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LAND SUITABILITY EVALUATION FOR THE PRODUCTION OF THE MAJOR CROPS IN THE SOUTHWESTERN PART OF THE ULUGURU MOUNTAINS, MOROGORO RURAL DISTRICT, TANZANIA

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PREFACE AND ACKNOWLEDGEMENTS

This work is a semi-detailed explanatory report for the soil map at a scale of 1:50,000 of southwestern Uluguru Mountains in Morogoro Rural District, Tanzania. It contains information that can be used for sound land use planning activities in the area, particularly for the production of the major crops (cabbage, potato and arabica coffee). The report will be a useful tool for use by the Researchers, District Agricultural & Livestock Development Officer (DALDO) and District Extension Officers in delivering their advisory services to farmers. Detailed description of soil properties is given in both report and map (in form of mapping units), which clearly identify the constraints and potentials of the study area. Ample information on economic suitability of various land use types in the area is also provided as a guidance to land use planning.

The authors wish to thank all those who in one way or another contributed to the successful completion of this work. Many thanks are due to the Norwegian Agency for Development Co-operation (NORAD) for providing funds to carry out this study through the SUA-NORAD TAN 091 project on Soils and Land Resources of Morogoro Rural and Urban Districts. Sincere thanks are also due to Dr. B.P. Mbilinyi of the Department of Agricultural Engineering and Land Planning, Sokoine University of Agriculture (SUA), for his technical assistance in Remote Sensing and Geographical Information Systems.

Prof. B.M. Msanya

Project leader May, 2001

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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
TEB = Total exchangeable basis
AWC = Available water capacity
CEC = Cation exchange capacity
ESP = Exchangeable sodium percent
MGP = (1-26)-Mgeta profile (no. 1 - 26)
ALES = Automated Land Evaluation System
BD = Bulk Density
BS = Base saturation
C:N = Carbon to Nitrogen ratio
ETo = Potential evapotranspiration
GIS = Geographical Information Systems
GM = Grss margin
LMU = Land mapping unit
LQ = Land quality
LUR = Land use rquirement
LUT = Land utilisation type
PRA = Participatory Rural Appraisal
URT = United Republic of Tanzania
SISTAN = Soil Informatio System for Tanzania
WRB = World Reference Base

EXECUTIVE SUMMARY

Land evaluation study was conducted on the southwestern slopes of the Uluguru Mountains in 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. The study area is located between latitudes 7°00′00″ and 7°11′23.5″S and longitudes 37°30′00″ and 37°38′36.6″E covering the villages of Kibaoni, Langali, Bunduki, Bumu, Kikeo, Luale, Mwarazi, Nyandira, Kibuko and Tchenzema. The areal extent is 419.64 km^2 (41,964 ha) with an average elevation ranging between 900 - 2700 m a.s.l.

The mean annual rainfall in the study area ranges from 1065 mm to 2450 mm. The rainfall distribution pattern is monomodal with the rainy season starting from December to May. The peak rainfall occurs in April in most places of the study area. The high altitude areas receive more rainfall than the lower areas. In some areas rainfall distribution tends more to be bimodal with two peaks occurring in October and in April. There is considerable temperature variability in the study area with the mean monthly temperature ranging from 17.4°C (July) to 22.4°C (December). At high elevations temperatures are much cooler. The shortest reference length of growing period is 180 days while the longest is 270 days.

The geology of the study area consists of a mixture of banded pyroxene granulites with occasional biotite-rich bands, foliated mica gneisses, hornblende gneisses and granulites and some iron-rich meta-anorthositic rocks, all belonging to the Usagaran system. In some places alluvial deposits and kaolinitic clays of Neogene age are found.

The study area consists of strongly dissected mountains with very steep plateau and ridge slopes of about 30-60% and narrow valleys and incisions. Lukwangule plateau is the highest peak in the study area reaching an altitude of 2,623 m a.s.l. The Lukwangule plateau is only slightly dissected and the surface forms quite a mature relief.

Two distinct drainage patterns exist in the study area. A sub-radial pattern which is related to the horse-shoe of high mountains from Mkumbaku through Lukwangule and Magari to Lupanga, which is currently represented by some of the larger rivers such as Mngazi, Mbakana and, in part, the Mgeta. A rectilinear pattern is exhibited where secondary streams and many main rivers show adjustment to geological structure and rock type. The pattern of the minor rivers follows the geological structure more closely and has resulted in river capture, reversed drainage and wind gaps. 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.

In the study area there are three major types of forests namely, mountain rain forest, tropical rainforest and miombo woodland. The mountain rain forest occurs on high mountain slopes, and has been declared forest reserve. Other areas have been afforested with conifers and eucalypts. The third major type of vegetation is the miombo woodland, whose typical species are *Brachystegia spp.* (miombo), *Isoberlina spp*. and *Acacia nigrescens*. Other vegetation types include ferns, guava, cypress, black wattle (*Acacia mearnsii*) and thatch grass (*Hyperrhenia rufa*). On the summit of Lukwangule plateau there is grassland whose vegetation is mainly composed of coarse grasses with few trees and other plants of temperate climate.

The current major land use types include smallholder rainfed and irrigated farming. Ridge and bench terrace cultivation of maize, millet and beans as staple foods is a common practice. 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.

Four major landform units namely, strongly dissected plateau, mountain ridges, piedmont slopes and v-shaped valley sides and incisions were identified in the study area. The soils associated with these landform units 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. According to the FAO-World Reference Base, seven major soil types were identified and classified. The soils of plateau and mountain ridge summits classify as Umbrisols, Cambisols, Leptosols and Acrisols; while those of the the slopes and piedmonts classify as Regosols, Phaeozems and Luvisols. In the river valley sides, river floors and incisions the soils are dominantly Fluvisols and Phaeozems. Generally the soils of the study area have poor soil fertility status. The topsoil reaction ranges from strongly to slightly acid (pH 5.1-6.5). Organic carbon and phosphorus contents are very low while nitrogen content varies from very low to low. The values of CEC are medium. Base saturation levels range from very low to medium in major part of the study area.

Most of the studied land mapping units (about 70% of the study area) are both physically and economically moderately suitable for all three studied land utilisation types (LUTs). The remaining 30% is either marginally or not suitable for the production of the LUTs. The most limiting factors for the production of the three studied LUTs are rooting condition, poor soil fertility and soil erosion hazards. Although most of the lands in the southwestern Uluguru Mountains have moderate potential and are economically moderately suitable for the production of cabbage, round potato and arabica coffee, production of round potato is economically more profitable than cabbage and coffee. Basing on the current farmers' observed and predicted yields, possibilities for obtaining higher yields under high input and improved management levels are high. This forms a strong base infavour of high investment in the area given the potential marketing possibilities in the expanding Morogoro municipality and Dar es Salaam city.

1.0 INTRODUCTION

Mountainous areas in Tanzania including Uluguru Mountains constitute an important agricultural land (Mwango, 2000). These areas are dependable sources of water and production of most crops including vegetables, potato and coffee. Due to favourable climatic conditions these areas and Uluguru Mountains in particular support large population densities (about 250 - 300 persons per km^2). Excessive deforestation, improper land management and cultivation of areas which are too steep for agriculture, are threatening the fragile ecosystem of these lands (Mwango, 2000). 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 crops such as maize, potato, beans, fruits, vegetables, and coffee, land productivity has remained low (Mwango, 2000). Few attempts, including the Uluguru Land Use Scheme (ULUS), Afforestation Schemes and Soil Erosion Control, have been initiated to solve the problem of low land productivity in these areas (Van Donge, 1992).

The need to increase production in mountainous areas is a prerequisite in order to supply food to the growing population both in rural and urban areas (United Republic of Tanzania (URT), 1992). Increasing production can be achieved to a great extent by formulation and implementation of proper land use planning policy (Temple, 1972; Kileo, 2000). However, formulation of land use policy requires knowledge on the potentials and constraints of the various agro-ecological zones for production of crops and livestock (Temple and Rapp, 1972). Such knowledge will lead to systematic land use planning to improve socio-economic conditions of the population as well as environmental conservation for future generation (Moberg *et al.,* 1982). Inappropriate land use leads to inefficient exploitation of natural resources, destruction of the land resources, poverty and social problems (Rossiter, 1996).

Land evaluation based on human, economic and physical resources is an important tool for attaining 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 (Msanya, 1980; Rossiter, 1996). To date only limited studies have been done in the mountainous areas of Tanzania and Uluguru Mountains in particular to establish proper land use plans based on principles of land evaluation (National Soil Service (NSS), 1986). Moreover, land evaluation studies that were carried out in Tanzania using traditional techniques cannot cope with the user demands and are time consuming and have limited versatility (Kimaro, 1989; Kimaro and Kips, 1991; Kimaro and Msanya, 1999; and Mwango, 2000). 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 programme, which is versatile and capable of handling and analysing large amounts of land resource data with increased efficiency in identification of areas with potential for different uses

(Kimaro, 1989; Kimaro and Kips, 1991). Introduction of ALES to rate lands both in physical and economic terms for a set of land use types in Tanzania is inevitable to allow quick generation of data and decision making on land use policies and timely generation of information to potential investors. The study was aimed at collecting information that would enable land users and investors to make proper decisions on land use planning in the Uluguru Mountains so as to meet the increasing demand for food and cash income for the rapidly growing population. The findings generated from the study could also be used in other areas with similar environmental conditions to provide firm base for future research and assessment of land potential and constraints.

In the current study, Automated Land Evaluation System (ALES) was applied to carry out land suitability assessment for three major crops (cabbage, potatoes and coffee) in the southwestern part of the Uluguru Mountains. Specifically the study addressed the following objectives:

i. To identify soils and landform characteristics of the study area.
ii. To characterise soils of the study area in terms of their physical and chemical properties.
iii. To classify the 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 production of cabbage, round potatoes and arabica coffee.

2.0 MATERIALS AND METHODS

2.1 Pre-field work activities

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

(1) The Geological map of the Uluguru Mountains: (Quarter degree sheet 201) at the scale of 125,000. *Geological survey of Tanganyika 1961. Geological Survey Department, Dodoma, Tanzania*.
(2) Topographic map of Mgeta. Sheet 201/1 at the scale of 1: 50,000. *Ministry of Lands, 1970. Survey and Mapping Division, Dar es Salaam, Tanzania*.
(3) Aerial photographs: Nos 143, 144, 145, 146, 149, 150, 151, 152, 153, 154 and 155 of 1978 at the scale of 1:67,000.
(4) Climatological data: Rainfall data for Tchenzema (1949-1983), Bunduki (1907-1990) and Mizungu station (1951-1986). Temperature of the study area was extrapolated using temperature data from the Morogoro Meteorological Station
(5) Reference crop evapotranspiration ET_o mm/day was calculated using the temperature method based on the Blaney-Criddle equation (FAO, 1991) as follows: $ET_o = p\ (0.46\ T + 8)$, 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
(6) The length of the growing period was calculated according to FAO (1984) methodology based on mean monthly rainfall and potential evapotranspiration (ET_o)
(7) Review of previous works and other relevant literature: Temple, 1972; Temple and Rapp, 1972; Kisanga, 1992 and Mwango, 2000.

