> <p>4 (high) [10-20 mg P/K] : 3</p> <p>5 (very high) [20-45 mg P/K] : 4</p> <p>7..... : 7</p> <p>2 (low) [1.1-2 %] &gt; p (available phosphorus)</p> <p>1 (very low) [0-5 mg P/K] : 1</p> <p>2 (low) [5-10 mg P/K] : 2</p> <p>3 (medium) [10-20 mg P/K] : 3</p> <p>4 (high) [20-45 mg P/K] : 4</p> <p>5 (very high) [45-80 mg P/K] : 5</p> <p>7..... : 7</p> <p>3 (medium) [1.2-5 %] &gt; p (available phosphorus)</p> <p>1 (very low) [0-5 mg P/K] : 1</p> <p>2 (low) [5-10 mg P/K] : 2</p> <p>3 (medium) [10-20 mg P/K] : 3</p> <p>4 (high) [20-45 mg P/K] : 4</p> <p>5 (very high) [45-80 mg P/K] : 5</p> <p>7..... : 7</p> <p>4 (high) [1.5-1 %] : -3</p> <p>7..... : -3</p> <p>3 (moderately acid) [5.5-6 no dimension] &gt; oc (organic carbon content)</p> <p>1 (very low) [0-.6 %] &gt; n (nitrogen content)</p> <p>1 (very low) [0-.1 %] &gt; p (available phosphorus)</p>

Matombo (Matombo automated land evaluation) Where Used		Decision Trees		Matombo (Matombo automated land evaluation) Where Used	
DtId Type	SLIRC,nr	DtId Type	SLIRC,m	DtId Type	SLIRC,o
18	Severity Level			21	Severity Level
>	cec (cation exchange capacity)	>	bs (base saturation)	>	dr (soil drainage)
1	(very low) [0-6 cmol(+) /kg] ... : 4	1	(very low) [0-20 %] ... : 4	1	(excessively drained) ... : 1
2	(low) [6-12 cmol(+) /kg] ... : 3	2	(low) [20-40 %] ... : 3	2	(somewhat excessively drained) ... : 1
3	(medium) [12-25 cmol(+) /kg] ... : 2	3	(medium) [40-60 %] ... : 2	3	(well drained) ... : 1
4	(high) [25-40 cmol(+) /kg] ... : 2	4	(high) [60-80 %] ... : 2	4	(imperfect drained) > df (duration of flooding)
5	(very high) [40-60 cmol(+) /kg] ... : 2	5	(very high) [80-200 %] ... : 2	1	(extremely short) [0-1] : 1
?	..... : 2	?	..... : 2	2	(very short) [1-5 days] ... : 1
2	(low) [6-12 cmol(+) /kg] > bs (base saturation)			3	(short) [5-15 days] ... : 2
1	(very low) [0-20 %] ... : 4			4	(moderately long) [15-30] : 2
2	(low) [20-40 %] ... : 3			5	(long) [30-90 days] ... : 3
3	(medium) [40-60 %] ... : 2			6	(very long) [90-180 da] ... : 4
4	(high) [60-80 %] ... : 2			7	(extremely long) [180-?] : 4
5	(very high) [80-200 %] ... : 2			?	..... : ?
?	..... : 2			5	(poorly drained) > df (duration of flooding)
3	(medium) [12-25 cmol(+) /kg] > bs (base saturation)			1	(extremely short) [0-1] : 2
1	(very low) [0-20 %] ... : 4			2	(very short) [1-5 days] ... : 2
2	(low) [20-40 %] ... : 3			3	(short) [5-15 days] ... : 3
3	(medium) [40-60 %] ... : 2			4	(moderately long) [15-30] : 3
4	(high) [60-80 %] ... : 2			5	(long) [30-90 days] ... : 4
5	(very high) [80-200 %] ... : 2			6	(very long) [90-180 da] ... : 4
?	..... : 2			7	(extremely long) [180-?] : 4
?	..... : 2			?	..... : ?
4	(high) [25-40 cmol(+) /kg] > bs (base saturation)			6	(very poorly drained) > df (duration of flooding)
1	(very low) [0-20 %] ... : 4			1	(extremely short) [0-1] : 3
2	(low) [20-40 %] ... : 3			2	(very short) [1-5 days] ... : 3
3	(medium) [40-60 %] ... : 2			3	(short) [5-15 days] ... : 4
4	(high) [60-80 %] ... : 2			4	(moderately long) [15-30] : 4
5	(very high) [80-200 %] ... : 2			5	(long) [30-90 days] ... : 4
?	..... : 2			6	(very long) [90-180 da] ... : 4
?	..... : 2			7	(extremely long) [180-?] : 4
?	..... : 2			?	..... : ?
19	Severity Level				
>	mp (mean annual precipitation)				
1	(very low) [0-200 mm] ... : 4				
2	(low) [200-400 mm] ... : 4				
3	(moderate) [400-800 mm] ... : 4				
4	(high) [800-1500 mm] ... : 2				
5	(very high) [1500-2000] ... : 1				
6	(extremely high) [2000] ... : 1				
?	..... : ?				
?	..... : ?				
0	Severity Level				
>	tpp (temperature in growing period)				
1	(very cool) [10-15 deg] : 3				
2	(cool) [15-17.5 degree] : 2				
3	(moderately cool) [17.5-20] : 2				
4	(moderately warm) [20-22.5] : 1				
5	(warm) [22.5-25 degree] : 1				
6	(very warm) [25-27.5] : 1				
7	(extremely warm) [27.5-30] : 1				
?	..... : ?				

