

SOIL CLASSIFICATION, PEDOGENESIS
AND LAND EVALUATION IN
KAPINI AREA LUSAKA
ZAMBIA

BY

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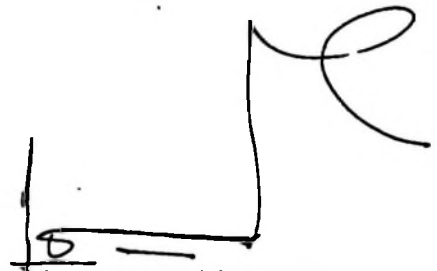
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DECLARATION

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SUMMARY

Back ground information related to classification, pedogenesis and land evaluation is briefly given. It includes information on geology, geomorphology, topography, drainage, climate and vegetation. Literature on soil classification in relation to local and international classification systems is reviewed. Literature review on pedogenesis critically focus on soil genesis work in Zambia in relation to important soil forming factors.

International and local land evaluation systems are reviewed together with concepts that are not used consistently and have often caused lots of confusion in land evaluation.

The results of the study can briefly be summarised as follows:

1. The soils are classified into four major orders: Oxisols, Ultisols, Alfisols and Inceptisols. (Soil Survey Staff 1975) or as Ferralsols, Luvisols, Acrisols, Regosols and Lithosols (F.A.O./UNESCO 1974). Classification is pursued up to the family level and sub-unit level respectively.
2. The major processes which are important in pedogenesis are: Eluviation Illuviation, Cumilation, Pedoturbation, Desilication, Ferrilization Decomposition and Synthesis. Geology was found to be the most important soil forming factor.

3. Most of the soils in the area are moderately suitable to crop production (60%). The major limitations to crop production are fertility (for the Oxisols), flooding, moisture availability, stoniness and rooting depth.
4. Socio-economically the area is not suited to cash crop production at subsistence and intermediate management levels.
5. The area has a high potential for crop production especially with improved management level.

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INTRODUCTION

Soil information by systematically identifying, grouping and delineating the different soils according to their genesis and their physical and chemical characteristics is required when interpretations towards land use potential are to be made. Present and potential land users (farmers and planners) can then be advised on how to use the land in the best possible way. In this study an area north of Lusaka was chosen for its variability in geology, resulting in sufficient differentiation in soils.

This study uses the modern methods to classify the soils (Soil Survey Staff, 1975 and FAO/UNESCO, 1974), evaluate their land qualities (FAO, 1976) and to explain their genesis as a way of finding out the adaptability of these methods to a selected area. The result of the study is a comprehensive land evaluation in which the suitability of a number of important crops under some relevant management systems is shown. Some social economical factors are considered to complete the overall picture of the suitable farming systems.

In the study area an agricultural development project has been going on for some years, but no soils data or land evaluation studies have been carried out. This work provides a basis for a rationale development of the area. It is hoped that this study will promote the use of the FAO framework for land evaluation (1976) in Zambia and will emphasize the importance of studying the genesis of the soils of Zambia.

The objectives of this study are summarised below:

- (a) To map the soils of the area.
- (b) To study the genesis of the soils from the different geological units.
- (c) To classify the soils using the U.S. Taxonomy (Soil Survey Staff, 1975) and the FAO-UNESCO legend (1974).
- (d) To evaluate the current and potential suitability of the soils for the production of various crops.

I. BACKGROUND INFORMATION OF THE AREA

I.1 Location:

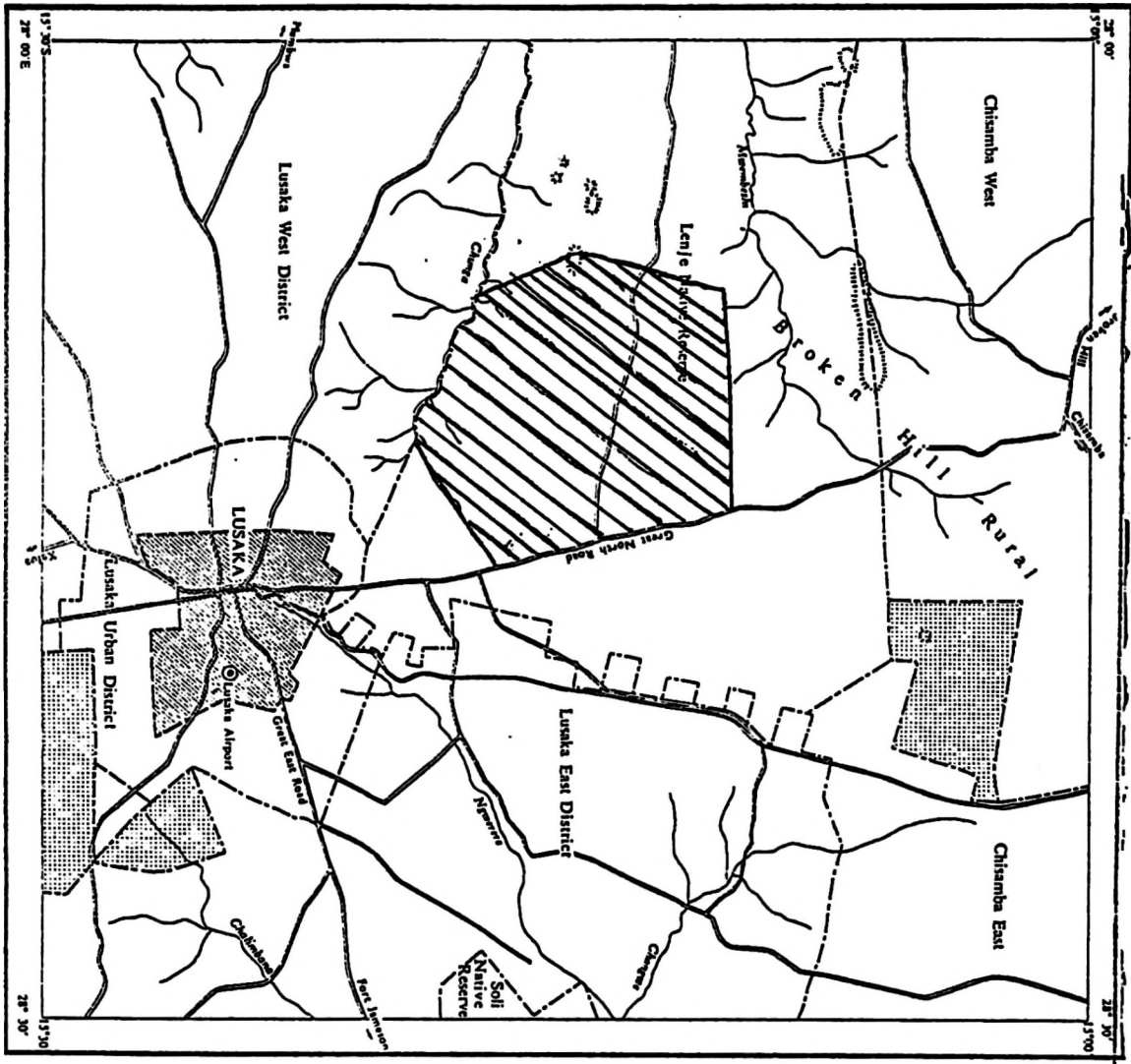
The study area is situated in Lusaka region, between longitudes $28^{\circ}00'$ and $28^{\circ}15'E$ and latitude $15^{\circ}12'$ and $15^{\circ}16'S$ (fig. 1). The boundaries of the study area are defined approximately by the Mwembeshi river in the north and the Chunga river in the south. In the eastern direction the area is bounded by the great north road (Lusaka - Kabwe road). The centre of the area is at the intersection of longitude $28^{\circ}10'E$ and latitude $15^{\circ}15'S$.

I.2 Geology:

The major geological units in the area of study are the Basement complex and the Katanga system. The Southern part of the study area is dominated by granites.

The Basement complex

The Basement complex is mainly composed of quartzites and gneisses. In the generalized geological map (fig. 2) quartzites are indicated as small horizontal bands found in isolated patches. They appear as low ridges in the landscape. The quartzites are mainly pure, totally recrystallised, medium to coarse - grained and massive rocks with no planar or linear structure. Quartzites form the parent material of soil mapping units 70 and 22.



LOCATION MAP

EXPLANATION

Scale in miles: 0, 5, 10 Miles








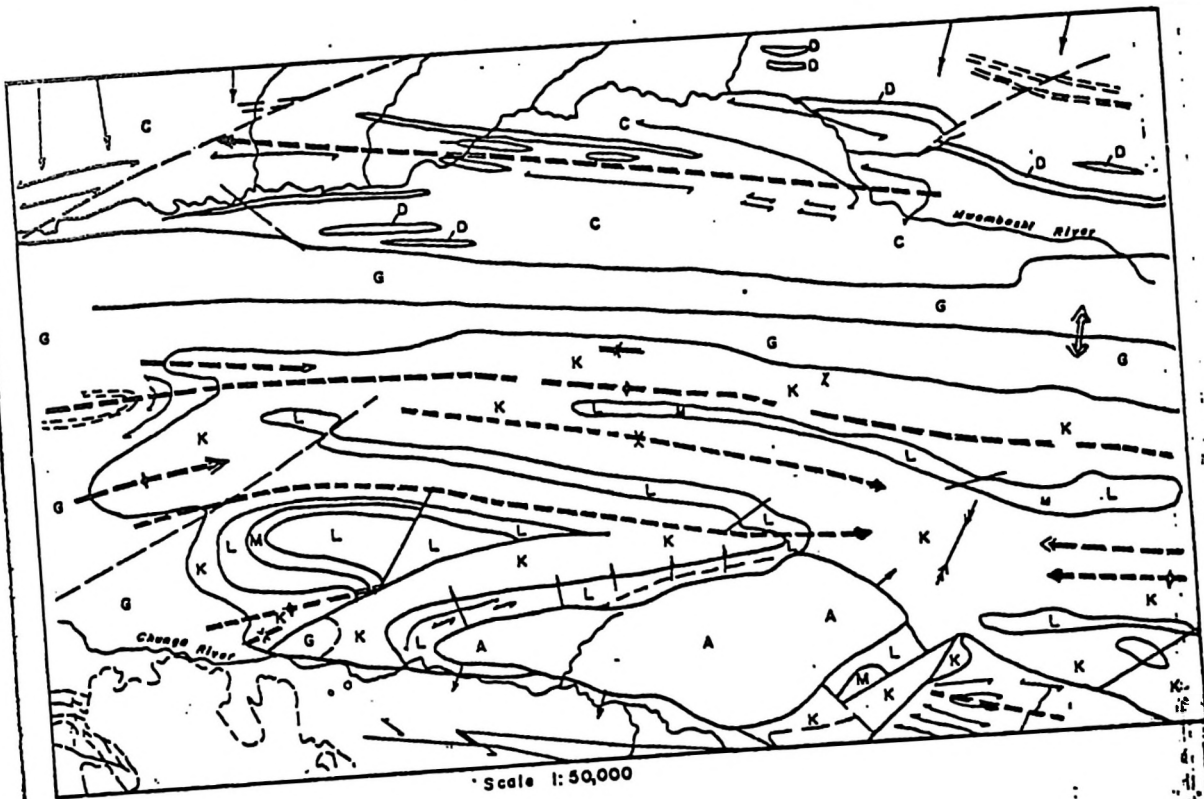
-  Administrative boundary
-  Lusaka City boundary
-  Main road
-  Railway
-  International airport
-  Forest Reserve Area
-  **SURVEY AREA**

Fig 2

GENERALISED GEOLOGY MAP OF KAPINI AREA

KEY

- A.....Granite
- K.....Limestone
- A,M,L,D.....Quartzite Ridges
- G.....Schist
- C.....Gneiss



Source : Simpson et al 1963

Rock outcrops of gneiss were observed across the Mwembeshi river (boundary of study area) and these were mainly quartz-muscovite-biotite gneiss and some schist with discrete granitic laminae, which may have formed as a result of variability in degree of metamorphism. Extensive outcrops of biotite schist were observed in the Mwembeshi region. This may indicate that part of the gneiss sequence was originally of sedimentary origin. Along the Mwembeshi river a probable strike of garnet-biotite augen gneiss was found. Small lenses of feldspars were found in association with gneiss. Gneiss is the parent material in soil mapping units 11 and 12.

Katanga System

The local formations within this system are the "Chunga" and "Cheta" formations. The Cheta formation overlies the Basement complex along the southern margins of the study area. The main composition of this formation are flaggy psammites, quartzites and schist. The commonest rock is quartz-muscovite-biotite schist which grades into highly psammitic quartz-muscovite flags. The formation is estimated to belong to the lower Katanga age (Simpson et al., 1963).

The Chunga was separated by Simpson et al. (1963) from the overlying Cheta formation on the basis of lithology and metamorphism. The formation is composed of calcareous

dolomite and dolomite limestone with schist members.

(Table 1). The limestone appears as rock outcrops in mapping units 31 and 33. In Mungule (Western part of the study area) banded argillaceous limestones are found. Schist which is the parent material of soil mapping units 41, 42 is composed of biotite, muscovite, garnet and chlorite. Garnet is rare while biotite is subordinate to muscovite.

Table 1: Variations of composition of rock belonging to the Cheta formation at Mungule (Simpson et al., 1963)

| <u>Rock type</u> | <u>Mg Co₃</u> <u>%</u> | <u>CaCo₃</u> <u>%</u> | <u>Insol*</u> <u>%</u> | <u>Total</u> <u>%</u> |
|---------------------|--------------------------------------|-------------------------------------|---------------------------|--------------------------|
| Limestone | 0.7 | 97.7 | 0.7 | 99.1 |
| Dolomitic limestone | 7.1 | 86.9 | 5.1 | 99.1 |
| Dolomite | 43.0 | 50.0 | 5.6 | 98.6 |

* Insol = insoluble

I.3 Geomorphology/Topography:

The area is part of Dixey's (1945) mid-Tertiary (Miocene) Peneplain of Central Africa, and Dalal-Clayton and English's (1983) level to gently undulating Degradational Plateau surface (Unit 2A). The Altitude ranges between 1125 and 1000 meters above sea level. The area is generally flat but undulates in the northern part and rolls in the western and southern part of the study area. Flat regions are usually separated by flat

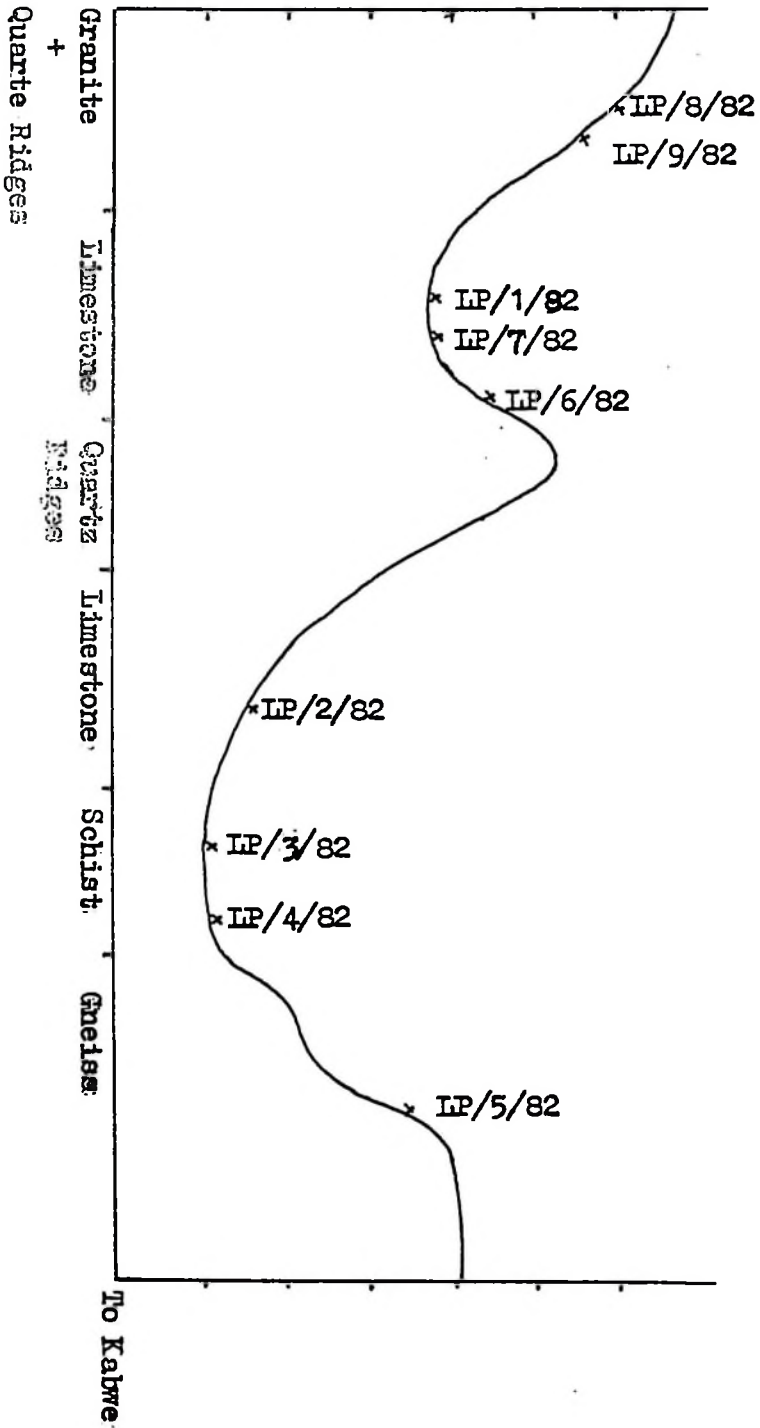
topped quartzitic hills and ridges. The ridges and hills are generally believed to be remnants of a Cretaceous Peneplain (Dixey, 1945, and Simpson et al., 1963).

The geomorphology of the area is mainly controlled by the geology. Dolomite/limestones give a typical karrenfeld topography, showing rock outcrops in generally flat to undulating areas (mapping unit 31, 32), whereas quartzites underlie broken country forming extensive ridges of several meters high (mapping units 11, 12) while granites underlie rolling land (mapping unit 52). The geological boundaries are usually indicated by steep downward slopes (Fig. 3).

I.4 Drainage:

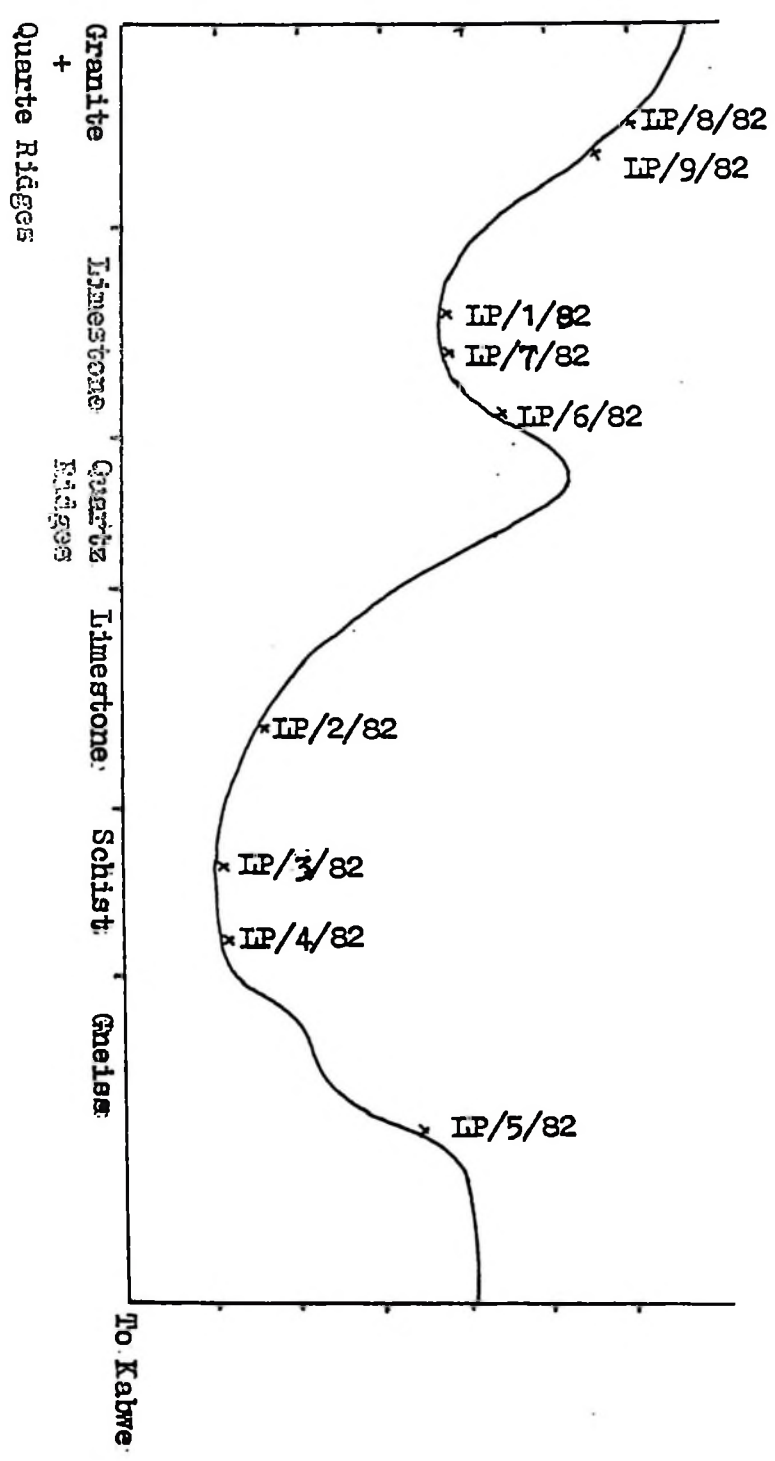
The area falls within the Chuzga - Mwembeshi drainage system, forming a watershed between the two rivers. The limestone area is flat and shows no drainage features. Around Chikumbi, water appears in shallow depressions or in quarries, an indication of ground water cavities or systems in limestone. The mica area also shows no drainage lines except for the region in which the schist meets the other geological rocks. Many streams are initiated as springs along the carbonate schist junctions. In the gneiss and granitic units a well developed dendritic drainage pattern exists. This pattern finally forms broad flat, seasonally waterlogged swampy areas (locally known as Dambos) which dry out in the dry season.

Fig. 3: Generalized cross section of the study area showing the location of the pits in relation to geology



Not to scale.

Fig. 3: Generalized cross section of the study area showing the location of the pits in relation to geology.



Not to scale.

I.5 Climate:

The climate in the study area, as indicated by the climatological data from the nearest meteorological station in Lusaka, is strongly seasonal (Table 2). The dry season extends from May to September while the wet season is from November to March. The coldest period is in June/July while the hottest season is during September/October. Frost very rarely occurs. In general, the climate may be called "tropical continental type" or according to Koppen and Trewartha tropical wet-dry climate (Cwa) (Strahler, 1975).

According to the percentage probability of of cumulative monthly rainfall amounts for Lusaka, the rainfall in the study area is very reliable (Table 3). Rainfall averages just above 800 mm per year.

The mean monthly temperature ranges from 15.6 to 24.2°C with a mean annual of 19.6°C, Mean Maximum and minimum temperatures are 26.2 and 14.7°C, respectively (Table 2).

I.6 Vegetation:

The vegetation is mainly savannah woodlands. Vegetation is strongly related to the geology of the area. The vegetation on limestone ranges from Acacia/Combretum woodlands to scrub grassland of Diplorhynchus and allied types. On the other geological units Isoberlinia globiflora and Brachystegia woodlands are found accompanied by Hyparhenia grasslands.

Table 2.