In preparation for the mapping of soils and landform characteristics in the field, stereoscopic examination of available aerial photographs scale (1: 67,000) was carried out in conjunction with the study of topographic map at a scale of 1:50,000 and geological map at a scale of 1:125,000. The elements landform/relief, drainage patterns, vegetation cover, land use and drainage conditions were considered as key interpretation attributes for mapping the lands of the southwestern Uluguru Mountains. Finally a physiographic interpretation map at a scale of 1:67,000 with a legend describing the major land units of the area was compiled. The land units established during this phase were then used as a base for the field survey and mapping.

Semi-structured questionnaires were prepared for gathering data and information on land use and socio-economics of the study area. Key attributes used for preparation of the questionnaire were: production packages, farming systems, capital and labour intensity, level of technical know-how, observed yields and prices, land tenure and farm size.

2.2 Field work activities

Systematic free survey at semi detailed scale (1:50,000) was carried out in the field to establish patterns of soils and other terrain characteristics such as landform, parent material, vegetation and land use (Dent and Young 1981). Using the base map, transects and sites for observation and sampling were selected through reconnaissance survey of the whole study area. At each observation site, data on soil morphological characteristics, landform, elevation, slope gradient, parent material, lithology, vegetation and land use were studied. Observations were done at an intensity of 8 observations per km^2 following procedures outlined by Dent and Young (1981). In each transect, soils were described using soil minipits to a depth of 50 cm and augering to 120 cm or to limiting layer. Correlation of the soil auger observations with landforms and parent materials enabled soils which are similar in characteristics and in arrangements of soil horizons to be singled out and mapped. In this way twelve land mapping units were identified and confirmed on the photo interpretation base map.

Based on the information obtained from field observations for each delineated land mapping unit, representative soil profile pits were identified. Global Positioning System (model GARMIN 12XL) was used to determine the geographical locations of the sites. Soil profile pits were dug to a depth of 2 m or to a limiting layer. A total of twenty six fully geo-referenced soil profile pits were studied and described according to FAO Guidelines for Soil Profile description (FAO, 1990; 1998). Moist and dry soil colours were described using Munsell Soil Colour Charts (Munsell Colour Company, 1992).

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

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 agro-economic suitability evaluation. Such data include: yields, prices, labour, size and status of the farm and levels of management, material inputs, cultural practices, marketing facilities. Information related to population, extension services and social organisations were also gathered. Thirty representative farmers and extension officers were interviewed during this exercise.

2.3. Post field work activities

2.3.1. 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.

2.3.2. Data processing and soil classification

The field and laboratory analytical data were entered into the digital soil data base management system SISTAN (Magoggo, 1991) and processed using Microsoft Word programme (Appendix 1). Other softwares used for data processing include Microsoft Excel and Freelance. 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).

2.3.3 Preparation of the soil map and legend

The soil map polygons were delineated on the basis of the following hierarchy of elements: geology, landforms and relative position in the landscape, slope classes and soil properties. The analogue map compiled from aerial photo interpretation and during field work was digitised and analysed using ARC/INFO and ARC/VIEW-GIS softwares to produce the final physiographic soil map with a legend elaborating the mapping units at the scale of 1:50,000 (Back cover). The map legend is also given in Table 4.

2.4 Land evaluation

The land evaluation method applied in this study basically follows the procedures laid down in the FAO Framework for Land Evaluation (FAO, 1976). Firstly the land utilization types (LUTs) were described. Data on land resources and socio-economics were coded using land characteristics specification dictionary into a digital dbase file. This step was followed by the comparison of the optimal environmental requirements of the LUTs with the actual conditions of the land; a process refered to as matching. The matching process in this study was done using the Automated Land Evaluation System (ALES) programme (Rossiter and Van Wambeke, 1989; 1994). The tracts of

the land being used for suitability assessment in this study are land mapping units of the soil map (Back cover).

2.4.1 Description of the land utilisation types (LUTs)

Land utilisation types in the study area were selected and described on the basis of field observations on farming systems, produce (varieties grown), labour input, farm size, land tenure, yields and prices of the produce as obtained by farmers. Information on land utilisation types was also used to generate data for screening by ALES.

2.4.2 Rating of land use requirements (LURs)

Land suitability in this study was assessed on the basis of those land use requirements (LURs) that were considered diagnostic for the identified LUTs. In the study area the diagnostic LURs taken into consideration are: moisture availability, nutrient availability, nutrient retention capacity, erosion hazard, temperature regime and tuber expansion and harvesting. LURs are composed of certain land characteristics (LCs). For example the LUR "Nutrient retention capacity" is composed of the LCs "apparent CEC, sum of basic cations and percentage base saturation".

Using land characteristics specifications and land use requirements, the expert models in the form of decision trees for each specific land utilisation type were constructed in ALES programme. These are structured representations of the reasoning processes (expert knowledge system) needed to reach decisions. Class limit sets in the decision trees for the selected LUTs were mainly based on literature sources and information obtained from PRA and field observations. Rating of the LURs was done using severity levels as follows: (1) no limitation, (2) moderate limitation, (3) severe limitation and (4) very severe limitation.

2.5 Land suitability classification

Land suitability classification takes into account a sustainable use of the lands basing on the environmental resources (physical suitability) and socio-economic factors (economic suitability) (FAO, 1976, Kimaro and Kips, 1991, Rossiter, 1995, 1996).

2.5.1 Physical suitability classification

Physical suitability ratings of the mapping units were determined using decision trees severity levels constructed in ALES computer programme. The rating followed the Liebig's 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 attainable 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.

2.5.2 Economic suitability classification

After the physical suitability classification, ALES programme was instructed to compute the economic suitability evaluation. In this study 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 used in this study were the gross margins. The same factors which were used to set class limits for the physical suitability evaluation were also used in economic suitability evaluation. ALES requires the evaluator to set the economic suitability class limits. These class limits are gross margins based on the maximum attainable yields.

3.0 RESULTS AND DISCUSSION

3.1. Physical environment

3.1.1. Location

The study was conducted on the southwestern slopes of the Uluguru Mountains in Morogoro Rural District. The approximate geographical co-ordinates are between latitudes 7°00′ and 7°11′23.5″S and longitudes 37°30′ and 37°38′36.6″E covering the villages of Kibaoni, Langali, Bunduki, Bumu, Kikeo, Luale, Mwarazi, Nyandira, Kibuko and Tchenzema. The areal extent is about 419.64 km^2 (41,964 ha) with an average elevation ranging between 900 - 2700 m a.s.l.

3.1.2. Climate

Rainfall

The mean annual rainfall in the study area ranges from 1065 mm at Mizungu Mgeta to 2450 mm at Tchenzema (Table 1). 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 high altitude areas receive more rainfall than the lower areas. The rainfall distribution at Bunduki tends more to bimodal pattern with two peaks occurring in October and in April (Mwango, 2000).

Temperature

There is considerable temperature variability in the study area with the mean monthly temperature ranging from 17.4°C (July) to 22.4°C (December). At Lukwangule plateau temperatures are much cooler.

Length of growing period (LGP)

The shortest reference LGP is 180 days while the longest is 270 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 (ET_o) plus the period required to evapotranspire an assumed amount of moisture (FAO, 1993, 1996).

Table 1. Climatic data of selected meteorological stations in the study area

Tchenzema station (Altitude 1670 m. a s l; 7^0 7′S & 37^0 36′E; from 1946 to 1983)													
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Rainfall (mean) (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 (^{o}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 (^{o}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 (^{o}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 (^{o}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 (^{o}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 (^{o}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
ET_o	135	135	134	130	124	117	116	119	124	128	132	136	
1/2 ET_o	68	68	67	65	62	58	58	60	62	64	66	68	
LGP	+	+	+	+	+					+	+	+	
Bunduki station (Altitude 1281 m. a s l; 7^0 2′S & 37^0 37′E; from 1907 to 1990)													
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Rainfall mean (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 (^{o}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 (^{o}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 (^{o}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 (^{o}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 (^{o}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 (^{o}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
ET_o	144	144	143	139	133	127	125	128	132	138	142	145	
1/2 ET_o	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	
Rainfall (mean) (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 (^{o}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 (^{o}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 (^{o}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 (^{o}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 (^{o}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 (^{o}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
ET_o	149	149	148	144	138	131	128	133	136	142	146	149	
1/2 ET_o	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.

