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

WICKAMA J.M. WICKAMA

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

1997

ABSTRACT

A pedological investigation was carried out in Kitanda village, Mbinga district (Tanzania) with the objectives of characterizing the soils in terms of their physical, chemical and mineralogical composition, classifying the soils of the village and assessing the potentials and constraints of the soils. Soil profiles representative of six mapping units covering an area of 5563 hectares were studied and classified according to FAO-UNESCO and USDA Soil Taxonomy systems.

Results indicate that most soils are red to dusky red, well drained, clayey, friable, slightly sticky to sticky and plastic. Soils of the river valleys are brown to dark grey, poorly drained, sandy clay loam to clay, slightly sticky and plastic. Soil pH ranges from slightly acid (6.1) to very strongly acid (4.8). Organic carbon ranges from very low (0.1%) to very high (5.5%). Cation exchange capacity (CEC) ranges from low (6 cmol(+)/kg) to medium (24 cmol(+)/kg). Base saturation ranges from 28% to 67%. Soil clay fractions are dominated by kaolinite and oxides of aluminum and iron. Most soil properties correlate well with landform. Pedogenically the soils are old, highly weathered and have a high potential for fixation of phosphorus. Soil micronutrient levels are optimal except for Zn in the moderately dissected piedmonts.

Soils classify as *Umbric Leptosols, Dystric Leptosols, Ferric Acrisols, Ferric Lixisols, Rhodic Ferralsols and Dystric Fluvisols* respectively for hill summits (H1), hill shoulders (H2), strongly dissected slope facet complex (H3), strongly dissected piedmonts (P1), moderately dissected piedmonts (P2) and river valleys (V).

The hilland has mostly shallow stony surface soils, steep slopes and high risk to soil erosion hence unsuitable for mechanized agriculture, but suitable for afforestation, development of catchment systems and tree crops. Piedmont soils are physically suitable for most crops grown in the area but are low in base saturation, nitrogen, and micronutrients especially zinc. The river valleys are poorly drained, low in base saturation, nitrogen and phosphorus but high in micronutrients. Due to perennial water availability these valleys are suitable for vegetable growing. Most of the studied soils have low to medium water retention capacities.

It is recommended that fertilizer application in most soils includes nitrogen, phosphorus, potassium and micronutrients due to their low supply in the soils. Rates for phosphorus should consider P-fixation. For most soils timeliness of cultural practises like tillage and planting will help avoid moisture stresses to crops. Soil management and conservation practises like the local tie ridge (*ngoro*) and conventional ridge cultivation systems are also recommended.

DECLARATION

I, Wickama Juma Marwa Wickama, do hereby declare that this dissertation is my own original work and that it has never been submitted for a degree award in any other University.

Signature ....

Date 20/11/1997

COPYRIGHT

ACKNOWLEDGEMENTS

I wish to express my sincere gratitudes to my supervisor Dr. B.M. Msanya for the utmost and constant dedication, guidance, and inspiration he gave me during the course of this study.

The Norwegian Agency for Development Co-operation (NORAD) is acknowledged for providing funds to carry out the research. The Miombo Woodland Research Project (MWRP) of the Sokoine University of Agriculture (SUA) is also thanked for supporting the field work.

Thanks are also due to Head of Department of Soil Science, Dr. J.P. Mrema, for providing the necessary facilities to carry out this work.

I am also grateful to Mr. D.N. Kimaro of the National Soil Service (NSS), ARI-Mlingano Tanga, for his tireless technical guidance and efforts during the field work; and to Mr. S.V. Assenga for assistance in cartographic work; and to Mr. J.P. Magoggo for his technical criticisms during the preparation of the memoir.

I am indebted to the technical and secretarial staff of the Department of Soil Science, SUA, for their invaluable assistance during the study.

Last but not least I wish to put on record the support and encouragement rendered to me by my wife Grace and my son Ibrahim.

DEDICATION

I wish to dedicate this work to my dear mother Fatuma Mobwe and my elder brother Ibrahim Chacha Marwa.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

ABBREVIATIONS AND SYMBOLS

1. FAO - Food and Agriculture Organization of United Nations
2. UNESCO - United Nations Educational Scientific and Cultural Organization
3. USDA - United States Department of Agriculture
4. NORAD - Norwegian Agency for Development Co-operation
5. SUA - Sokoine University of Agriculture
6. MWRP - Miombo Woodland Research Project
7. NSS - National Soil Service
8. ILACO - International Land Development Consultants
9. AEZ - agro ecological zone
10. BS - base saturation
11. TEB - total exchangeable bases
12. CAN - calcium ammoniun nitrate
13. AWC - available water capacity
14. Al sat. - aluminium saturation
15. CEC - cation exchange capacity
16. ESP - exchangeable sodium percentage
17. AI - aggregation index
18. pH - hydrogen ion concentration
19. DTPA - Diethylenetriaminepentaacetic acid
20. OC - organic carbon
21. KTP(1-7) - Kitanda profile (no. 1.....7)
22. AC profile - soil profile with A and C horizons only
23. cmol - centimoles
24. kg - kilogramme
25. ^{0} C - degrees Celcius

26. ml - millilitre
27. m - metre
28. cm - centimetre
29. ECw - electrical conductivity in water
30. a.s.l. - above sea level
31. g - gramme
32. % - percentage
33. cm^3 - cubic centimetre
34. vol - volume
35. mm - millimetre
36. nd - not determined
37. Mgm^{-3} - Megagrammes per cubic metre
38. kPa - kilopascals
39. C:N - carbon to nitrogen ration
40. mg - milligramme
41. K-air - Potassium saturated air dried clay samples
42. Mg-air - Magnessium saturated air dried clay samples
43. K-350/550 ^{0}C- Potassium saturated clay sample heated to 350 or 550 degrees Celcius
44. Mg-gly - Magnesium saturated glycol solvated clay sample
45. d-space - distance between clay mineral lattices
46. Θ - scanning angle for X-ray beams
47. ° ' E/S - location in degrees and minutes of geographical East and South
48. pF - suction pressure
49. μm - micrometre
50. Å - angstrom unit

CHAPTER ONE

1. INTRODUCTION

According to Buringh (1979), food and fibre production in the developing world is hampered by, among other factors, the unreliable climate, pests and diseases, poor post harvest techniques, and unfavourable soil conditions. In Tanzania, unfavourable soil conditions caused the collapse in the late 1940s of the famous "Tanganyika Groundnut Scheme" four years after its establishment (Kauzeni *et al.*, 1993). Soil information was not sought before initiation of this project.

Decline in crop yields per unit area due to decreasing fertility of soils in the arable lands of Tanzania is an area that has caused concern to the government and soil scientists for a long time now. Some remedial measures like proper soil and water management practices and fertilizer application have been developed to the district level (Samki and Harrop, 1984) although based on meagre soil information. In some districts, yields per unit area have not been improving despite adoption of fertilizer recommendations. Mbinga District for example, is reported to have the highest agricultural potential compared to other districts in Ruvuma Region (Avendano *et al.*, 1991). For over ten years now (from 1983 to date), there has been a progressive decline in yields per unit area in almost all crops (van Enckernvort and Komba, 1992). The decline in yields in Mbinga is reportedly caused by declining soil fertility which is contributed by poor soil management practices and inadequate use of fertilizers (Avendano *et al.*, 1991; Mchau, 1993).

Realizing the limitation of blanket and general fertilizer recommendations in Tanzania, and due to the vastness of the country, Samki (1989) suggested adoption and utilization of fertilizer rates based on soil specific research findings from neighbouring countries (Uganda, Kenya, Zambia, Zimbabwe, Malawi etc.) that have similar environmental characteristics. Soil information in Tanzania is however lacking, or, when available it is concentrated in only few areas (Kilasara *et al.*, 1993; Msanya and Magoggo, 1993).

Soil information for Mbinga District is generally lacking. The district has never conducted any formal soil survey for pedological characterization to cover the whole district at any scale larger than 1:2 000 000. The only pedological soil survey to have been conducted in the district was done by Baker (1970) at a scale of 1: 2 000 000. A soil fertility appraisal work by a team of Yugoslavian experts (Regional Development Director - Ruvuma, 1982) did not base its observations on analyzed chemical properties, nor were the pedological aspects of the soils considered.

In an effort towards generating soil data the National Soil Service (a government institution coordinating soil surveys in Tanzania) earmarked Ruvuma region as one of the priority areas for systematic soil survey and land evaluation (National Soil Service, 1976), but, to date no land resource survey has been undertaken in the region. Thus soils and land resources in Ruvuma, including those in Mbinga are largely unknown (National Soil Service, 1987).

It was therefore felt that any pedological investigation preferably through soils and land resources survey at a large scale (1:50 000 or larger) in Ruvuma region would provide soil information that is presently lacking. Such studies would generate database sufficiently detailed to allow determination of future soil management packages like fertilizer recommendations.

Recently, a bilateral project between Sokoine University of Agriculture and Kyoto University (Japan), called Miombo Woodland Research Project (MWRP) began doing soil and land resource inventories in some parts of Mbinga district, a pilot area representing part of the Miombo Woodlands of Tanzania. Several villages in the district were earmarked as pilot villages for the project. So far, some villages, including Lupilo, Tukuzi, Litembo and Mahenge have had their soils characterized and mapped. Their technical reports are available (Kimaro *et al.*, 1995a,b.; Kimaro *et al.*, 1996.; Msanya *et al.*, 1995a,b.; Magoggo *et al.*, 1996). The most recent field soil survey is that of Kitanda village to which the author contributed (Msanya *et al.*, 1996). The current study is a continuation of the soil and land resource survey already conducted in Kitanda village. Specifically this study intends to:

(i) characterize in detail the soils in terms of their physical, chemical and mineralogical composition,

(ii) classify the soils of the village using internationally recognised systems of soil classification commonly used in Tanzania i.e FAO-UNESCO and USDA-Soil Taxonomy, and

(iii) assess the potentials and constraints of the soils and land resources of the village.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Basic definitions

Pedology was defined by Birkeland (1974) as a branch of soil science that deals with soil genesis, morphology, classification and mapping of soils. The term "pedological investigation" is used in this study to imply application of soil science techniques to understand the genesis, morphology, type and spatial distribution of soils in a given area. The term "land resource characterization" is used in this study with the meaning of all organized and systematic activities and procedures done in the field and office with the objective of providing information about what features and attributes are found in a given land and what potential they have for use by mankind. In general terms land charaterization embraces soil and land resource surveys also referred to as soil surveys in this study. These surveys have traditionally remained the most preferred technique of collecting data related to land characterization.

2.2 Objectives of pedological investigations and land resource surveys

Pedological studies and land resource surveys are done in order to obtain a better understanding of spatial changes in the characteristics of the soil continuum so that soils may be used more efficiently for the benefit of mankind (Smyth, 1981). Soil and land resource surveys have traditionally been used for comparisons of environmental situations so that experience may be exchanged in many areas of land use for example transferring research findings to another area, farm planning, rural land classification, agricultural land evaluation, town master planning and settlement arrangement, forestry and forestry management, engineering purposes, international sharing of knowledge in soil science etc. (Coulter, 1964; Anderson *et al.*, 1978, Dent and Young, 1981; Landon, 1984). In ecological studies, soil and land resource surveys provide geographical information on soils which can be used to correlate with vegetation data to obtain a more complete picture of a given ecosystem (Breimer *et al.*, 1986)

In Tanzania, pedological studies and land resource surveys have been used for many purposes including soil characterization, soil classification, soil correlation, soil mapping and prediction of soil behaviour and consequences of certain land utilization types (Msanya and Magoggo, 1993).

2.3 Historical development of pedological studies and land resource characterization in Tanzania

The first attempt to classify and map the soils of Tanzania was probably that by Milne (1936). Milne published a provisional soil map of East Africa comprised of Tanganyika (now mainland Tanzania), Kenya, Uganda, Zanzibar, Nyasaland (now Malawi) and Rhodesia. Milne introduced the famous catena concept (a regular repetition of a certain sequence of soil profiles in association with a certain topography). His work summarized soil conditions in Tanzania into four groups:

(i) the tidal muds of mangrove forests or scrub fringing many of the inlets and river mouths and to a considerable extent in the delta of Rufiji river

(ii) the discontinous and shallow but fairly heavy red earths found on narrowred benches of coast and limestone immediately adjoining the coast

(iii) the deep sandy red earths, the favourite soils for sisal plantations occupying broad and low ridges

(iv) the most extensive and continuous types of all, a complex consisting of light coloured loose sands passing into sandy black or grey clays wherever waterlogged.

Realizing the important role landform played in the properties of the soils, Milne (1937) reclassified Tanzanian soils into nine groups; desert soils, saline soils, plain soils, non-laterized red earths, laterized red earths, plateau soils, podzolized soils, volcanic soils and loose sands. The major limitation in the work by Milne was that his classification was on a very general reconnaissance basis with very little consideration for analytical data.

Improving on Milne's work, Calton (1954) produced a soil map of Tanganyika which distinguished elluvial from illuvial soil types and several catenary associations. The soils were classified on pedological basis. His soil map suffered reliability as it mostly covered only the accessible areas like those adjacent to the railway lines or major roads. Inaccessible areas were not surveyed. The resultant scale of 1: 4 000 000 also limited the usefulness of his map for predictive purposes.

A similar landscape-based approach was adopted by Scott (1963) in his regional soil map of East Africa. Scott showed soil-topography associations. Like Calton (1954), his work had low reliability as it covered only the accessible areas. The 1: 4 000 000 scale of his soil map further reduced its predictive usefulness for regional planning purposes.

Anderson (1963) classified the soils of Tanzania using drainage and relief. Despite his attempt to give details on Tanzanian soils his work suffered the same constraints of limited access to the entire country hence the predictive usefulness of his work remained in those areas actually surveyed.

In his soil map for Africa, D'Hoore (1964) gave a very limited and highly generalized presentation of Tanzanian soils at a scale of 1: 5 000 000. This scale is too small for practical planning purposes at national and regional level.

Baker (1970) classified the soils of Tanzania. He carried out a nationwide appraisal of land resources. His work produced a 1: 2 000 000 soil map of Tanzania which was followed by four bulletins, one for each zone (he had divided the country into four zones) at a scale of 1: 1 000 000. Baker traversed most of the territory, but, even then some inaccessible areas remained unsurveyed and were later on delineated on the basis of aerial photographs. Baker described the land resources in terms of physiography, geology, rainfall, soils and vegetation. His work classified the soils of Tanzania into 31 units. The major limitation in Baker's work is that it was highly generalized. Only 40 soil profile pits were studied in the entire country which undermines its degree of representation of ground truths.

Other land resource studies conducted include those by Stuart and Duckworth (1969) in south west, Sheehy and Green (1969) in north east and Hathout (1973a) in south east Tanzania. These studies were not published but were later compiled into maps with scales ranging between 1: 2 000 000 and 1: 2 500 000 (Hathout, 1972b;1972c; 1973a). These studies used some soil properties for mapping, for example, soil colour (Scott, 1963), parent material (Baker, 1970) soil texture and drainage (Hathout, 1972a) etc.

Using a slightly different approach, Samki (1972) classified the soils of Tanzania on ecological basis in which rainfall and parent material were given more consideration. Samki's work resulted in 19 soil ecological zones. These soils were later on classified according to the legends of FAO-UNESCO (Samki, 1977), published on a 1: 2 000 000 map scale and eventually formed the basis for the district by district fertilizer recommendations (Samki and Harrop, 1984). The major limitation in Samki's work was its small scale.

Hathout (1983) published "A Soil Atlas of Tanzania" which was a compilation of results of various studies related to land evaluation and land capability classification in Tanzania. Like in the past studies this work was also published at a 1: 2 000 000 scale and therefore has a high degree of generalization.

De Pauw (1983) described the major agro-ecological zones (AEZ) of Tanzania and published a 1: 2 000 000 scale map describing the major land resources including soils in each zone. However, some areas were not surveyed at all in his work. The major part of Ruvuma region for example was not surveyed, and hence reliability of the soil information in his work is doubtful because it was derived from geological and topographical maps, satellite imagery, papers and small scale maps. In his work though, 18 major soil units can be identified for the whole country as presented in Table 1.

Table 1. Approximate aerial extent of different soil types in Tanzania

Soil Type	Area (Million hectares)	% Proportion
Cambisols	23.3	28.2
Ferralsos	12.5	15.1
Vertisols	7.2	8.7
Xerosols	5.9	7.1
Lithosols	5.6	6.8
Nitosols	4.8	5.8
Gleysols	4.7	5.7
Arenosols	4.0	4.8
Luvisols	3.2	3.9
Fluvisols	2.9	3.5
Planosols	2.4	2.9
Phaeozems	1.7	2.1
Solonchaks	1.3	1.6
Andosols	1.3	1.6
Chernozems	0.9	1.1
Histosols	0.5	0.6
Solonetz	0.4	0.4
Regosols	0.06	0.07

Source: Msanya and Magoggo (1993)

It can be argued that since Baker (1970) no systematic soil mapping has been undertaken to cover the entire country for a soil map of a scale larger than 1: 1 000 000. Instead, the regions have been conducting their own pedological and land resource studies at a larger scale (1: 500 000), but for different purposes.

According to Msanya and Magoggo (1993), more than half the country has been covered in this way. Examples of this type of land resource studies include the regional surveys of Kilimanjaro (Iseki, 1977), Mbeya (King, 1982), Tabora (Acres, 1983; Corker, 1982 & 1983; Mitchell, 1982 & 1984), Tanga (Agrar und Hydrotechnik, 1976a & b) and Rukwa (King et al. 1979; Rombulow-Pearce, 1980). Similar works have been done in Biharamulo and Ngara districts in Kagera region, Kahama and Meatu districts in Shinyanga and Mbulu district in Arusha region at a scale of 1: 250 000.

Magoggo (1992) and Kilasara *et al.* (1993) reported that a wide range of areas have been covered in terms of detailed soil survey and land evaluation studies of farms, estates, irrigation schemes and village areas. These projects are scattered throughout Tanzania and their areal extent is about 10 000 sq. km. which is negligible taking into consideration the vastness of the country. These studies however have a direct impact on the lands in question as they are being used to solve production constraints and for planning.

2.4 Pedological studies and land resource surveys in Ruvuma- Mbinga area

Most of the pre-independence pedological and land resource studies in Ruvuma region concentrated in the Singe - Tunduru area because of their agricultural and hydroelectric potential (Grantham, 1956; Glover, 1949). Characteristic of the resource studies of the period, soils were classified based on their underlying geology and not on chemical or mineralogical properties.

Northwood (1962) did some pedological studies in the Ruvuma region. His work concentrated in the Tunduru and Namaskata area and was done for cashewnut production. Northwood reported the soils in the area as being formed from Karoo sediments, light in texture except for valley clays. The hilltops were observed to have red sandy loams. Texture and drainage were the main criteria used for classifying soils.

Most of the soil works reported as covering the whole country collected little or no information at all from Ruvuma region and Mbinga district in particular. Studies by Milne, Anderson, Samki and De Pauw were not based on actual field traverses in Mbinga. They were derived from secondary data sources. Therefore, the country wide survey by Baker (1970) was probably the first to have made actual field observations in Mbinga district (the current study area). Mbinga was grouped in the "South west zone". The geological description by Baker locates the present study area in the "fault blocks adjoining lake Nyasa", an area Baker described as being dominated by hornblende-biotite-garnet gneiss and some granitic rocks.

Some appraisal on the fertility of the soils in Mbinga district was done by a team of Yugoslavian experts as part of the Regional Integrated Development Plan in the late 1970s (Regional Development Director - Ruvuma, 1982). Soils were mapped based on their assumed fertility, not on analyzed chemical or mineralogical properties.The entire work did not include any pedological aspects of the soils in the area. The scale used to map the soils was also too small (1:300 000) for any practical use at village or specific soil management level.

2.5 Soil conditions in Mbinga district

The first pedological description of soil conditions in Mbinga district is probably that of Baker (1970). He described the soils of the area as being mostly sandy to sandy loam, having low water holding capacity and low fertility. The soils are well drained, medium to slightly acid in reaction, often containing iron nodules and manganese concretions. Fragipans are common, soils are highly leached with low cation exchange capacity (CEC) with sandy clay loam subsoils. Their clay fraction is mostly kaolinite.

In Ndolela, (an area in Songea but very close and similar to Mbinga) a land resource study by the National Soil Service (1987) had different observations, the soils were found to be mostly clayey in the subsoils and sandy clay loam in the topsoils. Fragipans were not observed and relief was observed to be a major factor that influenced soil properties in the area. However, some observations similar to Baker's were also made. The soils were highly weathered, kaolinitic, of gneissic parent material and low in fertility. The soils mostly classified into Acrisols, Ferralsols and Lixisols.

A later study covering the entire district in a form of a rapid rural appraisal (Avendano *et al.*, 1991) observed that soils in Mbinga were mostly Humic and Haplic Acrisols with the position of each depending on the relief (toposequence). The soils were dominated by kaolinite and iron oxides on their clay fraction, deeply weathered with low (0.5%) to high (>3%) content of organic matter. Nitrogen and phosphorus were limiting in most areas, the CEC of most soils ranged from 3 - 15 cmol(+)/kg soil. Soil reaction was observed to vary from pH 5.2 to 6.8 while about 70% of the observed CEC was explained by the organic matter content of the soils. Unfortunately no soil maps were produced from this study nor are the soil conditions mentioned above referred to specific villages. There is no mention of scale or intensity of observations. This study also revealed soil fertility decline, poor soil management practises and uncontrolled deforestation in many parts of the district as being causative to the low crop yields being realized by farmers and to soil and land degradation in the area. Later, Mchau (1993) also observed significant mismanagement of the forest and other land resources in Mbinga which was associated with a decline in soil fertility and reduced productivity in the farming system.

The Sokoine University of Agriculture has recently began conducting land resource studies in some villages of Mbinga district. In Mahenge village, Magoggo *et al.* (1996) identified four soil types which correlated well with landform. Cambisols were found to occupy the piedmonts, Regosols on the hillslopes, Leptosols on the hill summits and Acrisols on the hill shoulders. Information on most soil properties and other land resources is similar that reported by Avendano *et al.* (1991) and Mchau (1993).

In a nearby village of Litembo similar observations were made by Kimaro *et al.* (1996). However, they observed that piedmonts in Litembo were occupied by Ferralsols and Acrisols which are soils that are more weathered than Cambisols. The valley bottoms in Litembo village were found to be comprised mainly of Fluvisols.

Msanya *et al.* (1995a) conducted a similar study in Lupilo village neighbouring Kitanda village, the site of this study. They identified six soil units in Lupilo village namely, Leptosols (on hill summits), Cambisols (on very steep linear slopes and in broad well drained river valleys), Acrisols and Luvisols (on strongly dissected piedmonts), Ferralsols (on the moderately dissected piedmonts) and the Fluvisols (in the almost flat, poorly drained river valleys). Again as was the case for Litembo and Mahenge villages, relief was identified as the major soil forming factor that affected soil properties in the area. Regarding soil properties, soil fertility decline, mismanagement of land and forest resources and low crop yields the authors had similar observations like previous studies in the district.

The most recent soil and land resource survey in Mbinga district for which the author of this dissertation contributed is that of Kitanda village (Msanya *et al.*, 1996). The survey identified three major landforms in the village, the hilland (H), the piedmonts (P) and the river valleys (V) which could be further divided into six mapping units on the basis of relief and drainage pattern (see Table 3). It was the intention of this study to use soils collected from the representative profiles in this survey for detailed characterization and classification so as to generate soil data which would form the basis of recommending some soil management practices in the area.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Site description

3.1.1 Location

Mbinga district is located within longitudes 34° 24'E and 35° 28'E and latitudes 10° 15'S and 11° 34'S. The approximate geographical coordinates for Kitanda village are 35° 06' 44.1" E and 10° 55' 24.6" S. The village is about 17 km from Mbinga town in the low Kigonsera Hills. According to De Pauw (1983) the village falls in the Hilly and Mountainous agro ecological zone (AEZ) HM3 which is characterized by altitude ranging from 900 m - 1500 m a.s.l. The approximate location of Kitanda village is shown in Figure 1.