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Matombo (Matombo automated land evaluation)
DtId Type ----- Whara Used -----
----- SLIRC,F -----
22 Severity Level
> sd (effective soil depth)
1 (very shallow) [0-20 cm] : 4
2 (shallow) [20-40 cm] : 4
3 (moderately deep) [40-80 cm] > prt (profile soil texture)
1 (clay) : 4
2 (sandy clay) : 3
3 (silty clay) : 4
4 (clay loam) : 3
5 (sandy clay loam) : 3
6 (silty loam) : 3
7 (silty clay loam) : 3
8 (sandy loam) : 3
9 (sand) : 3
10 (loamy sand) : 3
11 (loam) : 3
12 (silt) : 3
? : 7
4 (deep) [80-120 cm] > prt (profile soil texture)
1 (clay) : 3
2 (sandy clay) : 3
3 (silty clay) : 3
4 (clay loam) : 2
5 (sandy clay loam) : 2
6 (silty loam) : 2
7 (silty clay loam) : 2
8 (sandy loam) : 2
9 (sand) : 2
10 (loamy sand) : 2
11 (loam) : 2
12 (silt) : 2
? : 7
5 (very deep) [120-200 cm] > prt (profile soil texture)
1 (clay) : 2
2 (sandy clay) : 2
3 (silty clay) : 2
4 (clay loam) : 1
5 (sandy clay loam) : 1
6 (silty loam) : 1
7 (silty clay loam) : 1
8 (sandy loam) : 1
9 (sand) : 1
10 (loamy sand) : 1
11 (loam) : 1
12 (silt) : 1
? : 7

Matombo (Matombo automated land evaluation)
DtId Type ----- Whara Used -----
----- SLIRC,tg -----
23 Severity Level
> sl (dominant slope)
1 (flat to nearly level) : 1
2 (very gently sloping) : 1
3 (gently sloping) [2-5] : 1
4 (sloping) [5-10 %] : 1
5 (strongly sloping) [10 : 15] : 1
6 (moderately steep) [15-30 %] > st (surface soil texture)
1 (clay) : 3
2 (sandy clay) : 2
3 (silty clay) : 3
4 (clay loam) : 3
5 (sandy clay loam) : 2
6 (silty loam) : 3
7 (silty clay loam) : 3
8 (sandy loam) : 2
9 (sand) : 2
10 (loamy sand) : 2
? : 7
7 (steep) [30-60 %] > st (surface soil texture)
1 (clay) : 3
2 (sandy clay) : 3
3 (silty clay) : 3
4 (clay loam) : 1
5 (sandy clay loam) : 1
6 (silty loam) : 1
7 (silty clay loam) : 1
8 (sandy loam) : 2
9 (sand) : 2
10 (loamy sand) : 2
? : 7

24 Severity Level
> pr pH (profile pH)
1 (very strongly acid) [0-5 no dimension] > oc (organic carbon content)
1 (very low) [0-.6 %] > n (nitrogen content)
1 (very low) [0-.1 %] > p (available phosphorus)
1 (very low) [0-5 mg P/kg] : 4
2 (low) [5-10 mg P/kg] : 4
3 (medium) [10-20 mg P/kg] : 3
4 (high) [20-45 mg P/kg] : 3
5 (very high) [45-80 mg P/kg] : 3
? : 7
2 (low) [.1-.2 %] > p (available phosphorus)
1 (very low) [0-5 mg P/kg] : 2
2 (low) [5-10 mg P/kg] : 3
3 (medium) [10-20 mg P/kg] : 2
4 (high) [20-45 mg P/kg] : 2
5 (very high) [45-80 mg P/kg] : 2
? : 7
3 (medium) [.2-.5 %] > p (available phosphorus)
1 (very low) [0-5 mg P/kg] : 3
2 (low) [5-10 mg P/kg] : 3
3 (medium) [10-20 mg P/kg] : 2
4 (high) [20-45 mg P/kg] : 2
5 (very high) [45-80 mg P/kg] : 2
? : 7
4 (high) [.5-1 %] : 7
? : 7
2 (low) [-.6-1.25 %] > n (nitrogen content)
1 (very low) [0-.1 %] > p (available phosphorus)