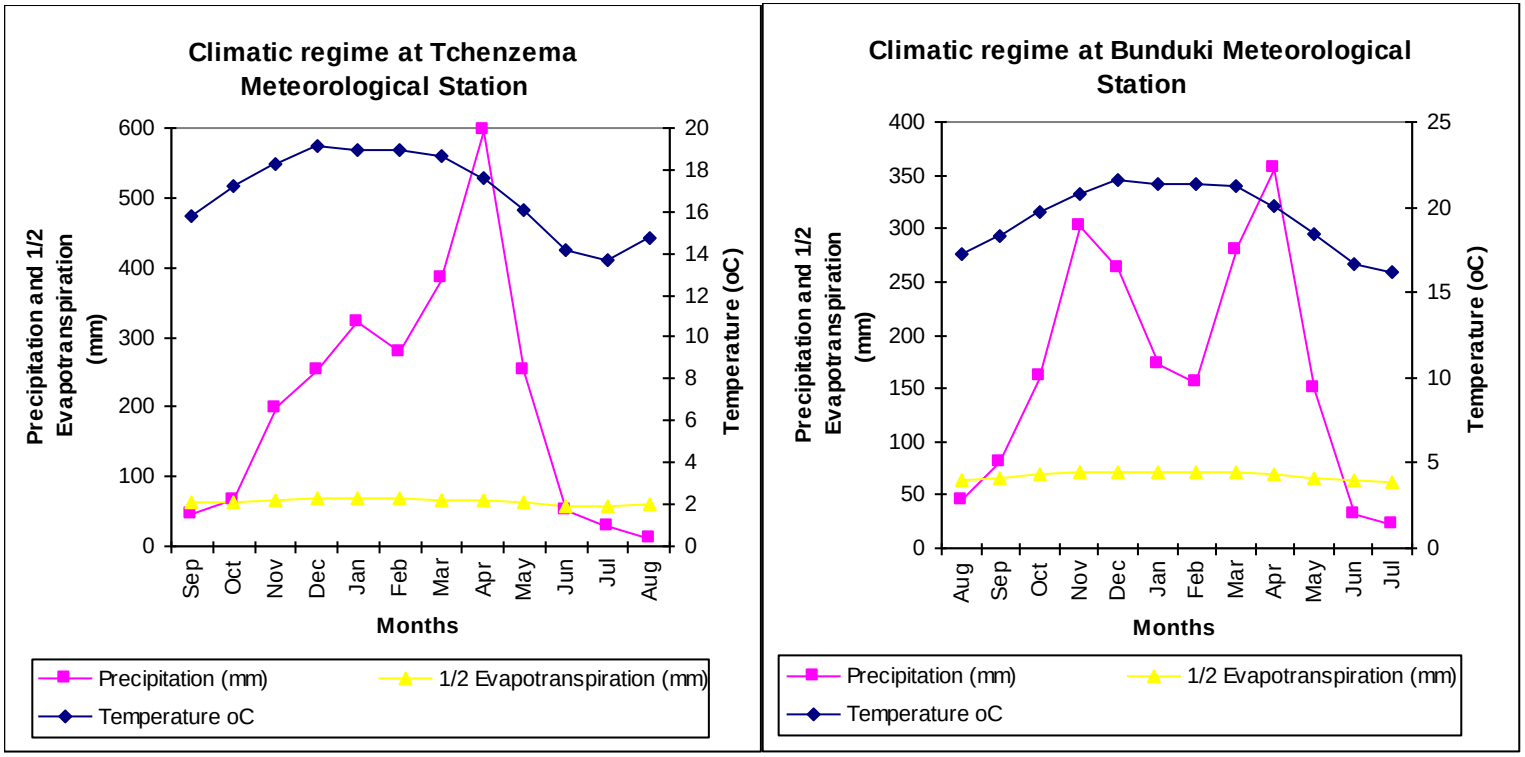

Figure 1. Climatic regimes at Tchenzema and Bunduki Meteorological Stations

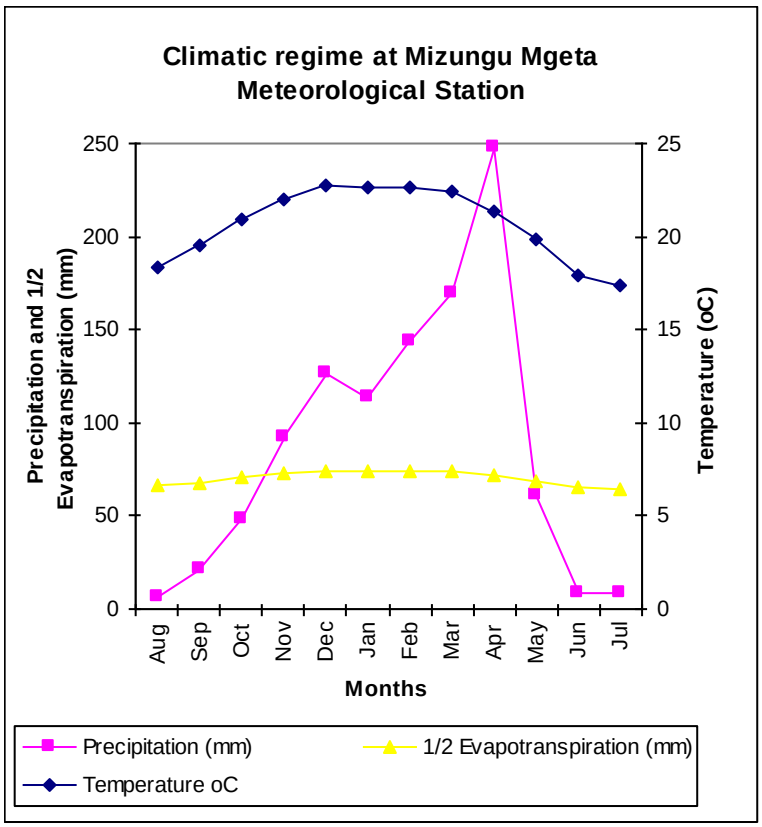

Figure 2. Climatic regimes at Mizungu Mgeta Meteorological Station

3.1.3. Geology, landforms and hydrology

Geology

The geology of the study area consists of a mixture of banded pyroxene granulites with occasional biotite-rich bands, foliated mica gneisses, hornblende gneisses and granulites and some iron-rich meta-anorthositic rocks, all belonging to the Usagaran system. In some places alluvial deposits and kaolinitic clays of Neogene age are found (Wright, 1959; Sampson and Wright, 1964).

Landforms

The study area consists of strongly dissected mountains consisting of very steep plateau and ridge slopes of about 30-60% and narrow valleys and incisions (Kimaro, 1997; Mwango, 2000). Lukwangule plateau is the highest peak in the study area reaching a height of 2,623 m a.s.l. The Lukwangule plateau is only slightly dissected and the surface forms quite a mature relief (Sampson and Wright, 1964).

Hydrology

Two distinct drainage-patterns exist in the study area. A sub-radial pattern which is related to the horse-shoe of high mountains from Mkumbaku through Lukwangule and Magari to Lupanga, which is corrently represented by some of the larger rivers

such as Mngazi, Mbakana and in part, the Mgeta. A rectilinear pattern is exhibited where secondary streams and many main rivers show adjustment to geological structure and rock type. The 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.

3.1.4. Vegetation and land use

Vegetation

In the study area there are three major types of forests namely, mountain rain forest, tropical rainforest and miombo woodland. The mountain rain forest occurs on high mountain slopes, and has been declared forest reserve. The areas around Bunduki, Kibuko, Tchenzema and Chigarafumi have been afforested with conifers and eucalypts. 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 include ferns, guava, Cypress, 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. The western foothills of the Uluguru Mountains is a lightly wooded country with very little open grassland. In some places opening up of land for cultivation has left the hill-slopes open without trees and with few grass vegetation.

Land use

The current major land use types include smallholder rainfed and irrigated farming. Ridge and bench terrace cultivation of maize, millet and beans as staple foods is a common practice. 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 common in some areas. Much greater area is devoted to cash crops production for sale in Morogoro municipality and Dar-es-Salaam city (Sampson and Wright, 1964; Kisanga, 1992; Mwango, 2000).

3.1.5. Major soils

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. Detailed description of soils is given in the section on mapping units description.

3.2 Mapping units description

The description of each land-mapping unit was done taking into consideration landform, parent materials, vegetation cover, and soil morphological, physical and

chemical properties. Some soil profiles representing the mapping units are presented in Appendix 1. An accompanying soil map with descriptive legend is presented in Back cover. The summary of the mapping units description is given in Table 2 while some soil morphological and physical properties are presented in Table 3. Chemical properties of the studied soils are summarised in Table 4 Figure 3 gives percentage particle size distribution with soil depth of some selected soils in the study area. Detailed chemical properties of these soils are presented in Appendix 1. Figure 4. gives soil moisture characteristics of some soils in the study area. Figures 5 and 6 represent relationship between some soil chemical properties of some selected soils in the study area with soil depth. A concise description of the soil-mapping units is therefore presented in conformity to the legend construction.

Mapping unit G11

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

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 unit is characterised by short grasses, ferns and very few scattered temperate tree species. The area is not used and not managed.

The thin topsoils (5 to 30 cm) are black, friable, sandy clay loam and it is weak to moderately structured while the subsoils to a depth of 70 cm are friable, dark brown, sandy clay and it is weakly structured. In some places stones and gravels limit the surface conditions. 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** are representative.

The available water capacity of these soils is extremely low (12 mm/18 cm to 49 mm/ 70 cm soil depth) owing to the limitation in depth. These values of AWC suggest that these soils do not store enough water, which is readily available for plant roots. The soils of this mapping unit have bulk density of 1.1–1.3 g/cc in the topsoils.

Table 2. Summary of the land mapping units description of southwestern Uluguru Mountains

Mapping unit symbol	Landform	Altitude (m. asl)	Dominant slope (%)	Vegetation/Land use	Soil description	Area	
						ha	%
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 2. Continued

SOILS DEVELOPED FROM META-ANORTHOSITE, META-GABROIC 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 Dystrudept*s), C*hromi-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 Hapludalf*s). The soils are represented by profiles MGP-26 and MGP-4 respectively.	1884	4.5

Table 2. Continued

SOILS DEVELOPED FROM COLLUVIUM DERIVED FROM META-ANORTHOSITE, META-GABRROIC ANORTHOSITE AND META-ANORTHOSITIC GABBRO (Cm)							
Cm1	Strongly dissected piedmont slopes	1100-1700	30-50	Few planted *Eucalyptus*. Cultivation of coffee, cabbage, green peas, cocoyam, maize, bananas and round potatoes	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 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.	2333	5.5
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 incisions	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

The soil pH is very strongly acid to strongly acid (pH 4.3-5.1). Nitrogen levels are high in the topsoils (0.54-0.7%). The available phosphorus contents are very low (0.78-1.4 mg/kg). Organic carbon contents are very high (6.2-10.9%). These soils have very low levels of exchangeable bases. The overall capacity of the soil to retain nutrients is high (31.5-38.4 cmol(+)/kg).

Mapping unit G12
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 brown loam topsoils derived from banded pyroxene granulites. In places rock outcrops occur.

The unit occupies very steep strongly dissected plateau slopes. The dominant slopes range between 40-60 % at mean elevation of about 2100 m a.s.l. This unit is characterised by natural forest reserve. In some scattered places cabbage, round potatoes, and coffee mixed with bananas and fruit trees are grown.

The textures of the topsoils (5 to 45 cm thick) are sandy loams to loams. The soils are friable with weak to strong subangular blocky structure. The subsoils to a depth of 120 cm are friable, sandy loams to loams with weak to moderate structure. In some places rock outcrops limit the surface conditions. The soils classify as **Hapli-Humic Umbrisols** (*Humic Dystrudepts*) and **Hapli-Orthidystric Cambisols** (*Typic Dystrudepts*). Profiles **MGP-7** and **MGP-16** are representative.

The soils are well to somewhat excessively drained and the rooting depth is limited at a depth ranging from 10 to 130 cm. The available water capacities of the soils range from very low (35 mm/50 cm soil depth) to low (81 mm/m soil depth) indicating that these soils do not store enough water readily available for plant roots. The soils of this mapping unit have bulk densities ranging between 1.1–1.2 g/cc in the topsoils and 1.5-1.7 g/cc in the subsoils.

The soil pH is very strongly acid (pH 4.5-4.8) in the topsoils to strongly acid (pH 5.3) in the subsoils. Total nitrogen levels are medium to high in topsoils (0.23-0.76%) and decreases with soil depth. Organic carbon contents are very high (6.1-11.3%) and decrease with soil depth. The available phosphorus is medium to high (7.5-54 mg/kg). The soils have very low to low levels of exchangeable bases. The overall capacity of the soil to retain nutrients is high as indicated by their high CEC values (34-40 cmol(+)/kg).

Mapping unit G21
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.

