AUTOMATED LAND EVALUATION FOR ALTERNATIVE USES IN SOUTH WESTERN PART OF THE ULUGURU MOUNTAINS IN MOROGORO RURAL DISTRICT, TANZANIA

BY

SIBAWAY BAKARI MWANGO

A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT FOR THE DEGREE OF MASTER OF SCIENCE (SOIL SCIENCE AND LAND MANAGEMENT) OF SOKOINE UNIVERSITY OF AGRICULTURE

ABSTRACT

An automated land evaluation was carried out in Mgeta Area, Morogoro Rural District, Tanzania to assess the potentials and constraints of the various land units for the production of low input rainfed cabbage, round potato and arabica coffee. A total area of 41,964 ha was covered in this study. Land resources database was established by conducting soil survey at semi-detailed level, whereas socio-economic data were collected using semi-structured questionnaires coupled with Participatory Rural Appraisal techniques (PRA). Soils were mapped at the scale of 1: 50,000 based on landforms, parent material and geology. According to the FAO World Reference Base (FAO, 1998), the soils of summits classify mostly as Umbrisols, Cambisols, Leptosols and Acrisols; those of the slopes and piedmonts classify mostly as Regosols, Phaeozems and Luvisols. In the river valley sides the soils are dominantly Fluvisols and Phaeozems. Mgeta soils have low to medium fertility status except those of the summits which have very low fertility status. The topsoil reaction ranges from strongly to slightly acid (pH 5.1 - 6.5). Organic carbon ranges from very low to very high (0.2 to 11.3 % OC) while phosphorus is rated as low to medium (P < 7 to 20 mg/kg). Nitrogen content varies from very low to high (0.01 to 5.8 %). The values of CEC are medium to high (12.4 to 40 cmol (+)/kg). Base saturation levels range from very low to very high (1.5 to 95 %). About 80 % of Mgeta Area is both physically and economically moderately suitable for round potatoes, 74 % for cabbage and 71 % for arabica coffee production. The remainder of the area is either unsuitable or marginally suitable for the three crops, the main limitations being soil depth, nutrient availability, nutrient retention and soil erosion hazards.

Improvement of soil fertility status is deemed necessary. This can be achieved through agro-forestry practices and appropriate fertiliser/manure application. Improvements of extension services, marketing and storage facilities are also recommended in order to encourage farmers to produce more on a sustainable basis under the prevailing socio-economic conditions.

DECLARATION

I, SIBAWAY BAKARI MWANGO, do hereby declare to the Senate of Sokoine University of Agriculture that the work that is reported in this dissertation is my own original work and that it has never been submitted in any University. All sources of information are acknowledged by reference to the authors.

Signature:.....

Date:.....15 . 11 . 2000.....

COPYRIGHT

ACKNOWLEDGEMENTS

I am indebted to the several persons who helped in several ways to enable me complete this dissertation. I would like to mention the following persons and institutions that in one way or another contributed to the successful completion of this work:-

First and foremost I wish to express my sincere gratitudes to my supervisor Prof. B.M. Msanya, for his constructive advises and criticisms, close supervision and guidance during the course of this study.

I greatly appreciate the financial assistance rendered to me by the Norwegian Agency for Development Co-operation (NORAD) to allow me follow the MSc. (Soil Science and Land Management) course. The SUA-NORAD TAN 091 project on "Soils and Land Resources of Morogoro Rural and Urban Districts" headed by Prof. B.M. Msanya is also thanked for partly supporting the research activities.

My thanks are extended to Mr. D.N. Kimaro of the National Soil Service, Tanga, and currently a PhD student at Sokoine University of Agriculture for the constructive criticisms and suggestions he made to improve the quality of my work.

Thanks are also due to the Head of Soil Science Department SUA, Dr. M. Kilasara, for providing the needed facilities in the Department for this work.

I wish also to thank Dr. B.P. Mbilinyi of the Department of Agricultural Engineering and Land Planning, SUA, (the Incharge of the Remote Sensing and Geographical Information Systems Laboratory) for the technical support and advises that he provided me.

The company, co-operation and support received from my colleagues Messrs E.P. Kileo and A.I.M. Munisi are also very much appreciated.

Thanks are also due to all the academic and technical staff of the Soil Science Department for their academic and technical support during the course of this study.

I would also like to put on record the moral and material support received from my fellow students and the Muslim Society of SUA (MSASUA).

Last but not least, I highly appreciate the care and love received from my mother and my late father in my schooling.

DEDICATION

This work is dedicated to all those who use most of their time to search and use new scientific findings to manage land resources to satisfy human needs for present and future generations while also maintaining the earth's ecosystems.

TABLE OF CONTENTS

page

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

FAO-Food and Agriculture Organisation of United Nations

UNESCO-United Nations Educational Scientific and Cultural Organisation

USDA-United States Department of Agriculture

NSS-National Soil Service

NORAD-Norwegian Agency for Development Co-operation

SUA-Sokoine University of Agriculture

ILACO-International Land Development Consultants

BS-Base saturation

TEB-Total exchangeable basis

AWC-Available water capacity

Al sat-Aluminium saturation

CEC-Cation exchange capacity

ESP-Exchangeable sodium percent

DTPA-Diethylenetriaminepentaacetic acid

OC-Organic carbon

MGP-(1-26)-Mgeta profile (no. 1 - 26)

CHAPTER ONE

INTRODUCTION

In Tanzania agriculture is the main industry, contributing over 60 % to the national economy (United Republic of Tanzania, 1999). It is estimated that 83 % of the active population is engaged in agriculture (Reuben, 1995). The most potential agricultural land is constituted by the mountainous areas such as Uluguru mountains (National Soil Service, 1986), Usambara mountains (Lundgren, 1980), Pare mountains and occupy about 30% of the land surface (Peberdy, 1969). In these areas population is increasing at a high rate thus creating land scarcity, excessive deforestation and increasing soil erosion which results to low productivity (Dregne, 1990).

In the Uluguru mountains for example the high population density (about 250 - 300 persons per km^2), excessive deforestation and cultivation of areas which are too steep for agriculture are threatening the fragile ecosystem (Paul, 1988). Erosion control has proved difficult due to rapid changes in land use systems (Temple, 1972; Kilasara *et al.*, 1993).

Despite the fact that mountainous areas have high potential for production of many tropical highland crops such as maize, potato, beans, fruits, vegetables, and coffee, land productivity remains low (National Soil Service, 1986). In these areas only few attempts (including the Uluguru Land Use Scheme (ULUS), Afforestation Schemes and Soil Erosion Control) have been made to solve the problem of low productivity (Van Donge, 1992).

The need to increase production in mountainous areas is a prerequisite to supply food to the growing urban population (United Republic of Tanzania, 1992). Increase in production can be controlled to a great degree by proper land use planning policy (Temple, 1972). Formulation of land use policies requires knowledge of the potentials and constraints of the various agro - ecological zones and production potential of each of them for a set of relevant crops and livestock species (Temple and Rapp, 1972). Systematic land use planning is therefore needed to insure not only the social conditions of the present population but also the conservation of the environment for future generations (Moberg, 1981). Inappropriate land use leads to inefficient exploitation of natural resources, destruction of the land resources, poverty and other social problems. The land is the ultimate source of wealth and the foundation on which many civilisations are constructed (Rossiter, 1996).

Land evaluation based on human, economic and physical resources is an important tool to attain proper land use planning of various agro-ecological zones especially in mountainous areas to ensure that land is not degraded and that it is used according to its capacity to satisfy human needs for present and future generation while also maintaining the eath's ecosystem (Msanya, 1980; Rossiter, 1996). To date only limited studies have been done in the mountainous areas of Tanzania and in particular Uluguru mountains to establish proper land use planning based on principles of land evaluation (National Soil Service, 1986). Moreover, land evaluation in Tanzania is still being done manually and can not cope with the user demands (Kimaro, 1989). Traditional (manual) land evaluation techniques are time consuming and have limited versatility (Kimaro, 1989; Kimaro and Kips, 1991; Kimaro and

Msanya, 1999). For this reason some investors and land use planners are still forced to do without adequate land evaluation studies.

Automated Land Evaluation System (ALES) is a computer tool which has gained popularity in rapid and versatile land suitability assessment for alternative land uses. It is capable of handling and analysing large amount of data for increased efficiency and identification of areas with potential for different uses (Kimaro, 1989; Kimaro and Kips, 1991). ALES gives results, which answer questions, like "where is the best land for each land use or what is the best land use for each land area".

Uluguru Mountains are important sources of water and are potentially suitable for many tropical highland crops, temperate vegetables, fruits, maize, and cash crops such as coffee. They are characterised by high population density, improper land management and hence land degradation, and decline in land productivity. Despite the high potential and importance of these areas, only limited studies have so far been done in the area to establish sound land use planning based on principles of land evaluation. These studies are moreover, only qualitative and are not representative of particular land units. They are therefore not adequate for land use planning and management. These land evaluations have been done manually something that makes them less convenient and difficult to accommodate large amounts of data. Therefore, introduction of computerised land evaluation systems such as ALES to rate lands for a set of land utilisation types in the study area and Tanzania in general is inevitable for quick ranking of potentials of land.

Automated Land Evaluation System (ALES) is a modern system that allows land evaluators to build models that can be used to construct their own land

evaluation expert system that once built they can be used to process land units and rank them into suitability classes in both physical and economic terms. Application of ALES for land evaluation will assist to generate required data for quick decision making on land use policies and management and timely generation of information to potential investors.

This study intends to apply the Automated Land Evaluation System (ALES) to carry out land suitability assessment for alternative uses in western part of the Uluguru mountains in Morogoro Rural District, Tanzania. Specifically the study addresses the following objectives:

i. To identify soils and terrain resources of the study area.

ii. To characterise soils of the study area in terms of their physical and chemical properties.

iii. To classify soils of the area using the FAO World Reference Base and the USDA Soil Taxonomy systems.

iv. To assess suitability of the study area with respect to the production of cabbage, round potatoes and arabica coffee using Automated Land Evaluation System.

CHAPTER TWO

LITERATURE REVIEW

2.1. Basic definitions and concepts on land evaluation

"***Land***": Is an area of the earth's surface, the characteristics of which embrace all reasonably stable, or predictably cyclic attributes of the biosphere vertically above and below this area, including those of the atmosphere, the soil and underlying geology, the hydrology, the plant and animal population, and the results of past and present human activity, to the extent that these attributes exert a significant influence on present and future uses of the land by humans (Rossiter, 1996).

"***Land evaluation***": Is the process of estimating the potential of land for alternative kind of uses such as arable farming, livestock production and forestry, together with uses that provide services or other benefits, such as water, catchment areas, recreation, tourism and wildlife conservation (FAO, 1976). Land evaluation depends on natural resource surveys for data and information.

Land evaluation include studies (i) To determine the important characteristics of land (ii) To classify soils into defined types and other classification units (iii) To establish and to plot on maps the boundaries between types of land and (iv) To correlate and to predict the adaptability of mapped land to various land uses under defined sets of management practices (Soil Survey Staff, 1951).

Land evaluation provides a rational basis for taking land use decisions based on analysis of relations between land estimates of required inputs, projected outputs and various land use types (FAO, 1976). Land evaluation is the basis for determining the best use of land and predicting the effects of changed land utilisation due to new

land uses and changes in land management. Thus land evaluation technology will determine whether a self - sufficiency in food and cash crop production will be attained given a set of environmental conditions (Dent and Young, 1981).

"*Land mapping unit*" *(LMU)*: Is a specific area of land that can be delineated on a map and whose land characteristics can be determined. It is the evaluation unit about which statements will be made regarding its land suitability.

"*Land characteristic*" *(LC)*: Is a single attribute of the land that can be directly measured or estimated in routine survey, including remote sensing and census as well as natural resources inventory

"*Land quality*" *(LQ)*: Is a complex attribute of land which acts in a manner distinct from the action of other land qualities in its influence on the suitability of land for a specified kind of use; the ability of the land to fulfil specific requirements for a land utilisation type (LUT). Land Utilisation Type 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 definition of a LUT may include a time-series of activity outputs. The description of a LUT is not a complete description of the farming or other land-use system: it 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. The definition of a LUT also includes attributes that limit the land use options by discarding those that are priori unfeasible over the entire evaluation area. It can not usually be measured or estimated in routine survey, and so must be inferred from a set of "diagnostic" Land Characteristic. Conducting land suitability of a given land

utilisation type, a comparison has to be made between the environmental requirements of the LUT and qualities of the land.

Land qualities are composed of one or more land characteristics which are measured in the field and laboratory (Verbesselt and Mertens, 2000). Land qualities include the following attributes: -

(i) ***"Moisture availability" (m)***: This land quality refers to the availability of moisture for plant growth as determined by water supply (rainfall), available water capacity of soils and water out-take by evapotranspiration.

(ii) ***"Temperature regime" (t)***: Each crop grows well at a particular range of temperature. This includes, mean annual temperature, and mean temperature for growing period, coldest month's temperature, mean annual minimum and maximum temperature.

(iii) ***"Erosion hazard" (e)***: This land quality refers to the removal of topsoils by water and/or wind thus lead to nutrient depletion thus affects plant growth and development. Therefore slope gradient and surface soil texture are used as the main criteria to determine the erosion hazards. However severity of erosion hazards can be reduced by management practices.

(iv) ***"Rooting condition" (r)***: Roots have the function of extracting moisture and nutrients from the soil and supporting the plant. Thus, if the rooting system is restricted plants will suffer. Rooting conditions are controlled by soil effective depth and soil compaction for root penetration. Therefore effective soil depth and soil texture are the land characteristics used to qualify this land quality.

(v) ***"Tuber expansion and harvesting" (tb)***: For tubers to expand well need favourable soil conditions. Thus, if the tuber is restricted from expanding will reduce harvesting. Tuber expansion is controlled by soil effective depth and soil compaction. Therefore effective soil depth and soil texture are the land characteristics used to qualify this land quality.

(vi) ***Oxygen availability (o)***: Poor drainage conditions prevent the diffusion of oxygen and causes plant stress. The occurrence of stress due to oxygen shortage among other factors depends on the porosity or level of the ground water table. Therefore soil drainage class are considered to rate this land quality.

(vii) ***Nutrient availability (na)***: This land quality refers to the presence and availability of plant nutrients in the soil as determined from soil chemical data. The land quality is rated by pH, organic carbon, available phosphorus, total nitrogen and potassium content of the soils.

(viii) ***Nutrient retention (nr)***: This land quality refers to the ability of the soil to retain nutrients. Cation Exchange Capacity (CEC), total exchangeable bases and base saturation are considered as diagnostic factors for this land quality. CEC indicates the capacity of the soil to retain and liberate nutrients (bases) to plants. The nutrient lost by leaching can be assessed and is thus a relevant land quality in the assessment of required fertiliser inputs.

"Land Use Requirements" (LUR): Is a condition of the land necessary for successful and sustained implementation of a specific LUT. A LUT may be defined as a set of LURs.

"Severity level", also called ***"factor level"*** or ***"degree of expression of a LQ":*** Is a ranking or classification of the LQ according to the degree of limitation or hazard associated with the LQ of a particular land 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.

"Land Suitability": Is the fitness of a given Land Mapping Unit (LMU) for a Land Utilisation Type (LUT), or the degree to which it satisfies the land user. In a more operational sense, suitability expresses how well the LMU matches the requirements of the LUT. It may be expressed on a continuos scale of "goodness" eg class 1 meaning "completely suited" upwards to some maximum meaning "completely unsuited".

2.2. Methods of land evaluation

Although FAO has proposed principles for land evaluation, no specific methodology is suggested to achieve the classification. In recent years, a number of methodologies have been developed under the FAO framework (FAO, 1984; Sys *et al.*, 1991). These methods are either based on land characteristics or land qualities. The methods include:

(i) ***"Simple limitation method"***: This is a simplest method for qualitative land evaluation in which interactions between land characteristics are not considered

(ii) ***"Limitation method"*** (FAO, 1976): Each of the land characteristics is evaluated on a relative scale of limitations. Limitations are imposed when land characteristics deviate from the optimal conditions. Five levels of limitations are discerned: no limitation (0), slight limitation (1), moderate limitation (2), severe limitation (3) and

very severe limitation (4). The number and intensity of the limitation define the final suitability class.

Class S1 Very suitable: land units with no or only 4 slight limitations

Class S2 Moderately suitable: land units with more than 4 slight limitations and/or no more than 3 moderate limitations.

Class S3 Marginally suitable: land units with more than 3 moderate limitations and/or more than 2 or more severe limitations

Class N1 Currently unsuitable: land units with more than 2 severe and/or very very severe limitation that can be corrected.

Class N2 Permanently unsuitable: land units with more than 2 severe and/or very severe limitations that can not be corrected.

(iii) "***Parametric methods***" (Sys *et al.*, 1991): In this method the limitation levels are rated on a scale of 0 to 100. The land index is calculated from the individual ratings. These indices can be used to predict yields if the yield under optimal conditions is known

(iv) "***Fuzzy set method***" (Tang *et al.*, 1992): The theory of fuzzy sets was established by Zadeh (1965) and was developed to deal with vaguely defined classes or categories. Although each of these classes conveys a useful meaning that is obvious for a certain community, a neat borderline between the belonging or not of a land unit to such a class is not evident. Thus, membership function used to describe the degree of belonging of a land unit to a set.

(v) "***Statistical land evaluation***": These predict independent factor(s) that limit dependent factor(s) such as plant growth and yield. The form of statistical relation is

not always obvious and several forms give similar results in terms of goodness of fit:

(a) *"Single predictor regression":* The methods include; single linear regression, non-linear regression, non-linear regression polynomials, non-linear regression transformed variables.

(b) *"Multivariate statistical methods":* The methods include; multiple linear regression, multiple non-linear regression and principle components.

(vi) *"Modelling"*:

(a) *"Mechanistic models"*: These attempt to explain how system works, from some first principles. They try to describe the functioning of processes, for example, crop growth based on photosynthetic reactions as influenced by temperature, light, vapour pressure etc.

(b) *"Empirical models"*: Simply attempt to characterise a system (mathematically) for predictive purposes.

(c) *"Stochastic modelling"*: Attempts to describe the static relation between land characteristics and their yields or land qualities. All realistic models contain large doses of subjectivity, judgement and empirical parameters.

2.3. Measures of economic land suitability evaluation

Economic land evaluation is for predicting the micro-economic value of implementing a given land-use system on a given land area. This is a more useful prediction of land performance than a purely physical evaluation, since many land-use decisions are made on the basis of economic value (Rossiter, 1995). Measures of economic suitability include the following:-

(i) "***Gross margin***": This is the cash flow in to the LUT, less the cash flow out of the LUT, on a per unit area, (normalised) or aggregate (per-field or per-farm) basis, in one accounting period (usually a year). This measure does not take into account the time value of money. Capital costs can be ignored altogether by using rental prices. Thus, the gross margin is not sensitive to interest rates, and as such is a good first approximation of financial feasibility. It is an approximate measure of economic suitability for annual or short-term rotational LUTs with few or no capital costs.

(ii) "***Capitalised value***": This variant of the gross margin accounts for the time value of money. The annual return from a steady-state investment is a percentage of the total value of the investment determined by the interest rate. So, the total value can be calculated as EV = GM/IR, where EV is the annual gross margin, and IR the interest rate at present. It is an appropriate measure of economic suitability in the same situations as the gross margin. The capitalised value is an approximation to the portion of the land's value that can be attributed to its productive capacity.

(iii) "***Discount Cash Flow Analysis***": Money to be received in future is considered less valuable than money at hand. To take into account this value of money, amount to be received or to be spent in future are discounted to their present value according to the formula:

$PV = FV\ [100/100 + IR]^{Y}$: where PV is the present value, FV is the future value, IR the interest rate at present, and y is the number of years from present, counting from zero. The present value of an annual cash flow becomes insignificant at some point in future that depends on the interest rate. A typical use of discounted cash flow is to evaluate the economic feasibility of agricultural projects such as land

reclamation, where an initial investment is expected to yield benefit in the future.

There are three measures derived from the discounted cash flow with which to evaluate land suitability, as follows:-

(a) "***Net present value" (NPV)***: This is the total value of cash flows to be generated by the LUT, summed over its planning horizon, discounted to the present.

(b) "***Internal rate of return" (IRR)***: This is the interest rate below which the project (land use option) becomes financially attractive.

(c) "***Benefit to cost ratio" (BCR)***: This is the present value of the cash-in divided by the present value of the cash-out.

(iv) "***Utility***": The economic measures presented to this point are all expected values. Because of uncertainty in the production system, mainly due to uncertainty of weather and prices, the expected value will not be attained every year; rather, the time series of net returns will have some variance.

(v) "***Non cash flow***": Other measures of value than cash may be appropriate in certain socio-economic settings. Examples are calories or a nutritional index as income to be maximised and amount of an input (e.g., labour) to be minimised. The net cash flow must still be favourable.

(vi) "***Economic suitability classes***": Once each land use-land area combination has been assigned an economic value by the land evaluation, the question arises as to its suitability, that is, the degree to which it satisfies the land user. The land use must be financially feasible (for example, it must result in a positive gross margin), but beyond this minimum standard, the concept of suitability depends on the financial expectations of the land users who will implement the LUT. The FAO framework

defines two suitability orders "S" (suitable) and "N" (not suitable), which are divided into five economic suitability classes: "S1" (highly suitable), S2 (suitable), S3 (marginally suitable), N1 (not suitable for economic reasons but physically suitable), and N2 (not suitable for physical reasons) The subdivision of the S order into three suborders is arbitrary, and can be expanded or contracted according to the evaluation. The physical evaluation separates class N2 from the other classes; no economic evaluation should be carried out for physically unsuited land use-land area combinations. The evaluator assign dividing points between the other classes, in the same units of measure as the economic analysis. The limit between S3 and N1 must be at least at the point of financial feasibility (i.e., gross margin, NPV, or IRR $\geq$ 0, BCR $\geq$ 1). The other limits depend on social factors such as farm size, family size, alternative employment or investment possibilities, and wealth expectations, these are specified in the LUT definition. (Rossiter, 1995)

3.4. Systems of land evaluation

The FAO Framework for land evaluation was developed in order to improve the technology for evaluating the suitability of land for specified kinds of use (FAO, 1976). It compares the requirements of the land utilisation type with the resources that are offered by the land. This requires information from three sources, namely the land, land utilisation type and economics. The FAO Framework for land evaluation (FAO, 1976) was designed to appraise the suitability of land for general crop production. The framework includes guidelines such as land evaluation for rainfed agriculture (FAO, 1983), irrigated agriculture (FAO, 1985), forestry (FAO, 1984), extensive grazing (FAO, 1991a); and steeplands (Siderius, 1986).

The USDA land capability classification (Klingebiel and Montigomery, 1961) ranks land from best to poorest by severity of land limitations for general agricultural use. It classifies land on the basis of whether it is arable or non-arable. This system does not specify certain land utilisation types, and therefore, it is qualitative.

Local systems of land evaluation such as the Zambian system (Soil Survey Unit, 1983), the Malawian system (Young and Goldsmith, 1977), the Iranian system (Soil Institute of Iran, 1970) etc have been developed based on their respective environments (Dent and Young, 1981).

Computer systems of land evaluation is recently gaining popularity in developing countries for their rapid and ability of handling large amount of data and rapid land suitability assessment for alternative land uses. The first implementation of the automated systems for land evaluation was the Land Evaluation Computer System (LECS) in Indonesia (Wood and Dent, 1983); LECS was later on incorporated into the FAO's Agricultural Planning Toolkit (APT). An Automated Land Evaluation System (ALES) (Rossiter, 1988) is another computer programme for land evaluation which comprises a map-unit based, expert-systems approach (Rossiter, 1990; Rossiter and Van Wambeke, 1995). Other computer programmes for land evaluation includes; Quantitative Evaluation of the Fertility of Tropical Soils (QUEFTS) (Janssen *et al.*, 1986) and a microLEIS computer program for land evaluation in Mediterranean climate (De la Rosa *at al.*, 1992). ALES and LECS are based on guidelines given in the FAO framework for land evaluation (FAO, 1976). They are capable of incorporating soil and other land characteristics to give a

complete agro-ecological and / or agro-economic suitability assessment (Elbersen, 1989).

2.5. Land Evaluation in Tanzania

2.5.1. General

Land evaluation studies in Tanzania date back in the early 1970s. Hathout (1972) compiled in map form some land qualities such as water availability, water holding capacity and natural soil fertility. The author compiled soil capability maps for the whole country and was an updated version of the work by Anderson (1976) on potential land use of Tanzania in which the main limitations to cropping were mapped. Conyers (1973) produced a map of broad agro-ecological zones of Tanzania. All these studies form broad reconnaissance and exploratory land resource inventory. Other studies include larger scale mapping of a number of regions and districts at scale between 1: 100,000 to 1: 500,000. About half the country has been covered in this way (Msanya and Magoggo, 1993). In most of these studies suitability of land for relevant land use systems and recommendations for sustained use of the land were made based on conventional land evaluation techniques.

A wide range of areas has been covered in terms of semi-detailed land evaluation studies of farms, estates, irrigation schemes and village areas. These project areas are scattered throughout the country, and their total area extent is about 10,000 sq. km (Msanya and Magoggo, 1993; Kilasara *et al.*, 1993) which is negligible taking into consideration the size of the country.

2.5.2. Land evaluation in mountainous areas

Mapping and land evaluation in mountainous areas have been scarce and inadequate, this is due to intricacy and difficulties in accessibility (Moberg, 1981). Few land evaluation studies have been carried in few areas of the Uluguru mountains. The studies by Msanya (1980) took into consideration only qualitative aspects of land evaluation. The qualitative nature of these studies coupled with lack of information with respect to the spatial distribution of soils are a limitation to extrapolation of results to other areas with similar ecological conditions.

Other studies include: The land capability classification in the Uluguru mountains which was done by Dumelow (1980) making use of rainfall and sedimentation data derived from the catchment area. Chemical and physical soil properties were studied under five typical vegetation types. This type of land evaluation is also qualitative, being based only on the type of vegetation present, the impact of man, the climate and topographical influence.

Moberg (1981) investigated the associations of two interconnected soils forming a continuum between the Uluguru mountain ranges and the Mindu mountains, and evaluated the factors and processes involved in the development of soils. In addition a comparison between the mineral composition of clay, silt, and sand was made. Land use potential of the area was also considered, but again in qualitative terms

Land evaluation in the Uluguru mountains for various crops was done by National Soil Service (1986) based on the available information provided by the FAO Crop Monitoring and Early Warning Systems Project in Dar es Salaam. The results obtained in this study are a generalisation based on secondary data. The study to

some extent indicates quantitatively the potential of the area for growing different crops.

2.6. Application of Automated Land Evaluation System (ALES) in Tanzania

The Automated Land Evaluation System (ALES) is a computer program in the form of an expert system that allows land evaluators to build models that can be used to compute both physical and economic suitability of land mapping units (Rossiter, 1988). As an expert system ALES does not provide knowledge or data and has no in-built criteria to evaluate land. It is an empty frame work, a shell that allows evaluators to construct their own "land evaluation expert system"(Rossiter and Van Wambeke, 1989) that once built, process land units and rank them into suitability classes, both in physical and economic terms.

In Tanzania ALES has been applied for smallholder low-input maize in Kilosa area by Kimaro (1989), Kimaro and Kips (1991), Kimaro and Msanya (1999). In these studies four systems of land evaluation were compared such as. ALES, LECS, QUEFTS and local (manual) system of land evaluation. Among these systems ALES indicated some promising opportunities for adaptation and application in Kilosa area.

ALES was also applied in Mbulu district to assess land suitability for smallholder rainfed cultivation, low input, mechanised agriculture, medium to high input, afforestation and extensive grazing based on soils and land resources information which was collected at the scale of 1: 20,000 (Magoggo and Meliyo, 1994). The results showed that ALES could be adopted in Mbulu district for the assessment of land use alternatives.

Despite the fact that the ALES model presently gives the user considerable freedom, it was suggested that certain fixed threshold levels based on long term research experience should be introduced in ALES (Kimaro, 1989). This includes introduction of certain threshold level to derive the yield factors, which are necessary in the evaluation and verification of the ALES results. Further studies are encouraged so as to exploit the system fully and to assess its adaptation and application.

ALES suitability classification is advantageous because once data are put into the ALES programme and the model has been build, several reports can be generated. The reports include physical and economic suitability evaluations, gross margins and predicted yields from each land mapping unit, the data can be queried and changed accordingly. Also the ALES output can be imported into GIS programmes for suitability maps production (Rossiter and Van Wambeke, 1989; Kimaro, 1989)

2.7. Important crops grown in Mgeta Area and their requirements

2.7.1. Arabica coffee (*Coffea arabica*)

Arabica coffee is produced in areas with a precipitation in the range of 800 - 2500 mm/year. The precipitation is optimum between 1400 - 1600 mm/ year, but the distribution is more important than the total. A well distributed rainfall with a drier period of 2 to 3 months for the initiation of flower buds is best (Sys, *et al.*, 1991). The minimum temperature for the growth of arabica coffee is 10 °C, though the absolute minimum is the frost limit. The maximum temperature is 30 °C. The mean optimum temperature for growth is 15 °C - 24 °C. Periods of mist and low clouds are beneficial. Excessive temperature cause die back, force rapid growth and early

bearing. Strong or cold winds are detrimental; banana windbreaks constitute an efficient protection.

Interms of soils, deep, slightly acid, friable, permeable, well drained, fertile clay to clay loam soils, with reasonable humus content are most suitable. The roots have high oxygen requirement, therefore poorly drained and massive heavy clay soils should be avoided. Subsoil moisture must be present at all time, but the topsoil must be drier for some part of the year to initiate flower buds through moisture stress. Sandy soils are satisfactory if underlain by a subsoil with a higher clay content.
pH range between 5.2 - 7.8, optimum pH is 5.6 - 6.6. No yield reduction at an electrical conductivity (EC) of < 0.5 dS/m, the yield reduction is 50% at 1 and 100% at 7 dS/m.

A high organic matter content is preferred. Nitrogen requirements are lower for shaded coffee. The most important nutrients are N and K, secondly P. The calcium requirement is fairly high. Mg deficiency lowers the quality of the production. Excessive K lowers the quality (Sys, *et al.*, 1991; London, 1991). Good commercial yield (clean green hulled beans) for rainfed arabica coffee 1.5 - 3.0 ton/ha and good smallholder yield range from 0.5 - to 1.2 ton/ha (Sys, et al., 1991; London, 1991)

2.7.2 Cabbage (*Brassica oleracea*)

The total precipitation should be at least 250 - 300 mm/growing cycle, and is optimal at 400 - 500 mm/growing cycle. A high relative humidity is desirable 60 - 90%. Below 60% wilting occurs. Germination of cabbage is observed in the temperature range of 5 - 37 °C. The optimum temperature for germination is 28 °C. The temperature range for the growth is 15 - 20 °C or an average monthly maximum

of 24 °C. A difference between day and night temperature of 11 °C is optimal. Most varieties tolerate up to - 6 °C. Long periods with temperature of < 5 however are harmful.

Cabbage is grown on soils with a wide range of texture, but loam is preferred. Lighter soils are suitable if the rainfall is high. The soil depth should be at least 0.2 m; the optimum soil depth is > 0.6 m. Well drained, moderately well to well drained soils are preferred. pH range between 5.5 - 8.2, optimum pH ranges between 6.2 - 7.5. No yield reduction at an electrical conductivity (EC) of < 1.8 dS/m; the yield reduction is 10% at 2.8; 25% at 4.4; 50% at 7.0; 100% at 12 dS/m and 50% yield reduction at an exchangeable sodium percentage (ESP) of 20.

Moderate to high, well-decomposed organic matter is beneficial. The most important nutrient elements include N, P and K. The crop is sensitive to Manganese and Molybdenum deficiency. Good commercial yield for rainfed cabbage range from 35 - 50 ton/ha and average farmer yield is between 10 - 40 ton/ha (Sys *et al.*, 1991; London, 1991).

2.7.3 Potato (*Solanum tuberosum*)

A precipitation of 300 - 700 mm/growing cycle is required. Excessive rainfall causes diseases. Hot and dry weather may cause wilting, even when sufficient soil moisture is available. The temperature range for the growth of potatoes is 8 - 30 °C. The growth is optimal at temperatures between 16 - 20 °C. The growth of tubers is inhibited at temperatures below 10 °C and above 27 °C. The optimal soil temperatures for tuber formation is 15 - 18 °C. Night air temperature below 15% and generally cool

weather favour tuber formation. High soil temperatures at planting cause the seed to rot and lead to poor emergence. The crop is damaged by frost.

Potatoes can grow on soils that have a fine sandy to (kaolinitic) clay texture, though loam to silty clay loam soils is preferred. Heavy clays cause a poor emergence, poorly shaped tubers and harvesting problems. The soils must be well structured and freely workable. Suitable soils are well drained and aerated and moderately deep (0.5 - 1.0 m) to deep (> 1.0 m). The maximum crop rooting depth is 0.6 m. Potatoes do not tolerate flooding. Slightly acid soils reduce the risk of scab. Soils that are cropped with potatoes are exhibited to a medium erosion hazard. pH range between 4.8 - 8.2, and optimum pH is between 5.6 - 7.0. No yield reduction at an electrical conductivity (EC) of < 1.7 dS/m; the yield reduction is 10% at 2.5; 25% at 3.8; 50% at 6; 100% at 10 dS/m and 50% yield reduction at an exchangeable sodium percentage (ESP) of 35%. The most important nutrient elements include N, P and K. Calcium is also required to some appreciable amount (Sys, *et al.*, 1991).

CHAPTER THREE

MATERIALS AND METHODS

3.1. Physical environment of the study area

3.1.1. Location

The study was conducted on the south-western slopes of the Uluguru Mountains covering 419.6 km^2 (41,964 ha) with an elevation ranging between 900 - 2700 m above sea level. The area is located between latitudes 7 ^{0} 00 $'$ and 7 ^{0} 11 $'$ 23.5 $''$ S and longitudes 37 ^{0} 0 30 $'$ and 37 ^{0} 38 $'$ 36.6 $''$ E in Tchenzema Ward, Mgeta Division. It includes the villages of Kibaoni, Langali, Bunduki, Bumu, Kikeo, Luale, Mwarazi, Nyandira, Kibuko and Tchenzema.

3.1.2. Climate

The area receives an annual rainfall ranging between 1200 and 3100-mm with a temperate like climate (Delobel et al., 1988). The long rains (masika) usually fall in February to June, followed by dry season between July and September. The short rains (vuli) occur in October to January, but small amount of precipitation usually prevails throughout the year. On the high plateau of the Uluguru Mountains frosts are known to occur and the weather is always cool.

3.1.3. Vegetation

Western foothills of the Uluguru Mountains are a lightly wooded country with very little open grassland. However native and exotic tree species have been grown and have replaced the natural vegetation to a very large extent. In some places opening up of

land for cultivation has led to soil erosion and leaving open grassy hill-slopes with no trees and very little soil.

There are three major types of forests namely, mountain rain forest, tropical rainforest and miombo woodland. The mountain rain forest occurs on high mountains, and has been declared government forest reserve. The areas around Bunduki, Kibuko, Tchenzema and Chigarafumi have been afforested with conifers and eucalyptus. The third major type of vegetation is the miombo woodland, whose typical species are *Brachystegia spp.* (miombo), *Isoberlina spp.* and *Acacia nigrescens*. The only timber of importance is *Pterocarpus angolensis* (mninga).

Other vegetation types includes ferns, guava, Cyprus, black wattle (*Acacia mearnsii*) and thatch grass (*Hyperrhenia rufa*). On the summit of Lukwangule plateau there is grassland whose vegetation is composed dominantly of coarse grasses with few trees and other plants of temperate climate.

3.1.4. Land use

The people are mainly smallholder farmers growing both cash and staple food crops under rainfed and irrigated conditions in risk prone environments. The current major land use is ridge and in some places bench terrace cultivation of maize, millet and beans as the staple foods. The crops are grown alternately and/or intercropped with cash crops like vegetables and round potatoes, whereas arabica coffee is mixed with bananas and some black wattle trees. Intercropping with deciduous fruit trees like citrus and peaches is also commonly done in some areas. Much greater area is devoted to cash

crops production for sale in Morogoro and Dar-es-Salaam (Sampson and Wright, 1964; Kisanga, 1992).

3.1.5. Geology

The northern part of the study area in the areas around Msanga, Changa, Magomba, and Bunduki, the eastern parts including the Lukwangule plateau and the north western areas within the Lukuyu, Homboza and Kiyangali villages are dominated by banded pyroxene granulites which cover an area of about 176 km^2 with occasional biotite- rich bands in some parts of the south east covering an area of 3.0 km^2. Banded pyroxene granulites belongs to Mbakana banded granulites (Lukwangule group) of Usagaran system (Wright, 1959).

In the far north-west foliated mica gneisses occupy about 15.0 km^2, whereas hornblende gneisses and granulites occupy 1.9 km^2. These rocks belong to the Mzumbe Acid Gneisses (Morogoro group) of the Usagaran system. Alluvium of Neogene age is also present and covers an area of about 1.0 km^2 (Sampson and Wright, 1964).

Kaolinitic clays (forest cap clays) of the Neogene age (Wright, 1959) are dominant in the central parts along Nyandira, some parts of Tchenzema and Kibuko and in the areas of Chigarafumi in the south-west. The kaolinitic clays cover a total area of about 19.0 km^2.

Other widespread rock types in the study area are meta-anorthosite, meta-gabbroic anorthosite and meta-anorthositic gabbro with some titaniferous magnetite and associated iron-rich rocks which belong to the Uluguru meta-anorthosite of the Usagaran

system (Sampson and Wright, 1964). These rock types are found in some central parts (Mgeta-Kibaoni, Langali, Lusanza, Vikoko, Bumu, Lusungi, and Mindu areas) and in the areas south of Kibuko and Tchenzema (Chibao, Minongwa, Ngao, Bende, Kikeo and Kitemera areas) (Wright, 1959). Meta-anorthositic rocks are also found in the west and south west of the study area around Sazima, Luale and Nzovu. These rock types cover a total area of about 118 km^2.

3.1.6. Landform and soils

The area consists of strongly dissected, very steep slopes of about 30-60% with narrow valleys in between in almost the whole of Mgeta area (NSS, 1986; Kimaro, 1997). Lukwangule plateau is the highest peak in Uluguru Mountains and Mgeta area in particular, reaching a height of 2,623 m. a.s.l. It is separated from the Kimhandu plateau by the Nyingwa gap which drops to about 1950 m. The edge of the Lukwangule block drops steeply to the west in the Kibuko-Tchenzema shell at about 1590 m and from there the slope is more gentle (Sampson and Wright, 1964). The Lukwangule plateau is one of the most striking surfaces in the whole Uluguru Mountain range. It is only slightly dissected and the surface forms a quite mature relief (Sampson and Wright, 1964).

The soils of the study area are a complex of moderate, well to somewhat excessively drained, dark yellowish brown to dark red, sandy clays to clays and shallow, well to somewhat excessively drained, dark reddish brown sandy clay loams to sandy clays (Kimaro, 1997). The soils around Kibuko and Tchenzema over a great part are

kaolinitic red and yellow clays (the forest cap clays). They are also developed on the south-west spur around Chigarafumi.

3.1.7. Hydrology

There appear to be two distinct drainage-patterns. A sub-radial pattern is related to the horse-shoe of high mountains from Mkumbaku through Lukwangule and Magari to Lupanga, which is demonstrated now by some of the larger rivers such as Mngazi, Mbakana and, in part, the Mgeta. A rectilinear pattern is exhibited where secondary streams and main rivers show adjustment to geological structure and rock type. This pattern of the minor rivers follows the geological structure more closely and has resulted in river capture, reversed drainage, wind gaps, etc. The edge of the meta-anorthosite is marked by the Mgeta, Mfunesi and Lukangazi river valleys for about two-thirds of its circumference, and this weakness is presumably the cause of the spiral course of the Mgeta River as it cuts back along the junction of rocks, capturing successively all the radial drainage from the north and west of the high-level plateaux.

3.2. Pre-field work

3.2.1. Collection of materials and relevant data

In this phase secondary climatic records were collected from three meteorological stations as indicated in Table 1. Only precipitation records were obtained from these stations, while temperature was extrapolated from the Morogoro Station and reference crop evapotranspiration ETo mm/day was calculated using the temperature method

based on the Blaney-Criddle equation (FAO, 1991b) as follows: ETo = p (0.46 T + 8), where T is the mean daily temperature, p is the mean daily percentage of total annual daytime hours x adjustment factor, which depends on minimum relative humidity, sunshine hours and daytime wind estimates (different values of p for different latitudes were given). The data were compiled and analysed to produce physical land suitability appraisal for agricultural land use planning.

Other tasks performed in this phase include literature search, collection and study of the materials listed below:

Topographic map of Mgeta. sheet 201/1 at the scale of 1: 50,000

Geological map of Uluguru: Quarter degree sheet 201 at the scale of 125,000

Aerial photographs of Mgeta Area at the scale of 1: 67,000

3.2.2. Interpretation of maps and aerial photographs

In preparation for the soil mapping, stereoscopic examination of the aerial photographs scale (1: 67,000) was carried out, whereas topographical map (scale 1: 50,000) and geological map (scale 1: 125,000) were also interpreted visually to complement the aerial photo interpretation (API). The elements vegetation cover, land use, landform / relief, geology and drainage patterns were considered in the interpretation and finally physiographic interpretation map at a scale of 1:67,000 was compiled and used as a base map for the field survey.

3.2.3. Questionnaire development

Semi-structured questionnaires were prepared for gathering data and information on land use and socio-economics of the studied area (Appendix 5).

3.3. Field work

3.3.1. Land resources survey

Free survey at semi detailed level (scale, 1: 50,000) was carried out using the results of the API to select observation and sampling points. At each observation site data on soil morphological characteristics, landform, elevation, slope gradient, parent material, lithology, vegetation and land use were measured and collected. Observation intensity was 1 observation per 0.5 km^2 (50 ha) in accordance with procedure outlined by Dent and Young (1981). At the beginning of the survey, reconnaissance of the whole study area was done followed by the selection of representative transects to locate observation sites and sampling points. In each transect, soils were described using soil auguring, minipits to a depth of 50 cm and profile pits dug to a depth of 2 metres or to lithic / paralithic contact whichever is shallowest. In total twenty six fully geo-referenced soil profile pits were excavated, studied, described and sampled. Geo-referencing was done using a portable Global Positioning System Receiver (model GARMIN 12XL).

Description of the soils and landforms was done following standard procedures as outlined in the FAO (1990) guidelines for soil description. The data collected were recorded on standard analogue field forms. Soil colour was determined by Munsell soil

colour charts (Munsell Colour Co. 1992). Correlation of the described soil auguring, landform and parent material enabled soils similar in characteristics and in arrangements of soil horizons to be singled out and mapped. Twelve mapping units were identified.

In each profile pit, bulk samples were also taken from every horizon for physical and chemical analysis. Undisturbed core samples were collected for determination of soil moisture characteristics and bulk density.

3.3.2. Land use and Socio-economic survey

Semi-structured questionnaires coupled with Participatory Rural Appraisal (PRA) techniques were used to collect and identify major land utilisation types and socio-economic data for use in ALES model for economic suitability evaluation. Such data include: yield (kg/ha), prices, labour, size and status of the farm and levels of management (land preparation, clearing, material inputs, plant care and cultural practices), market position, information related to population, extension services, farm and social organisations. The information and data were gathered from thirty representative farmers and extension officers.

3.4. Post field work

3.4.1. Laboratory methods

The disturbed soil samples were air dried and ground to pass through 2 mm sieve to obtain the fine earth fractions for chemical and physical determinations. Undisturbed

core samples were used for the determination of bulk density and moisture retention characteristics.

Soil texture was determined by hydrometer method after dispersing soil with calgon 5% (NSS, 1990). Bulk density was determined according to core sample method (Blake and Hartge, 1986). Soil moisture retention characteristics were studied using sand kaolin box for low suction values and pressure membrane apparatus for higher suction values (NSS, 1990).

pH was determined potentiometrically in water and in 1N KCl at the ratio of 1:2.5 soil-water and soil-KCl (McLean, 1982). Electrical conductivity (ECe) was determined by conductivity meter in a 1:2.5 soil-water suspension. Organic carbon was determined by the Walkley and Black wet oxidation method as outlined by Nelson and Sommers (1982). Total nitrogen was determined by Kjeldahl method (Bremner and Mulvaney, 1982). Available phosphorus was extracted by Bray and Kurtz-1 method (Bray and Kurtz, 1945) for soils with pH_{water} less than 7 and Olsen method for soils with pH_{water} above 7 and determined spectrophotometrically (Murphy and Riley, 1962; Watanabe and Olsen, 1965). Cation Exchange Capacity (CEC) and exchangeable bases were determined by saturating soil with neutral 1M NH4OAc and the adsorbed $NH4^+$ were displaced using 1M KCl and then determined by Kjeldahl distillation method for the estimation of CEC of the soil. The bases (Ca^{2+}, Mg^{2+}, Na^+, K^+) were determined by atomic absorption spectrophotometer (NSS, 1987). CEC of clay was calculated using

the formula outlined by Baize (1993) which corrects for the CEC contributed by organic matter (OM) as follows: CEC clay = ({CEC soil - (%OM * 2(}/ % clay] * 100.

Extractable micro nutrients including Cu, Fe, Mn and Zn were determined using DTPA extracting solution. The solution was prepared to contain 0.005M DTPA, 0.01 $CaCl_2$, 0.1M Triethanolamine (TEA) and adjusted to pH 7.3 with 1:1N HCl (Lindsay and Norvell, 1978). Twenty grams of the 2 mm sieved soil samples in 100 ml plastic bottles, 40 ml of 0.005M DTPA solution was added and the bottle screw capped tightly. The mixtures were then shaken for two hours on a reciprocating shaker at 175 revolutions per minute (rpm). The suspensions were filtered through Whatman No. 1 filter paper and the micro nutrients in the extract determined by Flame Emission - Atomic Absorption Spectrophotometer (FE-AAS).

Boron was determined in non-ashed extracts for soils with low organic matter content and dry combustion for soils with high content of organic matter. 30 ml of 0.01M $CaCl_2$ were added in 15 g soil samples (ashed and non-ashed) and digested at 150^0C for 5 minutes. The suspensions were filtered and NH4OAc-EDTA solution and Azomethine-H reagent were added into 2 mls filtrate. The boron content was then determined by measuring the absorbance on a colour spectrophotometer (Moberg, 2000).

3.4.2. Soil classification and data processing

Using both field and laboratory data, the soils were classified to level-3 of the FAO World Reference Base (FAO, 1998), and to subgroup level of the USDA Soil Taxonomy (Soil Survey Staff, 1998).

The field and laboratory analytical data recorded on the analogue forms were entered into the digital soil data base management system SISTAN (Magoggo, 1991). Other softwares used for data processing and report writing include Microsoft Excel, Microsoft Word and Freelance.

3.4.3. Cartography

After the field mapping, fine cartographic work was done to produce the soil map with its complete legend showing the major soil characteristics of each mapping unit. Soil map was digitised and analysed using ARC/INFO and ARC/VIEW GIS softwares and then produced at the scale of 1: 50,000 (Appendix 13).

3.4.4. Automated land evaluation using ALES

Land evaluation was carried out using Automated Land Evaluation System (ALES). Data on land resources (Appendix 2) and socio-economics were coded using land characteristics specification dictionary (Appendix 3) into a digital dbase file (Appendix 4) and analysed according to ALES format.

(i) Rating of Land Utilisation Types (LUTs) and land use requirements (LURs)

The suitability of the land was assessed on the basis of the land qualities and land use requirements (LURs). Interrelations of land characteristics (LCs) for a particular land quality were used to rate LURs. Class limits for the land utilisation type (LUT) were set on the basis of farmers'(experience and literature sources. LURs were rated as (1) no limitation, (2) moderate limitation, (3) severe limitation and (4) very severe limitation.

(ii) ALES model building

Land characteristics specifications (Appendix 3) and land use requirements for small holder improved low input rainfed cabbage, small holder improved low input rainfed potato and small holder low input rainfed arabica coffee (Appendices 6, 7 and 8) were prepared. In the ALES model building the n LCs (LC)LMU were aggregated into m Land Qualities (LQ)(LMU, LUT) Specific to Land Utilisation Type.

$S_{LMU} = f_{1\,LUT}(\{LQ\}_{LMU,LUT})$

$LQ_{LMU,LUT} = f_{2\,(LUT,LUR)}(\{LC\}_{LMU,LUR}),\ \forall LQ \in \{LUR\}_{LUT}$

where $\{LUR\}_{LUT}$ is the set of Land Use Requirements defined for the LUT. From each of these the value of a corresponding Land Quality was calculated; this is the so-called "matching" according to the FAO Framework. The notation ($\{LC\}_{LMU,LUR}$) shows that the set of diagnostic LCs to be used when evaluating a specific LQ is defined as part of the specification, of the corresponding LUR. In other words, each LQ was evaluated from its own set of diagnostic LCs. Note that some LCs may be diagnostic for more than one LQ. The subscript notation (LUT, LUR) means that the land use requirements LURs were defined within the context of specific production system LUT (Rossiter, 1996). Using land characteristics specifications and land use requirements, the expert ALES models in the form of decision trees for the three mentioned land utilisation types were built (Appendices 9, 10 and 11). The built models were then put into the ALES programme to be used for land suitability evaluation of the studied land utilisation types.

(iii) ALES suitability classification

Physical suitability ratings of the mapping units were determined using decision trees severity levels provided in ALES computer programme and following the Liebigs law of minimum (Rossiter and Van Wambeke, 1989), by which the most limiting LUR determines the suitability class. Four physical suitability classes were defined as (1) good potential, (2) moderate potential, (3) poor potential and (4) very poor potential. In the evaluation ALES was used to predict yields on the basis of limiting yield factors. Predictions were made by multiplying the chosen yield factors with the optimum yield. The yield factors used were derived from the proposed FAO suitability classes i.e. 80 - 100 % S1, 40 - 80 % S2, 20 - 40 % S3, and 0 - 20 % N of the optimum yield (FAO, 1984). The ALES yield factors were class 1 = 1, class 2 = 0.8, class 3 = 0.4 and class 4 = 0.2. These factors were used to predict the final physical suitability classification.