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Matombo (Matombo automated land evaluation)
DtId Type ----- Decision Trees ----- Matombo (Matombo automated land evaluation)
Where Used ----- Where Used -----
SLRS,r ----- SLRS,o -----

28 Severity Level
> sd (effective soil depth)
1 (very shallow) [0-20 cm] > prt (profile soil texture)
2 (shallow) [20-40 cm] > prt (profile soil texture)
1 (clay) ..... : 3
2 (sandy clay) ..... : 2
3 (silty clay) ..... : 2
4 (clay loam) ..... : 2
5 (sandy clay loam) ..... : 2
6 (silty loam) ..... : 3
7 (silty clay loam) ..... : 2
8 (sandy loam) ..... : 2
9 (sand) ..... : 3
10 (loamy sand) ..... : 3
11 (loam) ..... : 2
12 (silt) ..... : 3
? ..... : 7
3 (moderately deep) [40-80 cm] > prt (profile soil texture)
1 (clay) ..... : 3
2 (sandy clay) ..... : 2
3 (silty clay) ..... : 2
4 (clay loam) ..... : 2
5 (sandy clay loam) ..... : 2
6 (silty loam) ..... : 2
7 (silty clay loam) ..... : 2
8 (sandy loam) ..... : 2
9 (sand) ..... : 3
10 (loamy sand) ..... : 2
11 (loam) ..... : 2
12 (silt) ..... : 3
? ..... : 7
4 (deep) [80-120 cm] > prt (profile soil texture)
1 (clay) ..... : 2
2 (sandy clay) ..... : 1
3 (silty clay) ..... : 1
4 (clay loam) ..... : 1
5 (sandy clay loam) ..... : 1
6 (silty loam) ..... : 1
7 (silty clay loam) ..... : 1
8 (sandy loam) ..... : 2
9 (sand) ..... : 2
10 (loamy sand) ..... : 2
11 (loam) ..... : 2
12 (silt) ..... : 3
? ..... : 7
5 (very deep) [120-200 cm] > prt (profile soil texture)
1 (clay) ..... : 2
2 (sandy clay) ..... : 1
3 (silty clay) ..... : 1
4 (clay loam) ..... : 1
5 (sandy clay loam) ..... : 1
6 (silty loam) ..... : 1
7 (silty clay loam) ..... : 1
8 (sandy loam) ..... : 2
9 (sand) ..... : 2
10 (loamy sand) ..... : 2
11 (loam) ..... : 1
12 (silt) ..... : 2
? ..... : 7
7 ..... : 7

SLRS,rr ----- SLRS,rr -----

30 Severity Level
> dr (soil drainage)
1 (excessively drained) ..... : 1
2 (somewhat excessively) ..... : 1
3 (well drained) ..... : 1
4 (imperfect drained) ..... : 3
5 (poorly drained) ..... : 4
6 (very poorly drained) ..... : 4
? ..... : ?

31 Severity Level
> st (surface soil texture)
1 (clay) ..... : 1
2 (sandy clay) ..... : 2
3 (silty clay) ..... : 1
4 (clay loam) ..... : 2
5 (sandy clay loam) ..... : 2
6 (silty loam) ..... : 2
7 (silty clay loam) ..... : 2
8 (sandy loam) ..... : 3
9 (sand) ..... : 4
10 (loamy sand) ..... : 4
? ..... : 7

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29 Severity Level
> tgp (temperature in growing period)
1 (very cool) [10-15 deg] : 4
2 (cool) [15-17.5 deg] : 3
3 (moderately cool) [17. : 2
4 (moderately warm) [20- : 1
5 (warm) [22.5-25 deg] : 1
6 (very warm) [25-27.7 d : 1
7 (extremely warm) [27.7 : 2
? ..... : 7

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## Appendix 8: Guide to general evaluation of some soil chemical and physical properties

Compiled from Msanyu *et al.* (1996), 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		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 ratio indicate quality of organic matter:

C/N 8-13: good quality

C/N 14-20: moderate quality

C/N >20: poor quality

### 1. Soil reaction (pH water)

Extremely acid	>4.5	Neutral	6.6-7.3
Very strongly acid	4.5-5.0	Mildly alkaline	7.4-7.8
Strongly acid	5.1-5.5	Moderately alkaline	7.9-8.4
Medium acid	5.6-6.0	Strongly alkaline	8.5-9.0
Slightly acid	6.1-6.5	Very strongly alkaline	<9.0

### 1. 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

### 1. 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

## 1. Exchangeable calcium

Cmol(+)/kg soil	Very low	low	medium	high	Very high
Ca (clay soils)	<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 & sands)	<0.2	0.2-0.5	0.6-2.5	2.6-5.0	>5.0

## 1. Exchangeable magnesium

cmol(+)/kg soil	Very low	low	medium	high	Very high
Mg (clay 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

## 7. Exchangeable potassium

cmol(+)/kg soil	Very low	low	medium	high	Very high
K (clay 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

## 7. 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

## 7. 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

## 7. Available water capacity

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