3.1.2 Climate

The nearest climatic weather station is that found in Mbinga town hence its weather records have been used to infer climatic conditions in Kitanda village. Rainfall distribution in Mbinga district is monomodal. The rain starts in November and ends in May. Kitanda village falls in the relatively drier part of Mbinga district and is estimated to receive a total annual rainfall of slightly less than 1000 mm. The higher altitude areas in the district get an average rainfall ranging between 1200 to 1500 mm per annum (Mchau, 1993). The average annual temperatures for Mbinga district range from about 13°C in the Matengo highlands to about 30°C on the shores of Lake Nyasa (Mchau, 1993). Kitanda village is expected to be in between with mean annual temperatures between 20°C and 25°C. Minor seasonal variations in temperature exist whereby the dry season (May to September) is cooler than the rainy season. Rainfall data for a period of six years as received from the district authorities is summarized in Table 2.

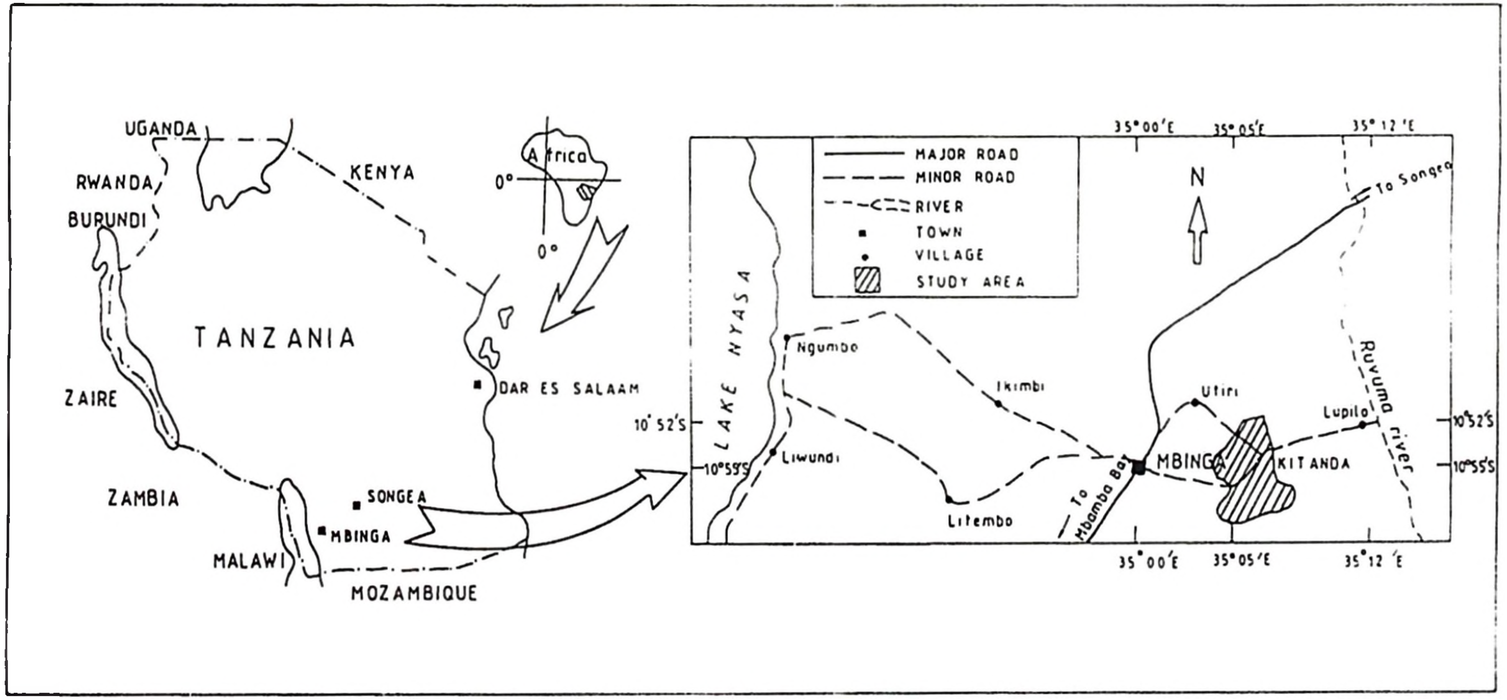


Figure 1. Location of the study area

Table 2. Rainfall distribution (mm) during the period 1988/89 - 1993/94 at Mbinga

Month	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Total
Year													
1988/89	-	56.0	70.1	179.2	198.3	110.1	253.7	139.9	35.0	-	-	-	1024.3
1989/90	-	-	82.0	200.0	149.9	188.5	166.4	137.3	15.5	-	-	-	939.6
1990/91	4.7	-	18.2	47.5	314.0	126.2	199.0	164.8	2.6	-	-	-	877.0
1991/92	-	-	79.4	182.6	218.5	179.3	151.5	65.5	64.4	-	-	-	941.2
1992/93	-	-	107.9	95.0	266.2	319.1	479.1	154.5	36.1	-	-	-	1457.9
1993/94	-	-	5.2	54.5	21.5	325.0	324.5	300.5	94.6	-	-	-	1125.8

Source: Msanya et al. (1995a)

3.1.3 Landform

Kitanda village has three major landform which correspond to altitude and setting. The hilland (H) at 1200 m to 1500 m a.s.l. occupies the highest position in the village. The piedmonts (P) lie in the middle and are found at 1100 m - 1400 m.a.s.l. The river valleys (V) at 1200 - 1250 m.a.s.l. form the lowest landscape. These landform have six soil mapping units, the hill summits (H1), the back slopes (H2), the strongly dissected slope facet complex (H3), the narrow strongly dissected piedmonts (P1), the broad gently dissected piedmonts (P2) and the river valleys (V).

3.1.4 Geology

The underlying geology in Kitanda village is comprised of garnet-sillimanite-cordierite-granulites and cordieritised amphibolites. These are old precambrian rocks of the archean period. Pockets of migmatised and hornfelsed granulites, migmatitic gneisses and amphibolites, charnockite, norite and enderbites are found (Geological Survey Department, 1956). The major parent rocks in this village are of metamorphic type and for this reason the term "metamorphosed granitic rocks" has also been used in this study for the description of the parent material of the surveyed area.

3.1.5 Vegetation and land use

The major vegetation in the area is the *Miombo woodland.* This vegetation is comprised of the following tree species, *Brachystegia spp.*, *Parinari curatefolia, Uapaka kirikiana, Pterocarpus angolensis* etc. (see Table 3). The grass undergrowth in most of the miombo woodlands includes *Hyparrhenia spp.* and *Cynodon spp.* etc. In Kitanda village, the miombo provide the major vegetation cover. Recent occupation of these lands for agricultural use has left this vegetation (miombo) concentrated on the hillands while the piedmonts and the valley bottoms are getting increasingly cleared of them.

Table 3. Characteristics of the various mapping units of Kitanda village

MAP SYMBOL	LANDFORM CHARACTERISTICS	SLOPE (%)	AREA (ha)	SOIL DESCRIPTION	VEGETATION / LAND USE
HILLAND (H), elevation 1200 to 1500 m above sea level					
H1	Hill summits and upper slopes	0-2	711	Shallow to moderately deep, well to somewhat excessively drained, yellowish red, very gravelly clays, with dark reddish brown, very gravelly sand clay loam topsoils; developed on mixed partially metamorphosed granitic rocks. In places rock outcrops, boulders, stones and gravels occur on/at the surface.	Natural forest; mainly *Miombo* woodland:*Brachystegia spp. Parinari curatelifolia, Uapaka kirikiana Cussonia arborea, Diplorhynchus candylocarpon*. Grasses mainly *Hyparrhenia rufa, Brycharia spp.* as undergrowth. Farming systems include few *ridge* and *ngoro*[1] *cultivation* used mainly for maize production.
H2	Moderately dissected steep hill slopes	25-50	258	Very shallow to shallow, well to excessively drained, dark red gravelly clays, with dark reddish brown, sandy clay loam topsoils; developed on mixed partially metamorphosed granitic rocks. In places rock outcrops and boulders occur.	Natural forest; mainly *Miombo* woodland: *Brachystegia spp., Parinari curatelifolia*. Grasses mainly *Hyparrhenia rufa* and Brycharia spp. Farming systems include few *ridge and ngoro cultivation* used mainly for maize production.
H3	Steep and strongly dissected slope facet complex	25-50	1 885	Very deep, well to somewhat excessively drained, dusky red clays, with thin dark reddish brown, sandy clay topsoils; developed on colluvial material derived from mixed partially metamorphosed granitic rocks.	Natural forest; mainly *Miombo* woodland: *Brachystegia spp., Parinari curatelifolia*. Grasses mainly *Hyparrhenia rufa, Brycharia spp., Themeda triandra*. Farming systems include *ridge and ngoro* cultivation with beans and maize as main crops. Coffee-Grevillea agroforestry, cultivation of bananas, mangoes is also practised.

[1] Ngoro = kind of a traditional tie-ridge cultivation system

Table 3. continued

PIEDMONTS (P), elevation 1100 to 1400 m above sea level					
P1	Gently undulating and strongly dissected very steep slopes with narrow interfluves sloping towards the streams	2-35	416	Very deep, well drained, dark red clays, with thin, black to dark reddish brown, sandy clay loam topsoils; developed on colluvium derived from mixed partially metamorphosed granitic rocks.	Coffee-Grevillea agroforestry and fruit crops (mangoes and bananas). *Ngoro* and *ridge* cultivation for maize and beans is practised on the steep slopes towards drainage valleys. The unit has few miombo trees on the steep slopes such as *Brachystegia spp.* and *Parinari spp.*
P2	Moderately dissected slopes, with broad interfluves and short steep slopes towards drainage streams	5-25	2 047	Very deep, well drained, dark red clays, with thin, black to dark reddish brown sandy clay loam topsoils; developed on colluvium derived from mixed partially metamorphosed granitic rocks.	*Ridge* cultivation with beans and maize; and coffee-grevillea agroforestry. There is also a natural forest of miombo trees such as *Brachystegia spp.* and *Parinari spp.* Small scale cultivation of pineapples is also practised.
RIVER VALLEYS (V), elevation 1200 to 1250 m above sea level					
V	Flat to almost U-shaped river floors	0-5	246	Very deep, very poorly drained, very dark gray, layered and mottled sandy clay loams to clay loams, with thick, dark reddish brown to very dark brown, sandy clay loam topsoils; developed on alluvial-colluvial material of diverse origin.	Flat, *ridge* and *ngoro* cultivation with maize and beans as main crops. Natural *miombo* woodland trees and grasses in waterways are common. Bamboo, *Hyparrhenia spp.* and *napia* grasses are common.

Derived from: Msanya *et al.* (1996)

3.2 Materials

3.2.1 Soils

Soils were obtained from the land resource survey of Kitanda village (Msanya *et al.*, 1996). A total of 33 disturbed samples from seven representative soil profiles were used for detailed characterization in the laboratory. For determination of bulk density and water retention characteristics, 24 undisturbed soil samples were collected from four soil profiles that had suitable conditions for their collection.

3.3 Methods

3.3.1 Soil analyses

Soil samples were air dried, ground and sieved through a 2 mm sieve (Gee and Bauder, 1986) to obtain the fine earth fraction. Particle size distribution was carried out by the hydrometer method (Gee and Bauder, 1986) after dispersing the soil using calgon. Water dispersible clay was determined following the methodology described by McKeague (1976), using water alone as dispersing agent. Soil aggregation index (AI) was computed using the formula provided by Breimer *et al.* (1986), i.e.

$$\mathbf{AI = 1 - (water\ dispersible\ clay\ content\ /\ total\ clay\ content) \times 100}$$

Bulk density was determined by the core method (Blake and Hartge, 1986). Water retention characteristics were determined as described by Peters (1965).

Soil pH was determined potentiometrically in a 1: 2.5 soil water ratio with a pH meter glass electrode (Peech, 1965). Electrical conductivity (ECw) was determined by an EC meter at a standard temperature of 25°C (Rhoades, 1982). Exchangeable bases were extracted using 1 N NH_4OAc and determined by atomic absorption spectrophotometer (Thomas, 1982). Cation exchange capacity (CEC) of the soils was determined by NH_4OAc

method at pH 7.0 (Hesse, 1971). Total exchangeable bases, base saturation, ESP, CEC of clay were determined by calculation. Organic carbon was determined by the Walkley and Black wet -acid dichromate digestion method (Nelson and Sommers, 1982). Total nitrogen was determined by the Kjeldahl digestion method (Bremner and Mulvaney, 1982). Available phosphorus was determined by the Bray-Kurtz I (Olsen and Sommers 1982). Sodium dithionite, ammonium oxalate, and sodium pyrophosphate extractable oxides of iron, aluminum and manganese were determined using the methods developed by Sheldrick (1984). Hematite and goethite (%) were calculated as being the difference between dithionite and oxalate extractable iron oxides (Parfitt and Childs 1988). Degree of crystallinity/ activity ratio was computed as being the ratio between the oxalate extractable iron (Fe_o) and dithionite extractable iron (Fe_d) (Jackson *et al.*, 1986). Micronutrients manganese, iron, copper and zinc were determined using the DPTA method (Cox, 1968). Exchangeable acidity and aluminum were analyzed using the method by Thomas (1982).

Soil samples for mineralogical analysis were prepared according to the method described by Msanya *et al.* (1995b). About 20 g of fine earth subsoil sample were first treated with 30% H_2O_2 in 500 ml beakers to remove organic matter and excess H_2O_2 evaporated on a water bath. Samples were dispersed by adding 1 ml 1 N NaOH and then 300 ml of deionized water. The samples were shaken overnight in an end over end shaker for maximum dispersion. The suspensions were transfered to 1000 ml cylinders made to volumes and allowed to settle. At appropriate time and depth according to Stokes law, clay fractions (< 2μm) were siphoned out of the cylinders into glass beakers. The clay fraction was mounted on a glass slide using five treatments; Mg^{2+} saturated air dry, K^+ saturated air dry, Mg^{2+} saturated ethylene glycol solvated, K^+ saturated heated to 350°C and K saturated heated to 550°C. A scanning angle of 3 - 30°, 3 - 15°, and 3 - 20° was used for Mg-air dried samples, Mg-glycol solvated samples and potassium saturated samples respectively. X-ray diffraction techniques were employed using a Shimadzu x-ray diffractometer model (XD - D1) equiped with Cu tube to study the mineralogy of the soils.

Identification of clay minerals was done using standard guidelines and books (Whittig, 1965; Brindley, 1980; Dixon and Weed, 1989). Relative abundance of clay minerals was semi-quantitatively assessed by measuring the peak height characteristics for respective mineral species (Araki and Kyuma, 1986).

3.3.2 Soil classification

Soils were classified up to level-2 soil names according to the FAO-UNESCO soil classification system (FAO, 1988) and up to family level according to the USDA Soil Taxonomy (Soil Survey Staff, 1990).

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Characteristics of the soils

4.1.1 Physical characteristics

Soil morphology

Some morphological properties of the soils are presented in Table 4 while a complete description of the soil profiles is given in appendix 1.

Profiles KTP-1 and KTP-7 represent soils of the strongly dissected part of the hilland (mapping unit H3). The soils are very deep (over 190 cm), well drained, friable, dark reddish brown to dusky red clays, with thin dark reddish brown sandy clay loam topsoils. Except for the topsoil (0-9 cm) in KTP-1, and (0-22 cm) KTP-7 the remaining depths of the two profiles are clayey with moderately strong medium subangular blocky structure. The subsoils have sesquioxide rich clay cutans indicating that there has been both clay illuviation into the Bt horizons and an advanced degree of pedogenesis.

Profile KTP-2 represents the strongly dissected piedmonts (mapping unit P1). These soils are very deep (over 190 cm), well drained friable, clays, with moderately thick, dark reddish brown sandy clay loam topsoils. The profile is clayey throughout in the subsoils and is of moderate medium subangular blocky structure. Iron and manganese nodules are detected from 80cm and below. The wet consistence is slightly sticky and slightly plastic on the surface and sticky and plastic in the subsoils indicating an increase in clay content in Bt horizons. Clay illuviation is the main pedogenic process in this soil.

Profile KTP-3 represents soils of the moderately dissected piedmonts (mapping unit P2). These soils are very deep (over 165 cm) well drained, dark red, very friable clays, with very thin brown, sandy loam topsoils. The soils are generally clayey in the subsoils, the topsoils are sandy loam. The wet consistence is mostly slightly sticky and plastic throughout the profile.

Table 4. Some morphological properties of the soils of Kitanda village

Profile/ Horizon	Depth (cm)	Texture	Colour (moist)	Structure	Consistence			Rock/ min. frag	Cutans	Pores	Boundary	Other features
					Dry	Moist	Wet					
KTP-1												
Ah	0-9	SCL	drb(5YR3/2)	mo,me,f,sbk	sh	fr	s,p	-	-	m,f,vf	cl,sm	Fe & Mn
Bt1	9-33	C	drb(2 5YR3/4)	mo,co,abk,sbk	h	fr	s,p	q	p,c,Fe	m,f,vf	grd,sm	nodules
Bt2	33-70	C	dur(10R3/4)	mo,co,abk,sbk	h	fr	s,p	-	p,c,Fe	m,f,vf	df,sm	in profile
Bt3	70-120	C	dur(10R3/4)	mo,co,abk,sbk	h	fr	s,p	-	-	m,f,vf	grd,sm	
Bt4	120-190	C	dr(2 5YR3/6)	mo,co,abk,sbk	h	fr	s,p	-	-	m,f,vf	-	
KTP-2												
Ap	0-15	SCL	drb(5YR3/2)	mo,me,f,sbk	-	fr	ss,p	-	-	m,f,vf	cl,wv	Crotovina,
Bt1	15-40	C	drb(5YR3/3)	mo,me,f,sbk	h	fr	s,p	-	-	fm,mf	grd,sm	Fe & Mn
Bt2	40-80	C	drb(2.5YR2 5/4)	mo,co,me,sbk	sh	fr	s,p	-	-	m,f,vf	grd,sm	nodules
Bt3	80-120	C	dur(10R3/4)	mo,co,me,sbk	sh	fr	s,p	q	-	m,f,vf	df,sm	in profile
Bt4	120-190	C	dur(10R3/4)	mo,co,me,sbk	sf	fr	s,p	-	-	m,f,vf	-	
KTP-3												
Ah	0-15	SL	br(5YR2.5/1)	w,me,f,sbk	-	vfr	ss,sp	-	-	m,f,vf	cl,sm	Fe & Mn
BA	15-35	SCL	drb(2 5YR2.5/4)	w,me,f,sbk	-	vfr	ss,p	-	-	m,f,vf	grd,sm	nodules
Bts1	35-80	C	dr(2 5YR3/6)	w,me,f,sbk	-	vfr	ss,p	-	-	m,f,vf	df,sm	at Bts2
Bts2	80-120	C	dr(2 5YR3/6)	w,me,f,sbk	-	vfr	ss,p	-	-	m,f,vf	df,sm	
Bts3	120-165	C	dr(2 5YR3/6)	w,me,f,sbk	-	vfr	ss,p	-	-	m,f,vf	-	
KTP-4												
Apg	0-20	SCL	drb(5YR3/2)	w,me,co,sbk	-	-	s,p	-	-	-	grd,sm	Yellow-red
2Cg	20-45	SCL	drb(5YR3/3)	-	-	-	s,p	-	-	-	cl,sm	mottles and
3cgr	45-60	SCL	dg(5YR4/1)	-	-	-	s,p	-	-	-	cl,sm	fibrous
4Cgr	60-80	SCL	vdg(5YR3/1)	-	-	-	s,p	-	-	-	cl,sm	materials in
5Cgr	80-100	CL	vdg(5YR3/1)	-	-	-	s,p	-	-	-	cl,sm	profile
6Cgr	100-120	SC	dg(7 5YR4/6)	-	-	-	s,p	-	-	-	cl,sm	
7Cr	120-150	C	dg(7.5YR4/6)	-	-	-	s,p	-	-	-	-	

Table 4. continued

KTP-5												
Ap	0-15	SCL	drb(5YR3/2)	w,me,f,sbk	-	fr	s,p	q	-	m,f,vf	cl,sm	Shallow
BA	15-25	SCL	drb(5YR3/3)	w,me,f,sbk	-	fr	s,p	q	-	m,f,vf	cl,sm	profile
BC/CB	25-90	C	dr(2.5YR3/6)	w,mo,f,sbk	h	fr	s,p	q	-	fmd,mf	-	
KTP-6												
Ah	0-10	SL	drb(5YR3/2)	w,mo,f,sbk	-	fr	s,p	q	-	m,med	cl,sm	Shallow
AC	10-20	SCL	drb(5YR3/3)	w,me,f,sbk	-	fr	s,p	q	-	m,med	grd,wv	profile
C	20-35	SCL	yr(5YR4/6)	w,me,f,sbk	-	fr	s,p	q	-	m,f	-	
KTP-7												
Ah	0-22	SCL	vdb(10YR2/2)	w,me,f,sbk	-	fr	s,p	-	-	co,med	cl,sm	High
BA	22-40	C	drb(5YR3/4)	w,me,f,sbk	-	fr	ss,p	q	-	m,me,co	grd,sm	biological
Bt1	40-80	C	dr(2.5YR3/6)	w,me,f,sbk	-	fr	s,p	q	-	fm,f	df,sm	activity
Bt2	80-130	C	r(10R4/6)	mo,me,co,sbk	-	fr	s,p	g	c	med,mf	df,sm	
Bt3	130-200	C	r(10R4/8)	mo,me,f,sbk	-	fr	s,p	q	c	fmed,vf	-	

Key:

Texture SCL= Sandy Clay Loam, C=clay, SL=Sandy Loam, CL=clay Loam

Colour: drb=dark reddish brown, dur=dusk red, dr=dark red, br=brown, r=red, dg=dark grey, vdg=very dark grey 10YR=hue, 3/4=value and chroma

Structure: mo=moderate, me=medium, f=fine, sbk=sub angular blocky, abk=angular blocky, w=weak, co=coarse

Consistence: sh=slightly hard, h=hard, sf=soft, fr=friable, vfr=very friable, s=sticky, ss=slightly sticky, p=plastic, sp= slightly plastic.

Rock/mineral fragments: q=quartz, g=granite

Cutans: p=patchy, c=clay cutans, Fe=sesquioxide cutans

Pores: m=many, f=fine, vf=very fine, fm=few, co=coarse, me=medium,

Boundary: cl=clear, sm=smooth, grd=gradual, df=diffuse.

Clay cutans are not observable in KTP-3 but there are frequent hard angular nodules of iron and manganese detected at 120 cm and below. The profile clearly indicates a higher degree of weathering.

Profile KTP-4 represents soils of the river valleys (mapping unit V). These soils are very deep, very poorly drained, dark grey to dark reddish brown, stratified, mottled, loams and sandy clay loams with thick, dark reddish brown sandy loam topsoils.The soils have a sticky and plastic consistence throughout their depth. Stratification indicates that these soils are depositional and probably the least developed among the three major landscapes in the village. Presence of yellowish red to brown Fe mottles at 20 cm and below is indicative of fluctuating water table levels which creates alternating oxidizing/reducing conditions within the profile. The soil has what the FAO (1988) defines as gleyic properties. The different strata observed in this profile represent a lithological discontinuity. The river valleys are situated in the lowest landscape which acts as the ultimate sink for materials from the adjacent landscapes. This unique position of the landscape gives the soils of the river valleys their fluvic properties.

Profile KTP-5 represents soils of the shoulders of the hilland (mapping unit H2). These soils are very shallow to shallow (15 cm), excessively drained, dark red, extremely gravelly friable clays, with very thin dark reddish brown, sandy clay loam topsoils. The soils have a sticky and plastic consistence throughout. The structure is generally weak, medium and fine subangular blocky. The limited depth, surface stoniness and high slopes (47%) are indicative of intense denudational processes taking place on this unit. Absence of a clearly developed B-horizon in profiles KTP-5 indicates that soil development has been minimal on this unit and this is due to steep slopes and faster rate of soil removal than formation and development (Stahler, 1950). Pedogenically KTP-5 is a young soil.

Profile KTP-6 reperesents soils of the sill summits (mapping unit H1). The soils are moderately shallow , well to somewhat excessively drained, yellowish red, very gravelly friable sand clays, having thin, black, very gravelly, clay loam topsoils. It is a typical AC profile with a sticky and plastic wet consistence. Absence of a B-horizon indicates that these soils have suffered intense denudation hence leaving the soil no time for horizonation processes to develop the profile. In terms of pedogenic development profile KTP-6 is most probably the youngest.