Table 3. Selected physical and morphological properties of the studied soils

Profile no.	Depth (cm)	Particle size distribution			Textural class	Colour	Drainage class	stractrure	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	moderate	1.1	20 mm/30 cm
	24/30-100	73	17	10	SL		excessive			
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)	somewhat	moderate	1.1	
	45-185	74	14	12	SL		excessive	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 3. 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	

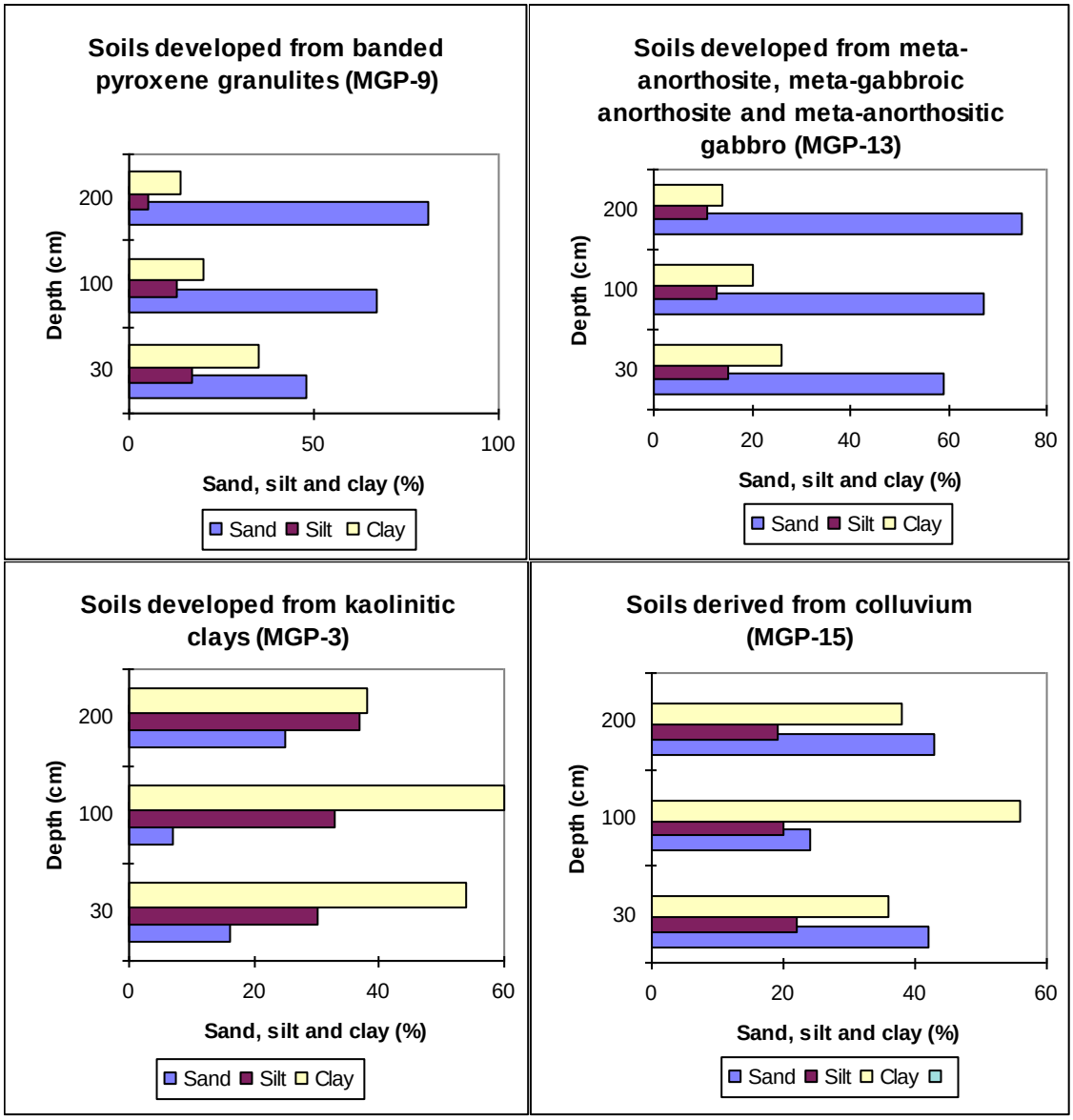

Figure 3. Particle size distribution of soils from different parent materials of the studied soils

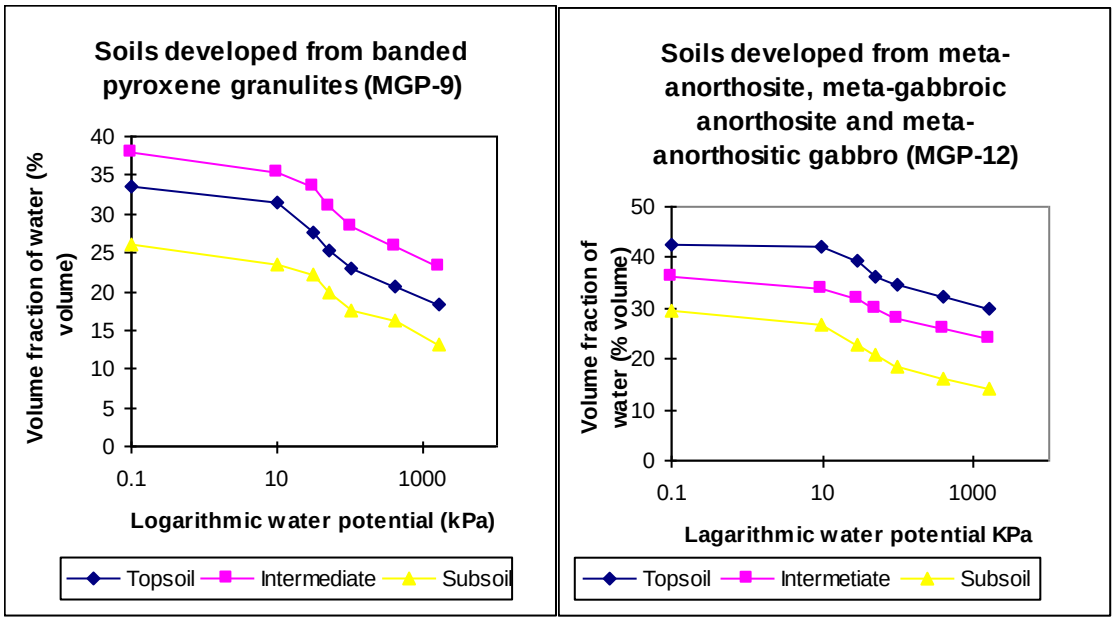

Figure 4. Soil moisture release curves of the soils of southwestern Uluguru Mountains developed from different parent materials

This unit occupies strongly dissected ridge summits with slopes ranging between 2 to 5 % at mean elevation of about 1250 m a.s.l. The dominant vegetation are *Eucalyptus spp.*, and grasses mainly *Hyperrhenia* and *Themeda spp,*. The unit is used for cultivation of maize, beans, pigeon peas with scattered fruit trees and bananas.

The topsoils (35 cm thick) have sandy clay loam textures. The soils are friable with moderate subangular blocky structure. The subsoils to a depth of 64 cm are friable, sandy loams and weakly structured. The soils classify as **Dystri-Lithic Leptosols** (*Lithic Ustorthents*) and **Epidystri-Ferralic Cambisols** (*Humic Dystrudepts*). Profiles **MGP-10** and **MGP-23** are representative.

The soils are well to somewhat excessively drained. The available water capacity is high (152 mm/m soil depth) indicating that these soils store enough water readily available for plant roots. The soils of this mapping unit have bulk densities of 1.3 g/cc in the topsoils and increases with soil depth to 1.5 g/cc in the subsoils.

The soil pH is slightly acid (pH 6.1) and increases with soil depth to neutral (pH 6.6). Nitrogen levels are low in topsoils (0.11-0.12%). Organic carbon content is medium (1.9%) in the topsoils. Both nitrogen and organic carbon levels tend to decrease with soil

depth. The available phosphorus contents are very low (<7 mg/kg). These soils have medium levels of exchangeable bases. The overall capacity of the soil to retain nutrients is medium.

Mapping unit G22

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.

The unit occupies strongly dissected ridge slopes with slopes ranging between 35 to 55 % at mean elevation of about 1000 m. a.s.l. The area is characterised by few scattered *Eucalyptus* trees and grasses mainly *Hyperrhenia* and *Themeda spp*. The lands are used for cultivation of maize, beans, pigeon peas fruit trees cowpeas and few scattered bananas.

The topsoils (10-30 cm thick) are sandy clay loams and sandy loams to sandy clays. They are friable with strong subangular blocky structure. The subsoils to a depth of 110 cm are friable, structureless and massive with sandy clay loam textures. In some places rock outcrops limit the surface conditions. The soils classify as **Eutri-Lithic Leptosols** (*Lithic Ustorthents*) and **Hapli-Hypereutric Regosols** (*Typic Udorthents*). Profiles **MGP-9** and **MGP-22** are representative.

The soils are well to somewhat excessively drained and the rooting depth is limited to depth ranging from 40 to 180 cm or deeper. The available water capacity of the deep soils in this mapping unit is high (143 mm/m soil depth). The bulk densities are 1.3 g/cc in the topsoils and increases with soil depth to 1.9 g/cc in the subsoils.

Soil reaction of the soils of this mapping unit is slightly acid to neutral (pH 6.5-6.6). These pH values are optimal for most crops. Nitrogen levels are low (0.12-13%) in topsoils. Organic carbon contents in these soils are medium (1.69-1.8%) in the topsoils and tend to decrease with soil depth. The available phosphorus levels are very low (<7mg/kg soil). The soils have very high levels of exchangeable bases. The soils have medium (16.5-17.8 cmol(+)/kg) levels of CEC.

Mapping unit M11

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.

This unit comprises the strongly dissected ridge summits with slopes ranging between 2-10 % at mean elevation of about 1500 m. a.s.l. The unit is characterised by grasses mainly *Hyperrhenia spp,* ferns and few scattered *Eucalyptus* trees. This land mapping unit is used for cultivation of maize, round potatoes, beans, pigeon peas, cowpeas and fruit trees.

The topsoils (10-20 cm thick) are clay loams to sandy clay loams. They are friable with moderately strong subangular blocky structure. The subsoils to a depth of 50 cm are friable, sandy clay loams and weakly structured. The soils classify as **Eutri-Lithic Leptosols** (*Lithic Udorthents*) and **Orthieutri-Ferralic Cambisols** (*Dystric Eutrudepts*). Profiles **MGP-12** and **MGP-24** are representative.

The soils are well to somewhat excessively drained. The available water capacity of the soils in this mapping unit is medium (112 mm/m soil depth). The bulk densities of these soils are 1.1 g/cc in the topsoils and tend to increase with soil depth to 1.8 g/cc in the subsoils.

The soil pH of these soils ranges from strongly acid (pH 5.5) in the topsoils to slightly acid (pH 6.4) in the subsoils. Nitrogen levels are low (0.17-0.19 %) in topsoils. Organic carbon contents in these soils are high (3.15-3.25 %) in topsoils while in the subsoils the levels are low (1.15 %). The available phosphorus levels are very low (6.1-6.4 mg/kg) in the topsoils. The soils have high levels of exchangeable bases. The overall capacity of the soil to retain nutrients is medium (CEC of 17.2 cmol(+)/kg).