Economic suitability classification was carried out using the predicted yields arrived at in the physical evaluation. As for physical evaluation FAO suitability classes were used as follows: S1 highly suitable, S2 moderately suitable, S3 marginally suitable, and N1 economically not suitable. Economic suitability class limits were set, the class limits were the gross margins based on the average yields. The same factors were used to set class limits as for the physical evaluation.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1. Climatic resources database for Mgeta Area

Some basic climatic data are given in Table 1. The mean annual rainfall in Mgeta Area ranges from 1065 mm at Mizungu Mgeta to 2450 mm at Tchenzema. The rainfall distribution pattern is monomodal (particularly at Tchenzema and Mizungu Mgeta) with the main rainy season from October to May in Tchenzema and Bunduki areas and from December to April in areas around Mizungu Mgeta. The peak rainfall occurs in April in most places of the study area (Figures 1 and 2). The higher altitude areas seem to get more rainfall than the lower areas. The rainfall distribution at Bunduki tends more to bimodal pattern with two peaks occuring in October and April.

There is a considerable temperature variability with the monthly maximum temperature ranging from 28.3 °C to 19.9 °C and monthly mininum temperature from 17.3 °C to 7.6 °C. At Lukwangule plateau temperatures are much cooler.

The longest reference length of growing period (LGP) is 270 days and the lowest is 180 days. LGP is the period of the year when moisture supply and temperature permit crop growth, and this is the period when rainfall exceeds half reference crop evapotranspiration (ETo) plus the period required to evapotranspire an assumed amount of moisture (FAO, 1993, 1996).

Table 1. Some important climatic data of Mgeta Area

Tchenzema station (Altitude 1670 m. a s l; 7° 7'S & 37° 36'E; from 1946 to 1983)													
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Precipitation (mm)	320.5	279.9	385.8	596.0	253.0	50.5	28.8	11.9	44.7	66.5	197.7	251.4	2450.2
Temp. average °C	18.9	18.9	18.7	17.6	16.1	14.2	13.7	14.7	15.8	17.2	18.3	19.1	16.9
Temp. maximum °C	24.1	24.3	24.1	22.2	20.8	19.9	19.8	20.9	22.4	23.8	24.4	24.6	22.6
Temp. minimum °C	13.6	13.4	13.4	12.9	11.4	8.5	7.6	8.4	9.2	10.6	12.1	13.7	11.2
Temp. day °C	20.7	20.8	20.7	19.2	17.8	16.2	15.9	16.9	18.2	19.6	20.5	21.1	18.9
Temp. night °C	16.8	16.8	16.7	15.9	14.4	12.1	11.5	12.4	13.5	14.9	16.1	17.3	14.9
Temp. Difference day/night °C	3.9	4.0	4.0	3.3	3.4	4.1	4.4	4.5	4.7	4.7	4.4	3.8	4.0
ETo	135	135	134	130	124	117	116	119	124	128	132	136	
1/2 ETo	68	68	67	65	62	58	58	60	62	64	66	68	
LGP	+	+	+	+	+					+	+	+	
Bunduki station (Altitude 1281 m. a s l; 7° 2'S & 37° 37'E; from 1907 to 1990)													
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Precipitation (mm)	173.5	155.2	279.6	356.6	151.0	32.7	22.6	45.0	79.9	161	303.2	262.9	2097.6
Temp. average °C	21.4	21.4	21.2	20.1	18.4	16.7	16.2	17.2	18.3	19.7	20.8	21.6	19.4
Temp. maximum °C	26.6	26.8	26.6	24.7	23.3	22.4	22.3	23.4	24.9	26.3	26.9	27.1	25.1
Temp. minimum °C	16.1	15.9	15.9	15.5	13.9	10.9	10.1	10.9	11.7	13.1	14.6	16.2	13.7
Temp. day °C	23.2	23.3	23.2	21.7	20.3	18.7	18.4	19.4	20.7	22.1	22.9	23.6	21.5
Temp. night °C	19.3	19.3	19.2	18.4	16.9	14.6	13.9	14.9	15.9	17.4	18.6	19.8	17.4
Temp. Difference day/night °C	3.9	3.9	4.0	3.3	3.4	4.1	4.5	4.5	4.8	4.7	4.3	3.8	4.1
ETo	144	144	143	139	133	127	125	128	132	138	142	145	
1/2 ETo	72	72	71	70	66	63	62	64	66	69	71	72	
LGP	+	+	+	+	+				+	+	+	+	

Table 1. continued

Mizungu mgeta station (Altitude 1097 m. a s l; 7^0 4'S & 37^0 35'E; from 1951 to 1986)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Precipitation (mm)	114.2	143.5	169.1	248.1	61.6	8.5	8.3	6.4	21.9	47.8	92.5	127.1	1064.6
Temp. average °C	22.6	22.6	22.4	21.3	19.8	17.9	17.4	18.4	19.5	20.9	22.0	22 8	20.6
Temp. Maximum °C	27.8	27.9	27.8	25.9	24.5	23.6	23.5	24.6	26.1	27.5	28.1	28.3	26.3
Temp. Minimum °C	17.3	17.1	17.1	16.7	15.1	12.2	11.3	12.1	12 9	14.3	15.8	17.4	14.9
Temp. day °C	24.4	24.5	24.4	22.9	21.5	19.9	19.6	20.6	21.9	23.3	24.2	24.8	22.7
Temp. night °C	20.5	20.5	20.4	19.6	18.1	15.8	15.2	16.1	17.2	18.6	19.8	20.9	18.6
Temp. difference day/night °C	3.9	4.0	4.0	3.3	3.4	4.1	4.4	4.5	4.7	4.5	4.4	3.9	4.1
ETo	149	149	148	144	138	131	128	133	136	142	146	149	
1/2 ETo	74	74	74	72	69	65	64	66	68	71	73	74	
LGP	+	+	+	+							+	+	

+: Denote growing period, where half potential evapotranspiration is less than precipitation at that particular month.

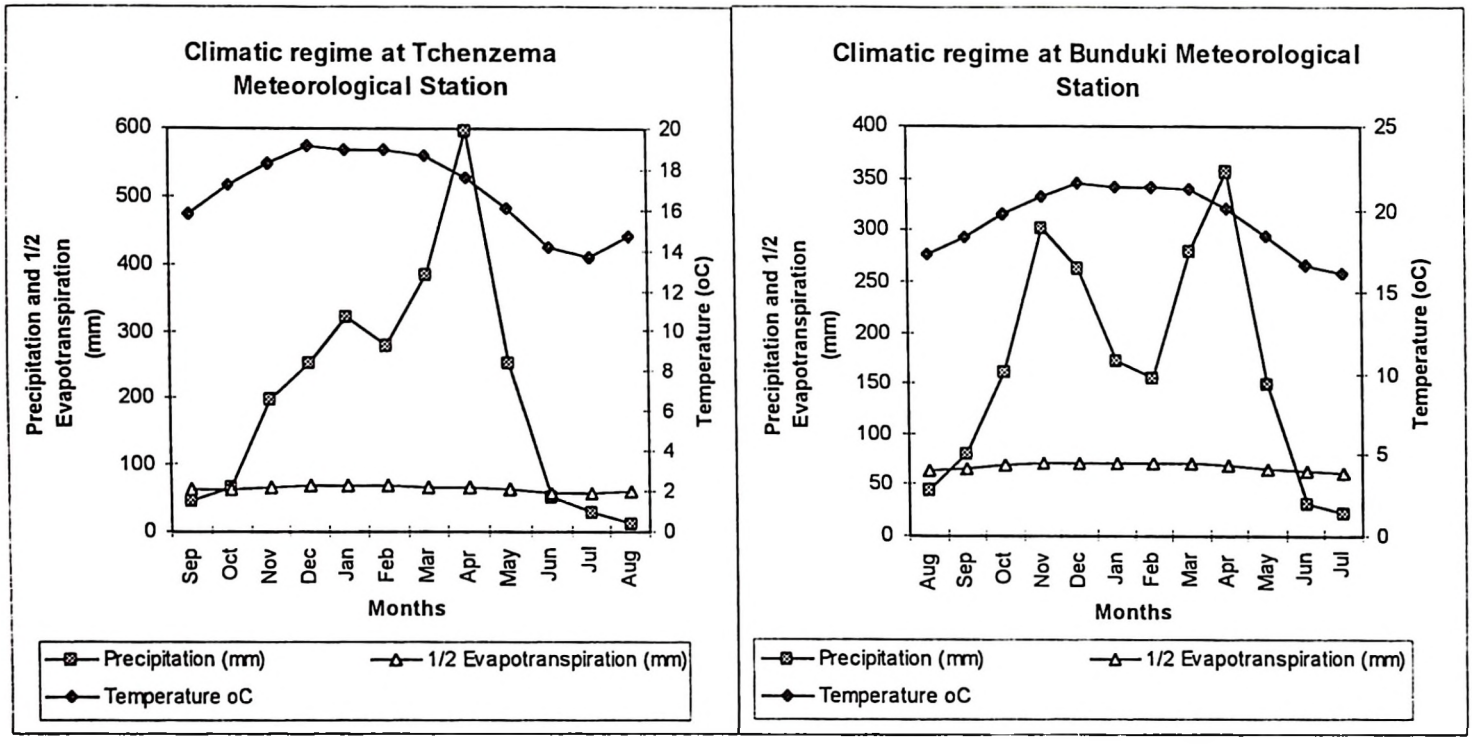

Figure 1. Climatic trends at Tchenzema and Bunduki Meteorological Stations

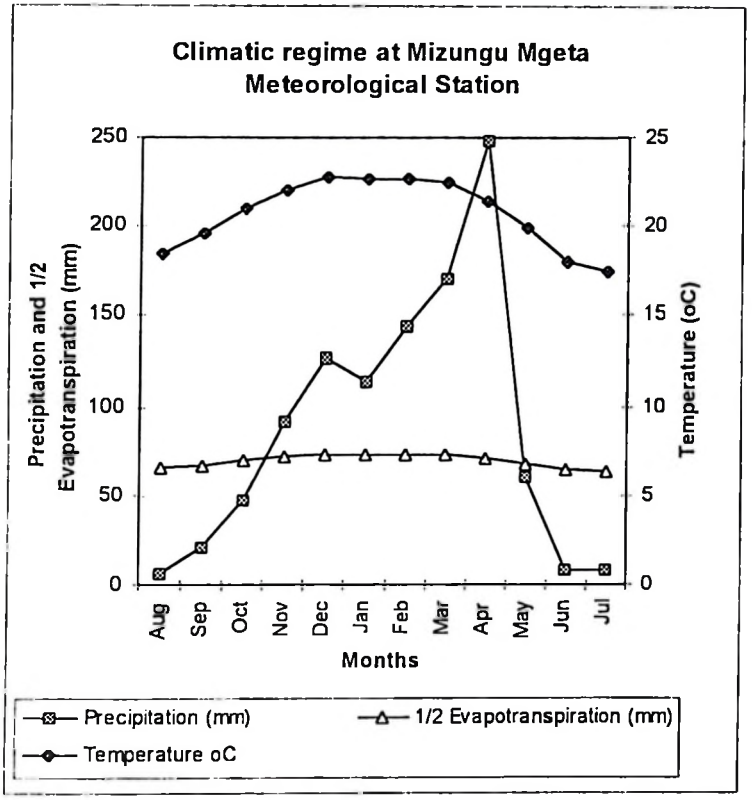

Figure 2. Climatic trend at Mizungu Mgeta Meteorological Station

4.2. Properties of Mgeta soils

4.2.1. Soil physical and morphological properties

Table 2 and Appendix 1 present the results of some physical and morphological characteristics of Mgeta soils, while a guide to general evaluation of some soil chemical and physical properties are given in Appendix 12.

Soil texture is the most stable physical characteristic of the soil which influences a number of other soil properties such as structure, consistence, soil moisture regime, permeability, infiltration rate, runoff rate, erodibility, workability, root penetration, and fertility (London, 1991). Clay, for instance has been reported to interact with organic matter and increases water and nutrient holding capacity and holds more water than sands due to its large surface area. The finer particles bind soils together into structural aggregates whilst the larger particles act as skeleton to the soil and making the soil aerated and permeable (Thomson and Troeh, 1985).

In Mgeta area most topsoils have a sandy clay loam, clay and sandy loam textures, with an exception of profiles MGP-12 and MGP-15 which have clay loam texture and MGP-16 which has loam texture. The subsoils of most profiles are sandy clay loams to sandy loams, clays to clay loams or sandy clay loams with an exception of profile MGP-16 which has loamy texture. In soils developed from meta-anorthosite, meta-gabbroic anorthosite and meta-anorthositic gabbro and banded pyroxene granulites parent materials, sand fractions increase with soil depth, while areas dominated by kaolinitic clays have relatively lower values of sand fractions in subsoils and higher values

in the deeper soils than topsoils. Silt fractions increase with depth in meta-anorthosite, meta-gabbroic anorthosite and meta-anorthositic gabbro and on kaolinitic clays. On the other hand silt fractions decrease with soil depth in banded pyroxene granulites. The subsoils of the profiles developed from kaolinitic clays have much higher content of clay than those developed fom other parent materials (Figure 3).

Most topsoils of Mgeta area have weak to strong, fine and medium subangular blocky stractures. Most subsoils in banded pyroxene granulites and kaolinitic clays have weak to strong very fine to coarse subangular blocky stractures while most subsoils and deeper horizons in meta-anorthosite, meta-gabbroic anorthosite and meta-anorthositic gabbro are stractureless massive (Table 2). Mgeta soils are soft when dry, friable when moist and non sticky to sticky, non plastic to plastic when wet except soil profiles MGP-9, MGP-12, MGP-24 which have slightly hard to hard consistence in topsoils. The subsoils are soft to slightly hard when dry, friable to firm when moist and non sticky to sticky, non plastic to plastic when wet (Appendix 1)

Table 2. Selected physical and morphological properties of Mgeta soils

Profile no.	Depth (cm)	Particle size distribution			Textural class	Colour	Drainage class	structrure	Bulk density (g/cc)	Available water capacity mm/m
		Sand	Silt	Clay						
MGP-1	0-20	63	15	22	SCL	vdg (10YR3/1)	well	moderate	1.3	
	20-45	59	16	25	SCL	vdgb (10YR3/2)		moderate	1.5	
	45-75	63	14	23	SCL	dyb (10YR3/4)		moderate	1.7	92 mm/75 cm
MGP-2	0-18	16	28	56	C	db (7.5YR4/4)	well	weak	1.1	
	18-46	12	34	54	C	sb (7.5YR5/6)		moderate	1.1	
	46-85	15	37	48	C	sb (7.5YR5/6		strong	1.1	104
	85-130	19	40	41	SiC	sb (7.5YR5/8)		moderate	1.2	
MGP-3	0-18/25	16	30	54	C	bl (7.5YR2.5/1)	well	weak	1.1	
	18/25-85	7	33	60	C	sb (7.5YR5/6)		moderate	1.2	
	85-193	25	37	38	CL	ry (7.5YR6/8)		moderate	1.3	101
MGP-4	0-15/18	6	32	62	C	dgb (10YR4/2)	well	weak	1.1	
	15/18-57/63	3	31	66	C	sb (7.5YR4/6)		moderate	1.2	
	57/63-130/140	22	46	32	CL	yb (10YR5/4)		weak	1.3	77
	130/140-235	73	15	12	SL	sb (7.5YR5/6)		massive	1.3	
MGP-5	0-25/30	22	26	52	C	vdg (5YR3/1)	well	moderate	1.1	
	25/30-95/110	25	43	32	CL	ry (7.5YR6/6)		massive	1.2	
	95/110-160	42	40	18	L	vpy (10YR8/3)		massive	1.2	103
MGP-6	0-24/30	60	20	20	SCL	bl(5YR2.5/1)	somewhat excessive	moderate	1.1	20 mm/30 cm
	24/30-100	73	17	10	SL					
MGP-7	40/50-95	64	20	16	SL	vdb (10YR2/2)	well	strong	1.1	
	95-150	80	8	12	SL	dyb (10YR3/4)		moderate	1.5	35 mm/ 50 cm
MGP-8	0-45	56	24	20	SL-SCL	py (2.5Y7/4)	somewha excessive	moderate	1.1	
	45-185	74	14	12	SL			massive	1.7	132
MGP-9	0-25/30	48	17	35	SCL	bl (7.5YR2.5/1)	well	strong	1.3	
	25/30-80/110	67	13	20	SCL	db (7.5YR3/2)		massive	1.8	
	80/110-180	81	5	14	SL			massive	1.9	143
MGP-10	0-14/24	69	5	26	SCL	vdb (7.5YR2.5/2)	well	moderate	1.3	
	14/24-30/35	66	8	26	SCL	db (7.5YR3/2)		moderate	1.5	
	30/35-44/64	75	9	16	SL	b (7.5YR4/3)		weak	1.5	
	44/64-140	87	3	10	SL	lb (7.5YR6/4)		massive	1.9	152
MGP-11	0-45	74	6	20	SCL	dob (2.5Y3/3	well	moderate	1.1	
	45-125	63	15	22	SCL	vdgb (10YR3/2)		massive	1.6	
	125-155	81	5	14	SL	vdgb (10YR3/2)		massive	1.6	167
	155-190	67	17	16	SL	dyb (10YR3/6)		massive		
MGP-12	0-15/20	43	19	38	CL	bl (7.5YR2.5/1)	well	moderate	1.1	
	15/20-30/50	51	15	34	SCL	dg (7.5YR5/1)		weak	1.5	
	30/50-150	67	15	18	SL	lg (7.5YR7/1)		massive	1.8	112

Table 2. Continued

Profile No	Depth (cm)	Sand	Silt	Clay	Textural class	Colour	Drainage class	Structure	Bulk density g/cc	Available water capacity mm/m
MGP-13	0-10 16	59	15	26	SCL	vdg (7.5YR3/1)	well	weak	1.3	
	10 16-66 80	67	13	20	SCL	dgb (10YR4/2)		massive	1.7	
	66 80-180	75	11	14	SL	w (7.5YR8/1)		massive	1 8	91
MGP-14	0-20 30	49	19	32	SCL	db (7.5YR3/2)	well	strong	1.4	
	20 30-65 75	33	23	44	C	sb (7.5YR5/8)		moderate	1.4	
	65 75-200	61	15	24	SCL	py (5Y7/3)		weak	1.6	97
MGP-15	0-40/50	42	22	36	CL	bl (7.5YR2.5/1)	well	strong	1.0	
	40/50-130/150	24	20	56	C	db (7.5YR3/4)		moderate	1.8	136
	130/150-200	43	19	38	CL	b (7.5YR4/4)		moderate	1.3	
MGP-16	0-5					dgb (10YR4/2)	well	weak	1.2	
	5-45	46	39.2	14.8	L	dyb (10YR3/4)		moderate	1.2	
	45-70	40	42	18	L	dyb (10YR4/6)		moderate	1.5	
	70-120	37	47	16	L	yb (10YR5/6)		weak	1.7	81
MGP-17	0-40	70	22	8	SL	dyb (10YR4/4)	well	weak	1.2	
	40-65	71	17	12	SL	db (7.5YR3/2)		moderate	1.3	
	65-115	74	17	9	SL	db (7.5YR3/4)		moderate	1.3	130
	115-185	77	16	7	SL-LS	vdgb (10YR3/2)		weak	1.5	
	185-200	86	7	7	LS	vdg (10YR3/1)		weak	1.4	
MGP-18	0-12	60	23	17	SL	vdg (10YR3/1)	well	weak	1.3	
	12-26	59	25	16	SL	vdgb (10YR3/2)		moderate	1.4	28 mm/ 26 cm
MGP-19	0-15	64	12	24	SCL	bl (10YR2/1)	well	strong	1.3	
	15-50/60	60	14	26	SCL	bl (10YR2/1)		moderate	1.6	69 mm/ 60 cm
MGP-20	0-35/40	55	20	25	SCL	bl (5YR2.5/1)	well	moderate	1.1	
	35/40-70	60	22	18	SL	db (7.5YR3/4)		weak		49 mm/ 70 cm
MGP-21	0-12/18	62	19	19	SCL	db (7.5YR3/4)	somewhat excessive	weak	1.3	12 mm/ 18 cm
MGP-22	0-20/28	45	18	37	SCL	db (7.5YR4/2)	somewhat excessive	strong	1.3	18.3 mm/ 28 cm
MGP-23	0-20/26	69	6	25	SCL	db (7.5YR3/2)	somewhat excessive	moderate	1.3	13.6 mm/ 26 cm
MGP-24	0-20/25	44	18	38	CL	bl (7.5YR2.5/1)	somewhat excessive	moderately strong	1.1	16.4 mm/ 25 cm
MGP-25	0-26/30	23	27	50	C	vdg (5YR3/1)	well	moderate	1.1	108.2
	26/30-85/100	26	44	30	CL	yb (10YR5/4)		massive	1.2	
	85/100-120	43	41	16	L	vpb (10YR8/3)		massive	1.2	
MGP-26	0-40/50	42	21	37	CL	bl (7.5YR2.5/1)	well	very strong	1.0	127.3
	40/50-135/150	26	21	53	C	sb (7.5YR5/8)		moderate	1.3	
	135/150-190	42	19	39	CL	b (7.5YR4/4)		moderate	1.3	

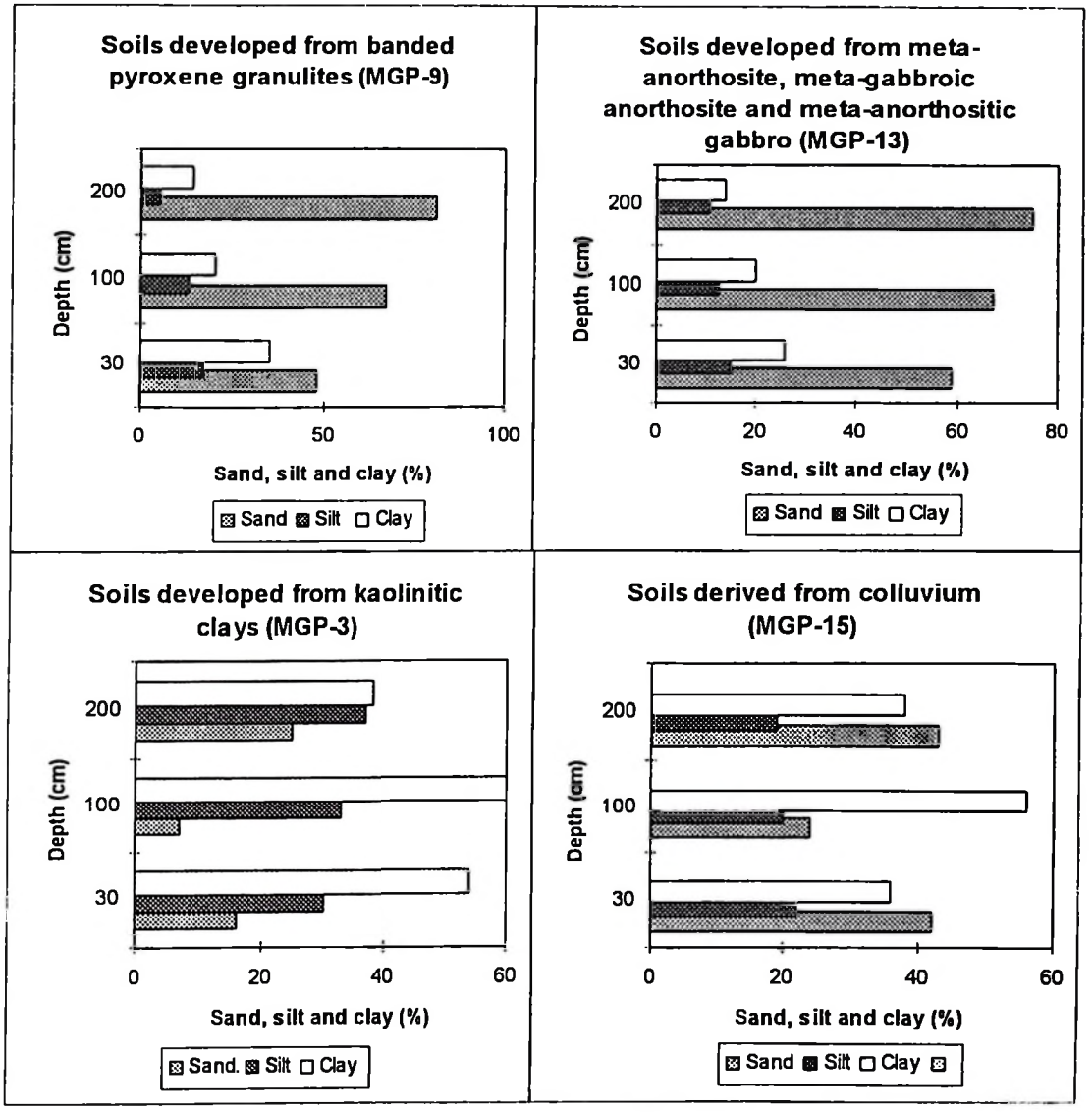

Figure 3. Particle size distribution from different parent materials of Mgeta soils

Bulk density is used as a guide to rate soil compaction, porosity, root penetration and aeration (London, 1991). Bulk densities above 1.8 g/cc for sands or 1.5 and 1.6 g/cc for silts and clays cause hinderance to root penetration (de Geus, 1973). The bulk densities of most topsoils range from 1.0 to 1.4 g/cc and 1.1 to 1.9 g/cc in the subsoils (Table 2). The bulk densities of most topsoils are relatively lower than those of the subsoils. The bulk density values of most soils do not pose any problem to root penetration and aeration.

Water retention characteristics for three depths surface (0 - 5 cm), intermediate (45 - 50 cm) and subsoil (95 - 100 cm) were determined and the results are presented in Table 2 and Figure 4. The available water capacity ranges from low to high (77 to 167 mm/m). Profiles/horizons having large amount of clay have relatively low available water than loamy textured profiles (Figure 4). This behaviour is probably due to large proportions of micropores in clay soils which hold water tenaciously making it unavailable to plants, contrary to loamy soils which have relatively large amount of mesopores which hold water some how loosely thus making it available to plants. Most of the topsoils have higher available water than the subsoil, this is probably due to high organic matter content in topsoils.

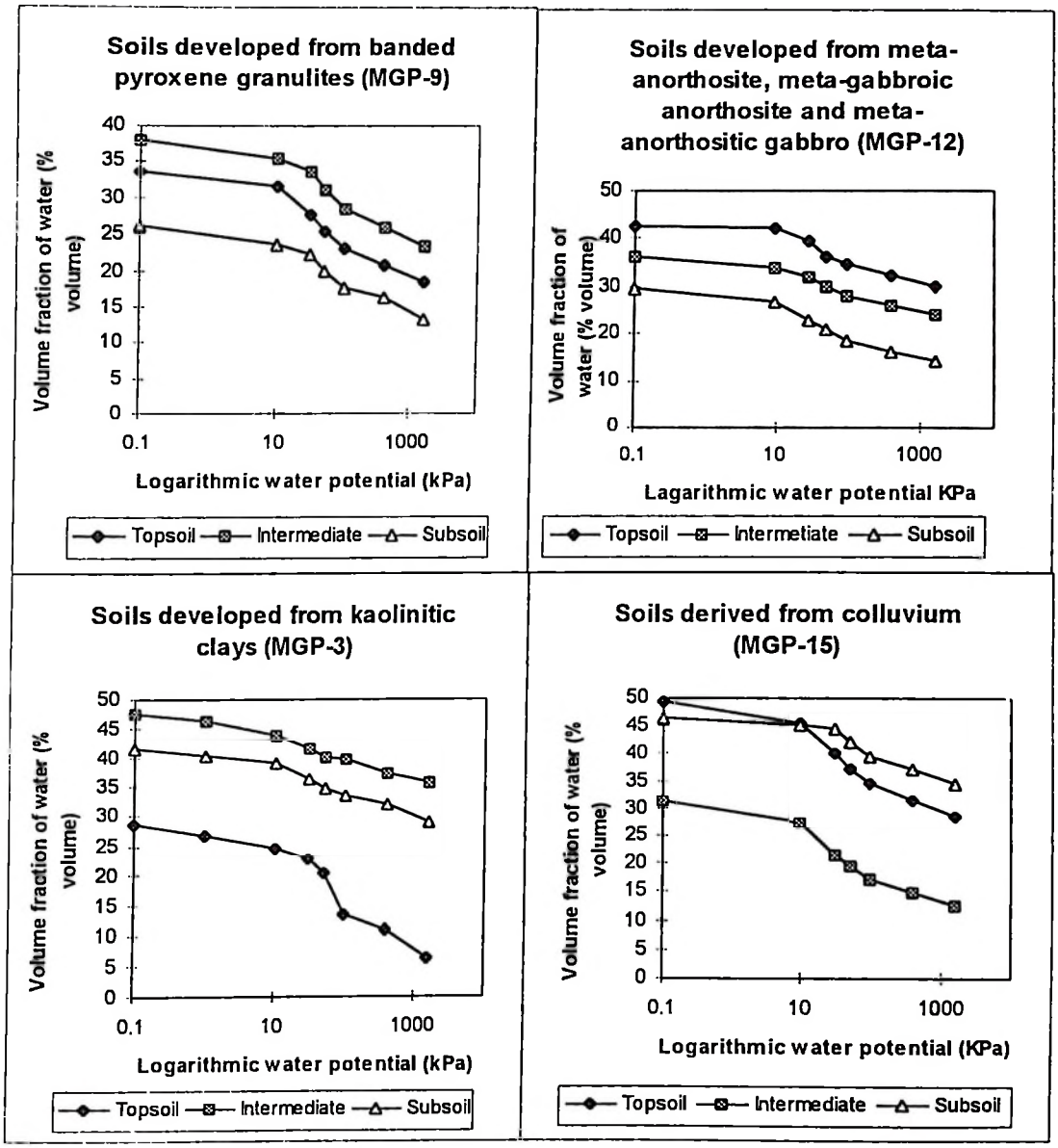

Figure 4. Soil moisture release curves of the soils of Mgeta developed from different parent materials.

4.2.2. Soil chemical properties

Soil reaction (pH)

Table 3 and Appendix 1 present some basic chemical characteristics of Mgeta soils. In most topsoils of Mgeta Area, the pH values range from strongly to slightly acid (5.1 to 6.5). The subsoils have pH values ranging from medium to slightly acid (5.6 to 6.5). The pH values of profiles MGP-7, MGP-16, MGP-17, MGP-20 and MGP-21 are extremely acidic in the topsoils whereas MGP-1 and MGP-4 have neutral pH subsoils. In general nearly all topsoils have lower pH values than subsoils, this trend is mostly due to leaching of exchangeable bases. Delta pH (pH_{water} - pH_{KCl}) values in all Mgeta profiles are positive, this tendence indicates that, the exchange complex of the colloidal fractions of the soils are mostly negatively charged (Bohn *et al.*, 1984). In general the exchangeable acidity for the studied soils is low less than 20% aluminium saturation, with an exception of profiles MGP-6, MGP-7, MGP-17, MGP-20 and MGP-21 have higher values of aluminium saturation ranging from 60 - 78% in topsoils and up to 16% in subsoils.

Organic carbon (OC) and total nitrogen (N)

Organic carbon content range from medium to very high (1.8 to 11.3 percent) in topsoils, with an exception of MGP-8, MGP-9 and MGP-22 which have very low and low (0.19 to 1.7 %) organic carbon respectively. The levels of organic carbon in the subsoils are low to very low.

Table 3. Some chemical properties of Mgeta soils

Profile no.	Effective soil depth (cm)	Horizon	pH		OC %	Tot. N (%)	C/N	Avail. P (Bray1) (mg P/kg)	CEC cmol(+)/ kg soil	% BS	Exch. bases cmol(+)/kg soil				Exch. Acidity cmol(+)/kg soil	
			H_2O	1N KCl							Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	H^{+}	Al^{3+}
MGP-1	75	Ap	5.6	4.2	5.06	0.51	9.9	4.4	17.2	60.7	7.07	3.10	0.15	0.10	0.11	0.1
		Bw	6.2	4.2	2.69	0.26	10.4	2.3	19.9	67.3	11.7	1.46	0.06	0.18	-	-
		BC	6.7	5.4	0.94	0.08	11.8	1.8	12.6	90.6	9.8	1.44	0.04	0.16	-	-
MGP-2	130	AP	6.2	5.2	6.73	0.28	23.9	1.24	25	50.6	10.0	2.44	0.08	0.14	-	-
		AB	6.4	4.9	0.81	0.10	8.2	0.11	14.1	52.7	4.71	2.56	0.03	0.12	-	-
		Bw	5.8	4.4	0.50	0.04	13.6	0.11	15.2	46.6	3.86	2.13	0.01	0.14	-	-
		BC	6.1	4.2	0.18	0.01	21.2	0.07	12.8	41.3	3.11	1.87	0.03	0.27	-	-
MGP-3	193	AP	5.5	4.3	5.17	0.3	13.	2.18	24.4	17.5	2.61	0.69	0.11	0.17	0.3	0.7
		Bt	5.4	4.0	0.83	0.06	12.9	0.62	10.4	14.4	0.88	0.50	0.04	0.07	0.2	1.1
		BC	5.8	4.0	0.30	0.01	35.4	0.88	8.0	13.9	0.65	0.23	0.04	0.19	0.1	1.0
MGP-4	235	AP	5.6	4.4	5.50	0.19	28.9	1.58	22.1	28.9	4.3	1.99	0.06	0.05	-	-
		Bt	6.4	5.0	0.45	0.057	7.9	1.46	21.2	29.7	4.05	2.17	0.04	0.05	-	-
		CB	6.8	4.8	0.32	0.015	20.6	6.8	9.2	68.7	3.87	2.35	0.04	0.07	-	-
		CR	6.6	4.4	0.04	0.011	2.6	131.6	12.0	27.2	1.64	1.52	0.06	0.05	-	-
MGP-5	160	Ah	5.5	4.5	6.18	0.18	33.7	3.98	12.4	55.1	4.62	1.68	0.38	0.14	0.08	0.08
		C1	5.6	4.0	0.26	0.019	13.6	0.67	10.0	35.9	2.59	0.79	0.04	0.17	0.15	0.55
		C2	6.0	4.0	0.20	0.0014	40.4	1.82	9.2	50.7	3.63	0.76	0.06	0.22	0.1	0.15
MGP-6	30	Ah	5.1	4.1	10.9	0.54	20.1	0.78	38.4	1.6	0.15	0.22	0.13	0.10	0.15	1.75
		CR	5.6	4.3	0.25	0.01	25	0.2	5.9	1.5	0.02	0.03	0.01	0.03	0.02	0.03
MGP-7	100	O													-	-
		Ah	4.8	3.8	11.3	0.76	14.8	7.54	40.0	4.4	0.78	0.657	0.22	0.09	0.75	4.1
		Bw	5.3	4.5	1.4	0.03	47.1	7.75	8.0	2.6	0.08	0.092	0.013	0.02	0.08	0.38
MGP-8	185	Ah	5.6	3.3	0.14	0.003	49.5	5.36	8.0	99.2	7.77	0.88	0.13	0.14	0.35	1.25
		C	6.7	3.2	0.06	0.0014	42.4	5.37	3.4	356.4	10.7	0.49	0.06	0.20	-	-
MGP-9	180	Ap	6.6	4.7	1.8	0.13	14	3.8	17.8	86.5	9.2	5.1	1.02	0.13	-	-
		C1	6.9	4.6	0.2	0.02	8.8	1.8	13.2	98.9	8.4	4.5	1.13	0.04	-	-
		C2	7.4	4.3	0.12	0.003	42.4	0.8	8.4	132.6	7.1	4.0	0.06	0.05	-	-
MGP-10	140	Ap	6.1	4.4	1.9	0.12	16.3	1.8	11.6	46.7	3.5	1.2	0.6	0.07	-	-
		AB	6.0	4.2	1.2	0.08	15.2	1.6	8.6	40.1	2.5	0.7	0.3	0.03	-	-
		Bw	6.3	4.3	0.8	0.04	21.8	4.5	4.4	42.7	1.3	0.3	0.2	0.03	-	-
		C	6.6	4.5	0.3	0.01	32.5	40.1	3.2	50.9	1.0	0.2	0.4	0.12	-	-
MGP-11	190	Ap	6.9	5.4	0.69	0.07	9.7	23.1	8.2	86.4	5.0	1.1	0.83	0.12	-	-
		2C	6.5	4.7	1.27	0.08	16.2	9.5	7.4	98.2	5.4	1.5	0.22	0.15	-	-
		3C	6.4	4.4	0.67	0.03	20.5	8.7	4.2	81.1	2.5	0.8	0.07	0.09	-	-
		4C	7.4	5.0	0.59	0.03	22.9	6.1	6.8	177.9	5.7	6.0	0.02	0.35	-	-

Table 3. continued

Profile no	Effective soils depth	Horizon	pH H_2O	pH KCl	OC%	N%	C/N	Avail. P (Bray 1) mg/kg	CEC cmol (+)/kg	BS%	Ca	Mg	K	Na	H	Al
MGP-12	150	Ap	5.5	4.0	3.25	0.19	17.0	6.4	17.2	62.1	8.2	1.98	0.32	0.15	0.2	1.1
		Bw	6.4	4.3	1.15	0.07	16.1	2.5	10	84.1	7.2	0.82	0.07	0.32	-	-
		C1	7.6	4 6	0.40	0.01	33.3	1.5	5.2	136.5	6.3	0 51	0.02	0.23	-	-
MGP-13	180	Ap	6.2	4.4	2.5	0.15	17.5	5.7	12.6	79.6	7.8	1.6	0.5	0.09	-	-
		C1	6.7	4.2	0.7	0.04	19.6	0.07	9.5	106.5	8.5	1.2	0.4	0.09	-	-
		C2	7.2	4.0	0.3	0.01	37.7	2.3	3.4	321.9	9.5	1.3	0.06	0.13	-	-
MGP-14	190	Ap	6.1	4.7	2.97	0.22	13.6	24.2	16.4	65.7	7.1	2.3	1.2	0.2	-	-
		Bt	6.4	4.9	0.79	0.04	18.3	4.6	10.6	66.5	4.8	1.8	0.3	0.3	-	-
		C	6.9	4.6	0.52	0.02	23.0	27.7	4.3	188.0	5.2	2.5	0.2	0.2	-	-
MGP-15	200	Ap	6.5	5.3	7.84	0.46	16.9	5.0	30.4	94.1	24.1	4.1	0.34	0.1	-	-
		Bt	6.5	4.9	1.43	0.13	10.9	0.6	8.8	127.4	8.1	2.9	0.06	0.09	-	-
		BC	6.8	4.7	0.27	0.03	9.4	19.4	10.4	121.1	9.0	3.5	0.04	0.15	-	-
MGP-16	120	Ah	4.5	3.7	6.1	0.23	26.5	54.0	34 2	21.7	3.2	4.1	0.09	0.02	0.8	1.2
		AB	4.7	3.8	2.89	0.11	26.4	56.0	29.9	21.0	2.69	3.51	0.07	0.03	0.5	1.4
		Bw	5.9	3.8	1.89	0.06	31.7	57.0	22.0	12.2	1.51	1.04	0.06	0.08	0.2	1.1
		BC	5.0	3.6	0.3	0.01	30.0	78.9	11.6	8.7	0.42	0.42	0.15	0.03	0.06	0.9
MGP-17	200	Ap	4.4	3.6	4 33	0.62	7.0	11.7	49.7	0.86	0.33	0 00	0.05	0.05	0.3	1.2
		Bh	5.0	3.7	1.2	0.2	6.0	61.9	49.2	13.1	5.10	1.22	0.05	0.08	0.2	1.2
		Bir	5.1	4.1	0.4	0.03	13.3	26.2	39.3	6.5	2.28	0 00	0.07	0.22	0.1	1.1
		BC	5.2	4.0	0.09	0.007	12.9	40.8	48.0	0.95	0.33	0.00	0.02	0.11	0.07	0.7
		2Ab	5.3	4.3	0.09	0.04	22.5	74.6	44.6	0.67	0 15	0 00	0.05	0.10	0.05	0.5
MGP-18	26	Ap	5.4	5.1	1.53	5.4	5.1	105.4	39.8	54.7	17.3	3.31	0.98	0.18	0.3	0.9
		Bw	5.8	5.2	4.56	5.8	5.2	102.8	37.2	56.9	16.9	3.14	1.00	0.14	0.15	0.5
MGP-19	60	Ah	6.2	5.1	2.4	0.18	13.7	52.7	14.4	86.7	8.1	3.8	0.45	0.1	-	-
		AB	6.2	4.9	1.98	0.13	14.7	26.0	12.4	82.6	6.7	3.13	0.27	0.14	-	-
MGP-20	70	Ah	4.3	3.9	9.1	0.7	20.1	1.4	32.5	4.4	0.25	0.22	0.39	0.56	0.17	1.94
		Bw	4.6	4.1	1.2	0.06	24.0	0.3	8.5	9.5	0.12	0.09	0.13	0.47	0.11	1.6
MGP-21	12/18	Ah	5.0	4.2	6.2	0.28	22.1	0.76	31.5	1.59	0.12	0.22	0.11	0.05	0.17	1.77
MGP-22	20/28	Ap	6.5	4.6	1.69	0.12	14.1	3.4	16.5	94	9.0	4.7	1.3	0.15	-	-
MGP-23	*20/26*	Ah	6.1	4.4	1.8	0.11	16.4	1.5	11.4	39	3.0	1.1	0.3	0.05	-	-
MGP-24	20/25	Ap	5.4	4.1	3.15	0.17	18.5	6.1	17.1	60.4	8.6	1.2	0.42	0.11	0.25	1.12
MGP-25	120	Ap	5.6	4.6	3.2	0.16	20	3.8	16.8	38.8	4.1	1.8	0.5	0.11	0.07	0.07
		C1	5.6	4.2	0.21	0.02	10.5	0.91	9.4	39.4	2.4	1.1	0.05	0.15	0.14	0.54
		C2	6.1	4.3	0.15	0.01	15.0	1.2	8.7	51.3	3.1	1 1	0.06	0.2	0.09	0.14
MGP-26	190	Ap	6.1	4.3	6.3	0.25	25.2	3.3	28.6	52.5	9.5	5.2	0.21	0.1	-	-
		Bt	6.4	4.6	0.66	0.08	8.3	1.6	12.5	57.8	5.1	2.0	0.05	0.08	-	-
		BC	6.8	4.8	0.31	0.03	10.3	35.2	11.1	63.4	5.0	1.9	0.03	0.11	-	-

Most of the topsoils have nitrogen levels ranging from low to high (0.12 to 5.8 %) with an exception of profile MGP-8 which has very low N values. All subsoils have very low N content except profile MGP-15, MGP-17, MGP-18 which have low N values and MGP-18 which has high N values. There is a positive correlation between organic carbon and total nitrogen. This trend was also found by Msanya, *et al.* (2000).

The C/N ratio gives an indication of the quality of the organic matter and in particular the degree of humification (London, 1991). The C/N ratio in the most topsoils of Mgeta Area range from 8 to 20. This range represents the soils with good to moderate quality organic matter respectively. However, there are some few profiles having C/N ratio greater than 20 showing poor quality organic matter.

Available phosphorus (P)

The topsoils of Mgeta area have low to medium levels of available phosphorus (less than 7 to 20 mg/kg), while profiles MGP-11, MGP-14, MGP-16, MGP-18 and MGP-19 have high values of P ranging from 23.1 to 105 mg/kg. Most of the soils with low P content situated on the summits and slopes. The low P content in these soils may be attributed by low pH values which intern enhances P-fixation capacity of the soils. The low levels of phosphorus in the soils indicate a potential problem of deficiency to sensitive crops.

Cation exchange capacity (CEC)

CEC is the measure of the capacity of soil to retain nutrients (against leaching) (Msanya *et al.*, 1996). The topsoils of Mgeta Area have medium to high values of CEC

(12.4 to 40 cmol (+)/kg), with an exception of profiles MGP-17 and MGP-10 and MGP-11 which have very high and very low CEC values respectively. The relatively high CEC values in the topsoils can be attributed to the higher values of OC content. The CEC values of subsoils are relatively lower than those of the topsoils. The values of CEC clay for most of clayey soils are relatively lower in topsoils while most of loamy soils have relatively higher values in topsoils as compared with subsoils. The low values of CEC clay in the subsoils indicate that the soils are highly weathered. The CEC usually gives an idea of the potential fertility of the soil. London, (1991) reported ranges between 15 to 25 cmol (+)/kg to be satisfactory for growth of most crops. Figure 5 indicates that, organic matter contributes more to the CEC of the soil than clay does.

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

The levels of exchangeable Ca in the soils of the study area are low to very high (0.78 to 24.1 cmol (+)/kg) except soil profiles MGP-6, MGP-17, MGP-20 and MGP-21 which have very low values (0.12 to 0.33 cmol (+)/kg). The levels of exchangeable Mg range from low to very high (0.7 to 5.2 cmol (+)/kg) except profiles MGP-6, MGP-20 and MGP-21 which have very low values in the topsoils. The levels of exchangeable Mg in subsoils range from low to high (0.8 to 4.5 cmol (+)/kg) except profiles MGP-6, MGP-7, MGP-17 and MGP-20 which have very low values (0.03 to 0.15 cmol (+)/kg). The levels of exchangeable K of Mgeta soils are very low to high (0.01 to 1.3 cmol (+)/kg). These levels of exchangeable bases are according to Msanya *et al.* (1996). The low values of these basic cations indicate that most of the soils are highly weathered. The

general trend as it is shown in Figure 6 indicates that, most of the basic cations decreases with depth in all soils except the soils developed from meta-anorthosite, meta-gabbroic anorthosite and meta-anorthositic gabbro where calcium content increases with depth. The increase in Ca levels with soil depth may be explained by the fact that, most of the soils developed from this rock type has topsoils overlying saprolite which are rich in calcium.

Base saturation

Levels of base saturation (BS) in most topsoils are medium to very high (40 to 99 %) except profiles MGP-3, MGP-6, MGP-7, MGP-17, MGP-20 and MGP-21 which have very low BS (0.86 to 17.5 %). Profiles MGP-4 and MGP-16 have low BS values ranging from (21 to 29 %) in the topsoils. Most of the subsoils and saprolites have relatively higher base saturation than topsoils due to the low CEC and high pH values in the subsoils.

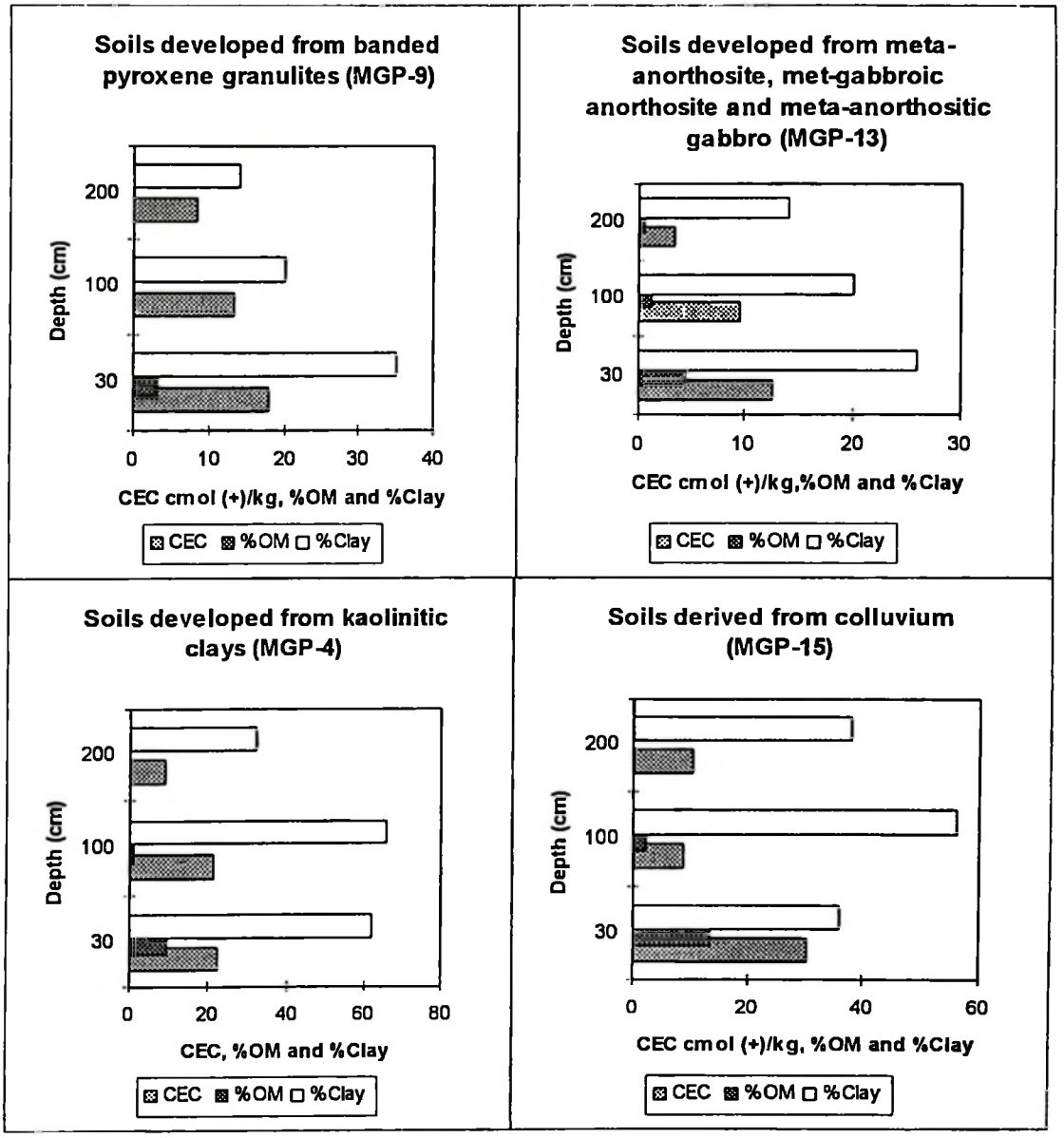

Figure 5. Variation of cation exchange capacity with organic matter and clay content of soils developed from different geological formations of Mgeta Area.