Lusaka City Airport
 Lat. 15°25'S LONG 28°18'E ALT. 1280M.

| Month | No. of Yrs. Available | Pressure (0800) | Thermograp Mean Temperature °C | Mean Max. Temperature °C | ABS MAX. Temp. °C | Mean of ABS Max. Temp. °C | Mean Min. Temp. °C | ABS Min. Temp. °C | Mean of ABS Min Temp. °C | Re. Hum % | Sunshine Hours per | Wind Speed Knots | Rainfall Total mm | 0.01" Rain Rain days |
|-----------|-----------------------|-----------------|--------------------------------|--------------------------|-------------------|---------------------------|--------------------|-------------------|--------------------------|-----------|--------------------|------------------|-------------------|----------------------|
| July | 26 | 878.0 | 15.6 | 22.7 | 28.3 | 26.4 | 9.6 | 5.4 | 6.7 | 54 | 8.7 | 7.7 | NIL | 0 |
| August | 26 | 876.4 | 18.0 | 25.4 | 33.9 | 29.7 | 11.7 | 3.9 | 7.5 | 54 | 9.6 | 8.5 | NIL | NIL |
| September | 26 | 875.1 | 21.3 | 28.9 | 35.0 | 33.0 | 14.7 | 6.7 | 10.6 | 41 | 9.7 | 8.9 | 1 | 1 |
| October | 26 | 873.2 | 24.2 | 31.2 | 37.8 | 34.9 | 17.8 | 10.6 | 14.2 | | 8.7 | 7.6 | 16 | 3 |
| November | 26 | 872.7 | 22.4 | 28.7 | 38.3 | 33.6 | 17.8 | 11.7 | 14.9 | 61 | 6.9 | 5.7 | 82 | 11 |
| December | 26 | 872.4 | 21.1 | 26.5 | 33.9 | 30.8 | 17.3 | 12.8 | 15.3 | 76 | 5.5 | 4.7 | 194 | 18 |
| January | 26 | 871.9 | 20.6 | 25.8 | 35.0 | 29.1 | 17.2 | 13.9 | 15.3 | 82 | 5.1 | 4.1 | 222 | 20 |
| February | 26 | 871.9 | 20.4 | 25.8 | 31.1 | 28.7 | 17.1 | 11.7 | 15.1 | 85 | 5.2 | 3.7 | 179 | 19 |
| March | 26 | 873.2 | 20.2 | 26.1 | 32.8 | 28.8 | 16.3 | 11.7 | 13.4 | 75 | 6.9 | 6.3 | 88 | 11 |
| April | 26 | 874.7 | 19.7 | 26.3 | 31.7 | 29.6 | 14.0 | 8.0 | 11.8 | | 8.5 | 7.2 | 15 | 3 |
| May | 26 | 876.4 | 17.6 | 24.6 | 29.4 | 28.2 | 12.2 | 7.2 | 8.9 | | 9.0 | 7.1 | 5 | 3 |
| June | 26 | 877.9 | 15.6 | 22.8 | 28.3 | 26.4 | 10.2 | 3.9 | 6.8 | 53 | 8.9 | 7.8 | 1 | 0 |
| Year | 26 | 874.5 | 19.6 | 26.2 | 38.3 | 29.9 | 14.7 | 3.9 | 11.9 | | 7.7 | 6.6 | 803 | 86 |

Source: Climatological summaries for Zambia period ending Dec. 1970 Dept. of Meteorology Lusaka.

TABLE 3.

- 10 -

PERCENTAGE PROBABILITY OF CUMULATIVE MONTHLY RAINFALL
AMOUNTS FOR LUSAKA. (mm).

| PROBABILITY | O | N | D | J | F | M | A | ANNUAL |
|-------------|------|-------|-------|-------|-------|-------|------|--------|
| 99 | 0 | 22.6 | 53.6 | 30.5 | 21.3 | 8.6 | 0 | 447.0 |
| 95 | 0 | 35.3 | 78.7 | 57.4 | 43.2 | 20.3 | 0 | 513.1 |
| 90 | 0 | 43.9 | 95.2 | 77.5 | 59.7 | 30.5 | 0 | 579.1 |
| 80 | 0 | 56.1 | 118.4 | 108.2 | 86.7 | 47.2 | 0 | 660.4 |
| 70 | 0 | 66.3 | 137.4 | 135.9 | 110.5 | 62.9 | 5.3 | 718.8 |
| 60 | 5.1 | 75.7 | 154.9 | 162.6 | 133.4 | 78.9 | 8.9 | 767.1 |
| 50 | 8.1 | 85.6 | 173.2 | 190.5 | 158.5 | 96.3 | 12.2 | 817.9 |
| 40 | 11.7 | 96.5 | 191.8 | 221.7 | 186.2 | 116.1 | 16.0 | 863.6 |
| 30 | 14.2 | 108.7 | 213.9 | 259.1 | 218.9 | 139.7 | 20.6 | 914.4 |
| 20 | 17.8 | 124.5 | 242.6 | 307.3 | 261.6 | 171.9 | 26.4 | 792.8 |
| 10 | 23.6 | 148.6 | 284.5 | 382.3 | 330.2 | 223.5 | 36.3 | 1056.6 |
| 5 | 28.2 | 170.7 | 322.6 | 452.1 | 395.5 | 271.8 | 42.4 | 1125.2 |
| 1 | 41.9 | 217.2 | 403.9 | 604.5 | 534.7 | 381.0 | 56.1 | 1249.7 |

SOURCE: Climate Data Publication No. 4. Department of Meteorology.

II. LITERATURE REVIEW

II. 1 Soil Classification:

Soil classification in Zambia dates back as far as the 1930's with the beginning of systematic soil surveys carried out by the Forestry Department of Northern Rhodesia. The soil was classified into broad soil groupings related to vegetation and land form types, e.g. Chipya and red upland soils. The result of these surveys was a vegetation-soil map of Northern Rhodesia (Trapnell et al., 1948) at a scale of 1:1,000,000. A modified form of this classification was also used when a 1:2500000 soil map of Zambia was produced as part of a co-operative inter Africa project (GRZ, 1965). This classification had major shortcomings and has now been abandoned for the more science based classification systems. Firstly, classification and soil mapping based on such new concepts as the "Soil catena" developed in East Africa (Milne, 1935) proved much more reliable. Secondly, field work carried out by the Soil Survey Unit at Mount Makulu Research Station (1967-81) has revealed more information about the soils which can not be reconciled or accommodated in the old system. And finally, the appearance of the USDA (Soil Survey Staff, 1975) and FAO/UNESCO (1974) systems with a more morpho-genetic approach, has made soil classification in Zambia to take a new turn. Below is a review of the three different classification systems that have been used

in Zambia. The problems related to their use are also briefly discussed.

II.1.1 The Zambia System

The local classification is a direct product of the improvements upon the soil classification system of the 1940's (Trapnell et al., 1948). The nomenclature is also borrowed from the old system. Basically the system is taxonomically divided into groups, subgroups and series. The group is the highest level of generalisation described on morphological or genetic basis. This level is hence related to soil forming factors and processes. In this respect climate and parent material are important in that order.

The sub-group is a sub-division of the group category. It is based on broad soil development properties such as degree of leaching.

The series category is the basic unit of soil classification consisting of soils which are essentially alike in all major profile characteristics. Soils in a series have basically the same color, texture, consistence, chemical and mineralogical properties. Classification names of the series belong to places where the soil was described comprehensively for the first time. Soil series may be subdivided into phases using characteristics that effect use

and management of the soil, but which do not vary sufficiently to differentiate the soils into separate series.

Many of the categories in the Soil Taxonomy can be lumped up into the subgroup or series level in the local system. The Zambian system of soil classification is a product of easily observed characteristics in the field, such as soil color, texture, landform, geology and vegetation, and does not heavily rely on laboratory data. Soil Classification units are described rather than defined and their central concept is stronger than the realisation of their boundaries.

The local system is much more easily translated into the F.A.O./UNESCO legend (1974), except for the artificial classes such as the Luvisols and Acrisols whose equivalents are difficult to find. The FAO/UNESCO legend is also more easily translated into the local system than the soil Taxonomy, because the FAO/UNESCO legend gives fixed names whereas the Soil Taxonomy uses formative elements in naming soils.

II.1.2 FAO/UNESCO LEGEND:

This system is an attempt at developing a universal classification system. Its authors, however, do not regard it as a classification system, but rather a "mono categorical" system. This implies that the level of generalisation

standards used made it impossible to develop a true hierarchical system comparable to that of the Soil Taxonomy. Despite having been called a mono-categorical system, some workers have come to regard it as a kind of a taxonomical system (Young, 1976) or a bicategorical scheme (Beinroth et al., 1979) in which 26 units are recognised and are sub divided into 106 sub units using connotative terms such as: Luvic, Dystric and Eutric. For more detailed mapping purposes the system provides 12 phases, 3 textural classes, and 3 slope classes.

The FAO/UNESCO legend is an artificial system, despite many of the soil grouping being natural, in the sense that it sets out precise limiting values, as expressed in the definition of diagnostic horizons. The FAO/UNESCO legend was not specifically made for strict scientific classification purposes and hence it is regarded as a compromise between a taxonomic and a technical classification.

The FAO/UNESCO legend uses traditional and popular names in assigning names to the soil units. In cases where traditional and popular names would be liable to cause confusion due to varying usage in different classification systems, new names were coined using formative elements that point to the properties of the soil in the style of the Soil Taxonomy (Soil Survey Staff, 1975) nomenclature.

Example of nomenclature used:

| | |
|---------------------------------|---|
| Traditionally established names | Podzols, Rendzinas, Solonchaks. |
| Populary used names | Ferralsols, Andosols Vertisols, Rankers. |
| Coined names | Nitosols, Acrisols Luvisols, Yermosols. |

II.1.3 Soil Taxonomy (1975):

This is a complex and comprehensive system developed over the past 26 years in the USA by the soil conservation service of the U.S. department of Agriculture (USDA). Several approximations were made before the 7th approximation was published in 1960 (Soil Survey Staff 1960). The Soil Taxonomy, which can rightly be termed as the 8th approximation (since the system is still undergoing a series of substantial revisions, especially on tropical soils), was published in 1975 .

As opposed to the FAO/UNESCO legend, Soil Taxonomy is a multicategorical system. This means that each of the several categories of classification in the system is an aggregation of taxa which are defined at the same level of abstraction and having a fewer number of classes in the higher categories and more number of classes in the lower

categories. Thus the system has orders (most of which are to be found in Zambia), sub-orders, great groups, sub-groups, families and series, in that decreasing order. The most impressive part of the system is its detail and comprehensiveness in describing the difference between the taxonomic levels. The presence or absence of a variety of combinations of diagnostic horizons and soil properties is used to differentiate orders, sub-orders, and great groups. The diagnostic criteria used are often related to the pedogenetic properties that operate in the soil profile under classification, e.g. Oxic, Spodic, Mollic or Histic epipedons. At sub-order level, soil moisture regimes, extreme chemical properties, and extreme mineralogical properties are used as differentiating criteria. The great groups are differentiated on the basis of properties that seem to be superimposed on the features that are diagnostic to the orders e.g. Pans or Plinthite. The great groups are sub-divided into sub-groups. The typic sub-groups represent the central concept of the particular great group category while others represent the intergrades from the typic to other great group categories. A third group of sub-groups represents extra grades that have additional aberrant properties to those of the central concept of the great groups.

In differentiating the family and the series taxonomic levels, the Soil Taxonomy uses criteria that are homogenous and important to practical uses of soil, especially to plant growth.

The basis for the identification of the different soil families is formed by certain properties selected to create taxa that will provide classes with great homogeneity in properties especially important to the growth of plants e.g. mineralogy and soil temperature. Series are sub-divisions of families that give greater homogeneity in properties in the rooting zone in the soil or the so called genetic soil. The series is the basic unit of soil mapping.

Smith (1965) explains that the Soil Taxonomy uses concepts of pedogenic processes in forming the higher classes, but when these processes do not fit as diagnostic criteria, some of their more prominent effects are selected as differential. The Soil Taxonomy is therefore known to be a morphometric system in that properties resulting from soil genesis are chosen as differential because these have the maximum number of accessory properties and are operational or are defined in terms of actual operations.

The nomenclature used in the soil taxonomy is different from the usual traditional nomenclature. The system coins its new names largely from greek and latin roots. The names

of the taxa above the category of series are short and connotative, that is, capable of mnemonic attachment.

In the chapters that deal with tropical soils, it has largely been assumed that the processes that operate in the soils of the tropics are similar to those that operate in the temperate soils although at widely differing rates and intensities. Therefore the classification of tropical soils in the Soil Taxonomy is made consistent with that of the temperate soils. The Soil Taxonomy separates the tropical soils mainly on the basis of degree of weathering, soil temperature regimes and degree of continuity of biological activity. The soils of the humid tropics are distinguished at the order, sub-order, or great group level with few exceptions. Soils of the arid tropics are differentiated at the family level because of seasonal moisture deficiency.

The soil Taxonomy, although very elaborate, has been the object of criticism especially as related to its nomenclature and precise value limits. Its use however is gaining popularity and some countries in South America (Costa de lemos, 1971) and South East Asia have adopted it as a national system. Some countries in Africa, like Zambia, use it for correlation purposes.

II.1.4 Some problems associated with the Soil Taxonomy and FAO/
UNESCO Legend

These two are discussed together because the problems related to their use in Zambia are almost similar. The first problem is related to the distinction and differentiation of the Oxic diagnostic horizon especially where it relates to the presence of 2:1 minerals e.g. micas. According to Soil Taxonomy, the Oxic horizon should virtually have no 2:1 layer minerals. Research and other investigations carried out by the Soil Survey Unit at Mt. Makulu, Zambia, indicate that the diagnostic properties outlined in the definition of this diagnostic horizon in the two classification system (The Soil Taxonomy and the FAO/UNESCO) do not exclude each other. Similar observations have been made by several workers around the world and especially in Africa (Herbillon 1981, Cook 1973, Sys 1969, Herbillon et al, 1966). It has especially been observed that the soils in Rwanda, Burundi and Northern Zaire pose a lot of problems in classifying because of the difficulties encountered in the differentiation of the Oxic and Argillic horizons. Jørgensen and Njøs (1978) found that in the Mochipapa series 2:1 and 1:1 minerals occurred simultaneously in abundance in the B horizon despite pronounced oxic properties. Hence, while there was supporting evidence for the presence of an Oxic horizon a contradiction was created by the presence of the 2:1 minerals for the

qualification of the Oxid horizon (according to the Soil Taxonomy and FAO/UNESCO legend). In the presence of such contradictions the FAO/UNESCO legend and the Soil Taxonomy are not very useful. Suggestions have been made in an attempt to overcome this problem.

Jørgensen and Njøs (1978) have suggested a possible modification in the requirements of the Oxid horizon within the two systems in order to strike a compromise. In this suggestion the requirements of an Oxid horizon would not only "exclusively" include 1:1 layer minerals but would also include weathering resistant 2:1 layer minerals whose presence would still not exclude an advanced stage of weathering associated with 1:1 minerals. A division is made related to the stability of the di- and trioctahedral 2:1 minerals. Dioctahedral 2:1 minerals are more resistant to weathering than the trioctahedral 2:1 minerals. Dioctahedral 2:1 minerals are more resistant to weathering than the trioctahedral 2:1 minerals. As an example the quartz-muscovite schist is found to be more resistant to weathering than gneiss as in gneiss biotite and feldspars provide two easily weatherable minerals. Consequently 2:1 mica dioctahedral minerals have to be considered as similar in diagnostic properties as the 1:1 clays with regard to their indicating the degree of weathering if there is to be no ambiguity in the use of the two systems.

It has also been suggested that the taxonomical problems related to the presence of muscovite in weathered soils could be solved by shifting the sand muscovite content requirement of 3% to 6%. Sys (1969) does not think this could solve the problem even if the muscovite content in the sand was shifted to 10%. Herbillon (1981) suggested that muscovite should be taken as a weatherable mineral when present in the fine sand fraction and hence the amounts allowed in an Oxisol profile must be greatly restricted. He further suggested that muscovite should be allowed to be present in the clay fraction in any amount (on assumption that it is no more weatherable), as long as it does not influence the negative charge (the CEC must remain at lower than 10 me/100 g clay in 1N NH_4Cl determination).

T' serstevens et al., (1978) and Huang and Kozak (1970) have both reported that the presence of 2:1 layered minerals such as muscovite do not exceed the requirement of an Oxic horizon since the abundance of iron and aluminium in the tropical soils renders most of 2:1 minerals especially the muscovite in the fine sand fraction, inactive by covering their surfaces.

The Soil Taxonomy suffers great imperfection in as far as the occurrence of mixed and interlayered minerals in Zambia is concerned. This imperfection is especially evident

in the mineralogical classes at the family level. The problem is that the Soil Taxonomy does not specify the place of the less dominant minerals. Neither does it give the percentage of the dominant minerals, because when mineralogical classes are based on percentage results can be ambiguously interpreted for use. However, it is felt that whatever purpose a particular classification system may have (genetic, applied, etc) the importance of expanding or swelling clays (in as far as they influence and effect cation exchange capacity (CEC), available water holding capacity (AWC) and soil acidity (pH)) must be stressed and be given high priority. This is because a 10% or even a 5% of expanding clays in a soil may be more important than 80% or 95% of the non-expanding clays such as kaolinite in as far as retention of plant nutrients and plant growth is concerned. Clay mineralogical work carried out in the Kaleya region in Southern Province of Zambia (Jørgensen, 1983) in lower laying relatively imperfectly drained areas has greatly highlighted this problem in Zambia. It was found that the soils were inter-layered mixtures of illite/kaolinite and smectites/kaolinite. Although kaolinite was always the dominant clay mineral the substantial amount of other 2:1 clay minerals gave great problems in interpretation for soil genesis and soil classification.

Apparently the soil taxonomy is not the only classification system to have this weakness. The INEAC soil classification system (Sys et al., 1961) also defined kaolisols as those soils with at least 50% 1:1 clay minerals without specifying, at least in the key, the nature or percentage of the associated minerals.

The cutans which are a major diagnostic criterion for the distinction of an Argillic horizon have been very controversial as they cannot be readily identified in the field. In the absence of thin section and the nature of the coarser texture surface horizon, cutans can not be identified with confidence. Sombroek and Siderius (1976), discussing the cutan determination in the identification of Nitosols, correctly observed that the clay skins or cutans are often the object of endless discussions for participants in a correlation field tour.

Among the diagnostic horizons, problems have mainly been encountered with the Mollic A horizon. The importance of its organic carbon value criterion is questioned because it can easily be depleted or increased. Observations carried out in both Zambia and Malawi (Cheatle, 1978, 1980) show that Mollic A horizons with 1.83% organic carbon got their organic carbon depleted to 0.26% on average after cultivation for a period of 14-20 years. The significance of this change

in the FAO/UNESCO legend for example is enormous. If the soil had been classified as Luvis Phaeozems, the change in organic carbon % would result in a reclassification as Eutric Nitosol. Ochtman and Debele (1976) observed that some soils have been wrongly classified in the FAO/UNESCO soil map of the world (1974) due to the phenomenon where, in the highlands, organic matter is depleted from the Luvis Phaeozems by erosion. After this depreciation of organic matter, the soils have to be reclassified as Eutric Nitosols, while low laying organic recipient Eutric Nitosols, have to be reclassified as Luvis Phaeozems. The use of such value criterion, that are bound to easily change is not in line with the soil classification philosophy which aims at using parameters that are nearly permanent or are not easily changed.

Although the Soil Taxonomy is very comprehensive and detailed, its detail on the tropical soils has been questioned by some workers (Young 1976, Jørgensen and Njøs, 1978). Despite much work having been done in Hawaii and South America, some of the characteristics of the tropical soils remain unaccounted for in the system. The Mochipapa series, the Kalomo series and the Nkolemfumu series are some of the soils in Zambia with characteristics that have been difficult to fit into the Soil Taxonomy system. An attempt to classify the Mochipapa series for example leads to intergrade between Oxisols and Entisols at the order level, Haplustox and

Quartzipsamments at the great group level. According to the Soil Taxonomy, classification at the sub-group level solves the intergrade question since this level shows the significant differences from any central concept in the higher taxonomical levels. It shows properties transitional to the higher classes, however, before classification is made at this level, a decision has to be made as to which of the two orders the soil belongs to, in terms of the development of its properties. This decision is difficult to make when the soil is a typical intergrade between the two orders. The point, however, is whether such arbitrary decisions should continue to be taken or whether new classes should be developed to take care of such new experiences. A suggestion, to have classes or rather new great groups, to take care of intergrades that are notoriously difficult to classify, has been made (Jørgensen and Njøs, 1978). This would include for example the introduction of great groups, in which clay content as low as 15% could be accepted in the oxic horizon, such as "Psammustox" and "Aremustox". In fact, the International Committee on classification of Oxisols (ICOMOX) in a circular letter No. 10 dated January 11, 1983 (Buol, 1983), has recognised this short coming and has recommended that the clay % requirements of oxisols be reduced to 8% from the 15% which had earlier on been accepted.

In the FAO/UNESCO legend, soil intergrades are not an

exception. In fact intergrades are much more common due to the fact that the system is formed by a generalisation of many similar classes coming from many parts of the world. For example the Luvisol soil unit is formed up by 29 local and regional soil groupings that have been merged.

The term "UDIC" in the Soil Taxonomy has been used with two slightly different connotations. This situation breeds ambiguity in view of the specific meaning given to other parameters, especially the moisture regime parameters. The term "Udic" is used both as a specific moisture regime diagnostic value as well as a sub-group name related to leaching i.e. more leached than the typic sub-group. During classification, therefore, a situation can occur in which soils with a similar moisture regime (say Ustic), belonging to two different orders may be classified into udic and ustic sub-groups due to textural differences or different mineral contents related to washing out of mineral material. Soils such as Udic Paleustolls are not a moisture regime sub-groups, as it would seem, but are related to deeper washing of carbonates within the profile. In Zambia such examples occur in the western part of the country where Bremmer, (1973) classified many profiles as Ustic Quartzipsamment or Udic Ustochrepts primarily due to textural differences related to washing out of mineral material. Most soil scientists in the country wonder whether it would not have been appropriate to provide a term specifically implying "Leached" or "Washed out",

rather than use Udic which has a specific meaning related to moisture regime.

The excessive reliance on chains of data material, especially laboratory data, required in the Soil Taxonomy has made the system unpopular in a country where the laboratories are ill equipped. The inavailability of soil moisture regime and temperature regime data (Brammer, 1973) has led to difficulties in the use of the Soil Taxonomy. To date due to doubts as to the real temperature regimes in the soils, workers have avoided using the "tropic" great group in soil classification. The inavailability of temperature regime data in some cases has led to the use of meteorological figures as surrogates for profile attributes especially between the uplands and valleys in the country.

II.2 Soil Genesis:

Soil genesis is defined here as the study which deals with factors and processes of soil formation. Pedogenesis is the term used for soil genesis when it is combined with soil classification studies. The factors of soil formation include the traditional external factors of soil formation that were first outlined by Dokuchaev in 1883 (Buol et al., 1973) and later worked out by Jenny (1941). The processes of soil formation include all internal chemical and physical soil

building and transforming processes (also known as pedogenic processes) such as Illuviation and Podzolization. Also included are weathering processes that are active and are acting on the rock, rock fragments, soft rock and the soil, especially the sand fraction. The weathering processes can be either geochemical or pedochemical although the two processes may occur simultaneously (Birkeland, 1974).

Soil genesis studies in Zambia were initiated in the 1940's by Trapnell et al. (1948). These were basically pedogenetic studies since they were combined with soil classification studies. In these studies no attention was paid to soil genesis as it is known today. Soil forming factors such as topography-geomorphology, geology and climate were related to different soils in a very generalised way and no attempt was made to study the internal soil forming process. Webster (1960, 1965) attempted to systematise soil genesis studies in the country by using the soil catena concept (Milne, 1935). He basically studied the effect of topography on soil formation in relation to physical, chemical and mineralogical composition of the soils. He found a relationship between soil composition and topography. His findings agreed with earlier soil survey work conducted in the country by Ballantyne (1956). More systematic soil genesis studies were conducted on major soil units of Zambia by Brammer (1973). These studies were very comprehensive, in that the soil

forming factors and processes were studied in detail.

In the past the importance of climate in soil formation has been over emphasised (Brammer, 1973; Magai, 1981; Clayton, 1980).

The 1000 mm rainfall isohyet is supposed to form a boundary between the highly leached soil and the less leached soils. Kalima (1983) has, however, shown that less leached soils e.g. the Chibesakunda and Milanga series, extensively occur above the 1000 mm isohyet. Although rainfall is an important soil forming factor, soil differences within the high rainfall area are not primarily due to rainfall. Parent material and length of weathering are equally responsible for the differences between the major soil regions. This statement which may be applied to Zambia as a whole agrees with the findings of Webster (1960). Webster contends that the concept of climatic zonality of soils does not work in Africa because climatic effects are masked by or are subsidiary to those of geomorphology and age, and that climate itself is often dependant on geomorphology. Trapnell (1943) also strongly disputes that climate is the most important soil forming factor in Zambia. On the basis of his extensive work covering nearly the whole country he contends that soil differences in Zambia are more basically a result of topography as the most important soil forming factor followed by geology,

age and climate in that order of importance. He points out that under African conditions differences in age of land surface are liable to cut across the broad zonal arrangements of climatic soil types as commonly perceived. Moreover climate has been shown to be greatly dependant on topography (Milne, 1935).

In conclusion, it is the author's view that the importance of climate as a soil forming factor has been exaggerated to some extent and that the arbitrary division of the soils of Zambia at 1000 mm isohyet into leached and less leached climatic soil types is too generalised and is not justified. The emphasis laid on climate as the most important soil forming factor in Zambia indicates a tendency to adopt the North America and Eurasian theories of soil formation. Whereas in North America and Eurasia climate is taken as the most important soil forming factor, other soil forming factors may be more important in Africa. Though environmental conditions such as highly varied rainfall, do produce different soil characteristics, rainfall decreases gradually in Zambia from the north to the south and therefore a clear boundary or highly varied rainfall conditions (rainfall change) is difficult to define. It is stressed here that factors like age, geology and topography, in relation to soil formation, should be studied in more detail.