Particle size distribution

All soil profiles are predominantly clayey except KTP-4, KTP-5 and KTP-6 in which the subsoils are predominantly of sandy clay loam texture. The texture in topsoils is sandy clay loam for all profiles except KTP-3 and KTP-6 which had sandy loamy texture. The textures of profiles KTP-5 and KTP-6 are qualified as very gravelly in all depths. The distribution of clay with soil depth (Table 5 and Figure 2) shows that for profiles KTP-1, KTP-2 and KTP-7 there is clay illuviation in the subsoils. This observation is supported by presence of clay cutans in these profiles and the increase in clay content with soil depth. Despite net increase of clay content with depth in KTP-3, clay cutans were not observable in the field. There is an increase in clay content with depth in KTP-4 though irregular. Presence of stratification in this profile means that the soil has a lithological discontinuity. Thus the clay distribution is more influenced by the nature of parent material in each stratum than illuviation of the clay from topsoils to subsoils. For profiles KTP-5 and KTP-6, there is clay increase with depth, but the landscape positions of these profiles (summits and backslopes) are a limiting factor to serious pedogenic development. The clay increase with depth in these shallow soils indicates that clay illuviation has been taking place but since these profiles are exposed to much denudation, the soil material has been removed and transported to the lower landscapes faster than soil development, hence absence of diagnostic B-horizons.

Table 5. Selected physical properties of soils of Kitanda village

Profile/Horizon	Depth (cm)	Particle size Distribution(%)			Texture class	Density (g/cm³)		Porosity (%)	Available water capacity	
		Sand	Silt	Clay		Bulk	Particle		vol (%)	mm/m
KTP-1										
Ah	0-9	66	8	26	SCL	1.2	2.67	56	14	
Bt1	9-33	34	18	48	C	nd	nd	nd	nd	
Bt2	33-70	24	12	64	C	1.5	2.78	46	17	176
Bt3	70-120	26	12	62	C	1.3	2.75	51	20	
Bt4	120-190	24	12	64	C	nd	nd	nd	nd	
KTP-2										
Ap	0-15	46	20	34	SCL	1.1	2.73	61	10	
Bt1	15-40	38	10	52	C	nd	nd	nd	nd	
Bt2	40-80	32	14	54	C	1.2	2.78	55	17	164
Bt3	80-120	32	12	56	C	1.2	2.73	56	19	
Bt4	120-190	30	10	60	C	nd	nd	nd	nd	
KTP-3										
Ah	0-15	77	6	17	SL	0.8	2.91	72	9	
BA	15-35	54	14	32	SCL	nd	nd	nd	nd	
Bts1	35-80	40	8	52	C	1.2	2.79	58	13	131
Bts2	80-120	38	10	52	C	1.1	2.85	59	19	
Bts3	120-165	34	10	54	C	nd	nd	nd	nd	
KTP-4										
Apg	0-20	54	18	28	SCL	nd	nd	nd	nd	
2Cg	20-45	63	16	21	SCL	nd	nd	nd	nd	
3Cgr	45-60	65	14	21	SCL	nd	nd	nd	nd	
4Cgr	60-80	60	8	32	SCL	nd	nd	nd	nd	nd
5Cgr	80-100	42	20	39	CL	nd	nd	nd	nd	
6Cgr	100-120	46	14	40	SC	nd	nd	nd	nd	
7Cgr	120-150	42	14	44	C	nd	nd	nd	nd	
KTP-5										
Ap	0-15	62	16	22	SCL	nd	nd	nd	nd	
BA	15-25	54	16	30	SCL	nd	nd	nd	nd	nd
BC/CB	25-90	42	14	44	C	nd	nd	nd	nd	
KTP-6										
Ah	0-10	77	8	15	SL	nd	nd	nd	nd	
AC	10-20	70	6	24	SCL	nd	nd	nd	nd	nd
C	20-35	56	18	26	SCL	nd	nd	nd	nd	
KTP-7										
Ah	0-22	64	12	24	SCL	1.0	2.59	63	10	
BA	22-40	42	14	44	C	nd	nd	nd	nd	
Bt1	40-80	34	12	54	C	1.2	2.70	56	17	157
Bt2	80-130	32	14	54	C	1.3	2.80	55	18	
Bt3	130-200	32	14	54	C	nd	nd	nd	nd	

nd = not determined

Table 5. Selected physical properties of soils of Kitanda village

Profile/Horizon	Depth (cm)	Particle size Distribution(%)			Texture class	Density (g/cm³)		Porosity (%)	Available water capacity	
		Sand	Silt	Clay		Bulk	Particle		vol (%)	mm/m
KTP-1										
Ah	0-9	66	8	26	SCL	1.2	2.67	56	14	
Bt1	9-33	34	18	48	C	nd	nd	nd	nd	
Bt2	33-70	24	12	64	C	1.5	2.78	46	17	176
Bt3	70-120	26	12	62	C	1.3	2.75	51	20	
Bt4	120-190	24	12	64	C	nd	nd	nd	nd	
KTP-2										
Ap	0-15	46	20	34	SCL	1.1	2.73	61	10	
Bt1	15-40	38	10	52	C	nd	nd	nd	nd	
Bt2	40-80	32	14	54	C	1.2	2.78	55	17	164
Bt3	80-120	32	12	56	C	1.2	2.73	56	19	
Bt4	120-190	30	10	60	C	nd	nd	nd	nd	
KTP-3										
Ah	0-15	77	6	17	SL	0.8	2.91	72	9	
BA	15-35	54	14	32	SCL	nd	nd	nd	nd	
Bts1	35-80	40	8	52	C	1.2	2.79	58	13	131
Bts2	80-120	38	10	52	C	1.1	2.85	59	18	
Bts3	120-165	34	10	54	C	nd	nd	nd	nd	
KTP-4										
Apg	0-20	54	18	28	SCL	nd	nd	nd	nd	
2Cg	20-45	63	16	21	SCL	nd	nd	nd	nd	
3Cgr	45-60	65	14	21	SCL	nd	nd	nd	nd	
4Cgr	60-80	60	8	32	SCL	nd	nd	nd	nd	nd
5Cgr	80-100	42	20	38	CL	nd	nd	nd	nd	
6Cgr	100-120	46	14	40	SC	nd	nd	nd	nd	
7Cgr	120-150	42	14	44	C	nd	nd	nd	nd	
KTP-5										
Ap	0-15	62	16	22	SCL	nd	nd	nd	nd	
BA	15-25	54	16	30	SCL	nd	nd	nd	nd	nd
BC/CB	25-90	42	14	44	C	nd	nd	nd	nd	
KTP-6										
Ah	0-10	77	8	15	SL	nd	nd	nd	nd	
AC	10-20	70	6	24	SCL	nd	nd	nd	nd	nd
C	20-35	56	18	26	SCL	nd	nd	nd	nd	
KTP-7										
Ah	0-22	64	12	24	SCL	1.0	2.59	63	10	
BA	22-40	42	14	44	C	nd	nd	nd	nd	
Bt1	40-80	34	12	54	C	1.2	2.70	56	17	157
Bt2	80-130	32	14	54	C	1.3	2.80	55	18	
Bt3	130-200	32	14	54	C	nd	nd	nd	nd	

nd = not determined

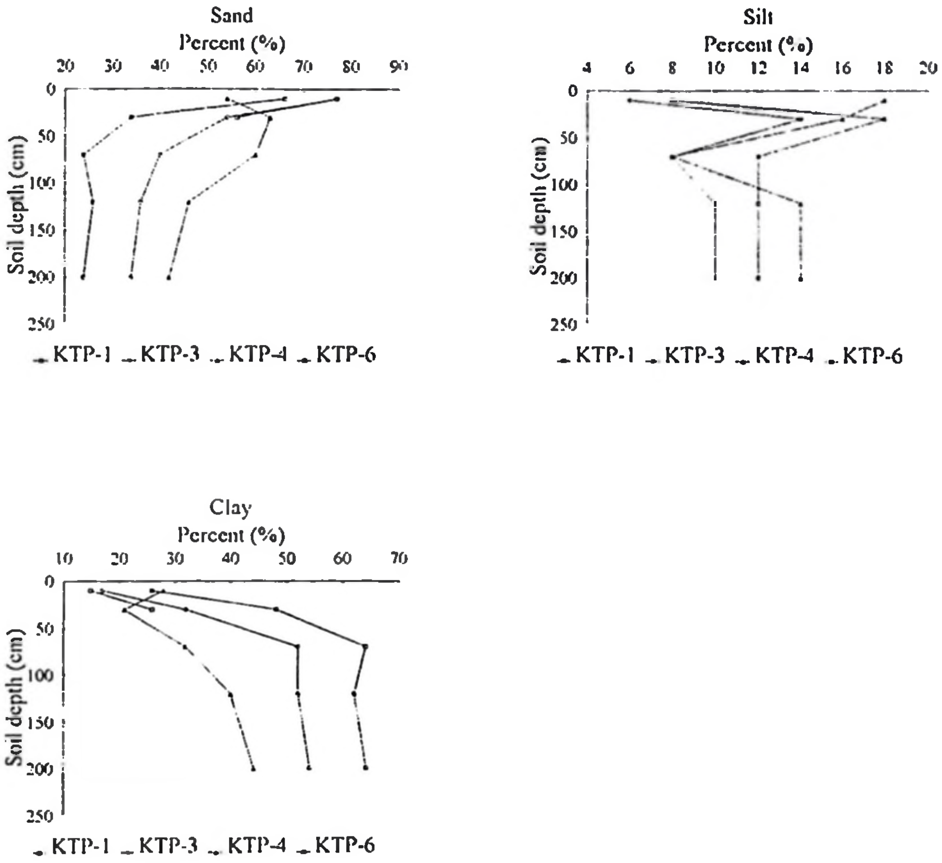


Figure 2. Particle size distribution versus soil depth

Bulk density, particle density and porosity

Bulk density, particle density, porosity and available water capacity were measured in only four profiles (KTP-1, KTP-2, KTP-3 and KTP-7). Samples were not taken from KTP-4 due to its permanent water saturation and KTP-5 and KTP-6 due to their shallow depth. Generally bulk density ranges from 0.8 - 1.2 Mgm^{-3} for topsoils and from 1.2 - 1.5 Mgm^{-3} for subsoils. The lowest topsoil bulk density value is in profile KTP-3 and the highest in profile KTP-1. Subsoils have higher bulk density values than the topsoils. The values ranged from 1.2 Mgm^{-3} for KTP-2, KTP-3 and KTP-7 to 1.5 Mgm^{-3} for KTP-1. According to Taylor *et al.* (1966) bulk density values of 0.9 - 1.2 Mgm^{-3} for most soils are considered normal for recently cultivated soils. For the soils not recently cultivated but not compacted like those of Kitanda values of 1.1 - 1.4 Mgm^{-3} are regarded as normal except for profile KTP-1 which has a bulk density of 1.5 Mgm^{-3} in the clayey subsoil, a condition which is likely to cause root impedance. Lower bulk density values in the topsoils relative to the subsoils can be attributed to the influence of organic matter and higher biological activity in those parts of the profiles.

In the topsoils, particle density ranges from 2.58 Mgm^{-3} for profile KTP-7 to 2.91 Mgm^{-3} for KTP-3. In the subsoils, it ranges from 2.73 Mgm^{-3} in KTP-2 to 2.85 Mgm^{-3} for KTP-3. Particle density is relatively high in KTP-3 and relatively low in KTP-7. The order of magnitude is KTP-3>KTP-2>KTP-1>KTP-7. This order is similar to the order of distribution of iron oxides in the studied soils. Generally, particle density increases with soil depth in most of the profiles. The low particle density values in topsoils suggest influence of organic matter while higher particle density values in the subsoils are probably related to an increase in iron oxides with soil depth (see Table 9). According to Landon (1991) soils rich in humus have low particle density (around 1.37 Mgm^{-3}) while those rich in iron oxides have a higher particle density (around 3.74 Mgm^{-3}). The particle density ranges from 2.6 to 2.9 Mgm^{-3} which suggests that the soils have moderate levels of humus, are more ferruginous and hence highly weathered. Soil fertility maintenance in these soils is crucial for their sustainable utilization. The highest total porosity value of 72% is observed in profile KTP-3 while the lowest is 56% observed in profile KTP-1. Total porosity in the subsoils ranges from 51% in KTP-1 to 59% in KTP-3. Generally there is a decrease in total porosity in all profiles from topsoil to subsoil thus indicating an increase in the degree of compaction in the subsoils. The overall order of the total porosity is KTP-3>KTP-7>KTP-2>KTP-1.

Water retention characteristics

Moisture retention capacities from 0.01 to 15 bars for profiles KTP-1, KTP-2, KTP-3 and KTP-7 are presented in Appendix 2 and Figure 3. Generally the available water capacity in each profile increases with soil depth as is the increase in clay content. The highest available water capacity in topsoils is observed in profile KTP-1 (14%) and the lowest in profile KTP-3 (9%). Profile KTP-1 has more available moisture (20%) than other profiles while profiles KTP-3 nd KTP-7 have the lowest (18%).

Available water capacity (mm/m) is highest in profile KTP-1 (176mm/m) and lowest in profile KTP-3 (131mm/m). The order is KTP-1>KTP-2>KTP-7>KTP-3 which parallels the clay content for the four profiles thus indicating that clay content has a great influence on the water retention capacities in the studied soils. The correlation between clay-plus-silt content of soils and moisture retention is positive for most soils (Salter *et al.*,1966; Jamison and Kroth, 1958). According to Landon (1991), the available water capacity (mm/m) for all the four profiles can be categorized as medium (120-180 mm/m). In view of the predominantly clayey texture of the soils, most of the unavailable water could be associated with micropores in which water is held more tenaciously and thus becomes unavailable to plants. Clay soils though high in residual water values are known to have low to moderate available water capacities (Hillel, 1982).

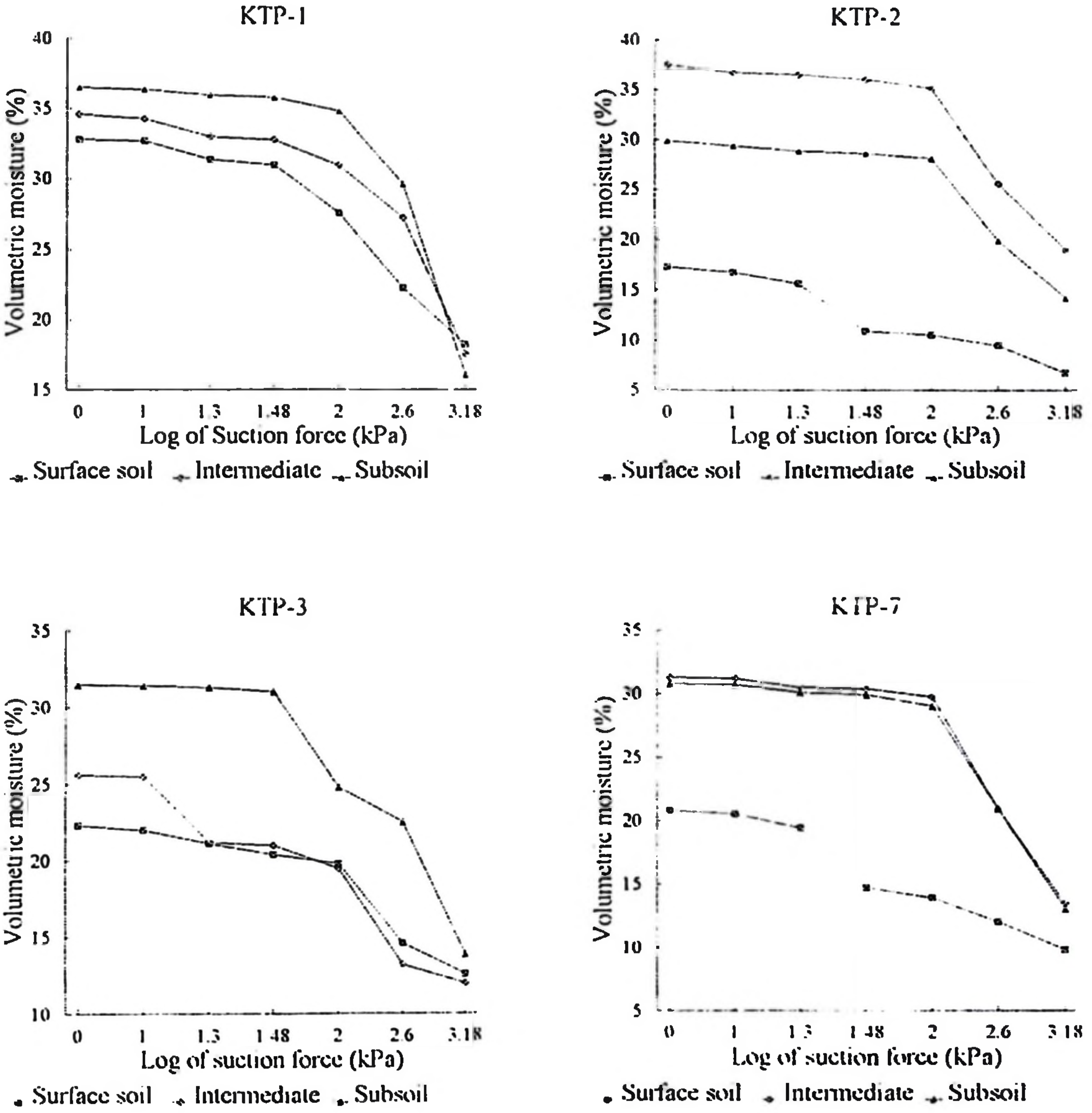


Figure 3. Moisture retention characteristics of some soils of Kitanda village

4.1.2 Chemical characteristics of the soils

Some of the chemical properties of soils from hilland, piedmonts and river valleys of Kitanda village are presented in Table 6 and Figure 4.

Soil pH and electrical conductivity

Soils of Kitanda village are generally acidic. The soil pH in the topsoils ranges from slightly acid (pH 6.1) for profile KTP-1 to strongly acid (pH 5.2) for KTP-3. The pH in the subsoils ranges from slightly acid (pH 6.1) for profile KTP-5 to very strongly acid (pH 5.0) for KTP-3. Generally the pH decreases with soil depth in all profiles except profile KTP-3 in which there is a slight increase of pH with depth and KTP-4 in which there is no clear trend. The soils in the river valleys have lower pH values than soils in the other landscape positions. Soils in the river valleys are formed from the acidic material transported from other landscapes (hilland and piedmonts) through erosion and deposition. Further lateral movement of water removes more bases leaving the soils more acidic and hence the low pH values observed.The electrical conductivity of all soils is less than 0.1 mS/cm a range indicating there is no salinity hazard at present.

Organic carbon and total nitrogen

Organic carbon contents in topsoils range from 2.4% (KTP-2) to 5.5% (KTP-6). Most topsoils have organic carbon around 3% or more which is high according to Landon (1991). Organic carbon in subsoils ranges from 3.5% for KTP-4 to 0.1% for KTP-1. For all profiles there is a regular decrease of percent organic carbon with soil depth except for KTP-4. This profile has an exceptionally high and irregular distribution of organic carbon with soil depth. Being situated in the river valley landscape, the soil has formed from different cycles of deposition of soil material and stratification is an evident morphological feature of the profile.

Table 6. Selected chemical properties of the soils of Kitanda village

Profile/ Horizon	Depth (cm)	pH	%OC	%N	C:N	P (mg/ kg)	CEC	Ca	Mg	K	Na	H	Al	% Al sat	% BS
							cmol (+)/kg								
KTP-1															
Ah	0-9	6.1	4.0	0.24	17	30	24	10.6	3.5	1.8	0.06	0.5	-		67
Bt1	9-33	5.9	1.1	0.07	16	7	10	3.6	1.6	0.65	0.02	0.4	-	-	53
Bt2	33-70	5.7	0.9	0.05	18	6	8	2.6	0.9	0.62	0.16	0.3	0.2	2.5	54
Bt3	70-120	5.6	0.7	0.03	23	1	7	1.6	0.7	0.98	0.02	0.5	0.2	2.8	47
Bt4	120-190	5.7	0.1	0.04	3	1	6	1.7	0.9	0.48	0.02	0.5	-	-	52
KTP-2															
Ap	0-15	5.6	2.4	0.18	13	6	18	6.6	1.4	1.52	0.02	0.3	0.4	2.2	53
Bt1	15-40	5.6	1.2	0.10	12	2	16	6.2	2.1	0.37	0.14	0.3	-	-	55
Bt2	40-80	5.7	0.5	0.06	8	1	10	3.9	1.3	0.21	0.04	0.2	1.5	15	55
Bt3	80-120	5.4	0.3	0.06	5	1	6	2.7	0.4	0.17	0.02	0.3	0.1	1.6	55
Bt4	120-190	5.4	0.2	0.04	5	1	6	2.2	0.5	0.33	0.05	0.5	0.2	3.3	51
KTP-3															
Ah	0-15	5.2	3.7	0.23	16	24	13	3.5	0.6	0.30	0.02	0.6	0.6	4.6	34
BA	15-35	5.0	2.2	0.13	17	10	8	2.6	0.8	0.10	0.02	0.5	0.6	7.5	44
Bts1	35-80	5.3	0.7	0.04	18	1	8	2.5	0.9	0.27	0.10	0.4	1.1	14	46
Bts2	80-120	5.7	0.3	0.05	16	1	8	3.5	0.6	0.13	0.08	0.4	-	-	56
Bts3	120-165	5.7	0.2	0.02	10	1	7	3.4	0.6	0.10	0.07	0.2	-	-	59
KTP-4															
Apg	0-20	5.3	3.9	0.25	16	5	14	4.0	1.2	0.20	0.03	0.5	0.2	1.4	39
2Cg	20-45	5.1	3.5	0.21	17	3	14	5.6	0.8	0.13	0.02	0.8	0.4	2.9	47
3Cgr	45-60	4.8	3.9	0.26	15	1	16	3.8	0.9	0.12	0.02	1.2	0.8	5	30
4Cgr	60-80	5.0	3.1	0.17	18	6	16	3.8	0.8	0.26	0.02	1.6	0.7	4.3	31
5Cgr	80-100	5.1	2.0	0.12	17	3	18	3.9	0.6	0.18	0.04	1.6	0.8	4.4	25
6Cgr	100-120	5.1	2.1	0.13	16	4	18	3.9	0.8	0.14	0.03	1.7	1.0	5.5	27
7Cgr	120-150	5.0	2.0	0.12	17	5	12	3.7	0.7	0.20	0.02	2.0	1.4	12	39
KTP-5															
Ap	0-15	6.0	2.9	0.16	18	46	20	10	2.1	1.21	0.02	0.3	-	-	67
BA	15-25	6.1	1.7	0.10	17	6	20	9.6	1.4	0.56	0.07	0.3	-	-	58
BC/CB	25-90	5.9	0.4	0.03	13	3	8	4.0	0.6	0.40	0.02	0.3	0.1	1.3	63
KTP-6															
Ah	0-10	5.7	5.5	0.32	18	11	24	7.8	2.3	0.85	0.06	0.3	0.1	0.4	46
AC	10-20	5.3	2.4	0.16	15	6	16	6.8	0.6	0.22	0.02	0.6	0.8	5	48
C	20-35	5.1	1.0	0.06	17	2	18	4.6	0.9	0.34	0.10	0.9	0.7	3.8	33
KTP-7															
Ah	0-22	5.7	3.4	0.22	15	3	17	5.2	2.2	1.61	0.02	0.3	0.1	0.5	53
BA	22-40	5.1	1.3	0.11	12	2	9	3.2	0.8	0.32	0.07	0.8	0.3	3.3	49
Bt1	40-80	4.9	0.6	0.06	10	2	8	2.0	0.1	0.13	0.02	1.4	0.6	7.5	28
Bt2	80-130	5.1	0.2	0.02	10	1	6	1.8	0.5	0.06	0.02	1.2	0.7	12	39
Bt3	130-200	5.3	0.4	0.01	40	1	6	2.1	0.2	0.07	0.02	1.0	0.9	15	40