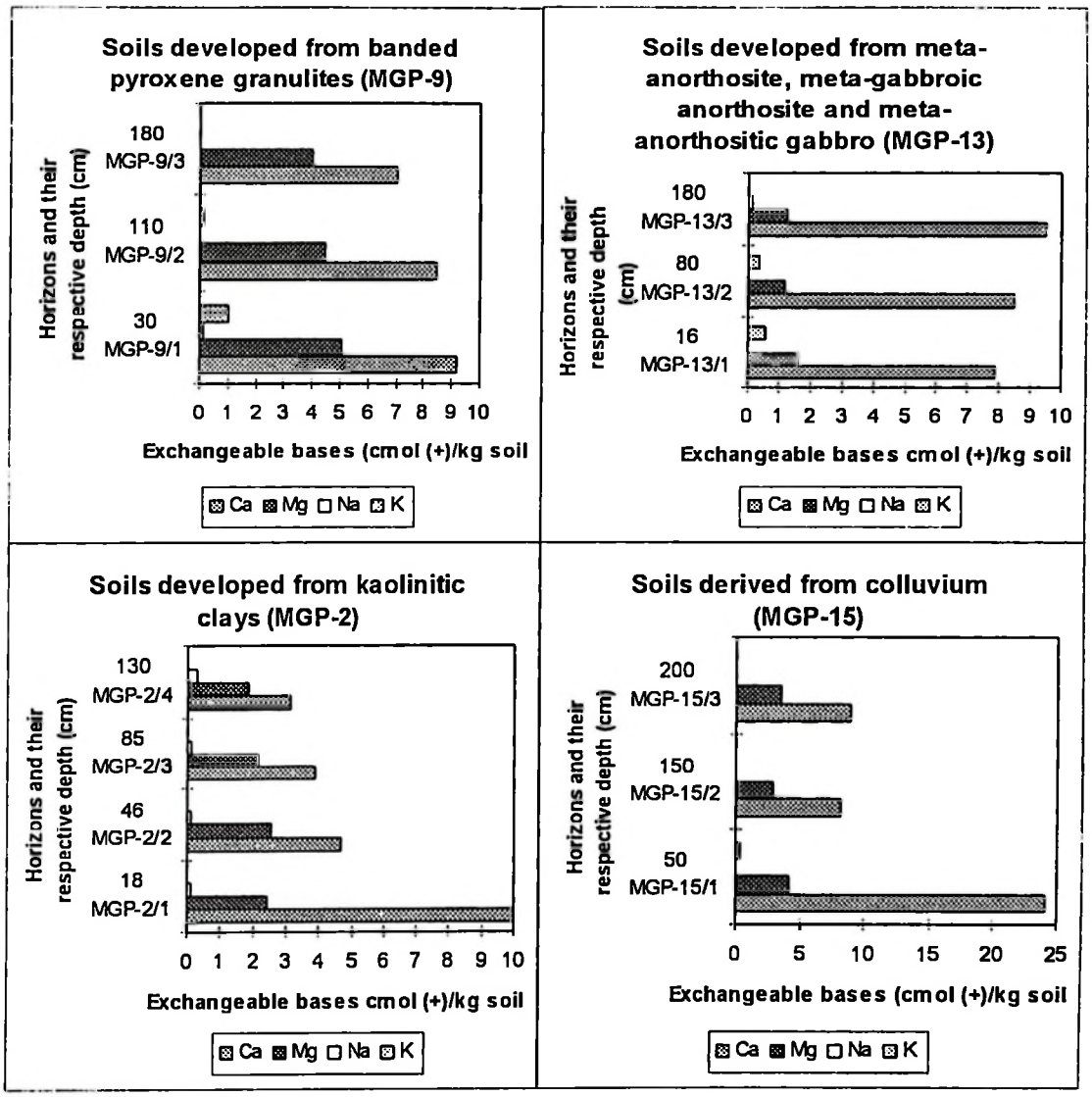

Figure 6. Distribution of exchangeable bases in soils of Mgeta developed from different parent materials.

Micronutrient elements Copper (Cu), Iron (Fe), Zinc (Zn), Manganese (Mn) and Boron (B)

Table 4 and Figure 7 presents the results of some important micronutrient elements of the study area. The concentration of micronutrient elements of most profiles decreases with soil depth, this was also noted by Bhandari and Randawa (1995). This situation is due to organic matter accumulation in the surface soils which apparently provide favourable environment for the availability of the micronutrients. The availability of micronutrient elements in most profiles are negatively correlated with soil pH. The levels of zinc and boron in all profiles is very low ranging from (0.01 to 0.9 mg/kg) and (0.01 to 0.2 mg/kg) respectively with an exception of MGP-17 which have higher boron value of (0.5 mg/kg) in subsoils and higher values of zinc (2.7 mg/kg) in topsoils and MGP-15 have 4.7 mg/kg zinc in topsoil. The values of copper range from (0.15 to 7.6 mg/kg) in topsoils to (29.7 mg/kg) in subsoils and (98.9 mg/kg) in the saprolite. The critical level for zinc by the DTPA method is estimated at (0.2 to 2.0 mg/kg) and that of copper ranges from (0.12 to 0.25 mg/kg) (Sims and Johnson, 1991). The levels of manganese range from low to very high (0.15 to 140 mg/kg). The iron levels are very high (21 to 206 mg/kg) in topsoils while the iron levels in subsoils are relatively lower (Table 4). The relatively high levels of iron in these soils could probably be associated with the parent materials from which these soils are derived, while the higher level of manganese in topsoils are probably associated with influence of organic matter.

Table 4. DTPA extractable micronutrients

Profileno.	Soil depth (cm)	Horizon	Extractable micronutrients mg/kg				
			Cu	Fe	Mn	Zn	B
MGP-1	75	Ap	0.8	67.9	27.2	0.4	0.07
		Bw	0.6	45.2	11.6	0.3	0.05
		BC	0.2	17.1	18.3	0.2	0.04
MGP-2	130	AP	0.7	37.5	52.7	0.3	0.1
		AB	0.2	21.1	20.7	0.09	0.04
		Bw	0.4	12.5	4.1	0.04	0.02
		BC	0.4	9.1	0.7	0.14	0.03
MGP-3	193	AP	0.4	30.7	8.2	0.3	0.09
		Bt	0.3	36.8	0.57	0.05	0.06
		BC	0.3	6.5	0.08	0.06	0.07
MGP-4	235	AP	7.6	46.2	140	0.52	0.05
		Bt	29.7	16.9	22.7	0.08	0.03
		CB	25.3	22.5	2.8	0.04	0.01
		CR	98.9	31.1	0.3	0.01	0.02
MGP-5	160	Ah	0.65	28	36.6	0.09	0.05
		C1	0.46	5.8	1.2	0.05	0.04
		C2	0.14	3.8	0.7	0.04	0.01
MGP-6	30	Ah	1.6	33.9	0.28	0.23	0.11
		CR	0.12	23.6	0.09	0.04	0.03
MGP-7	100	O	-	-	-	-	-
		Ah	0.67	215	0.15	0.09	0.17
		Bw	0.21	30.5	0.19	0.03	0.03
MGP-8	185	Ah	0.7	15.2	1.0	0.24	0.03
		C	0.19	11	4.7	0.07	0.04
MGP-9	180	Ap	1.13	44.1	10.2	0.22	0.06
		C1	0.59	23.1	10.4	0.09	0.02
		C2	0.41	9.8	7.9	0.07	0.02
MGP-10	140	Ap	0.9	65.6	6.35	0.11	0.09
		AB	0.55	31.4	1.17	0.06	0.05
		Bw	0.22	9.0	1.28	0.02	0.04
		C	0.12	3.4	0.08	0.03	0.02
MGP-11	190	Ap	0.4	20.8	9.8	0.39	0.09
		2C	0.8	54.8	21.6	0.43	0.02
		3C	0.8	38.1	4.4	0.11	0.04
		4C	0.8	29.0	10.0	0.21	0.02
MGP-12	150	Ap	0.6	54.2	1.2	0.10	0.06
		Bw	0.12	8.24	0.34	0.04	0.04
		C1	0.11	2.12	1.22	0.03	0.01
MGP-13	180	Ap	0.27	36.3	9.4	0.06	0.04
		C1	0.17	8.9	1.5	0.03	0.04
		C2	0.17	6.3	2.1	0.04	0.01
MGP-14	190	Ap	1.13	129	92.4	0.7	0.06
		Bt	0.62	40.9	4.0	0.24	0.02
		C	0.26	35.4	6.5	0.14	0.01
MGP-15	200	Ap	1.1	79.8	114	4.7	0.2
		Bt	0.6	38.7	8.1	0.6	0.04
		BC	0.6	27.5	11.1	0.6	0.02
MGP-16	120	Ah	0.45	75.3	0.95	0.14	0.11
		AB	0.21	31.6	0.64	0.09	0.09
		Bw	0.16	8.5	0.18	0.03	0.05
		BC	0.11	3.7	0.07	0.01	0.02
MGP-17	200	Ap	1.1	72.4	93.6	2.7	0.13
		Bh	0.6	36.1	40.3	0.9	0.5
		Bir	0.6	30.6	32.7	0.6	0.04
		BC	0.53	25.8	51.7	0.7	0.02
		2Ab	0.17	15.3	18.4	0.3	0.02

Table 4. continued

MGP-18	26	Ap	1.2	102	83.2	0.6	0.05
		Bw	0.6	36.3	7.3	0.18	0.02
MGP-19	60	Ah	0.67	71.7	30.1	0.3	0.06
		AB	0.77	101	14.1	0.1	0.04
MGP-20	70	Ah	0.15	206	0.18	0.13	0.04
		Bw	0.07	38.4	0.11	0.08	0.03
MGP-21	12/18	Ah	1.3	30.2	0.31	0.22	0.09
MGP-22	20/28	Ap	1.1	51.2	9.5	0.31	0.07
MGP-23	*20/26*	Ah	0.8	60.2	7.6	0.09	0.05
MGP-24	20/25	Ap	0.54	55.3	1.4	0.09	0.03
MGP-25	120	Ap	0.6	30	38.6	0.1	0.06
		C1	0.51	5.3	1.1	0.05	0.05
		C2	0.12	3.6	0.6	0.01	0.01
MGP-26	190	Ap	0.9	62.1	110.2	1.8	0.19
		Bt	0.6	35.6	9.0	0.4	0.04
		BC	0.6	20.1	10.3	0.4	0.02

The critical levels for manganese and iron are 1.0 - 5.0 mg/kg and 2.5 - 5 mg/kg respectively (Sims and Johnson, 1991).

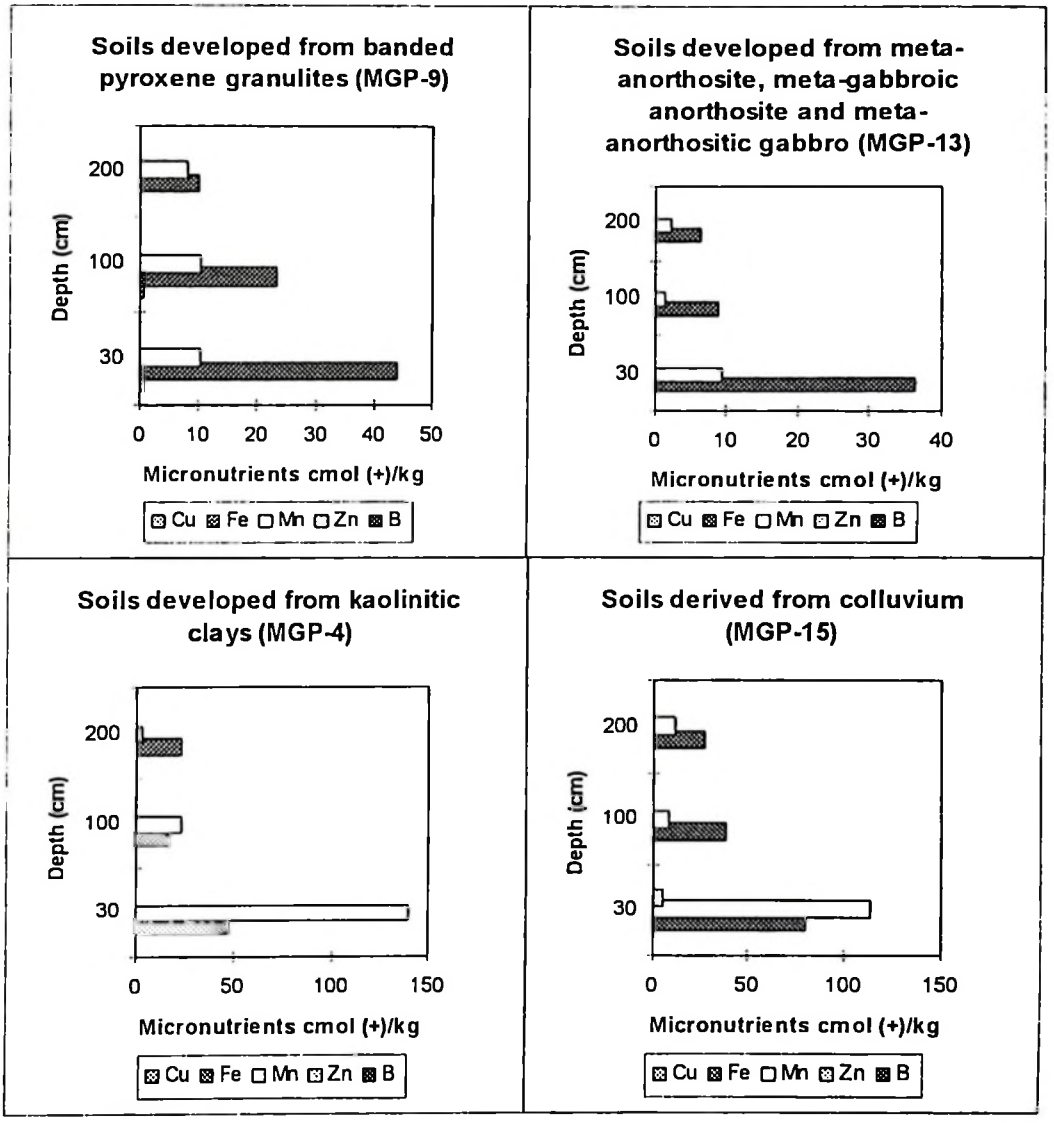

Figure 7. Distribution of micronutrients in soils of Mgeta developed from different parent materials

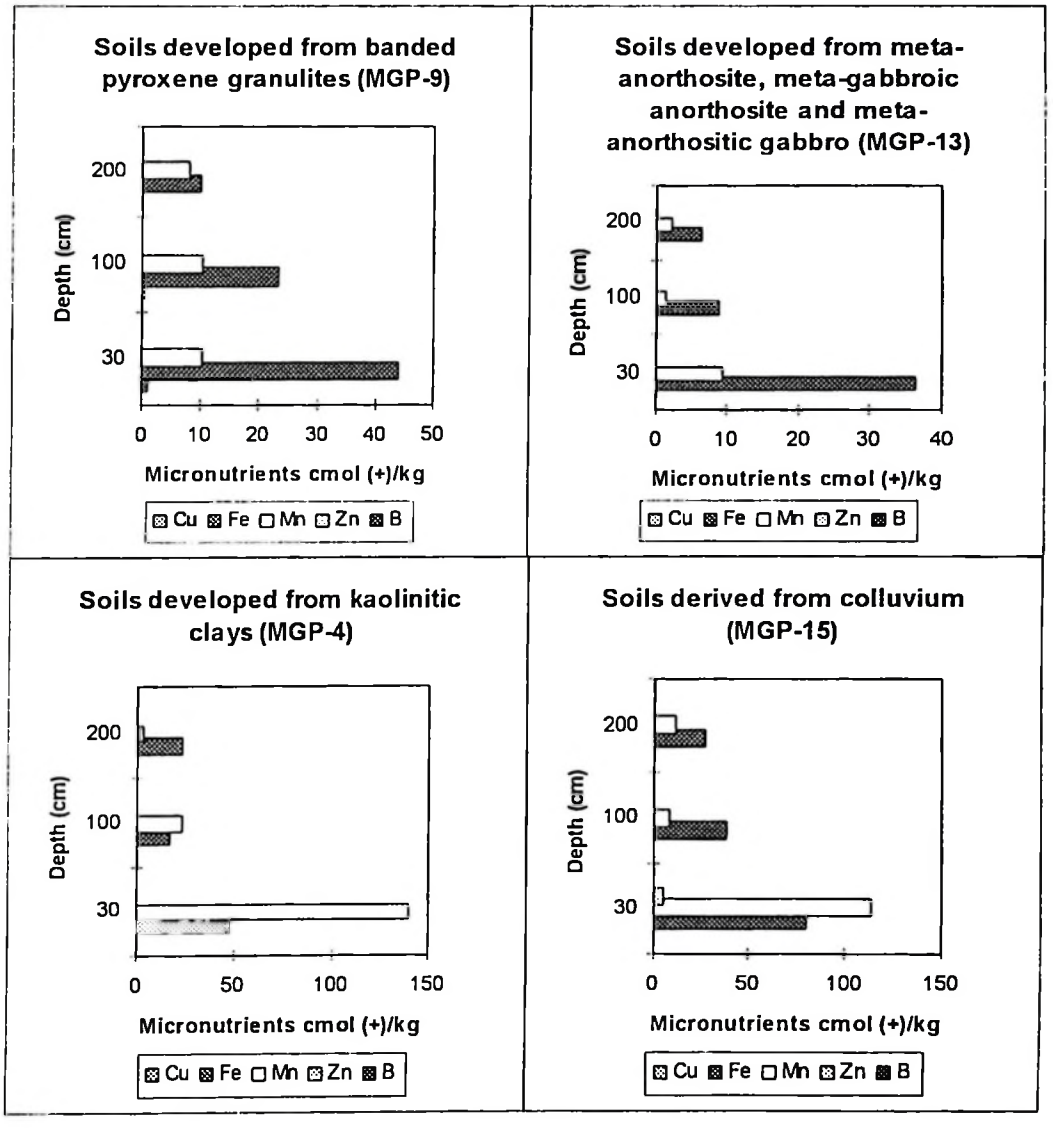

Figure 7. Distribution of micronutrients in soils of Mgeta developed from different parent materials

Nutrient balance

Table 4 presents nutrient ratios for topsoils of Mgeta Area. The Ca/Mg ratios of Mgeta soils are mostly optimal. However profiles MGP-8, MGP-13, MGP-15, MGP-18, and MGP-24 have relatively higher ratios, while profiles MGP-6, MGP-7, MGP-9, MGP-16, MGP-20, MGP-21, MGP-22 and MGP-26 have lower ratios. The optimal range for Ca/Mg ratios are between 2 and 4 which is considered favourable for most crops (London, 1991). When the ratio is equal or greater to 5:1, availability of Mg and P are reduced.

Mg/K ratios for most profiles range from 1 to 4. This range is considered optimal for nutrient uptake by plants (London, 1991). However, profiles MGP-1, MGP-2, MGP-3, MGP-4, MGP-8, MGP-12, MGP-15, MGP-16, MGP-19 and MGP-26 have Mg/K ratios between 6 and 45 which are likely to inhibit magnesium uptake by most crops.

Ca/TEB ratios in Mgeta soils mostly range from 0.43 to 0.87. These ratios indicate that calcium content in the studied soils is higher than other bases. However, profiles MGP-6, MGP-20 and MGP-21 have lower Ca/TEB ratios ranging from 0.18 to 0.25. The high Ca/TEB ratios affect uptake of other bases particularly Mg and/or K as Ca induced deficiency of Mg and/or K.

K/TEB saturation for Mgeta soils are above 2% except profiles MGP-1, MGP-2, MGP-4, MGP-8, MGP-15, MGP-16, and MGP-26 which have less than 2%. Landon (1991) reported that the favourable K/TEB saturation for most tropical crops is 2% or more.

Table 5. Nutrient ratios for topsoils of Mgeta soils

Prof.No	Ca/Mg	Mg/K	Ca/TEB	K/TEB
MGP-1	2.29	20.67	0.68	0.014
MGP-2	4.09	29.64	0.79	0.006
MGP-3	3.79	6.53	0.73	0.03
MGP-4	2.16	33.58	0.67	0.009
MGP-5	2.74	4.41	0.68	0.06
MGP-6	0.68	1.74	0.25	0.21
MGP-7	1.19	2.98	0.45	0.13
MGP-8	8.79	6.88	0.87	0.014
MGP-9	1.82	4.96	0.59	0.07
MGP-10	2.83	1.99	0.64	0.11
MGP-11	4.59	1.32	0.71	0.12
MGP-12	4.15	6.13	0.77	0.03
MGP-13	5.05	2.85	0.78	0.05
MGP-14	3.07	1.91	0.66	0.11
MGP-15	5.85	12.14	0.84	0.012
MGP-16	0.78	45.56	0.43	0.012
MGP-17	33	0.2	0.75	0.114
MGP-18	5.24	3.37	0.79	0.045
MGP-19	2.12	8.48	0.65	0.034
MGP-20	1.14	0.56	0.18	0.27
MGP-21	0.54	2	0.24	0.22
MGP-22	1.91	3.61	0.58	0.08
MGP-23	2.73	3.67	0.67	0.07
MGP-24	7.17	2.86	0.83	0.04
MGP-25	2.28	3.6	0.63	0.08
MGP-26	1.82	24.76	0.63	0.014

4.2.3. Soil classification

Soil morphological and other diagnostic features used in soil classification are presented in table 6 and 7. Table 8 presents the soil names according to the FAO World Reference Base (FAO, 1998) and USDA Soil Taxonomy (Soil Survey Staff, 1998) systems whereas soil map of the study area is presented in Appendix 13. Acoording to FAO-WRB soil classification system, the main soils of Mgeta Area are Umbrisols covering (25.3%), Cambisols (18.4%), Regosols (18.3%), Phaeozems (13.9%), Leptosols (11.9%), Fluvisols (7.8%), Luvisols (2.3%) and Acrisols (1.7%) of the total area. The summit areas dominated by banded pyroxene granulites occupied mainly with Leptosols (9.5%), Umbrisols (6.8%) and Cambisols (2.9%) while the slopes are occupied with Umbrisols (10.3%), Regosols (9.5%) and Leptosols (1.3%) of the total area. The summits dominated by meta-anorthosite, meta-gabbroic anorthosite and meta-anorthositic gabbro occupied with Cambisols (3.2%), Leptosols (1.1%) and Umbrisols (6.1%) while Regosols (6.1%) occupying mainly the slopes. The soils derived from colluvium are mainly Cambisols (5.5%), Phaeozems (3.9%), Regosols (2.7%) and Umbrisols (2.1%) of the total area. The main soils on the summits dominated by kaolinitic clays are Acrisols (1.7%) and Cambisols (1.2%) while the slopes have Luvisols (2.3%) and Phaeozems (2.3%) of the total area. The soils on the valley sides are mainly Phaeozems (7.8%) and Fluvisols (7.8%) of the total area.

The results show that some important qualifiers which were identified for separating the reference soil groups Phaeozems, Regosols and Cambisols into lower level units are missing in the FAO World Reference Base priority listing (FAO, 1998). Such qualifiers include: **Ferralic** and **Humic** for soil group Phaeozems, **Ferralic** for soil group Regosols and **Humic** for soil group Cambisol.

Table 7. Morphological and diagnostic features of Mgeta soils (USDA system)

Profile	Diagnostic surface horizons	Diagnostic subsurface horizons	Other diagnostic features
MGP-1	Mollic epipedon	Cambic horizon	Udic SMR, Isothermic STR
MGP-2	Ochric epipedon	Cambic horizon	Udic SMR, Isothermic STR, Resistant minerals
MGP-3	Ochric epipedon	Kandic horizon	Udic SMR, Isothermic STR, Resistant minerals
MGP-4	Ochric epipedon	Argillic horizon	Udic SMR, Isothermic STR, Resistant minerals
MGP-5	Umbric epipedon		Udic SMR, Isothermic STR, Resistant minerals
MGP-6	Umbric epipedon		Udic SMR, Isomesic STR
MGP-7	Umbric epipedon	Cambic horizon	Udic SMR, Isomesic STR, Resistant minerals
MGP-8	Ochric epipedon		Udic SMR, Isothermic STR, Resistant minerals
MGP-9	Ochric epipedon		Ustic SMR, Isothermic STR
MGP-10	Ochric epipedon	Cambic horizon	Ustic SMR, Isothermic STR
MGP-11	Mollic epipedon		Udic SMR, Isothermic STR, Lithologic discontinuities
MGP-12	Ochric epipedon	Cambic horizon	Ustic SMR, Isothermic STR
MGP-13	Ochric epipedon		Udic SMR, Isothermic STR
MGP-14	Mollic epipedon	Argillic horizon	Udic SMR, Isothermic STR
MGP-15	Mollic epipedon	Kandic horizon	Udic SMR, Isothermic STR
MGP-16	Ochric epipedon	Argillic horizon and Cambic horizon	Udic SMR, Isothermic STR
MGP-17	Ochric epipedon	Argillic horizon and Cambic horizon	Udic SMR, Isothermic STR,
MGP-18	Ochric epipedon	Cambic horizon	Udic SMR, Isothermic STR
MGP-19	Ochric epipedon		Udic SMR, Isothermic STR
Mgp-20	Umbric epipedon	Cambic horizon	Udic SMR, Isomesic STR
MGP-21	Ochric epipedon		Udic SMR, Isomesic STR, Lithic contact
MGP-22	Ochric epipedon		Ustic SMR, Isothermic STR, Lithic contact
MGP-23	Ochric epipedon		Ustic SMR, Isothermic STR, Lithic contact
MGP-24	Ochric epipedon		Udic SMR, Isothermic STR, Lithic contact
MGP-25	Umbric epipedon		Udic SMR, Isothermic STR
MGP-26	Mollic epipedon	Argillic horizon	Udic SMR, Isothermic STR

Table 8. Classification of the soils of Mgeta Area

Profile	FAO World Reference Base classification system			USDA Soil Taxonomy classification system			
	Level 1	Level 2	Level 3	Order	Suborder	Greatgroup	Subgroup
MGP-1	Phaeozems (PH)	Haplic Phaeozems	-	Mollisols	Udolls	Hapludolls	Typic Hapludolls
MGP-2	Cambisols (CM)	Ferralic Cambisols	Chromi-Ferralic Cambisols (Dystric)	Inceptisols	Udepts	Dystrudepts	Typic Dystrudepts
MGP-3	Acrisols (AC)	Chromic Acrisols	Chromi-Hyperdystric Acrisols (Haplic)	Ultisols	Udults	Hapludults	Typic Hapludults
MGP-4	Luvisols (LV)	Cutanic Luvisols	Epidystri-Cutanic Luvisols (Haplic)	Alfisols	Udalfs	Hapludalfs	Inceptic Hapludalfs
MGP-5	Umbrisols (UM)	Humic Umbrisols	Hapli-Humic Umbrisols	Entisols	Orthents	Udorthents	Typic Udorthents
MGP-6	Umbrisols (UM)	Humic Umbrisols	Hapli-Humic Umbrisols	Entisols	Orthents	Udorthents	Typic Udorthents
MGP-7	Umbrisols (UM)	Humic Umbrisols	Hapli-Humic Umbrisols	Inceptisols	Udepts	Dystrudepts	Humic Dystrudepts
MGP-8	Regosols (RG)	Hypereutric Regosols	Hapli-Hypereutric Regosols	Entisols	Orthents	Udorthents	Typic Udorthents
MGP-9	Regosols (RG)	Hypereutric Regosols	Hapli-Hypereutric Regosols	Entisols	Orthents	Udorthents	Typic Udorthents
MGP-10	Cambisols (CM)	Ferralic Cambisols	Epidystri-Ferralic Cambisols (Haplic)	Inceptisols	Udepts	Dystrudepts	Humic Dystrudepts
MGP-11	Fluvisols (FL)	Mollic Fluvisols	Hypereutri-Mollic Fluvisols (Haplic)	Mollisols	Udolls	Hapludolls	Fluventic Hapludolls
MGP-12	Cambisols (CM)	Orthieutric Cambisols	Orthieutri-Ferralic Cambisols (Haplic)	Inceptisols	Udepts	Eutrudepts	Dystric Eutrudepts
MGP-13	Regosols (RG)	Orthieutric Regosols	Hapli-Orthieutric Regosols	Entisols	Orthents	Udorthents	Typic Udorthents
MGP-14	Phaeozems (PH)	Gleyic Phaeozems	Hapli-Gleyic Phaeozems	Mollisols	Udolls	Argiudolls	Aquic Argiudolls
MGP-15	Phaeozems (PH)	Pachic Phaeozems	Hapli-Pachic Phaeozems	Mollisols	Udolls	Hapludolls	Fluventic Hapludolls
MGP-16	Cambisols (CM)	Orthidystric Cambisols	Hapli-Orthidystric Cambisols	Inceptisols	Udepts	Dystrudepts	Typic Dystrudepts

Table 8. continued

MGP-17	Cambisols (CM)	Orthidystric Cambisols	Hapli-Orthidystric Cambisols	Inceptisols	Udepts	Dystrudepts	Typic Dystrudepts
MGP-18	Cambisols (CM)	Orthieutric Cambisols	Hapli-Orthieutric Cambisols	Inceptisols	Udepts	Eutrudepts	Dystric Eutrudepts
MGP-19	Regosols (RG)	Endoleptic Regosols	Humi-Endoleptic Regosols (Hypereutric)	Entisols	Orthents	Udorthents	Typic Udorthents
MGP-20	Umbrisols (UM)	Humic Umbrisols	Hyperferrali-Humic Umbrisols (Haplic)	Inceptisols	Udepts	Dystrudepts	Humic Dystrudepts
MGP-21	Leptosols (LP)	Lithic Leptosols	Dystri-Lithic Leptosols (Haplic)	Entisols	Orthents	Udorthents	Lithic Udorthents
MGP-22	Leptosols (LP)	Lithic Leptosols	Eutri-Lithic Leptosols (Haplic)	Entisols	Orthents	Ustorthents	Lithic Ustorthents
MGP-23	Leptosols (LP)	Lithic Leptosols	Dystri-Lithic Leptosols (Haplic)	Entisols	Orthents	Ustorthents	Lithic Ustorthents
MGP-24	Leptosols (LP)	Lithic Leptosols	Eutri-Lithic Leptosols (Haplic)	Entisols	Orthents	Udorthents	Lithic Udorthents
MGP-25	Umbrisols (UM)	Anthric Umbrisols	Hapli-Anthric Umbrisols	Entisols	Orthents	Udorthents	Typic Udorthents
MGP-26	Phaeozems (PH)	Chromic Phaeozems	Hapli-chromic Phaeozems	Mollisols	Udolls	Argiudolls	Typic Argiudolls

4.2.4. Description of soil mapping units

The description of each soil mapping unit took into consideration landform, parent material, vegetation cover, soil morphological, physical and chemical properties. The summary of the mapping unit description is given in Table 9. The soil profiles description and their analytical data are given in Appendix 1.

Mapping unit G11

This unit is a complex of very shallow to shallow, somewhat excessively drained, dark brown sandy clay, and moderately deep, well drained, dark brown sandy loams, with very thin to very thick dark brown to black sandy clay loam topsoils developed from banded pyroxene granulites. In places rock outcrops, stones and gravels occur on the surface.

Setting

The unit is a strongly dissected plateau summit occupying the highest position in the mountainous landscape. The slopes range between 5 - 35 % at mean elevation of about 2600 m a.s.l. The lands are occupied with natural short grasses, ferns and very few scattered temperate tree species. The area is not used and not managed.

Soil profile characteristics

The topsoils (about 5 to 30 cm) are black, friable, sandy clay loam and it is weak to moderately structured coarse subangular and medium angular blocky. The subsoil to a depth of 70 cm is friable, dark brown, sandy clay and it is weakly structured fine and medium subangular blocky. The soils classify as *Hapli-Humic Umbrisols* (*Typic Udorthents*), *Hyperferrali-Humic Umbrisols* (*Humic Dystrudepts*) and *Dystri-Lithic Leptosols* (*Lithic Udorthents*). Profiles MGP-6, MGP-20 and MGP-21 respectively are representative.

Soil physical properties

The soils are well to somewhat excessively drained and the rooting is limited at depths ranging from 10 to 75 cm. The available water capacity is extremely low to very low owing to the limitation in depth. In some places the surface conditions are limited by stones and gravels.

Table 9. Summary of the mapping unit description of Mgeta soils.

Mapping unit symbol	Landform	Altitude (m. Asl)	Dominant slope (%)	Vegetation/Landuse	Soil description	Area ha	Area %
SOILS DEVELOPED FROM BANDED PYROXENE GRANULITES (G)							
G11	Strongly dissected plateau summits	2500-2700	5-35	Short grasses, ferns with very few scattered trees. Not used and not managed	Complex of: Rock outcrops, and very shallow to shallow, somewhat excessively drained, black to dark brown sandy clay, and moderately deep, well drained, dark brown sandy loams, with thin to very thick black sandy clay loam topsoils. The soil classify as *Dystri-Lithic Leptosols* (*Lithic Udorthents*) and *Hapli-Humic Umbrisols* (*Typic Udorthents*), *Hyperferrali-Humic Umbrisols* (*Humic Dystrudepts*). These soils are represented by soil profiles MGP-21, MGP-6 and MGP-20 respectively.	3756	8.9
G12	Strongly dissected plateau slopes	1800-2450	40-59	Natural forest reserve. In some places cultivation of coffee and ridge cultivation of cabbage and round potatoes	Complex of: Rock outcrops, and deep, well drained, dark yellowish brown sandy loams , with very thick very dark brown sandy loam topsoils. and deep, well drained, dark yellowish brown to yellowish brown, loams, with thin dark yellowish brown to yellowish brown loam topsoils, The soils classify as *Hapli-Humic Umbrisols* (*Humic Dystrudepts*), *Hapli-Orthidystric Cambisols* (*Typic Dystrudepts*). These soils are represented by soil profiles MGP-7 and MGP-16 respectively.	6659	15.9
G21	Strongly dissected ridges summits	1200-1300	2-5	*Hyperrhenia spp* and few planted *Eucalyptus*. Fallow land, ridge and bench terrace cultivation of maize, beans, and pigeon peas	Complex of: Rock outcrops,and shallow somewhat excessively drained, dark brown to brown sandy clay loams, and moderatetely deep, well drained, brown sandy loams, with very thick very dark brown to dark brown sandy clay loam topsoils. The soils classify as *Dystri-Lithic Leptosols* (*Lithic Ustorthents*) and *Epidystri-Ferralic Cambisols* (*Humic Dystrudepts*). The soils are represented by soil profiles MGP-23 and MGP-10 respectively.	1753	4.2
G22	Strongly dissected ridge slopes	800-1100	35-55	*Hyperrhenia spp* and few scattered planted *Eucalyptus*. Fallow land, ridge and bench terrace cultivation of maize, pigeon peas, fruit trees, bananas and cowpeas	Complex of: Rock outcrops, and shallow, somewhat excessively drained, dark brown to dark reddish brown, sandy loams to sandy clays, and very deep, well drained, dark brown, sandy clay loams, with thick black sandy clay loam topsoils. The soils classify as *Eutri-Lithic Leptosols* (*Lithic Ustorthents*) and *Hapli-Hypereutric Regosols* (*Typic Udorthents*). These soils represented by soil profiles MGP-22 and MGP-9.	7204	17.2

Table 9. Summary of the mapping unit description of Mgeta soils.

Mapping unit symbol	Landform	Altitude (m. Asl)	Dominant slope (%)	Vegetation/Landuse	Soil description	Area ha	Area %
SOILS DEVELOPED FROM BANDED PYROXENE GRANULITES (G)							
G11	Strongly dissected plateau summits	2500-2700	5-35	Short grasses, ferns with very few scattered trees. Not used and not managed	Complex of: Rock outcrops, and very shallow to shallow, somewhat excessively drained, black to dark brown sandy clay, and moderately deep, well drained, dark brown sandy loams, with thin to very thick black sandy clay loam topsoils. The soil classify as *Dystri-Lithic Leptosols* (*Lithic Udorthents*) and *Hapli-Humic Umbrisols* (*Typic Udorthents*), *Hyperferrali-Humic Umbrisols* (*Humic Dystrudepts*). These soils are represented by soil profiles MGP-21, MGP-6 and MGP-20 respectively.	3756	8.9
G12	Strongly dissected plateau slopes	1800-2450	40-59	Natural forest reserve. In some places cultivation of coffee and ridge cultivation of cabbage and round potatoes	Complex of: Rock outcrops, and deep, well drained, dark yellowish brown sandy loams , with very thick very dark brown sandy loam topsoils. and deep, well drained, dark yellowish brown to yellowish brown, loams, with thin dark yellowish brown to yellowish brown loam topsoils, The soils classify as *Hapli-Humic Umbrisols* (*Humic Dystrudepts*), *Hapli-Orthidystric Cambisols* (*Typic Dystrudepts*). These soils are represented by soil profiles MGP-7 and MGP-16 respectively.	6659	15.9
G21	Strongly dissected ridges summits	1200-1300	2-5	*Hyperrhenia spp* and few planted *Eucalyptus.* Fallow land, ridge and bench terrace cultivation of maize, beans, and pigeon peas	Complex of: Rock outcrops,and shallow somewhat excessively drained, dark brown to brown sandy clay loams, and moderatetely deep, well drained, brown sandy loams, with very thick very dark brown to dark brown sandy clay loam topsoils. The soils classify as *Dystri-Lithic Leptosols* (*Lithic Ustorthents*) and *Epidystri-Ferralic Cambisols* (*Humic Dystrudepts*). The soils are represented by soil profiles MGP-23 and MGP-10 respectively.	1753	4.2
G22	Strongly dissected ridge slopes	800-1100	35-55	*Hyperrhenia spp* and few scattered planted *Eucalyptus.* Fallow land, ridge and bench terrace cultivation of maize, pigeon peas, fruit trees, bananas and cowpeas	Complex of: Rock outcrops, and shallow, somewhat excessively drained, dark brown to dark reddish brown, sandy loams to sandy clays, and very deep, well drained, dark brown, sandy clay loams, with thick black sandy clay loam topsoils. The soils classify as *Eutri-Lithic Leptosols* (*Lithic Ustorthents*) and *Hapli-Hypereutric Regosols* (*Typic Udorthents*). These soils represented by soil profiles MGP-22 and MGP-9.	7204	17.2

Table 9. continued

SOILS DEVELOPED FROM META-ANORTHOSITE, META-GABBROIC ANORTHOSITE AND META-ANORTHOSITIC GABBRO (M)							
M11	Strongly dissected ridges summits	1400- 1600	2-10	*Hyperrhenia sp.* ferns and few planted *Eucalyptus.* Ridge cultivation of maize, green peas, round potatoes, pigeon peas, beans, cowpeas and fruit trees	Complex of: Rock outcrops, and shallow, somewhat excessively drained, dark grey to light grey, sandy clay loams, and very deep, well drained, light grey sandy clay loams with thick black to dark grey, clay loam to sandy clay loam topsoils. The soils classify as *Eutri-Lithic Leptosols* (*Lithic Udorthents*) and *Orthieutri-Ferralic Cambisols* (*Dystric Eutrudepts*). These soils represented by soil profiles MGP-24 and MGP-12 respectively	1819	4.3
M12	Strongly dissected ridges slopes	1400-1500	30-60	*Hyperrhenia spp* and few planted *Eucalyptus.* Cultivation of cabbage, coffee, beans, maize, round potatoes, pigeon peas, green peas, cowpeas, bananas and fruit trees	Complex of: Rock outcrops,and deep well drained, very dark grey clays over very pale brown clay loam saprolite, and very deep, well drained, very dark grey to dark greyish brown, sandy clay loams over white, sandy loams saprolite. The soils classify as *Hapli-Anthric Umbrisols* (*Typic Udorthents*) *Hapli-Orthieutric Regosols* (*Typic Udorthents*). These soils are represented by soil profiles MGP-25 and MGP-13.respectively.	5151	12.3
SOILS DEVELOPED FROM KAOLINITIC CLAYS (K)							
K11	Strongly dissected ridges summits	1500-1700	5-20	Ferns and few scattered planted *Eucalyptus, Brachystegia spp* and *Albizia spp.* Afforestation, Cultivation of coffee, green peas, round potatoes, beans, cabbages and fruit trees	Complex of: Very deep, well drained, strong brown clays to silty clays, with thick dark brown clay topsoils, and very deep, well drained, strong brown and reddish yellow clays, with thick black clay topsoils. The soils classify as *Chromi-Ferralic Cambisols* (*Typic Dystrudepts*), *Chromi-Hyperdystric Acrisols* (*Typic Hapludults*). These soils are represented by soil profiles MGP-2 and MGP-3 respectively	1212	2.9
K12	Strongly dissected ridges slopes	1450-1600	40-60	Few scattered planted *Eucalyptus, Brachystegia spp* and *Acacia mearsii.* Cultivation of maize, round potatoes, coffee, cabbage, green peas, bananas and fruit trees	Complex of: Rock outcrops, and very deep deep, well drained, brown to strong brown clays, with thick dark brown clay to clay loam topsoils, and very deep, well drained, strong brown to yellowish brown clay loams, with thick dark greyish brown clay topsols. The soils classify as *Hapli-Chromic Phaeozems* (*Typic Argiudolls*) *Epidystri-Cutanic Luvisols* (*Inceptic Hapludalfs*). The soils are represented by profiles MGP-26 and MGP-4. respectively.	1884	4.5
SOILS DEVELOPED FROM COLLUVIUM DERIVED FROM META-ANORTHOSITE, META-GABRROIC ANORTHOSITE AND META-ANORTHOSITIC GABBRO (Cm)							
Cm1	Strongly dissected piedmont	1100-1700	30-50	Few planted *Eucalyptus.* Cultivation of coffee, cabbage, green peas,	Complex of: Rock outcrops, and shallow, well drained, black sandy clays, and moderately deep, well drained, very dark greyish brown to dark yellowish brown sandy clay loams, with	2333	5.5

Table 9. continued

SOILS DEVELOPED FROM META-ANORTHOSITE, META-GABBROIC ANORTHOSITE AND META-ANORTHOSITIC GABBRO (M)							
M11	Strongly dissected ridges summits	1400- 1600	2-10	*Hyperrhenia sp.* ferns and few planted *Eucalyptus.* Ridge cultivation of maize, green peas, round potatoes, pigeon peas, beans, cowpeas and fruit trees	Complex of: Rock outcrops, and shallow, somewhat excessively drained, dark grey to light grey, sandy clay loams, and very deep, well drained, light grey sandy clay loams with thick black to dark grey, clay loam to sandy clay loam topsoils. The soils classify as *Eutri-Lithic Leptosols* (*Lithic Udorthents*) and *Orthieutri-Ferralic Cambisols* (*Dystric Eutrudepts*). These soils represented by soil profiles MGP-24 and MGP-12 respectively	1819	4.3
M12	Strongly dissected ridges slopes	1400-1500	30-60	*Hyperrhenia spp* and few planted *Eucalyptus.* Cultivation of cabbage, coffee, beans, maize, round potatoes, pigeon peas, green peas, cowpeas, bananas and fruit trees	Complex of: Rock outcrops, and deep well drained, very dark grey clays over very pale brown clay loam saprolite, and very deep, well drained, very dark grey to dark greyish brown, sandy clay loams over white, sandy loams saprolite. The soils classify as *Hapli-Anthric Umbrisols* (*Typic Udorthents*) *Hapli-Orthieutric Regosols* (*Typic Udorthents*). These soils are represented by soil profiles MGP-25 and MGP-13 respectively.	5151	12.3
SOILS DEVELOPED FROM KAOLINITIC CLAYS (K)							
K11	Strongly dissected ridges summits	1500-1700	5-20	Ferns and few scattered planted *Eucalyptus, Brachystegia spp* and *Albizia spp.* Afforestation, Cultivation of coffee, green peas, round potatoes, beans, cabbages and fruit trees	Complex of: Very deep, well drained, strong brown clays to silty clays, with thick dark brown clay topsoils, and very deep, well drained, strong brown and reddish yellow clays, with thick black clay topsoils. The soils classify as *Chromi-Ferralic Cambisols* (*Typic Dystrudepts*), *Chromi-Hyperdystric Acrisols* (*Typic Hapludults*). These soils are represented by soil profiles MGP-2 and MGP-3 respectively	1212	2.9
K12	Strongly dissected ridges slopes	1450-1600	40-60	Few scattered planted *Eucalyptus, Brachystegia spp* and *Acacia mearsii.* Cultivation of maize, round potatoes, coffee, cabbage, green peas, bananas and fruit trees	Complex of: Rock outcrops, and very deep deep, well drained, brown to strong brown clays, with thick dark brown clay to clay loam topsoils, and very deep, well drained, strong brown to yellowish brown clay loams, with thick dark greyish brown clay topsoils. The soils classify as *Hapli-Chromic Phaeozems* (*Typic* Argiudolls) *Epidystri-Cutanic Luvisols* (*Inceptic Hapludalfs*). The soils are represented by profiles MGP-26 and MGP-4. respectively.	1884	4.5
SOILS DEVELOPED FROM COLLUVIUM DERIVED FROM META-ANORTHOSITE, META-GABRROIC ANORTHOSITE AND META-ANORTHOSITIC GABBRO (Cm)							
Cm1	Strongly dissected piedmont	1100-1700	30-50	Few planted *Eucalyptus.* Cultivation of coffee, cabbage, green peas,	Complex of: Rock outcrops, and shallow, well drained, black sandy clays, and moderately deep, well drained, very dark greyish brown to dark yellowish brown sandy clay loams, with	2333	5.5

	slopes			cocoyam, maize, bananas and round potatoes	thick very dark grey sandy clay loam topsoils, and deep, well drained, very dark grey, clay over reddish yellow to very pale brown clay loams to loams saprolite, The soils classify as *Haplic Phaeozems* (*Typic Hapludolls*), *Hapli-Humic Umbrisols* (*Typic Udorthents*) *Humi-Endoleptic Regosols* (*Typic Udorthents*). These soils are represented by soil profiles MGP-1, MGP-5 and MGP-19 respectively.		
SOILS DEVELOPED FROM COLLUVIUM DERIVED FROM BANDED PYROXENE GRANULITES, IN PLACES META-ANORTHOSITE, META-GABRROIC ANORTHOSITE AND META-ANORTHOSITIC GABBRO (Cgm)							
Cgm1	Strongly dissected piedmont slopes	1500-1700	40-50	*Hyperrhenia spp* and few planted *Acacia mearsii* and *Eucalyptus*.. Cultivation of cabbage, coffee, green peas, beans, cauliflower, chinese, cowpeas, cocoyam, maize, round potatoes and peaches.	Complex of: Rock outcrops, and shallow, somewhat excessively drained, very dark grey to very dark greyish brown sandy loams, and very deep, well drained, dark brown and very dark greyish brown sandy loams, wth very thick dark yellowish brown sandy loam topsoils. The soils classify as *Hapli-Orthidystric Cambisols* (*Typic Dystrudepts*), *Hapli-Orthieutric Cambisols* (*Dystric Eutrudepts*). These soils are represented by soil profiles MGP-17 and MGP-18 respectively.	2332	5.5
SOILS DEVELOPED FROM COLLUVIUM DERIVED FROM BANDED PYROXENE GRANULITES, IN PLACES KAOLINITIC CLAYS (Cgk)							
Cgk1	Strongly dissected piedmont slopes	1600-1800	40-60	*Hyperrhenia spp* few planted *Eucalyptus* and *Acacia mearsii*. Cultivation of cabbage, coffee maize, green peas, beans, tomatoes, cauliflower, chinese cocoyam and peaches.	Complex of: Rock outcrops, and very deep, well drained, pale yellow sandy loams to sandy clay loams, and very deep, well drained, brown clays to clay loams, with very thick black clay loam topsoils. The soils classify as *Hapli-Hypereutric Regosols* (*Typic Udorthents*), *Hapli-Pachic Phaeozems* (*Fluventic Hapludolls*). These soils are represented by profiles MGP-8 and MGP-15 respectively.	1334	3.2
SOILS DEVELOPED FROM ALLUVIO-COLLUVIUM OF DIVERSE GEOLOGICAL FORMATIONS (V)							
V1	V-shaped valley sides and inscisions	1000-1550	40-50	*Hyperrhenia spp* and elephant grasses and few planted *Acacia mearsii* and *Eucalyptus*. Ridge cultivation of maize, green peas, cabbage, beans, potatoes, bananas and cauliflower.	Complex of: Rock outcrops, and very deep, well drained, dark olive brown sandy clay loams, and very deep, imperfectly drained, strong brown to pale yellow clay to sandy clay loams, with very thick dark brown sandy clay loam topsoils. The soils classify as *Hypereutri-Mollic Fluvisols* (*Fluventic Hapludolls*), *Hapli-Gleyic Phaeozems* (*Aquic Argiudolls*). These soils are represented by soil profiles MGP-11 and MGP-14 respectively.	6526	15.6

Soil chemical properties

Nitrogen levels are high in topsoils. The available phosphorus is low. Organic matter content are very high. The soil pH is very strongly acid to strongly acid. These soils have very low levels of exchangeable bases. The overall capacity of the soil to retain nutrients is high.

Mapping unit G12

This unit is a complex of deep, well drained, dark yellowish brown sandy loams, with very thin dark brown sandy clay loam topsoils, and deep to deep, well drained, dark yellowish brown to yellowish brown loams, with thin dark loam topsoils developed from banded pyroxene granulites. In places rock outcrops occur.