LAND EVALUATION.

Young (1976) has defined land evaluation as a process in which the potential of land for one use or other alternative uses is estimated. In more general terms land evaluation is the act of judging or expressing the worth or value of a tract of land for a certain use. FAO (1976) defined land evaluation as an act which concerns the assessment of land performance when used for specified purposes and involves the execution and interpretation of basic surveys of climate, soils vegetation and other aspects of land in terms of the requirements of alternative forms of land use, taking into consideration the economics of the proposed enterprises, the social consequences, beneficial or adverse for the environment. Land evaluation therefore is component concept of resources evaluation of which land use is the ultimate goal. Vink (1975) has defined land use as any kind of permanent or cyclic human intervention to satisfy human needs from the complex of natural and artificial resources.

The most important factors in land evaluation are land utilisation types, land qualities and social-economic factors. The interaction of the above three factors of land evaluation is extremely important. A clear understanding of the individual factors and their interrelationships, is necessary for accurate land evaluation.

Concepts of land evaluation:

The act of land evaluation is not of recent origin although the concept "land evaluation" has itself gained much popularity and usage with the appearance of the FAO framework for land evaluation (1976). The main reason why the FAO system was produced was to reach some form of international standardization and to cut down on the several land evaluation concepts that were coming up, and which in many cases had diverse meanings. This had made the understanding of the basic scientific land evaluation principles vague, resulting in several basic contradictions.

Soil versus land:

Soil is one of the most basic natural resources which has been very much confused or likened to the concept of land. In land evaluation literature one will come across land evaluation systems called "soil capability classification (e.g., that of Canada, cited in Weenenbos, 1975), and land capability classification (e.g., that of USA, Klingebiel and Montgomery, 1961). These systems are similar although they have different names. Basically, here, it is the concepts of soil and land that are not used consistently.

Although authoritative systems such as the Soil Taxonomy (soil survey staff, 1975) decline to give a precise meaning to the term soil, the FAO system has given the following

definition; "A soil is a three-dimensional body occupying the uppermost part of the earth's crust and having properties differing from the underlying rock material as a result of interaction between climate, living organisms (including human activity), parent material and relief over periods of time and which is distinguished from other soils in terms of differences in internal characteristics and/or in terms of gradient, slope - complexity, micro-topography, stoniness and rockiness of its surface", (FAO, 1974). In defining the concept of land the FAO frame work for land evaluation has adopted the concept of land defined by Christian and Stewart (1968).¹ Although some soil scientists consider the definition as not entirely comprehensive (Veenenbos, 1975), Christian and Stewart, and the FAO define land as: "A tract of land defined geographically as a specific area of the earth's surface; its characteristics embrace:

- (a) all reasonable stable - or predictable cyclic - attributes of the biosphere vertically above or below this area, including those of the atmosphere,
- (b) the soil and the underlying geology, the topography, the hydrology,
- (c) the plant and animal populations as well as

- (d) the results of past and present human activities to the extent that these attributes exert a significant influence on present and future uses of the land by man.

From the above, one will notice that the definition of land includes precisely all factors of soil formation, hence one can not fail to see why these two concepts have been used indiscriminately in land evaluation. The definition of land as given above presents itself as a landscape unit of a higher generalization having special physiographic or geomorphological features and boundary. The soil survey specialist recognises similar terrain units which, depending on the scale of study, are shown on the soil map. Soil is one of the several land resources that form up the concept of land and which must be evaluated together with the other land resources e.g. climate, vegetation, hydrology, topography, human resources, capital and other economic resources in land evaluation studies.

Capability versus suitability:

In land evaluation studies one will often come across land capability and land suitability systems (as in the U.K., U.S.A. and Iran respectively). The use of these terms has often led to some confusion as to its meaning. In the U.S.D.A. land capability system (Klingebiel and Montgomery, 1961),

capability denotes the capacity of a tract of land to produce goods. In the land suitability system (Soil Institute of Iran, 1970), suitability denotes the suitability of a tract of land for a defined use. The Zambian land use system (I.U.S. system, 1977) incorporates both land capability and suitability. The system defines land capability as the provision of an assessment of the overall suitability of the safe long term use of land for agricultural practices appropriate for the climate (and economic conditions of the area). Suitability is used in the so-called crop suitability classification which is said to provide an assessment of the suitability of a soil or piece of land for the cultivation of specified crops regardless of economic conditions (unless these are specifically included in the evaluation). A simple survey and analysis of the use of the words capability and suitability shows that both point or indicate the quality of land for uses that are inherent to the system of sustained agriculture that prevails in the area of investigation. Sustained agriculture means a system of land use, crops commonly grown, and management practices applied over lengths of times that have therefore proved within the economic and socio-economic situation that is characteristic for the region to be paying. It was under such staggering facts that the standardized system of F.A.O. (1976) found the words to be interchangeable and decided to drop the term land capability, which has a long association with the USDA system, for the term land suitability. As this

work follows the F.A.O. system no mention of land capability will be made in the discussion of land evaluation results in the study area.

Appraisal versus classification:

Other concepts used to indicate the evaluation of land for certain purposes are land appraisal and land classification. In comparison to the term capability and suitability, land appraisal is a more general expression. It indicates all methods of land evaluation or classification in all terms (whether in financial or yield terms). From the above discussion, land classification is a concept of land appraisal and hence land evaluation. Land classification can simply be defined as an arrangement of land evaluation results in classes for practical application purposes that are most useful. At the highest level of land appraisal, depending on the land evaluation system used, land classification is of a very practical significance because no exact data but mainly estimations are available for the factors determining the suitability of the land for the uses under consideration. This is the case in land system studies as has been applied by Christian and Stewart (1953, 1968). Land classification has either been confused as synonymous to land evaluation (as in L.U.S., 1977) or land evaluation has been confused as a branch of land classification (as in Mikonga, 1982). Land classification is not an arbitrary and purposeless exercise and can

not therefore be divorced from land evaluation, neither can it be equated to land evaluation since it is an inside job in land evaluation and serves the purpose of land evaluation.

Approaches to Land Evaluation:

A broad survey of different land evaluation approaches show certain activities that are common to all. These activities are:

- (a) consultations related to the objectives and constraints;
- (b) resource surveys and
- (c) the evaluation

The details of these activities vary greatly and the sequence and combinations in which they are carried out depends on circumstances such as survey intensity (detailed, semi-detailed or reconnaissance).

The criteria for judging the value of a tract of land for a certain use however differs with methods used in different evaluation approaches. An exact approach would seem to be a comparison of inputs and outputs especially in terms of money where inputs would include the cost of the following elements of production: seeds, fertilizers, management, harvesting, traction (farm power, animals, or

tractors), output would include revenue from produce. This rather too elaborate procedure would prove impracticable even for detailed studies in areas where sustained agriculture prevails. In areas where agriculture does not yet exist the procedure would prove impossible altogether. Instead, most of the land evaluation approaches use criteria by which they can adequately express the value of land. The most popular criteria has been the limitations approach which was first developed in the U.S.A. and is still in use there (Klingebiel and Montgomery, 1961). In this approach optimum use of arable land is the starting point and the value of land is estimated by certain limitations that decrease the optimum use of this land. The value of a tract of land decreases with increased number of limitations. As the value decreases, crop production is ruled out and the land is ultimately recommended for grasslands. Criticism of the limitations approach as used by USDA centres on the fact that the system is basically for general appraisal. It does not define the crops needed in terms of land utilization as used by Beek (1975) and FAO (1976). Secondly the criteria for downgrading a piece of land are not well defined in the sense that they are not qualified. The quantification should show and verify the impact of the criteria on the growing conditions of particular crops. Lastly, socio-economic factors are not considered. The socio economic factors from a very important land use resources factor. Attempts to improve upon the limitations approach above the level attained by the USDA have been done by the land use capability classification of the U.K. (Bibby and Mackney, 1969).

The United Kingdom system basically follows the principles of the U.S.D.A. system, but is adapted to local conditions. The U.K. system makes a slight deviation from the U.S.D.A. system by putting weight on a few land characteristics that have a greater diagnostic value for specified kinds of land use intensities.

For example the criteria "possibility of use of machines" gets a greater limitation "weight" as the slope gets steeper. This weighting is done for all criteria used and each criteria is rated. The final evaluation is a combination of ratings of the different criteria on the basis of the maximum possible class principle.

The Iranian system is also an improvement upon the limitations approach of the U.S.D.A. It incorporates many soil and land characteristics which are then taken into account as criteria for land evaluation. The same procedure is done for the irrigability land classification. The rating is of a qualitative nature. Each rating is weighted according to the importance that the characteristic has on a defined land utilisation. As in the U.K. system, the final land evaluation is based on the maximum land class principle. Unlike the U.S.D.A. system where the starting point is optimum usage, the standard land classification system of Iran is

based on the existing soil and land condition while the irrigability land classification is based on uncorrectable limitations.

The United States bureau of reclamation (U.S.B.R.) has also developed an irrigability land classification system. This is a land evaluation system in which an inventory of soil resources is not important. The system is not an evaluation of land for its suitability to crops but for the suitability of the land for irrigated agriculture. In this system of land evaluation, economic factors play an important role. Since the purpose of this work is mainly crop production for rainfed agriculture the U.S.B.R. system will not be discussed.

As can be seen from the above, the limitations approach is rather a negative approach to land evaluation in that the evaluation of land for a certain purpose starts from an ideal situation of land condition and limitations are then taken into account to down grade the land. A more positive approach would be to evaluate separately all the major parameters as expressed by the concept of land use resources and give them a value or rating with respect to the degree of their influence on land use. In this way plant requirements can find expression in a combination of these parameters, hence a parametric approach.

The parametric approach to land evaluation aims at expressing the suitability of land, for certain purposes in quantitative terms as opposed to the other approaches which use a qualitative approach in land evaluation as has been reviewed above. The principle of the system is to quantify how good or bad, or how large, medium or small, soil and other land attributes influence a particular land utilization. A survey of the parametric methods shows that they are based on a set of common factors.

They all recognise the various attributes that determine the suitability of a piece of land as independent mathematical factors. All the attributes are "weighted" or are given a numerical value on a non-linear scale of 0-10 or 0-100. Using mathematical formulas, the final rating of the value of a tract of land is found. The mathematical formulas may be additive, subtractive, multiplicative or a more combination of the above mentioned alternatives. The least or lowest favourable factor will always dominate the final suitability class.

The parametric approach was first comprehensively introduced by Stories (1935) in his publication "An Index for rating the agricultural value of soils". An earlier precursor and probably the first to develop the principle was Fackler in German in 1928. (quoted by Veenenbos, 1975). Refinements on the system was further carried out by Riquier

et al. (1970). The system differs from that of Stories in that it mainly considers intrinsic factors (mainly soil) whereas the Stories system considered both intrinsic and extrinsic factors.

The advantages of the parametric method over the qualitative methods of land evaluation have been summarized as follows:

- (a) each factor is given appropriate weight
- (b) the least dominant factor determines the final suitability class or productivity index
- (c) constant factors are disregarded
- (d) interacting factors can be expressed.

The major disadvantages of this system are, however, that all interactions are normally not known and that the weight of different parameters is numerically fixed.

The parametric method is particularly very useful when used within the F.A.O. framework. This study will take advantage of this to use the parametric method. To some extent, many land evaluation specialists believe that with the introduction of computers the parametric method will gain importance and be the major system for land evaluation in the near future (Verheye, 1982a, 1982b).

The Zambian and the FAO Land Evaluation System:

Two land evaluation systems will be discussed as these are important to this study. These are the Zambian system which is used in the country of study and the FAO system which is the basis of land evaluation in this study.

The Zambian land evaluation system:

This system uses a limitations approach to land evaluation reminiscent of the American System as developed by the then conservation and extension (Conex) section of the department of agriculture (1963).

The system differs from that of the USDA in that it was tailored to evaluate the suitability of land for rainfed, medium and large scale commercial farming for maize and tobacco mainly. Soya beans, sunflower and groundnuts were taken as minor cash crops. The system thus identifies the level of management as well as the crops to be grown, or it identifies the land utilization types as known in the modern systems (i.e. FAO, 1976). Below is the structure of the system (Table 6).

Table 4: A diagramatic representation of the land capability classification procedure of Zambia:

| ORDER | CATEGORY CLASS | SUB CLASS | UNIT |
|-------|------------------|-----------|-------------|
| S | Good arable land | S1 | S2mt |
| | | | S2m |
| C | | C1 | S2me |
| | | | S2t |
| | Unsuitable land | Uw | no subclass |
| | | no | no unit |

The order 'C' and 'S' basically indicate whether the top soil is clayey or sandy. Class CI and SI indicate good arable land, Sub classes C2s or C2s with one suffix letter indicate moderately good arable land. Sub classes C3s or S3s indicate poor arable land capability (See table 5).

The land capability classes outlined above are then matched with the agronomic requirement of crops to find the suitability of a particular crop on a particular piece of land. The crop requirements are outlined in a separate document entitled "crop suitability", technical guide No. 7 (Brammer, 1973b). Crop suitability is indicated by a rating in form of a number ranging from 1-4. The number indicates

Table 5: Land classification legend for Zambia

| Arable land | | Map colour |
|--|---|---|
| C1 | S1 Good arable land (No limitations) | C1 ... Dark red S1 ... Light red |
| C2 | S2 Moderately good arable land (limitations as below) | C2 ... Dark brown S2 ... Light brown |
| <u>Marginal arable land</u> | | |
| C3 | S3 Poor arable land (Limitations as below) | C3 ... Dark yellow S3 ... Light yellow |
| | S4t Very poor arable land (Limitation ...t only) | S4t... Very light yellow |
| <u>Grazing land</u> | | |
| Gw | Winter grazing land (limitations...W or W and as below) | Gw... Blue-green |
| G | Summer grazing land (limitations as below) | G ... Light green |
| <u>Unsuitable land</u> | | |
| Uw | Permanently wet land (limitation ... W only) | Uw ... Blue |
| U | Other unsuitable land (limitations as below) | U ... Purple |
| <u>Limitations applied (Except to C1, S1, S4t, Uw)</u> | | |
| d ... depth to limiting layer | t ... texture (heavy clay or deep sand) | |
| e ... erosion | w ... wetness | |
| g ... gravelly or stony topsoil | z ... gravelly or stony subsoil | |
| m ... layer termite mounds | (a ... alkali or salt) | |
| r ... rocks or irregular relief | (f ... fertility) | |
| s ... slope | | |

Source: Dept. of Agriculture, Zambia (1977).

suitability of the land capability class for a particular crop. 1 is the most suited and 4 is the least suited.

The land classification legend showing the range of classes in the system is given in table 6.

The disadvantages of the system (LUS) far outweigh the advantages.

- (a) The criteria for land capability classification still remains related to the production of maize and tobacco at commercial management level as was the case in the conex system (Dept. of Agric., 1963).
- (b) The land rating and land utilization ratings are not expressed in the same values therefore they can't be matched confidently.
- (b) The land capability rating do not express the interaction of many land characteristic as the class is determined by the most limiting characteristic.
- (d) All the disadvantages of the limitations approach are inherent in this system due to its U.S.D.A. relations.

The FAO Land Evaluation System (1976)

This system is used in this thesis for the evaluation of the land in the study area. The system and its use are fully discussed in the chapter on land evaluation methods.

III. MATERIALS AND METHODS

III.1 Soil Survey Methods:

Soil survey was done at semi detailed level. Aerial photographs (scale 1:30,000, 1971) were interpreted resulting into broad groupings of land based on physiography. From the geology map (scale 1:250,000, Simpson et al, 1963) five different forms of parent material were identified. The topographic map helped in identifying the drainage pattern of the area, showing relief and the river systems.

The semi-detailed scale was chosen because of its suitability for surveying large tracts of land as only enough detail was needed to make a meaningful land evaluation exercise indicating crop suitabilities.

The pre-field preparations were in the form of collection of data related to the survey area. Aerial photos in the scale 1:30,000 were collected. Geological maps, topographical maps, vegetation maps, hydrological information, climatological information and other statistical information related to the area (land and crops) were collected. The topographic map (scale 1:50,000) was used together with the aerial photos as field base maps.

Aerial Photo Interpretation (A.P.I.)

The area was first of all divided on the basis of physiography using the following elements (a) plains (b) highly dissected areas (c) rolling to hilly areas.

The highly dissected area is mainly associated with granite and gneiss parent material. The plain area had mainly schist and limestone parent material and the rolling area was basically composed of limestone and quartzitic rock ridges. The vegetation composition and type, as observed from aerial photos, corresponded to the units delineated according to physiography and geology. Using aerial photo interpretation, different drainage patterns were delineated. After having delineated the land on the basis of topography, geology, vegetation and drainage and having found their relationships, photo interpretation was made to identify possible wet soils, deep soils and shallow soils using the following elements which proved to be highly indicative of soil conditions in the area during a short preliminary visit.

1. aerial photo tone
2. aerial photo texture
3. density of footpaths
4. vegetation concentrations and types
5. extent of cultivation

The results of this effort was a physiographical aerial photo map.

Field work

The basic survey was a free survey at semi-detailed level. In this survey, specific locations of observation sites were chosen in specified mapping units as were distinguished in the preliminary photo-interpretation effort described in the preceding section. The sites were chosen in such a manner that observation of soil information and sampling could be done for (a) the confirmation of the composition of the mapping units, so called descriptive observation, and (b) for the purpose of locating soil boundaries, so called boundary observation. The basic problem that is usually encountered in a free survey which involves specific location sites is the exact location of the sites in the field and on the field map. Field navigation and photo interpretation with aerial photographs at a scale of 1:30,000 overcome this problem, although a further enlargement of the aerial photographs to a scale 1:20,000 would have been more appropriately suited.

A grid system was not used for the following reasons:

- (a) The topographic, geological, vegetation and drainage patterns were so obvious that their relationship to soil units was very apparent, hence many traverses

through the land were not necessary.

- (b) The use of aerial photographs for field navigation and location of soil description sites made the grid system less suitable for survey at semi-detail.
- (c) Time and available funds outruled the use of a grid system since a full time field team would have been required to systematically carry out a grid survey.
- (d) The purpose of survey did not need the accuracy which the grid system entails. The purpose of the survey, as mentioned in the objectives, was to make this survey a part of the systematic surveys being carried out in the country, which are aimed at identifying arable land and giving an indication of the possible well suited crops. These surveys will form a basis for detailed studies in soils and land evaluation later.
- (e) Grid surveys are more appropriate at detailed level unless terrain features and location by use of aerial photographs is useless.
Random observations were not used as these would not ensure appropriate density of observation per mapping unit as identified in the preliminary photo interpretation.

All observations and descriptions of the soils in the field were done according to F.A.O./UNESCO (1977) guidelines for soil profile description. In addition, all information related and important to soil classification according to the Soil Taxonomy (Soil Survey Staff, 1975) and land evaluation according to the land evaluation frame-work (FAO 1976) were collected where-ever possible. Soil sampling for laboratory analysis was done according to soil conservation service (1972).

Soil mapping:

Soil mapping was done according to the soil survey manual (1951). Using A.P.I. technics, the land was delineated in what may be termed land units. These land units consist of similar geology, topography, vegetation and drainage. Depending on the above distinction the land units were related to different soils. Further A.P.I. was done using appropriate elements, found to be related to soil characteristics in the area during a reconnaissance visit, to delineated the different soil units, (as related to the land units) into soil sub units, in terms of depth, topographic position, wetness and non arable land. On the basis of these distinctions, a preliminary soils A.P.I. map was produced at the scale of 1:30,000.

Field work was then carried out to supplement and supply soil data on the units delineated in the preliminary map, as well as to verify the homogeneity of theseparate units and to

determine the differences between the mapping units in the preliminary map.

Finally, soil distinction by A.P.I. combined with field work, led to the production of a final physical soil map in the scale 1:30,000. This map differs from the usual physiographic soil maps in that the mapping units are not only of a physiographic nature since physiography was just one of the several physical characteristics used in the production of the preliminary map.

The production of real soil map almost independent of physical environmental characteristics could hardly be done at this semi-detailed scale, as this would have required an immense input of time, labour and money.

Through out the soil mapping process it was assumed that physical environmental characteristics identified in each land unit were related to soil. Such a simplification may have overestimated the relationship between the two and it may also have under estimated the variability of soils within one sub-mapping unit. Hence the final map may not be called a 'pure' soil map and the soil mapping units on the final map are at best soil associations or soil complexes.

III.2 Laboratory Methods:

Preparation of samples:

The soils were air dried and ground to reduce aggregates and then sieved through a 2 mm sieve to obtain the fine earth fraction (materials less than 2 mm) for laboratory analysis.

Particle - size analyses:

After grinding and dispersion with Sodium hexametaphosphate and Sodium carbonate, clay was determined by the hydrometer method (Day, 1965), sand classes were determined by dry sieving, and USDA silt was calculated as $100 - (\text{clay} + \text{sand})$.

Bulk density :

The core sample method was used and the results were expressed in g/cm^3 (Blake, 1965).

Soil reaction (pH):

pH was determined by glass electrode in 0.01M CaCl_2 using a soil to salt-solution ratio of 1:5 on volume basis, pH was also determined in H_2O using a soil-solution ratio of 1:5.

Organic Carbon:

Organic carbon percentage was determined by the Walkley Black method (Allison, 1965), the results being multiplied by 1.3 to arrive at a total carbon figure (assuming 77% efficiency).

In order to convert organic carbon figures to organic matter percentage, the carbon figures should be multiplied by 1.72.

Exchangeable bases:

These were determined on the ammonium acetate extract at pH 7.0. Exchangeable calcium and magnesium were determined by atomic absorption while potassium and sodium were measured on a flame photometer.

Cation exchange capacity (CEC):

This was determined by leaching out the excess ammonium acetate with alcohol and final leaching with a sodium chloride solution to replace absorbed ammonia. Then subsequent distillation using a boric acid indicator solution and titration with hydrochloric acid.

Base Saturation:

This was calculated as
$$\frac{(Ca + Mg + K + Na) \times 100}{CEC}$$

Available phosphorus:

This was determined by Bray's No. 1 method using an ammonium fluoride, hydrochloric acid solution as an extractant and measured in a spectrophotometer (Bray and Kurtz, 1965).

CEC/100g clay:

This was calculated as $\frac{\text{CEC} \times 100}{\text{Clay}}$

Porosity:

This was calculated as the percentage of the bulk volume not occupied by solids according to the formular

$$st = 100 (1 - (Db/Pp)) = 100(Pp - Db/Pp)$$

where as:

st = Porosity

Pp = Particle density (assumed to be 2.65g/cm^3)

Db = Bulk density

Available Moisture:

Was calculated as the difference between wilting point and field capacity (pF 2.5 - pF 4.2).

Mineralogy:

Particle size separation was done by sieving and sedimentation. Mineralogy work was done on 20 to 0.2 μm and on 60 μm soil size fraction. Slides of clay layers were then used to identify the minerals of the clay fraction (less than 2 μm) and the fine sand fraction (60 μm) by x - ray diffraction analysis. A programable phillips diffractometer was used. The soil was glycolated or heated to expand or collapse its layers whenever its indentification was in doubt. Quantification of minerals

was done by comparing the X-ray diffractograms with standard data (Brown, 1961).

Micromorphology:

Following the preparation of thin sections (Jongererus and Heirtzberger, 1975) micromorphological characterisation was done using petrographic and scanning microscope.

Floating limit (upper plastic limit) and Rolling limit (lower plastic limit):

These were done using the Cassagrade apparatus as outlined by Njøs and Singh (1980).

Plastic index:

Plastic index was calculated according to Njøs and Singh (1980) using the following formula:

$$\text{Plastic index} = \text{Floating limit} - \text{Rolling limit}$$

OR

$$\text{Plastic index} = \text{upper plastic limit} - \text{lower plastic limit}$$

Sticky limit

The Sticky limit was taken as the water content (%) of soil sticking to a spatula as outlined by Njøs and Singh (1980).

Shrinking limit:

This was calculated according to Njøs and Singh (1980) using the following formular:

$$\frac{\text{loss in weight} \times 100}{\text{Net dry weight}}$$

Linear Shrinkage:

This was calculated according to the formular:

$$\frac{(1 - \text{length of dry soil}) \times 100}{\text{Starting length of soil}}$$

Njøs and Singh (1980).

Field trials methods:

- A complete Randomised Block design plot layout was used
- Crop spacing was = 80 x 20 cm
- Plot dimensions = 4 x 4 m
- Number of rows was = 5 per plot
- Number of plants per row = 20
- Number of plants per plot = 100
- Fertilizers applied = Ammonium nitrate
- The plots were replicated 4 time at 2 sites

III.3 Land Evaluation:

Land evaluation was done according to the FAO framework (1976) following a two stage approach. An attempt was made to quantify land evaluation in a parametric way. A qualitative

evaluation was followed whenever a land quality could not be quantified. To arrive at the final rating of a land quality, several characteristics that affect it were sub rated and combined using additive, multiplicative, or subtractive methods. The most limiting land quality determined the suitability of the crops in any mapping unit. Social economic studies were done using a questionnaire. A full description of the land evaluation methodology can be found in chapter IV. Section 5.