Mapping unit M12

Complex of deep, well drained, very dark grey clays over very pale brown clay loams 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.

This unit occupies strongly dissected ridge slopes with slopes ranging between 30-60 % at mean elevation of about 1450 m. a.s.l. The unit is characterised by grasses mainly *Hyperrhenia spp,* ferns and few scattered *Eucalyptus* and *Brachystegia spp.* This unit is used for cultivation of coffee, maize, beans, pigeon peas, and cowpeas, round potatoes, cabbages, bananas and fruit trees.

The topsoils (10-25 cm thick) are sandy clay loams, friable with weak to moderate subangular blocky structure. The subsoils to a depth of 110 cm are friable, sandy clay

loams, structureless and massive. In places surface rock outcrops, boulders and stones are common. The soils classify as **Hapli-Anthric Umbrisols** (*Typic Udorthents*) and **Hapli-Orthieutric Regosols** (*Typic Udorthents*). Profiles **MGP-13** and **MGP-25** are representative.

The soils are well drained. The available water capacity of the soils in this mapping unit is medium (91-108 mm/m soil depth). The bulk densities of these soils are 1.1-1.3 g/cc in the topsoils and tend to increase with soil depth to 1.7 g/cc in the subsoils.

The soil pH is medium acid to slightly acid (pH 5.6-6.2) in the topsoils. The subsoils are neutral in reaction (pH 6.7-7.2). Nitrogen levels are low in topsoils (0.15-0.16 %). Organic carbon contents are medium to high (2.5-3.2 %) in the topsoils. Both nitrogen and organic carbon levels tend to decrease with soil depth. The available phosphorus is low throughout (<7 mg/kg). The soils have medium to high levels of exchangeable bases. The overall capacity of the soil to retain nutrients is medium as indicated by their medium levels of CEC (12.6-16.8 cmol(+)/kg).

Mapping unit K11
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.

The unit comprises the strongly dissected ridge summits with slopes ranging between 5 and 15 % at mean elevation of about 1600 m a.s.l. The dominant vegetation is *Eucalyptus* trees, *Brachystegia spp, Albizia spp* and *Acacia mearsii*. This unit is used for cultivation of bananas, coffee, maize, beans, green peas and cowpeas, round potatoes, cabbages, and fruit trees.

The textures of the topsoils (20 cm thick) are mainly friable clays, with weak to moderate subangular blocky structure. The subsoils to a depth of 85 cm have clay textures with moderate to strong subangular blocky structure. The soils classify as **Chromi-Ferralic Cambisols** (*Typic Dystrudepts*) and **Chromi-Hyperdystric Acrisols** (*Typic Hapludults*). Profiles **MGP-2** and **MGP-3** are representatives.

The soils are well drained and the rooting depth is limited to a depth of 190 cm or deeper. The available water capacity of the soils in this mapping unit is medium (101-104 mm/m soil depth). The bulk densities of these soils are 1.1 g/cc in the topsoils while the subsoils have bulk density of 1.2-1.3 g/cc.

The soil pH ranges between strongly to slightly acid (pH 5.5-6.2) in the topsoils while subsoils are medium acid in reaction (pH 5.8-6.1). Nitrogen levels are medium in topsoils (0.28-0.3%) while those of organic carbon are very high (5.17-6.73%) in the topsoils. The available phosphorus contents are very low throughout (<7 mg/kg of soil). These soils have medium to high levels of exchangeable bases. The overall capacity of the soil to retain nutrients is medium (24.4-25 cmol(+)/kg).

Mapping unit K12
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 rock outcrops are common.

This unit occupies strongly dissected ridge slopes with slopes ranging between 40-60 % at mean elevation of about 1500 m a.s.l. *Eucalyptus* trees, *Brachystegia spp* and *Acacia mearsii* are the dominant vegetation types in the unit. Cultivation of coffee, bananas, yarms, maize, beans, cowpeas, round potatoes, cabbages, green peas and fruit trees is major land sue type.

The textures of the topsoils (15 cm thick) are clays with friable consistence and weak to strong sabangular blocky structure. The subsoils to a depth of 140 cm are friable, clays to clay loams and are weakly to moderately structured. In places surface rock outcrops occur. The soils classify as **Epidystri-Cutanic Luvisols** (*Inceptic Hapludalfs*) and **Hapli-Chromic Phaeozems** (*Typic Argiudolls*). Profiles **MGP-4** and **MGP-26** are representative.

The soils are well drained and the rooting depth is limited to a depth of 200 cm or deeper. The available water capacities of these soils range from low to medium (77-127.3 mm/m soil depth). The bulk densities of these soils are 1.0-1.1 g/cc in the topsoils while the subsoils have bulk density of 1.3 g/cc.

The soil pH in this unit is medium acid (pH 5.6-6.1) in the topsoils while subsoils are slightly acid to neutral (pH 6.4-6.8). Nitrogen levels are low to medium (0.19-0.25%) in topsoils while organic carbon levels in the topsoils are very high (5.5-6.3%). The available phosphorus levels are very low ((<7 mg/kg of soil). The soils have low levels of exchangeable bases. The overall capacity of the soil to retain nutrients is medium to high as indicated by their medium levels of CEC (22.1-28.6 cmol(+)/kg).

Mapping unit Cm1
Complex of shallow, somewhat excessively 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 loam topsoils, and deep, well drained, very dark grey clays 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 outcrops are common.

The unit comprises the strongly dissected piedmont slopes with the slopes ranging between 30 and 50 % at mean elevation of about 1400 m. a.s.l. The unit is characterised by *Eucalyptus* trees, *Brachystegia spp* and *Acacia mearsii*. This unit is used for cultivation of coffee, bananas, yarms, maize, beans, green peas, cocoyam, peas, cowpeas, round potatoes, cabbages, and fruit trees.

The textures of the topsoils (15 to 50 cm thick) are clays to sandy clay loams with moderate to strong subangular blocky structure. The subsoils to a depth of 75 cm have sandy clay loams to clay loams textures, friable consistence and moderate subangular blocky structure. The deeper subsoils to a depth below 75 cm are massive and structuress. In places surface rock outcrops, boulders, gravels and stones are common. The soils classify as **Haplic-Phaeozems** (*Typic Hapludolls*), **Hapli-Humic Umbrisols** (*Typic Udorthents*) and **Humi-Endoleptic Regosols** (*Typic Udorthents*). Profiles **MGP-1**, **MGP-5** and **MGP-19** are representative.

The soils are well drained and the rooting depth is limited to a depth of 60 cm or deeper. The available water capacities of these soils range from low to medium (69 mm/60 cm soil depth to103 mm/m soil depth). The bulk densities of these soils range between 1.1-1.3 g/cc in the topsoils while those of subsoils are between 1.5-1.6 g/cc.

The soil pH in this mapping unit is medium acid to slightly acid (pH 5.6 6.2) in the topsoils. Nitrogen levels range from low to high (0.18-0.51%) in topsoils while those of organic carbon in topsoils are very high (5.06 to 6.18%). The levels of both nitrogen and organic carbon tend to decrease with soil depth. The topsoils available phosphorus contents in this mapping unit are very low (<7 mg/kg of soil) but in some places the levels are high (52.7 mg/kg of soil). These soils have high levels of exchangeable bases. The soils in this unit have medium levels of CEC (12.4-17.2 cmol(+)/kg) suggesting that they have medium capacity to retain nutrients.

Mapping unit Cgm1

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. Rock outcrops are common.

This mapping unit occupies the strongly dissected piedmont slopes with the slopes ranging between 40-50 % at mean elevation of about 1600 m a.s.l. The dominant vegetation in the unit are grasses mainly *Hyperrhenia spp.* and scattered *Eucalyptus* trees, *Brachystegia spp.* and *Acacia mearsii*. It is used for cultivation of coffee, bananas, maize, beans, cowpeas, green peas, round potatoes, cabbages, cauliflower, chinese and fruit trees.

The topsoils textures (10 to 40 cm thick) are sandy loams with friable, weak to moderate subangular blocky structures. The subsoils to a depth of 115 cm have sandy loam textures, friable consistence and moderate subangular blocky structure. In places surface rock outcrops, boulders, gravels and stones occur. The soil classifies as **Hapli-Orthidystric Cambisols** (*Typic Dystrudepts*) and **Hapli-Orthidystric Cambisols** (*Dystric Eutrudepts*). Profiles **MGP-17** and **MGP-18** are representative.

The soils are well to somewhat excessively drained and the rooting depth is limited at depths of 26 to 200 cm or deeper. The available water capacities of these soils range from very low to medium (28 mm/26 cm soil depth to130 mm/m soil depth). The bulk densities range between 1.2-1.3 g/cc in the topsoils while in subsoils increases with depth to 1.5 g/cc.

The soil pH is very strongly acid to strongly acid (pH 4.4-5.4) in topsoils. Nitrogen levels in the topsoils are high (0.62-5.4%) while those of organic carbon are medium to very high (1.53-4.33%) and decrease with soil depth. The available phosphorus contents are medium to high (11.7-105.4 mg/kg). The soils have very low to medium levels of exchangeable bases. The soils of this mapping unit have very high levels of CEC (39.8-49.7 cmol(+)/kg) indicating that these soils have very high capacity to retain nutrients.

Mapping unit Cgk1
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. Rock outcrops are common.

This unit comprises the strongly dissected piedmont slopes with the slopes ranging between 40-60 % at mean elevation of about 1700 m a.s.l. Ggrasses mainly *Hyperrhenia spp.* and *Eucalyptus* trees, *Brachystegia spp* and *Acacia mearsii* are the common vegetation type in this unit. The major land used types in the unit are mainly cultivation of coffee, bananas, yarms, maize, beans, green peas, cowpeas, round potatoes, cabbages, cauliflower, chinese, cocoyams, tomatoes and fruit trees.

The topsoils textures (45 cm thick) are clay loams to sandy loams, friable and moderate to strongly structured. The subsoils to a depth of 200 cm have clay to sandy loam textures and are moderately structured. In places surface rock outcrops, boulders, gravels and stones are common. The soil classify as **Hapli-Hypereutric Regosols** (*Typic Udorthents*) and **Hapli-Pachic Phaeozems** (*Fluventic Hapludolls*). Profiles **MGP-8** and **MGP-15** are representative.

The soils are well to somewhat excessively drained and the rooting depth is limited to a depth of 200 cm or deeper. The available water capacities of these soils are medium (132-136 mm/m soil depth). The bulk densities range between 1.0-1.1 g/cc in the topsoils and increases with soil depth to 1.7-1.87 g/cc in subsoils.

The soil pH is medium acid to slightly acid (pH 5.6-6.5) in the topsoils and increases to neutral (pH 6.7-6.8) in subsoils. Nitrogen levels are very low to medium in topsoils (0.003-0.46%). Organic carbon contents range from very low to very high (0.14-7.84%). Both nitrogen and organic carbon show a general tendency to decrease with soil depth. The available phosphorus contents are very low (<7 mg/kg soil). These soils have high levels of exchangeable bases and low to high levels of CEC (8-30.4 cmol(+)/kg).