Setting

The unit occupies very steep strongly dissected plateau slopes, The slopes range between 40 - 60 % at mean elevation of about 2100 m. a.s.l. Most of the land is occupied by natural forest reserve. In some places ridge cultivation of cabbage and round potatoes grown alternately and coffee mixed with bananas and fruit trees.

Soil profile characteristics

The topsoils (about 5 to 45 cm) are very dark brown and dark greyish brown to dark yellowish brown, sandy loam and loam. The soils are friable, weak to moderately structured, fine and medium and strong structured, very fine and fine subangular blocky. The subsoils to a depth of 120 cm are dark yellowish brown, friable, sandy loams, and

loams, weak to moderately structured fine and medium subangular blocky. The soils classify as *Hapli-Humic Umbrisols* (*Humic Dystrudepts*) and *Hapli-Orthidystric Cambisols* (*Typic Dystrudepts*). Profiles MGP-7 and MGP-16 respectively are representative.

Soil physical properties

The soils are well to somewhat excessively drained and the rooting is limited at depths ranging from 10 to 130 cm. The available water capacity is very low to low owing to the limitation in depth. In some places the surface conditions are limited by rock outcrops.

Soil chemical properties

Nitrogen levels are medium to high in topsoils. The available phosphorus is medium to high. Organic matter content are very high. The soil pH is very strongly acid to strongly acid. The soils have very low to low levels of exchangeable bases. The overall capacity of the soil to retain nutrients is high.

Mapping unit G21

This unit is a complex of shallow, somewhat excessively drained, dark brown to brown sandy clay loams, and moderately deep, well drained, brown sandy loams, with very thick dark brown sandy clay loam topsoils developed from banded pyroxene granulites. In places rock outcrops occur.

Setting

The unit occupies strongly dissected ridge summits. The slopes range between 2 - 5 % at mean elevation of about 1250 m. a.s.l. Most of the area is fallow land occupied with grasses mainly *Hyperrhenia* and *Themeda spp*, The natural vegetation has been cleared and replaced with few scattered planted *Eucalyptus*, Farming system include intercropping and mixed ridge and bench terrace cultivation of maize, beans, pigeon peas with scattered fruit trees and bananas.

Soil profile characteristics

The topsoil (about 35 cm) are very dark brown and dark brown sandy clay loam. The soil are friable, moderately structured, very fine to medium subangula blocky. The subsoils to a depth of 64 cm are brown, friable, sandy loams, weakly structured, very fine subangular blocky. The soils classify as *Dystri-Lithic Leptosols* (*Lithic Ustorthents*) *Epidystri-Ferralic Cambisols* (*Humic Dystrudepts*). Profiles MGP-23 and MGP-10 respectively are representative.

Soil physical properties

The soils are well to somewhat excessively drained and the rooting is limited to a depth of 150 cm OR deeper. The available water capacity is high.

Soil chemical properties

Nitrogen levels are low in topsoils. The available phosphorus is low. Organic matter content is medium. The soil pH is slightly acid. These soils have medium levels of exchangeable bases. The overall capacity of the soil to retain nutrients is medium.

Mapping unit G22

This unit is a complex of shallow, somewhat excessively drained, dark brown and dark reddish brown sandy loams to sandy clays, and moderately deep to deep, well drained, very dark greyish brown to brown and dark brown sandy clay loams to sandy clays, with thick black sandy clay loam topsoils developed from banded pyroxene granulites. In places rock outcrops occur.

Setting

The unit occupies strongly dissected ridge slopes. The slopes range between 35 - 55 % at mean elevation of about 1000 m. a.s.l. In some places the area has been left as fallow land with grasses mainly *Hyperrhenia* and *Themeda spp.* The natural vegetation has been cleared and replaced with few scattered planted *Eucalyptus*. Farming system include intercropping and mixed ridge and bench terrace cultivation of maize, beans, pigeon peas fruit trees cowpeas and few scattered bananas.

Soil profile characteristics

The topsoils (about 10-30 cm) are black sandy clay loams to sandy loams and sandy clays. The soil is friable and it is strongly structured fine and medium subangular blocky. The subsoil to a depth of 110 cm are dark brown, friable, sandy clay loam and it is structureless massive. The soils classify as *Eutri-Lithic Leptosols* (*Lithic Ustorthents*) and *Hapli-Hypereutric Regosols* (*Typic Udorthents*). Profiles MGP-22 and MGP-9 respectively are representative.

Soil physical properties

The soils are well to somewhat excessively drained and the rooting is limited to depths ranging from 40 to180 cm or deeper. The available water capacity is high. In some places the surface conditions are limited by rock outcrops.

Soil chemical properties

Nitrogen levels are low in topsoils. The available phosphorus is low. Organic matter content is medium. The soil pH is neutral. The soils have very high levels of exchangeable bases. The overall capacity of the soil to retain nutrients is medium.

Mapping unit M11

This unit is a complex of shallow, somewhat excessively drained, dark grey to light grey, sandy clay loams, and very deep, well drained, light grey sandy clay loams, with thick black to dark grey clay loam to sandy clay loam topsoils developed from meta-anorthosite, meta-gabbroic anorthosite and meta-anorthositic gabbro. In places rock outcrops occur.

Setting

The unit occupies strongly dissected ridge summits. The slopes range between 2 - 10 percent at mean elevation of about 1500 m. a.s.l. In some places the area is dominated by grasses mainly *Hyperrhenia spp,* ferns and few scattered planted *Eucalyptus.* The natural vegetation has been cleared. Farming system include intercropping and alternately ridge cultivation of maize, round potatoes, beans, pigeon peas, cowpeas and fruit trees.

Soil profile characteristics

The topsoils (about 10-20 cm) are black to dark grey clay loams to sandy clay loams. The soils are friable, moderately strong structured, fine and medium subangular blocky. The subsoils to a depth of 50 cm are dark grey, friable, sandy clay loams, weakly structured medium and coarse subangular blocky. The soils classify as *Eutri-Lithic Leptosols* (*Lithic Udorthents*) and *Orthieutri-Ferralic Cambisols* (*Dystric Eutrudepts*). Profiles MGP-24 and MGP-12 respectively are representative.

Soil physical properties

The soils are well to somewhat excessively drained and the rooting is limited to a depth of 150 cm or deeper. The available water capacity is medium.

Soil chemical properties

Nitrogen levels are low in topsoils. The available phosphorus is low. Organic matter content is high. The soil pH ranges from strongly to moderately acid. The soils have high to very high levels of exchangeable bases. The overall capacity of the soil to retain nutrients is medium.

Mapping unit M12

This unit is a complex of deep, well drained, very dark grey clays over very pale brown clay loam saprolite, and very deep, well drained, dark greyish brown sandy clay loam over white sandy loams saprolite developed from meta-anorthosite, meta-gabbroic anorthosite and meta-anorthositic gabbro. In places rock outcrops occur.

Setting

The unit occupies strongly dissected ridge slopes. The slopes range between 30 - 60 % at mean elevation of about 1450 m. a.s.l. In some places the area is dominated by grasses mainly *Hyperrhenia spp,* ferns and few scattered planted *Eucalyptus* and *Brachystegia spp.* The natural vegetation has been cleared. Farming system include cultivation of coffee mixed with banana and fruit trees, intercropping and alternately ridge cultivation of maize, beans, pigeon peas, cowpeas, round potatoes, cabbages, bananas and fruit trees.

Soil profile characteristics

The topsoils (about 10-25 cm) are sandy clay loams, friable, weak and moderately structured, fine and medium subangular blocky. The subsoils to a depth of 110 cm are dark greyish brown, friable, sandy clay loams, structureless massive. The soils classify as *Hapli-Anthric Umbrisols* (*Typic Udorthents*) and *Hapli-Orthieutric Regosols* (*Typic Udorthents*). Profiles MGP-25 and MGP-13 respectively are representative.

Soil physical properties

The soils are well drained and the rooting is limited to a depth of 180 cm or deeper. The available water capacity is medium. In places surface rock outcrops, boulders and stones are common.

Soil chemical properties

Nitrogen levels are low in topsoils. The available phosphorus is low. Organic matter content is high to very high. The soil pH is moderately to slightly acid. The soils have

medium to high levels of exchangeable bases. The overall capacity of the soil to retain nutrients is medium.

Mapping unit K11

This unit is a complex of very deep, well drained, strong brown clays to silty clays, with thick dark brown clay topsoils, and very deep, well drained, strong brown and reddish yellow clays, with thick black clay topsoils developed from kaolinitic clays. In places rock outcrops occur.

Setting

The unit occupies strongly dissected ridge summits. The slopes range between 5 - 15 % at mean elevation of about 1600 m. a.s.l. The natural vegetation has been replaced with planted *Eucalyptus* trees, *Brachystegia spp, Albizia spp* and *Acacia mearsii*. Farming system include cultivation of coffee mixed with bananas and fruit trees, intercropping and alternately ridge cultivation of maize, beans, green peas, cowpeas, round potatoes, cabbages, and fruit trees.

Soil profile characteristics

The topsoils (about 20 cm) are black and dark brown clays, friable, weak, fine and medium crumbs and moderately structured, fine and medium subangular blocky. The subsoils to a depth of 85 cm are strong brown, friable, clay and it is moderate and strongly structured, fine and medium subangular blocky. The soils classify as *Chromi-*

Ferralic Cambisols (*Typic Dystrudepts*) and *Chromi-Hyperdystric Acrisols* (*Typic Hapludults*). Profiles MGP-2 and MGP-3 respectively are representatives.

Soil physical properties

The soils are well drained and the rooting is limited to a depth of 190 cm or deeper. The available water capacity is medium.

Soil chemical properties

Nitrogen levels are medium in topsoils. The available phosphorus is low. Organic matter content is very high. The soil pH is moderately to slightly acid. These soils have medium to high levels of exchangeable bases. The overall capacity of the soil to retain nutrients is medium.

Mapping unit K12

This unit is a complex of very deep, well drained, brown to strong brown clays, with very thick black clay to clay loam topsoils, and very deep, well drained, strong brown to yellowish brown clay loams, with thick dark greyish brown clay topsoils, developed from kaolinitic clays. In places there are rock outcrops.

Setting

The unit occupies strongly dissected ridge summits with slopes ranging between 40 - 60 % at mean elevation of about 1500 m. a.s.l. The natural vegetation has been cleared and replaced with very few planted *Eucalyptus* trees, *Brachystegia spp* and *Acacia mearsii*. Farming systems include cultivation of coffee mixed with banana, yarms and fruit trees,

intercropping and alternately ridge cultivation of maize, beans, cowpeas, round potatoes, cabbages, green peas and fruit trees.

Soil profile characteristics

The topsoils (about 15 cm) are dark greyish brown clays, friable, weak to very strongly structured, coarse, fine and very fine sabangular blocky. The subsoil to a depth of 140 cm are strong brown to yellowish brown, friable, clays to clay loams, weak to moderately structured, fine, medium and coarse subangular blocky. The soils classify as *Epidystri-Cutanic Luvisol* (*Inceptic Hapludalf*) and *Hapli-Chromic Phaeozems* (*Typic Argiudolls*). Profiles MGP-4 and MGP-26 respectively are representative.

Soil physical properties

The soils are well drained and the rooting is limited to a depth of 200 cm or deeper. The available water capacity is low. In places surface rock outcrops occur.

Soil chemical properties

Nitrogen levels are low in topsoils. The available phosphorus is low. Organic matter content is very high. The soil pH is moderately to slightly acid. The soils have low levels of exchangeable bases. The overall capacity of the soil to retain nutrients is medium.

Mapping unit Cm1

This unit is a complex of shallow, somewhat excesssively drained, black, sandy clays, and moderately deep, well drained, black and very dark greyish brown to dark yellowish brown sandy clays and sandy clay loams, with thick and very thick very dark grey and

dark yellowish brown sandy loams topsoils, and deep, well drained, very dark grey clay over reddish yellow to very pale brown clay loams to loams saprolite developed from colluvium derived from meta-anorthosite, meta-gabbroic anorthosite and meta-anorthositic gabbro. In places there are rock outcrops.

Setting

The unit occupies strongly dissected piedmont slopes with the slopes between 30 - 50 % at mean elevation of about 1400 m. a.s.l. The natural vegetation has been cleared and replaced with very few planted *Eucalyptus* trees, *Brachystegia spp* and *Acacia mearsii*. Farming system include cultivation of coffee mixed with banana, yarms and fruit trees intercropping and alternately ridge cultivation of maize, beans, green peas, cocoyam, peas, cowpeas, round potatoes, cabbages, and fruit trees.

Soil profile characteristics

The topsoils (about 15 to 50 cm) are very dark grey and black clay and sandy clay loams, moderate, to strongly structured, fine, medium and coarse subangular blocky. The subsoils to a depth of 75 cm are dark brown to dark yellowish brown, friable, sandy clay loams to clay loams, moderately structured, fine and medium subangular blocky and structureless massive. The soils classify as *Haplic-Phaeozems* (*Typic Hapludolls*) and *Hapli-Humic Umbrisols* (*Typic Udorthents*) and *Humi-Endoleptic Regosols* (*Typic Udorthents*). Profiles MGP-1, MGP-5 and MGP-19 respectively are representative.

Soil physical properties

The soils are well drained and the rooting is limited to a depth of 60 cm or deeper. The available water capacity is low. In places surface rock outcrops, boulders, gravels and stones are common.

Soil chemical properties

Nitrogen levels are low to medium in topsoils. The available phosphorus is low to high. Organic matter content is medium to very high. The soil pH is moderately to slightly acid. This soil has high to very high levels of exchangeable bases. The overall capacity of the soil to retain nutrients is medium.

Mapping unit Cgm1

This unit is a complex of shallow, somewhat excessively drained, very dark greyish brown sandy loams, with thick very dark grey sandy loam topsoils, and very deep, well drained, dark brown and very dark greyish brown sandy loams, with very thick dark yellowish brown sandy loam topsoils developed from colluvium derived from banded pyroxene granulites, in places meta-anorthosite, meta-gabbroic anorthosite and meta-anorthositic gabbro. In places there are rock outcrops.

Setting

The unit occupies strongly dissected piedmont slopes with the slopes between 40 - 50 % at mean elevation of about 1600 m. a.s.l. In some places the area is dominated by grasses mainly *Hyperrhenia spp.* The natural vegetation has been cleared and replaced with very

few planted *Eucalyptus* trees, *Brachystegia spp* and *Acacia mearsii*. Farming system include cultivation of coffee mixed with banana and fruit trees, intercropping and alternately ridge cultivation of maize, beans, cowpeas, green peas, round potatoes, cabbages, cauliflower, chinese bananas and fruit trees.

Soil profile characteristics

The topsoils (about 10 to 40 cm) are dark yellowish brown and very dark grey sandy loams, friable, weak to moderately structured fine granular and fine to medium subangular blocks. The subsoil to a depth of 115 cm are dark brown and very dark greyish brown, friable, sandy loam and it is moderately structured fine and medium subangular blocky. The soil classifies as *Hapli-Orthidystric Cambisol* (*Typic Dystrudept*) and *Hapli-Orthidystric Cambisols* (*Dystric Eutrudept*). Profiles MGP-17 and MGP-18 respectively are representative.

Soil physical properties

The soils are well to somewhat excessively drained and the rooting is limited at depths of 26 to 200 cm or deeper. The available water capacity is low. In places surface rock outcrops, bouders, gravels and stones occur.

Soil chemical properties

Nitrogen levels are low to medium in topsoils. The available phosphorus is medium to high. Organic matter content is medium to very high. The soil pH is very strongly to moderately acid. The soils have very low to medium levels of exchangeable bases. The overall capacity of the soil to retain nutrients is high to very high.

Mapping unit Cgk1

This unit is a complex of very deep, well drained, pale yellow sandy loams to sandy clay loams, and very deep, well drained, brown clays to clay loams, with very thick black clay loam topsoils developed from colluvium derived from banded pyroxene granulites, in places kaolinitic clays. In places there are rock outcrops.

Setting

The unit occupies strongly dissected piedmont slopes with the slopes between 40 - 60 % at mean elevation of about 1700 m. a.s.l. In some places the area is dominated by grasses mainly *Hyperrhenia spp.* The natural vegetation has been cleared and replaced with very few planted *Eucalyptus* trees, *Brachystegia spp* and *Acacia mearsii.* Farming system include cultivation of coffee mixed with banana yarms and fruit trees, intercropping and alternately ridge cultivation of maize, beans, green peas, cowpeas, round potatoes, cabbages, cauliflower, chinese, cocoyams, tomatoes and fruit trees.

Soil profile characteristics

The topsoils (about 45 cm) are black and pale yellow clay loams and sandy loams, friable, moderately to strongly structured, medium and coarse, fine and very fine subangular blocky. The subsoils to a depth of 200 cm are brown, friable, clay and sandy loam and it is moderately structured fine and medium subangular blocks. The soil classify as *Hapli-Hypereutric Regosol* (*Typic Udorthent*) and *Hapli-Pachic Phaeozem* (*Fluventic Hapludoll*). Profiles MGP-8 and MGP-15 respectively are representative.

Soil physical properties

The soils are well to somewhat excessively drained and the rooting is limited to a depth of 200 cm or deeper. The available water capacity is medium. In places surface rock outcrops, boulders, gravels and stones are common.

Soil chemical properties

Nitrogen levels are low to medium in topsoils. The available phosphorus is low. Organic matter content range from very low to very high. The soil pH is moderately to slightly acid. These soils have high to very high levels of exchangeable bases. The overall capacity of the soil to retain nutrients is low to medium.

Mapping unit V1

This unit is a complex of very deep, well drained, dark olive brown sandy clay loams, and very deep, imperfectly drained, strong brown to pale yellow clays to sandy clay loams, with very thick dark brown sandy clay loam topsoils developed from alluvio-colluvium of diverse geological formations. In places rock outcrops and boulders occur.

Setting

The unit occupies V-shaped valley sides and inscisions. The dominant slopes range between 40 - 50 % at mean elevation of about 1250 m. a.s.l. In some places the area is dominated by grasses mainly *Hyperrhenia spp* and elephant grasses. The natural vegetation has been cleared and replaced with very few planted *Eucalyptus* trees, *Brachystegia spp* and *Acacia mearsii*. Farming system include intercropping ridge

cultivation of maize, beans, green peas, cowpeas, round potatoes, cabbages, cauliflower, bananas and fruit trees.

Soil profile characteristics

The topsoils (about 21 to 40 cm) are dark olive brown and dark brown sandy clay loams, friable, moderate to moderately strong structured, fine and medium subangular blocky. The subsoils to a depth of 75 cm is strong brown, friable, clays to sandy clay loams and sandy loams, moderately structured medium and coarse subangular blocky. The soil classify as *Hypereutri-Mollic Fluvisol* (*Fluventic Hapludoll*) and *Hapli-Gleyic Phaeozem* (*Arquic Argiudoll*). Profiles MGP-11 and MGP-14 respectively are representative.

Soil physical properties

The soils are well to imperfectly drained and the rooting is limited to a depth of 190 cm or deeper. The available water capacity is medium to high. In places surface rock outcrops and boulders occur.

Soil chemical properties

Nitrogen levels are low to medium in topsoils. The available phosphorus is high. Organic matter content is low to medium. The soil pH is slightly acid to neutral. The soils have high to very high levels of exchangeable bases. The overall capacity of the soil to retain nutrients is low to medium.

4.3. Socio-economic setting of Mgeta Area

The socio-economic survey results in Mgeta Area indicate that the size of one household ranges from 2 to 8 persons. Most of the households include man, wife and children and

own a piece of land around the houses and/or at some distance from the houses. Most of the crops grown in Mgeta are cash crops which are sold to earn money to buy other necessities such as clothes, salt, sugar, kerosene and other requirements. Maize is grown as food crop. The money obtained from cash crops is also used for buying food when there is food shortage. Labour is normally contributed by the members of the family but some is hired. The level of education and technical knowledge is generaly low, but most farmers have adult or primary education. Many farmers are willing to receive and adopt new farming practices introduced by research and extension personnel. Some farmers of Mgeta Area receive credits from their local cooperatives for farming activities. The farmers are generally not well informed about marketing opportunities of their produce and about management requirements for different land utilization types.

4.4. Description of major land utilization types of Mgeta Area

Three major land utilization types (LUTs) were identified from the results of land use and socio-economic survey. These land utilization types are (a) small holder improved low input rainfed cabbage, (b) small holder improved low input rainfed round potato and (c) small holder low input rainfed arabica coffee. Table 10 present description of the LUTs and Tables 11, 12 and 13 presents agro-economic parameters for the mentioned LUTs.

4.4.1. Small holder improved low input rainfed cabbage

This LUT is practised by individual farmers on permanent cultivation basis with an average farm size of 0.4 ha using family and hired labour. The common farm

own a piece of land around the houses and/or at some distance from the houses. Most of the crops grown in Mgeta are cash crops which are sold to earn money to buy other necessities such as clothes, salt, sugar, kerosene and other requirements. Maize is grown as food crop. The money obtained from cash crops is also used for buying food when there is food shortage. Labour is normally contributed by the members of the family but some is hired. The level of education and technical knowledge is generaly low, but most farmers have adult or primary education. Many farmers are willing to receive and adopt new farming practices introduced by research and extension personnel. Some farmers of Mgeta Area receive credits from their local cooperatives for farming activities. The farmers are generally not well informed about marketing opportunities of their produce and about management requirements for different land utilization types.

4.4. Description of major land utilization types of Mgeta Area

Three major land utilization types (LUTs) were identified from the results of land use and socio-economic survey. These land utilization types are (a) small holder improved low input rainfed cabbage, (b) small holder improved low input rainfed round potato and (c) small holder low input rainfed arabica coffee. Table 10 present description of the LUTs and Tables 11, 12 and 13 presents agro-economic parameters for the mentioned LUTs.

4.4.1. Small holder improved low input rainfed cabbage

This LUT is practised by individual farmers on permanent cultivation basis with an average farm size of 0.4 ha using family and hired labour. The common farm

management practice is the ridge cultivation with / without grass strips on their edges and bench terrace cultivation system as an effort to control soil erosion and land degradation in general. Most of the farmers apply manure and fertilizers in their farms, the most common fertilizer being Urea. Pesticides like Thionex is used for this LUT with a low level of capital investment. The crop is grown singly and alternately with other crops like round potato, beans, green peas and maize in a year. Hybrid varieties mainly Glory and Romenco are used. The crop is planted in December/November and harvested in March/ April. The yield ranges from 3,500 to 10,500 kg/ha.

Table 10. Description of land utilization types (LUTs)

Land utilization type	Produce	Management	Labour intensity mandays/ha	Level of technical knowledge	Farm size (ha)	Land tenure	Yield range kg/ha
Small holder improved low-input rainfed cabbage	Cabbage, hybrid variaties (Romenco, Glory)	Ridges and bench terrace cultivation, single and alternately cropping, human labour (family & hired), manure, fertilizer and fungicide application	high 118-201	Low; credit, extension, storage and marketing required	0.2-0.6	Family farm	3500-7000
Smallholder improved low-input rainfed potatoes	Potatoes; local varieties	Ridges and bench terrace cultivation, single and alternately /intercropping, human labour (family & hired), manure, fertilizers and pesticide application	high 91-429	Low; credit, extension, storage market required	0.1-1.2	Family farm	1250-12500
Small holder low-input raifed coffee	Coffee local varieties	Mixed cropping, human labour (family & hired) and fungicide application	high 91-139	Low; credit, extension, market required	0.1-0.6	Family farm	200-1000

Table 11. Agro-economic database for smallholder improved low input rainfed round potatoes

Economic component	Unit	Smallholder improved low-input rainfed round potatoes	
		Range	Calculation based on optimum attainable yield
Yield	kg/ha	1250 - 12500	
Optimum attainable yield	kg/ha		13,750
Farm gate price of product	TSh/kg	70 - 130	100
Returns	TSh/ha	125000 - 1250000	1,375,000
Annual cost			
⇒ Labour inputs	mandays/ha		
◊ land preparation and soil conservation practices		23 - 45	34
◊ manure and fertilizer application		3 - 10	6
◊ planting		10 - 38	24
◊ weeding		15 - 20	17
◊ pesticides application		3 - 8	6
◊ harvesting		10 - 20	15
◊ postharvesting		6 - 313	160
◊ Total labour		91 - 429	262
◊ Sub-total labour cost at Tsh 600 per manday	TSh/ha	54,600 - 257,400	15,7200
⇒ Material input cost			
◊ seed (local variety)	TSh/ha	8,300 - 60,000	34,150
◊ manure and fertilizer		3,750 - 71,250	37,500
◊ pestcides		0 - 52,500	26,250
◊ Sub-total material input cost		20,800 - 160,000	97,900
Total cost		75,400 - 417,400	255,100
Gross margin (net benefit)		49,600 - 832,600	
Optimum gross margin			1,119,900

Table 12. Agro-economic database for smallholder low input rainfed coffee

Economic component	Unit	Smallholder low-input rainfed coffee	
		Range	Calculation based on optimum attainable yield
Yield	kg/ha	200 - 1000	
Optimum attainable yield	kg/ha		1,300
Farm gate price of product	TSh/ha	450	450
Returns	TSh/ha	90,000 - 450,000	585,000
Annual cost			
⇒ labour inputs	mandays/ha		
◊ weeding and prunning		23 - 33	28
◊ pesticides application		8 - 33	21
◊ harvesting		35 - 40	38
◊ postharvesting		13 - 41	27
◊ Total labour		91 - 139	114
◊ Sub-total labour cost at Tsh 600 per manday	TSh/ha	54,600 - 83,400	68,400
⇒ Material input cost	TSh/ha		
◊ pesticides		7,500 - 25,000	16,250
◊ Sub-total material input cost		7,500 - 25,000	16,250
Total cost		61,980 - 98,500	84,650
Gross margin (net benefit)		28,020 - 351,500	
Optimum gross margin			500,350

Table 13. Agro-economic database for smallholder improved low input rainfed cabbage

Economic component	Unit	Smallholder improved low-input rainfed cabbage	
		Range	Calculation based on optimum attainable yield
Yield	kg/ha	3,500 - 7000	
Optimum attainable yield	kg/ha		10,500
Farm gate price of product	TSh/kg	50 - 90	70
Returns	TSh/ha	245,000 - 490,000	735,000
Annual cost			
⇒ Labour inputs			
◊ land preparation and soil conservation practices	mandays/ha	25 - 38	32
◊ seedling husbandry		20 - 30	25
◊ manure and fertilizer application		5 - 13	9
◊ replanting		5 - 10	8
◊ weeding and prunning		18 - 25	22
◊ pesticides application		3 - 15	9
◊ harvesting		5 - 13	9
◊ postharvesting		13 - 102	58
◊ Total labour		118 - 201	172
◊ Sub-total labour cost at Tsh 600 per manday	TSh/ha	70,800 - 120,600	103,200
⇒ Material input cost			
◊ seed (hybrid variety)	TSh/ha	6,750 - 25.000	15,870
◊ manure and fertilizer		7,900 - 18,100	13,000
◊ pestcides		4,500 - 13,500	9,000
◊ Sub-total material input cost		27,500 - 51,900	37,870
Total cost		98,300 - 172,500	141,070
Gross margin (net benefit)		146,700 - 317,500	
Optimum gross margin			593,930

4.4.2. Small holder improved low input rainfed round potato

This LUT is practised by individual farmers on permanent cultivation basis with an average farm size of 0.6 ha using family and hired labour. The common farm management practice is the ridge and bench terrace cultivation system as an effort to control soil erosion and land degradation in general. Most of the farmers apply manure and fertilizers in their farms, the most common fertilizers being used are Urea and DAP (di-ammonium phosphate). Fungicides such as blue copper and dithane are used for the LUT with a low level of capital investment. The crop is grown singly or intercropped with beans and green peas and alternately grown with other crops like, cabbage, cauliflower, beans, green peas and maize in a year. Local varieties such as Sasamoa, Kikondo and Red potato are mostly grown. The crop is planted in September/October and harvested in January/February. The yield ranges from 1250 - 13,750 kg/ha.

4.4.3. Small holder low input rainfed arabica coffee

This LUT is practised by individual farmers on permanent cultivation basis with an average farm size of 0.4 ha using family and hired labour. Most of coffee trees are old and farmers have abandoned their farms without serious care due to prevailing low market prices. Most farmers do not apply manure and fertilizers in their farms. Fungicides such as blue copper and red copper are used for the LUT with a low level of capital investment. The crop is mixed grown with bananas, yarms and fruit trees. The yield ranges from 200 to 1,300 kg/ha.

4.5. ALES physical suitability classification

ALES physical suitability results for small holder improved low input rainfed round potato, small holder improved low input rainfed cabbage and small holder low input rainfed arabica coffee are given in Table 14. About 80% of the total area of Mgeta is moderately suitable (class 2) for the studied LUTs. Some soils of LMUs G11, G12, Cgmi, Cgk1 and K12 are marginally suitable (class 3) and they altogether form about 20% of the study area. The most limiting factors are erosion hazards, nutrient availability, nutrient retention and tuber expansion and harvesting.

About 74% of studied LMUs have moderate potential (class 2) for small holder improved low input rainfed cabbage whereas about 24% of the total area is marginally suitable (class 3). The most limiting factors are nutrient retention, nutrient availability and temperature regime. The Dystri-Lithic Leptosols (LMU G11) covering 2% of the unit is rated as not suitable (class 4). Rooting conditions is the most limiting factor.

As far as small holder low input rainfed arabica coffee is concerned, about 71% of the total area of Mgeta is moderately suitable (class 2) while 7% is marginally suitable (class 3) for the LUT. However, LMU G11 and some parts of LMUs G21, G22, M11 and Cgm1 altogether covering about 22% of the study area are ranked as not suitable (class 4) for the production of arabica coffee. Rooting conditions and nutrient retention are the most limiting factors.

Table 14. ALES physical suitability subclasses

LMUs	SOIL TYPE	CABBAGE	POTATO	ARABICA COFFEE	AREA (ha)
			RATING		
G11	Dystri-Lithic Leptosols 20% Hyperferrali-Humic Umbrisols 15% Hapli-Humic Umbrisols 60%	4r 3nr/t 3nr/t	3na/nr/tb 3na/nr 3nr	4r 4nr 4nr/r	4126
GI2	Hapli-Humic Umbrisols 65% Hapli-Orthidystric Cambisols 35%	2e/m/na/nr/t 2e/m/t	2m/na/nr/t 3na	2m/na/nr/r/t 2m/na/r/t	6438
G21	Dystri-Lithic Leptosols 30% Epidystri-Ferralic Cambisols 70%	2na/r/t 2na/t	2m/na/t/tb 2na/t	4r 2m/na/r	1605
G22	Eutri-Lithic Leptosols 45% Hapli-Hypereutric Regosols 55%	2e/na/r/t 2na/t	2e/m/na/t/tb 2na/t	4r 2m/na	7204
M11	Eutri-Lithic Leptosols 25% Orthieutri-Ferralic Cambisols 75%	3na 3na	2m/na/t/tb 2m/na/t	4r 2m/na	1819
M12	Hapli-Anthric Umbrisols 50% Hapli-Orthieutric Regosols 50%	2e/m/na//t 2e/m/na/nr/t	2e/m/na/nr/t 2e/m/na/nr/t	2e/m/na/nr/r 2m/na/nr	5151
Cm1	Humi-Endoleptic Regosols 32% Haplic Phaeozems 30% Hapli-Humic Umbrisols 38%	2e/m/na/r/t 2e/m/na/nr/t 3na	2e/t/tb 2e/na/nr/t 2e/na/t	3r 2m/na/nr/r 2e/m/na	2333
Cgm1	Hapli-Orthidystric Cambisols 50% Hapli-Orthieutric Cambisols 50%	2e/m/na/nr/t 2e/m/na/r/t	3na/nr 2m/na/t/tb	3na/nr 4r	2332
Cgk1	Hapli-Hypereutric Regosols 30% Hapli-Pachic Phaeozems 70%	3na 2e/na//t	3na 2e/m/na/nr/t	3na 2e/m/na/nr	1334
K11	Chromi-Ferralic Cambisols 40% Chromi-Hyperdystric Acrisols 60%	2m/na/nr/t 3nr	2m/na/nr/t 2m/na/nr/t	2m/na/nr 3na	1212
K12	Hapli-Chromic Phaeozems 50% Epidystri-Cutanic Luvisols 50%	2e/m/na/t 2e/m/na//t	2e/m/na/t 3e	2e/m/na 2e/m/na/nr	1884
V1	Hypereutri-Mollic Fluvisols 50% Hapli-Gleyic Phaeozems 50%	3na 2e/m/t	2e/m/na/t 2e/m/t	2m/na/t 2m/na	6526

m = moisture availability, na=nutrient availability, nr = nutrient retention capacity,
e = erosion hazard, t = temperature regime and tb = tuber expansion and harvesting.

4.6. ALES predicted yields

The ALES predicted yields are presented in Table 15. ALES does not calculate yields in case of permanently unsuitable land. In such cases zero yield is registered. The potato yields are high (about 11,000 kg/ha) in most mapping units except mapping unit G11 which has relatively lower yield (about 5,500 kg/ha). According to Sys *et al.* (1991) good commercial yield for rainfed round potato ranges between 25 - 35 ton/ha (25,000 - 35,000 kg/ha). For small holder low input production the area can be considered being moderately good for the production of round potato production.

Most LMUs are moderately productive for cabbage. The yields range from 4,200 to 8,400 kg/ha with only some few soils having zero yields. Accordind to Sys *et al.* (1991), the average farmer yield for rainfed cabbage ranges from 10 - 20 ton/ha (10,000 - 20,000) kg/ha).

ALES predicted yields for arabica coffee range from (572 to 1040 kg/ha) for all LMUs except LMUs G11 and Cgm1 which have zero and 260 kg/ha respectively. According to Sys *et al.* (1991) good small holder yield for rainfed arabica coffee ranges from 0.5 to 1.2 ton/ha (500 to 1200 kg/ha). Therefore, the results show that the studied area is favourable for arabica coffee production.

The results show that, yields predicted by ALES and those reported by farmers are in the same range for all LUTs (Tables 10 and 15). Kimaro and Kips (1991) made similar observations. However, obtaining reliable economic data for smallholder

Table 15. ALES predicted yields [kg/ha]

LMU	SOIL TYPE	CABBAGE		POTATO		ARABICA COFFEE	
		kg/ha					
		INDIVIDU-AL SOIL	OVER-ALL	INDIVIDU-AL SOIL	OVER-ALL	INDIVIDU-AL SOIL	OVER-ALL
G11	Dystri-Lithic Leptosols	0		5500		0	0
	Hyperferrali-Humic Umbrisols	4200	3150	5500	5500	0	
	Hapli-Humic Umbrisols	4200		5500		0	
G12	Hapli-Humic Umbrisols	8400		11000		1040	1040
	Hapli-Orthidystric Cambisols	8400	8400	5500	9075	1040	
G21	Dystri-Lithic Leptosols	8400		11000	11000	0	728
	Epidystri-Ferralic Cambisols	8400	8400	11000		1040	
G22	Eutri-Lithic Leptosols	8400		11000	11000	0	572
	Hapli-Hypereutric Regosols	8400	8400	11000		1040	
M11	Eutri-Lithic Leptosols	4200		11000	11000	0	780
	Orthieutri-Ferralic Cambisols	4200	4200	11000		1040	
M12	Hapli-Anthric Umbrisols	8400		11000	11000	1040	1040
	Hapli-Orthieutric Regosols	8400	8400	11000		1040	
Cm1	Humi-Endoleptic Regosols	8400		11000	11000	520	873.6
	Haplic Phaeozems	8400	6804	11000		1040	
	Hapli-Humic Umbrisols	4200		11000		1040	
Cgm1	Hapli-Orthidystric Cambisols	8400		5500	8250	520	260
	Hapli-Orthieutric Cambisols	8400	8400	11000		0	
Cgk1	Hapli-Hypereutric Regosols	4200		5500	9350	520	884
	Hapli-Pachic Phaeozems	8400	7140	11000		1040	
K11	Chromi-Ferralic Cambisols	8400	5880	11000	11000	1040	728
	Chromi-Hyperdystric Acrisols	4200		11000		520	
K12	Hapli-Chromic Phaeozems	8400		11000	8250	1040	1040
	Epidystri-Cutanic Luvisols	8400	8400	5500		1040	
V1	Hypereutri-Mollic Fluvisols	4200		11000	11000	1040	1040
	Hapli-Gleyic Phaeozems	8400	6300	11000		1040	

production is an area which needs further research especially on smallholder mixed/intercrop farming.

4.7. ALES calculated gross margins

ALES calculated gross margins (Table 16) show that, round potato has higher gross margins in all LMUs ranging from 275,000 to 825,000 TSh/ha/yr when compared to cabbage and arabica coffee which have gross margins ranging from 116,475 to 449,000 Tsh/ha/yr and from 69,050 to 372,000 Tsh/ha/yr respectively. The LMU Gl l was found to have zero gross margins as far as arabica coffee is concerned. The gross margins give an impression of whether the land is economically suitable for specific LUT under defined management level. It is an approptiate measure of economic suitability for annual or short-term rotational LUTs with few or no capital costs.

4.8. ALES economic suitability classification

ALES computes the economic evaluation after the physical evaluation. The economic evaluation is carried out using the predicted yields arrived at in the physical evaluation. The results of the economic evaluation are thus the predicted gross margin (net benefit) for each soil unit (Table 16). The economic evaluation results are given in Table 17.

Most LMUs (covering about 82% of the study area) are economically moderately suitable (S2) for small holder improved low input rainfed round potato. However, LMU

Table 16. Gross margins [TSh/ha/yr]

LMUs	SOIL TYPE	POTATO		CABBAGE		ARABICA COFFEE	
		INDIVI-DUAL	OVER-ALL	INDIVI-DUAL	OVER-ALL	INDIVI-DUAL	OVER-ALL
G11	Dystri-Lithic Leptosols	275,000		0		0	
	Hyperferrali-Humic Umbrisols	275,000		155,300		0	
	Hapli-Humic Umbrisols	275,000	275,000	155,300	116,475	0	0
G12	Hapli-Humic Umbrisols	825,000		449,300		372,100	
	Hapli-Orthidystric Cambisols	275,000	632,500	449,300	449,300	372,100	372,100
G21	Dystri-Lithic Leptosols			449,300		0	
	Epidystri-Ferralic Cambisols	825,000	825,000	449,300	449,300	372,100	260,470
G22	Eutri-Lithic Leptosols	825,000		449,300		0	
	Hapli-Hypereutric Regosols	825,000	825,000	449,300	449,300	372,100	204,655
M11	Eutri-Lithic Leptosols	825,000		155,300		0	
	Orthieutri-Ferralic Cambisols	825,000	825,000	155,300	155,300	372,100	279,075
M12	Hapli-Anthric Umbrisols	825,000		449,300		372,100	
	Hapli-Orthieutric Regosols	825,000	825,000	449,300	449,300	372,100	372,100
Cm1	Humi-Endoleptic Regosols	825,000		449,300		138,100	
	Haplic Phaeozems	825,000		449,300		372,100	
	Hapli-Humic Umbrisols	825,000	825,000	155,300	337,580	372,100	297,220
Cgm1	Hapli-Orthidystric Cambisols	275,000		449,300		138,100	
	Hapli-Orthieutric Cambisols	825,000	550,000	449,300	449,300	0	69,050
Cgk1	Hapli-Hypereutric Regosols	275,000		155,300		138,100	
	Hapli-Pachic Phaeozems	825,000	660,000	449,300	361,100	372,100	301,900
K11	Chromi-Ferralic Cambisols	825,000		449,300		372,100	
	Chromi-Hyperdystric Acrisols	825,000	825,000	155,300	272,900	138,100	231,700
K12	Hapli-Chromic Phaeozems	825,000		449,300		372,100	
	Epidystri-Cutanic Luvisols	275,000	550,000	449,300	449,300	372,100	372,100
V1	Hypereutri-Mollic Fluvisols	825,000		155,300		372,100	
	Hapli-Gleyic Phaeozems	825,000	825,000	449,300	302,300	372,100	372,100

Table 17. Economic suitability classes (based on gross margin)

		CABBAGE	POTATO	ARABICA COFFEE
LMUs	SOIL TYPE		RATING	
G11	Dystri-Lithic Leptosols	n2	S3	n2
	Hyperferrali-Humic Umbrisols	S3	S3	n2
	Hapli-Humic Umbrisols	S3	S3	n2
G12	Hapli-Humic Umbrisols	S2	S2	S2
	Hapli-Orthidystric Cambisols	S2	S3	S2
G21	Dystri-Lithic Leptosols	S2	S2	n2
	Epidystri-Ferralic Cambisols	S2	S2	S2
G22	Eutri-Lithic Leptosols	S2	S2	n2
	Hapli-Hypereutric Regosols	S2	S2	S2
M11	Eutri-Lithic Leptosols	S3	S2	n2
	Orthieutri-Ferralic Cambisols	S3	S2	S2
M12	Hapli-Anthric Umbrisols	S2	S2	S2
	Hapli-Orthieutric Regosols	S2	S2	S2
Cm1	Humi-Endoleptic Regosols	S2	S2	S3
	Haplic Phaeozems	S2	S2	S2
	Hapli-Humic Umbrisols	S3	S2	S2
Cgm1	Hapli-Orthidystric Cambisols	S2	S2	S3
	Hapli-Orthieutric Cambisols	S2	S2	n2
Cgk1	Hapli-Hypereutric Regosols	S3	S3	S3
	Hapli-Pachic Phaeozems	S2	S2	S2
K11	Chromi-Ferralic Cambisols	S2	S2	S2
	Chromi-Hyperdystric Acrisols	S3	S2	S3
K12	Hapli-Chromic Phaeozems	S2	S2	S2
	Epidystri-Cutanic Luvisols	S2	S3	S2
V1	Hypereutri-Mollic Fluvisols	S3	S2	S2
	Hapli-Gleyic Phaeozems	S2	S2	S2

G11 and the soil units Hapli-Orthidystric Cambisols, Hapli-Hypereutric Regosols and Epidystri-Cutanic Luvisols of LMUs G12, Cgk1 and K12 respectively, and which altogether occupy about 18% of the study area are economically marginally suitable (S3).

ALES economic suitability classification results for small holder improved low input rainfed cabbage shows that, about 74% of the total area are economically moderately suitable (S2) and 24% are economically marginally suitable (S3) for this LUT, except for the soil unit Dystri-Lithic Leptosols of LMU (G11) covering about 2% which is rated economically not suitable (n2) for physical limitations.

The economic suitability results for small holder low input rainfed arabica coffee reveals that, About 71% of the total area of Mgeta is economically moderately suitable (S2) while about 7% is economically marginally suitable (S3) for this LUT. LMUs having Leptosols and Hapli-Orthieutric Cambisols and LMU Cgm1 together forming 22% of the study area are economically not suitable (n2) for the production of arabica coffee due to physical limitations.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

Mgeta Area is mountainous characterised by strongly dissected ridges and plateau with ridge slopes and valleys. The area is underlain by metamorphic rocks with banded pyroxene granulites, meta-anorthosite, meta-gabbroic anorthosite and meta-anorthositic gabbro.

The rainfall pattern is monomodal (particularly at Tchenzema and Mizungu Mgeta) with its peak in April. The rainfall distribution at Bunduki is weakly bimodal with two peaks occurring in October and April. The length of growing period ranges from 180 to 270 days. The monthly maximum temperature range from 19.9 ^{o}C to 38.3^{o}C and monthly minimum temperature from 7.6^{o}C to 17.3^{o}C. Temperatures are much cooler at Lukwangule plateau.

Twelve soil mapping units characterised by various soil complexes were identified in Mgeta Area. Characteristics and distribution of these soils are largely controlled by parent materials and landforms. The soils developed from kaolinitic clays are complexes of deep to very deep, well drained clays. The soils developed from meta-anorthosite, meta-gabbroic anorthosite and meta-anorthositic gabbro are complexes of shallow to moderately deep, well drained clays to sandy clay loams overlying very deep saprolite. The soils developed from banded pyroxene granulites are complexes of very shallow to deep, somewhat excessively drained to well drained sandy clay loams to sandy loams

overlying saprolite or rock. The soils developed from colluvium of diverse geological formations are complexes of shallow to very deep, somewhat excessively drained to well drained clays, clay loams and sandy clay loams. The soils on valleys are complexes of moderately deep to very deep, well drained to imperfectly drained clays and sandy clay loams. Generally the Mgeta soils have low to medium soil fertility status. Poor physical soil conditions coupled with steep topography make the area susceptible to soil erosion.

The dominant soil groups classified according to FAO World Reference Base are Umbrisols, Phaeozems, Regosols, Cambisols, Leptosols, Luvisols, Fluvisols and Acrisols. Some important qualifiers which were identified for separating reference soil groups Phaeozems, Regosols and Cambisols into lower level units are missing in the FAO World Reference Base priority listing. Such qualifiers include: **Ferralic** and **Humic** for soil group Phaeozems, **Ferralic** for soil group Regosols and **Humic** for soil group Cambisols.

Three major land utilisation types (LUTs) namely small holder improved low input rainfed round potato, cabbage and small holder low input rainfed arabica coffee were identified in the study area. Land suitability classification by ALES indicate that, none of the soil mapping units is highly suitable for all the studied land utilisation types.

Most of the studied soil mapping units (covering > 70% of the studied area) are both physically and economically moderately suitable for all three studied LUTs. LMU G11 and some soils of LMUs G12, Cgk1 and K12 are physically and economically marginally suitable for round potatoes. Land mapping units M11 and some soils of LMUs G11, Cm1, Cgk1, K11 and V1 are physically and economically marginally suitable for

cabbage production while the soil unit Dystri-Lithic Leptosols (LMU G11) is economically not suitable. Some soils of LMUs Cm1, Cgm1, Cgk1 and K11 are both physically and economically marginally suitable for production of arabica coffee while LMU G11 and some soils in LMUs G21,G22, M11 and Cgm1 are economically not suitable. The most limiting factors for the production of the three studied LUTs are rooting condition, nutrient retention, nutrient availability and soil erosion hazards.

5.2. Recommendations

Further improvement is needed in the FAO World Reference Base for Soil Resources to include in the classification system qualifiers such as **Ferralic** and **Humic** for separating soil groups Phaeozems, Regosols and Cambisols into lower level units.

Appropriate agro-forestry farming systems such as alley cropping are recommended to supplement the existing ridge and bench terrace cultivation practices in the Mgeta Area in order to protect the lands from further erosion as well as to improve soil fertility.

Due to poor soil fertility of the studied soils, most of the soils are likely to respond to mineral and organic fertilisers. Research to determine rates and types of mineral and organic fertilisers should be carried out. The economics and social implications of both types of fertilisers should be investigated.

Credit facilities and /or subsidies on agricultural inputs especially fertilisers is highly recommended. Strong extension services is recommended in order to train farmers on the use and application of fertilisers and pesticides.

Cultivation of round potatoes is highly recommended as the best LUT in the Mgeta Area followed by cabbage due to their high economic returns under the current prevailing socio-economic conditions. Although arabica coffee can be produced in many places of the study area, the present economic returns for arabica coffee is not attractive. The strengthening of local co-operatives and improved marketing and storage services is highly recommended.

Further research on automated land evaluation for mixed/intercropping smallholder farming is highly recommended. Furthermore multidisplinary approaches towards automated land resources assessment and evaluation should also be emphasised.

Research should be carried out to estimate optimum yields and input levels and how these change with increasing limitations using various models (e.g. QUEFTS) and other techniques such as PRA to assess the reliability of the data on the economics of smallholder production.

Improvement on transport facilities including the use of cable vehicles in the Mgeta Area is strongly recommended to easen the burden of carrying agricultural produce from one point to another using human labour. Feasibility of introducing such kind of innovation should be studied.

6.0 REFERENCES

Anderson, B. (1976) Soil Atlas of Tanzania. 4th edition. Government Printers Dar es Salaam.

Baize, D. (1993) *Soil Science Analyses. A guide to current use*. John Wiley & Sons Ltd. West Sussex. pp 192.

Bhandari, A.R. and Randhawa, N.S. (1985) Distribution of Available Micronutrients in Soils of Apple Orchards in Himachal Pradesh. *Journal of the Indian Society of Soil Science* 33, 171-174.

Blake, G.R. and Hartge, K.H. (1986) Bulk density. In: *Methods of Soil Analysis*. Part 1. Physical and Mineralogical Methods *(Edited by Klute, A.)* 2nd edition Agronomy No. 9 American Society of Agronomy, Inc. Madison. Wisconsin, USA. pp 363-375.

Bray, R.H. and Kurtz, L.T. (1945) Determination of Total Organic and Available Forms of Phosphorus in Soils. *Soil Science* 59, 39 - 45.

Bremner, J.M. and Mulvaney, C.S. (1982) Total Nitrogen. In: *Methods of Soil Analysis*. Part 2. *(Edited by Page, A.L; Miller, R.H. and Keeney, D.R.)* American Society of Agronomy. Monograph No. 9, Madison,Wisconsin. pp 595 - 624.

Conyers, D. (1973) Agro-economic zones of Tanzania. In: *Soil Atlas of Tanzania. (Edited by Hathout, 1983)* Tanzania Publishing House, Dar es Salaam, Tanzania.

De Geus, J.G. (1973) *Fertilizer guide for the tropics and subtropics*. Zurich, Centre d' Etude de l'Azote, pp 68.

De la Rosa, D; Moreno, J.A; Garcia, L.V. and Almorza, J.(1992) MicroLEIS: A Microcomputer-based Mediterranean Land Evaluation Information System. *Soil Use and Management 8, 89-96.*

Delobel, J.C; Evers G.R. and Maerere, A.P (1988) *Position and Funtions of Deciduous Fruit Trees in the Farming Systems at Upper Mgeta, Uluguru Mountains*. Tanzania. Franco - Tanzania Horticulture project, SUA.