NB: - means not observed

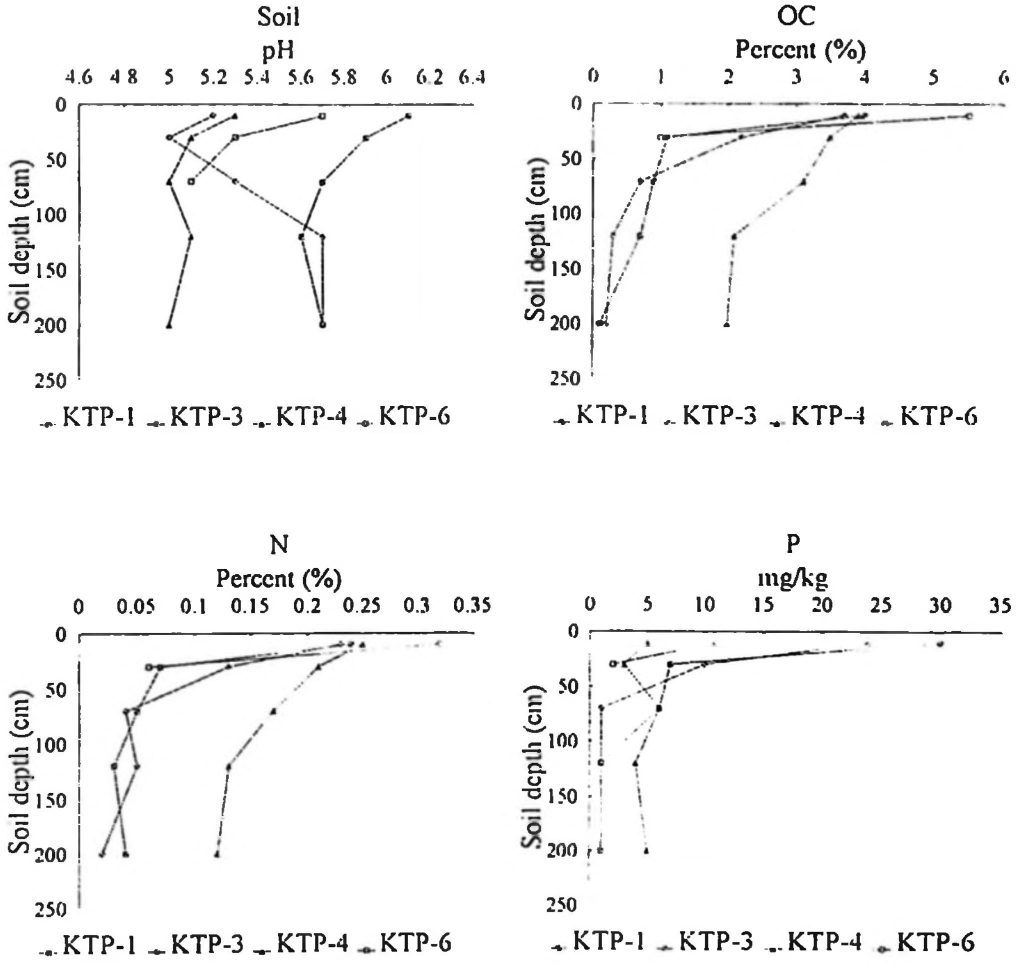
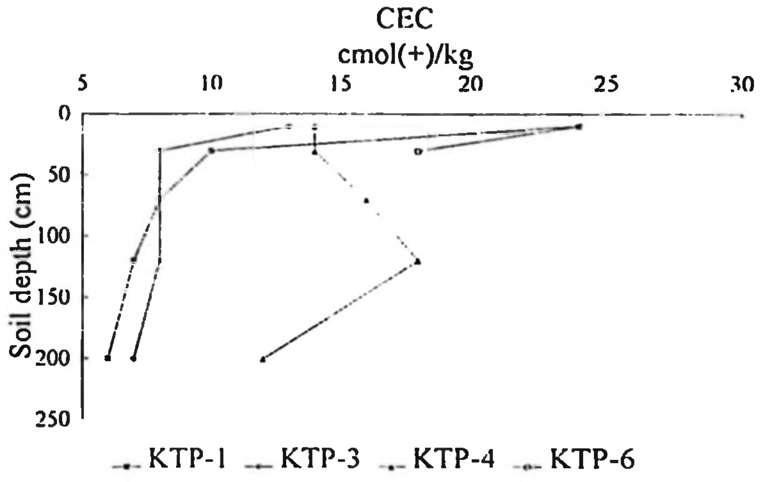


Figure 4. Selected chemical properties for some profiles of Kitanda.



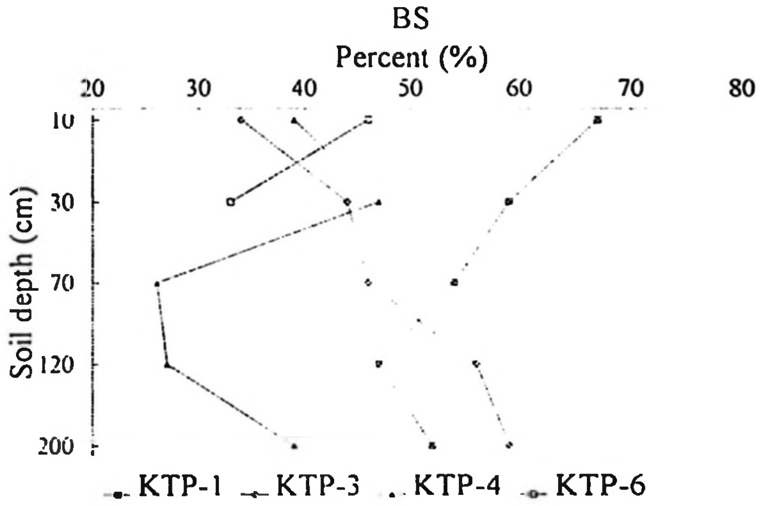


Figure 4 continued.

These features are referred to as fluvic properties (FAO, 1988). The relatively higher levels of organic carbon in the topsoils of all profiles is probably due to higher levels of organic matter in the surface soils as a result of decomposed surface vegetation. Burning of vegetation is a common practice in this village and it could exaggerate some of the observed organic carbon values especially for KTP-1, KTP-3 and KTP-6.

The relatively lower level of organic carbon in profile KTP-2 compared to other profiles is probably due to the land use practises. The profile is located in what used to be a coffee farm in the near past while the other profiles were dug from fresh sites. The effect of tillage in exposing the soil organic matter to faster rates of decomposition and hence low level in the soil has been explained by Donahue *et al.* (1990).The total nitrogen content in the soils follows a similar trend to the organic carbon in terms of amounts among profiles and distribution within each profile. A positive correlation between organic carbon and total nitrogen in soils has also been reported by Donahue *et al.* (1990). The levels of total nitrogen are mostly medium (0.21-0.50%) for the topsoils except KTP-2 and KTP-5 which have low levels of total nitrogen. In the subsoils nitrogen levels varied from low (0.1 - 0.2%) to very low (less than 0.1%).

The C/N ratios give an indication of the quality of the organic matter and in particular, the degree of humification (Landon, 1991). The C/N ratios in the topsoils of Kitanda village range from 13 to 18. This range represents soils of good to moderate quality organic matter. Profile KTP-2 has a C/N ratio of 13 (good quality organic matter). Other profiles have ratios ranging from 16 to 18 (moderate quality organic matter). The relatively narrower C/N ratio for profile KTP-2 is probably influenced by land use practices. The profile is located in what used to be a coffee farm and in which the "ngoro" (local tie-ridge) cultivation system has been practised. Beans are normally grown on the"ngoro" and their residues incorporated into the soil. The incorporation of legume residues in the soil tends to narrow the C/N ratio owing to their high nitrogen content. The slightly wider C/N ratio (18) for profile KTP-5 could probably be related to higher levels of erosion on this mapping unit as observed in the field. Since erosion sediment is the richest part of the soil containing high levels of organic matter and nitrogen (Donahue *et al.*, 1990), its loss leaves the soil with very little nitrogen reserves and hence wider C/N ratios. The quality of the organic matter in terms of C/N ratio in the soils of Kitanda can be regarded to be in the order piedmonts > river valleys > hilland.

Available phosphorus

The topsoil phosphorus levels range from high (> 20mg/kg) for profiles KTP-1, KTP-3, KTP-5 and KTP-6, to low (< 7 mg/kg) for profiles KTP-2, KTP-4 and KTP-7. In the subsoils, phosphorus levels are generally low. Surface soils have relatively higher levels of phosphorus probably from decomposed vegetation deposited onto the soil surface. The low levels of phosphorus in the soils indicate a potential problem of deficiency to sensitive crops and P-fixation in these soils. Therefore any future recommendation on phosphatic fertilizer use for these soils should consider this factor. For all profiles except KTP-4 there is a gradual decrease of phosphorus with soil depth which suggests that the observed levels of phosphorus are associated with the organic matter. The irregular decrease of phosphorus with soil depth in KTP-4 is most probably associated with its fluvic properties and the lithological discontinuity observed in this profile.

Cation exchange capacity (CEC)

The CEC in the topsoils of the studied soils ranges from 13 cmol(+)/kg of soil to 24 cmol(+)/kg of soil for profiles KTP-3, KTP-1 and KTP-6 . The levels are classified by Baize (1993) as being medium (12 - 25.0 cmol(+)/kg soil). The CEC in the subsoils is low (6-12 cmol(+)/kg soil) in all profiles except KTP-4 and KTP-6. There is a general decline of CEC with soil depth as does the organic carbon content (see Figure 4). Clay content though increases with soil depth. Organic matter, pH and clay content are factors known to affect the CEC of soils (Bohn *et al.*, 1985). The decrease of CEC with soil depth while the clay content increases, suggests that the observed CEC in the topsoils is mostly contributed by the organic matter while in the subsoils it is largely contributed by the clay fraction of the soil.

Exchangeable bases and base saturation

The distribution of the major exchangeable bases with soil depth is given in Figure 5. In profile KTP-1, exchangeable calcium and magnesium are high (10.6 cmol(+)/kg soil for calcium, 3.5 cmol(+)/kg soil for magnesium) in the topsoils. In the subsoils they become very low for calcium (1.6 cmol(+)/kg soil) and low for magnesium (0.7 cmol(+)/kg soil). Potassium levels in the topsoil are high (1.8 cmol(+)/kg soil) while sodium levels are very low (0.06 cmol(+)/kgsoil). In the subsoils these levels drop to low (0.4 cmol(+)/kg for potassium while the sodium levels remain very low (<0.1 cmol (+)/kg soil). Base saturation drops from 67% at the surface to 52% in the subsoils. There is a gradual decrease of bases and base saturation with soil depth except for sodium which has irregular decrease with depth. Calcium is the dominant cation accounting for nearly 80% of the total exchangeable bases. The general trend in all horizons was Ca>Mg>K>Na.

Profile KTP-2 has medium levels of calcium (6.6 cmol(+)/kg) and magnesium (1.4 cmol(+)/kg) in the topsoils. In the subsoils both calcium and magnesium are very low (<0.5 cmol for Ca and <0.25 cmol (+)/kg soil for Mg). Potassium levels in the topsoils are high (1.52 cmol(+)/kg) while in the subsoil they become low (0.3 cmol(+)/kg). Sodium levels are very low throughout the profile. Base saturation in profile KTP-2 remains almost uniform throughout. At the surface it is 53% and drops only to 51% at the bottom of the profile.

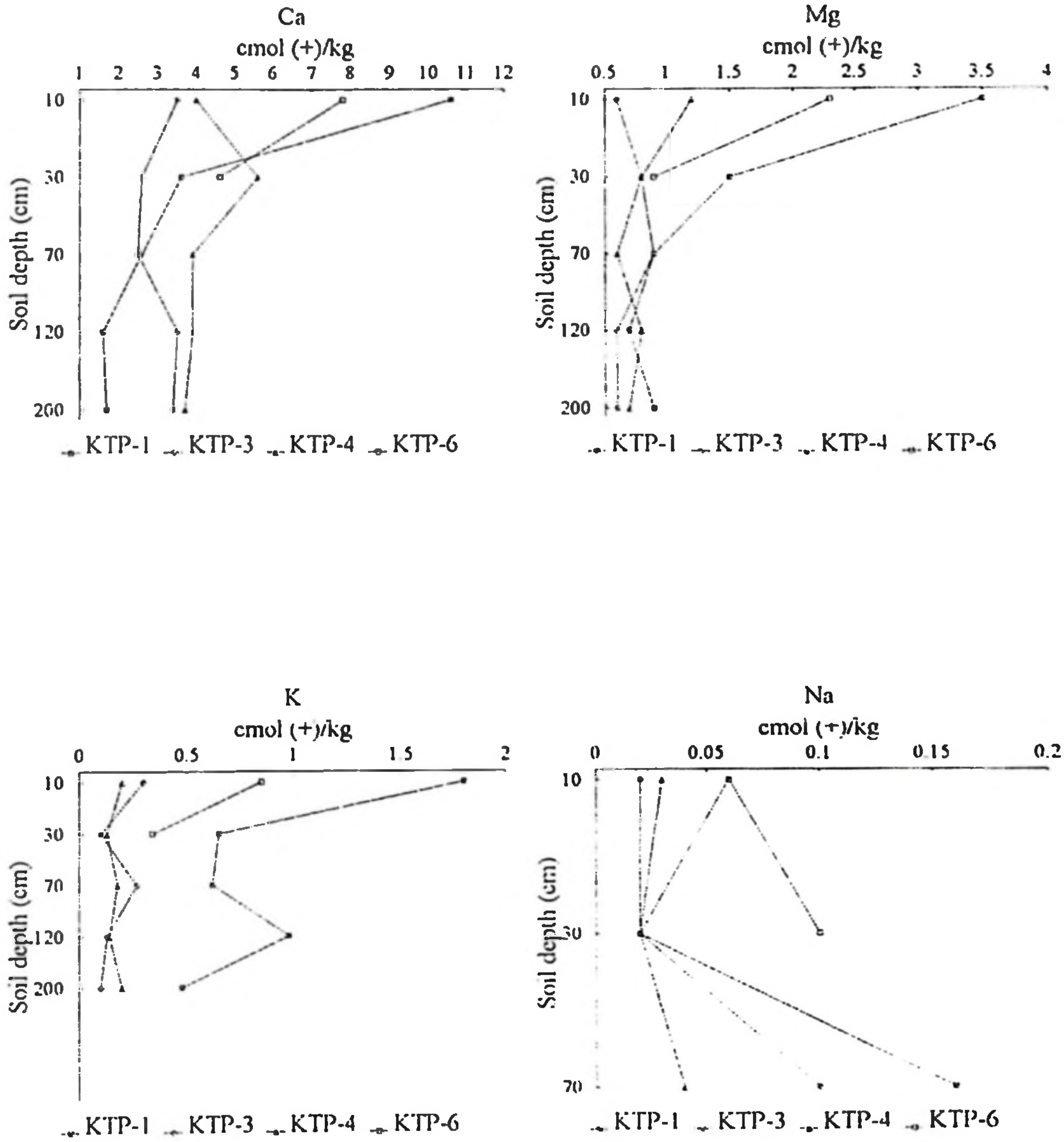


Figure 5. Distribution of exchangeable bases with soil depth

Calcium is the dominant cation throughout the depth of profile KTP-2. There is a gradual decline in the content of exchangeable bases with soil depth except for sodium which shows an irregular pattern of decrease with soil depth.

Profile KTP-3 has low calcium (about 3.5 cmol(+)/kg) and magnesium (about 0.6 cmol (+)/kg) throughout the profile. There is no clear pattern of distribution of calcium and magnesium with soil depth in this profile. Potassium level in the topsoil is low (0.3 cmol (+)/kg) and decreases to very low (0.1 cmol (+)/kg) in the subsoil. Sodium levels remain very low throughout profile KTP-3. Generally, there is an increase in base saturation with soil depth. The last two horizons have a base saturation slightly above 50%.

In profile KTP-4 the topsoil levels of calcium are low (4.0 cmol(+)/kg) and show irregular decline with soil depth to 3.7 cmol (+)/kg at 150 cm depth and below. Magnesium levels are medium (1.2 cmol (+)/kg) in the topsoil and are low in the subsoils and they show irregular decline with soil depth. Base saturation in profile KTP-4 remains below 50% throughout its depth.Base saturation shows an irregular decrease with soil depth. The irregular decrease of the exchangeable bases in profile KTP-4 is related to the fluvic properties observed in this profile.

Profiles KTP-5 and KTP-6 have similar characteristics in terms of exchangeable bases. Both profiles are shallow and represent the hilland. They have medium levels of calcium (about 10.0 cmol(+)/kg) and magnesium (about 2.0 cmol(+)/kg) in topsoils and gradually decrease to medium for calcium (about 4 cmol(+)/kg) and low for magnesium (about 0.6 cmol(+)/kg in the subsoils. The base saturation values of KTP-5 remain above 50% throughout, while those of KTP-6 are below 50% throughout the profile.

Profile KTP-7 has medium levels of calcium and magnesium (5.2cmol(+)/kg and 2.2 cmol(+)/kg respectively) at the surface and gradually decrease to very low levels in the subsoils (<2.0 cmol(+)/kg for calcium and <0.3 cmol(+)/kg for magnesium). There is decrease in the levels of both calcium and magnesium with soil depth. Potassium is high

(1.61 cmol(+)/kg) in the topsoils but very low (<0.13 cmol(+)/kg) in the subsoils. There is a regular decrease in potassium with soil depth while sodium shows an irregular decline. Calcium is the dominant cation accounting for nearly 50% of the exchangeable bases. Base saturation is generally below 50% throughout the subsoils.

Aluminium saturation

According to International Land Development Consultants (ILACO) (1981), aluminium toxicity in tropical soils is of more importance to crop performance than is the absolute pH or soil acidity. The highest aluminium saturation is 15% and is found in the subsoils of profiles KTP-2 and KTP-7. The lowest saturation is 0.4% and is in profile KTP-6. These levels are classified by Baize (1993) as very low (<10%). Only four profiles have slightly higher levels, KTP-2 (15%), KTP-3 (13.8%), KTP-4 (11.7%) and KTP-7 (15%). These levels are still low. For most profiles aluminium saturation increases with soil depth.

Micronutrients (Zn, Cu, Fe, Mn)

The status of some micronutrients in the soils of Kitanda is summarized in Table 7. The distribution of the four micronutrients in the top and subsoils is graphically presented in Figure 6.

The critical level for zinc by the DPTA method is estimated at 0.2 - 2.0 mg/kg (Sims and Johnson, 1991). The highest topsoil zinc levels is found in profile KTP-1 (3.7 mg/kg) while profile KTP-3 has the lowest value (0.46 mg/kg). In subsoils KTP-1 has the highest concentration (1.16 mg/kg) while KTP-3 had the least (0.14 mg/kg). Topsoils in all profiles have more zinc than the subsoils. Levels of zinc decrease with soil depth for all profiles. The accumulation of zinc in the topsoils is normally attributed to the influence of soil organic matter (Mitchell, 1971). Profile KTP-3 has relatively low levels of zinc in the subsoils (0.14 mg/kg). Soils represented by this profile may develop deficiencies if intensively cropped.

Table 7. Levels of some micronutrients in the soils of Kitanda village

Profile/ Horizon	Depth (cm)	Concentration (mg/kg soil)			
		Zn	Cu	Fe	Mn
KTP-1					
Ah	0-9	3.70	2.81	57.34	197.34
Bt1	9-33	0.92	2.82	50.63	24.79
Bt2	33-70	0.77	1.56	39.70	104.24
Bt3	70-120	1.16	1.81	29.02	105.25
Bt4	120-190	0.99	1.29	16.64	63.76
KTP-2					
Ap	0-15	1.23	18.27	64.43	141.68
Bt1	15-40	0.23	3.64	29.89	90.07
Bt2	40-80	0.27	2.25	24.93	86.53
Bt3	80-120	0.37	1.51	25.31	114.86
Bt4	120-190	0.30	0.96	19.10	83.49
KTP-3					
Ah	0-15	0.46	1.46	57.22	18.22
BA	15-35	0.20	1.59	42.34	18.22
Bts1	35-80	0.25	0.92	22.38	11.13
Bts2	80-120	0.17	0.47	12.16	1.54
Bts3	120-165	0.14	0.41	11.05	0.89
KTP-4					
Apg	0-20	0.82	4.52	228.53	134.60
2Cg	20-45	0.70	3.38	892.66	89.06
3Cgr	45-60	0.99	3.22	940.27	53.13
4Cgr	60-80	0.54	4.62	758.80	97.91
5Cgr	80-100	0.46	4.96	451.70	80.96
6Cgr	100-120	0.40	5.22	608.92	89.31
7Cgr	120-150	0.34	4.45	679.48	93.10
KTP-5					
Ap	0-15	1.02	1.35	67.78	58.70
BA	15-25	0.92	2.41	36.68	40.99
BC/CB	25-90	0.25	0.96	24.15	27.32
KTP-6					
Ah	0-10	1.42	2.81	126.80	54.14
AC	10-20	1.23	4.25	115.24	39.97
C	20-35	0.32	3.19	53.28	8.02
KTP-7					
Ah	0-22	0.73	1.48	70.44	26.31
BA	22-40	0.26	1.49	41.33	31.88
Bt1	40-80	0.19	0.87	22.76	27.32
Bt2	80-130	0.33	0.60	12.00	11.64
Bt3	130-200	0.22	0.42	11.70	6.96

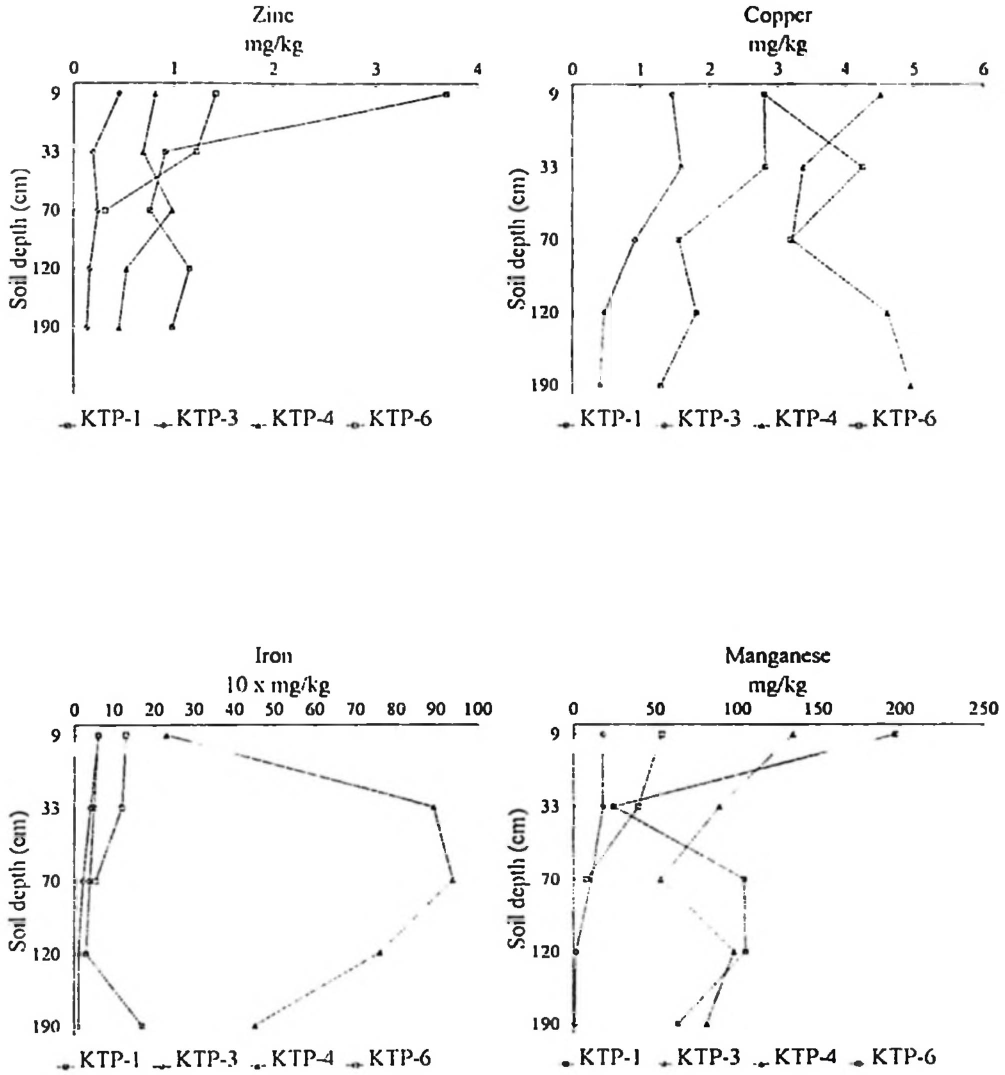


Figure 6. Distribution of micronutrients with depth in some soils of Kitanda.