III.4 Soil Classification:

Classification of the soil was done up to family level using the Soil Taxonomy (Soil Survey Staff, 1975) and up to the Sub unit level using the FAO/UNESCO legend (1974).

III.5 Soil genesis:

Soil genesis was studied using the macro analysis method. (Buol et. al., 1973). The soil was divided into macro grouping at group level or great group level (as used in the soil taxonomy, soil survey staff, 1975).

IV. RESULTS AND DISCUSSION

IV.1 Soil characteristics:

The general characteristics of the soils are discussed according to the different geological units (Table 10). Six major geological units have been identified.

Soils over limestone parent material:

A total of 3 mapping units were identified at semi-detailed soil survey level (31, 32, 33). The limestone parent material belongs to the Cheta formation of the Katanga system of the late Precambrian and lower Palaeozoic geological periods.

The deep (200 cm) soils occurring over limestone parent material (mapping unit 32) are very stable soils since they represent the most highly weathered soils in the area and have an Oxic B horizon.

The parent rock was not seen down to the depth of 3 meters. The soils exhibit an A, B, horizon stratification. Laboratory investigations revealed poor soil physical and chemical properties in terms of structure, pH, CEC and BSP.

Table 10: Showing Mapping Units in the different Geological Units

| Geological Unit | Mapping Units |
|-----------------|---------------|
| Gneiss | 11 |
| | 12 |
| Quartzitic rock | 70 |
| | 22 |
| Limestone | 31 |
| | 32 |
| | 33 |
| Schist | 41 |
| | 42 |
| Granite | 52 |
| Alluvial | 60 |

The moderately deep to deep soils exhibit an A, B, R horizon stratification (mapping unit 33). Although these soils are underlain by a limestone rock, all evidences show that they have not formed from limestone (see chapter 3). Soil forming processes are still very active in these soils. Soil reaction is very high (pH, CEC, BSP). Mapping unit 31 constitutes the shallow soil.

Description of Individual mapping units occurring over limestone parent material:

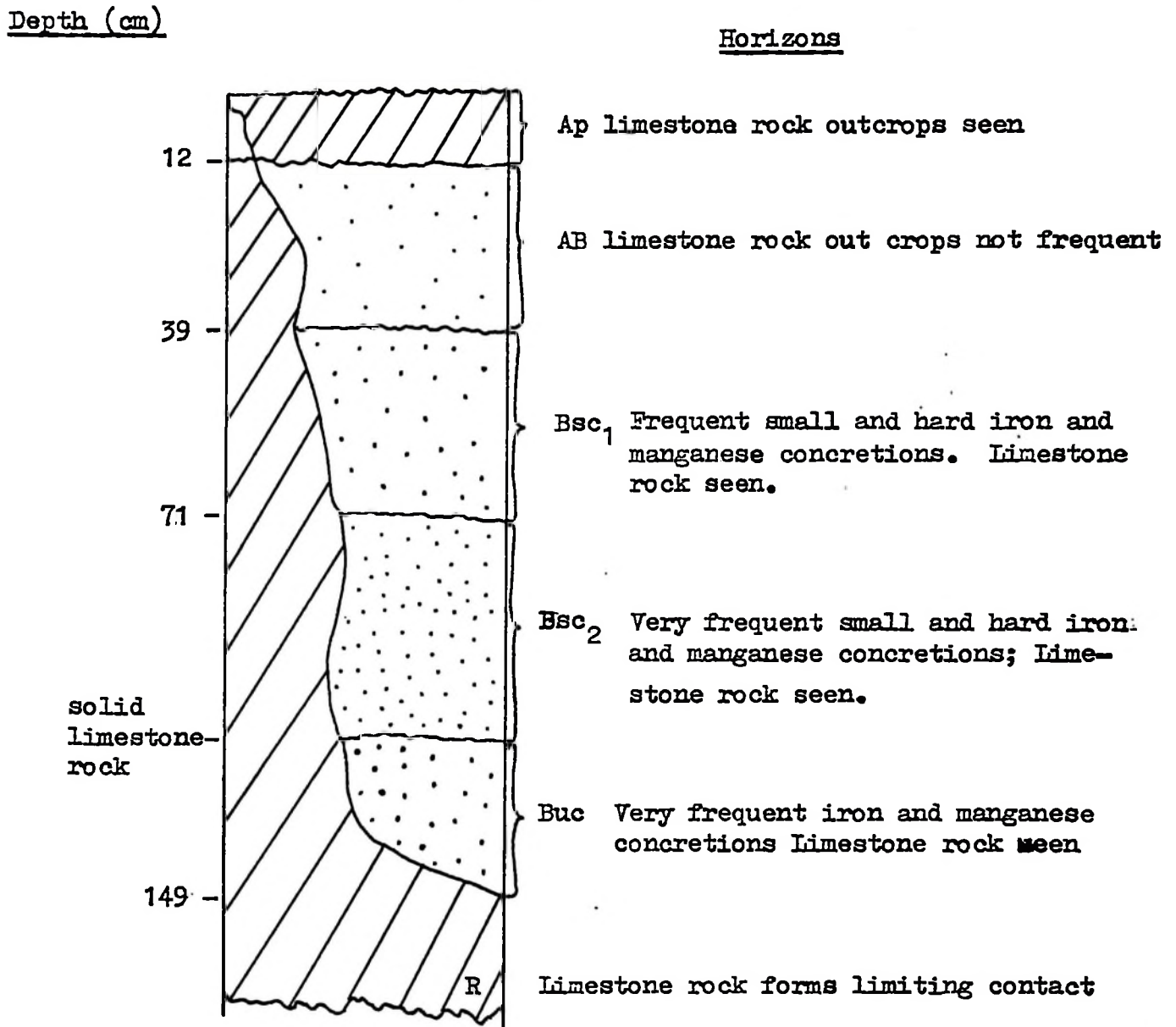
Mapping Unit 31:

Mapping unit 31 forms the shallow soils over limestone. They occur as intermediate soils between mapping unit 22 and mapping unit 32-33. The unit consists of limestone rock outcrops and gravelly soils.

Mapping Unit 33:

Consists of moderately shallow soils (less than 100 cm). Quartzitic gravels are found in the lower horizons. The gravels do not react to a treatment of HCl, although they lay right on top of the limestone which forms a lithic contact at 149 cm. The limestone does not show any signs of having been weathered. The limestone rock undulates within the soil profile (see Fig.4). The soil occurs on 0-1% slopes.

Figure 4: A soil profile (mapping unit 33), illustrating the major horizon feature and differentiation



Brief Profile Description for mapping unit 33:

Horizon

| <u>Designation</u> | <u>Depth</u> | |
|--------------------|--------------|---|
| Ap | 0-12 cm | Brown (10YR 5/3) moist, sandy clay loam; weak fine sub-angular blocky structure; clear smooth boundary. |
| BSc ₁ | 39-71cm | Strong brown (7.5YR 4/6) moist, clay; moderate medium sub-angular blocky structure; frequent iron and manganese concretions; clear wavy boundary. |

Brief soil characteristics:

- well drained
- soil depth is 140 cm
- pH in the soil is 5.6 in CaCl₂
- B.S.P. is more than 35%

Mapping Unit 32:

The soils of this mapping unit occur over limestone parent material. They are deep and clayey throughout the profiles. Top soil texture is clay loam; subsoil texture is clay. The soil is friable and soil structure is weak to moderate sub-angular blocky. Soil colour is dark red (2.5YR 3/6) dry and yellowish red (2.5YR 4/6) moist. The soil characteristics can be summarized as follows:

- well drained
- soil depth is over 200 cm.
- slope is 0. - 1%
- pH is 5.0 in the top horizon and 4.2 in the subsoil (CaCl₂)
- CEC is less than 16 me./100g soil clay
- the most dominant elements on the exchange complex are calcium and magnesium
- BSP is over 35% in the top soil and less than 35% in the subsoil
- organic carbon is 1.49% in the top soil and decreases with depth over 1m depth.

Brief Profile description:

| | | |
|-----|---------|--|
| A | 0-36 cm | Reddish brown (5YR 4/4) moist, clay; moderate fine sub-angular blocky; clear smooth boundary. |
| Bws | 36-80cm | Dark red (2.5YR 3/6) moist, clay; moderate medium sub-angular blocky; diffuse smooth boundary. |

Soils over schist (Quartz-muscovite-biotite schist) parent material:

Two soil mapping units (mapping units 41, 42) were identified over this parent material. The quartz-muscovite-biotite schist is of the Chunga formation of the Katanga system of the late Precambrian and lower Paleozoic geological

periods. The soils over this geological formation show deep weathering exhibiting only an A, B soil profile. The schist parent rock was not seen in the area, giving evidence of deep weathering of the parent rock. The chemical properties of the soil on schist are very good. Soil reaction is high and the soils are clayey throughout the profile. Evidence of active, on going soil forming processes was observed in the field and in the laboratory.

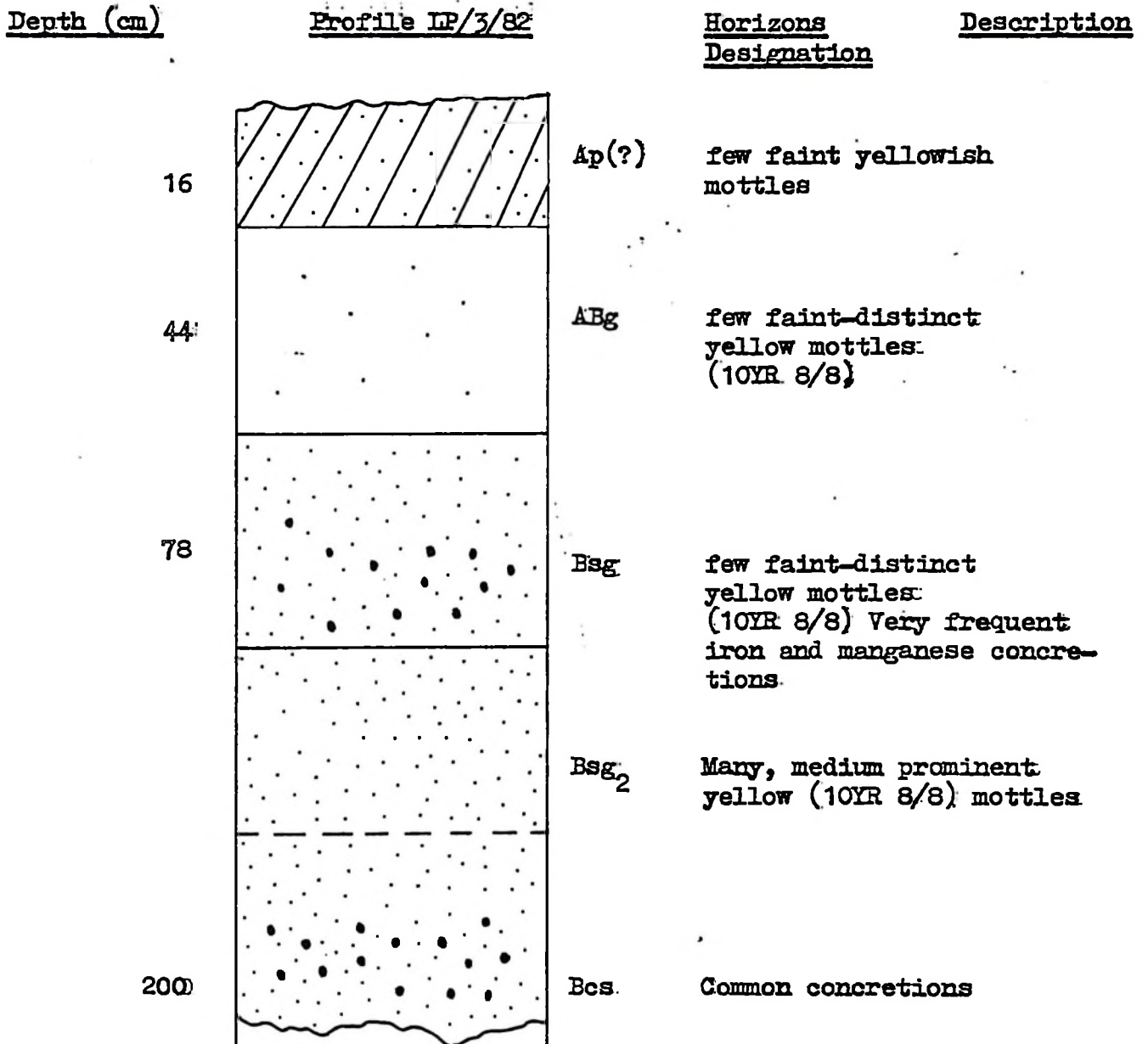
Mapping Unit 41:

The soils are well structured but show signs of poor drainage. They are mottled nearly throughout the profile. In the lower horizons the mottles develop into iron concretions (fig. 5). The properties of the mapping unit can be summarized as follows:

- soil texture is clay throughout the profile
- CEC is more than 16 me per 100g clay
- dominant elements on the exchange complex are Ca and Mg in that order
- BSP is higher than 60% throughout the profile
- pH is 5.7 (CaCl₂).

The features of the profile are similar to those of profile No. 4 (in the Appendix) except for concretions which are common in the lower horizons.

Figure 5: Soil profile of mapping unit 41, illustrating the major horizon features and differentiation



Mapping Unit 42:

The soils of this mapping unit are similar to those of mapping unit 41 except that the soils of mapping unit 42 are well drained and occur on lower slopes of 1-3%

- correspondingly, pH is higher than 5.5 throughout the profile (CaCl₂).
- the soil is deep (over 200 cm).
- drainage is moderate.
- permeability is moderate to slow.
- organic carbon is highest in the A horizon and decreases with depth.

Brief Profile Description for mapping unit 42

| <u>Horizon Designation</u> | <u>Depth (cm)</u> | |
|----------------------------|-------------------|--|
| Ap (g) | 0-16 | Very dark greying brown (2.5YR 3/2) moist, sandy clay; few fine yellowish mottles; clear smooth boundary. |
| Bsg | 44-78 | Yellowish brown (10YR 5/6) moist, clay; common, medium, distinct yellow (10YR 8/8) mottles; moderate medium to coarse sub-angular blocky, very frequent iron and manganese concretions, clear smooth boundary. |

Soils over gneiss parent material:

The gneiss material belongs to the Basement complex of the Precambrian geological period. The soils have a relatively high BSP and CEC. Some of the profiles (e.g. number five) show extremely high soil reaction (i.e. 100% B.S.P. and pH that is neutral). The soils show evidence of on going and active soil forming processes.

Mapping Unit 11:

These soils occur on gneiss parent material. They are deep and well drained, although the occurrence of mottles and sometimes plinthite (profile LP/10/82) may indicate drainage problems or hydromorphic conditions. Soil texture is loamy to sandy clay loam in the topsoil. In profile No. LP/5/82 an abrupt textural change occurred at 82 cm when soil texture changed from sandy clay loam to clay. Abrupt texture change verification was calculated according to Soil Taxonomy (soil survey staff 1975 P 47). Soil structure is massive to weak sub-angular blocky in the top soil. Subsoil structure is very weak sub-angular blocky except when an abrupt textural change occurs. Some of the properties of this mapping unit are summarised below:-

- C.E.C. is less than 16 me per 100g clay
- most dominant elements on the exchange complex are Ca⁺⁺ and Mg⁺⁺ in that order
- B.S.P. is higher than 35% in the top soil, but less in the subsoil.

- pH is 4.6 (CaCl₂) throughout the profile
- for the profiles exhibiting an abrupt textural change, soil reaction is very high throughout the profile, pH is 6.2 (CaCl₂) BSP is 100% in the top and higher than 60% in the rest of the soil horizons.

Mapping Unit 12:

The soils in this mapping unit are similar to the soil of mapping unit 11 except for the moderately shallow depth (less than 90 cm).

Soils over granite parent material:

The geological period of the parent material is not known because the parent material is igneous. The soil profiles exhibit an A, B, C horizonation. Over 80% of the area is covered by rock outcrops of granitic nature.

Mapping Unit 52 (Profiles 8 and 9):

These soils occur over granite parent material and are shallow (less than 50 cm) and gravelly. The gravel consists mainly of quartzitic material with few iron manganese concretions. A stoneline of quartzitic rock is found in the subsoil. These soils are:

- well drained
- topsoil texture is sandy loam
- subsoil texture is sandy clay loam

- soil reaction shows a pH 5.0 in the top soil but the soil pH is low in the subsoil (4.3 pH).
- BSP is higher than 60% in the top soil but it drops to 51% in the subsoil.
- Although potassium was expected to be the most dominant ion on the exchange complex, calcium was dominant followed by magnesium. This is usually only common in soils over limestone. This is evidence of the youthness of the soils.
- erosion gullies and rills were observed in the mapping unit.

Brief Profile Description

| <u>Horizon</u> | <u>Depth</u> | |
|----------------|--------------|--|
| A | 0-8 | Very dark brown (10YR 2/2) moist and dark grayish brown (10YR 4/2) dry, loamy sand; very weak fine sub-angular blocky; frequent fine gravels; clear smooth boundary. |
| B-C | 22-40 | Very frequent iron and manganese conc- reation; very frequent fine and coarse gravels; small and large stones. |

Soil over quartzitic rock:

Two mapping units were distinguished. Mapping unit 70 and 22. The soils of mapping unit 70 are shallow and rocky (80% rock outcrop) and are not described here.

Mapping Unit 22:

These soils are found on the footslopes of the quartzitic ridges and are very gravelly. Topsoil texture is sandy clay loam with a weak fine sub-angular blocky structure. Sub-soil texture is sandy clay and clay in the lower horizon. Gravels are found in all the horizons. The gravels increase gradually with depth. There is a gravel layer between 67-150 cm, composed mainly of quartzitic gravels and iron stone. At 150 cm quartz rocks are found which form a limiting layer to rooting.

The soils have:

- low CEC with calcium and magnesium as the dominant elements on the exchange complex
- BSP is higher than 30% (46%) in the top soil, but drops to below 30% in the subsoil.
- reaction shows pH of 4.6 (CaCl_2) throughout the sub-horizons.

Soils over alluvial parent material:

Mapping Unit 60:

These are hydromorphic soils in the river valleys whose parent material is formed from any of the parent rocks mentioned above (limestone, gneiss, schist or granite). No attempt was made to describe their morphological characteristics due to the complicated and varied nature of their distribution. The soils are formed from mainly alluvial and colluvial depositions. A more detailed study is needed to properly characterise them.

Summary:

Geology greatly affects the characteristics of the soil in Kapini (Table 6) as seen from the above discussion.

IV.2

Mineralogy and Interpretation of Mineralogical results:

In this study mineralogical analysis of the clay and fine sand fraction were done as an aid to understanding soil formation/genesis, to help in land evaluation and classification up to family level in the soil taxonomy (soil survey staff 1975). Mineralogical data is shown in appendix 1 for each profile.

Table 6: Summary of the major soil characteristics:

| Parent Material | Texture Topsoil | Texture Subsoil | Me CEC-Clay | BSP | H ₂ O | CaCl ₂ | Colour Subsoil |
|------------------|-----------------|-------------------|-------------|-----|------------------|-------------------|----------------|
| Gneiss | Sand loam | Sand loam to clay | 14 | 63 | 5.2 | 4.2 | 10YR |
| Limestone | Clay Loam | Clay | 11 | 7 | 4.7 | 4.1 | 2.5YR 5YR |
| Schist | Clay | Clay | 21 | 73 | 6.1 | 5.7 | 10YR |
| Granite | Sandy loam | Sandy Clay loam | 28 | 71 | - | - | 10YR |
| Quartzitic hills | Sandy loam | - | - | - | - | - | - |
| Quartzitic Ridge | - | - | - | - | - | - | - |

In this chapter the following kinds of minerals that were found in the clay fraction are discussed: 1:1 layer silicates, 2:1 layer silicates, oxides and hydroxides of iron and aluminium. Quartz and feldspars are the most important minerals in the sand fraction.

1:1 Layer silicates:

The most common 1:1 layer silicates found in the soils are kaolinite and traces of halloysite. This is in line with the general occurrence of these minerals in tropical soils especially in humid and semi-humid tropics. Although no attempt was made to verify the occurrence of different forms of kaolin minerals, the nature of the diffractograms showed that different forms of kaolin probably occur in the soils. Halloysite was identified by the characteristic rather weaker and broader basal X-ray diffractions compared to those of the platy kaolinite (Halloysite is known to be tabular).

Halloysite:

This 1:1 layer silicate was more common in the soil (profiles 5, 10, 11) developed over gneiss parent material. This may indicate that the halloysite is a product of weathered biotite mica and orthoclase feldspars which are common constituents of gneiss. Halloysite was also apparent in soil occurring over schist (profile 3). This soil represents moderately well drained conditions. The amount of halloysite in mapping unit 41 is very negligible. No trace of halloysite

was found in very old and deeply weathering soils of profiles 1 and 7, occurring over limestone parent material.

In conclusion it may be remarked that halloysite seems to indicate a less advanced stage of weathering in a soil profile since it is found in the moderately well drained profiles, profiles that seem to be affected by colluvial and is apparently absent from very old soil profiles.

Kaolinite:

This mineral was found in all the soil profiles as a dominant mineral representing over 50% of the clay minerals. Kaolinite was identified by its characteristic 7\AA peaks and the 3.5\AA second reflection peaks. The kaolinite peaks showed that the mineral structure was well crystallised in general.

Kaolinite is one of the minerals which is generally taken as indicative of the most advanced stage of weathering.

2:1 Layer silicates:

2:1 Layer silicates were found in most of the profiles. The most common were micas, especially muscovite and illite. The occurrence of micas is directly associated with acid and intermediate crystalline parent geology especially schist (mapping unit 41) and micaceous gneiss (mapping unit 11). Micas were found to be absent in soil over sedimentary rocks,

i.e. soils formed over limestone (mapping unit 31).

Smectites occurs in soil of mapping unit 11, may be due to the abrupt textural change at 82 cm depth which give rise to slow permeability and hence poor drainage, resulting in the recrystallisation of smectitic minerals.

Mixed layer minerals:

Mixed layer minerals were common in mapping units 41 and 11. They were mainly interstratifications of kaolinite and illite, and illite and smectites respectively.

Oxides and hydroxides of iron and aluminium:

These were mainly in the form of haematite (Fe_2O_3) and goethite ($\text{FeO}\cdot\text{OH}$). Traces of gibbsite ($\text{Al}(\text{OH})_3$) were also recorded but the peaks were not very intense. Differential Thermal Analysis (DTA) would have been a complementary tool to identify them well.

Haematite was more commonly present in well drained soils, although greater amounts were found in soils over limestone parent geology. (Mapping Unit 31).

Goethite occurred in association with haematite and was common in the soils on the upper and middle slopes. Goethite seems to be absent in low laying soils that are relatively

not very well drained. Lepidocrocite ($\text{FeO}\cdot\text{OH}$) which would be the most likely mineral to be present since it is common in hydromorphic soils or soils that show in situ hydromorphism was not identified at all. This may be due to the fact that it is (semi) amorphous, and that it can not be identified easily with X-ray diffraction.

Quartz and Feldspars:

The fine sand fraction was mostly made of quartz. Quartz was also a common member of the clay fraction. Feldspars were common in most of the profiles especially in soil profiles over gneiss parent material. The Feldspars may probably be common orthoclase and microcline, but in the fine sand fraction they could be plagioclase feldspars especially if of a colluvium origin.

IV.2. Interpretation of mineralogical results in relation to soil productivity.

Soil Productivity:

Although soil productivity is dealt with in a more systematic manner, in the chapter on land evaluation, the intention here is to give a general outline of the relation between soil mineralogy, major plant nutrient reserves and plant retention.

Since the major mapping units also represent the major geological units (see chapter 1) this outline will also show the importance of geology to nutrient availability. In all the mapping units, soil productivity is taken primarily as a function of the coarse mineralogy and secondly as a function of the finer fraction. The coarse fraction gives a good estimate of weatherable minerals in which plant nutrient reserves are found and the finer fraction provides surfaces for nutrient retention and may contribute nutrients to the soil solution.

Mapping Units 11, 12:

These units represents soils developed over gneiss parent material. The fine sand fraction is dominated by Quartz, and Feldspars. Both black (biotite) and white (muscovite) micas are common, although muscovite is most abundant. The presence of micas especially biotite which is a common constituent of gneiss gives these soils an appreciable amount of weatherable minerals. The abundance of feldspars (mainly orthoclase and microcline, which are associated with the occurrence of biotite, also give an abundance of weatherable minerals in the soil. The contribution of potassium (K^+) and magnesium (Mg^{++}) to soil by the above minerals of the fine sand fraction is extremely important. Muscovite and biotite are the major minerals in which K^+ is found although feldspars are important to a lesser extent.