Dent, D. and Young, A. (1981) *Soil Survey and Land Evaluation*. George Allen and Unwin, London, U. K. pp 278.

Dregne, H C. (1990) Erosion and soil productivity in Africa. *Journal of Soil And Water Conservation*. 45 (4). 431-436.

Dumelow, J. (1980) *The Application of Rainfall and Sedimentation Data to Land Capability Classification in the Uluguru Mountain Tanzania*. National Agrometeorological Committee of Tanzania.

Elbersen, G.W.W. (1989) *Linking Land Evaluation and Farming Systems via Modelling*. ITC (Draft report).

FAO (1976) *A Framework for Land Evaluation*. FAO Soils Bulletin 32. FAO, Rome pp 72.

FAO (1983) *Guidelines: Land Evaluation for Rainfed Agriculture*. FAO Soils Bulletin. 52, FAO, Rome. pp 156.

FAO (1984) *Guidelines: Land Evaluation for Rainfed Agriculture*. FAO Soils Bulletin No.52, FAO, Rome, Italy pp 237.

FAO (1984) *Land evaluation for forestry*: Forestry Paper 48. FAO, Rome, Italy.

FAO (1985) *Guidelines: Land Evaluation for Irrigated Agriculture*. FAO Soils Bulletin No. 55. Rome, Italy. pp 231.

FAO (1990) *Guideline for Soil Profile Description*. 3rd edition. FAO, Rome. pp 66

FAO (1991a) *Guidelines: Land Evaluation for Extensive Grazing*. FAO Soils Bulletin No. 58 Rome, Italy, pp 158.

FAO (1991b) *Application of climatic data for effective irrigation planning and management*. Training Manual, World Meteorological Organization, Rome Italy.

FAO (1993) *Agro-ecological assessment for national planning: the example of Kenya*. Soil Resources, Management and Conservation Service. FAO Land and Water Development Division, FAO Soil Bulletin 67. Rome

FAO (1996) *Agro-ecological zoning: Guidelines*. Soil Resources, Management and conservation service. FAO Land and Water Development Division. FAO. Soil Bulletin 73, Rome. Italy.

FAO (1998) *World Reference Base for Soil Resources* World Soil Resources Reports No 84. FAO, ISRIC-AISS-IBG. pp 88.

Hathout, S.A. (1972) Soils of Tanzania. In: *Soil Atlas of Tanzania (Edited by Hathout, 1983*. Tanzania Publishing House. Dar es Salaam, Tanzania.

ILACO (1991) *Agricultural compendium for rural development in the tropics and subtropics*. Elsevier Science Publishers, Amsterdam. pp 740.

Janssen, B.H; Guiking; F.T.C; Van der Eijk, D; Smaling, E.M.A; Wolf, J and Van Reuler, H. (1986) *Quantitative Evaluation of the Fertility of Tropical Soils (QUEFTS)*. Department of Soil Science and Plant Nutrition, Agricultural University of Wageningen.

Kilasara, M; Magoggo, J.P. and Msanya, B.M. (1993) Land resource management in Tanzania Paper presented at the workshop on formulation of Faculty of Agriculture Research Programme up to the year 2000. Sokoine University of Agriculture, Morogoro, Tanzania.

Kimaro, D.N. (1989) *Potentials and Constraints of the Kilosa Area for Rainfed Agriculture with Emphasis on Maize*. M.Sc thesis, ITC. Enschede, The Netherlands. pp 235.

Kimaro, D.N. (1997) Land Resources Database for Land Use Planning at District Level in Tanzania. Paper presented at FAO workshop on land information system for land use planning in Tanzania using GIS 4-5 December.1997. Dar es salaam, Tanzania. pp 8.

Kimaro, D.N. and Kips, Ph.A. (1991) Testing ALES in Tanzania: A case study in computerized physical and economic land suitability assessment for smallholder low-input maize. In: *Proceedings of the Second African Soil Science Society Conference on Soil and Water Management for Sustainable Productivity (Edited by Elgala, A. M; Parr, J. F; Hornick, S. B; Taha; T. A. and Simpson, M.E. 1993)*. The Egyptian International Center for Agriculture, Cairo, Egypt, November 4-10, 1991. pp 325-335.

Kimaro, D.N. and Msanya, B.M. (1999) Application of international computerized land evaluation systems to Tanzania conditions: A case study in Kilosa district. *Tanzanian Journal of Agricultural Science* (In press).

Kisanga, D.R. (1992) *Effect of Methods of Terracing on Some Physical and Chemical Properties of Soils of Mgeta, Morogoro, Tanzania.* M.Sc. Thesis Sokoine University of Agriculture, Morogoro Tanzania. pp 144.

Klingebiel, A.A. and Montgomery, P.H. (1961) *Land Capability Classification.* Agriculture Handbook No. 210, Soil Conservation Service, USDA. Washington D.C.

Lindsay, W. and Norvel, W.A. (1978) Development of DTPA. Soil test for zinc, iron, manganese and copper. Soil Science Society of America Journal 42, 421 - 428

London, J.R. (Ed.) (1991) *Booker Tropical Soil Manual.* A handbook for soil survey and agricultural land evaluation in the tropics and subtropics Longman Scientific & Technical Copublished in the USA with John Wiley and Sons, Inc New York, pp. 474.

Lundgren, L. (1980) *Soil Erosion in Tanzania Mountain Areas: Case Studies of Land Degradation and Recovery in Relation to Land Use and Physical Land Characteristics in the Uluguru and Usambara Mountains, Tanzania.* Stoung 39, Stockholm.

Magoggo, J.P. (1991) SISTAN version 2: *Soil Information System for Tanzania. User Manual and Reference Guide.* National Soil Service, Tanga, Tanzania.

Magoggo, J.P. and Meliyo, J.L. (1994) *Land Resources Inventory and Land Suitability Assessment of Mbulu District, Arusha, Region, Tanzania.* Vol. 5 Land Suitability Assessment Report R5. Ministry of Agriculture, National Soil Service, Agricultural Research Institute, Mlingano, Tanga, Tanzania.

McLean, E.O. (1982) Soil pH and lime requirement. In: *Methods of Soil Analysis, Part 2, (Edited by: Page, A.L; Miller, R.H. and Keeney, D.R).* American Society of Agronomy. Madison, Wisconsin, pp 199-224.

Moberg, J.P. (1981) Pedological features of two soil associations in the Morogoro area, Tanzania, in relation to future land use. The Royal Veterinary and Agricultural University of Copenhagen. pp. 35.

Moberg, J.P. (2000) Soil Analysis Manual. Chemistry Department, KVL, Copenhagen, Denmark.

Msanya, B.M. (1980) *Study of the Soils of a Toposequence on Metasedimentary Rocks of the Morogoro Region, Tanzania, with Special Attention to Texture Determination and Soil Classification.* MSc thesis, The state university of Ghent, Belgium. pp 87.

Msanya, B.M. and Magoggo, J.P. (1993) *Review of Soil Surveys (Soil Resource Inventories) in Tanzania.* Ecology and development paper No. 6. published by the ecology and development programme. The Agricultural University of Norway. pp. 45.

Msanya, B.M; Kimaro, D.N. and Magoggo, J.P. (1995) *Characteristics of Two Pedons and Their Implication for Environmental Management in Parts of Mbinga District, Tanzania.* Paper presented at the First Annual Faculty of

Agriculture Research Conference. August 28-30th 1995. Sokoine University of Agriculture, Morogoro, Tanzania.

Msanya, B.M; Wickama, J.M; Kimaro, D.N; Magoggo, J.P and Meliyo, J. L. (1996) *Investigation of the environmental attributes for agricultural development in Kitanda village, Mbinga District, Tanzania.* Technical Report No 5. Department of Soil Science, Faculty of Agriculture, Sokoine University of Agriculture, Morogoro, Tanzania and Ministry of Agriculture, National Soil Service, Agricultural Research Institute, Mlingano, Tanga, Tanzania.pp 38.

Msanya, B.M; Kimaro, D N; Shayo-Ngowi, A J and Kimbi, G. G. (1999) Pedological Characterization, Clay Mineralogy and Classification of Some Soils of Mikese Area, Morogoro District, Tanzania *Tanzania Journal of Agricultural Sciences 2 (1), 7 - 18.*

Msanya, B.M; Kimaro, D N; Mbogoni, J.D.J; Kimbi, G G; Kilasara. M and Deckers, J.S (2000) Factors influencing soil distribution and their implication for agricultural land management in Morogoro Urban District, Tanzania. Paper presented at the First University Wide Scientific Conference, Institute of Continuing Education, Sokoine University of Agriculture, Morogoro, Tanzania. 5th - 7th April 2000.

Munsell Color Co. (1992) *Munsell soil color charts.* Baltimore, Maryland, USA.

Murphy, J. and Riley, J.P. (1962) A Modified Single Solution Method for Determination of Phosphate in Natural Waters. *Analytica Chemica Acta 27, 31 - 36.*

National Soil Service (1986) *Land Resources and Agricultural Development Potentials of Selected Areas in Tanzania.* TARO-Agricultural Research Institute Mlingano Tanga- Tanzania. Miscellaneous Report M3.

National Soil Service (1987) *Laboratory Procedures for Routine Analysis.* 2nd edition TARO - Agricultural research institute, Mlingano, Tanga, Tanzania. pp. 59.

National Soil Service (1990) *Laboratory Procedures for Routine Soil Analysis.* 3rd edition. Agricultural Research Institute. Mlingano Tanga. Tanzania. Miscellaneous Report M13.

Nelson, D.W. and Sommers, L.E. (1982) Total carbon, organic carbon and organic matter. In: *Methods of Soil Analysis.* Part 2. Agronomy Monograph No. 9. 2nd edition (*Edited by Page, A.L; Miller, R.H. and Keeney, D.R.*) American Society of Agronomy Madison. Wisconsin. pp. 539-579.

Paul, J. (1988) *Farming Systems in the Upper Mgeta, Morogoro District.* Franco - Tanzania Horticulture Development Project, Sokoine University of Agriculture (SUA), Tanzania.

Peberdy, J.R. (1969) Rangeland. In: *East Africa: its peoples and resources. (Edited by Morgan, W.T.W.).* Oxford University Press, Nairobi. pp 153 – 176.

Reuben, S.O.M. (1995) *Performance of the Agricultural Sector Policy: Past, Present and Future.* The Future of Tanzania, Conference Report.

Rossiter, D.G. (1988) ALES: *A Microcomputer Program to Assist in Land Evaluation.* Department of Agronomy, Cornell University, Ithaca, New York.

Rossiter, D.G. (1990) ALES: A framework for land evaluation using a microcomputer. *Soil Use and Management 6, 7-20.*

Rossiter, D.G. (1995) Economic land evaluation: why and how. *Soil Use and Management 11, 132 - 140.*

Rossiter, D.G (1996) A theoretical framework for land evaluation. *Geoderma 72, 165-190.*

Rossiter, D.G. and Van Wambeke, A.R. (1989) *Automated Land Evaluation System: ALES version 2, User's Manual.* Department of Agronomy, Cornell University, Ithaca, New York.

Rossiter, D.G. and Van Wambeke, A.R. (1995) *Automated Land Evaluation System: ALES version 4.5, User's Manual.* Department of Soil, Crop and Atmospheric Science, Cornell University, Ithaca, New York.

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

Siderius, W. (Editor) (1986) *Land Evaluation for Land-use Planning and Conservation in Sloping Areas.* ILRI Publication 40. International Institute for Land Reclamation and Improvement (ILRI). Wageningen.

Sims, J.T. and Johnson, G.V. (1991) Micronutrient soil tests. In: *Micronutrient in Agriculture. 2nd edition. (Edited by Mortvedt, J.J; Cox, F.R; Shuman, L.M. and Welch, R.M.).* Soil Science Society of America, SSSA Book Series No. 4. Madison. Wisconsin. pp. 427 - 476.

Soil Institute of Iran (1970) *Manual of Land Classification for Irrigation.* Publication No. 205. Iranian Ministry of Agriculture, Tehran.

Soil Survey Staff (1951) *Soil Survey Manual*. Agricultural Handbook No. 18. Soil Conservation Service, USDA. Washington D.C. pp. 503.

Soil Survey Staff (1998) *Keys to Soil Taxonomy*. Soil conservation service, USDA. Washington D.C. pp 422.

Soil Survey Unit (1983) Soil Survey of Mount Makulu, Chilanga, Zambia. Report No. 1. pp.125.

Sys, C, Van Ranst, E; Debaveye, J. and Beernaert, F (1993) *Land Evaluation. Part 3:* Crop Requirements. Agricultural Publications No. 7. General Administration for Development Cooperation, Brussels, Belgium.

Tang Huajun; Debaveye, J, Ruan, D. and Van Ranst, E. (1992) *Land suitability classification based on fuzzy set theory*. ITC, Ghent, publication No 91/38.

Temple, P.H. (1972) Soil and Water Conservation Policies in the Uluguru Mountain. Tanzania. *Geografiska Annaler* 54 A (3-4), 110-123.

Temple, P.H. and Rapp, A. (1972) Landslides in the Mgeta Area Western Uluguru Mountains, Tanzania. *Geografiska Annaler* 54 A (3-4), 157-193.

Thompson, L.M and Troeh, F.R. (1985) *Soil and Soil Fertility*. Fourth edition. New York, USA Tata McGraw-Hill Publishing Company limited. P. 42 - 78.

United Republic of Tanzania (1992) National Soil and Water Conservation Programme (Draft report). Sectoral Planning Section, Ministry of Agriculture, Dar es Salaam, Tanzania.

United Republic of Tanzania (1999) Soil Fertility Initiative: Proposed initial preparation work, Ministry of Agriculture and Cooperatives, Dar es Salaam. Tanzania and FAO, Rome, Italy.

Van Donge, J.K. (1992) Agricultural Decline in Tanzania: the case of the Uluguru mountains. *African Affairs 91, 73 - 94.*

Verbesselt, J and Mertens, K. (2000) *Towards land evaluation in the Uluguru Mountains, Tanzania.* Catholic University Leuven, Belgium, pp 116.

Watanabe, F.S. and Olsen, S.R. (1965) Test of an Ascorbic Acid Method for Determining Phosphorus in Water and $NaHCO_3$ Extracts from Soil. *Soil Science Society of America Proceedings 29, 677 - 678.*

Wood, S.R. and Dent, F.J. (1983) *A Land Evaluation Computer System Methodology (LECS).* Ministry of Agriculture Government of Indonesia and FAO / UNDP.

Wright, A.E. (1959) *Geological Survey of Tanganyika.* First edition. Geological Survey Department, Dodoma, Tanzania.

Young, A. and Goldsmith, P.F. (1977) Soil survey and land evaluation in developing countries: Case study in Malawi. *Geographical Journal* 153, 407 - 438.

Zadeh, L.A. (1965) Fuzzy sets. *Information and control. 8, 338 - 353.*

APPENDICES

Appendix 1. Soil profile description and analytical data

Profile number : MGP-1 Mapping unit. Cm1 Agro-ecol zone:
Region : Morogoro District : Morogoro rural
Map sheet no : 201/1 Co-ordinates : 37° 36' 0.0" E: 7° 1' 59.9" S
Location : About 3 km from Bunduki mission to Langali
Elevation : 1600 m asl. Parent material: colluvium derived from meta-anorthosite, meta-gabbroic anorthosite and meta-anorthositic gabbro.
Landform: mountain; steeply dissected. Slope: 40 %; straight
Surface characteristics : Erosion: severe. Deposition: none
Natural drainage class : well drained

Described by S B. Mwango, B.M. Msanya, D.N. Kimaro and E.P. Kileo on 04/01/2000

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

Ap 0 - 20 cm: very dark greyish brown (10YR3/2) dry, very dark grey (10YR3/1) moist; sandy clay loam; soft dry, friable moist, slightly sticky and slightly plastic wet; moderate fine and medium subangular blocks, many fine pores; many fine and few medium roots; clear smooth boundary to

Bw 20 - 45 cm: dark brown (10YR3/3) dry, very dark greyish brown (10YR3/2) moist; sandy clay loam; slightly hard dry, friable moist, sticky and plastic wet; moderate fine and medium subangular blocks; many fine and few very fine pores; many very fine and few medium roots; gradual smooth boundary to

BC 45 - 75 cm: dark yellowish brown (10YR3/4) moist; sandy clay loam slightly hard dry, friable moist, sticky and plastic wet; moderate fine and medium subangular blocks; common fine and few medium pores; very fine and medium roots; abrupt smooth boundary

C 75 cm+: complex of meta-anorthosite, meta-gabbroic anorthosite and meta-anorthositic gabbro saprolite.

SOIL CLASSIFICATION:
World Reference Base WRB (FAO,1998) :Haplic Phaeozems
USDA Soil Taxonomy (Soil Survey Staff, 1998):Typic Hapludolls

ANALYTICAL DATA FOR PROFILE MGP-1

Horizon	Ap	Bw	BC
Depth (cm)	0-20	20-45	45-75
Clay %	22	25	24
Silt %	15	16	14
Sand %	63	59	62
Texture class	SCL	SCL	SCL
Bulk density g/cc	1.3	1.5	1.7
AWC mm/75cm			92
pH H_2O 1:2.5	5.6	6.2	6.7
pH KCl 1:2.5	4.2	4.2	5.4
EC 1:2.5 mS/cm	nd	nd	nd
Organic C %	5.06	2.69	0.94
Total N %	0.51	0.26	0.08
C/N	9.9	10.4	11.8
Avail. P Bray-1 mg/kg	4.4	2.3	1.8
Avail. P Olsen mg/kg	nd	nd	nd
CEC NH_4OAc emol(+)/kg	17.6	20.0	12.6
Exch. Ca emol(+)/kg	7.1	11.7	9.8
Exch. Mg emol(+)/g	3.1	1.46	1.44
Exch. K emol(+)/kg	0.15	0.06	0.04
Exch. Na emol(+)/kg	0.09	0.18	0.16
Exch. H emol(+)/kg	0.11	nd	nd
Exch. Al emol(+)/kg	0.1	nd	nd
TEB emol(+)/kg	10.4	13.4	11.5
Al saturation %	1.0	nd	nd
Exch. acidity emol(+) kg	0.2	nd	nd
Base saturation %	60.7	67.3	90.6
CEC clay emol(+)/kg	0.7	40.2	35.6
Cu mg/kg	0.8	0.6	0.2
Fe mg kg	67.9	45.2	17.1
Mn mg/kg	27.2	11.6	18.3
Zn mg/kg	0.4	0.3	0.2
B mg/kg	0.07	0.05	0.04

nd not determined

Profile number : MGP-2 Mapping unit: K11 Agro-ecol. zone
Region : Morogoro District : Morogoro rural
Map sheet no : 201 1: Co-ordinates : 37° 34' 18.5" E/ 7° 5' 37.7" S
Location : Vinyemba about 2km from Nyandira along the road to Kibuko
Elevation : 1640 m asl. Parent material: kaolinitic clays
Landform: mountain; steeply dissected. Slope. 15 %. convex
Surface characteristics . Erosion Deposition: none
Natural drainage class : well drained

Described by B.M. Msanya, S.B. Mwango, D.N. Kimaro and E.P. Kileo on 18/12/99

Soils are very deep, well drained, strong brown clays to silt clays, with thick dark brown clay topsoils.

Ap 0 - 18 cm: dark brown (7.5YR4/4) moist; clay; friable moist, sticky and plastic wet; weak fine and medium crumbs; many fine pores; few medium and many fine roots; abrupt smooth boundary to

AB 18 - 46 cm: strong brown (7.5YR5/6) moist; clay; firm moist, sticky and plastic wet, moderate fine and medium subangular blocks; many fine pores, many fine roots, gradual smooth boundary to

Bw 46 - 85 cm: strong brown (7.5YR5/6) moist; clay; firm moist, sticky and plastic wet; strong fine and medium subangular blocks; many fine and few medium pores; few small irregular fresh quartz fragments; few fine and coarse roots; clear smooth boundary to

BC 85 - 130 cm: strong brown (7.5YR5/8) moist; silt clay; friable moist, sticky and plastic wet; moderate fine and medium subangular blocks; many fine pores, very fine roots

SOIL CLASSIFICATION:
World Reference Base WRB (FAO, 1998): Chromi-Ferralic Cambisols (Dystric)
USDA Soil Taxonomy (Soil Survey Staff, 1998): Typic Dystrudepts

ANALYTICAL DATA FOR PROFILE MGP-2

Horizon	Ap	AB	Bw	BC
Depth (cm)	0-18	18-46	46-85	85-130
Clay %	56	54	48	41
Silt %	28	34	37	40
Sand %	16	12	15	19
Texture class	C	C	C	SiC
Bulk density g/cc	1.1	1.1	1.1	1.2
AWC mm/m				104.1
pH H_2O 1:2.5	6.2	6.4	5.8	6.1
pH KCl 1:2.5	5.2	4.9	4.3	4.2
EC 1:2.5 mS/cm	nd	nd	nd	nd
Organic C %	6.73	0.81	0.50	0.18
Total N %	0.28	0.10	0.04	0.01
C/N	23.9	8.2	13.6	21.2
Avail. P Bray-1 mg/kg	1.24	0.11	0.11	0.07
CEC NH_4OAc cmol(+)/kg	25	14.0	13.2	12.8
Exch. Ca cmol(+)/kg	10.0	4.7	3.9	3.1
Exch. Mg cmol(+)/g	2.4	2.6	2.1	1.9
Exch. K cmol(+)/kg	0.08	0.04	0.01	0.04
Exch. Na cmol(+)/kg	0.14	0.12	0.14	0.27
Exch. H cmol(+)/kg	nd	nd	0.05	nd
Exch. Al cmol(+)/kg	nd	nd	0.05	nd
TEB cmol(+)/kg	12.7	7.4	6.2	5.3
Al saturation %	nd	nd	0.8	nd
Exch. acidity cmol(+)/kg	nd	nd	0.1	nd
Base saturation %	50.6	52.7	46.6	41.3
CEC clay cmol(+)/kg	3.2	21.0	23.9	29.9
Cu mg/kg	0.7	0.2	0.4	0.4
Fe mg/kg	37.5	21.1	12.5	9.1
Mn mg/kg	52.7	20.7	4.1	0.7
Zn mg/kg	0.28	0.09	0.04	0.14
B mg/kg	0.10	0.04	0.02	0.03

nd not determined

Profile number : MGP-3 Mapping unit: K11 Agro-ecol. zone
Region : Morogoro
District : Morogoro rural
Map sheet no. : 201/1
Co-ordinates : 37° 33' 46 8" E/ 7° 5' 40 2" S
Location : Milengwe about 1km west of Nyandira-Kibuko road
Elevation : 1580 m asl. Parent material kaolinitic clays
Landform: mountain; steeply dissected. Slope: 2 %; convex
Surface characteristics : Erosion: . Deposition: none.
Natural drainage class : well drained

Described by B.M. Msanya, S.B. Mwango, D.N. Kimaro and E.P. Kilgo on 18/12/99

Soils are very deep, well drained, strong brown to reddish yellow clays to clay loams, with very thic black clay topsoils.

Ap 0 - 18/25 cm. black (7.5YR2.5/1) moist; clay; friable moist, slightly sticky and slightly plastic wet; weak medium subangular blocks, many fine pores; many fine roots; abrupt wavy boundary to

Bt 18/25 - 85 cm; strong brown (7.5YR5/6) moist, clay; friable moist, sticky and plastic wet; moderate fine and medium subangular blocks; continuous thin clay cutans; many fine pores; few medium angular fresh quartz fragments; many fine roots, gradual smooth boundary to

BC 85 - 193 cm: reddish yellow (7.5YR6/8) moist; clay loam; friable moist, sticky and plastic wet; moderate fine and medium angular blocks; patchy thin clay cutans, many fine pores; few medium angular fresh quartz fragments; very fine roots

SOIL CLASSIFICATION:
World Reference Base WRB (FAO,1998): Chromi-Hyperdystric Acrisols (Haplic)
USDA Soil Taxonomy (Soil Survey Staff, 1998): Typic Hapludults

ANALYTICAL DATA FOR PROFILE MGP-3

Horizon	Ap	Bt	BC
Depth (cm)	0-18 25	18/25-85	85-193
Clay %	54	60	38
Silt %	30	33	37
Sand %	16	7	25
Texture class	C	C	CL
Bulk density g/cc	1.1	1 2	1.3
AWC mm/m			101.3
pH H_2O 1 2 5	5.5	5.4	5.8
pH KCl 1,2.5	4.3	4.0	4 0
EC 1:2 5 mS/cm	nd	nd	nd
Orgame C %	5 17	0.83	0.30
Total N %	0.37	0.06	0.01
C/N	13.9	12.9	35 4
Avail. P Bray-1 mg/kg	2.2	0.6	0 9
Avail. P Olsen mg/kg	nd	nd	nd
CEC NH_4OAc emol(+)/kg	24.4	10.4	8
Exch. Ca emol(+)/kg	2.6	0.9	0.7
Exch. Mg emol(+)/g	0 7	0.5	0 2
Exch. K emol(+)/kg	0.11	0 04	0.04
Exch. Na emol(+)/kg	0.17	0.07	0.19
Exch. H emol(+)/kg	0 3	0.2	0 1
Exch. Al emol(+)/kg	0 7	1 1	1
TEB emol(+)/kg	3.6	1.5	1.1
Al saturation %	16.3	42.3	47 6
Exch. acidity emol(+) kg	1.00	1.3	1.1
Base saturation %	17.5	14.4	13.9
CEC clay emol(+) kg	4.8	12.6	18.4
Cu mg/kg	0.4	0.3	0.3
Fe mg/kg	30.7	36.8	6.5
Mn mg kg	8.20	0.57	0 08
Zn mg kg	0 28	0.05	0.06
B mg kg	0.09	0 06	0.07

nd not determined

Profile number : MGP-4 Mapping unit. KI2
Agro-ecol. zone:
Region : Morogoro: District . Morogoro rural
Map sheet no. : 201/1
Co-ordinates : 37° 33' 41.8" E/ 7° 5' 38.8" S
. Location : about 3km from Nyandira to Kibuko and 1km west of the road
Elevation : 1550 m asl Parent material. kaolinitic clays
Landform: mountain; steeply dissected. Slope: 62 %: straight
Surface characteristics : Erosion: . Deposition: none.
Natural drainage class : well drained

Described by D.N. Kimaro, S.B. Mwango, B.M. Msanya and E.P. Kileo on 18/12/99
Soils are very deep, well drained, strong brown to yellowish brown clay loams to clays with thick dark greyish brown clay topsoils

Ap 0 - 15/18 cm. dark greyish brown (10YR4/2) moist; clay; friable moist, sticky and plastic wet; weak coarse subangular blocks; many fine pores; few medium angular fresh quartz fragments; and few fine roots; abrupt wavy boundary to

Bt 15/18 - 57/63 cm: strong brown (7.5YR4/6) moist; clay; friable moist, very sticky and very plastic wet; moderate fine and medium subangular blocks; continuous thin clay cutans; few medium and many fine pores; few medium angular fresh quartz fragments; very fine roots; gradual wavy boundary to

CB 57/63 - 130/140 cm yellowish brown (10YR5/4) moist; clay loam; friable moist, sticky and plastic wet; weak medium and coarse subangular blocks; many very fine pores; few medium angular fresh quartz fragments; medium and very fine roots; diffuse wavy boundary to

C 130/140 - 235 cm: strong brown (7.5YR5/6) moist; sand loam; many very fine pores; very fine roots saprolite containing meta-anorthosite, meta-gobbroic anorthosite and meta-anorthositic gabbro.

SOIL CLASSIFICATION:
World Reference Base WRB (FAO, 1998): Epidystri-Cutanic Luvisols (Haplic)
USDA Soil Taxonomy (Soil Survey Staff, 1998): Inceptic Hapludalfs

ANALYTICAL DATA FOR PROFILE MGP-4

Horizon	Ap	Bt	CB	C
Depth (cm)	0-15.18	15.18-57/63	57/63-130/140	130/140-235+
Clay %	62	66	32	12
Silt %	32	31	46	15
Sand %	6	3	22	73
Texture class	C	C	CL	SL
Bulk density g/cc	1.1	1.2	1.3	1.3
AWC mm/m			77.2	
pH H_2O 1:2.5	5.6	6.4	6.8	6.6
pH KCl 1:2.5	4.4	5.0	4.8	4.4
Organic C %	5.50	0.46	0.32	0.04
Total N %	0.19	0.06	0.02	0.02
C/N	28.9	7.9	20.6	2.6
Avail. P Bray-1 mg/kg	1.6	1.5	6.8	131.6
Avail. P Olsen mg/kg	nd	nd	nd	nd
CEC NH_4OAc cmol(+)/kg	22.12	21.2	9.2	12.0
Exch. Ca cmol(+)/kg	4.3	4.1	3.9	1.6
Exch. Mg cmol(+)/g	2.0	2.2	2.4	1.5
Exch. K cmol(+)/kg	0.06	0.04	0.04	0.06
Exch. Na cmol(+)/kg	0.05	0.05	0.07	0.05
Exch. H cmol(+)/kg	nd	nd	nd	nd
Exch. Al cmol(+)/kg	nd	nd	nd	nd
TEB cmol(+)/kg	6.4	6.3	6.3	3.3
Al saturation %	nd	nd	nd	nd
Exch. acidity cmol(+)/kg	nd	nd	nd	nd
Base saturation %	28.9	29.7	68.7	27.2
CEC clay cmol(+)/kg	7.6	29.7	25.3	98.9
Cu mg/kg	0.4	0.4	0.6	0.1
Fe mg/kg	46.2	16.9	22.5	31.1
Mn mg/kg	140.1	22.7	2.8	0.3
Zn mg/kg	0.52	0.08	0.04	0.01
B mg/kg	0.05	0.03	0.01	0.02

nd not determined

Profile number : MGP-5 Mapping unit: Cm1 Agro-ecol. zone:
Region : Morogoro
District : Morogoro rural
Map sheet no. : 201/1
Co-ordinates : 37° 34' 51.6" E/ 7° 4' 9.8" S
Location : Kidongo chekundu about 2km from Nyandira to Langali
Elevation : 1580 m asl. Parent material: meta-anorthosite, meta-gabbroic anorthosite and meta-anorthositic gabbro.
Landform: mountain: steeply dissected. Slope: 58 %, straight
Surface characteristics : Stones: 10 % Erosion: Deposition: none.
Natural drainage class : well drained

Described by B.M. Msanya, F.P. Kileo, D.N. Kimaro and S.B. Mwango on 20/12/99

Soils are shallow, well drained, very dark grey clays over reddish yellow to very pale brown clay loam to loam saprolite of meta-anorthositic and meta-gabbroic rocks.

Ah 0 - 25/30 cm; very dark grey (5YR3/1) moist, bouldery clay; friable moist, slightly sticky and slightly plastic wet; moderate coarse and medium subangular blocks; many fine and few medium pores; few small spherical fresh quartz fragments; many fine and very fine roots; clear wavy boundary to

C1 25/30 - 95/110 cm; reddish yellow (7.5YR6/6) moist; clay loam; friable moist, slightly sticky and slightly plastic wet, structureless massive; many very fine and fine pores; very few small spherical fresh quartz fragments; few fine and very fine roots; clear wavy boundary to

C2 95/110 - 160 cm; very pale brown (10YR8/3) moist; loam; friable moist, non-sticky and non-plastic wet; structureless massive; many very fine pores; few fine and very fine roots.

SOIL CLASSIFICATION:
World Reference Base WRB (FAO, 1998): Hapli-Humic Umbrisols
USDA Soil Taxonomy (Soil Survey Staff, 1998): Typic Udorthents

ANALYTICAL DATA FOR PROFILE MGP-5

Horizon	Ah	C1	C2
Depth (cm)	0-25/30	25/30-95/110	95/110-160+
Clay %	52	32	18
Silt %	26	43	40
Sand %	22	25	42
Texture class	C	CL	L
Bulk density g/cc	1.1	1.2	1.2
AWC mm/m			103.3
pH H_2O 1:2.5	5.5	5.6	6.0
pH KCl 1:2.5	4.5	4.0	4.0
Organic C %	6.18	0.26	0.20
Total N %	0.2	0.02	0.01
C/N	33.7	13.6	40.4
Avail. P Bray-1 mg/kg	4.0	0.7	1.8
Avail. P Olsen mg/kg	nd	nd	nd
CEC NH_4OAc cmol(+)/kg	23.1	10.0	9.2
Exch. Ca cmol(+)/kg	4.6	2.6	3.6
Exch. Mg cmol(+)/g	1.7	0.8	0.8
Exch. K cmol(+) kg	0.4	0.04	0.06
Exch. Na cmol(+) kg	0.14	0.17	0.23
Exch. H cmol(+)/kg	0.08	0.15	0.10
Exch. Al cmol(+)/kg	0.08	0.55	0.15
TEB cmol(+)/kg	6.8	3.6	4.7
Al saturation %	1.2	13.3	3.1
Exch. acidity cmol(+) kg	0.15	0.70	0.25
Base saturation %	29.4	35.9	50.7
CEC clay cmol(+)/kg	3.6	28.5	47.3
Cu mg/kg	0.65	0.46	0.14
Fe mg/kg	28.0	5.8	3.8
Mn mg kg	36.6	1.2	0.7
Zn mg kg	0.09	0.05	0.004
B mg kg	0.05	0.04	0.01

nd = not determined

Profile number: MGP-6 Mapping unit: G11 Agro-ecol. zone:
Region : Morogoro
District : Morogoro rural
Map sheet no. : 201/1
Co-ordinates : 37° 37' 3.4" E; 7° 6' 31.7" S
Location : Lukwangule plateau
Elevation : 2620 m asl. Parent material: banded pyroxene granulites
Landform: plateau; rolling. Slope: 35 %; straight
Surface characteristics : Stones: 2 % Erosion: severe. Deposition: none
Natural drainage class: somewhat excessively drained.

Described by B.M. Msanya, E.P. Kileo, D.N. Kimaro and S.B. Mwango on 19/12/99

Soils are shallow, well drained, black sandy clay loams over slightly weathering rock.

Ah 0 - 24/30 cm: black (5YR2.5/1) moist; slightly stony sandy clay loam; friable moist, non-sticky and non-plastic wet; moderate coarse subangular blocks and medium angular blocks; many fine and very fine pores; few medium spherical weathered feldspar fragments; many fine and few coarse roots; clear wavy boundary to

CR 24/30 - 100 cm+: banded pyroxene granulites saprolite, slightly weathered, with original rock structures.

SOIL CLASSIFICATION:
World Reference Base WRB (FAO, 1998): Hapli-Humic Umbrisols
USDA Soil Taxonomy (Soil Survey Staff, 1998): Typic Udorthents

ANALYTICAL DATA FOR PROFILE MGP-6

Horizon	Ah	CR
Depth (cm)	0-24/30	24/30-100+
Clay %	20	10
Silt %	20	17
Sand %	60	73
Texture class	SCL	SL
Bulk density g/cc	1.1	nd
AWC mm/30cm	19.8	nd
pH H_2O 1:2.5	5.1	5.6
pH KCl 1:2.5	4.1	4.3
Organic C %	10.9	0.25
Total N %	0.54	0.01
C/N	20.1	25
Avail. P Bray-1 mg/kg	0.8	0.2
Avail. P Olsen mg/kg	nd	nd
CEC NH_4OAc cmol(+)/kg	38.4	5.9
Exch. Ca cmol(+)/kg	0.15	0.02
Exch. Mg cmol(+)/g	0.23	0.03
Exch. K cmol(+)/kg	0.13	0.01
Exch. Na cmol(+)/kg	0.09	0.03
Exch. H cmol(+)/kg	0.15	0.02
Exch. Al cmol(+)/kg	1.75	0.03
TEB cmol(+)/kg	0.6	0.09
Al saturation %	74.5	25
Exch. acidity cmol(+)/kg	1.9	0.04
Base saturation %	1.6	1.5
CEC clay cmol(+)/kg	4.9.0	50.4
Cu mg/kg	1.6	0.12
Fe mg/kg	33.9	23.6
Mn mg/kg	0.28	0.09
Zn mg/kg	0.23	0.04
B mg/kg	0.11	0.03

nd = not determined

Profile number : MGP-7 Mapping unit: G12 Agro-ecol. zone:
Region : Morogoro
District : Morogoro rural
Map sheet no. : 201/1
Co-ordinates : 37° 36' 20.2" E/ 7° 6' 3.2" S
Location : Urindi (Forest reserve)
Elevation : 2200 m asl Parent material: banded pyroxene granulites.
Landform: plateau; hilly. Slope: 59 %; straight
Surface characteristics : Outcrops: 5 % Erosion: severe. Deposition: none.
Natural drainage class : well drained

Described by B.M. Msanya, E.P. Kileo, D.N. Kimaro and S.B. Mwango on 19/12/99

Soils are deep, well drained, dark yellowish brown sand loams, with very thick very dark brown sandy loam topsoils.

O 0 - 40/50 cm:; many fine and medium roots; clear wavy boundary to

Ah 40/50 - 95 cm: very dark brown (10YR2/2) moist; sandy loam; friable moist, non-sticky and non-plastic wet; strong fine and very fine subangular blocks; many very fine and fine pores; few medium irregular fresh quartz fragments, many fine and few medium roots; clear smooth boundary to

Bw 95 - 150 cm: dark yellowish brown (10YR3/4) moist; sandy loam, friable moist, non-sticky and non-plastic wet; moderate fine and medium subangular blocks; many very fine pores; frequent medium irregular fresh quartz fragments; few coarse and very fine roots; clear smooth boundary to

CR 150 cm +: banded pyroxene granulites saprolite, slightly weathered, with original rock structures.

SOIL CLASSIFICATION:
World Reference Base WRB (FAO, 1998): Hapli-Humic Umbrisols
USDA Soil Taxonomy (Soil Survey Staff, 1998): Humic Dystrudepts

ANALYTICAL DATA FOR PROFILE MGP-7

Horizon	O	Ah	Bw
Depth (cm)	0-40/50	40/50-95	95-150+
Clay %	nd	16	12
Silt %	nd	20	8
Sand %	nd	64	80
Texture class	nd	SL	SL
Bulk density g/cc	nd	1.1	1.5
AWC mm/45cm	nd		34.8
pH H_2O 1:2.5	nd	4.8	5.3
pH KCl 1:2.5	nd	3.8	4.5
EC 1:2.5 mS/cm	nd	nd	nd
Organic C %	nd	11.3	1.4
Total N %	nd	0.76	0.03
C/N	nd	14.8	47.1
Avail. P Bray-1 mg/kg	nd	7.5	7.8
Avail. P Olsen mg/kg	nd	nd	nd
CEC NH_4OAc cmol(+)/kg	nd	40.0	8.0
Exch. Ca cmol(+)/kg	nd	0.78	0.08
Exch. Mg cmol(+)/g	nd	0.66	0.09
Exch. K cmol(+)/kg	nd	0.22	0.01
Exch. Na cmol(+)/kg	nd	0.10	0.02
Exch. H cmol(+)/kg	nd	0.75	0.08
Exch. Al cmol(+)/kg	nd	4.10	0.38
TEB cmol(+)/kg	nd	1.75	0.21
Al saturation %	nd	70.1	64.4
Exch. acidity cmol(+)/kg	nd	4.85	0.45
Base saturation %	nd	4.38	2.60
CEC clay cmol(+)/kg	nd	6.8	26.8
Cu mg/kg	nd	0.67	0.21
Fe mg/kg	nd	214.9	30.5
Mn mg/kg	nd	0.15	0.19
Zn mg/kg	nd	0.09	0.03
B mg/kg	nd	0.17	0.03

nd= not determined

Profile number : MGP-8 Mapping unit: Cgk1
Agro-ecol. zone:
Region : Morogoro
District : Morogoro rural
Map sheet no. : 201/1
Co-ordinates : 37° 35' 27.6" E 7 5' 36.2" S
Location : Mkongoro (about 2.5 km from Nyandira along the road to Tchenzema)
Elevation : 1680 m asl. Parent material colluvium derived from banded pyroxene granulites, in places kaolinitic clays
Landform: mountain; steeply dissected. Slope: 47 %; straight
Surface characteristics : Stones: 2 % Erosion: . Deposition: none
Natural drainage class : somewhat excessively drained.

Described by B.M. Msanya, E.P. Kileo, S.B. Mwango and D.N. Kimaro on 20/12/99

Soils are moderately deep, well drained, pale yellow sandy loams to sandy clay loams over sandy loam saprolite.

Ah 0 - 45 cm: pale yellow (2.5Y7/4) moist; bouldery sandy loam to sandy clay loam; friable moist, slightly sticky and slightly plastic wet, moderate medium and coarse subangular blocks; many fine and few medium pores; few small spherical fresh quartz fragments; many fine and few coarse roots; clear smooth boundary to

C 45 - 185 cm: sandy loam; friable moist, non-sticky and non-plastic wet; structureless massive; many very fine pores; fine and very fine roots saprolite containing meta-anorthosite, meta-gabbroic anorthosite and meta-anorthositic gabbro.

SOIL CLASSIFICATION:
World Reference Base WRB (FAO, 1998): Hapli-Hypereutric Regosols
USDA Soil Taxonomy (Soil Survey staff, 1998): Typic Udorthents

ANALYTICAL DATA FOR PROFILE MGP-8

Horizon	Ah	C
Depth (cm)	0-45	45-185+
Clay %	20	12
Silt %	24	14
Sand %	56	74
Texture class	SL-SCL	SL
Bulk density g/cc	1.1	1.7
AWC mm/m		131.7
pH H_2O 1:2.5	5.6	6.7
pH KCl 1:2.5	3.3	3.2
EC 1:2.5 mS/cm	nd	nd
Organic C %	0.14	0.06
Total N %	0.003	0.001
C/N	49.5	42.4
Avail. P Bray-1 mg/kg	5.4	5.4
Avail. P Olsen mg/kg	nd	nd
CEC NH_4OAc cmol(+)/kg	8	3.4
Exch. Ca cmol(+)/kg	7.8	10.7
Exch. Mg cmol(+)/g	0.9	0.5
Exch. K cmol(+)/kg	0.13	0.06
Exch. Na cmol(+)/kg	0.14	0.20
Exch. H cmol(+)/kg	0.35	nd
Exch. Al cmol(+)/kg	1.25	nd
TEB cmol(+)/kg	8.9	11.4
Al saturation %	12.3	nd
Exch. acidity cmol(+)/kg	1.6	nd
Base saturation %	99.2	356.4
CEC clay cmol(+)/kg	37.6	25
Cu mg/kg	0.7	0.19
Fe mg/kg	15.2	11.0
Mn mg/kg	1.0	4.7
Zn mg/kg	0.24	0.07
B mg/kg	0.03	0.04

nd = not determined

Profile number : MGP-9 Mapping unit: G22
Agro-ecol. zone:
Region : Morogoro
District : Morogoro rural
Map sheet no. : 201 1
Co-ordinates : 37° 34' 1.6" E/ 7° 1' 41.9" S
Location : At the junction to Tandari along Morogoro-Mgeta road
Elevation : 1056 m asl. Parent material: banded pyroxene granulites.
Landform: mountain: hilly. Slope: 15 %: straight
Surface characteristics : Stones: 5 % Erosion: . Deposition: none
Natural drainage class : well drained

Described by S.B. Mwango, E.P. Kileo, B.M. Msanya and D.N. Kimaro on 01/03/00

Soils are shallow, well drained, black sandy clay loams over dark brown saprolite

Ap 0 - 25/30 cm: very dark brown (7.5YR2.5/2) dry, black (7.5YR2.5/1) moist, slightly stony sandy clay loam; slightly hard dry, friable moist, sticky and plastic wet; strong fine and medium subangular blocks; many fine and few medium pores; few small irregular fresh feldspar fragments, many fine and medium roots, clear wavy boundary to

C1 25/30 - 80/110 cm: dark brown (7.5YR3/3) dry, dark brown (7.5YR3/2) moist, sandy clay loam; hard dry, friable moist, sticky and plastic wet, structureless massive, many fine and medium pores; frequent medium irregular weathered feldspar fragments, very fine and few fine roots; gradual wavy boundary to

C2 80/110 - 180 cm: sandy loam; slightly hard dry, friable moist, non-sticky and non-plastic wet; structureless massive; many fine pores; very fine roots

SOIL CLASSIFICATION:
World Reference Base WRB (FAO, 1998): Hapli-Hypereutric Regosols
USDA Soil Taxonomy (Soil Survey Staff, 1998): Typic Udorthents

ANALYTICAL DATA FOR PROFILE MGP -9

Horizon	Ap	C1	C2
Depth (cm)	0-25/30	25/30-80/110	80/110-180
Clay %	35	20	14
Silt %	17	13	5
Sand %	48	67	81
Texture class	SCL	SCL	SL
Bulk density g/cc	1.3	1.8	1.9
AWC mm/m			143.4
pH H_2O 1:2.5	6.6	7.0	7.4
pH KCl 1:2.5	4.7	4.6	4.3
EC 1:2.5 mS/cm	nd	0.02	0.02
Organic C %	1.78	0.20	0.12
Total N %	0.13	0.022	0.003
C/N	14.0	8.8	42.4
Avail. P Bray-1 mg/kg	3.8	1.9	0.8
Avail. P Olsen mg/kg	nd	2.3	1.3
CEC NH_4OAc cmol(+)/kg	17.8	13.2	8.4
Exch. Ca cmol(+)/kg	9.2	8.4	7.1
Exch. Mg cmol(+)/g	5.1	4.5	4.0
Exch. K cmol(+)/kg	1.02	0.13	0.06
Exch. Na cmol(+)/kg	0.13	0.04	0.05
Exch. H cmol(+)/kg	nd	nd	nd
Exch. Al cmol(+)/kg	nd	nd	nd
TEB cmol(+)/kg	15.4	13.1	11.1
Exch. acidity cmol(+)/kg	nd	nd	nd
Base saturation %	86.5	98.9	132.6
CEC clay cmol(+)/kg	32.9	61.4	55.5
Cu mg/kg	1.13	0.59	0.41
Fe mg/kg	44.1	23.1	9.8
Mn mg/kg	10.2	10.4	7.9
Zn mg/kg	0.22	0.09	0.07
B mg/kg	0.06	0.02	0.02

nd not determined

Profile number: MGP-10 Mapping unit: G21 Agro-ecol. zone:
Region : Morogoro
District : Morogoro rural
Map sheet no. : 201/1
Co-ordinates : 37° 34' 26.0" E; 7° 1' 27.5" S
Location : Kidiwa along the road to Tandari
Elevation : 1284 m asl. Parent material: banded pyroxene granulites.
Landform: mountain; steeply dissected. Slope: 4 %; straight
Surface characteristics : Erosion: . Deposition: none.
Natural drainage class : well drained

Described by S.B. Mwango, E.P. Kileo, B.M. Msanya and D.N. Kimaro on 01/03/00

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

Ap 0 - 14/24 cm: very dark brown (7.5YR2.5/2) moist; sandy clay loam; friable moist, non-sticky and non-plastic wet; moderate medium and fine subangular blocks; many fine and medium pores; many fine and common medium roots; clear wavy boundary to

AB 14/24 - 30/35 cm: dark brown (7.5YR3/2) moist; sandy clay loam; soft dry, friable moist, non-sticky and non-plastic wet; moderate fine and very fine subangular blocks; many fine and few medium pores; many fine and medium roots; clear wavy boundary to

Bw 30/35 - 44/64 cm: brown (7.5YR4/3) moist; sandy loam; loose dry, very friable moist, non-sticky and non-plastic wet; weak very fine subangular blocks; many fine and medium pores; many fine and medium roots; clear wavy boundary to

C 44/64 - 140 cm: light brown (7.5YR6/4) moist; loam sand; loose dry, very friable moist, non-sticky and non-plastic wet; structureless single grain; many very fine pores, common fine and medium roots

SOIL CLASSIFICATION:
World Reference Base WRB (FAO, 1998): Epidystri-Ferralic Cambisols (Haplic)
USDA Soil Taxonomy (Soil Survey Staff, 1998): Humic Dystrudepts

ANALYTICAL DATA FOR PROFILE MGP-10

Horizon	Ap	AB	Bw	C
Depth (cm)	0-14/24	14/24-30/35	30/35-44/64	44/64-140+
Clay %	26	26	16	10
Silt %	5	8	9	3
Sand %	69	66	75	87
Texture class	SCL	SCL	SL	LS
Bulk density g/cc	1.3	1.5	1.5	1.9
AWC mm/m				152.3
pH H_2O 1:2.5	6.1	6.0	6.3	6.6
pH KCl 1:2.5	4.4	4.2	4.3	4.5
EC 1:2.5 mS/cm	nd	nd	nd	nd
Organic C %	1.90	1.19	0.79	0.27
Total N %	0.12	0.08	0.04	0.01
C/N	16.3	15.2	21.8	32.5
Avail. P Bray-1 mg/kg	1.8	1.6	4.5	40.1
Avail. P Olsen mg/kg	nd	nd	nd	nd
CEC NH_4OAc cmol(+)/kg	11.6	8.6	4.4	3.2
Exch. Ca cmol(+)/kg	3.5	2.5	1.3	1.0
Exch. Mg cmol(+)/g	1.2	0.7	0.3	0.2
Exch. K cmol(+)/kg	0.6	0.3	0.2	0.4
Exch. Na cmol(+)/kg	0.07	0.03	0.03	0.12
Exch. H cmol(+)/kg	nd	nd	nd	nd
Exch. Al cmol(+)/kg	nd	nd	nd	nd
TEB cmol(+)/kg	5.4	3.5	1.9	1.6
Exch. acidity cmol(+)/kg	nd	nd	nd	nd
Base saturation %	46.7	40.1	42.7	50.9
CEC clay cmol(+)/kg	19.1	17.1	10.2	8.5
Cu mg/kg	0.9	0.55	0.22	0.12
Fe mg/kg	65.6	31.4	9.0	3.4
Mn mg/kg	6.35	1.17	1.28	0.08
Zn mg/kg	0.11	0.06	0.02	0.03
B mg/kg	0.09	0.05	0.04	0.02

nd not determined

Profile number : MGP-11 Mapping unit: V1 Agro-ecol. zone:
Region : Morogoro
District : Morogoro rural
Map sheet no. : 201/1
Co-ordinates : 37° 34' 4.4" E/ 7° 2' 22.2" S
Location : Lower river terrace of Mgeta river near Mgeta secondary school
Elevation : 1086 m asl. Parent material: unconsolidated mixed material. Landform: mountain; steeply dissected. Slope: 44 %; concave
Surface characteristics : Outcrops: 10 %. Erosion: . Deposition: none.
Natural drainage class : well drained

Described by D.N. Kimaro, E.P. Kileo, B.M. Msanya and S.B. Mwango on 01/03/00

Soils are moderately deep, well drained, dark olive brown sandy clay loams.