Mapping unit V1

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.

This unit comprises the V-shaped valley sides and incisions. The dominant slopes range between 40-50 % situated at a mean elevation of about 1250 m a.s.l. The area is characterised by grasses mainly *Hyperrhenia spp* and elephant grass. Scattered trees mainly *Eucalyptus*, *Brachystegia spp* and *Acacia mearsii* are common. It is used for cultivation of maize, cowpeas, beans, green peas, round potatoes, cabbages, cauliflower, bananas and fruit trees.

The textures of the topsoils (21 to 40 cm) are sandy clay loams with friable consistence and moderate to strong structure. The subsoils to a depth of 75 cm are friable and the textures are clays to sandy loams with moderate subangular blocky structure. In places surface rock outcrops and boulders occur. The soil classify as **Hypereutri-Mollic Fluvisols** (*Fluventic Hapludolls*) and **Hapli-Gleyic Phaeozems** (*Arquic Argiudolls*). Profiles **MGP-11** and **MGP-14** are representative.

The soils are well to imperfectly drained and the rooting depth is limited to a depth of 190 cm or deeper. The available water capacities of these soils range from low to high (97-167 mm/m soil depth). The bulk densities range between 1.1-1.4 g/cc in the topsoils and increases with soil depth to 1.6 g/cc in subsoils.

The soil pH is slightly acid to neutral (pH 6.1-6.9). Nitrogen levels are very low to medium in topsoils (0.07-0.22 %) while those of organic carbon range from low to high (0.69-2.97%). The available phosphorus levels are high (23.1-24.2 mg/kg of soil). The soils have high levels of exchangeable bases. The CEC levels of these soils range between low to medium (8.2-16.4 cmol(+)/kg).

Table 4. Soil chemical properties of the studied soils in the study area

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	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	13.2	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 4. 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	-	-

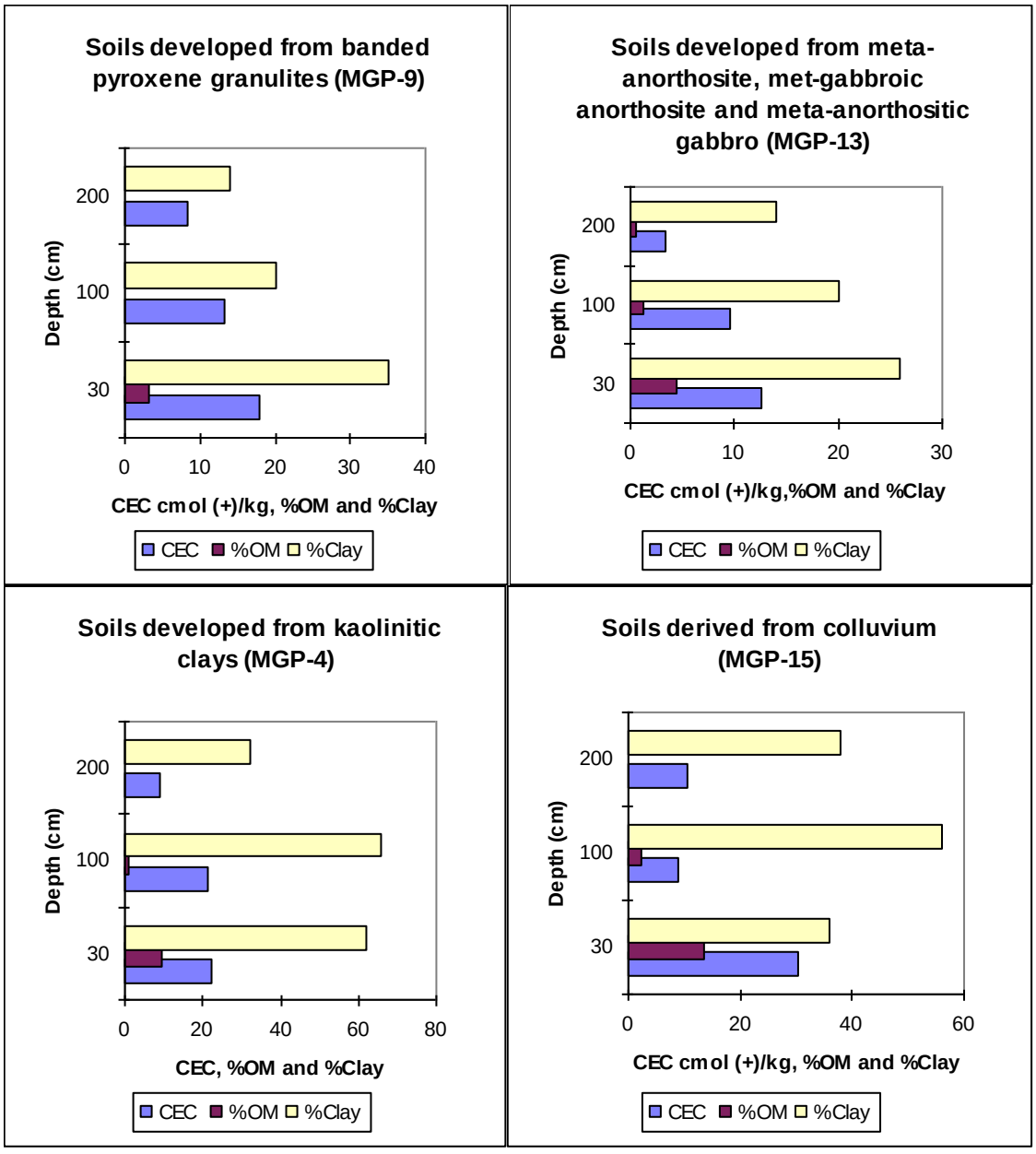

Figure 5. Variation of cation exchange capacity with organic matter and clay content of soils developed from different geological formations in the study area.

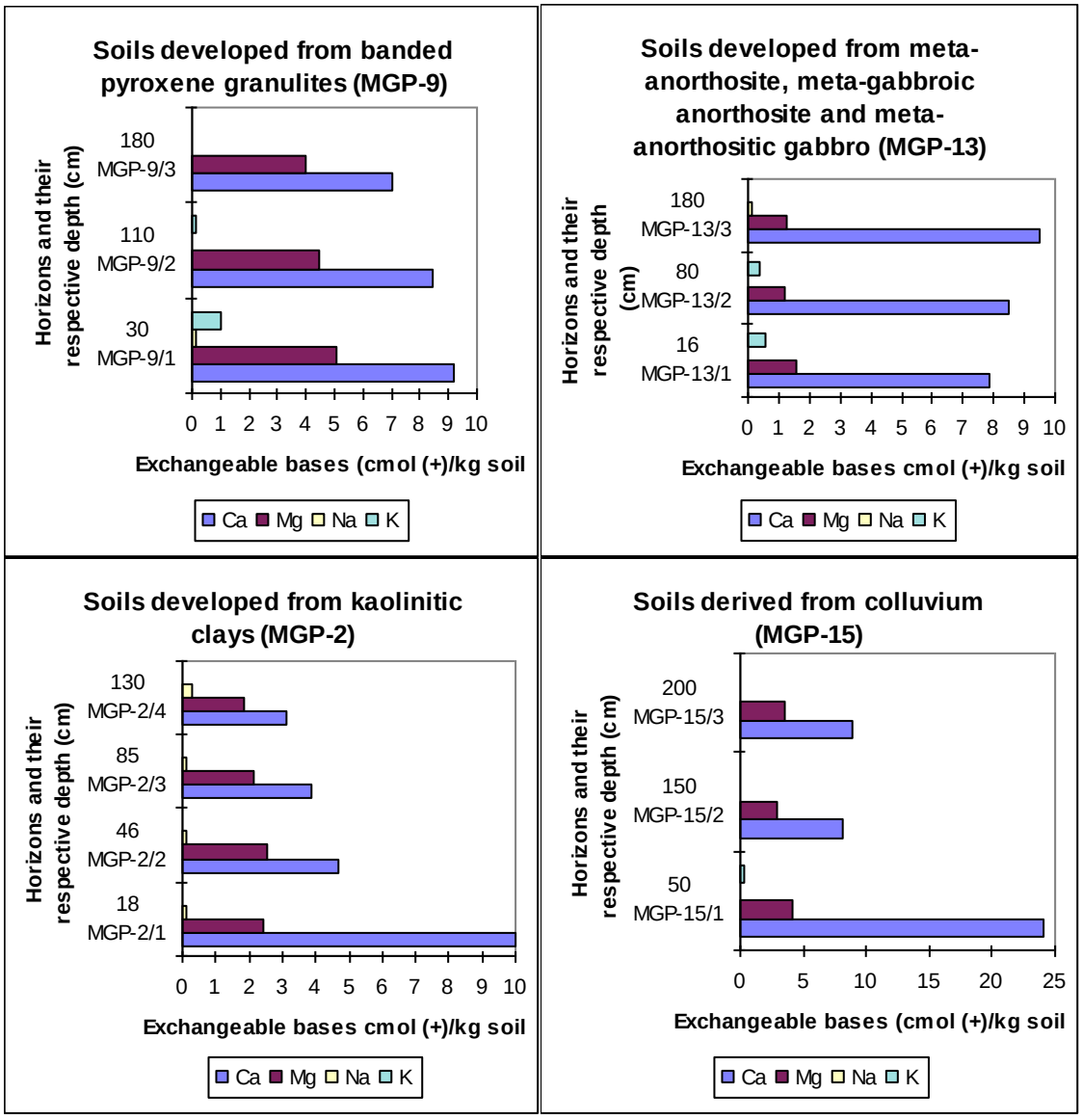

Figure 6. Distribution of exchangeable bases in soils of southwestern Uluguru Mountains developed from different parent materials.

3.3. Soil classification

Soil morphological and other diagnostic features used in soil classification are presented in tables 5 and 6. Table 7 presents the soil names according to the FAO World Reference Base (FAO, 1998) and USDA Soil Taxonomy (Soil Survey Staff, 1998) systems. According to FAO-WRB soil classification system, the main soils of the southwestern Uluguru Mountains 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 (41964 ha). The summit areas dominated by banded pyroxene granulites are occupied mainly with Leptosols (9.5%), Umbrisols (6.8%) and Cambisols (2.9%) while Umbrisols (10.3%), Regosols (9.5%) and Leptosols (1.3%) occupy mainly the slopes. The mountain ridge summits dominated by meta-anorthosite, meta-gabbroic anorthosite and meta-anorthositic gabbro are mainly occupied with Cambisols (3.2%), Leptosols (1.1%) and Umbrisols (6.1%) while Regosols (6.1%) occur mainly on the slopes. The soils of the piedmont slopes derived mainly from colluvium of are Cambisols (5.5%), Phaeozems (3.9%), Regosols (2.7%) and Umbrisols (2.1%). The main soils on the summits dominated by kaolinitic clays are Acrisols (1.7%) and Cambisols (1.2%) while Luvisols (2.3%) and Phaeozems (2.3%) occur mainly on the slopes. The soils on the valley sides, valley floors and incisions are mainly Phaeozems (7.8%) and Fluvisols (7.8%).