The clay mineral fraction is dominated by kaolinite, illite and smectites. The presence of illite and smectites do not only point to the availability of weatherable clay minerals but also point to the abundance of adsorption sites present in the clay fraction and the possibilities of greater cation exchange capacities. Smectite minerals are also known to provide Mg^{++} to the soil on weathering. Iron and aluminium oxide are not an important constituent of the soils of mapping units 11, 12.

Mapping unit 32:

This consists of soils developed over limestone parent material. The constituents of the sand fraction are mostly quartz. The soils are representative of soils that have been heavily weathered in the area of study. They have very little or no reserves of weatherable minerals in the fine sand fraction. The limestone (mainly dolomitic in nature ($CaMg(CO_3)_2$) has weathered to produce clay (mainly kaolinite) and lots of iron oxides and hydroxides. The absence of gibbsite ($Al(OH)_3$) indicates that the soils have not reached their ultimate stage of weathering.

The soils over limestone parent geology had the highest amount of iron oxides and hydroxides (goethite and haematite) which give the soil the characteristic deep red or dark red colours.

The shallow and moderately shallow soils of mapping units 31, 33:

These soils are underlain by limestone rocks which appear on the surface in an undulating manner. The soils are represented by profile No. 2.

The dominant clay mineral is kaolinite. Illite also occurs in substantial amounts. The fine sand fraction is dominated by mica and quartz. The soils have an abundant availability of weatherable minerals in the fine earth fraction. The soil is not highly weathered and is rather in the intermediate stage of weathering.

Soil mapping units 41, 42:

This mapping unit represents soils developed over schist parent material. Although the dominant mineral is kaolinite, illite is found in abundant amounts while halloysite is found in lesser amount. The fine earth fraction is dominated by quartz and a variety of 2:1 weatherable minerals which could not be differentiated by X-ray diffraction. This profile is in the intermediate weathering stage.

Soils of mapping unit 52:

These represent the soils formed over granite. These soils are very shallow (less than 50 cm) and are of very recent development. Their shallowness makes them less important for agriculture development although they may have

lots of weatherable minerals. The deep well drained patches of soil may be highly weathered and may contain appreciable amounts of gibbsite due to the nature of the parent material.

IV.3 Pedogenesis in the study area:

The method of soil genesis study used in the Kapini area is the Macro analysis method. The method divides the soil complex in the Kapini area into the Macro-groupings which are studied to arrive at an interpretation of the genesis of the soil. This is done on soil at group level or great group level to minimise detail.

Profile descriptions, laboratory analytical data in addition to environmental information study, has enabled the making of important observations that give an indication as to the genesis of the soil in the Kapini area. After listing the major observations, an account of the soil genesis for the different mapping units is summarised.

Mapping Unit 32 (Profile LP1-82 and LP7-82):

Soils developed over limestone:

The following characteristics were used as indicators of pedogenesis in this mapping unit:

- The soil profile in this mapping unit is very deep and the parent rock or limiting rock was not seen up to a depth of 3m, indicating that the soil is deeply weathered.

- There are no rock fragments in the profile, which indicates complete weathering of the coarse rock fragments (greater than 2 mm).
- Organic matter is restricted to the top A horizon, the rest of the profile being very uniform in appearance with diffuse or gradual horizon boundaries.
- Soil macro structure is weak subangular blocky with a strong micro structure.
- Bulk density is highest in the top soil and lowest in the sub-soil (1.5 - 1.3 g/cm³).
- BSP decreases from top to bottom of the profile (44% - 9%) as opposed to the pH which increases.
- Delta pH (pH CaCl₂ - pH water) is negative throughout the profile, an indication of the dominance of negative charges in the soil.
- Soil CEC/100g clay is very low (i.e. 11 me).
- Clay mineralogy is mainly kaolinite (more than 50%).
- It has large amounts of goethite and haemitite.
- It has no traces of 2:1 layer clay minerals.
- The sand fraction is composed of quartz.

- Thin section for micromorphological studies didn't show cutan
- Micromorphologically the soil is characterised by skeletal quartz grains in the fine sand and silt fraction.
- Plasma ordering is undulic (showing high iron content)
- Few ferric nodules with sharp edges. These could indicate that the soil has formed in situ.
- There are very few iron rich papules.

The major pedogenic processes that is responsible for the soil formation in mapping unit 31 is desilication. Desilication is the process in which there is a chemical migration of silica out of the soil resulting in the concentration of sesquioxides (goethite and haemitite in this case) so called ferrilization. It is probable that this process took place in more warm and humid conditions in an environment of continuous free drainage than exists today leading to the leaching of silica in solution (in the form of silicic acid) while iron precipitated as hydroxides which are immobile in the low pH conditions that prevailed. The absence of clay illuviation indicates that iron hydroxides could not be moved out of the solum together with clay. Decomposition of minerals by weathering has left very few primary minerals in the soil. The secondary minerals have further been highly weathered and broken down to produce kaolinite, a clay mineral that has

a very low C.E.C. The hydroxides which are dominant in the soil profile and which are pH dependent may also block the negative adsorption sites when not in discrete clusters.

The development of high iron content in the soil is responsible for the strong micro structure and aggregation in the soil.

Pedoturbation, the biological activities that churn and cycle soil material and homogenizes the solum is very important in this soil profile. The biological activity is strong throughout the profile and nests of animals and insects (fauna) were seen throughout. The Biological activities are probably responsible for some sub-angular blocky structures that are moderate or strong throughout the profile.

Mapping Unit 33: (Profile LP2-82)

The following characteristics were used as indicators of pedogenesis in this mapping unit:

- The soil profile in this soil mapping unit is deep but a limestone rock is encountered at varying depth between 0 and 149 cm depth.
- The soil has rock fragments in the B horizon which are quartzitic in nature an indication of a less advanced stage of weathering.

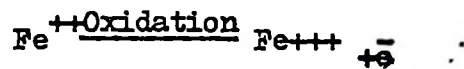
- Organic matter is restricted to the A horizon.
- The boundaries are sharp, abrupt or clear, indicating a relatively young soil.
- Soil structure is medium to moderate.
- Bulk density is highest in the A horizon and decreases with depth (1.2 - 1.0g/cm³).
- Soil reaction is near neutral (pH water 6.3), an indication of low leaching.
- BSP is high (71%) but decreases with depth to 38%.
- Delta pH (pH CaCl₂ - pH water) is negative.
- C.E.C. is 14 me per 100g clay.
- Clay mineralogy is mainly kaolinite (50%).
- Illite occurs in very substantial amounts (30%).
- Thin sections showed clay cutans and clay illuviation within the soil profile.
- The sand fraction (quartz and muscovite) is sharp and angular showing that it has not been transported, but is weathered in situ.
- Soil colour is brownish but not too red showing that oxidation is just becoming a more important process in this profile, an indication of intermediate stage of development.

- Manganese and iron concretions are found as a continuous layer laying on the surface of the limestone rock.

This is evidence that the soil is not developed from limestone since limestone does not show a saprolitic layer as it does not weather mechanically but chemically. Several pedogenic processes are probably responsible for the development of this soil profile; the most important of which are decomposition and synthesis. Decomposition is used in the context of mineral breakdown while synthesis relates to the formation of new minerals. Geochemical and pedochemical weathering are the major agents that accelerate decomposition in the soil. The geochemical weathering reactions that are important are: hydrolysis, solution and oxidation - reduction in alternating cycles. The above reactions are also important in pedochemical weathering including the shuttling of mineral elements from clay lattices, such as aluminium and potassium to hydrous oxides via exchange sites or into solution respectively.

The difference between geochemical weathering and pedochemical weathering is that geochemical weathering relates to the weathering of the initial soils material (parent rock etc.), while pedochemical weathering relates to weathering processes taking place within the soil itself. The two processes may occur simultaneously (Birkeland, 1974).

Oxidation is extremely important in this profile because the soil is well aerated and the underlying rock is either exposed or is not very deeply buried allowing enough supply of oxygen needed in oxidation. Due to the presence of iron rich minerals in fine sand fraction such as mica (i.e. biotite) the most important specific reaction is that of the oxidation of iron from ferrous to ferric (ions) state.



Since iron forms a part of the mineral structure of mica, its oxidation falls within the pedogenic process called decomposition because it leads to the disintegration of the mica mineral structure. The mica is disintegrated as the element iron changes its size and as it is transformed or converted to ferric form. Once the mica structure is broken apart, ions such as potassium (K^{+}) and magnesium (Mg^{++}) are released into the soil together with the iron. From the presence of iron concretions in the profile, it is obvious that the iron that is released, unites with hydroxyl (OH) and oxygen to form iron minerals that precipitate into concretions down the profile (to form the concretions that lay on top of the limestone rock).

Hydrolysis is the other important process that contributes to the pedogenesis of this profile. By hydrolysis is meant the attack by the hydronium ion on crystal structures. Hydronium is a highly charged hydrogen ion having a hydration shell. At

favourable pH, this hydrogen ion replaces the basic ions in either the clay minerals or the micas in the fine sand fraction. This action breaks up the mineral structure of the micas and clays. Silica and aluminium become soluble, while iron and manganese precipitate at the bottom of the profile on top of the limestone limiting rock. The kaolinite in the soil is not so much an indication of highly weathered conditions in the soil as it may have formed from the recombination of silica and aluminium that goes into solution after the breakdown of mineral structures in the processes of oxidation and hydrolysis, in a pedogenic process called Synthesis.

The presence of manganese concretions in the soil indicates a wetter period in the development of the soil profile. The chroma in the soil is low indicating a relatively young soil in its intermediate stage of weathering.

Although the soil is underlain by a limestone rock all evidence point to the fact that the profile or the soil solum is not developed from it. The soil is of colluvial origin, probably from some schist parent material on a relatively high elevation.

- The quartz and muscovite in the fine sand fraction has very sharp edges signifying development in situation after transportation.

- The soil has too high an amount of mica minerals to have formed from a limestone parent material.
- There is no gradual boundary between the limestone rock and soil solum, but a sharp boundary.
- The limestone rock itself does not show any signs of having been weathered. It is very smooth and has no cracks on it.

The slightly higher soil reaction (pH and BSP) shows that the limestone rock contributes mineral elements to the soil in solution as facilitated by geochemical weathering processes.

In summary, the soil of mapping unit 33 is possibly of colluvial origin and it is not developed from the underlying limestone rock. Geochemical and pedochemical weathering is taking place with Oxidation, Hydrolysis, Hydration and Solution processes predominating.

Mapping unit 31 and 52 (profile LP 12, LP 8 and LP 9)

The processes taking place are similar to those taking place in mapping unit 33. These processes are however of recent times and the soils are relatively much younger.

Mapping Unit 41 and 42:

The following characteristics were used as indicators of pedogenesis in these mapping units:

- The soil profiles in these mapping units are very deep as the parent materials were not seen at 3m depth, an indication of deep weathering
- There are no rock fragments in the profile, an indication of complete weathering of the coarse rock fragments
- Organic matter is restricted to the A horizon
- The profile is uniform and soil horizon boundaries are clear, gradual and diffuse
- Soil macro structure is moderate sub-angular to angular blocky
- Soil reaction is near neutral (pH 6.1 water)
- B.S.P. does not decrease with depth. It is nearly constant throughout the profile (lower value 73%)
- C.E.C. is less than 24 me but greater than 16 me per 100g clay (in NH_4AO_c)
- Fine sand mineralogy is mainly quartz and some mica.
- Clay mineralogy is mainly kaolinite with substantial amounts of illite.
- Iron may be present only in form of lepidocrocite (FeO OH); an indication of seasonal hydromorphism.

- Micromorphologically the skeletal grains of fine sand and silt were dominantly quartz. These are not readily moved and have not been moved, concentrated or reorganised by soil forming processes. This shows that all soil formation has affected the rest of S. matrix (Soil Matrix).
- Plasma ordering showed aseptic and septic features. Locally skeletal was much less than 462 and 463, showing movement, concentration and re-organisation by soil forming process.
- Clay cutans were few, showing that the process of soil eluviation is not very strong.
- The glaebules that were noticed are ferric nodules or ferric concretions.
- Nodules are glaebules with an undifferentiated internal fabric, showing undifferentiated rocks and soil fabric.
- Concentrations are glaebules with a generally concentric fabric.
- The nodules signify in situ hydromorphism.
- Ferric nodules of a few mm to 1 cm with diffuse boundaries enhanced the hypothesis of in situ hydromorphism.
- Concretions showed an on going process of accretion.

The major pedogenic processes of soil formation in mapping units 41, and 42 are mainly related to decomposition through pedochemical weathering and the reactions are: hydrolysis, hydration, and oxidation - reduction cycles.

Synthesis also occurs in this process and leads to the formation of new minerals. During the period of geochemical weathering the parent rock of schist was weathered to produce heavy clay soils with very deep profiles. However the heavy clay restricts the quick movement of water through the profile. This results in what is called in situ hydromorphism which is not originated from the ground water table. However, since rainfall is seasonal the soil is saturated with water only during the rainy season and it is dry during the dry period. It has an ustic moisture regime (soil survey staff 1975). These conditions within the soil lead to active hydrolysis and oxidation - reduction cycles.

In hydrolysis the hydronium attacks the crystal structures of the minerals, in the profile, of mainly mica origin (as explained in mapping unit 33) to liberate iron, silica and aluminium.

Hydration, the association of water molecules or hydroxyl groups to minerals also help in the breaking down of the minerals especially their edges.

Oxidation - ,reduction cycles are important in that they help in the break - down of the minerals within the profile as described in mapping unit 33. This leads to a hydromorphic forming process coined by Brinkman (1969) as ferrolysis. In this process the cation exchange capacity of a soil is destroyed due to exchange reactions involving iron in seasonally alternating cycles of reduction oxidation.

The results of all these reactions is that:-

- The iron released from the break down of minerals is often in a hydrous ferric oxide form (lepidocrocite- FeO OH) in the soil material and gives it the characteristic yellowish mottling (LP3-82 in appendix). Impended drainage restricts the leaching of ions released by the break down of the minerals, resulting in the accumulation of silica (giving the soil a high soil reaction (pH and BSP)) and aluminium. The concentration of Al and Si may lead to re-crystallization to form halloysite, when the bases are not lost or kaolinite when the bases are lost. Inter layered minerals may also form in the case of high Al content. The low C.E.C, me/100g clay which gives the soil the oxic characteristic at sub-group level may be due to ferrolysis.

In conclusion it may be said that the soil is not very old and not very young. It is basically in its intermediate stage of weathering. Hydromorphic conditions are not a severe feature since hydromorphism is essentially insitu and not a result of under ground water.

Mapping Unit 11 and 12 (profiles LP 5 and LP 12)

The following characteristics were used as indicators of pedogenesis in these mapping units:

- The profiles in these mapping units are deep but mapping unit 12 has moderately shallow soil underlain by rock or plinthite.
- There are rock fragments within the profile.
- Organic matter is not restricted to the A horizon in some cases and this may indicate a buried horizon (soil survey staff 1975).
- soil macro structure is weak to moderate sub-angular blocky.
- Bulk density decreases from the top soil to the sub-soil (1.6 - 1.2 g/cm³).
- Soil reaction is neutral (7.0 pH water).
- Delta pH (pH CaCl₂ - pH water) is negative

In conclusion it may be said that the soil is not very old and not very young. It is basically in its intermediate stage of weathering. Hydromorphic conditions are not a severe feature since hydromorphism is essentially insitu and not a result of under ground water.

Mapping Unit 11 and 12 (profiles LP 5 and LP 12)

The following characteristics were used as indicators of pedogenesis in these mapping units:

- The profiles in these mapping units are deep but mapping unit 12 has moderately shallow soil underlain by rock or plinthite.
- There are rock fragments within the profile.
- Organic matter is not restricted to the A horizon in some cases and this may indicate a buried horizon (soil survey staff 1975).
- soil macro structure is weak to moderate sub-angular blocky.
- Bulk density decreases from the top soil to the sub-soil (1.6 - 1.2 g/cm³).
- Soil reaction is neutral (7.0 pH water).
- Delta pH (pH CaCl₂ - pH water) is negative

- C.E.C. clay/100g is 11 me at 50 cm.
- There is an abrupt textural change at 82 cm.
- Below 82 cm are found separations of iron which form large concretions.
- Mineralogical studies show that the clay fraction consists of kaolinite in the largest amounts (50%), followed by illites and smectites.
- The fine sand fraction shows the presence of quartz, feldspars and mica.
- Micromorphological studies showed clay movement and many clay cutans.
- The cutans were mainly organo-ferri-argillans .
- Big meta - isotubules were identified in the horizons together with ferri - argillans.
- The plasma is aseptic to weakly undulic and locally sepic.

The pedogenic process taking place in this mapping unit are mainly Eluviation, Enrichment and Cumulization.

The soils of mapping unit 11 and 12 are probably of colluvial origin, especially the soils occurring between the depth of 0-80 cm, upon which a sudden textural, mineralogical and chemical change occurs. Enrichment of material to these soils from soils of higher elevations still continues in form

of mineral elements in solution and through surficial addition of solid soil material by moving water and by gravity. This explains the high BSP of 67-100% and a high pH of 7.0 in water.

Because of the sudden changes of soil texture within the profile it is probable that the pedological process of cumulation in form of aeolian additions of soil particles to the surface of the soil solum may have been important. This addition of the soil material may have buried the soil, creating the complex or duplex profiles that are sometimes encountered in this mapping unit.

The area of survey occurs near the soils that have been affected by the Kalahari desert (300 km) and have Kalahari parent material which was deposited by aeolian process. The dynamics and physics of blown sand are not dealt with here to prove or disprove the assertion that the soils of mapping unit 11 and 12 have been affected by aeolian activities due to the complexity of the derived equation.

As mentioned earlier, Eluviation and Illuviation are probably the major pedogenic processes in these soils. Clay and other soil material are moved down the profile and are illuviated in the B horizon to form an argillic horizon. This processes is also called lessivage.

The presence of smectite within the soil profile may be attributed to the synthesis of mineral elements in solution especially the recombination of Mg^{++} and silica when the movement of water is restricted at 80 cm depth (neo-formation).

IV.4 Soil Classification in the study area:

Mapping unit 32: (Profile LP 1 and 7/82)

Of the surface horizons described in the FAO/UNESCO legend (1974) and Soil Taxonomy (1975) the surface horizon in this mapping unit meets the requirements for an Ochric horizon as follows:-

- There are no rock structures in the horizon.
- The horizon does not include fresh sediments that are finely stratified.
- The horizon does not meet the structure requirements for a Mollic or an Umbric surface horizon
- The horizon does not meet the colour requirements for a Mollic surface horizon.
- It does not meet the thickness requirements for a Mollic surface horizon.
- The horizon does not have enough or sufficient organic matter to meet the requirements for a Mollic top horizon.
- And finally the N value is not low enough to meet the requirements for a Mollic surface horizon.

Sub-surface diagnostic horizons:

The sub-soil meets the requirements of an Oxic B horizon as follows:

- $(\text{CEC} \times \frac{100}{\text{CL}})$ is less than 16 between 15 cm and 2 cm depth.

The horizon does not meet the requirements of an Argillic or Natric horizon.

- The horizon is greater than 30 cm thick.
- $(\text{BSP} + \text{Al} \times \frac{100}{\text{CL}})$ is less than 10.
- There are not traces of aluminosilicates in the sand fraction.
- Clay is greater than 15% or as per amendment made by ICOMOX (Buol, 1983) clay is greater than 8%.
- The sub horizons are all either gradual or diffuse.
- The sub soil has less than 5% by volume rock structure.

Al = Me, aluminium extractable with 1 KCl per 100g clay

Bases = Me, bases extractable with NH_4OAC per 100g clay

CEC = Cation exchange capacity (me CEC per 100g clay).

* (CL) Clay content (%) calculation:

This was calculated first by finding out if water content at 155bar tension (%) was greater or less than 40%. If it is found to be less than 40% clay content is taken to be equal to the clay measured in the fine fraction. If, however, water content at 15 bar tension is found to be less than 40% as was the case in this mapping unit, we try to find out if the ratio between water content and measured clay is greater than 0.4, (i.e. $\frac{W}{C}$ is greater than 0.4). If it is less than 0.4, as was the case in this study clay content is taken as equal to measured clay in the fine earth fraction. If on the other hand the ratio is found to be greater than 0.4 then clay content is given by:-

CL = 2.5 x moisture content in % at 15 bar tension.

Classification according to FAO/UNESCO legend (1974):

At unit level the soil is classified as ferralsol on the basis of an oxic horizon and at sub-unit level the soil is classified as Rhodic Ferralsol as follows:

- The soil has dark red (moist) and red (dry) colour.
- Has a CEC of more than 1.5 per 100g clay throughout the Oxic horizon within 125 cm of the surface.
- The soil lacks an Umbric A horizon.
- The soil lacks Plinthite with 125 cm of the surface.
- It is classified as Rhodic Ferralsol (FR).

Classification according to Soil Taxonomy (1975):

- At the order level the soils are classified as Oxisol due to the presence of an Oxic B horizon.
- At sub order level the soil is classified as Ustox because:-
 - They are not associated with Aquic conditions.
 - They do not have a Torric moisture regime.
 - They are not associated with high humic conditions.
 - And they do not have a short dry season like the Oxisol near the equator.
 - They have an Ustic moisture regime.

- At great group level, of the four Ustox great groups defined by the Soil Taxonomy the soils meet the requirements for the Haplustox (Profile LP/1/82) or Eustrustox (Profile LP/7/82):

- They do not have a Sombric horizon.
- They do not have 1.5 me or less per 100g clay, cation retention capacity.
- They either have BSP of 50% or more (by NH_4OA_c) throughout the profile (Eustrustox, profile LP/7/82) or BSP of less than 50% (Haplustox, profile LP/1/82).

- At subgroup level:

The soil as classified as Typic Eustrustox/Haplustox since the soil typifies the great group and all diagnostic properties of the order, sub-order and great group to which the soil belongs are in clearly expressed form, showing no intergrade or extragrade to other taxonomic groups.

- At family level the soil is classified as follows:

Typic Eustrustox/Haplustox, Clayey, kaolinitic, hyperthermic:

- Particle size class: clayey
- Mineralogy: kaolinitic
- Temperature regime: hyperthermic

Table 7: Summary table showing classification according to Soil Taxonomy for mapping unit 32:

| Order | Sub-Order | Great-group | Sub-group | Family | Tentative Series |
|--------|-----------|-------------|------------|-------------|------------------|
| Oxisol | Ustox | Haplustox/ | Typic | Typic | |
| | | Eustrustox | Haplustox/ | Eustrustox/ | |
| | | | Eustrustox | Haplustox | |
| | | | | | clayey |
| | | | | | kaolinitic |
| | | | | | hyperthemic |

Mapping Unit 33: (Profile LP/2/82)

Master horizons: 3 master horizons characterized the soil profile of this mapping unit and these are: A, B and R horizons. A and B horizons are defined as in soil mapping unit 32, while the R horizon is the hard rock underlying the soil mantle.

Surface diagnostic horizons (epipedon):

The surface horizon meets the requirements of an Ochric surface horizon, as follows:

- There are no rock structure in the horizon.
- No fresh sediments that are finely stratified are included in the horizon.
- It does not meet the structure requirements for a Mollic horizon although it meets the color requirements.
- It does not meet the thickness requirements for a Mollic horizon.

Sub-surface diagnostic horizons:

The sub-surface diagnostic horizon meets the requirements for an Argillic horizon as follows:

- The horizon is greater than one tenth the combined thickness of all over laying horizons.
- The horizon is greater than 15 cm thick.

- There is a recognisable Eluvial horizon.
 - Peds are present in the horizon.
 - The clay skins are on some vertical and horizontal ped surfaces and also in some fine pores.
 - And finally the total clay in the horizon is greater than the total clay of the Eluvial horizon + 3 (i.e. $Tc_H > (Tc_E + 3)$).
- Tc_H = Total measured clay % in fine earth fraction (less than 2 mm).
- Tc_E = Total measured clay % in fine earth fraction (less than 2 mm) of Eluvial horizon.

Classification according to FAO/UNESCO (1974):

The soil is classified as Luvisol at unit level as follows:

- It has an Argillic horizon.
- A base saturation of 50% or more (by NH_4OA_c) within 125 cm of the surface.
- It lacks an Arbic E. horizon over-laying a slow permeable horizon diagnostic for Planosols.
- Has Ferric properties which rules out Nitosols.
- Lacking the Tonguing diagnostic for Podzoluvisols.
- Lacking an Aridic moisture regime.

Classification at sub-unit level:

Ferric Luvisol as follows:

- The soil shows Ferric properties due to presence of iron concretions.
- It lacks an Albic E horizon, a calcic horizon, concentrations of soft Powdery lime, and Plinthite within 125 cm of the surface.
- Lacking Hydromorphic properties within 50 cm of the surface.