Ap 0 - 45 cm: light olive brown (2.5Y5/4) dry, dark olive brown (2.5Y3/3) moist, sandy clay loam; soft dry, friable moist, non-sticky and non-plastic wet, moderate fine and medium subangular blocks; many fine and medium pores; few medium spherical fresh quartz fragments; many fine and common medium roots; clear smooth boundary to

2C 45 - 125 cm: dark brown (10YR3/3) dry, very dark greyish brown (10YR3/2) moist; sandy clay loam; soft dry, friable moist, non-sticky and non-plastic wet; structureless massive; many fine and few medium pores; few small spherical slightly weathered gneiss fragments; many fine and coarse roots, gradual broken boundary to

3C 125 - 155 cm: very dark greyish brown (10YR3/2) dry, very dark greyish brown (10YR3/2) moist; sandy loam; very friable moist, non-sticky and non-plastic wet; structureless massive; many fine pores; common fine and coarse roots; gradual irregular boundary to

4C 155 - 190 cm: dark yellowish brown (10YR3/6) moist; sandy loam; very friable moist, non-sticky and non-plastic wet; structureless massive; many fine and few medium pores; common medium and few coarse roots

SOIL CLASSIFICATION:
World Reference Base WRB (FAO, 1998): Hypereutri-Mollic Fluvisols (Haplic)
USDA Soil Taxonomy (Soil Survey Staff,1998): Fluventic Hapludolls

ANALYTICAL DATA FOR PROFILE MGP-11

Horizon	Ap	2C	3C	4C
Depth (cm)	0-45	45-125	125-155	155-190+
Clay %	20	22	14	16
Silt %	6	15	5	17
Sand %	74	63	81	67
Texture class	SCL	SCL	SL	SL
Bulk density g/cc	1.1	1.6	1.6	nd
AWC mm/m		166.8		
pH H_2O 1:2.5	6.9	6.5	6.4	7.4
pH KCl 1:2.5	5.4	4.7	4.4	5.0
EC 1:2.5 mS/cm	nd	nd	nd	0.03
Organic C %	0.69	1.27	0.67	0.59
Total N %	0.07	0.08	0.03	0.03
C/N	9.7	16.2	20.5	22.9
Avail. P Bray-1 mg/kg	23.1	9.5	8.7	6.1
Avail. P Olsen mg/kg	nd	nd	nd	6.9
CEC NH_4OAc emol(+)/kg	8.2	7.4	4.2	6.8
Exch. Ca emol(+)/kg	5.0	5.4	2.5	5.7
Exch. Mg emol(+)/g	1.1	1.5	0.8	6.0
Exch. K emol(+)/kg	0.83	0.22	0.07	0.02
Exch. Na emol(+)/kg	0.12	0.15	0.09	0.35
Exch. H emol(+)/kg	nd	nd	nd	nd
Exch. Al emol(+)/kg	nd	nd	nd	nd
TEB emol(+)/kg	7.1	7.3	3.4	12.1
Al saturation %	nd	nd	nd	nd
Exch. acidity emol(+)/kg	nd	nd	nd	nd
Base saturation %	86.4	98.2	81.1	177.9
CEC clay emol(+)/kg	28.5	13.5	13.0	29.0
Cu mg/kg	0.4	0.8	0.8	0.8
Fe mg/kg	20.8	54.8	38.1	29.0
Mn mg/kg	9.8	21.6	4.4	10.0
Zn mg/kg	0.39	0.43	0.11	0.21
B mg/kg	0.09	0.02	0.04	0.02

nd = not determined

Profile number : MGP-12 Mapping unit: MH Agro-ecol zone:
Region : Morogoro
District : Morogoro rural
Map sheet no. : 201 1
Co-ordinates : 37 33' 9.4" E 7 4' 52.3" S
Location : Lusungi village
Elevation : 1420 m asl Parent material: meta-anorthosite, meta-gabbroic anorthosite and meta-anorthositic gabbro.
Landform: mountain; steeply dissected. Slope: 5 %; concave
Surface characteristics : Erosion: . Deposition: none.
Natural drainage class : well drained

Described by D N. Kimaro, E P Kileo, B.M. Msanya and S.B. Mwango on 02/03/00

Soils are moderately deep, well drained, dark grey sandy clay loams, with thick black clay loam topsoils.

Ap 0 - 15/20 cm: dark grey (7.5YR4/1) dry, black (7.5YR2.5/1) moist, clay loam; hard dry, friable moist, slightly sticky and slightly plastic wet; moderately strong fine and medium subangular blocks; few fine and medium pores; few medium irregular fresh quartz fragments; many fine and common medium roots; clear wavy boundary to

Bw 15/20 - 30/50 cm: grey (7.5YR6/1) dry, dark grey (7.5YR5/1) moist, sandy clay loam; slightly hard dry, friable moist, slightly sticky and slightly plastic wet; weak medium and coarse subangular blocks; few fine and medium pores; few medium irregular weathered gneiss fragments; common fine and few medium roots; clear wavy boundary to

C 30/50 - 150 cm: (7.5YR8/1) dry, light grey (7.5YR7/1) moist; sandy loam; soft dry, very friable moist, non-sticky and non-plastic wet; structureless massive; many fine and medium pores; and common fine roots

SOIL CLASSIFICATION:
World Reference Base WRB (FAO, 1998): Orthieutri-ferralic Cambisols (Haplic)
USDA Soil Taxonomy (Soil Survey Staff, 1998): Dystric Eutrudepts

ANALYTICAL DATA FOR PROFILE MGP-12

Horizon	Ap	Bw	C
Depth (cm)	0-15/20	15/20-30/50	30/50-150
Clay %	38	34	18
Silt %	19	15	15
Sand %	43	51	67
Texture class	CL	SCL	SL
Bulk density g/cc	1.1	1.5	1.8
AWC mm/m			112.1
pH H_2O 1:2.5	5.5	6.4	7.6
pH KCl 1:2.5	4.0	4.3	4.6
EC 1.2.5 mS/cm	nd	nd	0.02
Organic C %	3.25	1.15	0.40
Total N %	0.19	0.07	0.01
C/N	17.0	16.1	33.3
Avail. P Brav-1 mg/kg	6.4	2.5	1.5
Avail P Olsen mg/kg	nd	nd	1.6
CEC NH_4OAc emol(+)/kg	17.2	10	5.2
Exch. Ca emol(+)/kg	8.2	7.2	6.3
Exch. Mg emol(+)/g	1.98	0.82	0.51
Exch. K emol(+)/kg	0.32	0.07	0.02
Exch. Na emol(+)/kg	0.15	0.32	0.23
Exch. H emol(+)/kg	0.2	nd	nd
Exch. Al emol(+)/kg	1.1	nd	nd
TEB emol(+)/kg	10.7	8.4	7.1
Al saturation %	9.3	nd	nd
Exch. acidity emol(+)/kg	1.3	nd	nd
Base saturation %	62.1	84.1	136.5
CEC clay emol(+)/kg	15.6	17.6	14.3
Cu mg/kg	0.6	0.12	0.11
Fe mg/kg	54.2	8.24	2.12
Mn mg/kg	1.2	0.34	1.22
Zn mg/kg	0.10	0.04	0.03
B mg/kg	0.06	0.04	0.01

nd not determined

Profile number : MGP-13 Mapping unit: M12
Agro-ecol. zone:
Region : Morogoro
District : Morogoro rural
Map sheet no. : 201/1
Co-ordinates : 37° 33' 12.6" E/ 7° 4' 51.6" S
Location : Lusungi village along the road to Bunu
Elevation : 1370 m asl.
Parent material: meta-anorthosite, meta-gabbroic anorthosite and meta-anorthositic gabbro.
Landform: mountain; hilly. Slope: 50 %; straight
Surface characteristics : Erosion: . Deposition none
Natural drainage class : well drained

Described by E.P. Kilasi, B.M. Msanya, S.B. Mwango and D.N. Kimaro on 02/03/00

Soils are very shallow, well drained, very dark grey sandy clay loams over dark greyish brown to white sandy clay loam to loam saprolite.

Ap 0 - 10/16 cm: very dark grey (7.5YR3/1) moist; sandy clay loam; friable moist, non-sticky and non-plastic wet; moderately weak fine and medium subangular blocks; many fine and medium pores; many fine and common medium roots; clear wavy boundary to

C1 10/16 - 66/80 cm: dark greyish brown (10YR4/2) moist; sandy clay loam; very friable moist, non-sticky and non-plastic wet, structureless massive; many fine and few medium pores; common fine and medium roots; clear wavy boundary to

C2 66/80 - 180 cm: white (7.5YR8/1) moist; sandy loam; very friable moist, non-sticky and non-plastic wet; structureless massive; many fine and medium pores; medium and few very fine roots

SOIL CLASSIFICATION:
World Reference Base WRB (FAO,1998): Hapli-Orthieutric Regosols
USDA Soil Taxonomy (Soil Survey Staff, 1998): Typic Udorthents

ANALYTICAL DATA FOR PROFILE MGP-13

Horizon	Ap	C1	C2
Depth (cm)	0-10 16	10/16-66/80	66/80-180+
Clay %	26	20	14
Silt %	15	13	11
Sand %	59	67	75
Texture class	SCL	SCL	SL
Bulk density g/cc	1.3	1.7	1.8
AWC mm/m			90.9
pH H_2O 1.2 5	6.2	6.7	7.2
pH KCl 1.2 5	4.4	4.2	4.0
EC 1.2 5 mS/cm	nd	nd	0.01
Organic C %	2.53	0.71	0.32
Total N %	0.15	0.04	0.01
C/N	17.5	19.6	37.7
Avail. P Bray-1 mg/kg	5.7	0.07	2.3
Avail. P Olsen mg/kg	nd	nd	1.3
CEC NH_4OAc emol(+)/kg	12.6	9.52	3.4
Exch. Ca emol(+)/kg	7.8	8.5	9.5
Exch. Mg emol(+)/kg	1.6	1.2	1.3
Exch. K emol(+)/kg	0.5	0.4	0.06
Exch. Na emol(+)/kg	0.09	0.09	0.13
Exch. H emol(+)/kg	nd	nd	nd
Exch. Al emol(+)/kg	nd	nd	nd
TEB emol(+)/kg	10.0	10.1	10.9
Al saturation %	nd	nd	nd
Exch. acidity emol(+)/kg	nd	nd	nd
Base saturation %	79.6	106.5	321.9
CEC clay emol(+)/kg	14.6	34.6	16.0
Cu mg/kg	0.27	0.17	0.17
Fe mg/kg	36.3	8.9	6.3
Mn mg/kg	9.4	1.5	2.1
Zn mg/kg	0.06	0.03	0.04
B mg/kg	0.04	0.04	0.01

nd- not determined

Profile number : MGP-14 Mapping unit: V1 Agro-ecol. zone:
Region : Morogoro: District : Morogoro rural
Map sheet no. : 201/1
Co-ordinates : 37° 35' 20.0" E/ 7° 5' 36.6" S
Location : Kilumba village along mbakana river
Elevation : 1540 m asl. Parent material: unconsolidated mixed material. Landform: mountain, hilly. Slope: 35 %; concave
Surface characteristics : Outerops: 5 % Stones: 2 % Erosion: . Deposition:cm
Natural drainage class : well drained

Described by S.B. Mwango, D.N. Kimaro, B.M. Msanya and E.P. Kileo on 03/03/00

Soils are very deep, well drained, strong brown to pale yellow clay to sand clay loams, with very thick dark brown sand clay loam topsoils.

Ap 0 - 20/30 cm: dark brown (7.5YR3/2) moist; bouldery sandy clay loam; friable moist, sticky and plastic wet; moderately strong fine and medium subangular blocks; many fine and few medium pores; few medium irregular fresh gneiss fragments; many fine and very fine roots; clear wavy boundary to

Bt 20/30 - 65/75 cm: strong brown (7.5YR5/8) moist; clay; many medium prominent sharp 2.5YR3/6 mottles; firm moist, sticky and plastic wet; moderate medium and coarse subangular blocks; continuous thin clay cutans; few fine and common medium pores; few medium irregular fresh gneiss fragments; medium and common very fine roots; clear irregular boundary to

BC 65/75 - 190 cm: pale yellow (5Y7/3) moist; sandy clay loam; many medium prominent clear 2.5YR4/6 mottles; friable moist, non-sticky and non-plastic wet; weak medium and fine subangular blocks; many fine and few fine pores; frequent small irregular weathered gneiss fragments, medium and very fine roots

C 190cm+: saprolite containing meta-anorthosite, meta-gabbroic anorthosite and meta-anorthositic gabbro.

SOIL CLASSIFICATION:
World Reference Base WRB (FAO, 1998): Hapl-Gleyic Phaeozems
USDA Soil Taxonomy (Soil Survey Staff, 1998): Aquic Argiudolls

ANALYTICAL DATA FOR PROFILE MGP-14

Horizon	Ap	Bt	BC
Depth (cm)	0-20/30	20/30-65/75	65/75-190
Clay %	32	44	24
Silt %	19	23	15
Sand %	49	33	61
Texture class	SCL	C	SCL
Bulk density g/cc	1.4	1.4	1.6
AWC mm/m			96.5
pH H_2O 1:2.5	6.1	6.4	6.9
pH KCl 1:2.5	4.7	4.9	4.6
EC 1:2.5 mS/cm	nd	nd	0.03
Organic C %	2.97	0.79	0.52
Total N %	0.22	0.04	0.02
C/N	13.6	18.3	23.0
Avail. P Bray-1 mg/kg	24.2	4.6	27.7
Avail. P Olsen mg/kg	nd	nd	27.8
CEC NH_4OAc cmol(+)/kg	16.4	10.6	4.3
Exch. Ca cmol(+)/kg	7.1	4.8	5.2
Exch. Mg cmol(+)/g	2.3	1.8	2.5
Exch. K cmol(+)/kg	1.2	0.3	0.2
Exch. Na cmol(+)/kg	0.2	0.3	0.2
Exch. H cmol(+)/kg	nd	nd	nd
Exch. Al cmol(+)/kg	nd	nd	nd
TEB cmol(+)/kg	10.8	7.0	8.1
Exch. acidity cmol(+)/kg	nd	nd	nd
Base saturation %	65.7	66.5	188.0
CEC clay cmol(+)/kg	19.0	17.7	10.1
Cu mg/kg	1.13	0.62	0.26
Fe mg/kg	128.9	40.9	35.4
Mn mg/kg	92.4	4.0	6.5
Zn mg/kg	0.70	0.24	0.14
B mg/kg	0.06	0.02	0.01

nd= not determined

Profile number : MGP-15 Mapping unit: Cgk1 Agro-ecol. zone:
Region : Morogoro: District : Morogoro rural
Map sheet no. : 201/1
Co-ordinates : 37° 35' 26.9" E/ 7° 5' 41.6" S
Location : Lokongolo about 3km from Nyandira along the road to Tchenzema
Elevation : 1690 m asl. Parent material: colluvium derived from banded pyroxene granulites, in places kaolinitic clays
Landform: mountain; hilly. Slope: 45 %; straight
Surface characteristics : Erosion: . Deposition: none.
Natural drainage class : well drained

Described by D.N. Kimaro, E.P. Kileo, B.M Msanya and S.B. Mwango on 03/03/00

Soils are very deep, well drained, brown clays to clay loams, with very thick black clay loam topsoils.

Ap 0 - 40/50 cm: dark brown (7.5YR3/2) dry, black (7.5YR2.5/1) moist; clay loam; soft dry, friable moist, slightly sticky and slightly plastic wet; strong fine and very fine subangular blocks; many medium and few fine pores; very few medium irregular fresh gneiss fragments; many fine and very fine roots; clear wavy boundary to

Bt 40/50 - 130/150 cm: dark brown (7.5YR3/4) dry, brown (7.5YR4/3) moist; clay; slightly hard dry, friable moist, sticky and plastic wet; moderate medium and fine subangular blocks; continuous thin clay cutans; common medium and few fine pores; few medium irregular slightly weathered gneiss fragments; many fine and few medium roots; diffuse irregular boundary to

BC 130/150 - 200 cm: brown (7.5YR4/4) moist; clay loam; friable moist, sticky and plastic wet; moderate medium and fine subangular blocks; few fine and common medium pores; frequent small irregular weathered gneiss fragments; few fine and common very fine roots

SOIL CLASSIFICATION:
World Reference Base WRB (FAO, 1998): Hapli-Pachic Phaeozems
USDA Soil Taxonomy (Soil Survey Staff, 1998): Fluventic Hapludolls

ANALYTICAL DATA FOR PROFILE MGP-15

Horizon	Ap	Bt	BC
Depth (cm)	0-40/50	40/50-130/150	130/150-200
Clay %	36	56	38
Silt %	22	20	19
Sand %	42	24	43
Texture class	CL	C	CL
Bulk density g/cc	1.0	1.8	1.3
AWC mm/m		136.4	
pH H_2O 1:2.5	6.5	6.5	6.8
pH KCl 1:2.5	5.3	4.9	4.7
EC 1:2.5 mS/cm	nd	nd	nd
Organic C %	7.84	1.43	0.27
Total N %	0.46	0.13	0.03
C/N	16.9	10.9	9.4
Avail. P Bray-1 mg/kg	5.0	0.6	19.4
Avail. P Olsen mg/kg	nd	nd	nd
CEC NH_4OAc cmol(+)/kg	30.4	8.8	10.4
Exch. Ca cmol(+)/kg	24.1	8.1	9.0
Exch. Mg cmol(+)/g	4.1	2.9	3.5
Exch. K cmol(+)/kg	0.34	0.06	0.04
Exch. Na cmol(+)/kg	0.10	0.09	0.15
Exch. H cmol(+)/kg	nd	nd	nd
Exch. Al cmol(+)/kg	nd	nd	nd
TEB cmol(+)/kg	28.6	11.2	12.6
Exch. acidity cmol(+)/kg	nd	nd	nd
Base saturation %	94.1	127.4	121.1
CEC clay cmol(+)/kg	9.2	6.9	24.6
Cu mg/kg	1.1	0.6	0.6
Fe mg/kg	79.8	38.7	27.5
Mn mg/kg	113.5	8.1	11.1
Zn mg/kg	4.7	0.6	0.6
B mg/kg	0.20	0.04	0.02

nd- not determined

Profile number : MGP-16 Mapping unit: G12 Agro-ecol. zone:
Region : Morogoro
District : Morogoro rural
Map sheet no. : 201/1
Co-ordinates : 37° 36' 0.0" E/ 7° 7' 0.1" S
Location : 4 km east of Tchenzema mission
Elevation : 1880 m asl. Parent material: banded pyroxene granulites.
Landform: mountain; hilly. Slope: 40 %; straight
Surface characteristics : Outcrops: 10 % Erosion: moderate. Deposition: none.
Natural drainage class : well drained

Described by D.N. Kimaro, E.P. Kileo, B.M. Msanya and S.B. Mwango on 04/03/00

Soils are deep, well drained, yellowish brown to dark yellowish brown loams, with thin dark greyish brown topsoils.

Ah 0 - 5 cm: brown (10YR5/3) dry, dark greyish brown (10YR4/2) moist, stony loam; soft dry, friable moist, slightly sticky and slightly plastic wet; weak fine subangular blocks and granular; many fine pores; many fine roots; clear smooth boundary to

AB 5 - 45 cm: dark yellowish brown (10YR3/6) dry, dark yellowish brown (10YR3/4) moist; loam; soft dry, friable moist, slightly sticky and slightly plastic wet; moderate fine and medium subangular blocks; many fine and few medium pores; many fine and common medium roots; clear smooth boundary to

Bw 45 - 70 cm: dark yellowish brown (10YR4/6) moist; loam; soft dry, friable moist, slightly sticky and slightly plastic wet; moderate fine and medium subangular blocks; many fine pores; few fine roots; clear smooth boundary to

BC 70 - 120 cm: yellowish brown (10YR5/6) moist; loam; soft dry, friable moist, non-sticky and non-plastic wet; weak fine and medium subangular blocks; many very fine pores; few fine roots; clear smooth boundary to

SOIL CLASSIFICATION:
World Reference Base WRB (FAO, 1998): Hapli-Orthidystric Cambisols
USDA Soil Taxonomy (Soil Survey Staff, 1998): Typic Dystrudepts

ANALYTICAL DATA FOR PROFILE MGP-16

Horizon	Ah	AB	Bw	BC
Depth (cm)	0-5	5-45	45-70	70-120
Clay %	13	15	18	16
Silt %	37	39	42	47
Sand %	50	46	40	37
Texture class	L	L	L	L
Bulk density g/cc	1.2	1.2	1.5	1.7
AWC mm/m				81
pH H_2O 1:2.5	4.5	4.7	5.9	5.0
pH KCl 1:2.5	3.7	3.8	3.8	3.6
EC 1:2.5 mS/cm	nd	nd	nd	nd
Organic C %	6.1	2.9	1.9	0.3
Total N %	0.23	0.11	0.06	0.01
C/N	26.5	26.4	31.7	30
Avail. P Bray-1 mg/kg	54	56	57	78.9
Avail. P Olsen mg/kg	nd	nd	nd	nd
CEC NH_4OAc cmol(+)/kg	34.2	29.9	22.0	11.6
Exch. Ca cmol(+)/kg	3.2	2.7	1.51	0.42
Exch. Mg cmol(+)/g	4.1	3.51	1.04	0.42
Exch. K cmol(+)/kg	0.09	0.07	0.06	0.15
Exch. Na cmol(+)/kg	0.02	0.03	0.08	0.03
Exch. H cmol(+)/kg	0.8	0.5	0.2	0.06
Exch. Al cmol(+)/kg	1.2	1.4	1.1	0.9
TEB cmol(+)/kg	7.4	6.3	2.69	1.02
Al saturation %	14.0	18.2	29.0	46.9
Exch. acidity cmol(+)/kg	2.0	1.9	1.3	0.96
Base saturation %	21.7	21.0	12.2	8.7
CEC clay cmol(+)/kg	101.3	134.9	84.04	66.0
Cu mg/kg	0.45	0.21	0.16	0.11
Fe mg/kg	75.3	31.6	8.5	3.7
Mn mg/kg	0.95	0.64	0.18	0.07
Zn mg/kg	0.14	0.09	0.03	0.01
B mg/kg	0.11	0.09	0.05	0.02

nd= not determined

Profile number : MGP-17 Mapping unit: Cgm1 Agro-ecol. zone:
Region : Morogoro District : Morogoro rural:
Map sheet no. : 201/1: Co-ordinates : 37° 34' 59.9" E/ 7° 7' 0.1" S
Location : 1km west of Tchenzema mission
Elevation : 1640 m asl. Parent material: colluvium derived from banded pyroxene granulites, in places meta-anorthosite, meta-gabbroic anorthosite and meta-anorthositic gabbro.
Landform: mountain; hilly. Slope: 45 %; straight
Surface characteristics : Erosion: . Deposition: none.
Natural drainage class : well drained

Described by B.M. Msanya, S.B. Mwango, D.N. Kimaro and E.P. Kileo on 07/03/00

Soils are very deep, well drained, dark brown sandy loam to very dark greyish brown and very dark grey loam sands, with very thick dark yellowish brown sandy loam topsoils.

Ap 0 - 40 cm: brown (10YR5/3) dry, dark yellowish brown (10YR4/4) moist; sandy loam; soft dry, friable moist, non-sticky and non-plastic wet; weak fine granular; many fine and common medium pores; few medium irregular fresh gneiss fragments; many fine and common medium roots; gradual smooth boundary to

Bw1 40 - 65 cm: dark brown (7.5YR3/4) dry, dark brown (7.5YR3/2) moist; sandy loam; soft dry, friable moist, slightly sticky and slightly plastic wet; moderate fine and medium subangular blocks; many fine and medium pores; frequent medium irregular fresh gneiss fragments; many fine and common medium roots; gradual smooth boundary to

Bw2 65 - 115 cm: brown (7.5YR4/4) dry, dark brown (7.5YR3/4) moist; sandy loam; hard dry, friable moist, slightly sticky and slightly plastic wet; moderate fine and medium subangular blocks; many fine and medium pores; few medium irregular slightly weathered gneiss fragments; many fine and common medium roots; gradual smooth boundary to

BC 115 - 185 cm: very dark greyish brown (10YR3/2) moist; sandy loam to loam sand; soft dry, friable moist, slightly sticky and slightly plastic wet; weak fine and medium subangular blocks; many fine and few very fine pores; few medium irregular weathered gneiss fragments; many fine and common medium roots; gradual smooth boundary to

2Ab 185 - 200 cm: very dark grey (10YR3/1) moist; loam sand; soft dry, friable moist, sticky and plastic wet; weak fine and medium subangular blocks; many fine pores; few medium irregular fresh gneiss fragments; few fine roots

SOIL CLASSIFICATION:
World Reference Base WRB (FAO, 1998): Hapli-Orthidystric Cambisols
USDA Soil Taxonomy (Soil Survey Staff, 1998): Typic Dystrudepts

ANALYTICAL DATA FOR PROFILE MGP-17

Horizon	Ap	Bw1	Bw2	BC	2Ab
Depth (cm)	0-40	40-65	65-115	115-185	185-200+
Clay %	8	12	9	7	7
Silt %	22	17	17	16	7
Sand %	70	71	74	77	86
Texture class	SL	SL	SL	SL-LS	LS
Bulk density g/cc	1.2	1.3	1.3	1.5	1.4
AWC mm/m			129.5		
pH H_2O 1:2.5	4.4	5.0	5.1	5.2	5.3
pH KCl 1:2.5	3.7	4.1	4.0	4.3	4.4
Organic C %	4.33	1.20	0.40	0.09	0.90
Total N %	0.62	0.2	0.03	0.007	0.04
C/N	7.0	6.0	13.3	12.9	22.5
Avail. P Bray-1 mg/kg	11.7	61.9	26.2	40.8	74.6
CEC NH_4OAc cmol(+)/kg	49.7	49.2	39.3	47.9	44.6
Exch. Ca cmol(+)/kg	0.33	5.10	2.28	0.33	0.15
Exch. Mg cmol(+)/g	0.00	1.22	0.00	0.00	0.00
Exch. K cmol(+)/kg	0.05	0.05	0.07	0.02	0.05
Exch. Na cmol(+)/kg	0.05	0.08	0.22	0.11	0.10
Exch. H cmol(+)/kg	0.3	0.2	0.1	0.07	0.05
Exch. Al cmol(+)/kg	1.2	1.2	1.1	0.7	0.5
TEB cmol(+)/kg	0.43	6.45	2.57	0.46	0.3
Al saturation %	73.6	15.7	30.0	60.3	62.5
Exch. acidity cmol(+)/kg	1.5	1.4	1.2	0.77	0.55
Base saturation %	0.86	13.1	6.5	0.95	0.67
CEC clay cmol(+)/kg	434.9	375.5	421.3	680.7	592.4
Cu mg/kg	1.1	0.6	0.6	0.53	0.17
Fe mg/kg	72.4	36.1	30.6	25.8	15.3
Mn mg/kg	93.6	40.3	32.7	51.7	18.4
Zn mg/kg	2.7	0.9	0.6	0.7	0.3
B mg/kg	0.13	0.5	0.04	0.022	0.02

nd= not determined

Profile number : MGP-18 Mapping unit: Cgm1
Agro-ecol. zone:
Region : Morogoro
District : Morogoro rural:
Map sheet no. : 201/1
Co-ordinates : 37° 34' 0.1" E/ 7° 7' 0.1" S
Location : Horticultural unit of Tchenzema mission
Elevation : 1600 m asl. Parent material: colluvium derived from banded pyroxene granulites, in places meta-anorthosite, meta-gabbroic anorthosite and meta-anorthositic gabbro.
Landform: mountain; hilly. Slope: 45 %; straight
Surface characteristics : Erosion: . Deposition: none
Natural drainage class : well drained

Described by B.M. Msanya, S.B. Mwango, D.N. Kimaro and E.P. Kileo on 09/03/00

Soils are shallow, well drained, very dark greyish brown sandy loams with thick very dark grey sandy loam topsoils.

Ap 0 - 12 cm: very dark grey (10YR3/1) moist; sandy loam; friable moist, slightly sticky and slightly plastic wet, weak fine and medium subangular blocks; many fine and few medium pores; many fine and very fine roots; clear smooth boundary to

Bw 12 - 26 cm: very dark greyish brown (10YR3/2) moist; sandy loam, friable moist, sticky and plastic wet; moderate fine and medium subangular blocks; many fine and few medium pores; few fine and common medium roots; clear smooth boundary to

C 26 cm+: saprolite containing meta-anorthosite, meta-gabbroic anorthosite and meta-anorthositic gabbro.

SOIL CLASSIFICATION:
World Reference Baes WRB (FAO, 1998): Hapli-Orthieutric Cambisols
USDA Soil Taxonomy (Soil Survey Staff, 1998): Dystric Eutrudepts

ANALYTICAL DATA FOR PROFILE MGP-18

Horizon	Ap	Bw
Depth (cm)	0-12	12-26
Clay %	17	16
Silt %	23	25
Sand %	60	59
Texture class	SL	SL
Bulk density g/cc	1.3	1.4
AWC mm/26 cm		28.2
pH H_2O 1:2.5	5.4	5.8
pH KCl 1:2.5	5.1	5.2
EC 1:2.5 mS/cm	nd	nd
Organic C %	1.53	4.56
Total N %	0.12	0.39
C/N	12.8	11.7
Avail. P Brav-1 mg/kg	105.4	102.8
Avail. P Olsen mg/kg	nd	nd
CEC NH_4OAc cmol(-)/kg	39.77	37.18
Exch. Ca cmol(-)/kg	17.3	16.9
Exch. Mg cmol(-)/g	3.3	3.1
Exch. K cmol(-)/kg	0.98	1.00
Exch. Na cmol(-)/kg	0.18	0.14
Exch. H cmol(-)/kg	0.3	0.15
Exch. Al cmol(+)/kg	0.9	0.5
TEB cmol(-)/kg	21.8	21.1
Al saturation %	4.0	2.3
Exch. acidity cmol(+)/kg	1.2	0.65
Base saturation %	54.7	56.9
CEC clay cmol(-)/kg	202.9	134.1
Cu mg/kg	1.2	0.6
Fe mg/kg	102.4	36.3
Mn mg/kg	83.2	7.3
Zn mg/kg	0.6	0.18
B mg/kg	0.05	0.02

nd - not determined

Profile number : MGP-19 Mapping unit: Cm1 Agro-ecol. zone:
Region : Morogoro: District : Morogoro rural
Map sheet no. : 201/1
Co-ordinates : 37° 34' 30.0" E/ 7° 2' 46.0" S
Location : Mgeta Kibaoni (about 1.5km from Mgeta along the road to Langali
Elevation : 1060 m asl. Parent material: colluvium derived from meta-anorthosite, meta-gabbroic anorthosite and meta-anorthositic gabbro.
Landform: mountain; hilly. Slope: 55 %; straight
Surface characteristics : Outcrops: 40 % Stones: 15 % Erosion: . Deposition: none.
Natural drainage class : well drained

Described by B.M. Msanya, S.B. Mwango, D.N. Kimaro and E.P. Kileo on 10/03/00

Soil: Soils are shallow, well drained, black strong structured gravelly sandy clay loam over black moderate structured gravelly sandy clay loam on slightly weathered bedrock

Ah 0 - 15 cm: black (10YR2/1) moist; stony sandy clay loam; friable moist, slightly sticky and slightly plastic wet; strong fine and medium subangular blocks; many fine and common medium pores; few small irregular slightly weathered fragments, many fine and common medium roots; clear smooth boundary to

AB 15 - 50/60 cm: black (10YR2/1) dry, black (10YR2/1) moist; sandy clay loam, slightly hard dry, friable moist, slightly sticky and slightly plastic wet; moderate medium subangular blocks; many fine and few medium pores; few small irregular slightly weathered fragments; many fine and common medium roots; clear wavy boundary to

CR 50/60cm+ : meta-anorthosite, meta-gabbroic anorthosite and meta-anorthositic gabbro saprolite, slightly weathered, with original rock structure.

SOIL CLASSIFICATION:
World Reference Base WRB (FAO, 1998): Humi-Endoleptic Regosols (Hypereutric)
USDA Soil Taxonomy (Soil Survey Staff, 1998): Typic Udorthents

ANALYTICAL DATA FOR PROFILE MGP-19

Horizon	Ah	AB
Depth (cm)	0-15	15-50/60
Clay %	24	26
Silt %	12	14
Sand %	64	60
Texture class	SCL	SCL
Bulk density g/cc	1.3	1.6
AWC mm/60cm		69
pH H_2O 1:2.5	6.2	6.2
pH KCl 1:2.5	5.1	4.9
EC 1:2.5 mS/cm	nd	nd
Organic C %	2.4	1.98
Total N %	0.18	0.13
C/N	13.7	14.7
Avail. P Bray-1 mg/kg	52.7	25.9
Avail. P Olsen mg/kg	nd	nd
CEC NH_4OAc cmol(+)/kg	14.4	12.4
Exch. Ca cmol(+)/kg	8.1	6.7
Exch. Mg cmol(+)/g	3.8	3.1
Exch. K cmol(+)/kg	0.45	0.27
Exch. Na cmol(+)/kg	0.09	0.14
Exch. H cmol(+)/kg	nd	nd
Exch. Al cmol(+)/kg	nd	nd
TEB cmol(+)/kg	12.5	10.2
Al saturation %	nd	nd
Exch. acidity cmol(+)/kg	nd	nd
Base saturation %	86.7	82.6
CEC clay cmol(+)/kg	25.3	21.4
Cu mg/kg	0.7	0.8
Fe mg/kg	71.7	101.2
Mn mg/kg	30.1	14.1
Zn mg/kg	0.3	0.1
B mg/kg	0.06	0.04

nd= not determined

Profile number : MGP-20 Mapping unit: G11
Agro-ecol. zone:
Region : Morogoro:
District : Morogoro rural
Map sheet no. : 201/1
Co-ordinates : 37° 37' 13.32" E/ 7° 6' 50" S
Location : Lukwangule plateau
Elevation : 2600 m asl. Parent material: banded pyroxene granulites. Landform: plateau; rolling. Slope: 25 %; concave
Surface characteristics : Stones: none Erosion: severe. Deposition: none.
Natural drainage class : well drained

Described by B.M. Msanya, E.P. Kileo, D.N. Kimaro and S.B. Mwango on 19/12/99

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

Ah 0 - 35/40 cm: black (5YR2.5/1) moist; sandy clay loam; friable moist, slightly-sticky and slightly-plastic wet; moderate coarse subangular blocks and medium angular blocks; many fine and very fine pores; few medium spherical weathered feldspar fragments; many fine and few coarse roots; clear wavy boundary to

Bw 35/40 - 70 cm: dark brown (7.5YR3/4) moist; sandy loam; friable moist; slightly-sticky and slightly-plastic wet; weak; fine and medium subangular blocks; many fine and very fine pores; few medium irregular slightly weathered feldspar fragments; few fine roots clear smooth boundary to

CR 70 cm+: banded pyroxene granulites saprolite, slightly weathered, with original rock structure.

SOIL CLASSIFICATION:
World Reference Base WRB (FAO, 1998): Hyperferrali-Humic Umbrisols (Haplic)
USDA Soil Taxonomy (Soil Survey Staff, 1998): Humic Dystrudepts

ANALYTICAL DATA FOR PROFILE MGP-20

Horizon	Ah	Bw
Depth (cm)	0-35/40	35/40-70
Clay %	25	18
Silt %	20	22
Sand %	55	60
Texture class	SCL	SL
Bulk density g/cc	1.1	nd
AWC mm/70cm		48.9
pH H_2O 1:2.5	4.3	4.6
pH KCl 1:2.5	3.9	4.1
EC 1:2.5 mS/cm	0.16	0.14
Organic C %	9.1	1.2
Total N %	0.65	0.06
C/N	20.1	24.0
Avail. P Bray-1 mg/kg	1.4	0.3
Avail. P Olsen mg/kg	nd	nd
CEC NH_4OAc cmol(+)/kg	32.5	8.5
Exch. Ca cmol(+)/kg	0.25	0.12
Exch. Mg cmol(+)/g	0.22	0.09
Exch. K cmol(+)/kg	0.39	0.13
Exch. Na cmol(+)/kg	0.56	0.47
Exch. H cmol(+)/kg	0.17	0.11
Exch. Al cmol(+)/kg	1.94	1.6
TEB cmol(+)/kg	1.42	0.81
Al saturation %	57.7	66.4
Exch. acidity cmol(+)/kg	2.1	1.7
Base saturation %	4.4	9.5
CEC clay cmol(+)/kg	4.4	24.2
Cu mg/kg	0.15	0.07
Fe mg/kg	206	38.4
Mn mg/kg	0.18	0.11
Zn mg/kg	0.13	0.08
B mg/kg	0.04	0.03

nd= not determined

Profile number : MGP- 21 Mapping unit: G11 Agro-ecol. zone:
Region : Morogoro
District : Morogoro rural
Map sheet no. : 201/1
Co-ordinates : 37° 37' 10" E/ 7° 6' 57" S
Location : Lukwangule plateau
Elevation : 2650 m asl Parent material: banded pyroxene granulites.
Landform: plateau; rolling. Slope: 10 %: convex
Surface characteristics : Rock outcrops: 5% Stones: 20 % Erosion: severe. Deposition: none.
Natural drainage class: somewhat excessively drained.

Described by S. B. Mwango. B.M. Msanya, E.P. Kileo. D.N. Kimaro 19/12/99

Soils are very shallow, somewhat excessively drained, dark brown sandy clay loams over hard rock.

Ah 0 - 12/18 cm: dark brown (7.5YR3/4) moist; stony sandy clay loam; friable moist, non-sticky and non-plastic wet; weak coarse subangular blocks and medium angular blocks; many fine and very fine pores; few medium spherical weathered feldspar fragments; many fine and few coarse roots; clear wavy boundary to

R banded pyroxene granulites hard rock.

SOIL CLASSIFICATION:
World Reference Base WRB (FAO. 1998): Dystri-Lithic Leptosols (Haplic)
USDA Soil Taxonomy (Soil Survey Staff, 1998): Lithic Udorthents

ANALYTICAL DATA FOR PROFILE MGP-21

Horizon	Ah
Depth (cm)	0-12/18
Clay %	19
Silt %	19
Sand %	62
Texture class	SCL
Bulk density g/cc	1.3
AWC mm/18cm	12
pH H_2O 1:2.5	5.0
pH KCl 1:2.5	4.2
Organic C %	6.2
Total N %	0.28
C/N	22.1
Avail. P Bray-1 mg/kg	0.76
CEC NH_4OAc cmol(+)/kg	31.5
Exch. Ca cmol(+)/kg	0.12
Exch. Mg cmol(+)/g	0.22
Exch. K cmol(+)/kg	0.11
Exch. Na cmol(+)/kg	0 05
Exch. H cmol(+)/kg	0.17
Exch. Al cmol(+)/kg	1.77
TEB cmol(+)/kg	0.5
Al saturation %	78
Exch. acidity cmol(+)/kg	1.94
Base saturation %	1.59
CEC clay cmol(+)/kg	53.3
Cu mg/kg	1.3
Fe mg/kg	30.2
Mn mg/kg	0.31
Zn mg/kg	0.22
B mg/kg	0.09

nd= not determined

Profile number : MGP-22 Mapping unit: G22
Agro-ecol. zone:
Region : Morogoro
District : Morogoro rural
Map sheet no. . 201/1
Co-ordinates : 37° 34' 1" E/ 7° 00' 49" S
Location : Peko Msegese, east of the main road to Mgeta
Elevation : 1050 m asl. Parent material: banded pyroxene granulites.
Landform: mountain; hilly. Slope: 55 %; straight
Surface characteristics : Rock outcrops: 50% Stones: 10 % Erosion: .Deposition: none.
Natural drainage class : somewhat excessively drained

Described by S.B. Mwango, E.P. Kileo, B.M. Msanya and D.N. Kimaro on 04/03/00

Soils are shallow, somewhat excessively drained, dark brown sandy clay loams over hard rock.

Ap 0 - 20/28 cm: dark brown (7.5YR3/2) dry, dark brown (7.5YR4/2) moist; slightly stony sandy clay loam; slightly hard dry, friable moist, sticky and plastic wet; strong fine and medium crumby; many fine and few medium pores; few small irregular fresh feldspar fragments; many fine and medium roots; clear wavy boundary to

R banded pyroxene granulites hard rock.

SOIL CLASSIFICATION:
World Reference Base WRB (FAO, 1998): Eutri-Lithic Leptosols (Haplic)
USDA Soil Taxonomy (Soil Survey Staff. 1998): Lithic Ustorthents

ANALYTICAL DATA FOR PROFILE MGP -22

Horizon	Ap
Depth (cm)	0-20/28
Clay %	37
Silt %	18
Sand %	45
Texture class	SCL
Bulk density g/cc	1.3
AWC mm/28cm	18.3
pH H_2O 1:2.5	6.5
pH KCl 1:2.5	4.6
EC 1:2.5 mS/cm	nd
Organic C %	1.69
Total N %	0.12
C/N	14.1
Avail. P Bray-1 mg/kg	3.4
CEC NH_4OAc cmol(+)/kg	16.5
Exch. Ca cmol(+)/kg	9.0
Exch. Mg cmol(+)/g	4.7
Exch. K cmol(+)/kg	1.3
Exch. Na cmol(+)/kg	0.15
Exch. H cmol(+)/kg	nd
Exch. Al cmol(+)/kg	nd
TEB cmol(+)/kg	15.5
Exch. acidity cmol(+)/kg	nd
Base saturation %	94
CEC clay cmol(+)/kg	28.8
Cu mg/kg	1.1
Fe mg/kg	51.2
Mn mg/kg	9.5
Zn mg/kg	0.31
B mg/kg	0.07

nd- not determined

Profile number : MGP-23 Mapping unit: G21 Agro-ecol. zone:
Region : Morogoro
District : Morogoro rural
Map sheet no. : 201/1
Co-ordinates : 37° 32' 33" E/ 7° 01' 50" S
Location : Peko Msegese, west of the road to Mgeta
Elevation : 1260 m asl. Parent material: banded pyroxene granulites.
Landform: mountain; steeply dissected. Slope: 5 %; straight
Surface characteristics : Rock outcrops: 10% stones: 15% Erosion: Deposition: none.
Natural drainage class : somewhat excessively drained

Described by S.B. Mwango, E.P. Kileo, B.M. Msanya and D.N. Kimaro on 04/03/00

Soils are shallow, somewhat excessively drained, dark brown to brown sandy clay loams over hard rock.

Ah 0 - 20/26 cm: dark brown (7.5YR3/2) moist; sandy clay loam; friable moist, non-sticky and non-plastic wet; moderate medium and fine subangular blocks; many fine and medium pores; many fine and common medium roots; clear wavy boundary to

R banded pyroxene granulites hard rock.

SOIL CLASSIFICATION:
World Reference Base WRB (FAO, 1998): Dystri-Lithic Leptosols (Haplic)
USDA Soil Taxonomy (Soil Survey Staff, 1998): Lithic Ustorthents

ANALYTICAL DATA FOR PROFILE MGP -23

Horizon	Ah
Depth (cm)	0-20/26
Clay %	25
Silt %	6
Sand %	69
Texture class	SCL
Bulk density g/cc	1.3
AWC mm / 22 cm	13.6
pH H_2O 1:2.5	6.1
pH KCl 1:2.5	4.4
EC 1:2.5 mS/cm	nd
Organic C %	1.8
Total N %	0.11
C/N	16.4
Avail. P Bray-1 mg/kg	1.5
Avail. P Olsen mg/kg	nd
CEC NH_4OAc cmol(+)/kg	11.4
Exch. Ca cmol(+)/kg	3.0
Exch. Mg cmol(+)/g	1.1
Exch. K cmol(+)/kg	0.3
Exch. Na cmol(+)/kg	0.05
Exch. H cmol(+)/kg	nd
Exch. Al cmol(+)/kg	nd
TEB cmol(+)/kg	4.45
Base saturation %	39
CEC clay cmol(+)/kg	20.8
Cu mg/kg	0.8
Fe mg/kg	60.2
Mn mg/kg	7.6
Zn mg/kg	0.09
B mg/kg	0.05

nd= not determined

Profile number : MGP-24 Mapping unit: M11 Agro-ecol zone:
Region : Morogoro
District : Morogoro rural
Map sheet no. : 201/1
Co-ordinates : 37° 31' 50" E/ 7° 6' 7" S
Location : about 2 km south west of Mwarazi village
Elevation : 1450 m asl. Parent material: meta-anorthosite, meta-gabbroic anorthosite and meta-anorthositic gabbro.
Landform: mountain; steeply dissected. Slope: 5 %, concave
Surface characteristics : Rock outcrops: 5% Stones: 2% Erosion: . Deposition: none
Natural drainage class : well drained

Described by D.N. Kimaro, E.P. Kileo, S.B. Mwango and B.M. Msanya on 05/03/00

Soils are shallow, somewhat excessively drained, black clay loams over hard rock.

Ap 0 - 20/25 cm: dark grey (7.5YR4/1) dry, black (7.5YR2.5/1) moist; clay loam; hard dry, friable moist, slightly sticky and slightly plastic wet; moderately strong fine and medium subangular blocks; few fine and medium pores; few medium irregular fresh quartz fragments; many fine and common medium roots; clear wavy boundary to

R meta-anorthosite, meta-gabbroic anorthosite and meta-anorthositic gabbro hard rock.

SOIL CLASSIFICATION:
World Reference Base WRB (FAO. 1998): Eutri-Lithic Leptosols (Haplic)
USDA Soil Taxonomy (Soil Survey Staff. 1998): Lithic Udorthents

ANALYTICAL DATA FOR PROFILE MGP-24

Horizon	Ap
Depth (cm)	0-20/25
Clay %	38
Silt %	18
Sand %	44
Texture class	CL
Bulk density g/cc	1.1
AWC mm/25cm	16.4
pH H_2O 1 2 5	5.4
pH KCl 1:2 5	4.1
Organic C %	3.15
Total N %	0.17
C/N	18.5
Avail P Bray-1 mg/kg	6.1
CEC NH_4OAc cmol(+)/kg	17.1
Exch. Ca cmol(+)/kg	8.6
Exch. Mg cmol(+)/g	1.2
Exch. K cmol(+)/kg	0.42
Exch. Na cmol(+)/kg	0.11
Exch. H cmol(+)/kg	0.25
Exch. Al cmol(+)/kg	1.12
TEB cmol(+)/kg	10.33
Al saturation %	9.8
Exch. acidity cmol(+)/kg	1.37
Base saturation %	60.4
CEC clay cmol(+)/kg	16.4
Cu mg/kg	0 54
Fe mg/kg	55.3
Mn mg/kg	1.4
Zn mg/kg	0.09
B mg/kg	0.03

nd not determined

Profile number : MGP-25 Mapping unit: M12 Agro-ecol. zone:
Region : Morogoro
District : Morogoro rural
Map sheet no. : 201/1
Co-ordinates : 37° 31' 50" E/ 7° 44' 15" S
Location : about 1.5 km south west of Mwarazi village
Elevation : 1400 m asl. Parent material: meta-anorthosite, meta-gabbroic anorthosite and meta-anorthositic gabbro.
Landform: mountain; steeply dissected. Slope: 54 %, straight
Surface characteristics : Stones: 2 % Erosion: . Deposition: none.
Natural drainage class : well drained

Described by S.B. Mwango, B.M. Msanya, E.P. Kileo and D.N. Kimaro on 05/03/00

Soils are shallow, well drained, very dark grey clays over very pale brown clay loam to loam saprolite from meta-anorthosite, meta-gabbroic anorthosite and meta-anorthositic gabbro rocks.

Ap 0 - 26/30 cm: very dark grey (5YR3/1) moist; clay; friable moist, slightly sticky and slightly plastic wet; moderate coarse and medium subangular blocks; many fine and few medium pores; few small spherical fresh quartz fragments; many fine and very fine roots; clear wavy boundary to

C1 26/30 - 85/100 cm: yellowish brown (10YR5/4) moist; clay loam; friable moist, slightly sticky and slightly plastic wet; structureless massive, many very fine and fine pores; very few small spherical fresh quartz fragments; few fine and very fine roots; clear wavy boundary to

C2 85/100 - 120 cm: very pale brown (10YR8/3) moist; loam; friable moist, non-sticky and non-plastic wet; structureless massive; many very fine pores, few fine and very fine roots.