Generally, all profiles have adequate levels of copper. According to Sims and Johnson (1991), the critical level for copper by the DPTA-method (used in this study) ranges from 0.12 to 0.25 mg/kg. None of the profiles has copper less than 0.12 mg/kg. In the topsoils copper is highest in profile KTP-2 (18.77 mg/kg) while profile KTP-5 has the lowest (1.35 mg/kg). In subsoils, the highest level is in KTP-4 (5 mg/kg) while the lowest is in KTP-3 (0.4 mg/kg). There is a gradual decrease in the levels of copper with soil depth except in profile KTP-4 which has an irregular distribution throughout the profile probably due to the fluvic properties observed in this profile. The availability of copper in the soils is influenced by, among other factors, level of organic matter, soil pH, calcium carbonate and phosphorus levels (Sims and Johnson, 1991). Organic matter is probably the major contributor of the observed levels of copper in the topsoils of Kitanda. The relatively higher concentration of copper in the topsoils of KTP-2 is most probably associated with the land use in this unit. The profile is located in a former coffee farm. The copper levels could therefore be associated with copper fungicides normally sprayed in coffee farms. High levels of copper have been found in Kilimanjaro region coffee farms (Mkindi, 1990). Profile KTP-4 was found to have more copper than the other profiles which is probably due to its landscape position, being in the valley bottom which is a position of enrichment.

Iron levels in all profiles are higher than the critical range 2.5 - 5.0 mg/kg (Sims and Johnson, 1991). The relatively high levels of iron in these soils could probably be associated with the parent materials from which these soils are derived. However, as the parent materials were not analyzed, this remains an area that may need further research. In all profiles except profile KTP-4 there is a regular decrease of concentration of iron with soil depth. Profile KTP-4 has an irregular distribution of iron in the profile. Highest levels of iron in the surface soils are observed in profile KTP-4 (228.53 mg/kg) while the lowest are observed in KTP-3 (57.22 mg/kg). In the subsoils highest levels of iron are observed in KTP-4 (940.27 mg/kg) while the lowest are in KTP-3 (11.05 mg/kg). Two factors may have contributed to the relatively high levels of iron in profile KTP-4, the landscape in which the profile is located is an accumulation area and hence continuous soil enrichment with soil nutrient elements, also soil conditions in KTP-4 are dominated by reduction processes as indicated by the presence of mottles in the profile (see Appendix 1). Low soil pH and redox conditions in soils are known to favour solubilization of ferric forms of iron into the more soluble forms of ferrous iron and hence the higher concentration of iron in such soils (Romheld and Marschner, 1986).

Levels of manganese in the soils of Kitanda are generally above the critical level of 1.0 - 5.0 mg/kg (Sims and Johnson, 1991). In topsoils the highest levels of manganese are observed in profile KTP-1 (197 mg/kg) and the lowest levels are observed in KTP-3 (18.22 mg/kg). In the subsoils highest manganese levels are observed in profile KTP-2 (114 mg/kg) while the lowest is observed in profile KTP-3 (0.89 mg/kg). Generally, there is a decrease of manganese with soil depth in all profiles. The higher levels of manganese in the topsoils are probably associated with influence of organic matter. Despite a higher concentration of manganese in the topsoils and its gradual decrease in the subsoils, manganese levels in the subsoils of profile KTP-4 remained uniform, most probably due to reducing conditions dominating this profile.

4.1.3 Mineralogical characteristics of the soils

Results indicate that the clay fractions of the soils have similar mineralogy. This could be attributed to the fact that soils are developed from the same type of parent material (Geological Survey Department, 1956). In all mapping units, the strongest diagnostic peaks were at 7.15Å and 3.59Å which are both first and second order reflections of kaolinite respectively, thus indicating that these soils are dominated by kaolinite. Lack of appreciable levels of smectites in these soils suggests that they have already undergone an intense degree of weathering. Other minerals detected at low intensity include gibbsite and quartz which are represented by 4.38Å and 4.86Å peaks for gibbsite and 3.34Å peak for quartz.

Saturating samples with glycol and potassium did not change the magnitude of the observed peaks thus suggesting absence of expanding clay minerals in the studied soils. Heating to 350°C did not change the diagnostic peaks 7.15Å and 3.59Å. Heating of potassium saturated samples to 550°C resulted in the disappearance of all diagnostic peaks, which confirms that peaks 7.15Å and 3.59Å were of kaolinite (Whittig and Allardice, 1986).

Presence of kaolinite in the river valleys (KTP-4) is probably attributed to inheritance of these minerals from kaolinitic material detached and transported through water erosion and deposited in the river valleys. Since smectites were not detected in the higher landscapes, inheritance of kaolinitic materials from other landscapes seems to be the most plausible explanation for the dominance of kaolinite in the soils of the river valleys.

Figure 7 gives diagnostic x-ray diffractograms for the studied subsoil samples. The mineralogical composition of the samples is present in Table 8 and the relative abundance of the clay minerals is summarized in Table 9.

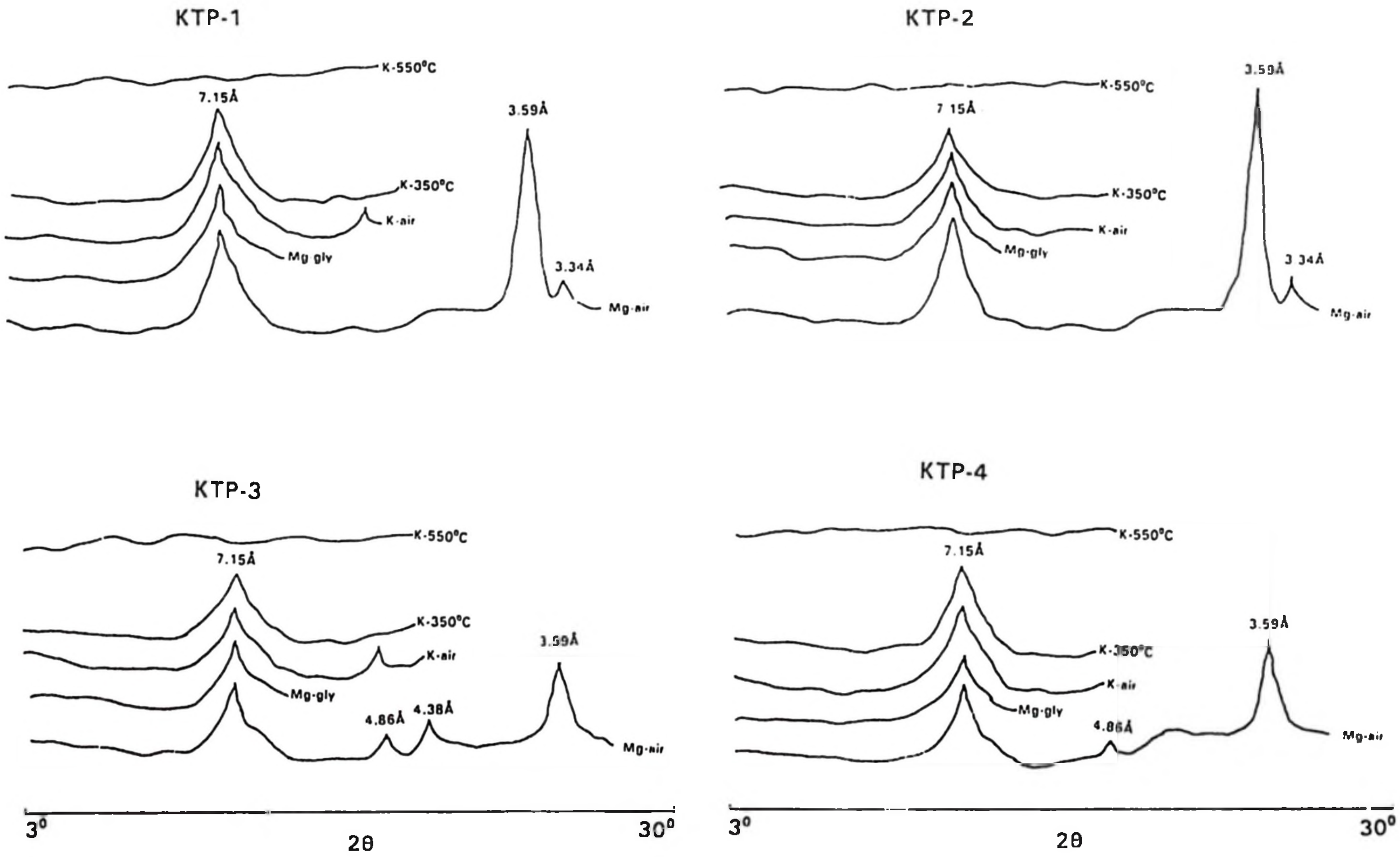


Figure 7. X-ray diffractograms of subsoil clay fractions of Kitanda soils

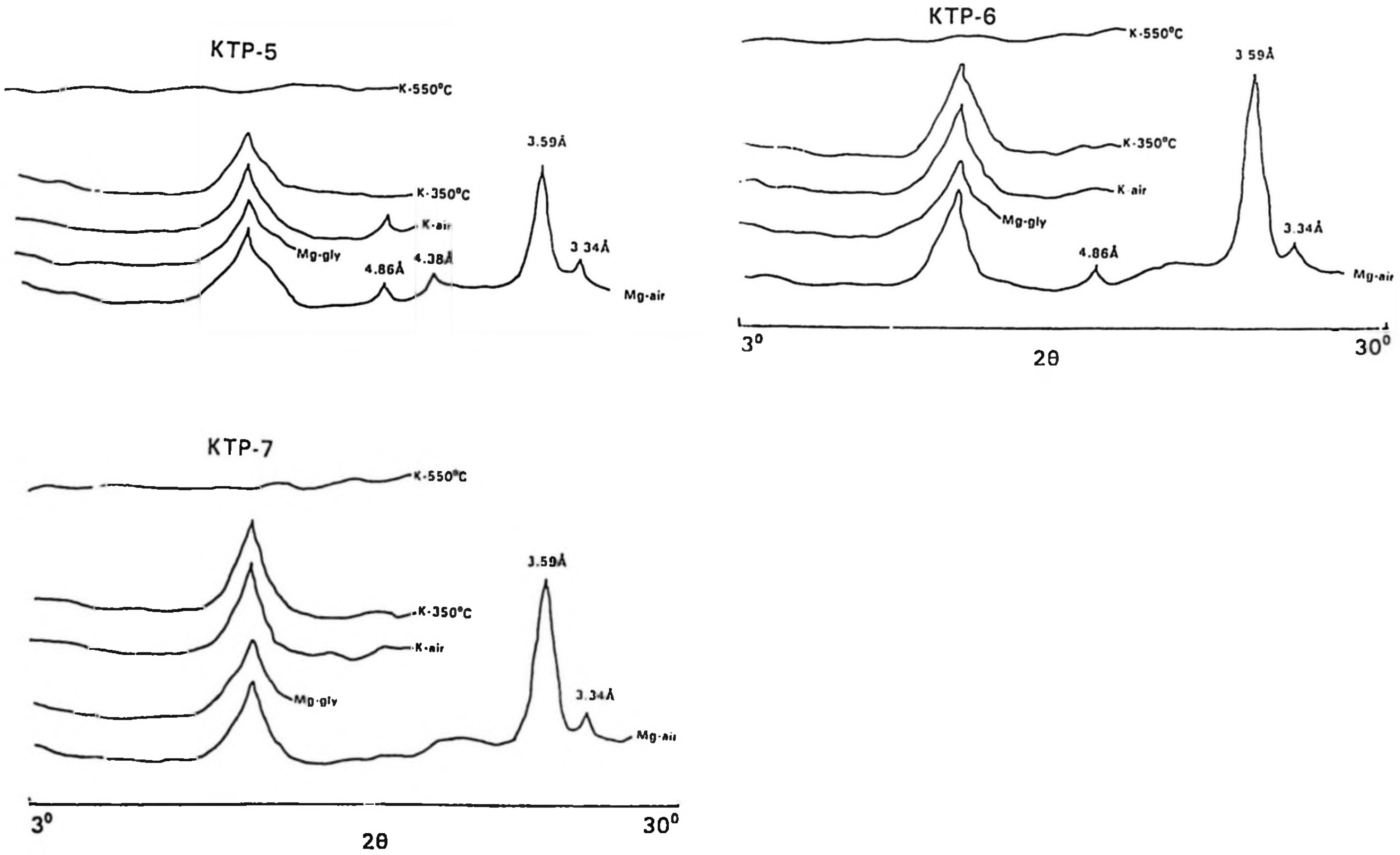


Figure 7. continued

Table 8. Mineralogical composition of Kitanda soils

Profile	d- space (Å)					Diagnostic Minerals
	Mg-sat.	Mg-gly	K-sat.	K-350 ° C	K-550 ° C	
KTP-1	3.59		7.15		No peak	Kaolinite
	7.15	7.15	4.86	7.15		Quartz
	3.34					Gibbsite
	4.38					
	4.86					
KTP-2	3.59				No peak	Kaolinite
	7.15	7.15	7.15	7.15		Quartz
	3.34					
KTP-3	3.59				No peak	Kaolinite
	7.15	7.15	7.15	7.15		Gibbsite
	4.38		4.86			
	4.86					
KTP-44	3.59				No peak	Kaolinite
	7.15	7.15	7.15	7.15		Gibbsite
	4.38		4.86			
	4.86					
KTP-47	3.59				No peak	Kaolinite
	7.15	7.15	7.15	7.15		Gibbsite
	4.38		4.86			
	4.86					
KTP-5	3.59				No peak	Kaolinite
	7.15	7.15	7.15	7.15		Quartz
	3.34		4.89			Gibbsite
	4.38					
	4.86					
KTP-6	3.59				No peak	Kaolinite
	7.15	7.15	7.15	7.15		Quartz
	3.34		4.86			Gibbsite
	4.38					
	4.86					
KTP-7	3.59		7.15		No peak	Kaolinite
	7.15	7.15	4.86	7.15		Quartz
	3.34					Gibbsite
	4.38					
	4.86					

Table 9. Relative amounts of the clay minerals in the soils of Kitanda village

Profile/ Horizon	Depth (cm)	Mineral species			
		Kaolinite	Smectite	Gibbsite	Quartz
KTP-1	120 - 190	****	nd	*	*
KTP-2	120 - 190	****	nd	*	*
KTP-3	120 - 165	****	nd	**	nd
KTP-4	60 - 120	****	nd	**	nd
KTP-5	25 - 90	****	nd	**	**
KTP-6	20 - 35	****	nd	**	*
KTP-7	130 - 200	****	nd	*	*

NB nd not identified.
* less than 15%
** 15% - 30%
*** 30 - 60%
**** more than 60%

Free oxides (Fe, Al, Mn,)

Levels of free oxides based on three extraction methods are presented in Table 10. Values for dithionite extractable iron oxides (Fe_d) are larger than those for oxalate extractable iron oxides (Fe_o) and the pyrophosphate extractable iron oxides (Fe_p) in all profiles. Similar observations were made elsewhere by Parfitt and Childs (1988) who attributed it to high dissolution of goethite, ferrihydrite and hematite in dithionite extractant than in the other two extractants. With the exception of profile KTP-4 which has a lithological discontinuity, levels of Fe_d and Fe_o generally increase with soil depth in all profiles thus suggesting the presence of crystalline oxides of iron in these profiles. Likewise, predominance of Fe_d over Fe_o suggests that, in these profiles, the crystalline oxides of iron exceed the non-crystalline oxides (Schwertmann, 1984a). Levels of pyrophosphate iron (Fe_p) are more in the topsoils and progressively decrease with soil depth. Similar observations were made by Parfitt and Childs (1988) who attributed it to falling levels of organic matter with soil depth. The pyrophosphate extractant is known to extract more efficiently the free oxides associated with organic matter in the soil (Sheldrick, 1984). The order is KTP-3>KTP-2>KTP-4>KTP-1>KTP-7>KTP-5>KTP-6.

Table 10. Free oxides in the soils of Kitanda village

Profile/ Depth (cm)	Iron oxides			Manganese oxides			Aluminum oxides		
	Fe_d	Fe_o	Fe_p	Mn_d	Mn_o	Mn_p	Al_d	Al_o	Al_p
KTP-1									
0-9	3.48	1.01	1.01	0.35	0.31	0.39	1.02	0.45	0.35
9-33	4.43	2.00	1.04	0.25	0.34	0.18	0.86	0.46	0.36
33-70	4.68	2.10	0.99	0.24	0.25	0.08	1.09	0.49	0.31
70-120	5.00	1.71	0.80	0.28	0.29	0.07	0.92	0.56	0.23
120-190	5.54	1.41	0.81	0.22	0.21	0.05	0.85	0.65	0.22
KTP-2									
0-15	3.66	1.59	0.89	0.35	0.39	0.16	0.81	0.58	0.59
15-40	4.87	1.33	0.87	0.38	0.36	0.17	1.17	0.75	0.59
40-80	4.47	1.64	0.66	0.34	0.39	0.06	1.11	0.67	0.57
80-120	5.94	1.88	0.80	0.43	0.47	0.07	0.90	0.68	0.48
120-190	5.17	1.50	0.71	0.34	0.29	0.04	0.74	0.52	0.23
KTP-3									
0-15	5.40	1.19	0.86	0.08	0.07	0.05	2.97	1.25	0.81
15-35	5.04	1.23	0.90	0.05	0.06	0.04	3.49	0.91	0.57
35-80	4.90	1.81	0.81	0.03	0.03	0.02	3.46	1.35	0.56
80-120	6.03	1.68	0.76	0.02	0.01	0.01	3.63	0.87	0.57
120-165	6.20	1.87	0.68	0.02	0.01	0.01	1.04	0.55	0.54
KTP-4									
0-20	5.31	2.93	1.97	0.13	0.17	0.18	1.69	1.08	0.82
20-45	7.33	4.21	2.56	0.04	0.05	0.06	2.40	1.80	1.00
45-60	10.7	6.03	4.04	0.06	0.12	0.05	2.65	1.54	0.23
60-80	4.63	2.34	1.81	0.02	0.02	0.03	3.28	1.76	0.52
80-100	4.68	2.53	1.63	0.01	0.02	0.03	2.23	1.41	0.53
100-120	3.60	1.50	1.21	0.01	0.01	0.03	2.01	1.08	0.42
120-150	4.17	1.43	1.11	0.01	0.01	0.02	1.96	0.89	0.19
KTP-5									
0-15	2.9	1.17	0.83	0.12	0.16	0.09	1.06	1.17	0.19
15-25	3.01	1.09	1.07	0.11	0.12	0.19	2.38	0.77	0.24
25-90	7.15	1.04	0.81	0.07	0.03	0.04	1.14	0.36	0.24
KTP-6									
0-10	2.83	1.07	0.97	0.07	0.07	0.11	2.15	1.30	0.42
10-20	3.38	1.50	0.91	0.05	0.05	0.07	2.76	0.90	0.36
20-35	3.37	0.99	0.81	0.02	0.02	0.03	1.58	0.46	0.13
KTP-7									
0-22	3.24	1.09	0.87	0.10	0.07	0.14	2.42	1.12	0.27
22-40	4.43	1.01	0.64	0.08	0.06	0.09	1.98	0.72	0.15
40-80	3.71	1.71	1.04	0.06	0.05	0.07	2.36	2.00	0.04
80-130	4.31	1.31	0.94	0.04	0.02	0.02	1.82	0.56	0.06
130-200	3.54	1.84	1.00	0.04	0.04	0.02	1.84	0.73	0.01

Subscripts: d = dithionite method o = oxalate method p = pyrophosphate method

Oxides of manganese decrease from surface soils to subsoils suggesting that their higher concentration in topsoils is probably linked to organic matter. More aluminum oxides were extracted by the dithionite than the other extractants. This observation is contrary to what was reported by Parfitt and Childs (1988) and Parfitt and Webb (1984) who observed oxalate extractable aluminum oxides to be more than dithionite extractable aluminum oxides. Soils used in their studies however were of volcanic origin and hence rich in allophanes. Presence of free oxides of iron, manganese and aluminum and the predominance of crystalline forms of these oxides in these soils suggests that they are strongly weathered. According to van Wambeke (1992) such soils tend to lose fertility within a few years of intensive use unless measures are taken to restore their fertility. Soils rich in sesquioxides also tend to fix phosphorus. Application of phosphatic fertilizers in Kitanda village must therefore consider this factor in terms of application rates if any reasonable response is expected.

Weathering status of the soils

Parameters related to weathering (water dispersible clay content, aggregation index, hematite and goethite content, crystallinity index, silt/clay ratio and CEC_{clay}) and their respective values in the soils of Kitanda village are summarized in Table 11 and Figure 8. The water dispersible clay content is 10% or less in all profiles except KTP-1 and KTP-2 in which the values are greater slightly greater than 10% particularly in the top sections of the profiles. In the subsoils of all profiles the water dispersible clay contents are less than 10% and in most cases much less than this value reaching as far low as 2%. Low values of water dispersible clays are associated with a higher degree of weathering in the soils. The FAO (1988), considers a value of 10% or less to represent a degree of weathering sufficient for a ferralic-B (oxic) horizon, a highly weathered subsoil horizon mostly found in the humid tropics where conditions allow a faster rate of weathering of the soils (Sanchez, 1976). Since most soils had less than 10% of water dispersible clay content it can be

Table 11. Some parameters related to degree of weathering for the soils of Kitanda village

Profile/ Horizon	Depth (cm)	Water dispersible clay (%)	Aggregation index (AI)	Hematite + Goethite (%)	Fe_o / Fe_d	Silt/Clay ratio	CEC-clay cmol (+)/ kg clay
KTP-1							
Ah	0-9	6	77	2.47	0.29	0.31	92
Bt1	9-33	18	63	2.43	0.45	0.38	21
Bt2	33-70	2	97	2.58	0.45	0.19	13
Bt3	70-120	2	97	3.29	0.34	0.19	11
Bt4	120-190	2	97	4.13	0.25	0.19	9
KTP-2							
Ap	0-15	12	65	2.07	0.43	0.59	53
Bt1	15-40	14	73	3.54	0.27	0.19	31
Bt2	40-80	12	78	2.83	0.37	0.26	18
Bt3	80-120	2	98	4.06	0.32	0.21	11
Bt4	120-190	2	97	3.67	0.29	0.17	10
KTP-3							
Ah	0-15	2	8	4.21	0.22	0.35	26
BA	15-35	2	94	3.81	0.24	0.44	25
Bts1	35-80	4	92	3.09	0.37	0.15	15
Bts2	80-120	2	96	4.35	0.28	0.19	15
Bts3	120-165	2	96	4.33	0.30	0.33	15
KTP-4							
Apg	0-20	2	93	2.38	0.55	0.64	50
2Cg	20-45	4	81	3.12	0.57	0.76	67
3Cgr	45-60	2	90	4.65	0.56	0.67	76
4Cgr	60-80	4	88	2.29	0.51	0.25	50
5Cgr	80-100	2	95	2.15	0.54	0.52	47
6Cgr	100-120	6	85	2.1	0.42	0.35	45
7Cgr	120-150	6	86	2.74	0.34	0.32	27
KTP-5							
Ap	0-15	10	55	1.73	0.40	0.73	91
BA	15-25	8	73	1.92	0.36	0.53	66
BC/CB	25-90	2	95	6.11	0.15	0.32	18
KTP-6							
Ah	0-10	4	73	1.76	0.38	0.53	160
AC	10-20	8	67	1.88	0.44	0.25	67
C	20-35	10	62	2.38	0.29	0.69	69
KTP-7							
Ah	0-22	8	67	2.15	0.34	0.50	71
BA	22-40	8	82	3.42	0.23	0.32	20
Bt1	40-80	6	89	2.00	0.46	0.22	15
Bt2	80-130	2	96	3.00	0.30	0.26	11
Bt3	130-200	2	96	1.70	0.52	0.26	11

Note: (i) Fe_o = Oxalate extracted Iron oxides (ii) Fe_d = Dithionite extracted iron oxides