Classification according to Soil Taxonomy:

The soil is classified as an Alfisol at order level:

- It has an Argillic horizon.
- It has no Fragipan.
- BSP is greater than 50% within 125 cm.

At sub-order level the soil is classified as an Ustalf

- It has an Ustic moisture regime.
- It has chromas that are too low for Aquic conditions.

At great group level the soil is classified as a Paleustalf

- It has no Duripan.
- It has no Plinthite.
- It has no Natric horizon.
- The hue of the soil is no redder than 5YR.

At sub-group level the soil is classified as Oxic Paleustalf:

- C.E.C. is less than 24 meg per 100g clay (NH_4OAc).
- B.S.P. is less than 75% in all parts of the Argillic horizon.
- The soil are intergrades between Paleustalfs and Ustox.

At family level the soil is classified as follows:

Oxic, Paleustalfs, clayey, kaolinitic hyperthermic:

- Particle size class: clayey
- Mineralogy: kaolinitic
- Temperature regime: hyperthermic

Table 8: Summary table showing classification according to Soil Taxonomy for mapping unit 33:

| Order | Sub-order | Great-group | Sub-group | Family | Tentative Series |
|---------|-----------|-------------|------------|-----------------|------------------|
| Alfisol | Ustalf | Paleustalf | Oxic | | |
| | | | Paleustalf | Oxic Paleustalf | |
| | | | | clayey | |
| | | | | kaolinitic | Mushemi |
| | | | | hyperthermic | |

Mapping unit 31: (shallow phase of Prof. IP2) Profile 12.

Master horizons: 2 master horizons characterised this mapping unit and these are A and R.

Surface diagnostic horizons: (epipedon)

- The surface horizon meets the requirements of the Ochric A horizon.
- It is too thin and does not meet the requirements for all the other surface horizons.
- It does not meet the color, and the structure requirement of a Mollic or an Umbric epipedon.
- It may have rock structures (gravel) in it.

Sub-surface horizons (epipedon).

- The soil is shallow, less than 20 cm and usually less than 10 cm to the limiting layer which is limestone rock.

Classification according to FAO/UNESCO (1974):

At unit level the soils are classified as Regosol where there is an Ochric A horizon to the depth of 20 cm. and an absence of a diagnostic B horizon or as a Lithosol where the ochric A is less than 10 cm.

At sub-unit level the soils are classified as Dystric Regosol And as Lithosols.

- There are no sub-units for the Lithosols.
- The Regosols are classified as Dystric because:-
 - They have an ustic moisture regime
 - They do not have a BSP (NH_4OA_c) of more than 50%.

Classification according to Soil Taxonomy:

At order level: The soils are classified as Entisols.

- They do not have a ~~salic~~ salic horizon.
- They do not have calcic, Petrocalcic, Gypsic or Petrogypsic horizons nor a Duripan.
- They do not have a Cambic, Argillic, Natric, Oxic, Spodic horizons or vertic properties.
- They have no Mollic, Umbric or Playgen epipedon or any other epipedon apart from an Ochric 'A'.

At sub-order level the soils are classified as Orthents:

- They have a Lithic and sometimes Paralithic contact that is shallower than 25 cm.
- Soil texture is sandy loam to sandy clay loam.
- They have no Aquic properties.
- They have no diagnostic properties except an Ochric A horizon.

At great group level they are classified as Ustorthents

- They have an Ustic moisture regime
- They have a Hyperthermic temperature regime

At sub-group level the soils are classified as Lithic Ustorthents

- They have a Lithic contact within 50 cm (i.e. at 20 cm usually).

At family level the soils are classified as Lithic Ustorthents, fine loamy, siliceous, hyperthermic.

- Particle size class: fine loamy
- Mineralogy: siliceous
- Temperature regime: hyperthermic

Table 9: Summary table showing classification according to Soil Taxonomy for unit 31:

| Order | Sub-order | Great-group | Sub-group | Family | Series |
|----------|-----------|-------------|--------------------|---|--------|
| Entisols | Orthents | Ustorthents | Lithic-Ustorthents | Lithic Ustorthents fine loamy siliceous hyperthermic | |

Mapping units 41, 42, 12, 11 (IP3, IP4 and IP5, IP12, respectively in pairs (i.e. described together)

All these mapping units meet the requirements for an Ochric surface horizon and Argillic sub-surface horizons as outlined and identified in mapping unit 33. The soils are characterised by 2 master horizons and these are the A and B horizons.

Mapping units 41, 42:

Classification according to the FAO/UNESCO legend yields Luvisols at the unit level as is defined and outlined in mapping unit 33.

At sub unit level the soils are classified as Gleyic Luvisol. This is because of hydromorphic properties that occur within 50 cm of the surface as explained by the FAO/UNESCO legend (page 29).

- They have mottles due to segregation of iron
- They have iron-manganese concretion larger than 2 mm

It is probable that some well drained soils do occur within these mapping units. These would be classified as Ferric Luvisols due to Ferric properties as defined by FAO/UNESCO legend (p. 28).

Classification according to Soil Taxonomy:

Mapping units 41, 42, are classified as follows:

At order level the soils are classified as Alfisols

- They have an Ochric epipedon.
- They have an Argillic horizon.
- They lack Vertic properties.
- They have B.S.P. (by sum of cations) of more than 35% (i.e. 70%).
- They have no Fragipan.

At sub-order level the soils are classified as Ustalf

- They do not have Duripan.
- They do not have Plinthite.
- Their hues are not redder than 10YR.
- The common coarse mottles do not have hue of 7.5YR or redder.

At sub-group level the soils are classified as Oxic Haplustalfs

- C.E.C. (by NH_4OAc) is less than 24 me per 100g clay
- B.S.P. is greater than 70% in mapping unit 41 and greater than 50% in mapping unit 42.
- They are intergrades between Haplustalfs and Ustox.

At family level the soils are classified as Oxic Haplustalf,
clayey, kaolinitic, hyperthermic

- Particle size class: clayey
- Mineralogy: kaolinitic
- Temperature: hyperthermic

Table 11: Summary table showing classification according to Soil Taxonomy
for mapping units 41, 42

| Order | Sub-order | Great-group | Sub-group | Family | Series |
|----------|-----------|-------------|----------------------|--|--------|
| Alfisols | Ustalf | Haplustalf | Oxic Haplu- stalf | Oxic Haplu- stalf clayey kaolinitic hyperthermic | Ipafu |

Mapping unit 11, 12 (IP5 and IP13):

In the FAO/UNESCO legend the soil is classified at unit level
as Luvisols

- The soils have an Argillic B horizon.
- They do not have an Albic E. horizon.
- They have no Tonguing that is diagnostic for Podzoluvisols.
- They have an Ustic moisture regime.
- Clay % decreases by more than 20% within 125 cm.
- B.S.P. is more than 50% ~~through~~ out the profile (i.e. more than 80%).

At sub unit level the soils are classified as Ferric Luvisols

- Ferric is coined at sub-unit level because the soils have no Plinthite.
- They have no hydromorphic properties.
- They have no Albic E horizon.
- They have no Vertic or Calcic properties.
- They show Ferric properties.

Classification according to Soil Taxonomy:

Mapping units 12, 11 are classified as Alfisols at order level as identified in mapping units 41, 42.

At sub-order level as Ustalf as identified in mapping units 41, 42.

At great group level the soils are classified as Haplustalfs

- They have no Duripan.
- They have no Plinthite.
- They have no Argillic horizon.
- Their clay content decreases by more than 20% within the profile.
- They do not have hue that are redder than 5YR.

As sub-group level the soils are classified as Oxic haplustalfs:

- They have a CEC of less than 24 me per 100g clay.
- They are intergrades between Haplustalfs and Ustox.

At family level the soils are classified as Oxic Haplustalfs fine loamy kaolinitic hyperthermic

- Texture class: fine loamy
- Mineralogy class: kaolinitic
- Temperature regime: hyperthermic

Table 12: Summary table showing classification according to Soil Taxonomy for mapping units 11 and 12

| Order | Sub-Order | Great-group | Sub-group | Families | Series |
|---------|-----------|-------------|-----------------|---|--------|
| Alfisol | Ustalf | Haplustalf | Oxic Haplustalf | Oxic Haplustalf clayey kaolinitic hyperthermic | Kado. |

Inclusions that could not be mapped but which were observed during the soil survey are as follows:-

- Plinthustalfs
- Paleustalfs
- Psammentic Haplustalfs

Mapping Unit 52:

According to FAO/UNESCO legend this soil is classified as Regosol as identified in mapping unit 31.

At sub-unit level it is classified as Eutric Regosol.

- It has a high base saturation percentage.

According to Soil Taxonomy the soil is classified as Lithic ustorthents coarse loamy siliceous hyperthermic as identified in mapping unit 31 except for the coarse loamy texture.

Table 13: Summary table showing classification according to Soil Taxonomy for mapping unit 52

| Order | Sub-Order | Great-group | Sub-group | Family | Series |
|----------|-----------|-------------|--------------------|--|----------|
| Entisols | Orthents | Ustorthents | Lithic-Ustorthents | Lithic Ustorthents coarse loamy siliceous hyperthermic | Chilanga |

Mapping unit 22:

In the FAO/UNESCO legend the soil is classified as Dystric Regosol as identified in mapping unit 31.

According to Soil Taxonomy the soil is classified at order, sub-order and great group as Ustorthents as identified in mapping unit 31.

It is classified as Typic Ustorthents at sub-group level because of the following:

- It has an Ustic moisture regime
- It has no Vermic properties
- It has no Vertic properties

As the family level it is classified as Typic Ustorthents clayey kaolinitic hyperthermic

Table 14: Summary table showing classification according to Soil Taxonomy for mapping unit 22

| Order | Orthents | Great-group | Sub-group | Family | Series |
|----------|----------|-------------|-------------------|--|---------|
| Entisols | Orthents | Ustorthents | Typic Ustorthents | Typic Ustorthents clayey kaolinitic hyperthermic | Unknown |

IV.5 Land evaluation:

5.1 Methodology:

5.1.1 General

The land evaluation method followed in this study is the two stage approach of the FAO - framework (FAO, 1976). Unlike the parallel approach in which the physical and economic factors are evaluated simultaneously, the two stage approach carries

out a separate economic evaluation after the physical evaluation. Veldkamp (1980, 1979), in his land evaluation studies in Eastern Sierra Leone and Western Liberia, and in Nigeria uses a two stage approach. He separates the economic analysis so as to obtain a constant physical base, which can be re-evaluated with changed economic conditions. Land characteristics and therefore land qualities are considered to be more or less constant with time apart from annual dynamics. In this study the economic viability of land use on different mapping units will be discussed in chapter IIV. The major problems related to the use of the FAO framework are concerned with the expression of the economic viability of land and the question of the critical values for suitability class limits.

In the FAO (1976) land evaluation system, it is acceptable to qualitatively evaluate the physical and environmental characteristics, however is not clear whether the economic viability of a piece of land should be expressed qualitatively or quantitatively. Veldkamp (1979, 1980) used a qualitative approach in his economic evaluation in Nigeria.

The framework (FAO, 1976) has also not solved the question of the critical values for suitability class limits. This was clearly shown by the work of Young and Goldsmith in Malawi (1977).

The following basic elements: land, crops and management levels will be defined and discussed in the paragraphs 5.1.2 and 5.1.3 respectively. In paragraph 3.5 the determination of the suitability is outlined.

The object and purpose of this study is to rate and evaluate the land use possibilities for food and cash crops. Each crop will be studied to relate its growth requirements to land qualities of the mapping units and management levels resulting in a suitability determination.

5.1.2 Land qualities:

In this study land is considered on the basis of land qualities. A land quality is defined by (FAO, 1976 and; Beek and and Bernema, 1972) as a complex attribute of land which acts in a manner distinct from the action of other land qualities in its influence on the suitability of land for specific kinds of use. It is a characteristic of land (compound or single) with a direct relation to crop growth or performance. Mutual independence is assumed between the different land qualities although characteristics used to identify one land quality may be used to identify another. In table 16 the land qualities relevant to the Kapini area are listed.

Table 16: Relevant land qualities of the Kapini area

- Availability of nutrients.
- Availability of moisture.
- Availability of oxygen in the rooting zone.
- Impediment of root development.
- Presence of surface stones and rock outcrops.
- Presence of surface flooding.
- Soil erodibility.
- Workability.

The land qualities availability of oxygen and presence of surface flooding are dealt seperately because they affect land utilization types in a slightly different manner.

The study area is considered to have a homogenous climate due to its limited extent. The crops chosen for the land evaluation are suited to this climatic region and therefore the following land qualities related to climate have not been included: temperature regimes, radiation energy and photoperiod, climate hazards affecting plant growth, air humidity as affecting plant growth and drying periods for ripening of crops. No elements were found in toxic amounts, hence all land qualities related to soil toxicity, salinity or alkalinity were not considered relevant. (F.A.O., 1976, Beek and Bennema, 1972).

5.1.3 Land utilisation types:

A land utilisation type is defined by FAO (1976) as a kind of land use described in a degree of detail than that of a major kind of use. Each land utilization type is defined under a management level. Three management levels have been distinguished on the basis of:

- (a) technology employed
- (b) intensity of labour, and capital
- (c) level of technical know-how of the farmers
- (d) farm sizes
- (e) infra-structure
- (f) income level.

Three management levels have been distinguished; traditional, intermediate and commercial. Table 18 outlines the major differences between the three levels.

Use possibilities for forestry, livestock, fisheries, hunting and tourism or recreation have not been considered. The study is concerned only with use possibilities for a few selected agricultural food and cash crops (table 17). The key attributes related to the land utilization types include both the crops and management levels (table 18). An attribute is an inherent characteristic within a land utilization type. It can not be separated from it and is used to distinguish the land utilisation type.

Table 17: The crops considered in this study:

| <u>Name of crop</u> | <u>Scientific Name</u> |
|---------------------|-------------------------|
| Maize | Zea mays |
| Cotton | Gossypium hirsutum |
| Wheat | Triticum Aestivum |
| Groundnuts | Arachys hypogea |
| Tomato | Lycopersicon esculentum |
| Citrus | Citrus spp |

5.1.4 Determination of suitability:

The determination of suitability follows the following steps: rating, matching process, suitability class of each land quality and the final suitability rating of the mapping unit as derived from the most limiting land quality. These steps are described and explained below:

5.1.4.1 Rating:

This is the stage at which the factors used in land evaluation for the final realisation of a suitability class of a mapping unit are given a weighed value. This value can be expressed in qualitative terms (i.e. low, high, moderate, good or bad) or in quantitative terms (i.e. 1, 4, 6, 2). The value given either qualitative or quantitative, expresses the importance of a certain class limit within one land evaluation factor or attribute in terms of crop production. This procedure

Table 18: Key attributes of Management Levels and land utilisation types

| Management Level | Produce | Market Orientation | Technology | Labour | Income level | Capital | Farm sizes | Infrastructure |
|------------------|---------|--------------------|-----------------|--------|--------------|------------------|------------|----------------|
| Traditional | Maize | | Low Tech. | | | | | |
| | G/muts | | - Hoe | Family | very | very | 1-3ha | Poor |
| | Cotton | Subsistence | - No fertiliser | labour | low | low | small | foot path |
| | Tomato | | - or chemicals | | | | | |
| | Fruits | | | | | | | |
| Intermediate | Maize | | Moderate | | | | | |
| | G/muts | subsistence | - Tech. | | | Low | | |
| | Cotton | and commercial | - Cattle | Family | Mode- | but can | small | |
| | Tomato | | drawn | and | rate | get | 3-10 | road but not |
| | Fruits | | implements | hired | | small loans from | ha | well |
| | | | - tractor | labour | | AgriCo. | small | |
| | | | hiring | | | Finance | | |
| | | | - some | | | Co. | | |
| | | | fertiliser | | | (AFG) | | |
| Commercial | maize | | High techn. | | | | | |
| | G/muts | Commercial | - Tractor | Perma- | | very | | All weather |
| | Cotton | | drawn | nent | | high | | roads to |
| | Tomato | | implements | labour | High | commer- | over | the farm and |
| | Fruits | | - fertilisers | hired | | cial | 100ha | in the field |
| | | | - insecticides | labour | | loans | very | |
| | | | - chemicals | | | from | big | |
| | | | | | | AFG | | |
| | | | | | | and | | |
| | | | | | | Commer- | | |
| | | | | | | cial | | |
| | | | | | | banks | | |

is called Rating. It is done on both the land qualities and suitability requirement in each land utilisation types. The land quality rating ranges from 1 to 4. Rating 1 is the most favourable and rating 4 is the least favourable. All land qualities are rated from each mapping unit. A complex way was followed in rating the land qualities that are affected by several characteristics. The several characteristics that affect a land quality were pooled together by summation or multiplicative methods to realise the final rating for that land quality.

The suitability rating of a land utilization type depends on the most limiting land quality. Each land utilization type has specific land quality rating requirements. The requirements of a land utilisation type are a set of land qualities which determine the production and management conditions of a specific land utilisation type. For a mapping unit to fall in the suitability class of a land utilisation types it must satisfy its requirements or be better, hence the matching process.

5.1.4.2 Matching process:

FAO (1976) defines matching as the process of mutual adaptation and adjustment of the descriptions of land utilisation types and the known land qualities.

The matching process is carried out after the rating process to compare the land qualities of the land mapping units with the requirements of the land utilisation types. This comparison is facilitated by expressing the requirements of each land utilisation type in a rating system identical to that used for land. The matching process leads to the determination of the suitability of land utilisation types in each mapping unit.

5.1.4.3 Suitability:

Land suitability is defined by FAO (1976) as the fitness of a given type of land for a specified kind of land use. In this study two types of suitability are described. The first suitability or sub-suitability is the suitability of a type of land utilisation type as related to one land quality. The second type of suitability is the overall suitability which is determined by the most limiting land quality as expressed by pooling all sub-suitabilities.

Table 19: Description of the Land-Suitability classes as given by

FAO (1976) and its structure (Table 20) —

| |
|--|
| Class S1 highly suitable: Land having no significant limitation to sustained application of a given use, or only minor limitations that will not significantly |
|--|

reduce productivity or benefits and will not raise inputs above an acceptable level.

Class S2 moderately suitable: Land having limitations which in aggregate are moderately severe for sustained application of a given use; the limitations will reduce productivity or benefits and increase required inputs to the extent that the overall advantage to be gained from the use, although still attractive, will be appreciably inferior to that expected on class S1 land.

Class S3 Marginally suitable: Land having limitations which in aggregate are severe for sustained applications of a given use and will so reduce productivity or benefits, or increase required inputs, that this expenditure will be only marginally justified.

Class N1 currently not suitable: Land having limitations which may be surmountable in time but which can not be corrected with existing

knowledge at current acceptable cost;
the limitations are so severe as to
preclude successful sustained use of
the land in the given manner.

Class N2 permanently not suitable: Land having limitations
which appear so severe as to preclude
any possibilities of successful sus-
tained use of the land in the given
manner.

Table 20: Structure of Suitability Classification (after F.A.O. 1976)

| <u>Order</u> | <u>Class</u> | <u>Sub-Class.</u> | <u>Unit</u> |
|-----------------|--------------|-------------------|-------------|
| S-Suitable | S1 | S2m | S2e-1 |
| | S2 | S2e | S2e-2 |
| | S3 | S2me | etc. |
| N-Not suitable: | N1 | N1m | |
| | N2 | N1e | |

NB: the system is fully explained in Chapter 5.2 on the page that
follows (p. 128).

5.2. The suitability tables (and how to use them):

The results of land evaluation are finally expressed in tables that show the suitability of land utilization types in each mapping unit. Basically 4 tables are given in each evaluation. Firstly a table giving the rating of a land quality is given. It also shows the mapping unit that meet the requirement for a high or low rating.

Taking into consideration the minimum requirements for a land quality in each land utilisation type (class), a second table showing the relationship between land requirements and crop requirements is given. The second table gives the rating that is required for a particular crop to be given a high suitability class (i.e. S1) or a low suitability class (i.e. S3). The third table is a result of the matching between the land quality rating in each mapping unit (1st table). The third table gives the final suitability of each land utilization type (crop) in each mapping unit.

For a land quality that affect crops differently, a separate but same suitability rating procedure is done depending on how the crop is affected. i.e. available moisture capacity is rated separately for deep rooting crops, moderately deep rooting crops and shallow rooting crops. The final suitability is also considered separately in each mapping unit.

The 4th set of tables gives a summary of the final suitability ratings for each land utilisation type (as shown in the 3rd table). The summary tables show the current and potential suitability.

Current suitability is a suitability classification based on the suitability of land for a specified land utilisation type in its present condition, without major land improvements (FAO 1976). Potential suitability is a suitability classification based on the suitability of land for a given use after specified major land improvements have been completed where necessary (FAO, 1976).

In each summary table, for each land utilisation type, is given the overall suitability ratings. The overall suitability rating is determined by the most limiting land quality which is indicated by a lower case letter (i.e. S2m) at sub class level. The overall rating also gives the degree of limitation to productivity and management requirements at unit level. This is shown by an arabic number following a hyphen (i.e. S2m-1).

5.2.1 Determination of land qualities:

In this section is discussed the determination of the land qualities. Their impact on management is also discussed together with the effect on crop requirements.

5.2.2 Availability of moisture:

Available water is determined using the concept of available water holding capacity (A.W.C.). Since the climate is homogenous and all the soil mapping units occur in one

agro - climatic zone. (Bunyolo et al, 1980). Agro-climate was not taken as a determinant factor.

Determination of A.W.C.

A.W.C. is determined for each soil horizon. The following formula is used for its calculation per horizon (after Veldkamp 1980):

- $A.W.C. = \Delta pF \cdot d_s \cdot (100 - G/100)$. Where
- A.W.C. is the available water holding capacity in vol. %
- ΔpF is the difference of moisture content at pF 2.5 and pF 4.2 (field capacity and wilting point respectively).
- d_s is the bulk density (g/cm^3)
- G is the gravel content (weight %)

Specific A.W.C. and its calculation:

The concept of specific A.W.C. is included to cater for the calculation of specific moisture needs for different crops. In this concept the rooting depth of crops is extremely important.

- AWC_s - for shallow rooting crops
- AWC_d - for deep rooting crops
- AWC_{vd} - for very deep rooting crops

The relevant available moisture decreases with the depth at which the roots of a crop becomes fewer. At a depth at which the plant roots of a specified crop do not occur the available moisture can not be utilised by the plant. At this depth soil moisture becomes irrelevant, hence the decreasing coefficients with depth.

Specific AWC (AWC_s , AWC_d , AWC_{vd}), is then calculated using AWC calculated per soil horizon and a soil moisture coefficient as the major factor. (The coefficients are discussed below):-

Coefficients for the calculation of specific AWC: (AWC_s , AWC_d , AWC_{vd})

The co-efficients are meant to show, in a decreasing manner the importance of AWC for every 10 cm increase in soil depth, for the shallow, deep and very deep rooting crops (Table 21). The deepest depth at which AWC is significantly important for the different crops has been estimated at the following depths:

- 60 cm per shallow rooting crops
- 90 cm per deep rooting crops
- 150 cm per very deep rooting crops

The co-efficient are given in table 5 for each 10 cm increase in depth, for each shallow, deep and very deep rooting crops. The specific A.W.C. for each type of crop, depending on rooting depth (AWC_s , AWC_d , AWC_{vd}), is calculated using the following formular:

Table 21: Co-efficients used in the calculation of specific A.W.C.
(AWC_s, AWC_d, AWC_{vd})

| <u>Depth (cm)</u> | <u>Shallow(s)</u> | <u>Deep (d)</u> | <u>Very deep (vd)</u> |
|-------------------|-------------------|-----------------|-----------------------|
| 0 - 10 | 1.0 | 1.0 | 1.0 |
| 10 - 20 | 1.0 | 1.0 | 1.0 |
| 20 - 30 | 0.9 | 1.0 | 1.0 |
| 30 - 40 | 0.5 | 0.8 | 0.9 |
| 40 - 50 | 0.3 | 0.6 | 0.75 |
| 50 - 60 | 0.1 | 0.4 | 0.6 |
| 60 - 70 | 0.0 | 0.2 | 0.5 |
| 70 - 80 | 0.0 | 0.15 | 0.4 |
| 80 - 90 | 0.0 | 0.1 | 0.35 |
| 90 - 100 | 0.0 | 0.0 | 0.3 |
| 100 - 110 | 0.0 | 0.0 | 0.2 |
| 110 - 120 | 0.0 | 0.0 | 0.15 |
| 120 - 130 | 0.0 | 0.0 | 0.1 |
| 130 - 140 | 0.0 | 0.0 | 0.05 |
| 140 - 150 | 0.0 | 0.0 | 0.05 |
| 150 - 160 | 0.0 | 0.0 | 0.0 |

$$AWC (s, d, \text{ or } vd) = a_1 \cdot b_1 + \dots + a_n \cdot b_n$$

- where a is the coefficient given in table 21
- where b is the AWC calculated per soil horizon
- where n is the number of horizons for each rooting class:
 6 for shallow rooting, 9 for deep rooting and 15 for very deep
 rooting crops.
- AWC is finally given in mm.