SOIL CLASSIFICATION:
World Reference Base WRB (FAO, 1998): Hapli-Anthric Umbrisols
USDA Soil Taxonomy (Soil Survey Staff, 1998): Typic Udorthents

ANALYTICAL DATA FOR PROFILE MGP-25

Horizon	Ap	C1	C2
Depth (cm)	0-26/30	26/30-85/100	85/100-120+
Clay %	50	30	16
Silt %	27	44	41
Sand %	23	26	43
Texture class	C	CL	L
Bulk density g/cc	1.1	1.2	1.2
AWC mm/m			108.2
pH H_2O 1:2.5	5.6	5.6	6.1
pH KCl 1:2.5	4.6	4.2	4.3
Organic C %	3.2	0.21	0.15
Total N %	0.16	0.02	0.01
C/N	20	10.5	15.0
Avail. P Bray-1 mg/kg	3.8	0.91	1.2
Avail. P Olsen mg/kg	nd	nd	nd
CEC NH_4OAc cmol(+)/kg	16.8	9.4	8.7
Exch. Ca cmol(+)/kg	4.1	2.4	3.1
Exch. Mg cmol(+)/g	1.8	1.1	1.1
Exch. K cmol(+)/kg	0.5	0.05	0.06
Exch. Na cmol(+)/kg	0.11	0.15	0.20
Exch. H cmol(+)/kg	0.07	0.14	0.09
Exch. Al cmol(+)/kg	0.07	0.54	0.14
TEB cmol(+)/kg	6.51	3.7	4.46
Al saturation %	1.06	12.74	3.04
Exch. acidity cmol(+)/kg	0.14	0.68	0.23
Base saturation %	38.8	39.4	51.3
CEC clay cmol(+)/kg	11.5	28.9	51.1
Cu mg/kg	0.6	0.51	0.12
Fe mg/kg	30.0	5.3	3.6
Mn mg/kg	38.6	1.1	0.6
Zn mg/kg	0.1	0.05	0.005
B mg/kg	0.06	0.05	0.01

nd= not determined

Profile number : MGP-26 Mapping unit: K12 Agro-ecol. zone:
Region : Morogoro: District : Morogoro rural
Map sheet no. : 201/1
Co-ordinates : 37° 35' 9" E/ 7° 5' 29" S
Location : Lukweme, along the Nyandira-Tchenzema road
Elevation : 1650 m asl. Parent material: kaolinitic clays
Landform: mountain; hilly. Slope: 45 %; straight
Surface characteristics : Erosion: . Deposition: none.
Natural drainage class : well drained
Described by D.N. Kimaro, E.P. Kileo, B.M. Msanya and S.B. Mwango on 05/03/00

Soils are very deep, well drained, brown clays to clay loams, with very thick black clay loam topsoils.

Ap 0 - 40/50 cm: dark brown (7.5YR3/2) dry, black (7.5YR2.5/1) moist; clay loam; soft dry, friable moist, slightly sticky and slightly plastic wet; very strong fine and very fine subangular blocks; many medium and few fine pores; very few medium irregular fresh gneiss fragments; many fine and very fine roots; clear wavy boundary to

Bt 40/50 - 135/150 cm: strong brown (7.5YR5/8) dry, brown (7.5YR4/4) moist; clay; slightly hard dry, friable moist, sticky and plastic wet; moderate medium and fine subangular blocks; continuous thin clay cutans; common medium and few fine pores; few medium irregular slightly weathered gneiss fragments; many fine and few medium roots; diffuse irregular boundary to

BC 135/150 - 190 cm: brown (7.5YR4/4) moist; clay loam; friable moist, sticky and plastic wet; moderate medium and fine subangular blocks; few fine and common medium pores; frequent small irregular weathered gneiss fragments; few fine and common very fine roots

SOIL CLASSIFICATION:
World Reference Base WRB (FAO, 1998): Hapli-Chromic Phaeozems
USDA Soil Taxonomy (Soil Survey Staff, 1998): Typic Argiudolls

ANALYTICAL DATA FOR PROFILE MGP-26

Horizon	Ap	Bt	BC
Depth (cm)	0-40/50	40/50-135/150	135/150-190
Clay %	37	53	39
Silt %	21	21	19
Sand %	42	26	42
Texture class	CL	C	CL
Bulk density g/cc	1.0	1.3	1.3
AWC mm/m		127.3	
pH H_2O 1:2.5	6.1	6.4	6.8
pH KCl 1:2.5	4.3	4.6	4.8
EC 1:2.5 mS/cm	nd	nd	nd
Organic C %	6.3	0.66	0.31
Total N %	0.25	0.08	0.03
C/N	25.2	8.3	10.3
Avail. P Bray-1 mg/kg	3.3	1.6	35.2
Avail. P Olsen mg/kg	nd	nd	nd
CEC NH_4OAc cmol(+)/kg	28.6	12.5	11.1
Exch. Ca cmol(+)/kg	9.5	5.1	5.0
Exch. Mg cmol(+)/g	5.2	2.0	1.9
Exch. K cmol(+)/kg	0.21	0.05	0.03
Exch. Na cmol(+)/kg	0.10	0.08	0.11
Exch. H cmol(+)/kg	nd	nd	nd
Exch. Al cmol(+)/kg	nd	nd	nd
TEB cmol(+)/kg	15.01	7.23	7.04
Base saturation %	52.5	57.8	63.4
CEC clay cmol(+)/kg	18.6	19.3	25.7
Cu mg/kg	0.9	0.6	0.6
Fe mg/kg	62.1	35.6	20.1
Mn mg/kg	110.2	9.0	10.3
Zn mg/kg	1.8	0.4	0.4
B mg/kg	0.19	0.04	0.02

nd not determined

Appendix 2. Land attributes database for Mgeta Area

Mapping unit	Soil unit	Altitude (m. a s l)	Mean annual rainfall (mm)	Rainfall during the growing period (mm)	Mean annual temp. °C	Length of growing period (LGP)	Length dry season (months)	Slope %	Soil depth (cm)	Drain age	Texture surface	Texture profile	Bulk density g/cc
G11	MGP-6	2620	2450	2350	10.4	8	4	35	30	swex	SCL	SCL	1.1
	MGP-20	2600	2450	2350	10.5	8	4	25	70	well	SCL	SCL	1.1
	MGP-21	2650	2450	2350	10.2	8	4	10	18	swex	SCL	SCL	1.1
G12	MGP-7	2200	2450	2350	13.4	8	4	59	100	well	SL	SL	1.1
	MGP-16	1880	2450	2350	15.5	8	4	40	120	well	L	L	1.2
G21	MGP-10	1284	1065	895	19.4	6	6	4	140	well	SCL	SL	1.3
	MGP-23	1260	1065	895	19.4	6	6	5	26	swex	SCL	SCL	1.3
G22	MGP-9	1056	1065	895	20.9	6	6	15	180	well	SCL	SCL	1.3
	MGP-22	1050	1065	895	20.9	6	6	55	28	swex	SCL	SCL	1.3
M11	MGP-12	1420	2450	2350	18.5	8	4	5	150	well	CL	SCL	1.1
	MGP-24	1450	2450	2350	18.5	8	4	5	25	swex	CL	CL	1.1
M12	MGP-13	1370	2450	2350	18.8	8	4	50	180	well	SCL	SCL	1.3
	MGP-25	1400	2450	2350	18.2	8	4	54	120	well	C	CL	1.1
K11	MGP-2	1640	2450	2350	17.1	8	4	15	130	well	C	C	1.1
	MGP-3	1580	2450	2350	17.5	8	4	2	193	well	C	C	1.1
K12	MGP-4	1550	2450	2350	17.6	8	4	62	235	well	C	C	1.1
	MGP-26	1650	2450	2350	17.0	8	4	45	190	well	CL	C	1.0
Cm1	MGP-1	1600	2098	1923	17.3	9	3	40	75	well	SCL	SCL	1.3
	MGP-5	1580	2450	2350	17.5	8	4	58	160	well	C	CL	1.1
	MGP-19	1060	2450	2350	20.8	8	4	55	60	well	SCL	SCL	1.3
Cgk1	MGP-8	1680	2450	2350	16.8	8	4	47	185	swex	SCL	SL	1.1
	MGP-15	1690	2450	2350	16.9	8	4	45	200	well	CL	C	1.1
Cgm1	MGP-17	1640	2450	2350	17.1	8	4	45	200	well	SL	SL	1.2
	MGP-18	1600	2450	2350	17.3	8	4	45	26	well	SL	SL	1.3
V1	MGP-11	1086	1065	895	20.7	6	6	44	190	well	SCL	SCL	1.1
	MGP-14	1540	2450	2350	17.7	8	4	35	190	well	SCL	C	1.4

Appendix 2 continued

Mapping unit	Soil unit	Bulk density subsurface	AWC mm/m	Surface pH (H_2O)	Profile pH (H_2O)	OC%	N	P	K	Ca	Mg	CEC soil	CEC clay	TEB	Acidity	BS %
G11	MGP-6	1.1	20	5.1	5.6	10.9	0.54	0.78	0.13	0.15	0.23	38.4	4.9	0.6	1.9	1.6
	MGP-20	1.1	49	4.3	4.6	9.1	0.65	1.4	0.39	0.25	0.22	32.5	4.4	1.42	2.1	4.4
	MGP-21	-	12	5.0	5.0	6.2	0.28	0.76	0.11	0.12	0.22	31.5	53.3	0.5	1.94	1.6
G12	MGP-7	1.5	35	4.8	5.3	11.3	0.76	7.5	0.22	0.78	0.66	40	6.8	1.75	4.85	4.4
	MGP-16	1.5	81	4.7	5.9	6.1	0.23	54	0.09	3.2	4.1	34.2	101.3	7.4	2.0	21.7
G21	MGP-10	1.5	152.3	6.1	6.7	1.9	0.12	1.8	0.6	3.5	1.2	11.6	19.1	5.4	-	46.7
	MGP-23	-	13.6	6.1	6.1	1.8	0.11	1.5	0.3	3.0	1.1	11.4	20.8	4.45	-	39
G22	MGP-9	1.8	143.4	6.6	7.0	4.8	0.13	3.8	1.02	9.2	5.1	17.8	32.9	15.4	-	86.5
	MGP-22	-	18.3	6.5	6.5	1.69	0.12	3.4	1.3	9.0	4.7	16.5	28.8	15.5	-	94
M11	MGP-12	1.5	112.1	5.5	6.4	3.25	0.19	6.4	0.32	8.2	1.98	17.2	15.6	10.7	1.3	62.1
	MGP-24	-	16.4	5.4	5.4	3.15	0.17	6.1	0.42	8.6	1.2	17.1	16.4	10.3	1.37	60.4
M12	MGP-13	1.7	90.9	6.2	6.7	2.53	0.15	5.7	0.5	7.8	1.6	12.6	14.6	10	-	79.6
	MGP-25	1.2	108.2	5.6	5.6	3.2	0.16	3.8	0.5	4.1	1.8	16.8	11.5	6.51	0.14	38.8
K11	MGP-2	1.1	104.1	6.2	6.4	6.73	0.28	1.24	0.08	10.0	2.4	25.0	3.2	12.7	-	50.6
	MGP-3	1.2	101.1	5.5	5.4	5.17	0.37	2.2	0.11	2.6	0.7	24.4	4.8	3.6	1.0	17.5
K12	MGP-4	1.2	77.2	5.6	6.4	5.5	0.19	1.6	0.06	4.3	2.0	22.12	7.6	6.4	-	28.9
	MGP-26	1.3	127.3	6.1	6.4	6.3	0.25	3.3	0.21	9.5	5.2	28.6	18.6	15.01	-	52.5
Cml	MGP-1	1.5	92.0	5.6	6.4	5.06	0.51	4.4	0.15	7.1	3.1	17.6	0.7	10.4	0.2	60.7
	MGP-5	1.2	103.3	5.5	5.6	6.18	0.2	4.0	0.4	4.6	1.7	12.4	22.7	6.8	0.15	55.1
	MGP-19	1.6	69.0	6.2	6.2	2.4	0.18	52.7	0.45	8.1	3.8	14.4	25.3	12.5	-	86.7
Cgkl	MGP-8	1.7	131.7	5.6	6.7	0.14	0.003	5.4	0.13	7.8	0.9	8.0	37.6	8.9	1.6	99.2
	MGP-15	1.8	136.4	6.5	7.8	7.8	0.46	5.0	0.34	24.1	4.1	30.4	9.2	28.6	-	94.1
Cgml	MGP-17	1.3	129.5	4.4	5.1	4.3	0.62	11.7	0.05	0.33	0.0	49.7	434.9	0.43	1.5	0.86
	MGP-18	1.4	28.2	5.4	5.8	1.5	0.12	105.4	0.98	17.3	3.3	39.7	202.9	21.8	1.2	54.7
Vl	MGP-11	1.6	166.8	6.9	6.5	0.69	0.07	23.1	0.83	5.0	1.1	8.2	28.5	7.1	-	86.4
	MGP-14	1.6	96.5	6.1	6.4	2.9	0.23	24.2	1.2	7.1	2.3	16.4	19	10.8	-	65.7

Appendix 3. Land characteristics specification

Rf crop-i (Rainfed cropping - improved traditional management) Land characteristics

LC Id		LC Name		Class Units	Infer from
	Formula	Class Code	Class Name	Upper Limit	
SI		Dominant slope class		7	
1	1		flat to nearly level	1	%
2	2		very gently sloping	2	
3	3		gently sloping	5	
4	4		sloping	15	
5	5		moderately sloping	30	
6	6		steep	60	
7	7		very steep	100	
T-GP		Mean temperature during the growing period		6	degrees C
1	1		extremely cool	5	
2	2		very cool	7.5	
3	3		cool	10	
4	4		moderately cool	12.5	
5	5		moderately warm	15	
6	6		warm	17.5	
7	7		very warm	20	
8	8		extremely warm	22.5	
T - an		Mean annual temperature		6	degrees C
1	1		extremely cool	5	
2	2		very cool	7.5	
3	3		cool	10	
4	4		moderately cool	12.5	
5	5		moderately warm	15	
6	6		warm	17.5	
7	7		very warm	20	
8	8		extremely warm	22.5	
T - anm		Mean annual minimum temperature		7	degrees C
1	1		extremely cool	5	
2	2		very cool	7.5	
3	3		cool	10	
4	4		moderately cool	12.5	
5	5		moderately warm	15	
6	6		warm	17.5	
7	7		very warm	20	

Appendix 3. continued

T - anx		Mean annual maximum temperature	9		degrees C
1	1	extremely cool		5	
2	2	very cool		7.5	
3	3	cool		10	
4	4	moderately cool		12.5	
5	5	moderately warm		15	
6	6	warm		17.5	
7	7	very warm		20	
8	8	very very warm		25	
9	9	extremely warm		30	
TD		Temperature difference between day and night	8		degrees C
1	1	extremely cool		5	
2	2	very cool		7.5	
3	3	cool		10	
4	4	moderately cool		12.5	
5	5	moderately warm		15	
6	6	warm		17.5	
7	7	very warm		20	
8	8	extremely warm		22.5	
T - mc		Mean daily minimum temperature of coldest month	8		degrees C
1	1	extremely cool		5	
2	2	very cool		7.5	
3	3	cool		10	
4	4	moderately cool		12.5	
5	5	moderately warm		15	
6	6	warm		17.5	
7	7	very warm		20.5	
8	8	extremely warm		22.5	
ST		Surface soil texture	12		no dimension
1	1	sand			
2	2	loamy sand			
3	3	silty clay			
4	4	clay			
5	5	sandy clay			
6	6	sandy loam			
7	7	loam			
8	8	sandy clay loam			
9	9	clay loam			
10	10	silty clay loam			
11	11	silty loam			
12	12	silt			

Appendix 3. continued

pH			Soil acidity / alkalinity (H_2O)	6		no dimension
	1	1	very strongly acid		5	
	2	2	strongly acid		5.5	
	3	3	moderately acid		6	
	4	4	slightly acid		6.5	
	5	5	neutral		7.5	
	6	6	alkaline		9	
pH-prof			Soil acidity / alkalinity (H_2O)	6		no dimension
	1	1	very strongly acid		5	
	2	2	strongly acid		5.5	
	3	3	moderately acid		6	
	4	4	slightly acid		6.5	
	5	5	neutral		7.5	
	6	6	alkaline		9	
CEC			Cation exchange capacity (0 - 50)	5		cmol (+)/kg
	1	1	very low		6	
	2	2	low		12	
	3	3	medium		25	
	4	4	high		40	
	5	5	very high		100	
Dr			Soil drainage class (FAO class)	7		
	1	1	very poor			
	2	2	poor			
	3	3	imperfect			
	4	4	moderately well			
	5	5	well			
	6	6	somewhat excessive			
	7	7	excessive			
K			Potassium content (0 - 50 cm)	3		cmol (+)/kg
	1	1	very low		0.2	
	2	2	low		0.4	
	3	3	medium		1.2	
	4	4	high		2.0	
	5	5	very high		10	
Mg			Magnesium content (0 - 50 cm)	5		cmol (+)/kg
	1	1	very low		0.3	
	2	2	low		1.0	
	3	3	medium		3.0	
	4	4	high		6.0	
	5	5	very high		100	

Appendix 3. continued

Ca			Calcium content (0 - 50 cm)	5		cmol (+)/kg
	1	1	very low		2	
	2	2	low		5	
	3	3	medium		10	
	4	4	high		20	
	5	5	very high		100	
LGP			Reference length of growing period	9		days
	1	1	extremely short		120	
	2	2	very short		150	
	3	3	short		180	
	4	4	medium		210	
	5	5	medium		240	
	6	6	long		270	
	7	7	very long		300	
	8	8	extremely long		330	
	9	9	almost continuous		365	
N			Nitrogen content (0 - 50 cm)	4		%
	1	1	very low		0.1	
	2	2	low		0.2	
	3	3	medium		0.5	
	4	4	high		10.0	
P			Phosphorus content (0 - 50 cm)	3		
	1	1	low		7	mg p/kg
	2	2	medium		20	
	3	3	high		100	
P - an			Mean annual precipitation	6		mm
	1	1	very low		750	
	2	2	low		1000	
	3	3	moderate		1500	
	4	4	high		2000	
	5	5	very high		2500	
	6	6	extremely high		3000	
AWC			Available water capacity	6		mm/m
	1	1	extremely low		25	
	2	2	very low		50	
	3	3	low		100	
	4	4	medium		150	
	5	5	high		200	
	6	6	very high		200	

Appendix 3. continued

Sd			Effective soil depth	6		cm
	1	1	very shallow		20	
	2	2	shallow		40	
	3	3	moderately shallow		60	
	4	4	moderately deep		80	
	5	5	deep		120	
	6	6	very deep		1000	
OC			Organic carbon	5		%
	1	1	very low		0.6	
	2	2	low		1.25	
	3	3	medium		2.5	
	4	4	high		3.5	
	5	5	very high		20	
CEC-C			Cation exchange capacity of clay	3		cmol(+)/kg
	1	1	low		5	
	2	2	medium		15	
	3	3	high		450	
TEB			Total exchangeable bases	5		cmol(+)/kg
	1	1	very low		1.6	
	2	2	low		2	
	3	3	medium		2.8	
	4	4	high		3.5	
	5	5	very high		30	
BS			Base saturation	5		%
	1	1	very low		20	
	2	2	low		40	
	3	3	medium		60	
	4	4	high		80	
	5	5	very high		100	
ECe			Soluble salts	4		mS/cm
	1	1	non saline		2	
	2	2	slightly saline		8	
	3	3	moderately saline		15	
	4	4	strongly saline		50	
R-G			Rainfall during the growing period	6		mm
	1	1	very low		250	
	2	2	low		300	
	3	3	moderate		350	
	4	4	high		800	
	5	5	very high		1000	
	6	6	extremely high		2500	

Appendix 3. continued

L-D			Reference length of dry season	6		days
	1	1	very short		15	
	2	2	short		30	
	3	3	medium		120	
	4	4	long		150	
	5	5	very long		180	
	6	6	extremely long		360	
Al			Aluminium saturation	5		%
	1	1	very low		10	
	2	2	low		30	
	3	3	medium		50	
	4	4	high		80	
	5	5	very high		100	

Appendix 4. Coding of land attributes database for Mgeta area

Mapping unit	Soil unit	Altitude (m. a s l)	Mean annual rainfall (mm)	Rainfall during the growing period (mm)	Mean annual temp. °C	Mean annual maximum temp.	Temp. Difference day/night	Length of growing period (LGP)	Length dry season (months)	Slope %	Soil depth (cm)	Drainage	Texture surface	Texture profile	AWC mm/m
G11	MGP-6	2620	5	6	1	2	1	5	3	6	2	6	8	8	1
	MGP-20	2600	5	6	1	2	1	5	3	5	3	5	8	8	2
	MGP-21	2650	5	6	1	2	1	5	3	4	1	6	8	8	1
G12	MGP-7	2200	5	6	1	3	1	5	3	6	4	5	6	6	2
	MGP-16	1880	5	6	2	3	1	5	3	6	4	5	7	7	3
G21	MGP-10	1284	3	5	3	6	1	3	5	3	5	5	8	6	5
	MGP-23	1260	3	5	3	6	1	3	5	3	2	6	8	8	1
G22	MGP-9	1056	3	5	4	6	1	3	5	4	5	5	8	8	4
	MGP-22	1050	3	5	4	6	1	3	5	6	2	6	8	8	1
M11	MGP-12	1420	5	6	3	4	1	5	3	3	5	5	9	8	4
	MGP-24	1450	5	6	3	4	1	5	3	3	2	6	9	9	1
M12	MGP-13	1370	5	6	3	4	1	5	3	6	5	5	8	8	3
	MGP-25	1400	5	6	3	4	1	5	3	6	4	5	4	9	4
K11	MGP-2	1640	5	6	2	4	1	5	3	4	5	5	4	4	4
	MGP-3	1580	5	6	2	4	1	5	3	2	5	5	4	4	4
K12	MGP-4	1550	5	6	2	4	1	5	3	7	5	5	4	4	3
	MGP-26	1650	5	6	2	4	1	5	3	6	5	5	9	4	4
Cm1	MGP-1	1600	5	6	2	5	1	6	3	6	3	5	8	8	3
	MGP-5	1580	5	6	2	4	1	5	3	6	5	5	4	9	4
	MGP-19	1060	5	6	4	4	1	5	3	6	3	5	8	8	3
Cgk1	MGP-8	1680	5	6	2	4	1	5	3	6	5	5	8	6	4
	MGP-15	1690	5	6	2	4	1	5	3	6	5	5	9	4	4
Cgm1	MGP-17	1640	5	6	2	4	1	5	3	6	5	5	6	6	4
	MGP-18	1600	5	6	2	4	1	5	3	6	2	5	6	6	2
V1	MGP-11	1086	3	5	4	6	1	3	5	6	5	5	8	8	5
	MGP-14	1540	5	6	3	4	1	5	3	6	5	5	8	4	3

Appendix 4 continued

Mapping unit	Soil unit	Surface pH (H_2O)	Profile pH (H_2O)	OC%	N	P	K	Ca	Mg	CEC soil	CEC clay	Al. Sat.	TEB	BS %
G11	MGP-6	2	3	5	4	1	1	1	1	4	1	4	1	1
	MGP-20	1	1	5	4	1	2	1	1	4	1	4	1	1
	MGP-21	1	1	5	3	1	1	1	1	4	3	4	1	1
G12	MGP-7	1	2	5	4	2	2	3	2	4	2	4	2	1
	MGP-16	1	3	5	3	3	1	3	4	4	3	2	5	2
G21	MGP-10	4	5	3	2	1	3	3	3	2	3	1	5	3
	MGP-23	4	4	3	2	1	2	2	3	2	3	-	5	2
G22	MGP-9	5	5	5	2	1	4	3	4	3	3	1	5	5
	MGP-22	4	4	3	2	1	4	3	4	3	3	-	5	5
M11	MGP-12	2	4	4	2	1	2	3	3	3	3	1	5	4
	MGP-24	2	2	4	2	1	3	2	3	3	3	1	5	4
M12	MGP-13	4	5	4	2	1	3	3	3	3	1	1	5	4
	MGP-25	3	3	4	2	1	3	2	3	3	2	1	5	2
K11	MGP-2	4	4	5	3	1	1	2	3	3	1	1	5	3
	MGP-3	2	2	5	3	1	1	2	2	3	1	3	5	1
K12	MGP-4	3	4	5	2	1	1	2	3	3	2	1	5	2
	MGP-26	4	4	5	3	1	2	3	4	4	3	-	5	3
Cm1	MGP-1	3	4	5	4	1	1	3	4	3	1	1	5	4
	MGP-5	2	3	5	2	1	2	3	3	3	3	1	5	3
	MGP-19	4	4	3	2	3	3	3	4	3	3	1	5	5
Cgk1	MGP-8	3	5	1	1	1	1	3	2	2	3	2	5	5
	MGP-15	4	6	5	3	1	2	5	4	4	2	1	5	5
Cgm1	MGP-17	1	2	5	4	2	1	1	1	5	3	2	1	1
	MGP-18	2	3	3	2	3	3	4	4	4	3	1	5	3
V1	MGP-11	5	4	2	1	3	3	2	3	2	3	1	5	5
	MGP-14	4	4	4	3	3	3	3	3	3	3	1	5	4

Appendix 5. Questionnaire for socio-economic data collection in western part of the Uluguru mountains, Morogoro rural district, Tanzania.

A. General information

Questionnaire number:
Name of interviewer:
Date:
Name of respondent:
Tribe:
Religion:
Agroecological zone (De Pauw, 1984):
Landscape: Mountanous
Land mapping unit:
Soil type:
Mtaa / village:
Ward: Tchenzema
Division: Mgeta
District: Morogoro rural
Region: Morogoro
GPS Coordinates:

B. Specific information concerning respondent

Question:	Value:	Response:
Gender:	Male / Female	
Marital status:	Married / Single / Divorced / Widowed	
Age of respondent:	Years	
Since when have you been here:	Years	
Occupation:	Agriculture / Business / Political leader /Traditional leader/ Employee /Other (specify)	
Ownership:	Bought, Inherited, Rented, Shared, Other (specify)	
Education of respondent:	Level of education	
Major source of income	Farming activities / Non-farm activities / Both / Others (specify)	
What is your average monthly income?	Tsh.	

Family composition:

Category	Members (number)	How many contribute to the work on the farm?	Off-farm work
Adults:			
Male			
Female			
Children:			
Male			
Female			
Elderly people:			
Male			
Female			

C. Farm characteristics

Plot number	What is the size of the plot? (ha)	Crops: Cabbage, Coffee, Potatoes, (Other spcify)	Soil constraints: Waterlogging, Labour, Weed, Fertility, Stoniness, Rooting, pests, Other (specify)	Estimated yield per plot (kg or Bags)	Topography : Ridge or Valley, Flat or Steep slopes	Distance : Plot-residene	Is this plot permanently used for this kind of crop?	Interviewer remarks
1.								
2.								
3.								
4.								
5.								

D. Other farm characteristics

Distance from farm to market:
Do you keep any livestock?
If no, why?
If yes;
Type:
Quantity:
Function / products:

Amount consumed/sold:
Constraints of production:

Production cost in (T sh): Grazing/ Pests and diseases control/ Milking

Supplementary feeds/ Extension services

Market position:
Market price per unit:

Do you have credit? Yes / No.
If yes;
Purpose:

Conditions:

Sources: Bank / Cooperative / Family / Middleman:

Do you receive any extension service?

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

Where do you get your firewood from?
Cost?
Where do you get your water from?

E. Crop information

Crop:	Where is the best place to grow this crop?	Total Area per crop **(ha)**	Crop production system: **M**ixed, **I**ntercropping, **M**onoculture, **A**groforestry	Residues after harvesting: **R**emoved, **L**eft, **B**urnt, Others.	Yield **(kg / ha, bag /ha)**	Percent of yield that is used for home consumption	Percent of yield that is sold on farm or market	Price obtained on farm or market per unit **(/ kg, / bag)**

Total benefits: (T. Shilling)
Sales in: field / farmhouse / local market
What is the most important crop to you?
Why?
What are the main crop requirements or soil constraints?

Specific information per crop:

Questionnaire number:
Name of respondent:
Crop:
Variety:
Crops sequence in one year:
If multiple cropping, which crops?

If perennial crop,
Life time of crop:
Age of crop:
Name all harvesting years (1,2,3,4,5,...)
What are the main difficulies concerning this crop?

1. Management level: Input Low / Medium / High

2. Initial package:

i. Seeds

Do you apply: Yes / No:
When:
Material required: kg, Price (per kg):
Own labour required: Mandays, Cost per Manday:
Hired labour required: Mandays, Cost per Manday:
Total cost of labour:
Transport: Cost of transport:
Total cost:

ii. Planting / Replanting

Do you practice: Yes / No:
When:
How: Mannual / :
Materials used:
Own labour required: Mandays, Cost per manday:
Hired labour required: Mandays, Cost per manday:
Total cost of labour:
Transport: Cost of transport:
Total cost:

iii. Pesticides / Herbicides

Do you apply: Yes / No:
Type:
When:
Material required: Price per kg:
Own labour required: Mandays, Cost per manday:
Hired labour required: Mandays, Cost per manday:
Total cost of labour:
Transport: Cost of transport:
Total cost:
Are you aware of any impact of this on the environment?
Have you already noticed this?

3. Production package

i. Land preparation

Do you practice: Yes / No:
When:
How: Mannual / Animal traction / Tractor / Othres specify:
Own labour required: Mandays, Cost per manday:
Hired labour required: Mandays, Cost per manday:
Total cost of labour:
Transport: Cost of transport:
Total cost:

ii. Weeding

Do you practice: Yes / No:
When:
How: Mannual / Animal traction / Tractor / Others specify:
Material used:
Own labour required: Mandays, Cost per manday:
Hired labour required: Mandays, Cost per manday:
Total cost labour:
Total cost:

iii. Prunning

Do you practice: Yes / No:
When:
How: Mannual / :
Material used:
Own labour required: Mandays, Cost per manday:
Total cost of labour:
Total cost:

iv. Irrigation

Do you practice: Yes / No:
If yes, when:
How:
Material used: Cost of material (each year):
Own labour required: Mandays, Cost per manday:
Hired labour required: Mandays, Cost per manday:
Total cost of labour:
Total cost:

4. Soil conservation

Have you ever experienced erosion in any of your plots?
What kind of erosion?
Do you practice: Yes/ No
Why?
When?
Type:
How: manual/
Material used: Cost?
Owned labour required: Mandays, Cost per day:
Hired labour rewuired: Mandays, Cost per day:
Total cost of labour:
Total cost :

5. Land improvement activities:

Fertilizer:

Do you practice : Yes / No
When:
How : manual / :
Kind of fertilizer: N / P / K / Manure / Lime
Material used:

	Quantity (kg)	Price / kg (T. Sh.)	Total cost (T. Sh.)
N:			
P:			
K:			

Own labour required : Mandays, Cost per manday:
Hired labout required: Mandays, Cost per manday:
Total cost of labour :
Transport: Cost of transport:
Total cost:

6. Harvesting / postharvesting

i. Harvesting:

When:
How: Mannual / :
Material used:
Own labour required: Mandays, Cost per manday:
Hired labour required: Mandays, Cost per manday:
Total cost of labour:
Transport: Cost of transport:

ii. Postharvesting

Do you practice: Yes / No:
When:
How: Mnnual / :
Material used:
Own labour required: Mandays, Cost per manday:
Hired labour required: Mandays, Cost per manday:
Total cost of labour:
Transport: Cost of transport:
Total cost:

B. Prospects:

Are the yields improving (+) or declining (-)?
What is the cause of this?
Is your farm area adequate?
Would you like more land?
Why?

How do you see the future?

Appendix 6. Rating of land use requirements for smallholder improved low input rainfed cabbage cultivation system (growing period 100 - 150 days)

Land quality	Diagnostic factor	Unit	Factor rating			
			Highly suitable (S1)	Moderately suitable (S2)	Marginaly suitable (S3)	Not suitable (n)
Moisture availability	precipitation of growing period	mm	350-800	800-1000 300-350	>1000 250-300	<250
Temperature regime	mean temp. of the growing cycle	°C	13-24	24-30 10-13	30-35 5-10	>35 <5
	temp. difference day/night	°C	8-14	14-16 8-4	16-18 4-2	>18 <2
Erosion hazard	terraced slope gradient	%	< 30	30-60	60-80	>80
	surface soil texture	-	S, LS, SL	L, SCL, SiL,	SiCL, CL SC	Si, SiC, C
Oxygen availability	soil drainage	drainage class	moderate well, somewhat excessive, excessive	imperfect,	poor	very poor
Rooting condition	effective soil depth	cm	>60	60-50	50-20	<20
	Texture	-	L, SCL, SiC, SL, SC, CL	C, LS, SiCL, SiL	S, Si	-
Nutrient availability	soil reaction	pH (H_2O)	6.0-7.5	7.5-8.0 5.5 - 6.0	8.0-8.5 5.0 - 5.5	>8.5 <5.5
	organic carbon	%	>0.8	<0.8	-	-
	total nitrogen	%	> 0.23	0.23 - 0.15	0.15 - 0.1	<0.1
	available phosphorus	mg p/kg	> 47	47 - 10	10 - 4	< 4
	potassium content	cmol (+)/kg	> 3.8	3.8 - 1.2	1.2 - 0.5	<0.5
Nutrient retention capacity	apparent CEC	cmol(+)/k g clay	>16	<16 (+)	-	-
	sum of basic cations	cmol(+)/k g soil	>3.5	3.5-2	<2	-
	base saturation	%	>35	35-20	<20	-

Appendix 7. Rating of land use requirements for smallholder improved low input rainfed potatoes cultivation system (growing period 90-120 days)

Land quality	Diagnostic factor	Unit	Factor rating			
			Highly suitable (S1)	Moderately suitable (S2)	Marginaly suitable (S3)	Not suitable (n)
Moisture availability	precipitation of growing period (first 4 months}	mm	> 450	250 - 160 450-800	160 - 120 800-1000	< 120 >1000
Temperature regime	mean temp. of the growing cycle	°C	13 - 24	24 - 27 13 - 10	27 - 30 10 - 8	> 30 < 8
	average. temp difference between day/night	°C	> 5	< 5	-	-
Erosion hazard	terraced slope gradient	%	> 30	30-60	60-80	> 80
	surface soil texture	-	S, LS, SL	L, SCL, SiL,	SiCL. CL SC	Si, SiC. C
Oxygen availability	soil drainage	drainage class	moderate, well, excessive, somewhat excessive	imperfect,	poor	very poor
Tuber expansion and harvesting	effective soil depth	cm	> 60	60 - 40	40 - 20	< 20
	texture	-	L, SCL, SiL, CL, SC, SL,	C, SiCL	LS. SiC, Si	S
Nutrient availability	soil reaction	pH (H_2O)	5.6 - 7.0	7.0 - 8.0 5.2 - 5.6	8.0 - 8.2 5.2 - 4.8	> 8.2 <4.8
	organic carbon	%	> 0.8	0.8- 1.2	< 0.8	-
	total nitrogen	%	> 0.1	0 1 - 0.02	0.02-0.01	<0.01
	available phosphorus	mg p/kg	> 36	36 - 8	8 - 1	< 1
	potassium content	cmol (+)/kg	> 3	3 -0.5	0.5 -0.1	< 0.1
Nutrient retention capacity	apparent CEC	cmol(+)/ kg clay	> 16	< 16 (+)	-	-
	sum of basic cations	cmol(+)/ kg soil	> 3.5	3.5 - 2	< 2	-
	base saturation	%	35 - 100	< 35	-	-

Appendix 8. Rating of land use requirements for smallholder low input rainfed arabica coffee cultivation system

Land quality	Diagnostic factor	Unit	Factor rating			
			Highly suitable (S1)	Moderately suitable (S2)	Marginally suitable (S3)	Not suitable (n)
Moisture availability	annual precipitation	mm	1200 - 1800	1800 - 2000 1000 - 1200	> 2000 800 - 1000	< 800
	length dry season (months: P < 1/2PET)	months	1 - 4	4 - 5 0 - 1	5 - 6	> 6
Temperature regime	mean annual max. temperature	°C	22 - 28	28 - 30 22 - 20	30 - 32 20 - 18	> 32 < 18
	mean monthly min. temp. of coldest month	°C	10 - 19	19 - 21 10 - 7	21 - 23 7 - 4	> 23 < 4
	mean annual temp.	°C	16 - 22	22 - 24 16 - 15	24 - 26 15 - 14	> 26 < 14
Erosion hazard	terraced slope gradient	%	< 30	30-60	60-80	>80
	surface soil texture	-	S, LS, SL	L, SCL, SiL,	SiCL, CL SC	Si. SiC. C
Oxygen availability	soil drainage	drainage class	well, excessive, somewhat excessive	moderately well	imperfect	poor. very poor
Rooting condition	effective soil depth	cm	> 150	150 - 100	100 - 50	< 50
	soil texture	-	SiCL, CL, SCL, L	C, SC	SL, SiL	SiC. LS. S. Si
Nutrient availability	soil reaction	pH (H_2O)	5.6 - 6.6	6.6 - 7.4 5.6 - 5.4	7.4 - 7.8 5.4 - 5.2	> 7.8 < 5.2
	organic carbon	%	> 1.2	1.2 - 0.8	< 0.8	-
	total nitrogen	%	> 0.2	0.2 - 0.1	0.1 -0.05	< 0.05
	available phosphorus	mg p/kg	> 26	26 - 5	5 - 2	< 2
	potassium content	cmol (+)/kg	> 4.2	4.2 - 1.4	1.4 - 0.2	< 0.2
Nutrient retention capacity	apparent CEC	cmol(+)/kg clay	> 16	< 16 (+)	-	-
	sum of basic cations	cmol(+)/kg soil	> 4	4 - 2.8	2.8 - 1.6	< 1.6
	base saturation	%	> 50	50 - 35	35 - 20	< 20

Appendix 9. ALES decision trees for small holder improved low input rainfed cabbage

Mgeta (Mgeta automated land evaluation) Decision Trees

DtId Type Where Used

---

1 Severity Level SILIRC,e

> sl (dominant slope)

1 (flat to nearly level) : 1 (good)

2 (very gently sloping) : 1 (good)

3 (gently sloping) [2-5 : 1 (good)

4 (sloping) [5-15 %].... : 1 (good)

5 (moderately sloping) [15-30 %] > st (surface soil texture)

1 (sand)..... : 1 (good)

2 (loamy sand)..... : 1 (good)

3 (silty clay)..... : 2 (moderate)

4 (clay)..... : 2 (moderate)

5 (sandy clay)..... : 1 (good)

6 (sandy loam)..... : 1 (good)

7 (loam)..... : 2 (moderate)

8 (sandy clay loam)..... : 1 (good)

9 (clay loam)..... : 2 (moderate)

10 (silty clay loam).... : 2 (moderate)

11 (silty loam)..... : 2 (moderate)

12 (silt)..... : 2 (moderate)

?..... : ?

6 (steep sloping) [30-60 %] > st (surface soil texture)

1 (sand)..... : 2 (moderate)

2 (loamy sand)..... : 2 (moderate)

3 (silty clay)..... : 2 (moderate)

4 (clay)..... : 2 (moderate)

5 (sandy clay)..... : 2 (moderate)

6 (sandy loam)..... : 2 (moderate)

7 (loam)..... : 2 (moderate)

8 (sandy clay loam)..... : 2 (moderate)

9 (clay loam)..... : 2 (moderate)

10 (silty clay loam).... : 2 (moderate)

11 (silty loam)..... : 3 (poor)

12 (silt)..... : 3 (poor)

?..... : ?

7 (moderately steep) [60 : =6

8 (very steep) [80-100 %] > st (surface soil texture)

1 (sand)..... : 3 (poor)

2 (loamy sand)..... : 3 (poor)

3 (silty clay)..... : 4 (very poor)

4 (clay)..... : 4 (very poor)

5 (sandy clay)..... : 3 (poor)

6 (sandy loam)..... : 3 (poor)

7 (loam)..... : 3 (poor)

8 (sandy clay loam)..... : 3 (poor)

9 (clay loam)..... : 3 (poor)

10 (silty clay loam).... : 4 (very poor)

11 (silty loam)..... : 4 (very poor)

12 (silt)..... : 4 (very poor)

?..... : ?

?..... : ?

2 Severity Level SILIRC,na

> pH (pH surface)

1 (very strongly acid) [0-5 no dimension] > oc (organic carbon)

1 (very low) [0-.6 %] > n (nitrogen content)

1 (very low) [0-.1 %]... : 4

2 (low) [.1-.2 %]..... : 3

3 (medium) [.2-.5 %].... : 2

4 (high) [.5-10 %]..... : 2

?..... : ?

2 (low) [.6-1.25 %]..... : =1

3 (medium) [1.25-2.5 %] > n (nitrogen content)

Mgeta (Mgeta automated land evaluation)

DtId Type Where Used

---

2 Severity Level SILIRC,na

(continued)

1 (very low) [0-.1 %]... : 3

2 (low) [.1-.2 %]..... : 2

3 (medium) [.2-.5 %].... : 2

4 (high) [.5-10 %]..... : 2

?..... : ?

4 (high) [2.5-3.5 %].... : =3

5 (very high) [3.5-20 %] > n (nitrogen content)

1 (very low) [0-.1 %]... : 3

2 (low) [.1-.2 %] > p (available phosphorus)

1 (low) [0-7 mg P/kg]... : 2

2 (medium) [7-20 mg P/kg : 2

3 (high) [20-100 mg P/kg : 1

?..... : ?

3 (medium) [.2-.5 %] > p (available phosphorus)

1 (low) [0-7 mg P/kg]... : 2

2 (medium) [7-20 mg P/kg : 2

3 (high) [20-100 mg P/kg : 1

?..... : ?

4 (high) [.5-10 %] > p (available phosphorus)

1 (low) [0-7 mg P/kg]... : 2

2 (medium) [7-20 mg P/kg] > k (potassium content)

1 (very low) [0-.2 cmol(: 2

2 (low) [.2-.4 cmol(+)/k : 2

3 (medium) [.4-1.2 cmol(: 2

4 (high) [1.2-2 cmol(+)/ : 1

5 (very high) [2-10 cmol : 1

?..... : ?

3 (high) [20-100 mg P/kg : =2

?..... : ?

?..... : ?

?..... : ?

2 (strongly acid) [5-5.5 no dimension] > oc (organic carbon)

1 (very low) [0-.6 %] > n (nitrogen content)

1 (very low) [0-.1 %]... : 4

2 (low) [.1-.2 %] > p (available phosphorus)

1 (low) [0-7 mg P/kg]... : 2

2 (medium) [7-20 mg P/kg : 2

3 (high) [20-100 mg P/kg : 2

?..... : ?

3 (medium) [.2-.5 %] > p (available phosphorus)

1 (low) [0-7 mg P/kg]... : 2

2 (medium) [7-20 mg P/kg] > k (potassium content)

1 (very low) [0-.2 cmol(: 2

2 (low) [.2-.4 cmol(+)/k : 2

3 (medium) [.4-1.2 cmol(: 2

4 (high) [1.2-2 cmol(+)/ : 2

5 (very high) [2-10 cmol : 1

?..... : ?

3 (high) [20-100 mg P/kg : =2

?..... : ?

4 (high) [.5-10 %]..... : =3

?..... : ?