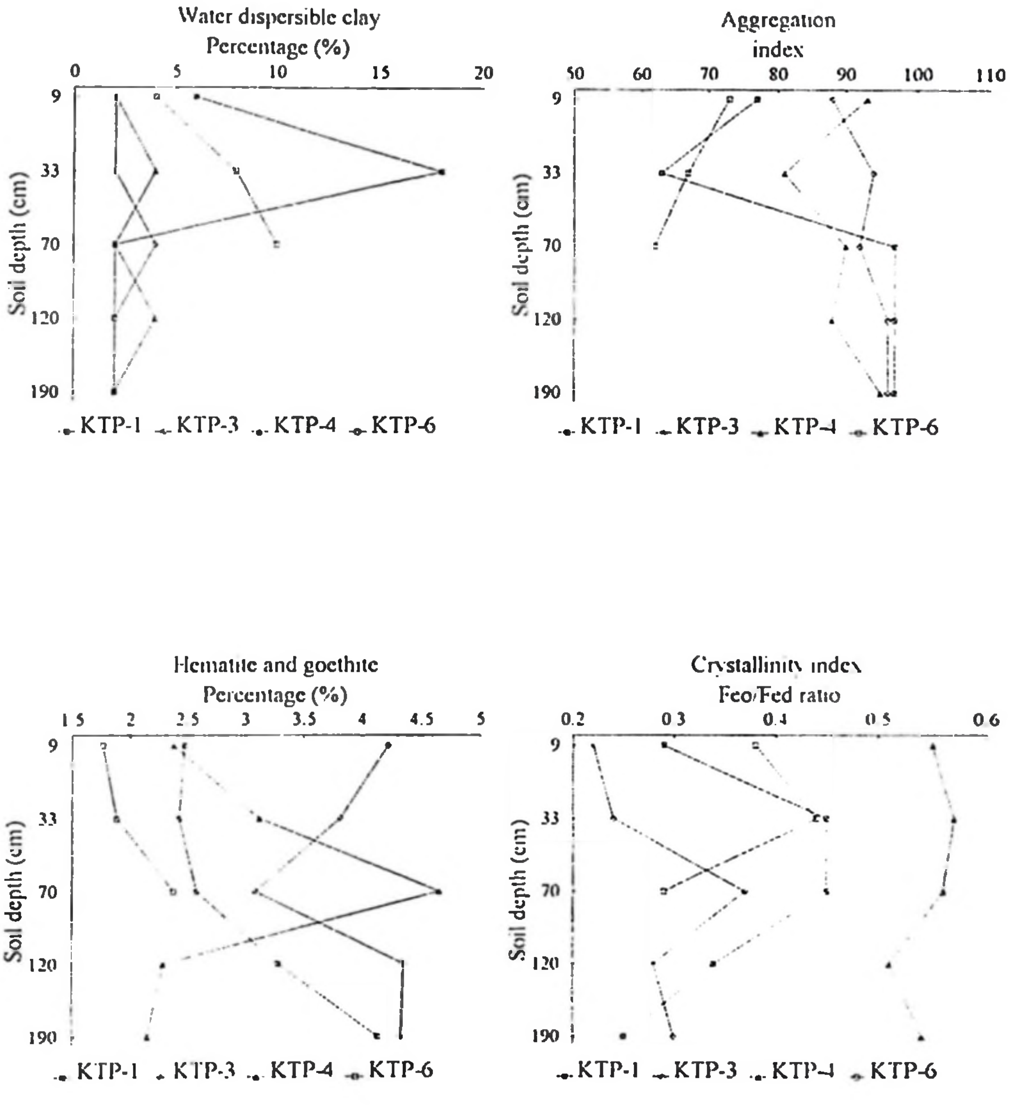
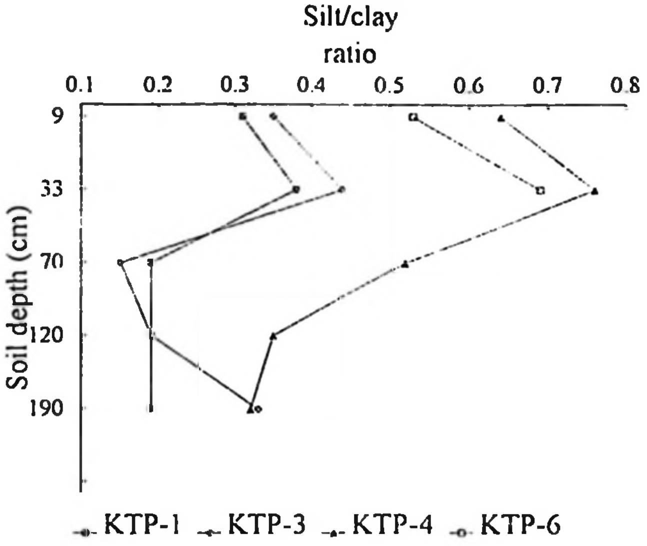


Figure 8. Weathering intensity indices versus soil depth for Kitanda soils



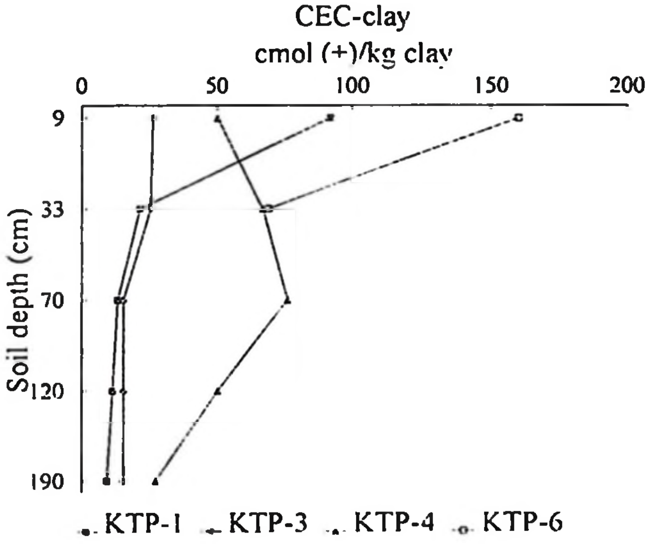


Figure 8 continued

assumed that Kitanda village has soils which are highly weathered.

The aggregation index of topsoils is highest in KTP-4 and lowest in KTP-5. Generally, aggregation index increases with soil depth in all profiles except KTP-4 probably due to the depositional position and fluvic characteristics of this profile. The increase of aggregation index with soil depth is probably due to the increase in the proportions of sesquioxides with soil depth observed in most of the studied profiles (see Table 10). This pattern is also seen in the distribution of hematite and goethite in all profiles except KTP-4. The general trend of the index and hence the structural aggregate stability is KTP-3>KTP-4>KTP-1>KTP-7>KTP-2>KTP-5>KTP-6. This is similar to that reported by Breimer *et al.* (1986) in Kenya in terms of soil types in which Ferralsols (as was KTP-3) were observed to have a higher aggregation index than Acrisols and Nitisols. Sesquioxides act as binding materials and hence soils rich in sesquioxides (as was KTP-3) tend to have higher aggregation index than those with low levels (Breimer, *et al.*, 1986).

Use of Fe oxides (hematite and goethite) as indicator of degree of weathering that a soil has undergone is based on the resistance to weathering for various minerals in the soil as stipulated by Jackson and Sherman (1953) and later by Jackson (1964). Accordingly hematite and goethite are considered to represent minerals that are highly resistant to weathering and therefore their presence in a soil in any significant amount will indicate that the soil has undergone a considerable degree of weathering. Soils having high values of these oxides are therefore considered to be more weathered. According to Parfitt and Childs (1988) Fe oxides (hematite and goethite) in soils can be estimated as the difference between Na-dithionite extractable iron and ammonium oxalate extractable iron. These are presented in Table 11. In the soils of Kitanda village more Fe oxides are found in the soils of the piedmonts than other landscapes. In most of the studied profiles hematite and goethite levels generally increase with soil depth thus indicating an increase in sesquioxides with soil depth. In topsoils, highest levels of hematite and goethite are found in profile KTP-

3 (4.21%) while the lowest level is observed in KTP-5 (1.73%). For subsoils, KTP-4 has the highest level (4.65%) whereas KTP-7 has the lowest level (1.7%). On average the distribution of hematite and goethite is in the order of KTP-3>KTP-2>KTP-4>KTP-1>KTP-7>KTP-5>KTP-6. The higher levels of hematite and goethite in soils of the piedmonts suggest that these soils are more weathered than those of the other mapping units. Since the piedmonts have almost level gradients, most of the soil development has been in situ with minimal disturbance from erosion or deposition. The higher proportion of hematite in the piedmonts indicates predominance of oxidation reactions. During field inspections it was observed that these soils are well drained getting redder and having more iron nodules with soil depth. Redder soil colours are associated with increased hematite and goethite contents (Torrent *et al.*, 1983). The comparatively low values of hematite and goethite in the hill summits and the backslopes (H1 and H2) are probably linked to higher rates of denudational processes taking place on these units. Soil erosion, landscape and topographic factors affect distribution of both hematite and goethite in soils (Schwertmann, 1984b). In the river valleys the level of hematite and goethite is slightly higher than in the other landscapes and is irregularly distributed with depth. This is most probably due to the fluvic properties of the soils.

Degree of crystallinity is a parameter normally used to determine the proportion of crystalline iron oxides (extracted by Na-dithionite) as compared to non-crystalline oxides of iron (extracted by ammonium oxalate). Proportionally, the more crystalline the soil material is the more it has been subjected to weathering processes. Schwertmann is cited by Jackson *et al.* (1986) as having used the ratios of acid oxalate extractable iron (Fe_o) to that of Na-dithionite extractable iron (Fe_d) for the determination of degree of crystallinity of soil materials. The latter is known to have a larger proportion of crystalline iron oxides while the former has a large proportion of non-crystalline (amorphous) iron oxides (Sheldrick, 1984). The ratio Fe_o /Fe_d becomes smaller with advanced crystallinity in a soil material which reflects an advanced level of weathering. In all the soils studied the value of the ratio Fe_o /Fe_d is less than unity thus indicating the dominance of hematite and goethite in these soils and probably an advanced stage of weathering (Jackson *et al.* 1986). The Fe_o /Fe_d ratios for profile KTP-4 are higher than those for the other profiles thus indicating that this profile is younger than the other profiles. The lowest values for degree of crystallinity are observed in profile KTP-3 (representing the broad piedmonts) implying that they are more weathered than the other profiles.

The silt/clay ratios of the soils are higher in topsoils than in subsoils which indicates that there has been clay movement from the surface horizons to the underlying B-horizons. The highest topsoil silt/clay ratio (0.73) is observed in profile KTP-5 while the lowest ratio (0.31) is found in profile KTP-1. Profile KTP-4 has the highest subsoil silt/clay ratio (0.76) while profile KTP-3 has the lowest ratio (0.15). The silt/clay ratio of 0.2 or less is characteristic for the ferrallic B-horizon as used in FAO-UNESCO soil classification system (FAO, 1988). Such values are observed in profiles KTP-1, KTP-2 and KTP-3. Morever according to van Wambeke (1962) the silt/clay ratios of 0.25 or less represent soils which are highly weathered. These values are observed in all profiles except KTP-4 and KTP-5. The magnitude of the silt/clay ratios in the studied soils is generally in the order KTP-5>KTP-4>KTP-6>KTP-7>KTP-3>KTP-2>KTP-1. On the basis of the silt/clay ratios it can be said that the intensity of weathering in Kitanda village is in the sequence: piedmonts > hilland > river valleys. The importance of CEC_{clay} as a weathering index is based on three principles (i) that type and amount of clay minerals in soils change with degree and stage of weathering (Jackson and Sherman, 1953) (ii) that generally clay minerals tend to weather from 2:2 and 2:1 mineral types to 1:1 types and finally into oxides (Jackson, 1964) and (iii) that each clay mineral has its diagnostic range of CEC value (Landon, 1991). In the subsoils where the influence of organic matter is minimal, CEC_{clay} values can be particularly useful in indicating what mineral dominates the clay fraction in the soil. In profiles KTP-1 and KTP-7 (from same mapping unit), the CEC_{clay} ranges from 9 to 21 cmol (+)/kg. Generally the CEC_{clay} values decrease with soil depth. In these two profiles, the CEC_{clay} at 120 cm depth and below is around 10 cmol (+)/kg. This value corresponds to that of kaolinite (Donahue *et al.*, 1990; Landon, 1991). According to Jackson and Sherman (1953) kaolinite represents an advanced weathering stage in the soil. The predominance of CEC_{clay} values characteristic of kaolinite in these profiles suggests that they are highly weathered and pedogenically old soils. The CEC_{clay} values in profile KTP-2 vary from 10 to 31 cmol (+)/kg. The CEC_{clay} decreases with soil depth. The higher values were observed closer to the surface soils thus indicating influence of organic matter in the observed CEC_{clay}. The deeper horizons at 150 cm and below have CEC_{clay} of 10 to 11 cmol (+)/kg which is characteristic of kaolinitic type of clay minerals. This profile too shows a high degree of weathering. Similar observations were made for profile KTP-3. In profile KTP-4 the CEC_{clay} values observed are higher than those associated with kaolinitic minerals. X-ray diffraction analysis (see Figure 7 and Table 8) however showed that the clay fraction is dominated by kaolinite. Expanding clay minerals were not detected. This profile has fluvic properties due to its depositional landscape. The CEC_{clay} values observed are most probably influenced by the organic matter that remains fairly high throughout the depth of this profile. Profiles KTP-5 and KTP-6 are both shallow soils. The profiles do not have well developed B-horizons and therefore these profiles are fairly young. The CEC_{clay} values in these profiles are most probably influenced by the young age of the soils and organic matter. The values of CEC_{clay} indicate that, soils of Kitanda village are largely kaolinitic. From a pedogenic point of view, the soils are of advanced weathering stage. The intensity of degree of weathering seems to be in the order piedmonts > hilland > river valleys.

4.2 Soil classification

The soils are classified according to the FAO-Unesco Classification system as

Acrisols (KTP-1, KTP-7) which cover 34% of village area, Lixisols (KTP-2) covering 7%, Ferralsols (KTP-3) covering 37%, Fluvisols (KTP-4) covering 4% and Leptosols (KTP-5, KTP-6) which cover 18% of village area. These correspond to Ultisols (KTP-1, KTP-2, KTP-3 and KTP-7) and Entisols (KTP-4, KTP-5 and KTP-6) in the USDA Soil Taxonomy. In terms of areal extent the order is Ferralsols > Acrisols > Leptosols > Lixisols > Fluvisols.

Similar observations were made in the neighbouring village of Lupilo by Msanya *et al.* (1995a) where Ferralsols were observed to form the largest soil type in that village. Acrisols form the second largest soil type in Kitanda village. The Humic and *Haplic Acrisols* reported by Avendano *et al.* (1991) as being common in Mbinga were not observed in Kitanda. The Acrisols in Kitanda village are *Ferric Acrisols* and do not have enough accumulation of organic matter to classify as *Humic Acrisols*. High soil temperatures like those in Kitanda village are reported to promote faster rates of organic matter decomposition leading to low level of organic matter in soils (van Wambeke, 1992).

Fluvisols form the smallest soil type in Kitanda village. In the studies conducted by Msanya *et al.* (1995a) and Kimaro *et al.* (1996) in Lupilo and Litembo villages respectively, Fluvisols are in a higher proportion. The relatively smaller proportion of the Fluvisols in Kitanda village is probably linked with the narrower widths of the river valleys in Kitanda compared to Lupilo or Litembo village where they are broader. In terms of occurence of soil types in relation to landform, Leptosols were observed to occur on the hill summits, Ferralsols on broad and moderately dissected piedmonts, Acrisols are observed in the steep and strongly dissected part of the hilland while Fluvisols were observed in the river valleys. A similar pattern was observed by Msanya *et al.* (1995a) and Kimaro *et al.* (1996) in Lupilo and Litembo village respectively. The occurence of Leptosols on the hill summits of Kitanda village is probably associated with repeated cycles of erosion and denudation which removes soil material from this landscape hence resulting into the shallow depths (typical of Leptosols) of the soils on the hill summits. The diagnostic horizons and other features of the soils studied are presented in Table 12. Soil names are given in Table 13.

Table 12. Diagnostic horizons and features of the studied representative soils

Profile	Diagnostic horizons	Other diagnostic features
KTP-1	*ochric A (ochric epipedon); *argic B (argillic horizon)	ustic SMR; isohyperthemic STR;*ferric properties; abrupt textural change to B horizon
KTP-2	*ochric A (ochric epipedon); *argic B (kandic horizon)	ustic SMR; isohyperthermic STR; *ferric properties
KTP-3	*ochric A (ochric epipedon); *ferrallic B (kandic horizon)	ustic SMR; isohyperthermic STR; *ferric properties
KTP-4	*ochric A (ochric epipedon)	*gleyic properties (aquic SMR); isohyperthermic STR; *fluvic properties (irregular decrease of OC with depth)
KTP-5	*ochric A (ochric epipedon)	ustic SMR; isohyperthermic STR; rudic phase; limited depth
KTP-6	*umbric A (umbric epipedon)	ustic SMR; isohyperthermic STR; limited depth; rudic phase
KTP-7	*ochric A (ochric epipedon); *argic B (argillic horizon)	ustic SMR; isohyperthermic STR; *ferric properties

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

Table 13. Classification of Kitanda soils

SOIL PROFILE	FAO-Unesco legend classification		USDA Soil Taxonomy				
	Level 1	*Level 2*	*Order*	*Suborder*	*Greatgroup*	*Subgroup*	*Family*
KTP-1	Acrisol	Ferric Acrisol (ACf)	Ultisol	Humult	Kandihumult	Ustic Kandihumult	Very fine clayey, kaolinitic, isohyperthermic, acid, very deep, Ustic Kandihumult
KTP-2	Lixisol	Ferric Lixisol (LXf)	Ultisol	Humult	Kandihumult	Ustic Kandihumult	Fine clayey, kaolinitic, isohyperthermic, acid, very deep. Ustic Kandihumult
KTP-3	Ferralsol	Rhodic Ferralsol(FRr)	Ultisol	Ustult	Kanhaplustult	Rhodic Kanhaplustult	Fine clayey, kaolinitic, isohyperthermic, acid, very deep, Rhodic Kanhaplustult
KTP-4	Fluvisol	Dystric Fluvisol (FLd)	Entisol	Aquent	Fluvaquent	Aeric Fluvaquent	Fine clayey, kaolinitic, isohyperthermic, acid, very deep, Aeric Fluvaquent
KTP-5	Leptosol	Eutric Leptosol (LPe), rudic phase	Entisol	Orthent	Ustorthent	Lithic Ustorthent	Fine clayey, kaolinitic, isohyperthermic, acid, Lithic Ustorthent
KTP-6	Leptosol	Umbric Leptosol (LPu), rudic phase	Entisol	Orthent	Ustorthent	Lithic Ustorthent	Fine loamy, kaolinitic, isohyperthermic, acid, Lithic Ustorthent
KTP-7	Acrisol	Ferric Acrisol (ACf)	Ultisol	Ustult	Kanhaplustult	Typic Kanhaplustult	Fine clayey, kaolinitic, isohyperthermic, acid, very deep, Typic Kanhaplustult

The occurence of Fluvisols in the river valleys is most probably associated with the depositional nature of this landscape while Ferralsols occurence in the broad piedmonts is probably associated with the relatively higher rates of weathering observed in this landform (see Table 10).

Lixisols are observed in the strongly dissected piedmonts. This observation is different from earlier studies in the district. Magoggo *et al.* (1996) observed Cambisols in similar landform in Mahenge village. Kimaro *et al.* (1996) observed Ferralsols while Msanya *et al.* (1995a) observed both Ferralsols and Luvisols in similar landform. The observed differences are probably associated with different rates of weathering and movements (both vertical and lateral) of soil constituents within the profiles at each site. According to Sanchez (1976) higher rates of weathering commonly found in the tropics often lead to highly weathered soils. Both Ferralsols, Lixisols and Acrisols are among soils considered to be highly weathered. The fragipans reported by Baker (1970) as being common in Mbinga were not observed in Kitanda village. However the Fe and Mn nodules were observed in especially Acrisols and Lixisols and hence their ferric properties.

4.3 Constraints and potentials of the studied soils

Due to unavailability of comprehensive climatic data on the village, and supporting socio-economic data it is presently not possible to conduct a fitting land suitability evaluations for various crops grown or which can be grown in the village. Below is a general interpretation of the field and analytical data to highlight the constraints and potentials of the land units studied.

4.3.1 Physical conditions

The main physical constraints encountered in the hilland (H), include shallowness of the soils, surface stoniness, steep slopes and high risk to erosion. Erosion is largely contributed by the high rate of deforestation of the natural vegetation of the hilland. Mapping unit H1 (hill summit and broader slopes), has shallow soils and sufficient surface stoniness to become a limitation. Similar conditions exist in mapping unit H2 (the hilland shoulders) with an additional limitation of high risk to erosion due to steep slopes. Steep slopes are also found in mapping unit H3 (strongly dissected part of the hilland). The above limitations make the hilland (H1, H2 and H3) unsuitable for mechanized agriculture. Deep rooted crops will not do well on mapping units H1 and H2 due to soil shallowness. The hilland can, however, be used for afforestation and establishment of perennial tree crops. As most of these units occupy the highest positions among the three landscapes, afforestation seems to be the most reasonable use of these units as they may also serve as water catchment areas. Physical conditions in the piedmonts (mapping units P1, and P2) do not pose any serious limitation to establishment of most crops. The piedmonts have adequate soil depth and aeration. The gentle slopes found on these piedmonts allow for mechanization as well as growing of seasonal crops. Soils of the piedmonts though, have low water holding capacity. Use of these soils must address itself to good soil moisture management. Soils in the river valleys are poorly drained with narrow bottoms. These two conditions limit mechanization of the river valleys. These valleys are suitable for horticultural purposes and establishment of off-season crops.

4.3.2 Chemical conditions

A guide on the rating of various analytical parameters of soils is provided in Appendix 3. Data on exchangeable bases of the soils of Kitanda village is provided in Table 14. Chemical conditions in the soils studied indicate that soil pH is a potential limitation for the soils in the broad piedmonts (KTP-3). The pH is strongly acid in the topsoil but becomes medium with soil depth. Use of acid-forming fertilizers like the sulphate of ammonia is discouraged in this mapping unit. Nitrogen is limiting in the narrow piedmonts (KTP-2) and the back slopes (KTP-5). It is medium elsewhere in the village.

Table 14. Interpretation ratings for exchangeable cations of Kitanda soils

Profile No.	Map Unit	Exchangeable Calcium (cmol(+)/kg soil)		Exchangeable Magnesium (cmol(+)/kg soil)		Exchangeable Potassium (cmol(+)/kg soil)	
		Topsoil (0-20cm)	Subsoil (30-150cm)	Topsoil (0-20cm)	Subsoil (30-150cm)	Topsoil (0-20cm)	Subsoil (30-150cm)
KTP-1	H3	High (10.6)	Low (2.6-1.7)	High (3.52)	Medium (0.7-1.64)	High (1.8)	Medium (0.48-0.98)
KTP-2	P1	Medium (6.6)	Low (2.2-3.9)	Medium (1.4)	Low-Medium (0.4-1.3)	High (1.52)	Very low-Low (0.17-0.21)
KTP-3	P2	Low (3.5)	Low (2.5-3.7)	Low (0.6)	Low (0.6-0.8)	Low (0.3)	Very low-Low (0.10-0.30)
KTP-4	V	Low (4.0)	Low to medium (3.7-5.6)	Medium (1.2)	Low (0.6-0.9)	Low (0.2)	Very low to low (0.07-0.19)
KTP-5	H2	Medium (10.0)	Very low (0.6)	Medium (2.10)	Low (0.6)	High (1.21)	Very low (0.40)
KTP-6	H1	Medium (7.8)	Medium (4.6)	Low (2.3)	Low (0.9)	Medium (0.85)	Low (0.34)
KTP-7	H3	Medium (5.2)	Low-Medium (1.8-5.2)	Low (2.2)	V.low to Low (0.1-0.8)	High (1.61)	Very low (0.06-0.32)

The low reserves of nitrogen in the subsoils of Kitanda village will lead to nitrogen deficiencies once the soils are intensively cultivated. Hence there is a need for application of nitrogen fertilizers. Phosphorus is also limiting in the river valleys (KTP-4), narrow piedmonts (KTP-2) and the strongly dissected hilland (KTP-7). Related to this is the high potential for phosphorus fixation in these soils. Any future application of phosphate fertilizers in this area must consider this factor. The availability of nutrients for uptake by plants depends not only upon absolute levels but also on individual nutrient ratios (Mengel and Kirkby, 1987). Hence consideration of nutrient balance is also crucial. The Ca/Mg ratio in the soils of Kitanda is 3 to 5 in the topsoils which is rated by Euroconsult (1989) as optimal for most crops. The Ca/Mg ratio of 4 to 6 in the subsoils however is not favourable for deep-rooted crops. The Mg/K ratios of 3 to 6 are beyond the optimal range of 1 and 4 for most crops, and this poses a slight limitation related to potential K-deficiency. The K/TEB saturation for most of the soils is more than 2%, which is favourable for most tropical crops. However, in some soils, like those of the broad piedmonts (KTP-3) and the river valleys (KTP-4), the saturation is less than 2%, indicating potential problems of K-deficiency.