Table 22: Rating of AWC_s (for shallow rooting crops (tomato):

| AWC_s (mm) | Rating | Mapping units |
|-----------------|--------|-------------------------|
| Less than 40 | 4 | - |
| 40 - 50 | 2 | 52, 22 |
| Greater than 50 | 1 | 32,33,31,41,42,11,12,60 |

Table 23a: Minimum land quality rating requirement for shallow rooting crops (tomatoes):

| Rating | Crop |
|--------|--------|
| 2 | Tomato |

Table 23b: Minimum suitability requirement for shallow rooting crops (tomatoes):

| Suitability | Rating |
|-------------|--------|
| S1 | 1 |
| S2 | 1 |
| S3 | 2 |
| M1 | 3 |
| M2 | 4 |

Table 24: Final suitability rating for the land quality availability of moisture for shallow rooting crops

| <u>Mapping unit</u> | <u>For shallow rooting crops (tomato)</u> |
|---------------------|---|
| 11 | S1 |
| 12 | S1 |
| 22 | S3 |
| 32 | S1 |
| 33 | S1 |
| 31 | S1 |
| 41 | S1 |
| 42 | S1 |
| 52 | S3 |
| 60 | S1 |

Table 25: Rating of AWC_d (for deep rooting crops) Maize, Wheat and G/muts

| AWC_d (mm) | Rating | Mapping units |
|------------------|--------|----------------|
| Less than 50 | 3 | 52, 22 |
| 50 - 100 | 2 | 33, 31, 11, 12 |
| Greater than 100 | 1 | 32, 41, 42, 60 |

The crops will have the lowest suitability class (S3) when they have a low rating (i.e. 3) and a high suitability class when they have a favourable or high rating (i.e. 1 or 2) as indicated in table 26.

Table 26: Suitability requirements for maize, wheat and groundnuts:

| Suitability | Maize | Wheat | Groundnuts |
|-------------|-------|-------|------------|
| S1 | 1 | 1 | 1 |
| S2 | 1 | 1 | 2 |
| S3 | 2 | 2 | 3 |
| N1 | 3 | 3 | 4 |
| N2 | 4 | 4 | - |

Table 27: Final suitability rating for the land quality availability of moisture for deep rooting crops (Matching process)

| Mapping unit | Maize | Wheat | groundnuts |
|--------------|-------|-------|------------|
| 11 | S3 | S3 | S2 |
| 12 | S3 | S3 | S2 |
| 22 | N1 | N1 | S3 |
| 32 | S1 | S1 | S1 |
| 33 | S3 | S3 | S2 |
| 31 | S3 | S3 | S2 |
| 41 | S1 | S1 | S1 |
| 42 | S1 | S1 | S1 |
| 52 | N1 | N1 | S3 |
| 60 | S2 | S2 | S1 |

Table 28: Rating of AWC_{vd} for very deep rooting crops (cotton and citrus)

| AWC _{vd} (mm) | Rating | Mapping units |
|------------------------|--------|----------------|
| Less than 100 | 3 | 52, 22, 31 |
| 100 - 120 | 2 | 32, 33, 11, 12 |
| Greater than 120 | 1 | 41, 42, 60 |

The very deep rooting crops will have the lowest land suitability class (i.e. S3) in the mapping units that have a rating of 3 and higher suitability ratings respectively for the mapping units with high ratings (i.e. 1 or 2) as indicated in table 29.

Table 29: Suitability requirements (cotton and citrus):

| Suitability | Cotton | Citrus |
|-------------|--------|--------|
| S1 | 1 | 1 |
| S2 | 2 | 2 |
| S3 | 3 | 3 |
| N1 | 4 | 4 |
| N2 | - | - |

Table 30: Final suitability rating for the land quality availability of moisture for very deep rooting crops:

| Mapping units | Cotton | Citrus |
|---------------|--------|--------|
| 11 | S2 | S2 |
| 12 | S2 | S2 |
| 22 | S3 | S3 |
| 32 | S2 | S2 |
| 33 | S2 | S2 |
| 31 | S3 | S3 |
| 41 | S1 | S1 |
| 42 | S1 | S1 |
| 52 | S3 | S3 |
| 60 | S1 | S1 |

5.2.3 Availability of oxygen:

Among the plants that have been selected for this land evaluation exercise there is a variation in their oxygen requirement. For example maize and tomato react very strongly to lack of aeration, while cotton and groundnuts are more tolerant.

Actual ground water level measurements were made during the rainy season. Perforate tubes of 1 meter long and 5 cm wide had been sunk into the ground through drilled auger holes.

However, no groundwater was observed in any of the tubes, because of low rainfall. Therefore a qualitative rating is given to the soil drainage class of the different mapping units. Farmers say that mapping units 41 and 42 can indeed be wet during some wet years. Literature (about Chisemba area) also indicates wetness problem in the area. The occurrence of surface water logging is kept separate from the land quality availability of oxygen and will be discussed as a separate land quality.

Table 31: Rating availability of oxygen for shallow and deep rooting crops:

| Drainage | Rating | Mapping units |
|---|--------|------------------------------|
| Well drained; no water logging and no gray mottles and red mottles within 1 m. | 1 | 11, 12, 22, 32, 33 52, 31 |
| Moderately well drained; no water logging within 1 m but red mottles occur within 1 m. | 2 | 42, 41 |
| Poorly drained; water within 1 m with many gray mottles | 4 | 60 |

Below (table 32) is the weighed matching process showing the relationship between land requirements and crop requirements.

Table 32: Crop requirements for land quality availability of oxygen (shallow and deep rooting crops)

| Suitability | Maize | Wheat | G/nuts | Tomato |
|-------------|-------|-------|--------|--------|
| S1 | 1 | 1 | 1 | 1 |
| S2 | 1 | 1 | 1 | 1 |
| S3. | 2 | 2 | 2 | 2 |
| M1 | 3 | 3 | 3 | 3 |
| N2 | 4 | 4 | 4 | 4 |

Table 33: Final suitability rating for the land quality availability of oxygen (shallow and deep rooting crops):

| Mapping units | Maize | Wheat | G/Nuts | Tomato |
|---------------|-------|-------|--------|--------|
| 11 | S1 | S1 | S1 | S1 |
| 12 | S1 | S1 | S1 | S1 |
| 22 | S1 | S1 | S1 | S1 |
| 32 | S1 | S1 | S1 | S1 |
| 33 | S1 | S1 | S1 | S1 |
| 31 | S1 | S1 | S1 | S1 |
| 41 | S3 | S3 | S3 | S3 |
| 42 | S3 | S3 | S3 | S3 |
| 52 | S1 | S1 | S1 | S1 |
| 60 | N2 | N2 | N2 | N2 |

Table 34: Rating of availability of oxygen for very deep rooting crops (cotton/fruits)

| Drainage | Rating | Mapping units |
|---------------------------------------|--------|--------------------|
| Well drained as explained in table 31 | 1 | 33, 31, 32, 52, 22 |
| Moderately well drained as above | 2 | 11, 12, 41, 42 |
| Poorly drained as above | 4 | 60 |

Rating 2 is the minimum that is required for cotton and fruits to perform well as shown in table 35.

Table 35: Minimum suitability requirements for cotton and fruits

| Suitability | Cotton | Citrus |
|-------------|--------|--------|
| S1 | 1 | 1 |
| S2 | 1 | 1 |
| S3 | 2 | 2 |
| N1 | 3 | 3 |
| N2 | 4 | 4 |

Table 36: Final suitability rating for the land quality availability of oxygen (cotton and fruits)

| Mapping unit | Cotton | Citrus |
|--------------|----------------|----------------|
| 11 | S3 | S3 |
| 12 | S3 | S3 |
| 22 | S1 | S1 |
| 32 | S1 | S1 |
| 33 | S1 | S1 |
| 31 | S1 | S1 |
| 41 | S3 | S3 |
| 42 | S3 | S3 |
| 52 | S1 | S1 |
| 60 | N ₂ | N ₂ |

5.2.5 Land quality soil fertility:

This quality has been rated or evaluated in various ways by several workers. This is usually so because of the availability or the importance of certain data within a particular study area. Veldkamp (1978), in a land evaluation case study in the tropical valleys of Nigeria, based his soil fertility land quality evaluation on the natural availability of nutrients, so called natural fertility. He discusses the various nutritive chemical elements that are necessary for crop production and

rates them for the final suitability rating for the land quality soil fertility e.g. Nitrogen, Phosphorus, Potassium and Sulphur. He then followed this up to see the response of crops to applied nutrients. All ratings were done qualitatively.

Chinene (1980) in an attempt to follow the FAO framework for land evaluation bases his availability of nutrient land quality evaluation and rating on CEC and an assumed presence of few nutrients because the soil is highly weathered(?). In another less intensive study in Sierra Leone and Liberia, Veldkamp (1980) used averaged effective cation exchange capacity (C.E.C.) (Soil and clay), Al-ratio and Gravel content. He uses other fertility related characteristics as separate land qualities e.g. Iron Toxicity, 'P' Fixation, Salinity and Acid Sulphate conditions.

In this land evaluation study several characteristics that affect the land quality soil fertility have been rated separately. They are put together by summation method for the final rating of the soil fertility land quality. The nutrient status of the soil is expressed in the rating of the characteristic 'BSP'. Nutrient retention is expressed in the rating of the characteristic 'CEC' and 'clay type'. The release of nutrients or replenishment of nutrients within the soil is expressed by the presence of weatherable minerals in the soil as quantified from X-ray diffractograms. Soil reaction and 'P' fixation are expressed

from pH. Other important nutrients such as nitrogen are expressed within the framework of such land qualities as flooding and water stagnation or aeration.

The evaluation is then related to the performance of Maize using two management levels on two of the most extensive and important mapping units (11 and 41). It can be seen that the concept of soil fertility as evaluated in this study corresponds to that of Veldkamp (1980) and that of the soil science society of America (1971) who define it as the status of a soil with respect to the amount and availability to plants of elements necessary to plant growth, and as defined by the soil survey manual (1951), as the quality that enables the soil to provide the proper balance for the growth of specific plants when other factors such as light, temperature, moisture and the physical conditions of the soil are favourable.

The fertility land quality could not be rated directly as it involved many attributes such as pH, BSP, CEC, presence of weatherable minerals, clay type and P fixation. The rating of the soil fertility land quality was done by sub-rating the characteristics. The characteristics pH, B.S.P., C.E.C., clay mineral type, weatherable minerals and P fixation are rated, respectively, below to yield the final rating of the land quality and fertility.

pH, H₂O (1:5):

pH controls the availability, toxicity and preferential up take of nutrients. It was measured in Ca Cl₂ and H₂O but the rating given here is that of H₂O measurements.

Table 37: pH fertility characteristic:

| pH (H ₂ O) | Rating | Rating occurs in mapping units |
|-----------------------|--------|--------------------------------|
| 4.5 - 5.5 | 4 | 32 |
| 5.5 - 5.9 | 2 | 52, 22, 42 |
| Greater than 5.9 | 1 | 31, 33, 41, 11, 12, 60 |

Table 38: Base saturation percentage (BSP) (Fertility characteristic)

| BSP | Rating | Rating occurs in mapping units |
|--------------|--------|--------------------------------|
| 100 - 50 | 1 | 11, 12, 41, 60, 22 |
| 50 - 35 | 2 | 52, 52, 33, 31 |
| Less than 35 | 3 | 32 |

B.S.P. gives an indication of nutrient availability in relation to the dominance of cations on the exchange complex.

Cation exchange capacity (CEC) me 100g/clay fertility characteristic:

C.E.C. indicates that applied nutrients will be retained by the soil and not rapidly lost by leaching.

Table 39: C.E.C. fertility characteristic:

| me 100g/clay | Rating | Rating occurs in mapping units |
|-----------------|--------|--------------------------------|
| Less than 10 | 4 | 32 |
| 10 - 16 | 3 | 33,31,11,12 |
| 16 - 24 | 2 | 41, 42 |
| Greater than 24 | 1 | 22, 52, 60 |

Clay Mineral components:

The clay mineral component of the soil may indicate the general behaviour of the soil. It was expected that the clay mineral components would be reflected by the cation exchange capacity levels in the soil. It was, however, found that even when clay minerals that would generally give high CEC were present no high CEC was recorded. This may indicate a deficiency in the method of analysis.

Table 40: Clay mineral component fertility characteristic

| Clay mineral components | Rating | Mapping units |
|----------------------------------|--------|----------------|
| - Kaolinite, Traces of illite | 4 | 32, 33, 31, . |
| - Kaolinite,illite Halloysite | 2 | 41, 42, 22, 52 |
| - Kaolinite,illite smectites | 1 | 11, 12, 60 |

Presence of weatherable minerals in the fine sand fraction:

This may give an indication of the future fertility status of the soil.

Table 41: Presence of weatherable minerals fertility characteristic:

| Weatherable minerals | Rating | mapping units |
|--------------------------|--------|------------------------|
| Micas, smectites, illite | 1 | 11, 60, 12 |
| Micas, illite | 2 | 33, 31, 22, 52, 41, 42 |
| None | 4 | 32 |

'P' Fixation

This is indicated by the presence of the oxides, pH and clay content. Phosphate fixation is the removal of soluble phosphate ions to form a precipitate. It was assumed that low pH values make aluminium and iron active in 'P' fixation while high pH values necessitate the activity of calcium in 'P' fixation. The following results were obtained for the top 30 cm (table 42).

Table 42: 'P' Fixation fertility characteristic

| pH (H ₂ O) | Rating | Rating occurs in mapping units |
|-----------------------|--------|--------------------------------|
| Greater than 5 | 1 | All mapping units |
| Less than 5 | 2 | 32 |

Final rating for the land quality soil fertility (table 43):

This is achieved by the summation of all sub-rating.

Table 43: Final rating for the land quality soil fertility

| Sum rating of sub ratings | Final rating | Mapping units |
|---------------------------|--------------|------------------------|
| Less than 6 | 1 | 60 |
| 6 - 12 | 2 | 11, 12, 22, 41, 42, 52 |
| 12 -15 | 3 | 33, 31 |
| 15 -18 | 4 | 32 |

Table 44: Crop minimum rating requirements for the different characteristics:

| | Maize | Wheat | Cotton | G/nuts | Citrus | Tomato |
|----------------------|-------|-------|--------|--------|--------|--------|
| pH | 2 | 2 | 2 | 1 | 3 | 3 |
| BSP | 2 | 2 | 2 | 2 | 3 | 3 |
| CEC | 2 | 2 | 2 | 3 | 3 | 3 |
| Clay mineral | 2 | 2 | 2 | 3 | 3 | 3 |
| Weatherable minerals | 2 | 2 | 2 | 3 | 3 | 3 |
| 'p' | 2 | 2 | 2 | 3 | 3 | 3 |
| Sum rating | 12 | 12 | 12 | 15 | 18 | 18 |
| Rating requirement | 2 | 2 | 2 | 3 | 4 | 4 |

The sum rating for crops ~~when~~ compared to the sum rating of the land quality shows that the crop is not suited below its sum rating figure. Thus maize is more suited in the range 12-15 up to the range less than 6 but it is not suited in the range 15-18. The suitability ratings are shown in table 45.

Table 45: Suitability requirements for fertility:

| Suitability | Maize | Wheat | Cotton | G/nuts | Citrus | Tomatoes |
|-------------|-------|-------|--------|--------|--------|----------|
| S1 | 1 | 1 | 1 | 1 | 1 | 1 |
| S2 | 1 | 1 | 1 | 2 | 2 | 2 |
| S3 | 2 | 2 | 2 | 3 | 3 | 3 |
| N1 | 3 | 3 | 3 | 4 | 4 | 4 |
| N2 | 4 | 4 | 4 | - | - | - |

Table 46: Suitability rating for various land utilisation types for the land quality soil fertility:

| Mapping Unit | Maize | Cotton | Wheat | G/muts | Tomatoes | Citrus |
|--------------|-------|--------|-------|--------|----------|--------|
| 11 | S3 | S3 | S3 | S2 | S2 | S2 |
| 12 | S3 | S3 | S3 | S2 | S2 | S2 |
| 22 | S3 | S3 | S3 | S2 | S2 | S2 |
| 32 | N2 | N2 | N2 | N1 | N1 | N1 |
| 33 | N1 | N1 | N1 | S3 | S3 | S3 |
| 31 | N1 | N1 | N1 | S3 | S3 | S3 |
| 41 | S3 | S3 | S3 | S2 | S2 | S2 |
| 42 | S3 | S3 | S3 | S2 | S2 | S2 |
| 52 | S3 | S3 | S3 | S2 | S2 | S2 |
| 60 | S1 | S1 | S1 | S1 | S1 | S1 |

5.2.5 Impediment of root development:

For the rating of this land quality the following factors are used: soil depth, gravel content, and presence of heavy clay layer in which water movement is restricted within 100 cm depth. In case where the plant roots can reach the water at relatively shallow depth soil depth is not considered important.

Soil Depth:

Table 47: Rating the land quality impendment to root development;
soil depth characteristic

| Soil depth (cm) | Rating | Rating occurs in mapping units |
|------------------|--------|--------------------------------|
| Less than 25 | 4 | 52 |
| 25 - 50 | 3 | 31, 22 |
| 50 - 100 | 2 | 33, 12 |
| Greater than 100 | 1 | 32, 41, 42, 11, 60 |

Table 48: Gravel content characteristic in root development

| Gravel content % | Rating | Rating occurs in mapping units |
|------------------|--------|--------------------------------|
| Non | 1 | 11, 32, 41, 42, 60 |
| 25 - 50% | 2 | 22, 33, 31, 12 |
| Greater than 50 | 3 | 52 |

Table 49: Clay layer impeding water movement characteristic

| Depth cm | Rating | Mapping units |
|-----------------|--------|---------------|
| 0 - 80 | 2 | 11, 12 |
| Greater than 80 | 1 | the rest |

Table 50: Final rating for the land quality impediment to root development:

| Sum rating of sub-ratings | Final rating | Mapping units |
|---------------------------|--------------|----------------|
| 3 or less | 1 | 32, 41, 42, 60 |
| 4 - 5 | 2 | 33, 11 |
| 6 - 7 | 3 | 31, 22, 12 |
| More than 7 | 4 | 52 |

Table 51: Crop minimum rating requirements for the different characteristics:

| Characteristic | Maize | Wheat | Cotton | G/muts | Oranges | Tomatoes |
|---------------------------|-------|-------|--------|--------|---------|----------|
| Depth | 2 | 3 | 1 | 3 | 1 | 2 |
| Gravel content | 2 | 2 | 2 | 2 | 2 | 2 |
| Clay layer impeding water | 1 | 2 | 1 | 2 | 1 | 2 |
| Sum rating | 5 | 7 | 4 | 7 | 4 | 6 |
| Final rating | 2 | 3 | 2 | 3 | 2 | 3 |

N.B: Final ratings and sum ratings of the land quality and land utilisation types are expressed in some numerical ranges (figures).

Table 52: Suitability requirement for the land quality impediment to root development:

| Suitability | Maize | Wheat | Cotton | Tomato | Fruits | G/nuts |
|-------------|-------|-------|--------|--------|--------|--------|
| S1 | 1 | 1 | 1 | 1 | 1 | 1 |
| S2 | 1 | 2 | 1 | 2 | 1 | 2 |
| S3 | 2 | 2 | 2 | 2 | 2 | 2 |
| N1 | 3 | 3 | 3 | 3 | 3 | 3 |
| N2 | 4 | - | 4 | - | 4 | - |

Table 53: Suitability rating for various land utilisation types for the land quality impediment to root development (matching process).

| Mapping units | Maize | Cotton | Wheat | G/nuts | Tomato | Fruits (oranges) |
|---------------|-------|--------|-------|--------|--------|------------------|
| 11 | S3 | S3 | S2 | S2 | S2 | S3 |
| 12 | N1 | N1 | S3 | S3 | S3 | N1 |
| 22 | N1 | N1 | S3 | S3 | S3 | N1 |
| 32 | S1 | S1 | S1 | S1 | S1 | S1 |
| 33 | S3 | S3 | S2 | S2 | S2 | S3 |
| 31 | N1 | N1 | S3 | S3 | S3 | N1 |
| 41 | S1 | S1 | S1 | S1 | S1 | S1 |
| 42 | S1 | S1 | S1 | S1 | S1 | S1 |
| 52 | N2 | N2 | N2 | N1 | N1 | N2 |
| 60 | S1 | S1 | S1 | S1 | S1 | S1 |

5.2.6 Presence of surface stones and rock outcrops:

For this land quality the rating is based on the percentage of land occupied by stones, rocks and boulders, singularly or in combination. These are generally known as rock outcrops.

The crop requirements for this land quality pose a problem since they are really an expression of the management levels needed as this land quality is a hinderance to cultivation and not to crop growth. Hence, the procedure here will be to rate the land quality itself and also rate the management levels vis a vis traditional, intermediate and commercial.

Table 54: Rating the land quality presence of surface stones and rock-outcrops:

| Rock outcrops % | Rating | Mapping units |
|------------------|--------|------------------------|
| Less than 5% | 1 | 32, 41, 42, 11, 12, 60 |
| 5 - 20% | 2 | 33 |
| 20 - 30% | 3 | 31, 22 |
| Greater than 30% | 4 | 52 |

Table 55: Interpretation of the crop minimum requirements for the land quality presence of rock out-crops into suitability classes.

| Suitability | Traditional | | Intermediate | | Commercial | |
|-------------|---------------|--------|----------------|--------|----------------|--------|
| | Cereal & Veg. | Citrus | Cereals & Veg. | Citrus | Cereals & Veg. | Citrus |
| S1 | 1 | 1 | - | - | - | - |
| S2 | 1 | 2 | - | 1 | - | - |
| S3 | 2 | 3 | 1 | 2 | 1 | 1 |
| N1 | 3 | 4 | 2 | 3 | 2 | 2 |
| N2 | 4 | - | 3 | 4 | 3 | 3 |

Table 56: Final suitability rating for the land quality presence of surface stones and rock (out-crops):

| Mapping units | Traditional | | Intermediate | | Commercial | |
|---------------|---------------|--------|----------------|--------|----------------|--------|
| | Cereal & Veg. | Citrus | Cereals & Veg. | Citrus | Cereals & Veg. | Citrus |
| 11 | S2 | S1 | S3 | S2 | S3 | |
| 12 | S2 | S1 | S3 | S2 | S3 | S3 |
| 22 | N1 | S2 | N2 | N1 | N2 | N2 |
| 32 | N1 | S3 | N2 | N1 | N2 | N2 |
| 33 | S3 | S2 | N1 | S3 | N1 | N1 |
| 31 | N1 | S3 | N1 | N1 | N2 | N2 |
| 41 | S2 | S1 | S3 | S2 | S3 | S3 |
| 42 | S2 | S1 | S3 | S2 | S3 | S3 |
| 52 | N2 | N1 | N1 | N2 | N1 | N1 |
| 60 | S2 | S1 | S3 | S2 | S3 | S3 |

5.2.7 Flooding land quality:

Flooding is a complementary land quality to the availability of oxygen land quality. Flooding can affect crop production within a very short time. For example, flooding reduces availability of oxygen in the soil to zero within 1 to 2 days of flooding and nitrogen availability is greatly affected. The aerobic microorganisms worsen the situation by rapidly using all the oxygen that may be present in the soil. When flooding occurs, replenishment of oxygen by way of atmospheric O_2 diffusion through the water to the soil is also very slow such that it can not match the rate at which oxygen is being exhausted in soil. With zero amounts of oxygen in the soil, anaerobic condition set in, this stimulates the multiplication of anaerobic and facultative anaerobic bacteria. These further reduce a variety of other components, using, not oxygen, but other oxidizing elements to reduce such elements as nitrates. Hence, although nitrates might be present in small amounts after flooding, the work of these micro-fauna completely reduces it.

The land quality presence of flooding and discharge stagnation is intended for areas where flooding (surface water) occurs and water is stagnated for one or more days due to slow drainage discharge, laterally or vertically. This land quality is especially important for mapping units with heavy clay throughout the profile, and which lay on flat to very flat land.

The final suitability ratings that will be realised by this land quality should only be used during the rainy season. For this land quality the characteristics, observed flooding (seasonal), slope and drainage (internal) will be sub-rated and summed for the final rating.