2 (low) [.6-1.25 %]..... : =1

3 (medium) [1.25-2.5 %] > n (nitrogen content)

1 (very low) [0-.1 %]... : 3

2 (low) [.1-.2 %] > p (available phosphorus)

1 (low) [0-7 mg P/kg]... : 3

2 (medium) [7-20 mg P/kg] > k (potassium content)

1 (very low) [0-.2 cmol(: 3

2 (low) [.2-.4 cmol(+)/k : 2

Mgeta (Mgeta automated land evaluation) Decision Trees

```
DtId Type                                   Where Used
-------------------------------------------------------------------------------
2    Severity Level                         SILIRC,na
(continued)
                3 (medium) [.4-1.2 cmol( : 2
                4 (high) [1.2-2 cmol(+)/ : 2
                5 (very high) [2-10 cmol : 2
                ?........................ : ?
             3 (high) [20-100 mg P/kg : =2
             ?........................... : ?
          3 (medium) [.2-.5 %] > p (available phosphorus )
             1 (low) [0-7 mg P/kg]... : 2
             2 (medium) [7-20 mg P/kg] > k (potassium content)
                1 (very low) [0-.2 cmol( : 2
                2 (low) [.2-.4 cmol(+)/k : 2
                3 (medium) [.4-1.2 cmol( : 2
                4 (high) [1.2-2 cmol(+)/ : 2
                5 (very high) [2-10 cmol : 1
                ?........................ : ?
             3 (high) [20-100 mg P/kg : =2
             ?........................... : ?
          4 (high) [.5-10 %]...... : =3
          ?........................... : ?
       4 (high) [2.5-3.5 %].... : =3
       5 (very high) [3.5-20 %] : =3
       ?........................... : ?
    3 (moderately acid) [5.5-6 no dimension] > oc (organic carbon)
       1 (very low) [0-.6 %] > n (nitrogen content)
          1 (very low) [0-.1 %]... : 3
          2 (low) [.1-.2 %] > p (available phosphorus )
             1 (low) [0-7 mg P/kg]... : 2
             2 (medium) [7-20 mg P/kg : 2
             3 (high) [20-100 mg P/kg : 2
             ?........................ : ?
          3 (medium) [.2-.5 %].... : 2
          4 (high) [.5-10 %]...... : 2
          ?........................... : ?
       2 (low) [.6-1.25 %]..... : =1
       3 (medium) [1.25-2.5 %] > n (nitrogen content)
          1 (very low) [0-.1 %]... : 3
          2 (low) [.1-.2 %]....... : 2
          3 (medium) [.2-.5 %].... : 2
          4 (high) [.5-10 %]...... : 2
          ?........................... : ?
       4 (high) [2.5-3.5 %].... : =3
       5 (very high) [3.5-20 %] : =3
       ?........................... : ?
    4 (slightly acid) [6-6.5 no dimension] > oc (organic carbon)
       1 (very low) [0-.6 %] > n (nitrogen content)
          1 (very low) [0-.1 %]... : 3
          2 (low) [.1-.2 %]....... : 2
          3 (medium) [.2-.5 %] > p (available phosphorus )
             1 (low) [0-7 mg P/kg]... : 2
             2 (medium) [7-20 mg P/kg : 2
             3 (high) [20-100 mg P/kg] > k (potassium content)
                1 (very low) [0-.2 cmol( : 2
                2 (low) [.2-.4 cmol(+)/k : 2
                3 (medium) [.4-1.2 cmol( : 2
                4 (high) [1.2-2 cmol(+)/ : 1
                5 (very high) [2-10 cmol : 1
                ?........................ : ?
             ?........................... : ?
          4 (high) [.5-10 %]...... : =3
```

Mgeta (Mgeta automated land evaluation)

```
DtId Type                                   Where Used
-------------------------------------------------------------------------------
2    Severity Level                         SILIRC,na
(continued)
       2 (low) [.6-1.25 %] > n (nitrogen content)
          1 (very low) [0-.1 %]... : 3
          2 (low) [.1-.2 %]....... : 2
          3 (medium) [.2-.5 %] > p (available phosphorus )
             1 (low) [0-7 mg P/kg]... : 2
             2 (medium) [7-20 mg P/kg : 2
             3 (high) [20-100 mg P/kg : 1
             ?........................ : ?
          4 (high) [.5-10 %]...... : =3
          ?........................... : ?
       3 (medium) [1.25-2.5 %]. : =2
       4 (high) [2.5-3.5 %].... : =2
       5 (very high) [3.5-20 %] : =2
       ?........................... : ?
    5 (neutral) [6.5-7.5 no  : =4
    6 (alkaline) [7.5-9 no d : =3
    ?........................... : ?

3    Severity Level                         SILIRC,m
 > r-g (rainfall during the growing period)
    1 (very very low) [0-100 mm] > awc (available water capacity)
       1 (extremely low) [0-25  : 4
       2 (very low) [25-50 mm/m : 4
       3 (low) [50-100 mm/m]... : 4
       4 (medium) [100-150 mm/m : 3
       5 (high) [150-200 mm/m]. : 3
       6 (very high) [200-400 m : 3
       ?........................ : ?
    2 (very low) [100-250 mm] > awc (available water capacity)
       1 (extremely low) [0-25  : 3
       2 (very low) [25-50 mm/m : 3
       3 (low) [50-100 mm/m]... : 3
       4 (medium) [100-150 mm/m : 2
       5 (high) [150-200 mm/m]. : 2
       6 (very high) [200-400 m : 2
       ?........................ : ?
    3 (low) [250-300 mm].... : =2
    4 (moderate) [300-350 mm : 2
    5 (high) [350-800 mm]... : 1
    6 (very high) [800-1000  : 2
    7 (extremely high) [1000-2500 mm] > awc (available water capa
       1 (extremely low) [0-25  : 3
       2 (very low) [25-50 mm/m : 3
       3 (low) [50-100 mm/m]... : 2
       4 (medium) [100-150 mm/m : 2
       5 (high) [150-200 mm/m]. : 2
       6 (very high) [200-400 m : 3
       ?........................ : ?
    ?........................... : ?
```

Mgeta (Mgeta automated land evaluation) Decision Trees

```
DtId Type                                   Where Used
-------------------------------------------------------------------------------
4    Severity Level                         SILIRC,nr
 > cec-c (cation exchange capacity of clay)
   1 (low) [0-5 cmol(+)/kg] > teb (total exchangeable bases)
      1 (very low) [0-1.6 cmol : 3
      2 (low) [1.6-2 cmol(+)/kg] > bs (base saturation)
         1 (very low) [0-20 %]... : 3
         2 (low) [20-40 %]..... : 2
         3 (medium) [40-60 %].... : 2
         4 (high) [60-80 %]..... : 2
         5 (very high) [80-100 %] : 2
         ?..................... : ?
      3 (medium) [2-2.8 cmol(+ : =2
      4 (high) [2.8-3.5 cmol(+ : =2
      5 (very high) [3.5-30 cm : =2
      ?..................... : ?
   2 (medium) [5-15 cmol(+)/kg] > teb (total exchangeable bases)
      1 (very low) [0-1.6 cmol : 2
      2 (low) [1.6-2 cmol(+)/k : 2
      3 (medium) [2-2.8 cmol(+ : 2
      4 (high) [2.8-3.5 cmol(+ : 2
      5 (very high) [3.5-30 cm : 1
      ?..................... : ?
   3 (high) [15-450 cmol(+)/kg] > teb (total exchangeable bases)
      1 (very low) [0-1.6 cmol : 2
      2 (low) [1.6-2 cmol(+)/k : 2
      3 (medium) [2-2.8 cmol(+ : 2
      4 (high) [2.8-3.5 cmol(+ : 1
      5 (very high) [3.5-30 cm : 1
      ?..................... : ?
   ?..................... : ?

5    Severity Level                         SILIRC,o
 > dr (soil drainage class)
   1 (very poorly drained). : 4
   2 (poorly drained)..... : 3
   3 (imperfectly drained). : 2
   4 (moderately well drain : 1
   5 (well drained)....... : 1
   6 (somewhat excessively  : 1
   7 (excessively drained). : 1
   ?..................... : ?
```

Mgeta (Mgeta automated land evaluation)

```
DtId Type                                   Where Used
-------------------------------------------------------------------------------
6    Severity Level                         SILIRC,r
 > sd (effective soil depth)
   1 (very shallow) [0-20 c : 4
   2 (shallow) [20-40 cm] > pt (profile soil texture)
      1 (sand)..... : 4
      2 (loamy sand)..... : 4
      3 (silty clay)..... : 2
      4 (clay)..... : 2
      5 (sandy clay)..... : 2
      6 (sandy loam)..... : 2
      7 (loam)..... : 2
      8 (sandy clay loam)..... : 2
      9 (clay loam)..... : 2
      10 (silt clay loam)..... : 2
      11 (silty loam)..... : 2
      12 (silt)..... : 3
      ?..... : ?
   3.1 (moderately shallow) [40-60 cm] > pt (profile soil textur
      1 (sand)..... : 3
      2 (loamy sand)..... : 2
      3 (silty clay)..... : 2
      4 (clay)..... : 2
      5 (sandy clay)..... : 2
      6 (sandy loam)..... : 2
      7 (loam)..... : 2
      8 (sandy clay loam)..... : 2
      9 (clay loam)..... : 2
      10 (silt clay loam)..... : 2
      11 (silty loam)..... : 2
      12 (silt)..... : 3
      ?..... : ?
   3 (moderately deep) [60-80 cm] > pt (profile soil texture)
      1 (sand)..... : 3
      2 (loamy sand)..... : 2
      3 (silty clay)..... : 1
      4 (clay)..... : 1
      5 (sandy clay)..... : 1
      6 (sandy loam)..... : 1
      7 (loam)..... : 1
      8 (sandy clay loam)..... : 1
      9 (clay loam)..... : 1
      10 (silt clay loam)..... : 1
      11 (silty loam)..... : 2
      12 (silt)..... : 3
      ?..... : ?
   4 (deep) [80-120 cm].... : =4
   5 (very deep) [120-1000  : =4
   ?..... : ?

7    Severity Level                         SILIRC,t
 > t-gp (mean temperature during the growing season)
   1 (extremely cool) [0-5 degrees C] > td (temperature differen
      1 (extremely cool) [0-5  : 4
      2 (very cool) [5-7.5 deg : 3
      3 (cool) [7.5-10 degrees : 3
      4 (moderately cool) [10- : 3
      5 (moderately warm) [12. : 3
      6 (warm) [15-17.5 degree : 3
      7 (very warm) [17.5-20 d : 4
      8 (extremely warm) [20-2 : 4
   2 (very cool) [5-7.5 degrees C] > td (temperature difference d
```

```
Mgeta (Mgeta automated land evaluation)                          Decision Trees
DtId Type                                  Where Used
-------------------------------------------------------------------------------
7    Severity Level                        SILIRC,t
(continued)
      1 (extremely cool) [0-5  : 3
      2 (very cool) [5-7.5 deg : 3
      3 (cool) [7.5-10 degrees : 2
      4 (moderately cool) [10- : 2
      5 (moderately warm) [12. : 2
      6 (warm) [15-17.5 degree : 3
      7 (very warm) [17.5-20 d : 3
      8 (extremely warm) [20-2 : 4
      ?....................... : ?
   3 (cool) [7.5-10 degrees C] > td (temperature difference day/night)
      1 (extremely cool) [0-5  : 3
      2 (very cool) [5-7.5 deg : 3
      3 (cool) [7.5-10 degrees : 2
      4 (moderately cool) [10- : 2
      5 (moderately warm) [12. : 3
      6 (warm) [15-17.5 degree : 3
      7 (very warm) [17.5-20 d : 3
      8 (extremely warm) [20-2 : 4
      ?....................... : ?
   4 (moderately cool) [10-12.5 degrees C] > td (temperature difference day/nigh
t)
      1 (extremely cool) [0-5  : 3
      2 (very cool) [5-7.5 deg : 2
      3 (cool) [7.5-10 degrees : 2
      4 (moderately cool) [10- : 2
      5 (moderately warm) [12. : 2
      6 (warm) [15-17.5 degree : 2
      7 (very warm) [17.5-20 d : 3
      8 (extremely warm) [20-2 : 3
      ?....................... : ?
   5 (moderately warm) [12.5-15 degrees C] > td (temperature difference day/nigh
t)
      1 (extremely cool) [0-5  : 2
      2 (very cool) [5-7.5 deg : 2
      3 (cool) [7.5-10 degrees : 1
      4 (moderately cool) [10- : 1
      5 (moderately warm) [12. : 1
      6 (warm) [15-17.5 degree : 2
      7 (very warm) [17.5-20 d : 2
      8 (extremely warm) [20-2 : 3
      ?....................... : ?
   6 (warm) [15-17.5 degrees C] > td (temperature difference day/night)
      1 (extremely cool) [0-5  : 2
      2 (very cool) [5-7.5 deg : 2
      3 (cool) [7.5-10 degrees : 1
      4 (moderately cool) [10- : 1
      5 (moderately warm) [12. : 1
      6 (warm) [15-17.5 degree : 2
      7 (very warm) [17.5-20 d : 2
      8 (extremely warm) [20-2 : 3
      ?....................... : ?
   7 (very warm) [17.5-20 d : =6
   8 (extremely warm) [20-2 : =6
   ?....................... : ?
```

Appendix 10. ALES decision trees for small holder improved low input rainfed round potatoes

```
Mgeta (Mgeta automated land evaluation)                                  Decision Treee
DtId Type                                  Where Used
-------------------------------------------------------------------------------------
8     Severity Level                       SILIRP,e
 > sl (dominant slope)
   1 (flat to nearly level) : 1 (good)
   2 (very gently sloping)  : 1 (good)
   3 (gently sloping) [2-5  : 1 (good)
   4 (sloping) [5-15 %].... : 1 (good)
   5 (moderately sloping) [ : 1 (good)
   6 (steep sloping) [30-60 %] > st (surface soil texture)
      1 (sand)............... : 1 (good)
      2 (loamy sand)......... : 1 (good)
      3 (silty clay)......... : 2 (moderate)
      4 (clay)............... : 2 (moderate)
      5 (sandy clay)......... : 2 (moderate)
      6 (sandy loam)......... : 1 (good)
      7 (loam)............... : 2 (moderate)
      8 (sandy clay loam)..... : 2 (moderate)
      9 (clay loam).......... : 2 (moderate)
      10 (silty clay loam).... : 2 (moderate)
      11 (silty loam)........ : 2 (moderate)
      12 (silt).............. : 3 (poor)
      ?...................... : ?
   7 (moderately steep) [60-80 %] > st (surface soil texture)
      1 (sand)............... : 2 (moderate)
      2 (loamy sand)......... : 2 (moderate)
      3 (silty clay)......... : 3 (poor)
      4 (clay)............... : 3 (poor)
      5 (sandy clay)......... : 2 (moderate)
      6 (sandy loam)......... : 2 (moderate)
      7 (loam)............... : 2 (moderate)
      8 (sandy clay loam)..... : 2 (moderate)
      9 (clay loam).......... : 2 (moderate)
      10 (silty clay loam).... : 3 (poor)
      11 (silty loam)........ : 4 (very poor)
      12 (silt) ............. : 4 (very poor)
      ?...................... : ?
   8 (very steep) [80-100 %] > st (surface soil texture)
      1 (sand)............... : 3 (poor)
      2 (loamy sand)......... : 3 (poor)
      3 (silty clay)......... : 4 (very poor)
      4 (clay)............... : 4 (very poor)
      5 (sandy clay)......... : 3 (poor)
      6 (sandy loam)......... : 3 (poor)
      7 (loam)............... : 4 (very poor)
      8 (sandy clay loam)..... : 3 (poor)
      9 (clay loam).......... : 4 (very poor)
      10 (silty clay loam).... : 4 (very poor)
      11 (silty loam)........ : 4 (very poor)
      12 (silt)............... : 4 (very poor)
      ?...................... : ?
   ?......................... : ?
```

```
Mgeta (Mgeta automated land evaluation)
DtId Type                                  Where Used
-------------------------------------------------------------------------------------
9     Severity Level                       SILIRP,m
 > r-gs (rainfall during the GP (first 4 months of GP))
   1 (very very low) [0-120 mm] > awc (available water capacity)
      1 (extremely low) [0-25  : 4 (very poor)
      2 (very low) [25-50 mm/m : 4 (very poor)
      3 (low) [50-100 mm/m]... : 4 (very poor)
      4 (medium) [100-150 mm/m : 3 (poor)
      5 (high) [150-200 mm/m]. : 2 (moderate)
      6 (very high) [200-400 m : 2 (moderate)
      ?...................... : ?
   2 (very low) [120-160 mm] > awc (available water capacity)
      1 (extremely low) [0-25  : 3 (poor)
      2 (very low) [25-50 mm/m : 2 (moderate)
      3 (low) [50-100 mm/m]... : 2 (moderate)
      4 (medium) [100-150 mm/m : 2 (moderate)
      5 (high) [150-200 mm/m]. : 2 (moderate)
      6 (very high) [200-400 m : 2 (moderate)
      ?...................... : ?
   3 (low) [160-250 mm] > awc (available water capacity)
      1 (extremely low) [0-25  : 2 (moderate)
      2 (very low) [25-50 mm/m : 2 (moderate)
      3 (low) [50-100 mm/m]... : 2 (moderate)
      4 (medium) [100-150 mm/m : 1 (good)
      5 (high) [150-200 mm/m]. : 1 (good)
      6 (very high) [200-400 m : 1 (good)
      ?...................... : ?
   4 (moderate) [250-350 mm] > awc (available water capacity)
      1 (extremely low) [0-25  : 2 (moderate)
      2 (very low) [25-50 mm/m : 1 (good)
      3 (low) [50-100 mm/m]... : 1 (good)
      4 (medium) [100-150 mm/m : 1 (good)
      5 (high) [150-200 mm/m]. : 1 (good)
      6 (very high) [200-400 m : 1 (good)
      ?...................... : ?
   5 (high) [350-450 mm]... : =4
   6 (very high) [450-850 m : 2 (moderate)
   7 (very very high ) [850 : 3 (poor)
   8 (extremely high) [1000 : 4 (very poor)
   ?......................... : ?

10    Severity Level                       SILIRP,na
 > pH (pH surface)
   1 (very strongly acid) [0-5 no dimension] > oc (organic carbon)
      1 (very low) [0-.6 %] > n (nitrogen content)
         1 (very low) [0-.1 %] > p (available phosphorus )
            1 (low) [0-7 mg P/kg]... : 4
            2 (medium) [7-20 mg P/kg : 3
            3 (high) [20-100 mg P/kg : 3
            ?...................... : ?
         2 (low) [.1-.2 %] > p (available phosphorus )
            1 (low) [0-7 mg P/kg]... : 3
            2 (medium) [7-20 mg P/kg] > k (potassium content)
               1 (very low) [0- 2 cmol( : 3
               2 (low) [.2-.4 cmol(+)/k : 2
               3 (medium) [.4-1.2 cmol( : 2
               4 (high) [1.2-2 cmol(+)/ : 2
               5 (very high) [2-10 cmol : 2
               ?...................... : ?
            3 (high) [20-100 mg P/kg : =2
            ?...................... : ?
         3 (medium) [.2-.5 %].... : =2
         4 (high) [.5-10 %]..... : -2
```

Mgeta (Mgeta automated land evaluation) Decision Trees

DtId Type Where Used

10 Severity Level SILIRP,na
(continued)

```
          ?..................... : ?
      2 (low) [.6-1.25 %]..... : =1
      3 (medium) [1.25-2.5 %]. : =1
      4 (high) [2.5-3.5 %].... : =1
      5 (very high) [3.5-20 %] : =1
      ?..................... : ?
   2 (strongly acid) [5-5.5 no dimension] > oc (organic carbon)
      1 (very low) [0-.6 %] > n (nitrogen content)
         1 (very low) [0-.1 %] > p (available phosphorus )
            1 (low) [0-7 mg P/kg] > k (potassium content)
               1 (very low) [0-.2 cmol( : 4
               2 (low) [.2-.4 cmol(+)/k : 3
               3 (medium) [.4-1.2 cmol( : 3
               4 (high) [1.2-2 cmol(+)/ : 3
               5 (very high) [2-10 cmol : 3
               ?..................... : ?
            2 (medium) [7-20 mg P/kg] > k (potassium content)
               1 (very low) [0-.2 cmol( : 3
               2 (low) [.2-.4 cmol(+)/k : 2
               3 (medium) [.4-1.2 cmol( : 2
               4 (high) [1.2-2 cmol(+)/ : 2
               5 (very high) [2-10 cmol : 2
               ?..................... : ?
            3 (high) [20-100 mg P/kg : =2
            ?..................... : ?
         2 (low) [.1-.2 %] > p (available phosphorus )
            1 (low) [0-7 mg P/kg]... : 2
            2 (medium) [7-20 mg P/kg] > k (potassium content)
               1 (very low) [0-.2 cmol( : 2
               2 (low) [.2-.4 cmol(+)/k : 2
               3 (medium) [.4-1.2 cmol( : 2
               4 (high) [1.2-2 cmol(+)/ : 2
               5 (very high) [2-10 cmol : 1
               ?..................... : ?
            3 (high) [20-100 mg P/kg] > k (potassium content)
               1 (very low) [0-.2 cmol( : 2
               2 (low) [.2-.4 cmol(+)/k : 2
               3 (medium) [.4-1.2 cmol( : 2
               4 (high) [1.2-2 cmol(+)/ : 2
               5 (very high) [2-10 cmol : 1
               ?..................... : ?
            ?..................... : ?
         3 (medium) [.2-.5 %].... : =2
         4 (high) [.5-10 %]...... : =2
         ?..................... : ?
      2 (low) [.6-1.25 %]..... : =1
      3 (medium) [1.25-2.5 %]. : =1
      4 (high) [2.5-3.5 %].... : =1
      5 (very high) [3.5-20 %] : =1
      ?..................... : ?
   3 (moderately acid) [5.5-6 no dimension] > oc (organic carbon)
      1 (very low) [0-.6 %] > n (nitrogen content)
         1 (very low) [0-.1 %] > p (available phosphorus )
            1 (low) [0-7 mg P/kg]... : 3
            2 (medium) [7-20 mg P/kg : 2
            3 (high) [20-100 mg P/kg : 2
            ?..................... : ?
         2 (low) [.1-.2 %] > p (available phosphorus )
            1 (low) [0-7 mg P/kg] > k (potassium content)
               1 (very low) [0-.2 cmol( : 2
```

Mgeta (Mgeta automated land evaluation)

DtId Type Where Used

10 Severity Level SILIRP,na
(continued)

```
               2 (low) [.2-.4 cmol(+)/k : 2
               3 (medium) [.4-1.2 cmol( : 2
               4 (high) [1.2-2 cmol(+)/ : 2
               5 (very high) [2-10 cmol : 1
               ?..................... : ?
            2 (medium) [7-20 mg P/kg] > k (potassium content)
               1 (very low) [0-.2 cmol( : 2
               2 (low) [.2-.4 cmol(+)/k : 2
               3 (medium) [.4-1.2 cmol( : 2
               4 (high) [1.2-2 cmol(+)/ : 2
               5 (very high) [2-10 cmol : 1
               ?..................... : ?
            3 (high) [20-100 mg P/kg] > k (potassium content)
               1 (very low) [0-.2 cmol( : 2
               2 (low) [.2-.4 cmol(+)/k : 1
               3 (medium) [.4-1.2 cmol( : 1
               4 (high) [1.2-2 cmol(+)/ : 1
               5 (very high) [2-10 cmol : 1
               ?..................... : ?
            ?..................... : ?
         3 (medium) [.2-.5 %].... : =2
         4 (high) [.5-10 %]...... : =2
         ?..................... : ?
      2 (low) [.6-1.25 %]..... : =1
      3 (medium) [1.25-2.5 %]. : =1
      4 (high) [2.5-3.5 %].... : =1
      5 (very high) [3.5-20 %] : =1
      ?..................... : ?
   4 (slightly acid) [6-6.5 : =3
   5 (neutral) [6.5-7.5 no  : =3
   6 (alkaline) [7.5-9 no d : =2
   ?..................... : ?
```

Mgeta (Mgeta automated land evaluation) Decision Trees

```
DtId Type                                   Where Used
-------------------------------------------------------------------------------
11   Severity Level                         SILIRP,nr
 > cec-c (cation exchange capacity of clay)
   1 (low) [0-5 cmol(+)/kg] > teb (total exchangeable bases)
      1 (very low) [0-1.6 cmol : 3 (poor)
      2 (low) [1.6-2 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) [80-100 %] : 2 (moderate)
         ?..................... : ?
      3 (medium) [2-2.8 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) [80-100 %] : 2 (moderate)
         ?..................... : ?
      4 (high) [2.8-3.5 cmol(+ : 2 (moderate)
      5 (very high) [3.5-30 cm : 2 (moderate)
      ?..................... : ?
   2 (medium) [5-15 cmol(+)/kg] > teb (total exchangeable bases)
      1 (very low) [0-1.6 cmol : 3 (poor)
      2 (low) [1.6-2 cmol(+)/k : 2 (moderate)
      3 (medium) [2-2.8 cmol(+ : 2 (moderate)
      4 (high) [2.8-3.5 cmol(+ : 2 (moderate)
      5 (very high) [3.5-30 cm : 2 (moderate)
      ?..................... : ?
   3 (high) [15-450 cmol(+)/kg] > teb (total exchangeable bases)
      1 (very low) [0-1.6 cmol : 3 (poor)
      2 (low) [1.6-2 cmol(+)/k : 2 (moderate)
      3 (medium) [2-2.8 cmol(+ : 2 (moderate)
      4 (high) [2.8-3.5 cmol(+ : 2 (moderate)
      5 (very high) [3.5-30 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) [80-100 %] : 1 (good )
         ?..................... : ?
      ?..................... : ?
   ?..................... : ?

12   Severity Level                         SILIRP,o
 > dr (soil drainage class)
   1 (very poorly drained). : 4
   2 (poorly drained)..... : 3
   3 (imperfectly drained). : 2
   4 (moderately well drain : 1
   5 (well drained)....... : 1
   6 (somewhat excessively  : 1
   7 (excessively drained). : 1
   ?..................... : ?
```

Mgeta (Mgeta automated land evaluation)

```
DtId Type                                   Where Used
-------------------------------------------------------------------------------
13   Severity Level                         SILIRP,t
 > t-gp (mean temperature during the growing season)
   1 (extremely cool) [0-5 degrees C] > td (temperature differen
      1 (extremely cool) [0-5  : 4
      2 (very cool) [5-7.5 deg : 3
      3 (cool) [7.5-10 degrees : 3
      4 (moderately cool) [10- : 3
      5 (moderately warm) [12. : 3
      6 (warm) [15-17.5 degree : 3
      7 (very warm) [17.5-20 d : 3
      8 (extremely warm) [20-2 : 3
      ?..................... : ?
   2 (very cool) [5-7.5 deg : =1
   3 (cool) [7.5-10 degrees C] > td (temperature difference day/
      1 (extremely cool) [0-5  : 3
      2 (very cool) [5-7.5 deg : 2
      3 (cool) [7.5-10 degrees : 2
      4 (moderately cool) [10- : 2
      5 (moderately warm) [12. : 2
      6 (warm) [15-17.5 degree : 2
      7 (very warm) [17.5-20 d : 2
      8 (extremely warm) [20-2 : 2
      ?..................... : ?
   4 (moderately cool) [10- : 2
   5 (moderately warm) [12.5-15 degrees C] > td (temperature dif
t)
      1 (extremely cool) [0-5  : 2
      2 (very cool) [5-7.5 deg : 1
      3 (cool) [7.5-10 degrees : 1
      4 (moderately cool) [10- : 1
      5 (moderately warm) [12. : 1
      6 (warm) [15-17.5 degree : 1
      7 (very warm) [17.5-20 d : 1
      8 (extremely warm) [20-2 : 1
      ?..................... : ?
   6 (warm) [15-17.5 degree : =5
   7 (very warm) [17.5-20 d : =5
   8 (extremely warm) [20-2 : =5
   ?..................... : ?
```

Mgeca (Mgeca automated land evaluation) Decision Trees

```
DtId Type                                   Where Used
-------------------------------------------------------------------------------
14   Severity Level                         SILIRP,tb
 > sd (effective soil depth)
   1 (very shallow) [0-20 cm] > st (surface soil texture)
      1 (sand)..................... : 4
      2 (loamy sand)............... : 4
      3 (silty clay)............... : 4
      4 (clay)..................... : 3
      5 (sandy clay)............... : 3
      6 (sandy loam)............... : 3
      7 (loam)..................... : 3
      8 (sandy clay loam).......... : 3
      9 (clay loam)................ : 3
      10 (silty clay loam)......... : 3
      11 (silty loam).............. : 3
      12 (silt).................... : 3
      ?............................ : ?
   2 (shallow) [20-40 cm] > st (surface soil texture)
      1 (sand)..................... : 4
      2 (loamy sand)............... : 3
      3 (silty clay)............... : 2
      4 (clay)..................... : 2
      5 (sandy clay)............... : 2
      6 (sandy loam)............... : 2
      7 (loam)..................... : 2
      8 (sandy clay loam).......... : 2
      9 (clay loam)................ : 2
      10 (silty clay loam)......... : 2
      11 (silty loam).............. : 2
      12 (silt).................... : 3
      ?............................ : ?
   3.1 (moderately shallow) [40-60 cm] > pt (profile soil texture)
      1 (sand)..................... : 3
      2 (loamy sand)............... : 2
      3 (silty clay)............... : 2
      4 (clay)..................... : 2
      5 (sandy clay)............... : 2
      6 (sandy loam)............... : 2
      7 (loam)..................... : 2
      8 (sandy clay loam).......... : 2
      9 (clay loam)................ : 2
      10 (silt clay loam).......... : 2
      11 (silty loam).............. : 2
      12 (silt).................... : 3
      ?............................ : ?
   3 (moderately deep) [60-80 cm] > st (surface soil texture)
      1 (sand)..................... : 3
      2 (loamy sand)............... : 2
      3 (silty clay)............... : 2
      4 (clay)..................... : 1
      5 (sandy clay)............... : 1
      6 (sandy loam)............... : 1
      7 (loam)..................... : 1
      8 (sandy clay loam).......... : 1
      9 (clay loam)................ : 1
      10 (silty clay loam)......... : 1
      11 (silty loam).............. : 1
      12 (silt).................... : 2
      ?............................ : ?
   4 (deep) [80-120 cm]..... : =4
   5 (very deep) [120-1000  : =4
   ?............................ : ?
```

Appendix 11. ALES decision trees for small holder low input rainfed arabica coffee

```
Mgeta (Mgeta automated land evaluation)                    Decision Trees
DtId Type                              Where Used
-------------------------------------------------------------------------------


15   Severity Level                    SHLIRCF,t
 > t-anx (mean annual maximum temperature)
   1 (extremely cool) [0-5  : 4
   2 (very cool ) [5-7.5 de : 4
   3 (cool) [7.5-10 degrees : 4
   4 (moderately cool) [10- : 4
   5 (moderately warm) [12.5-15 degrees C] > t-mc (mean monthly temperature of c
oldest month)
      1 (extremely cool) [0-5  : 4
      2 (very cool) [5-7.5 deg : 3
      3 (cool) [7.5-10 degrees : 3
      4 (moderately cool) [10- : 3
      5 (moderately warm) [12. : 4
      6 (warm) [15-17.5 degree : 4
      7 (very warm) [17.5-20 d : 4
      8 (extremely warm) [20-2 : 4
      ?........................ : ?
   6 (warm) [15-17.5 degrees C] > t-mc (mean monthly temperature of coldest mont
h)
      1 (extremely cool) [0-5  : 3
      2 (very cool) [5-7.5 degrees] > t-an (mean annual temperature)
         1 (extremely cool) [0-5  : 4
         2 (very cool) [5-7.5 deg : 4
         3 (cool) [7.5-10 degrees : 3
         4 (moderately cool) [10- : 3
         5 (moderately warm) [12. : 3
         6 (warm) [15-17.5 degree : 2
         7 (very warm) [17.5-20 d : 2
         8 (extremely warm) [20-2 : 2
         ?........................ : ?
      3 (cool) [7.5-10 degrees] > t-an (mean annual temperature)
         1 (extremely cool) [0-5  : 4
         2 (very cool) [5-7.5 deg : 4
         3 (cool) [7.5-10 degrees : 3
         4 (moderately cool) [10- : 2
         5 (moderately warm) [12. : 2
         6 (warm) [15-17.5 degree : 2
         7 (very warm) [17.5-20 d : 2
         8 (extremely warm) [20-2 : 2
         ?........................ : ?
      4 (moderately cool) [10-12.5 degrees] > t-an (mean annual temperature)
         1 (extremely cool) [0-5  : 3
         2 (very cool) [5-7.5 deg : 3
         3 (cool) [7.5-10 degrees : 3
         4 (moderately cool) [10- : 2
         5 (moderately warm) [12. : 2
         6 (warm) [15-17.5 degree : 2
         7 (very warm) [17.5-20 d : 1
         8 (extremely warm) [20-2 : 2
         ?........................ : ?
      5 (moderately warm) [12. : =4
      6 (warm) [15-17.5 degree : =4
      7 (very warm) [17.5-20 d : =4
      8 (extremely warm) [20-2 : =2
      ?........................ : ?
   7 (very warm) [17.5-20 degrees C] > t-mc (mean monthly temperature of coldest
month)
      1 (extremely cool) [0-5  : 4
      2 (very cool) [5-7.5 degrees] > t-an (mean annual temperature)
         1 (extremely cool) [0-5  : 4
         2 (very cool) [5-7.5 deg . 4
         3 (cool) [7.5-10 degrees : 4
         4 (moderately cool) [10- : 3
```

```
Mgeta (Mgeta automated land evaluation)
DtId Type                              Where Used
-------------------------------------------------------------------------------
15   Severity Level                    SHLIRCF,t
(continued)
         5 (moderately warm) [12. : 3
         6 (warm) [15-17.5 degree : 2
         7 (very warm) [17.5-20 d : 2
         8 (extremely warm) [20-2 : 2
         ?........................ : ?
      3 (cool) [7.5-10 degrees] > t-an (mean annual temperature)
         1 (extremely cool) [0-5  : 3
         2 (very cool) [5-7.5 deg : 3
         3 (cool) [7.5-10 degrees : 3
         4 (moderately cool) [10- : 3
         5 (moderately warm) [12. : 2
         6 (warm) [15-17.5 degree : 2
         7 (very warm) [17.5-20 d : 2
         8 (extremely warm) [20-2 : 2
         ?........................ : ?
      4 (moderately cool) [10-12.5 degrees] > t-an (mean annual tempera
         1 (extremely cool) [0-5  : 3
         2 (very cool) [5-7.5 deg : 3
         3 (cool) [7.5-10 degrees : 3
         4 (moderately cool) [10- : 3
         5 (moderately warm) [12. : 2
         6 (warm) [15-17.5 degree : 2
         7 (very warm) [17.5-20 d : 2
         8 (extremely warm) [20-2 : 2
         ?........................ : ?
      5 (moderately warm) [12. : =4
      6 (warm) [15-17.5 degree : =4
      7 (very warm) [17.5-20 d : =4
      8 (extremely warm) [20-2 : =2
      ?........................ : ?
   8 (very very warm) [20-25 degrees C] > t-mc (mean monthly temperatur
est month)
      1 (extremely cool) [0-5  : 3
      2 (very cool) [5-7.5 degrees] > t-an (mean annual temperature)
         1 (extremely cool) [0-5  : 3
         2 (very cool) [5-7.5 deg : 3
         3 (cool) [7.5-10 degrees : 3
         4 (moderately cool) [10- : 3
         5 (moderately warm) [12. : 2
         6 (warm) [15-17.5 degree : 2
         7 (very warm) [17.5-20 d : 2
         8 (extremely warm) [20-2 : 1
         ?........................ : ?
      3 (cool) [7.5-10 degrees] > t-an (mean annual temperature)
         1 (extremely cool) [0-5  : 3
         2 (very cool) [5-7.5 deg : 3
         3 (cool) [7.5-10 degrees : 3
         4 (moderately cool) [10- : 2
         5 (moderately warm) [12. : 2
         6 (warm) [15-17.5 degree : 2
         7 (very warm) [17.5-20 d : 1
         8 (extremely warm) [20-2 : 1
         ?........................ : ?
      4 (moderately cool) [10-12.5 degrees] > t-an (mean annual tempera
         1 (extremely cool) [0-5  : 3
         2 (very cool) [5-7.5 deg : 3
         3 (cool) [7.5-10 degrees : 3
         4 (moderately cool) [10- : 3
         5 (moderately warm) [12. : 2
         6 (warm) [15-17.5 degree : 1
         7 (very warm) [17.5-20 d : 1
```

```
Mgeta (Mgeta automated land evaluation)                                  Decision Trees
DtId Type                                Where Used
-------------------------------------------------------------------------------------
15   Severity Level                      SHLIRCF,t
(continued)
        8 (extremely warm) [20-2 : 1
        ?......................... : ?
     5 (moderately warm) [12. : =4
     6 (warm) [15-17.5 degree : =4
     7 (very warm) [17.5-20 d : =4
     8 (extremely warm) [20-2 : =2
     ?......................... : ?
  9 (extremely warm) [25-3 : =8
  ?......................... : ?

16   Severity Level                      SHLIRCF,na
 > pH-prof (pH profile)
  1 (very strongly acid) [0-5 no dimension] > oc (organic carbon)
    1 (very low) [0-.6 %] > n (nitrogen content)
      1 (very low) [0-.1 %] > p (available phosphorus )
        1 (low) [0-7 mg P/kg] > k (potassium content)
          1 (very low) [0-.2 cmol( : 4 (very poor)
          2 (low) [.2-.4 cmol(+)/k : 4 (very poor)
          3 (medium) [.4-1.2 cmol( : 3 (poor)
          4 (high) [1.2-2 cmol(+)/ : 3 (poor)
          5 (very high) [2-10 cmol : 3 (poor)
          ?......................... : ?
        2 (medium) [7-20 mg P/kg] > k (potassium content)
          1 (very low) [0-.2 cmol( : 4 (very poor)
          2 (low) [.2-.4 cmol(+)/k : 3 (poor)
          3 (medium) [.4-1.2 cmol( : 3 (poor)
          4 (high) [1.2-2 cmol(+)/ : 3 (poor)
          5 (very high) [2-10 cmol : 3 (poor)
          ?......................... : ?
        3 (high) [20-100 mg P/kg : =2
        ?......................... : ?
      2 (low) [.1-.2 %] > p (available phosphorus )
        1 (low) [0-7 mg P/kg]... : 3 (poor)
        2 (medium) [7-20 mg P/kg : 3 (poor)
        3 (high) [20-100 mg P/kg : 2 (moderate)
        ?......................... : ?
      3 (medium) [.2-.5 %] > p (available phosphorus )
        1 (low) [0-7 mg P/kg] > k (potassium content)
          1 (very low) [0-.2 cmol( : 3 (poor)
          2 (low) [.2-.4 cmol(+)/k : 3 (poor)
          3 (medium) [.4-1.2 cmol( : 2 (moderate)
          4 (high) [1.2-2 cmol(+)/ : 2 (moderate)
          5 (very high) [2-10 cmol : 2 (moderate)
          ?......................... : ?
        2 (medium) [7-20 mg P/kg] > k (potassium content)
          1 (very low) [0-.2 cmol( : 3 (poor)
          2 (low) [.2-.4 cmol(+)/k : 2 (moderate)
          3 (medium) [.4-1.2 cmol( : 2 (moderate)
          4 (high) [1.2-2 cmol(+)/ : 2 (moderate)
          5 (very high) [2-10 cmol : 2 (moderate)
          ?......................... : ?
        3 (high) [20-100 mg P/kg : 2 (moderate)
        ?......................... : ?
      4 (high) [.5-10 %]..... : =3
      ?......................... : ?
    2 (low) [.6-1.25 %] > n (nitrogen content)
      1 (very low) [0-.1 %] > p (available phosphorus )
        1 (low) [0-7 mg P/kg] > k (potassium content)
          1 (very low) [0-.2 cmol( : 3 (poor)
          2 (low) [.2-.4 cmol(+)/k : 3 (poor)
```

```
Mgeta (Mgeta automated land evaluation)
DtId Type                                Where Used
-------------------------------------------------------------------------------------
16   Severity Level                      SHLIRCF,na
(continued)
        ?......................... : ?
      3 (medium) [1.25-2.5 %]. : =2
      4 (high) [2.5-3.5 %].... : =2
      5 (very high) [3.5-20 %] : =2
      ?......................... : ?
  2 (strongly acid) [5-5.5 : =1
  3 (moderately acid) [5.5-6 no dimension] > oc (organic carbon)
    1 (very low) [0-.6 %] > n (nitrogen content)
      1 (very low) [0-.1 %] > p (available phosphorus )
        1 (low) [0-7 mg P/kg] > k (potassium content)
          1 (very low) [0-.2 cmol( : 3 (poor)
          2 (low) [.2-.4 cmol(+)/k : 2 (moderate)
          3 (medium) [.4-1.2 cmol( : 2 (moderate)
          4 (high) [1.2-2 cmol(+)/ : 2 (moderate)
          5 (very high) [2-10 cmol : 2 (moderate)
          ?......................... : ?
        2 (medium) [7-20 mg P/kg] > k (potassium content)
          1 (very low) [0-.2 cmol( : 3 (poor)
          2 (low) [.2-.4 cmol(+)/k : 2 (moderate)
          3 (medium) [.4-1.2 cmol( : 2 (moderate)
          4 (high) [1.2-2 cmol(+)/ : 2 (moderate)
          5 (very high) [2-10 cmol : 2 (moderate)
          ?......................... : ?
        3 (high) [20-100 mg P/kg] > k (potassium content)
          1 (very low) [0-.2 cmol( : 3 (poor)
          2 (low) [.2-.4 cmol(+)/k : 2 (moderate)
          3 (medium) [.4-1.2 cmol( : 2 (moderate)
          4 (high) [1.2-2 cmol(+)/ : 2 (moderate)
          5 (very high) [2-10 cmol : 2 (moderate)
          ?......................... : ?
        ?......................... : ?
      2 (low) [.1-.2 %] > p (available phosphorus )
        1 (low) [0-7 mg P/kg] > k (potassium content)
          1 (very low) [0-.2 cmol( : 2 (moderate)
          2 (low) [.2-.4 cmol(+)/k : 2 (moderate)
          3 (medium) [.4-1.2 cmol( : 2 (moderate)
          4 (high) [1.2-2 cmol(+)/ : 2 (moderate)
          5 (very high) [2-10 cmol : 2 (moderate)
          ?......................... : ?
        2 (medium) [7-20 mg P/kg] > k (potassium content)
          1 (very low) [0-.2 cmol( : 2 (moderate)
          2 (low) [.2-.4 cmol(+)/k : 2 (moderate)
          3 (medium) [.4-1.2 cmol( : 2 (moderate)
          4 (high) [1.2-2 cmol(+)/ : 2 (moderate)
          5 (very high) [2-10 cmol : 2 (moderate)
          ?......................... : ?
        3 (high) [20-100 mg P/kg : 2 (moderate)
        ?......................... : ?
      3 (medium) [.2-.5 %] > p (available phosphorus )
        1 (low) [0-7 mg P/kg]... : 2 (moderate)
        2 (medium) [7-20 mg P/kg : 2 (moderate)
        3 (high) [20-100 mg P/kg : 1 (good)
        ?......................... : ?
      4 (high) [.5-10 %]..... : =3
      ?......................... : ?
    2 (low) [.6-1.25 %] > n (nitrogen content)
      1 (very low) [0-.1 %] > p (available phosphorus )
        1 (low) [0-7 mg P/kg] > k (potassium content)
          1 (very low) [0-.2 cmol( : 3 (poor)
          2 (low) [.2-.4 cmol(+)/k : 3 (moderate)
```

Mgeta (Mgeta automated land evaluation) Decision Trees

DtId Type Where Used

16 Severity Level SHLIRCF,na
(continued)

```
                3 (medium) [.4-1.2 cmol( : 2 (moderate)
                4 (high) [1.2-2 cmol(+)/ : 2 (moderate)
                5 (very high) [2-10 cmol : 2 (moderate)
                ?..................... : ?
             2 (medium) [7-20 mg P/kg] > k (potassium content)
                1 (very low) [0-.2 cmol( : 3 (poor)
                2 (low) [.2-.4 cmol(+)/k : 3 (poor)
                3 (medium) [.4-1.2 cmol( : 2 (moderate)
                4 (high) [1.2-2 cmol(+)/ : 2 (moderate)
                5 (very high) [2-10 cmol : 2 (moderate)
                ?..................... : ?
             3 (high) [20-100 mg P/kg : =2
             ?..................... : ?
          2 (low) [.1-.2 %] > p (available phosphorus )
             1 (low) [0-7 mg P/kg] > k (potassium content)
                1 (very low) [0-.2 cmol( : 2 (moderate)
                2 (low) [.2-.4 cmol(+)/k : 2 (moderate)
                3 (medium) [.4-1.2 cmol( : 2 (moderate)
                4 (high) [1.2-2 cmol(+)/ : 2 (moderate)
                5 (very high) [2-10 cmol : 2 (moderate)
                ?..................... : ?
             2 (medium) [7-20 mg P/kg : 2 (moderate)
             3 (high) [20-100 mg P/kg : 2 (moderate)
             ?..................... : ?
          3 (medium) [.2-.5 %] > p (available phosphorus )
             1 (low) [0-7 mg P/kg] > k (potassium content)
                1 (very low) [0-.2 cmol( : 2 (moderate)
                2 (low) [.2-.4 cmol(+)/k : 2 (moderate)
                3 (medium) [.4-1.2 cmol( : 2 (moderate)
                4 (high) [1.2-2 cmol(+)/ : 2 (moderate)
                5 (very high) [2-10 cmol : 2 (moderate)
                ?..................... : ?
             2 (medium) [7-20 mg P/kg : 2 (moderate)
             3 (high) [20-100 mg P/kg] > k (potassium content)
                1 (very low) [0-.2 cmol( : 2 (moderate)
                2 (low) [.2-.4 cmol(+)/k : 2 (moderate)
                3 (medium) [.4-1.2 cmol( : 2 (moderate)
                4 (high) [1.2-2 cmol(+)/ : 2 (moderate)
                5 (very high) [2-10 cmol : 1 (good)
                ?..................... : ?
             ?..................... : ?
          4 (high) [.5-10 %]..... : =3
          ?..................... : ?
       3 (medium) [1.25-2.5 %]. : =2
       4 (high) [2.5-3.5 %].... : =2
       5 (very high) [3.5-20 %] : =2
       ?..................... : ?
    4 (slightly acid) [6-6.5 : =3
    5 (neutral) [6.5-7.5 no  : =3
    6 (alkaline) [7.5-9 no d : =2
    ?..................... : ?
```

Mgeta (Mgeta automated land evaluation)

DtId Type Where Used

17 Severity Level SHLIRCF,m

```
 > p-an (mean annual precipitation)
   1 (very low) [0-750 mm]. : 4
   2 (low) [750-1000 mm] > l-d (length of dry season)
      1 (very short) [0-15 day : 2
      2 (short) [15-30 days].. : 2
      3 (medium) [30-120 days] : 2
      4 (long) [120-150 days]. : 2
      5 (very long) [150-180 d : 3
      6 (extremely long) [180- : 3
      ?..................... : ?
   3 (moderate) [1000-1500 mm] > l-d (length of dry season)
      1 (very short) [0-15 day : 2
      2 (short) [15-30 days].. : 2
      3 (medium) [30-120 days] : 1
      4 (long) [120-150 days]. : 2
      5 (very long) [150-180 d : 2
      6 (extremely long) [180- : 3
      ?..................... : ?
   4 (high) [1500-2000 mm] > l-d (length of dry season)
      1 (very short) [0-15 day : 2
      2 (short) [15-30 days].. : 1
      3 (medium) [30-120 days] : 1
      4 (long) [120-150 days]. : 1
      5 (very long) [150-180 d : 2
      6 (extremely long) [180- : 3
      ?..................... : ?
   5 (very high) [2000-2500 mm] > l-d (length of dry season)
      1 (very short) [0-15 day : 2
      2 (short) [15-30 days].. : 2
      3 (medium) [30-120 days] : 2
      4 (long) [120-150 days]. : 2
      5 (very long) [150-180 d : 3
      6 (extremely long) [180- : 3
      ?..................... : ?
   6 (extremely high) [2500 : 4
   ?..................... : ?
```

Mgeta (Mgeta automated land evaluation) Decision Trees

```
DtId Type                                   Where Used
-------------------------------------------------------------------------------
18   Severity Level                         SHLIRCF,nr
 > cec-c (cation exchange capacity of clay)
   1 (low) [0-5 cmol(+)/kg] > teb (total exchangeable bases)
      1 (very low) [0-1.6 cmol : 4
      2 (low) [1.6-2 cmol(+)/kg] > bs (base saturation)
         1 (very low) [0-20 %]... : 4
         2 (low) [20-40 %]..... : 3
         3 (medium) [40-60 %].... : 2
         4 (high) [60-80 %]..... : 2
         5 (very high) [80-100 %] : 2
         ?..................... : ?
      3 (medium) [2-2.8 cmol(+ : =2
      4 (high) [2.8-3.5 cmol(+ : 2
      5 (very high) [3.5-30 cm : 2
      ?..................... : ?
   2 (medium) [5-15 cmol(+)/kg] > teb (total exchangeable bases)
      1 (very low) [0-1.6 cmol : 3
      2 (low) [1.6-2 cmol(+)/k : 2
      3 (medium) [2-2.8 cmol(+ : 2
      4 (high) [2.8-3.5 cmol(+ : 2
      5 (very high) [3.5-30 cm : 2
      ?..................... : ?
   3 (high) [15-450 cmol(+)/kg] > teb (total exchangeable bases)
      1 (very low) [0-1.6 cmol : 3
      2 (low) [1.6-2 cmol(+)/k : 2
      3 (medium) [2-2.8 cmol(+ : 2
      4 (high) [2.8-3.5 cmol(+ : 2
      5 (very high) [3.5-30 cm : 1
      ?..................... : ?
   ?...................... : ?

19   Severity Level                         SHLIRCF,o
 > dr (soil drainage class)
   1 (very poorly drained). : 4
   2 (poorly drained)..... : 4
   3 (imperfectly drained). : 3
   4 (moderately well drain : 2
   5 (well drained)....... : 1
   6 (somewhat excessively  : 1
   7 (excessively drained). : 1
   ?...................... : ?
```

Mgeta (Mgeta automated land evaluation)

```
DtId Type                                   Where Used
-------------------------------------------------------------------------------
20   Severity Level                         SHLIRCF,r
 > sd (effective soil depth)
   1 (very shallow) [0-20 c : 4
   2 (shallow) [20-40 cm].. : 4
   3.1 (moderately shallow) [40-60 cm] > pt (profile soil textur
      1 (sand)............... : 4
      2 (loamy sand)......... : 3
      3 (silty clay)......... : 3
      4 (clay)............... : 3
      5 (sandy clay)......... : 3
      6 (sandy loam)......... : 3
      7 (loam)............... : 3
      8 (sandy clay loam)..... : 3
      9 (clay loam).......... : 3
      10 (silt clay loam)..... : 3
      11 (silty loam)........ : 3
      12 (silt).............. : 4
      ?...................... : ?
   3 (moderately deep) [60-80 cm] > pt (profile soil texture)
      1 (sand)............... : 4
      2 (loamy sand)......... : 3
      3 (silty clay)......... : 3
      4 (clay)............... : 2
      5 (sandy clay)......... : 2
      6 (sandy loam)......... : 2
      7 (loam)............... : 2
      8 (sandy clay loam)..... : 2
      9 (clay loam).......... : 2
      10 (silt clay loam)..... : 2
      11 (silty loam)........ : 2
      12 (silt).............. : 3
      ?...................... : ?
   4 (deep) [80-120 cm] > pt (profile soil texture)
      1 (sand)............... : 3
      2 (loamy sand)......... : 2
      3 (silty clay)......... : 2
      4 (clay)............... : 2
      5 (sandy clay)......... : 2
      6 (sandy loam)......... : 2
      7 (loam)............... : 2
      8 (sandy clay loam)..... : 2
      9 (clay loam).......... : 2
      10 (silt clay loam)..... : 2
      11 (silty loam)........ : 2
      12 (silt).............. : 3
      ?...................... : ?
   5 (very deep) [120-1000 cm] > pt (profile soil texture)
      1 (sand)............... : 3
      2 (loamy sand)......... : 2
      3 (silty clay)......... : 2
      4 (clay)............... : 1
      5 (sandy clay)......... : 1
      6 (sandy loam)......... : 2
      7 (loam)............... : 1
      8 (sandy clay loam)..... : 1
      9 (clay loam).......... : 1
      10 (silt clay loam)..... : 1
      11 (silty loam)........ : 2
      12 (silt).............. : 3
      ?...................... : ?
   ?...................... : ?
```

```
Mgeta (Mgeta automated land evaluation)                          Decision Trees
DtId Type                                Where Used
-------------------------------------------------------------------------------
20   Severity Level                      SHLIRCF,r
(continued)
21   Severity Level                      SHLIRCF,e
 > sl (dominant slope)
   1 (flat to nearly level) : 1 (good)
   2 (very gently sloping)  : 1 (good)
   3 (gently sloping) [2-5  : 1 (good)
   4 (sloping) [5-15 %].... : 1 (good)
   5 (moderately sloping) [ : 1 (good)
   6 (steep sloping) [30-60 %] > st (surface soil texture)
      1 (sand)............... : 1 (good)
      2 (loamy sand)......... : 1 (good)
      3 (silty clay)......... : 2 (moderate)
      4 (clay)............... : 2 (moderate)
      5 (sandy clay)......... : 2 (moderate)
      6 (sandy loam)......... : 1 (good)
      7 (loam)............... : 1 (good)
      8 (sandy clay loam)..... : 1 (good)
      9 (clay loam).......... : 2 (moderate)
      10 (silty clay loam).... : 2 (moderate)
      11 (silty loam)........ : 2 (moderate)
      12 (silt).............. : 3 (poor)
      ?...................... : ?
   7 (moderately steep) [60-80 %] > st (surface soil texture)
      1 (sand)............... : 2 (moderate)
      2 (loamy sand)......... : 2 (moderate)
      3 (silty clay)......... : 3 (poor)
      4 (clay)............... : 2 (moderate)
      5 (sandy clay)......... : 2 (moderate)
      6 (sandy loam)......... : 2 (moderate)
      7 (loam)............... : 2 (moderate)
      8 (sandy clay loam)..... : 2 (moderate)
      9 (clay loam).......... : 3 (poor)
      10 (silty clay loam).... : 3 (poor)
      11 (silty loam)........ : 3 (poor)
      12 (silt).............. : 3 (poor)
      ?...................... : ?
   8 (very steep) [80-100 %] > st (surface soil texture)
      1 (sand)............... : 3 (poor)
      2 (loamy sand)......... : 3 (poor)
      3 (silty clay)......... : 4 (very poor)
      4 (clay)............... : 4 (very poor)
      5 (sandy clay)......... : 3 (poor)
      6 (sandy loam)......... : 3 (poor)
      7 (loam)............... : 3 (poor)
      8 (sandy clay loam)..... : 3 (poor)
      9 (clay loam).......... : 4 (very poor)
      10 (silty clay loam).... : 4 (very poor)
      11 (silty loam)........ : 3 (poor)
      12 (silt).............. : 4 (very poor)
      ?...................... : ?
   ?...................... : ?
```

Appendix 12. Guide to general evaluation of some soil chemical and physical properties [Compiled from Baize (1993), ILACO (1991) London (1991) and Msanya *et al.* (1996)].

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
Organic carbon %	< 0.60	0.60-1.25	1.26-2.50	2.51-3.50	> 3.5
Total N %	< 0.10	0.10-0.20	0.21-0.50	> 0.50	

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

2. Soil reaction

Soil reaction (pH H_2O) is classified as follows

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

3. Available phosphorus

mg p/kg soil	Low	Medium	High
Available p (Bray-Kurtz 1)	< 7	7 - 20	> 20
Available p (Olsen)	< 5	5 - 10	> 10

Available phosphorus is determined by the Bray-Kurtz 1 method if the pH H_2O of the soil is less than 7.0. In soils with a pH H_2O of more than 7.0 the Olsen method is used.

4. Cation exchange capacity (CEC)

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

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

5. Exchangeable calcium

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

6. Exchangeable magnesium

cmol (+)/kg soil	Very low	Low	Medium	High	Very high
Mg (clayey soils)	< 0.3	0.3 - 1.0	1.1 - 3.0	3 1 - 6.0	> 6.0
Mg (loamy soils)	< 0.25	0.25 - 0.75	0.75 - 2.0	2.1 - 4.0	> 4.1
Mg (sandy soils)	< 0.2	0.2 - 0.5	0.5 - 1.0	1.1 - 2.0	> 2.0

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

7. Exchangeable potassium

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

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

8. Exchangeable sodium

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

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

9. Soil sodicity

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

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

10. Basic infiltration rate (IR)

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

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

11. Available water capacity (AWC)

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

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

12. Aluminium saturation

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

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