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 Cambisols.

Table 5. Morphological and diagnostic features of the studied soils (FAO-WRB system)

Profile	Diagnostic horizons	Other diagnostic features
MGP-1	Mollic horizon and Cambic horizon	-
MGP-2	Ochric horizon and Cambic horizon	Ferralic, Dystric, Chromic
MGP-3	Ochric horizon and Argic horizon	Chromic, Hyperdystric
MGP-4	Ochric horizon and Argic horizon	Cutanic
MGP-5	Umbric horizon	Humic
MGP-6	Umbric horizon	Humic
MGP-7	Umbric horizon and Cambic horizon	Humic
MGP-8	Ochric horizon	Hypereutric
MGP-9	Ochric horizon	Hypereutric
MGP-10	Ochric horizon and Cambic horizon	Ferralic, Epidystric
MGP-11	Mollic horizon	Hypereutric
MGP-12	Ochric horizon and Cambic horizon	Ferralic, Orthieutric
MGP-13	Ochric horizon	Orthieutric
MGP-14	Mollic horizon and Argic horizon	Gleyic
MGP-15	Mollic horizon and Argic horizon	Pachic
MGP-16	Ochric horizon and Cambic horizon	Orthidystric
MGP-17	Ochric horizon and Cambic horizon	Orthidystric
MGP-18	Ochric horizon and Cambic horizon	Orthieutric
MGP-19	Ochric horizon	Humic, Hypereutric
Mgp-20	Umbric horizon and Cambic horizon	Humic
MGP-21	Ochric horizon	Dystric
MGP-22	Ochric horizon	Eutric
MGP-23	Ochric horizon	Dystric
MGP-24	Ochric horizon	Eutric
MGP-25	Umbric horizon	Anthric
MGP-26	Mollic horizon and Argic horizon	

Table 6. Morphological and diagnostic features of the studied 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 7. Classification of the soils of southwestern Uluguru Mountains

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

Table 7. continued

Profile	FAO World Reference Base classification system			USDA Soil Taxonomy classification system			
	Level 1	Level 2	Level 3	Order	Suborder	Greatgroup	Subgroup
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
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

3.4. Land evaluation

3.4.1 Description of land utilisation types (LUTs)

Three major land utilisation types (LUTs) were identified from the results of land use and socio-economic survey carried out in the southwestern Uluguru Mountains. These land utilisation types are (a) smallholder improved low input rainfed cabbage, (b) smallholder improved low input rainfed round potato and (c) smallholder low input rainfed arabica coffee. The selected LUTs were evaluated on the basis of management levels social preferences and type of crops grown in the area. A brief description of the selected LUTs is presented in Table 8. Tables 9, 10 and 11 present the summary of the agro-economic survey results for the three selected LUTs.

Smallholder improved low input rainfed cabbage

This LUT is practised by 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 and bench terrace cultivation system as an effort to control soil erosion. Most of the farmers apply manure and fertilisers in their farms, the most common fertiliser being urea. Pesticides such as Thionex are used to protect the crop from damage by crop pests. 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. Generally, the level of capital investment is low.

Smallholder improved low input rainfed round potato

This LUT is practised by 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. Most of the farmers apply manure and fertilisers in their farms. The most common fertilisers being used are Urea and DAP (di-ammonium phosphate). Fungicides such as blue copper and dithane are also used. 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. The level of capital investment is generally low.

Smallholder low input rainfed arabica coffee

This LUT is practised by 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 fertilisers in their farms. Fungicides such as blue copper and red copper are used on a small scale. The crop is grown with some bananas, yams and fruit trees. The yield ranges from 200 to 1,300 kg/ha.

Table 8. Description of land utilisation types in southwestern Uluguru Mountains

Land utilisation 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)	Ridge 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 potato	Potatoes; Local varieties	Ridge 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	Flat cultivation, 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 9. Agro-economic results for smallholder improved low input rainfed cabbage in southwestern Uluguru Mountains

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 fertiliser application		5 – 13	9
◊ replanting		5 – 10	8
◊ weeding and pruning		18 - 25	22
◊ pesticides application		3 – 15	9
◊ harvesting		5 – 13	9
◊ post-harvesting		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 fertiliser		7,900 - 18,100	13,000
◊ pesticides		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

Table 10. Agro-economic results for smallholder improved low input rainfed round potato in southwestern Uluguru Mountains

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 fertiliser application		3 - 10	6
◊ planting		10 - 38	24
◊ weeding		15 - 20	17
◊ pesticides application		3 - 8	6
◊ harvesting		10 - 20	15
◊ post-harvesting		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 fertiliser		3,750 - 71,250	37,500
◊ pesticides		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 11. Agro-economic results for smallholder low input rainfed coffee in the southwestern Uluguru Mountains

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 pruning		23 - 33	28
◊ pesticides application		8 - 33	21
◊ harvesting		35 - 40	38
◊ post-harvesting		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

3.4.2 Land suitability classification

In this study both biophysical as well as socio-economic resources were evaluated for the lands of southwestern Uluguru Mountains and the results are presented below.

Physical suitability classification

The physical suitability classification for smallholder improved low input rainfed cabbage, smallholder improved low input rainfed round potato and smallholder low input rainfed arabica coffee in the study area is presented in Table 12. Predicted yield levels are presented in Table 13.

About 74% of the study area is classified as physically having moderate potential for smallholder improved low input rainfed cabbage whereas about 24% of the total area is classified as physically having poor potential for the production of cabbages. The most limiting factors are nutrient retention, nutrient availability and temperature regime. Some parts of land mapping unit (LMU) G11 with shallow soils and covering only 2% of the unit are rated as having very poor potential for cabbage production. Rooting condition is the most limiting factor. According to ALES programme zero yield is predicted when land is classified as physically having very poor potential (Rossiter and Van Wambeke, 1994; Rossiter, 1995, 1996). In the study area most LMUs have moderate potential for production of cabbage with yields predictions ranging between 4,200 to 8,400 kg/ha. Some few areas have poor potential with zero yield predictions. According to Sys *et al.* (1993), the average commercial farmer's yield for rainfed cabbage ranges from 10 to 20 ton/ha. The smallholder yields in the study area are only about 40% of the commercial production. This clearly demonstrates that under high levels of inputs and improved management it is possible to obtain higher yields in the study area.

About 80% of the total area is physically classified as having moderate potential for the production of smallholder improved low input rainfed round potato. Some parts of LMUs G11, G12, Cgm1, Cgk1 and K12 forming about 20% of the study area are classified as having poor potential for the production of round potato (Tables 12 and 13). The most limiting factors are erosion hazards, nutrient availability, nutrient retention and conditions of tuber expansion and harvesting. The potato yields are high (about 11,000 kg/ha) in most mapping units except mapping unit G11 (Table 13) which has relatively lower yields (about 5,500 kg/ha). According to Sys *et al.* (1993) good commercial yield for rainfed round potato ranges between 25 to 35 ton/ha. For smallholder low input production the study area can be rated as being potential for the production of round potato.

As far as smallholder low input rainfed arabica coffee is concerned, 71% of the total study area has moderate potential for the production of coffee, while 7% has poor potential for the production of this LUT. However, LMU G11 and some parts of LMUs G21, G22, M11 and Cgm1 altogether covering about 22% of the study area are classified as having very poor potential for the production of arabica coffee. Rooting conditions and nutrient retention are the most limiting factors. 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 (Table 13). According to Sys *et al*. (1993) good smallholder 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 study area has favourable conditions for the production of arabica coffee.

Economic suitability classification

The economic suitability classification is carried out using the predicted yields arrived at in the physical evaluation. The results of the economic evaluation are thus the predicted gross margins for each mapping unit (Table 14). The economic suitability classification results are presented in Table 15.

The economic suitability classification for smallholder improved low input rainfed cabbage indicates that, about 74% of the total area is moderately suitable and 24% is marginally suitable (S3) for this LUT with gross margins ranging from 116,475 to 449,000 Tsh/ha/yr (Tables 14 and 15). Some parts of LMU G11 covering about 2% are rated as not suitable for the production of cabbage due to very poor physical limitations of the lands.

Most LMUs (covering about 82% of the study area) are moderately suitable for smallholder improved low input rainfed round potato. However, LMU G11 and some areas of LMUs G12, Cgk1 and K12, which together occupy about 18% of the study area, are marginally suitable (Table 15). The predicted gross margins (Table 14) show that, round potato has higher gross margins in all LMUs ranging from 275,000 to 825,000 TSh/ha/yr.

The economic suitability results for small holder low input rainfed arabica coffee reveals that, about 71% of the total study area is moderately suitable while about 7% is marginally suitable for this LUT. The LMUs having shallow soils (G11, G21, G22, M11) and LMU Cgm1 together forming 22% of the study area are not suitable for the production of arabica coffee due to poor physical limitations. The gross margins for arabica coffee ranges from 69,050 to 372,000 Tsh/ha/yr

From the results of physical and economic suitability classification most of the lands in the southwestern Uluguru Mountains have moderate potential and are economically moderately suitable for the production of cabbage, round potato and arabica coffee. It is also apparent from this study that production of round potato is economically more profitable in the area when compared to the production of cabbage and coffee. Basing on the current farmers' observed and predicted yields possibilities for obtaining higher yields under high input and improved management levels are high. This forms a strong base in favour of high investment in the area given the potential marketing possibilities in the expanding Morogoro municipality and Dar es Salaam city.