4.3.3 Clay mineralogy

The dominance of kaolinitic clay minerals and oxides of iron in the soils of Kitanda village poses several limitations. The CEC of such soils tends to be low, base saturation is normally low and the soils tend to have a high capacity for fixing phosphorus. Kaolinitic soils (like those of Kitanda village) require higher rates of phosphorus fertilizers before any meaningful response can be obtained (Sanchez, 1976). Soils dominated by this mineralogy tend to have low water holding capacity as the mineral lattices of these minerals do not expand appreciably to hold more water (van Olphen, 1977). Therefore use of fertilizers, especially phosphate needs to consider phosphate fixation capacity of these soils.

Considering the low capacity for holding cations against leaching (low CEC) for the studied soils, it is important that fertilizer application be done in splits. Also, the low - medium water holding potential of these soils demands that timeliness in all cultural practices like cultivation and planting be emphasized so as to avoid potential moisture stresses that may result from any delay in such operations.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Based on the observations in this study it can generally be concluded that:

(i) Topography is the major factor influencing soil formation and most soil properties in Kitanda village.

(ii) Soils in Kitanda village are mostly sandy clay loam on surface, clayey in subsoils and very deep except on the hill summits and shoulders. The soils are well drained except in the river valleys, weak to moderately structured and friable with Fe and Mn nodules in some places. Kitanda soils are acidic, poor in chemical fertility. The soils have optimal supply of micronutrients except Zn which is potentially lacking in the broad piedmonts. Copper is higher in the soils where coffee is cultivated and is probably due to copper fungicides commonly used in coffee farms. The clay fraction is dominated by kaolinite and sesquioxides.

(iii) The soils in Kitanda village are highly weathered. In terms of pedogenic development the weathering intensity is in the order; piedmonts > hilland > river valleys. Piedmonts have relatively older soils than the other landform. The hilland are second while the river valleys have the youngest soils.

(v) The soils in Kitanda village classify into five soil units. The soils and their proportion in the village land are Ferralsols (37%), Acrisols (34%), Leptosols (18%), Lixisols (7%) and Fluvisols (4%).

(vi) Shallowness of the soils, steep slopes and surface stoniness are major limitations on the hilland. The hilland is suitable for afforestation and tree crops. The piedmonts are suitable for most crops grown in the village but their major limitation is chemical fertility. The river valleys are limited in width and drainage and hence unsuitable for mechanization but have good potential for horticultural purposes.

5.2 Recommendations

It is recommended that:

(i) Clearing of the hillands be stopped. These lands should best be left intact and protected as catchment areas. This is particularly so in the shallow soils of the hilland where soil depth, steep slopes and surface stoniness are major limitations for deep rooted crops and mechanized agricultural implements. Bush fires should be controlled and afforestation of already cleared hillands should be done. Cultural practises that encourage conservation of moisture and prevent soil loss like the local *ngoro* cultivation must be encouraged.

(ii) Fertilizers be applied in splits due to low CEC values of the soils. Use of inorganic N, P and K fertilizers will be necessary as the levels of these nutrients are generally low in most of the soils. The low pH levels in most of the soils imply possibilities of P-fixation problems, hence P-fertilizer recommendations should take this factor into consideration. Use of non-acidifying inorganic fertilizers like calcium ammonium nitrate (CAN) should be preferred.

(iii) The piedmonts have a potential deficiency of micronutrients. Zinc seems to be available in lower levels than other micronutrients and this is particularly so in the broad piedmonts. Inclusion of micronutrients in the fertilizer regime for the piedmonts is recommendable. Iron is especially high in the river valleys and there is a risk of creating an imbalance in the uptake of calcium and phosphorus unless these nutrients are added to offset the imbalance.

(iv) Climatic data for Kitanda should be recorded so as to permit sound planning on the use of the available land resources in the future.

(v) Livestock keeping e.g. cattle keeping be encouraged. To avoid soil and land degradation, zero-grazing as opposed to extensive grazing would probably be the most recommended practise.

REFERENCES

Acres, B.D.(edit.) (1983). Soils of Tabora Region, Tanzania.*Tabora Rural Intergrated Development Project - Land Use Component. Vol. 1: Main Report*, pp 211.; Vol. 2: Profile Descriptions and Analytical Data, pp 53. Land Resources Development Centre. Surbiton, UK. Project Rec. no. 67.

Agrar und Hydrotechnik, (1976a). *Tanga Water Master Plan.* Vol. IV. Soils. Essen Germany. pp 43.

Agrar und Hydrotechnik, (1976b). *Reconnaissance Survey of Lower Mkomazi Valley, Tanga Region. Suppliment: Soil Survey.* Essen Germany. pp 43.

Anderson, B. (1963). Soils of Tanganyika. Ministry of Agriculture, Bulletin No. 16. Dar-es-Salaam.

Anderson J.L., P.N Kennedy and R.A. Lewis (1978). Landscape planning units; Incorporating soil data into regional and local land use planning. *Journal of Soil & Water Conservation* 33, 193-195.

Araki, S. and K. Kyuma (1986). Chemical and mineralogical characteristics of red and/ or yellow colored soil materials in relation to lithology and weathering indices. *Soil Science and Plant Nutrition* 32 (2), 265 - 271.

Avendano, J., B.D. Gurung, F. Artigas, T. Delobel, E. Manang and R. Metsch (1991). Analysis of the Coffee based Farming System of the Matengo Highlands, Mbinga District, Tanzania. *Paper presented at the final seminar 10th International course for development oriented Research in Agriculture.* International Agricultural Centre, Wageningen, The Netherlands.

Baiz D. (1993). *Soil science analyses. A guide to current use.* John Wiley & Sons Ltd. West Sussex. pp 192.

Baker, R.M. (1970). Soils of Tanzania. Mimiograph. Ministry of Agriculture. Dar-es-Salaam.

Birkeland, P.W. (1974). *Pedology, weathering and geomorphological research*. Oxford University press. New York. pp 286

Blake, G.R. and K.H. Hartge (1986). Bulk density. *In:Methods of Soil Analysis*. Part 1. 2nd edition (Edited by A. Klute). Agronomy Monograph No.9. Soil Science Society of America. Madison. Wisconsin. pp 364 - 376.

Bohn, H.L., B.L. McNeal and G.A. O'connor (1985). *Soil Chemistry*. 2nd edition. Wiley Interscience Publication. New York. pp 341.

Breier R.F., A.J. van Kekem and H. van Reuler (1986). *Guidelines for soil survey and land evaluation in ecological research.* MAB Technical notes 17. UNESCO. Paris. pp 125.

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

Brindley, G.W. (1980). Quantitative x-ray mineral analysis of clays. In: *Crystal structure of clay minerals identification.* Edited by Brindley, G.W. and G. Brown. Monographs no. 5. Mineralogical society. London. pp 411 - 438.

Buringh, P. (1979). *Introduction to the study of soils in the tropical and subtropical regions.* Centre for Agricultural Publishing and documentation. Wageningen. pp 120.

Calton, W.E. (1954). Catena in relation to classification of East African Soils. In *Transactions of the V International Congress on Soil Science*, Leopodville, vol. IV. pp 58 - 61.

Corker, I.R. (1982). Human Carrying Capacity Assessment for Tabora Region, Tanzania. *Tabora Rural Intergrated Development Project - Land Use Component Report,* pp 29 Land Resources Development Centre. Surbiton, UK. Project Rec. no. 65.

Corker, I.R. (1983). Land Use Planning Handbook. *Tabora Rural Intergrated Development Project - Land Use Component* pp 178 Land Resources Development Centre.

Surbiton, UK. Project Rec. no. 66.

Coulter, J.K. (1964). Soil surveys and their applications in tropical agriculture. *Tropical Agriculture* 41, 185 -196.

Cox, F.R. (1968). Development of a yield reponse prediction and manganese soil test interpretation for soyabeans. *Agronomy Journal* 60, 521 -524.

D'Hoore, J.L. (1964): Soil Map of Africa. Commission for Technical Cooperation in Africa, Lagos, Publication No. 23.

De Pauw, E. (1983). *Soils and physiography of Tanzania: Consultant report.* Ministry of Agriculture, Tanzania.

Dent, D. and A. Young (1981). *Soil survey and land Evaluation.* Chapman & Hall London. pp 278.

Dixon, J.B. and S.B. Weed (1989). *Minerals in soil environment.* 2nd edition, Soil Science Society of America. Madison, Wisconsin. pp 671 - 698.

Donahue R.W. Miller and J.C. Shickluna (1990). *Soils: An introduction to soils and plant growth.* 5th edition. Prentice-Hall of India Ltd. New Delhi. pp 667.

EUROCONSULT (1989). Agricultural compendium for rural development in the tropics and subtropics. Elsevier Science Publishers, Amsterdam. pp 740.

FAO (1988). *FAO - Unesco Soil Map of the World. Revised Legend.* World Soil Resources Report 60. FAO. Rome, Italy. pp 138.

Gee, G.W. and J.W. Bauder (1986). Particle size analysis. In: *Methods of Soil Analysis.* Part1. 2nd edition. (Edited by A. Klute). Agronomy Monograph No. 9. Soil Science Society of America. Madison. Wisconsin. pp 383-412.

Geological Survey Department (1956). *Geology of Tanganyika:* Songea 86-S.W. Quarter degree sheet 298. Dodoma.

Glover, P.E. (1949). Report on the Vegetation, Soils, and Ecology of the Blocks "A", "B" and "C" Southern Province. O.F.C. *Southern Province Report*, John Phillips (unpublished) pp 214.

Grantham, D.R. (1956). The Tunduru - Ruvuma Area of the Southern Province. A Reconnaissance of the Geology, Soils, Vegetation and Hydro-electric Potential. *Bulletin of Geological Survey of Tanganyika*. Dar-es-Salaam.

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

Hathout, S.A. (1972b). Soils of South West Tanzania. In: *Soil Atlas f Tanzania* Hathout, 1983. Tanzania Publishing House. Dar-es-Salaam.

Hathout, S.A. (1972c). Soils of North East Tanzania. In: *Soil Atlas of Tanzania*. Hathout, 1983. Tanzania Publishing House. Dar-es-Salaam.

Hathout, S.A. (1973a). Soil of South East Tanzania. In: *Soil Atlas of Tanzania*. Hathout, 1983. Tanzania Publishing House. Dar-es-Salaam.

Hathout, S.A. (1983). *Soil Atlas of Tanzania*. Tanzania Publishing House. Dar-es-Salaam.

Hesse, P.R. (1971). *A Textbook of Soil Chemical Analysis*. John Murray Ltd., London. pp 388.

Hillel, D. (1982). *Introduction to soil physics.* Academic Press, New York. pp 207.

International Land Development Consultants (ILACO) (1981). *Agricultural compendium for rural development in the tropics and subtropics.* Elsevier Scientific Publishing Co. Amsterdam. pp 739.

Iseki, A. (1977). Soils of Kilimanjaro Region. Kilimanjaro Agricultural Development Project. *Annual Progress Report*, vol. 2, pp 180

Jamison, V.C. and E.M. Kroth (1958). Available moisture storage in relation to textural compositon and organic matter content of Missouri soils. *Soil Science Society of American Proceedings* 22, 189 - 192.

Jackson, M.L. (1964). Chemical composition of soils. In: *Chemistry of the soils (edited by F.E. Bear)*. Reinhold Publishing Corporation. New York. pp 70 - 141.

Jackson, M.L. and G.D. Sherman (1953). Chemical weathering of minerals in soils. *Advances in Agronomy* 5, 219.

Jackson, M.L., C.H. Lim and L.W. Zelazny (1986). Oxides, hydroxides and alluminosilicates. In: *Methods of Soil Analysis*. Part 1. 2nd edition. Physical and Mineralogical Methods. Edited by A. Klute. Agronomy monograph No.9. American Society of Agronomy.Madison. Wisconsin. pp 101-150.

Kauzeni, A.S., I.S. Kikula, S.A. Mohammed, J.G. Lyimo and D.B. Dalal-Clayton (1993). *Landuse Planning and Resource Assessment in Tanzania: A case study*. Environmental planning issues No.3. International Institute for Environment and Development. London.

Kilasara, M., J.P. Magoggo, and B.M. Msanya (1993). Land Resource Management in Tanzania. In: *Proceedings of the Faculty of Agriculture Research Workshop* held at the Institute of Continuing Education 21st - 23rd March 1993, SUA Morogoro. Edited by A.J.P. Tarimo, D.F. Rutatora, and A.Z. Mattee. Sokoine University of Agriculture. Morogoro. Tanzania.

Kimaro, D.N., B.M. Msanya and J.P. Magoggo (1995a). *Pedological investigations of sites for slash and burn experiment in Lupilo village and soil erosion studies in Tukuzi village, Mbinga District, Tanzania. Miombo Woodland Research Project, Natural Resources Study Team, Technical Report 2.* National Soil Service, Agricultural Research Institute, Mlingano, Tanga and Sokoine University of Agriculture, Morogoro, Tanzania.

Kimaro, D.N., B.M. Msanya and J.P. Magoggo (1995b). Considerations of some land qualities in relation to land Management in Lupilo village, Mbinga District, Tanzania. In: *Meeting Farmer's Needs Through Agricultural Research. Proceedings of the first Faculty of Annual Research Conference*. Sokoine University of Agriculture, Morogoro, 28th - 30th August, 1995. Edited by A.Z. Matee, K.P. Sibuga, J.M.R Semoka and M. Tsunoda. pp 174-184.

Kimaro, D.N., J.L. Meliyo, B.M. Msanya, J.P. Maggogo and J.M. Wickama (1996). *Investigation of environmental factors for land management in Litembo village, Mbinga District, Tanzania. Miombo Woodland Research Project, Natural Resources Study Team, Technical Report 4*. Ministry of Agriculture, National Soil Service, Agricultural Research Institute, Mlingano, Tanga and Department of Soil Science, Faculty of Agriculture, Sokoine University of Agriculture, Morogoro, Tanzania.

King, R.B., C.W. Rombulow-Pearce, I.S. Kikula, G. Ley and J.A. Kamasho (1979). Land Resources of Rukwa. *A Reconnaissance assessment*. Bureau of Resource assessment and Land Use Planning (BRALUP), University of Dar-es-Salaam. Tanzania.

King, R.B. (1982). Land System Map of Mbeya Region. Mbeya Rural Intergrated Development Project no. 26, pp 9.

Landon, J.R. (editor) (1984). Booker Tropical Soil Manual. *A handbook for soil survey and agricultural land evaluation in the tropics and subtropics*. Longman Inc., New York. pp 450.

Landon, J.R. (editor) (1991). Booker Tropical Soil Manual. *A handbook for soil survey and agricultural land evaluation in the tropics and subtropics.* Longman Scientific & Technical Publishers, Essex. pp 474.

Magoggo, J.P. (1992). Soil Survey in Tanzania: State and Perspectives. *Paper presented at the International Conference for Heads of Soil Survey Institutions*. ITC, Enschede. Netherlands.

Magoggo, J.P., B.M. Msanya and D.N. Kimaro (1996). *Environmental profile for agricultural production and development of conservation strategies in Mahenge village, Mbinga District, Tanzania. Miombo Woodland Research Project, Natural*

Resources Study Team, Technical Report 3. Ministry of Agriculture, National Soil Service, Agricultural Research Institute, Mlingano, Tanga and Department of Soil Science, Faculty of Agriculture, Sokoine University of Agriculture, Morogoro, Tanzania.

Mchau, J.M.J. (1993). Evaluation of agroforestry adoption in Mbinga district, Tanzania. *M.Sc. thesis.* University College of North Wales, Bangor. pp 142.

McKeagueA. (ed.) (1976). *Manual on soil sampling and and methods of analysis.* Canada Soil Survey Committee. Soil Research Institute. Ottawa. Canada. pp 213

Mengel, K. and E.A. Kirkby (1987). *Principles of plant nutrition.* 4th ed. International Potash Institute, Bern, Switzerland. pp 687.

Milne, G. (1936). "A provisional soil map of East Africa". Amani memories, 4 Mill Bank, London SN1.

Milne, G. (1937). A Reconnaissance journey through parts of Tanganyika territory. Annual Report. East African Agricultural Research Institute Amani. *Journal of Ecology* vol. XXXV No. 1 & 2.

Mitchell, A.J.B. (edit.) (1983). Land Evaluation and Land Use Planning in Tabora region, Tanzania.*Tabora Rural Intergrated Development Project - Land Use Component Report,* pp 206. Land Resources Development Centre. Surbiton, UK. Project Rec. no. 116.

Mitchell, A.J.B. (edit.) (1984). Land Evaluation and Land Use Planning in Tabora region, Tanzania.*Tabora Rural Intergrated Development Project - Land Use Component. Final Report,* ODA Project Report No. 116. Land Resources Development Centre, Overseas Development Adminstration. Tolworth. UK.

Mitchell, R.L. (1971). Trace elements in soils. In: *Trace elements in soils and crops.* Tech. Bull. 21. Ministry of Agriculture and Fisheries, London. pp 8 - 20.

Mkindi, G.I. (1990). Effects of spraying coffee with copper fungicides on the copper status of soils of Moshi District, Tanzania. *MSc dissertation*. Sokoine University of Agriculture. Morogoro. pp 112.

Msanya, B.M. and J.P. Magoggo (1993). *Review of soil surveys (soil resource inventories) in Tanzania*. Ecology and Development Paper No. 6. Ecology and Development Programme. Agricultural University of Norway, Ås, Norway. ISBN 0804-2144.

Msanya, B.M., D.N. Kimaro, and J.P. Magoggo (1995a). *Pedological investigations and land resources characterization in Lupilo village, Mbinga District, Tanzania. Miombo Woodland Research Project, Natural Resources Study Team, Technical Report 1*. Department of Soil Science, Faculty of Agriculture, Sokoine University of Agriculture, Morogoro and Ministry of Agriculture, National Soil Service, Agricultural Research Institute, Mlingano, Tanga, Tanzania.

Msanya, B.M., D.N. Kimaro and J.P. Magoggo (1995b). Characteristics of two pedons and their implication for environmental management in parts of Mbinga District, Tanzania. In: *Meeting Farmer's Needs Through Agricultural Research. Proceedings of the first Faculty of Annual Research Conference*. Sokoine University of Agriculture, Morogoro, 28th - 30th August, 1995. Edited by A.Z. Mattee, K.P. Sibuga, J.M.R Semoka and M. Tsunoda. pp 185-199.

Msanya, B.M., J.M. Wickama, D.N. Kimaro, J.P. Maggogo and J.L. Meliyo (1996). *Investigation of environmental attributes for agricultural development in Kitanda village, Mbinga District, Tanzania. Miombo Woodland Research Project, Natural Resources Study Team, Technical Report 5*. Department of Soil Science, Faculty of Agriculture, Sokoine University of Agriculture, Morogoro, and Ministry of Agriculture, National Soil Service, Agricultural Research Institute, Mlingano, Tanga Tanzania.

National Soil Service (1976. Systematic Soil Survey and Land Evaluation in the

United Republic of Tanzania. Selection of Priority Survey areas. *Working Paper Suppliment to Technical paper No. 3.* Ministry of Agriculture, Crop Development Division, Tanga. Tanzania

National Soil Service (1986); Land Resources and Agricultural Development Potentialsof Selected Areas in Tanzania. *Miscellaneous Paper Series No. M3* TARO-Agricultural Research Institute Mlingano, Tanga. Tanzania.

National Soil Service (1987); Soils and their Potential for Agricultural Development at Ndolela, Songea District. *Reconnaissance Soil Survey Report.* TARO- Agricultural Research Institute Mlingano, Tanga. Tanzania.

Nelson, D.W. and L.E. Sommers (1982). Total carbon, organic carbon and organic matter. In: *Methods of Soil Analysis*, part 2, 2nd edit. (eds. A.L. Page, R.H. Miller and D.R. Keeney). ASA, SSSA Monograph no. 9, Madison, Wisconsin. pp. 539-579.

Northwood, P.J. (1962). Cashew production in the Southern Province of Tanganyika. *East African Agricultural and Forestry Journal.* Vol. XXVIII pp 35 - 39.

Olsen, S.R. and L.E. Sommers (1982). Phosphorus. In: *Methods of Soil Analysis*, part 2. Agronomy monograph No. 9 (Edited by A.L. Page, R.H. Miller, and D.R. Keeney). American Society of Agronomy. Madison, Wisconsin. pp. 403-430.

Parfitt R.L. and T.H. Webb (1984). Allophane in some south island yellow brown - brown shallow and stony soils and high country and upland yellow-brown earths. *New Zealand Journal of science* 27, 37 - 40.

Parfitt, R.L. and C.W. Childs (1988). Estimation of forms of Fe and Al: A review and analysis of contrasting soils by dissolution and moessbauer methods. *Australian Journal of Soil Resources* 26, 121 - 144.

Peech, M. (1965). Hydrogen-ion activity. In: *Methods of Soil Analysis,* part 2. Edited by C.A. Black. Agronomy Monograph No. 9, 1st edition. Soil Science Society of America. Madison, Wisconsin. pp. 914-925.

Peters, D.B. (1965). Determination of field capacity. In: *Methods of Soil Analysis*, part 1. Edited by C.A Black. Agronomy Monograph No.9. American

Society of Agronomy. Madison, Wisconsin. pp. 281.

Regional Development Director-Ruvuma, (1982). *Ruvuma Regional Integrated Development Plan*. RDD-Ruvuma. Songea. pp 535.

Rhoades, J.D. (1982). Soluble salts. In: *Methods of Soil Analysis*. part 2. Agronomy monograph No. 9 (Edited by A.L. Page, R.H. Miller, and D.R. Keeney). American Society of Agronomy. Madison. Wisconsin. pp 149 - 158; 167 - 180.

Rombulow-Pearce, C.W. (1980). A Soil Map of Rukwa Region With Explanatory Notes. *Working Paper 2*. Uyole Agricultural Centre, Mbeya, Tanzania.

Romheld, V., and H. Marschner (1986). Mobilization of iron in the rhizosphere of different plant species. *Advances in Plant Nutrition*. 2, 155 - 204.

Salter, P.J., J. Berry and J.B. William (1966). The influence of texture on moisture characteristics of soils. III. Quantitative relationship between particle size composition and available water capacity. *Journal of Soil Science* 17, 93 - 98.

Samki, J.K. (1972). Soil Fertility Investigations. Establishment of ecological zone as the first step. *Mimiograph*. Ministry of Agriculture. Dar-es-Salaam.

Samki, J.K. (1977). Soil ecological zones - FAO/UNESCO system. *Mimiograph*. Ministry of Agriculture. Dar-es-Salaam.

Samki, J.K. and J.F. Harrop (1984). Fertilizer Recommendations in Tanzania on a District by District basis. National Soil Service, Tanzania Agricultural Research Organisation. Ministry of Agriculture and Livestock Development. Dar-es-Salaam. pp 67.

Samki, J.K. (1989). Soil formation, classification and land evaluation of soil development over gneiss, limestone, and marine sediments in Mlingano, Tanga, Tanzania. *PhD thesis*. Sokoine University of Agriculture, Morogoro. Tanzania. pp 270.

Sanchez, P.A. (1976). *Properties and management of soils in the tropics*. John Wiley & Sons, Inc. New York. pp 618.

Schwertmann, U. (1984a). Iron oxides in some ferruginous soils of India. *Clay Research* 3, (1) 23 - 30.

Schwertmann, U. (1984b). The effect of pedogenetic environments on iron oxide minerals. *Advances in Soil Science*. 1, 171 - 200.

Scott, R.M. (1963). Soils. In: *Natural Resources of East Africa*. Edited by E.W. Russell, 95 - 105.