Table 12. Physical suitability classification for smallholder improved low input rainfed cabbage, potato and arabica coffee in southwestern Uluguru Mountains

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

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

Table 13. Predicted yields [kg/ha] for low input rainfed cabbage, potato and arabica coffee in the southwestern Uluguru Mountains

LMs	SOIL TYPE	CABBAGE		ROUND POTATO		ARABICA COFFEE	
		kg/ha					
		INDIVIDUAL SOIL	OVERALL	INDIVIDUAL SOIL	OVERALL	INDIVIDUAL SOIL	OVERALL
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	

Table 14. Predicted gross margins [TSh/ha/yr] for low input rainfed cabage, potato and arabica coffee in southwestern Uluguru Mountains

LMUs	SOIL TYPE	CABBAGE		ROUND POTATO		ARABICA COFFEE	
		INDIVI-DUAL	OVER-ALL	INDIVI-DUAL	OVER-ALL	INDIVIDUAL	OVERALL
G11	Dystri-Lithic Leptosols	0		275,000		0	
	Hyperferrali-Humic Umbrisols	155,300		275,000		0	
	Hapli-Humic Umbrisols	155,300	116,475	275,000	275,000	0	0
GI2	Hapli-Humic Umbrisols	449,300		825,000		372,100	
	Hapli-Orthidystric Cambisols	449,300	449,300	275,000	632,500	372,100	372,100
G21	Dystri-Lithic Leptosols	449,300				0	
	Epidystri-Ferralic Cambisols	449,300	449,300	825,000	825,000	372,100	260,470
G22	Eutri-Lithic Leptosols	449,300		825,000		0	
	Hapli-Hypereutric Regosols	449,300	449,300	825,000	825,000	372,100	204,655
M11	Eutri-Lithic Leptosols	155,300		825,000		0	
	Orthieutri-Ferralic Cambisols	155,300	155,300	825,000	825,000	372,100	279,075
M12	Hapli-Anthric Umbrisols	449,300		825,000		372,100	
	Hapli-Orthieutric Regosols	449,300	449,300	825,000	825,000	372,100	372,100
Cm1	Humi-Endoleptic Regosols	449,300		825,000		138,100	
	Haplic Phaeozems	449,300		825,000		372,100	
	Hapli-Humic Umbrisols	155,300	337,580	825,000	825,000	372,100	297,220
Cgm1	Hapli-Orthidystric Cambisols	449,300		275,000		138,100	
	Hapli-Orthieutric Cambisols	449,300	449,300	825,000	550,000	0	69,050
Cgk1	Hapli-Hypereutric Regosols	155,300		275,000		138,100	
	Hapli-Pachic Phaeozems	449,300	361,100	825,000	660,000	372,100	301,900
K11	Chromi-Ferralic Cambisols	449,300		825,000		372,100	
	Chromi-Hyperdystric Acrisols	155,300	272,900	825,000	825,000	138,100	231,700
K12	Hapli-Chromic Phaeozems	449,300		825,000		372,100	
	Epidystri-Cutanic Luvisols	449,300	449,300	275,000	550,000	372,100	372,100
V1	Hypereutri-Mollic Fluvisols	155,300		825,000		372,100	
	Hapli-Gleyic Phaeozems	449,300	302,300	825,000	825,000	372,100	372,100

Table 15. Economic suitability classification for low input rainfed cabbage, round potato and arabica coffee in southwestern Uluguru Mountains

		CABBAGE	ROUND 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
GI2	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

4.0 CONCLUSIONS AND RECOMMENDATIONS

4.1. Conclusions

The southwestern Uluguru area is mountainous characterised by strongly dissected plateau, mountain ridges and valley sides and incisions. Metamorphic rocks with banded pyroxene granulites, meta-anorthosite, meta-gabbroic anorthosite and meta-anorthositic gabbro are the main rocks forming the main complex of the parent materials for the soils in the area.

Twelve land mapping units characterised by various soil complexes were identified in the southwestern Uluguru Mountains area. Parent materials and landforms largely control the characteristics and distribution of these soils. 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. Poor physical soil conditions coupled with steep topography make the area susceptible to soil erosion. Generally the soils in the area have low soil fertility status.

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 including 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 smallholder improved low input rainfed cabbage, round potato and smallholder low input rainfed arabica coffee were identified and evaluated in the study area. Land suitability classification indicates that, none of the land mapping units is highly suitable for all the studied land utilisation types.

Most of the land in study area (about 70%) is both physically and economically moderately suitable for all three studied land utilisation types. The remaining 30% are either marginally or not suitable for the production of the LUTs. The most limiting factors for the production of the three studied LUTs are rooting condition, poor soil fertility and soil erosion hazards.

The study demonstrated that ALES is a useful tool that provides automated procedures for land resources evaluation and hence an important tool in the formulation of land use plans.

4.2. Recommendations

Due to poor soil fertility in the area, it is apparent that most of the soils are likely to respond to mineral and organic fertilisers. Therefore, it is strongly recommended that 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.

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

Further improvement is needed in the FAO World Reference Base soil classification system to better suit the local conditions in Morogoro Rural District and other similar areas in Tanzania.

Cultivation of round potatoes is highly recommended as the best LUT in the southwestern Uluguru Mountains area followed by cabbage due to their high economic returns under the prevailing socio-economic conditions. Although arabica coffee can be produced in many places of the study area, the present economic returns for arabica coffee are not attractive. To improve the production of coffee in the area it is recommended that, the local co-operatives, improved marketing and storage services should be strengthened. Credit facilities and /or subsidies on agricultural inputs especially fertilisers is highly recommended.

Further research on land evaluation for mixed/intercropping smallholder farming is highly recommended. It is suggested that multidisplinary approaches towards automated land evaluation should be emphasised. Furthermore, research should be carried out to estimate optimum yields and input levels and how these change with fast changing land use types in the context of smallholder production.

Strong extension services are strongly recommended in order to train farmers on the use and application of fertilisers and pesticides.

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

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6.0 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	nd	nd	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 cmol(+)/kg	17.6	20.0	12.6
Exch. Ca cmol(+)/kg	7.1	11.7	9.8
Exch. Mg cmol(+)/g	3.1	1.46	1.44
Exch. K cmol(+)/kg	0.15	0.06	0.04
Exch. Na cmol(+)/kg	0.09	0.18	0.16
Exch. H cmol(+)/kg	0.11	nd	nd
Exch. Al cmol(+)/kg	0.1	nd	nd
TEB cmol(+)/kg	10.4	13.4	11.5
Al saturation %	1.0	nd	nd
Exch. acidity cmol(+)/kg	0.2	nd	nd
Base saturation %	60.7	67.3	90.6
CEC clay cmol(+)/kg	0.7	42.2	39
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	nd	nd	nd	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. Kileo 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	nd	nd	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
Organic 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 cmol(+)/kg	24.4	10.4	8
Exch. Ca cmol(+)/kg	2.6	0.9	0.7
Exch. Mg cmol(+)/g	0.7	0.5	0.2
Exch. K cmol(+)/kg	0.11	0.04	0.04
Exch. Na cmol(+)/kg	0.17	0.07	0.19
Exch. H cmol(+)/kg	0.3	0.2	0.1
Exch. Al cmol(+)/kg	0.7	1.1	1
TEB cmol(+)/kg	3.6	1.5	1.1
Al saturation %	16.3	42.3	47.6
Exch. acidity cmol(+)/kg	1.00	1.3	1.1
Base saturation %	17.5	14.4	13.9
CEC clay cmol(+)/kg	12.2	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	nd	nd	77.2	nd
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	5.1	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, E.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	nd	nd	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	4.1	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	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	nd	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	26.6
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	nd	nd	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	33.3	62.6	57.0
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	nd	nd	nd	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	22.7
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	nd	166.8	nd	nd
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 cmol(+)/kg	8.2	7.4	4.2	6.8
Exch. Ca cmol(+)/kg	5.0	5.4	2.5	5.7
Exch. Mg cmol(+)/g	1.1	1.5	0.8	6.0
Exch. K cmol(+)/kg	0.83	0.22	0.07	0.02
Exch. Na cmol(+)/kg	0.12	0.15	0.09	0.35
Exch. H cmol(+)/kg	nd	nd	nd	nd
Exch. Al cmol(+)/kg	nd	nd	nd	nd
TEB cmol(+)/kg	7.1	7.3	3.4	12.1
Al saturation %	nd	nd	nd	nd
Exch. acidity cmol(+)/kg	nd	nd	nd	nd
Base saturation %	86.4	98.2	81.1	177.9
CEC clay cmol(+)/kg	29.1	13.5	13.5	29.8
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: M11 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	nd	nd	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 Bray-1 mg/kg	6.4	2.5	1.5
Avail. P Olsen mg/kg	nd	nd	1.6
CEC NH_4OAc cmol(+)/kg	17.2	10	5.2
Exch. Ca cmol(+)/kg	8.2	7.2	6.3
Exch. Mg cmol(+)/g	1.98	0.82	0.51
Exch. K cmol(+)/kg	0.32	0.07	0.02
Exch. Na cmol(+)/kg	0.15	0.32	0.23
Exch. H cmol(+)/kg	0.2	nd	nd
Exch. Al cmol(+)/kg	1.1	nd	nd
TEB cmol(+)/kg	10.7	8.4	7.1
Al saturation %	9.3	nd	nd
Exch. acidity cmol(+)/kg	1.3	nd	nd
Base saturation %	62.1	84.1	136.5
CEC clay cmol(+)/kg	15.6	17.6	21.2
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 Bumu
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. Kileo, 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	nd	nd	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 cmol(+)/kg	12.6	9.52	3.4
Exch. Ca cmol(+)/kg	7.8	8.5	9.5
Exch. Mg cmol(+)/g	1.6	1.2	1.3
Exch. K cmol(+)/kg	0.5	0.4	0.06
Exch. Na cmol(+)/kg	0.09	0.09	0.13
Exch. H cmol(+)/kg	nd	nd	nd
Exch. Al cmol(+)/kg	nd	nd	nd
TEB cmol(+)/kg	10.0	10.1	10.9
Al saturation %	nd	nd	nd
Exch. acidity cmol(+)/kg	nd	nd	nd
Base saturation %	79.6	106.5	321.9
CEC clay cmol(+)/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 : Outcrops: 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	nd	nd	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	nd	136.4	nd
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 E.P. Kileo, D.N. Kimaro, 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	nd	nd	nd	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	nd	nd	129.5	nd	nd
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 S.B. Mwango, B.M. Msanya, 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	nd	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 Bray-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 stractured gravelly sandy clay loam over black moderate stractured 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	nd	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	nd	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	nd	nd	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	nd	127.3	nd
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. 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	^{o}C	13-24	24-30 10-13	30-35 5-10	>35 <5
	temp. difference day/night	^{o}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(+)/kg clay	>16	<16 (+)	-	-
	sum of basic cations	cmol(+)/kg soil	>3.5	3.5-2	<2	-
	base saturation	%	>35	35-20	<20	-

Appendix 3. 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	^{o}C	13 - 24	24 - 27 13 - 10	27 - 30 10 - 8	> 30 < 8
	average. temp. difference between day/night	^{o}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 4. 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	^{o}C	22 - 28	28 - 30 22 - 20	30 - 32 20 - 18	> 32 < 18
	Mean monthly min. temp. of coldest month	^{o}C	10 - 19	19 - 21 10 - 7	21 - 23 7 - 4	> 23 < 4
	mean annual temp.	^{o}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 5. Guide to general evaluation of some soil chemical and physical properties [Compiled from ILACO (1991), London (1991), Baize (1993) 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

Extremely acid	pH <4.5	Neutral	pH 6.6 to 7.3
Very strongly acid	pH 4.5 to 5.0	mildly alkaline	pH 7.4 to 7.8
Strongly acid	pH 5.1 to 5.5	moderate alkaline	pH 7.9 to 8.4
Medium acid	pH 5.6 to 6.0	strongly alkaline	pH 8.5 to 9.0
Slightly acid	pH 6.1 to 6.5	very strongly alkaline	pH > 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.