Sheehy, T.J. and H.B. Green (1969). Land Resources of North East Tanzania. Unpublished.

Sheldrick, B.H. (editor) (1984). *Analytical methods manual*. Minister of Supply and Services. Ottawa. Canada.

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

Smyth, A.J. (1981). The objectives of soil surveys of various intensties, In: *Soil resource inventories and development planning*. Proceedings of workshop held at Cornell University 1977 - 1978. Techn. Monogr. 1, SMSS, USDA, Washington, D.C. pp 25 - 35.

Soil Survey Staff (1990). *Keys to Soil Taxonomy*. Agency for International Development, United States Department of Agriculture. Soil Management Support Services Technical Monograph no. 19. Virginia Polytechnic Institute and State University. pp 422.

Stahler, A.N. (1950). Equilibrium theory of erosional slopes approached by frequency distribution analysis. *American Journal of Science* 248, 673 - 696.

Stuart, G. and W. Duckworth (1969). Land Resources of South West Tanzania.

Unpublished.

Taylor, H. M., G.M. Roberson and J.J. Parker (1966). Soil strenght penetration relations for medium textured soil materials. *Soil science* 102, 18 - 22.

Thomas, G.W. (1982). Exchangeable cations. In: *Methods of Soil Analysis*, part 2. Agronomy monograph No. 9 (Edited by A.L. Page, R.H. Miller, and D.R. Keeney). American Society of Agronomy. Madison, Wisconsin. pp 159 - 164.

Torrent, J., U. Schwertmann, H. Fecher and F. Alferez (1983). Quantitative relationships between soil color and hematite content. *Soil Science* 136, 354 -358.

van Enckernvort P.L.A. and O.P. Komba (1992 unpublished). *Fertilizer Use and Crop Production in Ruvuma region Tanzania. Technical Field Report*. Kilimo/FAO Fertilizer Programme. Regional Agriculture and Livestock Development Officer's office. Songea.

van Olphen, H. (1977). *An introduction to clay colloid chemistry*. 2nd ed. John Wiley & sons. New York. pp 318.

van Wambeke, A. (1962). Criteria of classifying tropical soils by age. *J. Soil Sci.* 13, 124 - 134

van Wambeke, A. (1992). *Soils of the tropics: Properties and appraisal*. McGraw-Hill Inc. New York. pp 343

Whittig, L.D. (1965). X-ray diffraction techniques for mineral identification and mineralogical composition. In: *Methods of soil analysis*. Edited by C.A. Black. Agronomy 9. American Society of Agronomy, Madison, Wisconsin. pp 671 - 698.

Whittig, L.D. and W.R. Allardice (1986). X-Ray diffraction techniques. In: *Methods of Soil Analysis*. Part 1. 2nd edition. Physical and Mineralogical Methods. Edited by A. Klute. Agronomy monograph No.9. American Society of Agronomy.Madison. Wisconsin. pp 331 - 362.

APPENDICES

Appendix 1: Soil profile descriptions

Profile number : KTP-1 Mapping unit: H3
Agro-ecol. zone:
Region : Ruvuma
District : Mbinga
Map sheet no. : 298/3
Coordinates : 35° 8' 16 4" E/10° 36' 14.8" S
Location : Kiblang'oma area (near chairman's farm)
Elevation : 1240 m asl. Parent material: metamorphic rocks.
Landform: hill; steeply dissected. Slope: 25 %; straight
Surface characteristics: Erosion: severe. Deposition: none.
Natural drainage class : well drained. Described by B.M. Msanya, J.M. Wickama, D.N. Kimaro and J L. Meliyo on 18/12/95

Soil: *Very deep, well drained, dark reddish brown to dusk red, clays, with thin dark reddish brown, sandy clay loam topsoils; developed on colluvium derived from mixed metamorphic rocks*. The mapping unit is a slope facet complex characterized by rolling to steeply dissected slopes with very deep red soils.The unit has agricultural potential coupled with soil conservation i.e ridges and ngoro soil conservation systems. The unit has very deep V-shaped drainage streams (dendritic) with permanent water flow which follow fault lines. Presently there is mismanagement of catchments through grazing and burning.

Ah 0 - 9 cm: dark reddish brown (5YR3/2) dry, dark reddish brown (5YR3/2) moist, sandy clay loam; slightly hard dry,friable moist, sticky and plastic wet; moderate medium and fine subangular blocks; many fine and very fine pores; few coarse and many fine roots; clear smooth boundary to

Bt1 9 - 33 cm: dark reddish brown (2.5YR3/4) dry, dark reddish brown (2.5YR3/4) moist; clay, hard dry, friable moist, sticky and plastic wet; moderate coarse angular blocks and strong medium subangular blocks; patchy thin clay + iron hydroxide cutans, many fine and very fine pores; few small angular fresh quartz fragments; frequent small spherical hard Fe & Mn nodules, few coarse and common fine roots; gradual smooth boundary to

Bt2 33 - 70 cm: dusky red (10R3/4) dry, dusky red (10R3/4) moist, clay: hard dry, friable moist, sticky and plastic wet;moderate coarse angular blocks and strong medium subangular blocks; patchy thin clay + iron (hydr)oxide cutans; many fine and very fine pores; frequent small spherical hard Fe & Mn nodules; medium and few fine roots; diffuse smooth boundary to

Bt3 70 - 120 cm: dusky red (10R3/4) dry, dusky red (10R3/4) moist; clay; hard dry, friable moist, sticky and plastic wet; moderate coarse angular blocks and strong medium subangular blocks; many fine and very fine pores; frequent small spherical hard Fe & Mn nodules; coarse and fine roots; gradual smooth boundary to

Bt4 120 - 190 cm: dark red (2.5YR3/6) dry, dark red (2.5YR3/6) moist; clay, hard dry, friable moist, sticky and plastic wet; moderate coarse angular blocks and strong medium subangular blocks; many fine and very fine pores; frequent medium spherical hard Fe & Mn nodules; coarse and fine roots

SOIL CLASSIFICATION: FAO legend: **Ferric Acrisol**
USDA-Soil Taxonomy: **Ustic Kandihumult**

Profile number : KTP-2 Mapping unit:P1 Agro-ecol. zone:
Region : Ruvuma
District : Mbinga
Map sheet no. : 298/3
Coordinates : 35° 8'31.6" E/10° 55'50.9"S
Location : Kiblang'oma area
Elevation: 1180 m asl. parent material: metamorphic rocks. Landform: footslope undefined; undulating Slope: 5%; straight:Surface characteristics : Erosion: moderate. Deposition none. Natural drainage class : well drained. Described by D.N. Kimaro, J.L. Meliyo, B.M. Msanya and J.M. Wickama on 18/12/95

Soil: *Very deep, well drained, dark red to dusky red, clays, with moderately thick, dark reddish brown sandy clay loam topsoils; developed on colluvium derived from mixed metamorphic rocks* The profile was located in a site which was a coffee farm in the near past.

Ap 0 - 15 cm: dark reddish brown(5YR3/2) moist. sandy clay loam; friable moist, slightly sticky and slightly plastic wet; moderate medium and fine subangular blocks; few fine and many fine pores; few small spherical hard nodules; many fine and very fine roots; krotovina, termites and insect nests seen; clear wavy boundary to

Bt1 15 - 40 cm: dark reddish brown (5YR3/3) dry, dark reddish brown (5YR3/3) moist; clay; hard dry, friable moist,sticky and plastic wet; moderate medium and fine subangular blocks, few medium and many fine pores; common fine and very fine roots, gradual smooth boundary to

Bt2 40 -80 cm: dark reddish brown (2.5YR3/4) dry, dark reddish brown (2.5YR2.5/4) moist; clay; slightly hard dry, friable moist, sticky and plastic wet; moderate coarse subangular blocks and medium subangular blocks; many fine and very fine pores; frequent medium spherical hard nodules; few coarse and common fine roots; gradual smooth boundary to

Bt3 80 - 120 cm: dusky red (10R3/4) dry, dusky red (10R3/4) moist; clay; slightly hard dry, friable moist, sticky and plastic wet; moderate coarse and medium subangular blocks, many fine and very fine pores; very few small angular fresh quartz fragments; frequent medium spherical soft Fe & Mn nodules; very fine roots; diffuse smooth boundary to

Bt4 120 - 190 cm. dusky red (10R3/4) dry, dusky red (10R3/4) moist, clay; soft dry, friable moist, sticky and plastic wet; moderate coarse and medium subangular blocks, many fine and very fine pores; frequent small spherical soft Fe & Mn nodules; very fine roots

SOIL CLASSIFICATION:FAO legend: **Ferric Lixisol**
USDA-Soil Taxonomy: **Ustic Kandihumult**

Profile number : KTP-3 Mapping unit: P2
Agro-ecol. zone:
Region : Ruvuma
District : Mbinga
Map sheet no. : 298/3
Coordinates : 35° 5' 39.5" E/10° 55' 44.0" S
Location : Muungano area (close to a rocky hill)
Elevation : 1368 m asl.Parent material:metamorphic rocks.Landform:piedmont plain;Rolling. Slope:15.5 %; straight Surface characteristics : Erosion: moderate Deposition: none. Natural drainage class : well drained Described by D.N. Kimaro, B.M. Msanya, J.M Wickama and J.L Meliyo on 19/12/95

Soil:*Very deep, well drained, dark red clays, with very thin, brown, sandy loam topsoils; developed on colluvium derived from mixed metamorphic rocks.* The mapping unit is a piedmont moderately dissected. The unit has agricultural potential provided indiscriminate burning and clearing is controlled. Good soil management is essential for sustainable use of this unit.

Ah 0 - 15 cm brown (5YR2 5/1) moist; sandy loam; very friable moist, slightly sticky and slightly plastic wet; weak medium and fine subangular blocks; many very fine pores; common coarse and many fine roots; clear smooth boundary to

BA 15 - 35 cm: dark reddish brown (2.5YR2.5/4) moist; sandy clay loam; very friable moist, slightly sticky and plastic wet; weak medium and fine subangular blocks; many very fine pores; common coarse and many fine roots; gradual smooth boundary to

Bts1 35 - 80 cm. dark red (2.5YR3/6) moist; clay; very friable moist, slightly sticky and plastic wet, weak medium and fine subangular blocks; many very fine pores; few coarse and fine roots; diffuse smooth boundary to

Bts2 80 - 120 cm: dark red (2.5YR3/6) moist; clay; very friable moist, slightly sticky and plastic wet, weak medium and fine subangular blocks; many very fine pores; few coarse and fine roots; diffuse smooth boundary to

Bts3 120 - 165 cm: dark red (2.5YR3/6) moist; clay; very friable moist, slightly sticky and plastic wet; weak medium and fine subangular blocks; many very fine pores; frequent large angular hard fe & mn nodules; very few coarse and fine root

SOIL CLASSIFICATION: FAO legend: **Rhodic Ferralsol**
. USDA-Soil Taxonomy: **Rhodic Kanhaplustult**

Profile number . KTP-4 Mapping unit: V Agro-ecol. zone:
Region : Ruvuma
District : Mbinga
Map sheet no. : 298/3
Coordinates : 35° 6'46.8" E/10° 5' 32.6" S
Location : River Mbangamao valley about 1km west of village centre. Elevation:1250 m asl. Parent material:unconsolidated mixed material.Landform: alluvial/flood plain; flat or almost flat. Slope: 1 %; straight Surface characteristics : Outcrops: 2 % Erosion: moderate. Deposition none.Natural drainage class: Very poorly drained.Described by B.M. Msanya, J.M. Wickama, D.N. Kimaro and J.L. Meliyo on 19/12/95

Soil: *Very deep, very poorly drained, dark grey to dark reddish brown, stratified, mottled, loams and sandy clay loams with thick, dark reddish brown sandy loam topsoils; developed on alluvial-colluvium derived from highly weathered mixed metamorphic rocks* The mapping unit is in a valley bottom

Apg 0 - 20 cm: dark reddish brown (5YR3/2) moist; sandy clay loam; common medium faint clear 5YR5/6 yellowish red mottles; sticky and plastic wet; weak medium and coarse subangular blocks; many medium and fine roots; fresh and partly decomposed fibres present; gradual smooth boundary to

2Cg 20 - 45 cm: dark reddish brown (5YR3/2) moist; sandyclay loam, many medium distinct clear 7.5YR6/8 reddish yellow mottles; sticky and plastic wet; many medium and fine roots; fresh and partly decomposed fibrous materials present; clear smooth boundary to

3Cgr 45 - 60 cm: dark grey (5YR4/1) moist; sandy clay loam; few fine faint diffuse 7.5YR4/6 strong brown mottles; sticky and plastic wet; few medium and fine roots; fresh and partly decomposed fibrous materials present; clear smooth boundary to

4Cgr 60 - 80 cm: very dark grey (5YR3/1) moist ;sandy clay loam; many fine faint diffuse 7.5YR4/4 brown mottles; sticky and plastic wet;; partly decomposed fibrous materials present; clear smooth boundary to

5Cgr 80 - 100 cm: very dark grey (5YR3/1) moist; clay loam; common medium distinct clear 7.5YR4/6 strong brown mottles; sticky and plastic wet; partly decomposed fibrous materials present; clear smooth boundary to

6Cgr 100 - 120 cm: dark grey (7.5YR4/6) moist; sandy clay; few fine faint diffuse 7.5YR4/6 strong brown mottles, sticky and plastic wet; partly decomposed fibrous materials present; gradual smooth boundary to

7Cr 120 - 150 cm: dark grey (7.5YR4/6) moist; clay; sticky and plastic wet; partly decomposed fibrous materials present

SOIL CLASSIFICATION: FAO legend: **Dystric Fluvisol**
USDA-Soil Taxonomy: **Aeric Fluvaquent**

Profile number : KTP-5 Mapping unit: H2
Agro-ecol. zone:
Region : Ruvuma
District : Mbinga
Map sheet no. : 298/3
Coordinates : 35° 6' 49.0" E/10° 56' 16.4" S
Location : Muungano area
Elevation : 1380 m asl. Parent material: metamorphic rocks.Landform: hill; steeply dissected. Slope: 47 %; straight.Surface characteristics : Outcrops: 1 % Stones:1 % Erosion: moderate. Deposition: none. Natural drainage class : somewhat excessively drained.Described by B.M. Msanya, J.L. Meliyo, D.N. Kimaro and J.M.Wickama on 19/12/95

Soil: *Very shallow to shallow, excessively drained, dark red, extremely gravelly clays with very thin, dark reddish brown, sandy clay loam topsoils; developed on mixed metamorphic rocks. In places occur rock outcrops.* The soils are very young and limited by depth.

Ap 0 - 15 cm: dark reddish brown (5YR3/2) moist; sandyclay loam; friable moist, sticky and plastic wet; weak medium and fine subangular blocks; many fine and very fine pores; frequent large angular fresh quartz fragments; many fine and very fine roots; clear smooth boundary to

BA 15 - 25 cm: dark reddish brown (5YR3/3) moist; very gravely sandy clay loam; friable moist, sticky and plastic wet; weak medium and fine subangular blocks; many fine and very fine pores; frequent medium angular fresh quartz fragments; many fine and very fine roots; clear smooth boundary to

BC/CB 25 - 90 cm. red (2.5YR4/6) dry, dark red (2.5YR3/6) moist; gravelly clay; hard dry, friable moist, sticky and plastic wet; weak medium and fine subangular blocks; few medium and many fine pores; frequent medium angular fresh quartz fragments; common fine and few medium roots

SOIL CLASSIFICATION:
FAO legend: **Eutric Leptosol**
USDA-Soil Taxonomy: **Lithic Ustorthent**

Profile number : KTP-6 Mapping unit: H1
Agro-ecol. zone:
Region : Ruvuma
District : Mbinga
Map sheet no. : 298/3
Coordinates : 35° 5' 8.5" E/10° 53' 56.4" S
Location : Msenga area (near the border with Utiri village). Elevation:1460 m asl. Parent material: metamorphic rocks.Landform: hill summit; flat or almost flat.Slope:1%; convex. Surface characteristics : Outcrops: 1 % Stones: 10 % Erosion:moderate. Deposition: none. Natural drainage class : well drained. Described by D.N. Kimaro, B.M. Msanya, J.M. Wickama and J.L. Meliyo on 20/12/95

Soil: *Moderately shallow, well to somewhat excessively drained, yellowish red, gravelly sandy clays with thin black, gravelly clay loam topsoils; developed on mixed metamorphic rocks. In places rock outcrops, boulders, stones and gravel appear at or near the surface.* The mapping unit has potential for aforestation coupled with other soil conservation measures. The soil is limited in depth.

Ah 0 - 10 cm: dark reddish brown (5YR3/2) moist; very gravelly sandy loam; friablemoist, slightly sticky and slightly plastic wet; weak medium and fine subangular blocks; many fine and medium pores; frequent large angular fresh quartz fragments; many medium and few coarse roots; clear smooth boundary to

AC 10 - 20 cm: dark reddish brown (5YR3/3) moist; very gravelly sandy clay loam; friable moist, slightly sticky and plastic wet; weak medium and fine subangular blocks; many fine and medium pores; frequent large angular fresh quartz fragments; many medium and few coarse roots gradual wavy boundary to

C 20 -35 cm: yellowish red (5YR4/6)moist;very gravelly sandy clay loam; friable moist, sticky and plastic wet; weak medium and fine subangular blocks; few medium and many fine pores; frequent medium angular fresh e and medium roots;

SOIL CLASSIFICATION:
FAO legend: **Umbric Leptosol**
USDA-Soil Taxonomy: **Lithic Ustorthent**

Profile number : KTP-7 Mappingunit: H3 Agro-ecol. zone:
Region : Ruvuma
District : Mbinga
Map sheet no. : 298/3
Coordinates : 35° 5" 51.0' E/10° 53" 10.3' S
Location : Rudisha-Msenga(Border with Utiri village)Elevation:1340 m asl. Parent material: metamorphic rocks. Landform: hill; hilly. Slope: 42 %; straight Surface characteristics :Stones:2 % Erosion: moderate. Deposition: none. Natural drainage class : well drained. Described by B.M. Msanya, D.N. Kimaro, J.L. Meliyo and J.M. Wickama on 20/12/95

Soil: *Very deep, well drained, dark reddish brown to red, clays, with thin dark reddish brown, sandy clay loam topsoils; developed on colluvium derived from mixed metamorphic rocks.* It has good agricultural potential if soil conservation and management are practiced.

Ah 0 - 22 cm: very dark brown (10YR2/2) moist; sandy clay loam; friable moist, sticky and plastic wet, weak medium and fine subangular blocks; coarse and many medium pores; few small spherical soft nodules; many medium and fine roots; many crotovinas present high biological activity; clear smooth boundary to

BA 22 - 40 cm: dark reddish brown (5YR3/4) moist; clay; very friable moist, slightly sticky and plastic wet; weak medium and fine subangular blocks; many medium and few coarse pores; very few small irregular weathered quartz fragments;few medium irregular hardnodules; few medium and many fine roots; many crotovinas and high biological activity present; gradual smooth boundary to

Bt1 40 - 80 cm: red (2.5YR2/8) dry, dark red (2.5YR3/6) moist; clay; slightly hard dry, friable moist, sticky and plastic wet; moderate medium angular blocks and coarse subangular blocks; continuous thin clay cutans; few medium and many fine pores; few medium irregular weathered quartz fragments; few medium irregular soft nodules; coarse and medium roots; many crotovinas present and high biological activity; diffuse smooth boundary to

Bt2 80 - 130 cm: red (10R4/8) dry, red (10R4/6) moist; clay; slightly hard dry, friable moist, sticky and plastic wet; moderate medium and coarse subangular blocks; continuous thin clay cutans; few medium and many fine pores, few small spherical fresh granite fragments; few medium spherical soft nodules; very fine and coarse roots; many crotovinas present and high biological activity present; diffuse smooth boundary to

Bt3 130 - 200 cm: red (10R4/8) dry, red (10R4/8) moist; clay, slightly hard dry, friable moist, sticky and plastic wet; moderate medium and fine subangular blocks; continuous thin clay cutans; few medium and many very fine pores; frequent small spherical fresh quartz fragments; frequent medium spherical soft nodules; coarse and fine roots; many crotovinas and high biological activity present.

SOIL CLASSIFICATION: FAO legend: **Ferric Acrisol**
USDA-Soil Taxonomy: **Typic Kanhaplustult**

Appendix 2. Moisture retention characteristics of some selected soils of Kitanda village.

Profile/ Suction (Kpa)	Volumetric moisture content (%)		
	Surface soil (0-10cm)	Mid-horizon (45-50cm)	Subsoil (95-100cm)
KTP-1			
0.1	33.0	35.0	36.6
1.0	32.8	34.6	36.5
10	32.7	34.3	36.4
20	31.4	33.0	36.0
30	31.0	32.8	35.8
100	27.6	31.0	34.9
398	22.3	27.3	29.7
1500	18.3	17.6	16.1
AWC	**14.4**	**17.0**	**20.3**
KTP-2			
0.1	17.9	39.4	30.5
1.0	17.3	37.5	29.9
10	16.8	36.7	29.4
20	15.6	36.5	28.8
30	10.9	36.0	28.6
100	10.5	35.1	28.1
398	9.5	25.6	19.9
1500	6.7	19.0	14.2
AWC	**10.1**	**17.7**	**15.2**
KTP-3			
0.1	22.5	25.8	31.8
1.0	22.3	25.6	31.5
10	22.0	25.5	31.4
20	21.2	21.2	31.3
30	20.4	21.0	31.0
100	19.8	19.5	24.8
398	14.6	13.2	22.5
1500	12.6	12.0	13.9
AWC	**9.4**	**13.4**	**17.5**
KTP-7			
0.1	21.4	31.4	30.8
1.0	20.8	31.3	30.8
10	20.5	31.2	30.7
20	19.4	30.5	30.1
30	14.7	30.4	29.9
100	13.9	29.7	29.0
398	12.0	20.9	20.9
1500	9.8	13.4	13.0
AWC	**10.4**	**17.8**	**17.6**

AWC = available water capacity.

Appendix 3. Guide to general evaluation of some chemical and physical properties

Compiled from Baize (1993), EUROCONSULT (1989) and Landon (1991)

1. Organic matter and total nitrogen

	Very low	Low	Medium	High	Very high
Organic matter %	< 1.0	1.0-2.0	2.1-4.2	4.3-6.0	> 6.0
Organic C %	< 0.60	0.60-1.25	1.26-2.50	2.51-3.50	> 3.50
Total N %	< 0.10	0.10-0.20	0.21-0.50	> 0.50	

C/N ratios give an indication of the quality of the organic matter:
C/N 8 - 13 : good quality
C/N 14 - 20: moderate quality
C/N > 20 : poor quality

2. Soil reaction

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	moderately alkaline	pH 7.9 to 8.4
medium acid	pH 5.6 to 6.0	strongly alkaline	pH 8.5 to 9.0
slightly acid	pH 6.1 to 6.5	very strongly alkaline	pH > 9.0

3. Available phosphorus

mg/kg	Low	Medium	High
Avail. P (Bray-Kurtz I)	< 7	7-20	> 20
Avail. P (Olsen)	< 5	5-10	> 10

Available phosphorus is determined by the Bray-Kurtz I method if the pH H_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	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	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	Very low	Low	Medium	High	Very high
Mg (clayey soils)	< 0.3	0.3-1.0	1.1-3.0	3.1-6.0	> 6.0
Mg (loamy soils)	< 0.25	0.25-0.75	0.75-2.0	2.1-4.0	> 4.1
Mg (sandy soils)	< 0.2	0.2-0.5	0.5-1.0	1.1-2.0	> 2.0

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

7. Exchangeable K

cmol(+)/kg	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	Very low	Low	Medium	High	Very high
Na	< 0.10	0.10-0.30	0.31-0.70	0.71-2.00	> 2.00

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

9. Soil sodicity

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

ESP < 15% up to 50 percent yield reduction of sensitive crops (maize, beans)
ESP 16-25% up to 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 2.5-25.0 cm/h	rapid
IR > 25.0 cm/h	very rapid

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

11. Available water capacity (AWC)

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

Available water capacity is the capacity of the soil to store water that is readily available for uptake by plant roots; usually expressed in millimeters of water per metre depth of soils; technically the difference between the percentage of soil water at field capacity (normally taken as the water content at pF 2.0) and the percentage at wilting point (taken as the water content at pF 4.2). This is applicable for most tropical soils.

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.