Table 57: Rating the flooding land quality. The observed flooding characteristic:

| Observed flooding 1 season | Rating | Mapping units |
|--|--------|-----------------|
| Flooding rain water for more than one day | 3 | 42, 41, 60 |
| Flooding rain water stagnates for less than 2 hours (flash floods) | 1 | All other units |

Table 58: The slope characteristic in the flooding land quality:

| Slope % | Rating | Mapping units |
|---------|--------|-----------------|
| 0 - 2 | 3 | 41, 60 |
| 3 - 5 | 1 | All other units |

Table 59: The Internal drainage characteristic in the flooding land quality:

| Drainage | Rating | Mapping units |
|----------|--------|---------------|
| Well | 1 | All units |
| Moderate | 2 | 41, 42 |
| Poor | 4 | 60 |

Table 60: Final rating for the land quality presence of flooding and discharge stagnation:

| Sum rating of sub ratings | Final rating | Mapping units |
|---------------------------|--------------|---------------|
| 3 | 1 | All units |
| 4 - 8 | 2 | 41, 42 |
| More than 8 | 4 | 60 |

Table 61: Crop requirements for the land quality presence of flooding and discharge stagnation:

| Maize | Wheat | Cotton | Groundnuts | Citrus | Tomatoes |
|-------|-------|--------|------------|--------|----------|
| 2 | 2 | 2 | 2 | 2 | 2 |

Table 62: Suitability rating requirements for the land quality presence of flooding and discharge stagnation into suitability classes:

| Suitability | Maize | Wheat | Cotton | G/nuts | Citrus | Tomato |
|-------------|-------|-------|--------|--------|--------|--------|
| S1 | 1 | 1 | 1 | 1 | 1 | 1 |
| S2 | 1 | 1 | 1 | 1 | 1 | 1 |
| S3 | 2 | 2 | 2 | 2 | 2 | 2 |
| N1 | 3 | 3 | 3 | 3 | 3 | 3 |
| N2 | 4 | 4 | 4 | 4 | 4 | 4 |

Table 63: Suitability rating for various land utilisation types:

| Suitability | Maize | Wheat | Cotton | G/nuts | Orange | Tomato |
|-------------|-------|-------|--------|--------|--------|--------|
| 11 | S1 | S1 | S1 | S1 | S1 | S1 |
| 12 | S1 | S1 | S1 | S1 | S1 | S1 |
| 22 | S1 | S1 | S1 | S1 | S1 | S1 |
| 32 | S1 | S1 | S1 | S1 | S1 | S1 |
| 33 | S1 | S1 | S1 | S1 | S1 | S1 |
| 31 | S1 | S1 | S1 | S1 | S1 | S1 |
| 41 | S3 | S3 | S3 | S3 | S3 | S3 |
| 42 | S1 | S1 | S1 | S1 | S1 | S1 |
| 52 | S1 | S1 | S1 | S1 | S1 | S1 |
| 60 | N2 | N2 | N2 | N2 | N2 | N2 |

5.2.8 Workability land quality:

For this land quality the following soil characteristics are used:

- The plasticity index is the moisture at which soil can be used well without rupturing, paddling or distroying its structure.
- Stickness limit - this is the moisture at which the soil becomes sticky and difficult to use with machinery and other agricultural tools.
- These characteristics are sub-rated and then summed up to give the final land quality rating.

Table 64: Rating workability land quality. Plastic index characteristic:

| Plastic index 0-40 cm depth | Rating | Mapping units |
|--------------------------------|--------|---------------|
| 0 - 2 | 4 | 33, 31 |
| 3 - 4 | 3 | 22, 52 |
| 4 - 8 | 2 | 33, 11, 12 |
| Greater than 8 | 1 | 41, 42 |

Low plastic index indicates that the soil structure can easily be destroyed or paddled while high plastic index indicates that the soil can be worked at a wide moisture range without any danger of damaging to its structure.

Table 65: Sticky-limit characteristic in workability land quality:

| Stick limit: 0 - 40 cm | Rating | Mapping units |
|---------------------------|--------|--------------------|
| 10 - 14 | 4 | 41, 42 |
| 15 - 20 | 2 | 22, 52, 11, 12, 33 |
| Greater than 20 | 1 | 33, 31 |

Low stick limits indicates that the soil gets sticky and difficult to work at relatively low moisture level. High values indicate that the soil does not easily become sticky except at high moisture levels.

Table 66: Final rating of the land quality workability:

| Sum of sub-ratings | Final ratings | Mapping units |
|--------------------|---------------|-------------------|
| 2 - 4 | 1 | 11, 12, 31 |
| 5 - 7 | 2 | 41,42,22,52,32,33 |
| 8 | 4 | - |

Table 67: Land utilisation requirements for the land quality workability:

| Traditional | | Intermediate | | Commercial | |
|----------------|--------|----------------|--------|----------------|--------|
| Cereals & Veg. | Fruits | Cereals & Veg. | Fruits | Cereals & Veg. | Fruits |
| 2 | 2 | 2 | 2 | 2 | 2 |

Table 68: Interpretation of the crop minimum requirements for the land quality workability into suitability class:

| Suitability | Traditional | | Intermediate | | Commercial | |
|-------------|----------------|--------|----------------|--------|----------------|--------|
| | Cereals & Veg. | Citrus | Cereals & Veg. | Citrus | Cereals & Veg. | Citrus |
| S1 | 1 | 1 | 1 | 1 | 1 | 1 |
| S2 | 1 | 1 | 1 | 1 | 1 | 1 |
| S3 | 2 | 2 | 2 | 2 | 2 | 2 |
| N1 | 3 | 3 | 3 | 3 | 3 | 3 |
| N2 | 4 | 4 | 4 | 4 | 4 | 4 |

Table 69: Final suitability ratings for the land quality workability

| | | Traditional | | Intermediate | | Commercial | |
|----|----|----------------|--------|----------------|--------|----------------|--------|
| | | Cereals & Veg. | Fruits | Cereals & Veg. | Fruits | Cereals & Veg. | Fruits |
| 11 | S1 | S1 | S1 | S1 | S1 | S1 | S1 |
| 12 | S1 | S1 | S1 | S1 | S1 | S1 | S1 |
| 22 | S3 | S3 | S3 | S3 | S3 | S3 | S3 |
| 32 | S3 | S3 | S3 | S3 | S3 | S3 | S3 |
| 33 | S3 | S3 | S3 | S3 | S3 | S3 | S3 |
| 31 | S1 | S1 | S1 | S1 | S1 | S1 | S1 |
| 41 | S3 | S3 | S3 | S3 | S3 | S3 | S3 |
| 42 | S3 | S3 | S3 | S3 | S3 | S3 | S3 |
| 52 | S3 | S3 | S3 | S3 | S3 | S3 | S3 |
| 60 | N2 | N2 | N2 | N2 | N2 | N2 | N2 |

5.2.9 Soil erodibility land quality:

The assessment of susceptibility to erosion can be very complicated when using all environmental factors that affect soil erosion. The most common way of assessing soil erosion is through equations that use certain indices or indicators of erosion i.e. the Universal soil loss equation (USLE) (Wischmeier and Smith 1966). Besides the USLE, soil erodibility equation indices have been formulated, some of which are shown below:

- Dispersion ration (Middleton 1930)
- Erosion ratio (Middleton 1930)
- Clay ratio
- Surface aggregates (WSA) 3 mm - 0.5 m
- Slaking loss/water stable aggregates above 2mm
- Slaking loss
- Moisture equivalent; above 2mm
- Dry aggregates stability (D.S.A.) 2.3 mm

In this land evaluation, another erodibility index simply called erosion susceptibility (E.S.) has been coined and it is used for the assessment of the land quality soil erodibility together with slope and soil depth. Most of the indices were found to be unsuitable because they contradicted observed erosion on the different soil mapping units.

Erosion susceptibility (ES) 0-40 cm depth:

This index assumes that clay and coarse sandy are less erodible than fine sand and silt. Clay has high adhesiveness while sand is too heavy to be easily moved by water. Experience in Zambia (McLean 1971, soil survey unit 1968 - 1982) shows that soil with a high % of fine sand and silt are more erodible. Erosion susceptibility (E.S.) in this index is expressed as:

$$E.S. = \frac{\% \text{ clay} + \% \text{ Coarse sand}}{\% \text{ silt} + \% \text{ Fine sand}}$$

A high figure indicates that the soil is less susceptible to erosion.

Table 70: Erosion susceptibility in erodibility land quality:

| E.S. | Rating | Mapping units |
|-------------------|--------|----------------|
| Less than 1 | 3 | 33, 42, 41 |
| 1 - 1.40 | 2 | 11, 12, 31, 32 |
| Greater than 1.40 | 1 | 22, 52, 60 |

Soil depth as a factor in soil erodibility:

This works on the principle that shallow soil will get quickly saturated with rain water giving rise to water run off which would subsequently erode the soil.

Table 71: Soil depth characteristic in erodibility land quality:

| Soil depth (cm) | Rating | Mapping units |
|-----------------|--------|------------------------------|
| Less than 50 | 3 | 22, 52, 31 |
| Greater than 50 | 1 | 41, 42, 60, 33 11, 12, 32 |

Slope:

Soil erosion by moving water is mainly a factor of slope. The greater the slope (steepness and length) the faster the water moves and the greater is soil erosion. In the final rating of the land quality erosion susceptibility, slope ratings will not be incomparated by the summation method as has been done in the previous land qualities, but by a multiplicative method. This is due to the great effect that slope has on this land quality.

A high figure indicates that the soil is less susceptible to erosion.

Table 70: Erosion susceptibility in erodibility land quality:

| E.S. | Rating | Mapping units |
|-------------------|--------|----------------|
| Less than 1 | 3 | 33, 42, 41 |
| 1 - 1.40 | 2 | 11, 12, 31, 32 |
| Greater than 1.40 | 1 | 22, 52, 60 |

Soil depth as a factor in soil erodibility:

This works on the principle that shallow soil will get quickly saturated with rain water giving rise to water run off which would subsequently erode the soil.

Table 71: Soil depth characteristic in erodibility land quality:

| Soil depth (cm) | Rating | Mapping units |
|-----------------|--------|------------------------------|
| Less than 50 | 3 | 22, 52, 31 |
| Greater than 50 | 1 | 41, 42, 60, 33 11, 12, 32 |

Slope:

Soil erosion by moving water is mainly a factor of slope. The greater the slope (steepness and length) the faster the water moves and the greater is soil erosion. In the final rating of the land quality erosion susceptibility, slope ratings will not be incomparated by the summation method as has been done in the previous land qualities, but by a multiplicative method. This is due to the great effect that slope has on this land quality.

Table 72: Slope characteristic in erodibility land quality:

| Slope angle % | Rating | Mapping units |
|----------------|--------|----------------|
| 0 - 1 | 1 | 41, 32, 60 |
| 1 - 3 | 2 | 42, 33, 31, 11 |
| Greater than 3 | 3 | 22, 52, 12 |

Slope length was not taken into account due to the scale of the map.

Table 73: Sum rating of erodibility land quality:

Pooling of sub-ratings by summation and multiplicative method i.e. (soil depth + E.S.) x slope.

| Sub-rating | Rating | Mapping units |
|-----------------|--------|----------------|
| Less than 6 | 1 | 60, 32 |
| 6 - 10 | 2 | 11, 41 |
| 8 - 10 | 3 | 12, 31, 33, 42 |
| Greater than 10 | 4 | 22, 52 |

Table 74: Final suitability for the land quality soil erodibility for all crops:

| Mapping units | Suitability class | |
|---------------|-------------------|-----------|
| | Current. | Potential |
| 11 | S2 | S1 |
| 12 | S3 | S2 |
| 22 | N1 | S3 |
| 31 | S1 | S1 |
| 32 | S3 | S2 |
| 33 | S3 | S2 |
| 41 | S2 | S1 |
| 42 | S3 | S2 |
| 52 | N1 | N3 |
| 60 | S1 | S1 |

5.2.10 Summary and final suitability rating tables for all land utilisation types:

The summary and final suitability rating tables are given below. Section 5.2.1 explains how to use and interpret them. These tables form the final result of the land evaluation exercise followed in this thesis.

Table 75:

SUMMARY AND FINAL SUITABILITY RATINGS FOR COTTON IN ALL MAPPING UNITS

| Land Quality | 11 | 12 | 22 | 32 | 33 | 31 | 41 | 42 | 52 | 60 |
|------------------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|
| | Current Potential | Current Potential | Current Potential | Current Potential | Current Potential | Current Potential | Current Potential | Current Potential | Current Potential | Current Potential |
| Availability of moisture (m) | S2 S1 | S2 S1 | S3 S2 | S2 S1 | S2 S1 | S2 S1 | S1 S1 | S1 S1 | S3 S3 | S1 |
| Fertility (f) | S3 S2 | S3 S1 | S3 S2 | N2 N1 | N1 S3 | N1 S3 | S1 S2 | S1 S2 | S3 S2 | S1 S1 |
| Oxygen (o) | S3 S2 | S3 S2 | S2 S1 | S2 S1 | S2 S1 | S2 S1 | S3 S2 | S3 S2 | S2 S1 | N2 S2 |
| Root development (c) | S3 S2 | N1 S3 | N1 S3 | S2 S1 | S3 S2 | N1 S1 | S2 S1 | S2 S1 | N2 N1 | S2 S1 |
| Flooding (d) | S2 S1 | S2 S1 | S2 S1 | S2 S1 | S2 S1 | S2 S1 | S2 S1 | S2 S1 | S2 S1 | N2 S2 |
| Surface stones (s) | S2 S1 | S2 S1 | N1 S3 | S2 S1 | S3 S2 | N1 S3 | S2 S1 | S2 S1 | N2 N1 | S1 |
| Workability (w) | S2 S1 | S2 S1 | S3 S2 | S3 S2 | S3 S2 | S2 S1 | S3 S2 | S3 S2 | S3 S2 | N2 S2 |
| Erosion (e) | S2 S1 | S3 S2 | N1 S3 | S1 | S3 S2 | S3 S2 | S2 S1 | S3 S2 | N1 S3 | S1 |
| Overall rating | S3ro-3 | N1r-1 | N1ra-3 | N2r-3 | N1r-2 | N1rs-2 | S3ou-2 | S3ou-1 | N2rs-4 | N2od-4 |

Note: From the table above, it is only mapping units 11, 41 and 42 that are marginally suitable for the growth of cotton. The rest of the area is either currently not suitable or permanently not suitable.

Table 76: Summary and Final Suitability Rating for Citrus in all soil mapping units

| Land quality | 11 | 12 | 22 | 32 | 33 | 31 | 41 | 42 | 52 | 60 |
|-----------------------------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| Availability of moisture(m) | S2 S1 | S2 S1 | S3 S2 | S2 S1 | S2 S1 | S3 S2 | S1 S1 | S1 S1 | S3 S2 | S1 S1 |
| Fertility (f) | S2 S1 | S2 S1 | S2 S1 | N1 S3 | S3 S2 | S3 S2 | S2 S1 | S2 S1 | S2 S1 | S1 S1 |
| Oxygen (o) | S3 S2 | S3 S2 | S2 S1 | S2 S1 | S2 S1 | S2 S1 | S3 S2 | S3 S2 | S2 S1 | N2 S2 |
| Root (r) | S3 S2 | N1 S3 | N1 S3 | S2 S1 | S3 S2 | N1 S3 | S2 S1 | S2 S1 | N2 N1 | S2 S1 |
| Development | S2 S1 | S2 S1 | S2 S1 | S2 S1 | S2 S1 | S2 S1 | S3 S2 | S2 S1 | S2 S1 | N2 S2 |
| Flooding (d) | S1 | S1 | S3 S2 | S1 S2 | S2 S1 | S3 S2 | S1 S1 | S1 S1 | N1 S3 | S1 S1 |
| Surface stones (s) | S1 | S1 | S3 S2 | S1 S2 | S2 S1 | S3 S2 | S1 S1 | S1 S1 | N1 S3 | S1 S1 |
| Workability (w) | S2 S1 | S2 S1 | S3 S2 | S3 S2 | S3 S2 | S2 S1 | S3 S2 | S3 S2 | S3 S2 | N2 S2 |
| Erosion (e) | S2 S1 | S3 S2 | N1 S3 | S1 S3 | S3 S2 | S3 S1 | S2 S1 | S3 S2 | N1 S1 | S1 S1 |
| Overall rating | S30-3 | N1r-2 | N1r-3 | N1r-3 | S3rf-3 | N1r-3 | S3od-2 | S3ou-1 | N2rs-4 | N2od-4 |

Note: Table 76 shows that mapping units 11, 41, 42, are marginally suitable to citrus production, while the rest are either currently unsuitable or permanently unsuitable.

Table 771

SUMMARY AND FINAL SUITABILITY RATINGS FOR TOMATO IN ALL SOIL MAPPING UNITS

| Land Quality | 11 | 12 | 22 | 32 | 33 | 31 | 41 | 42 | 52 | 60 |
|-----------------------------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| Availability of moisture(m) | S2 S1 | S2 S1 | S3 S2 | S2 S1 | S2 S1 | S2 S1 | S2 S1 | S2 S1 | S2 S1 | S1 S1 |
| Fertility(f) | S2 S1 | S2 S1 | S2 S1 | N1 S3 | S3 S2 | S3 S2 | S2 S1 | S2 S1 | S2 S1 | S1 S1 |
| Oxygen (o) | S2 S1 | S3 S1 | S3 S1 | S1 S1 | S2 S1 | S3 S2 | S2 S1 | S2 S1 | S1 - | S1 - |
| Root (r) Development | S2 S1 | S3 S2 | S3 S2 | S1 S2 | S2 S1 | N1 S1 | S1 S1 | S1 S1 | N1 S2 | N2 S2 |
| Flooding (d) | S2 S1 | S2 S1 | S2 S1 | S2 S1 | S2 S1 | S2 S1 | S3 S2 | S2 S1 | S2 S1 | N2 S2 |
| Surface stones (s) | S2 S1 | S2 S1 | N1 S3 | S2 S1 | S3 S2 | N1 S1 | S2 S1 | S2 S1 | N2 - | S2 S1 |
| Workability (w) | S2 S1 | S2 S1 | S3 S2 | S3 S2 | S3 S2 | S2 S1 | S3 S2 | S3 S2 | S3 S2 | N2 S2 |
| Erosion (e) | S2 S1 | S3 S2 | N1 S3 | S1 S3 | S3 S2 | S3 S1 | S3 S1 | S2 S2 | N1 S1 | S1 S1 |
| Overall rating | S2m-1 | S3r-2 | N1se-3 | N1r-3 | S3f-2 | N1rs-3 | S3du-2 | S3u-2 | N2sr-4 | N2or-4 |

Note: Mapping unit 11 is moderately suitable, mapping unit 12, 41, 42, 33 are marginally suitable, while mapping units 22, 32, 31, 52, 60 are either currently unsuitable or permanently unsuitable for tomato.

Table 70: SUMMARY AND FINAL SUITABILITY RATINGS FOR HAIZE IN ALL SOIL MAPPING UNITS

| Land quality | 11 | 12 | 22 | 32 | 33 | 31 | 41 | 42 | 52 | 60 |
|------------------------------|-----------|-----------|-----------|-----------|-----------|---------|-----------|-----------|---------|---------|
| Availability | Current | Current | Current | Current | Current | Current | Current | Current | Current | Current |
| | Potential | Potential | Potential | Potential | Potential | | Potential | Potential | | |
| Availability of moisture (m) | S3-2 | S3-2 | N1-S3 | S2-S1 | S3-S2 | S2 | S2-S1 | S2-S1 | N1-S1 | S2 |
| | S3-2 | S3-2 | N1-S3 | S2-S1 | S3-S2 | S2 | S2-S1 | S2-S1 | N1-S1 | S2 |
| Fertility (r) | S3-S1 | S3-S1 | S3-S1 | N2-S3 | N1-S2 | N1 | S2-S1 | S2-S1 | S2-S1 | S1 |
| | S3-S1 | S3-S1 | S3-S1 | N2-S3 | N1-S2 | N1 | S2-S1 | S2-S1 | S2-S1 | S1 |
| Oxygen (o) | S2-S1 | S2-S1 | S2-S1 | S2-S1 | S2-S1 | S2 | S3-S2 | S3-S2 | S2-S2 | N2 |
| | S2-S1 | S2-S1 | S2-S1 | S2-S1 | S2-S1 | S2 | S3-S2 | S3-S2 | S2-S2 | N2 |
| Root (r) | S3-S2 | N1-S3 | N1-S3 | S2-S1 | S3-S2 | N1 | S2-S1 | S2-S1 | N2-S1 | S2 |
| | S3-S2 | N1-S3 | N1-S3 | S2-S1 | S3-S2 | N1 | S2-S1 | S2-S1 | N2-S1 | S2 |
| Development | S2-S1 | S2-S1 | S2-S1 | S2-S1 | S2-S1 | N1 | S3-S2 | S2-S1 | S2-S1 | N2 |
| | S2-S1 | S2-S1 | S2-S1 | S2-S1 | S2-S1 | N1 | S3-S2 | S2-S1 | S2-S1 | N2 |
| Flooding (d) | S2-S1 | S2-S1 | S2-S1 | S2-S1 | S2-S1 | N1 | S3-S2 | S2-S1 | S2-S1 | N2 |
| | S2-S1 | S2-S1 | S2-S1 | S2-S1 | S2-S1 | N1 | S3-S2 | S2-S1 | S2-S1 | N2 |
| Surface Stones (a) | S2-S1 | S2-S1 | N1-S3 | S2-S1 | S3-S2 | N1 | S2-S1 | S2-S1 | N2-S1 | S2 |
| | S2-S1 | S2-S1 | N1-S3 | S2-S1 | S3-S2 | N1 | S2-S1 | S2-S1 | N2-S1 | S2 |
| Workability (w) | S2-S1 | S2-S1 | S3-S3 | S3-S1 | S3-S2 | S2 | S3-S2 | S3-S2 | S3-S2 | N2 |
| | S2-S1 | S2-S1 | S3-S3 | S3-S1 | S3-S2 | S2 | S3-S2 | S3-S2 | S3-S2 | N2 |
| Erosion (e) | S2-S1 | S3-S1 | N1-S2 | S1-S2 | S3-S2 | S3 | S2-S2 | S3-S2 | N1-S1 | S1 |
| | S2-S1 | S3-S1 | N1-S2 | S1-S2 | S3-S2 | S3 | S2-S2 | S3-S2 | N1-S1 | S1 |
| Overall rating | S3a-1 | N1r-3 | N1m-3 | N2f-4 | N1f-3 | N1rs-3 | S3do-2 | S3do-1 | N2rs-4 | N2ard-4 |
| | S3a-1 | N1r-3 | N1m-3 | N2f-4 | N1f-3 | N1rs-3 | S3do-2 | S3do-1 | N2rs-4 | N2ard-4 |

Note: Mapping units 11, 41, 42 are marginally suitable. The rest of the units are either currently or permanently unsuitable.

| Land quality | 11 | 12 | 22 | 32 | 33 | 31 | 41 | 42 | 52 | 60 |
|-----------------|-------|-------|--------|-------|-------|--------|--------|--------|--------|---------|
| Availability | S3 | S3 | N1 | S2 | S3 | S3 | S2 | S2 | N1 | S1 |
| of moisture(m) | S2 | S2 | S3 | S1 | S2 | | S1 | S1 | | |
| Fertility (f) | S3 | S3 | S3 | N2 | N1 | N1 | S3 | S3 | S3 | S1 |
| | S1 | S1 | S1 | S3 | S2 | | S1 | S1 | | |
| Oxygen (o) | S2 | S2 | S2 | S2 | S2 | S2 | S3 | S2 | S2 | N2 |
| | S1 | S1 | S1 | S1 | S1 | | S2 | S2 | | S2 |
| Root (r) | S2 | S3 | S3 | S1 | S2 | N1 | S2 | S2 | N2 | N2 |
| Development | S1 | S2 | S2 | S2 | S1 | | | | | S2 |
| Flooding (d) | S2 | S2 | S2 | S2 | S2 | S2 | S3 | S2 | S2 | N2 |
| | S1 | S1 | S1 | S1 | S1 | | | | | S2 |
| Surface stones | S1 | S1 | S3 | S1 | S2 | N1 | S1 | S1 | N2 | S1 |
| (s) | S1 | S1 | S2 | S1 | S1 | | S1 | S1 | | S1 |
| Workability (w) | S2 | S2 | S3 | S3 | S3 | S2 | S2 | S2 | S3 | N2 |
| | S1 | S1 | S2 | S2 | S2 | | | | | |
| Erosion (e) | S2 | S3 | N1 | S1 | S3 | S3 | S2 | S3 | N1 | S1 |
| | S1 | S2 | S3 | S3 | S2 | | | | | |
| Overall rating | S3m-1 | S3m-1 | N1me-3 | N2f-3 | N1f-2 | N1ra-3 | S3df-2 | S3fo-2 | N2rs-4 | N2ord-4 |

Note: Mapping units 11, 12, 41, 42 are marginally suitable, while the rest are either currently or permanently unsuitable.

Table 801 SUMMARY AND FINAL SUITABILITY RATINGS FOR GROUNDWATS IN ALL SOIL MAPPING UNITS.

| Land quality | 11 | 12 | 22 | 32 | 33 | 34 | 41 | 42 | 52 | 60 |
|------------------------------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| Availability of moisture (m) | S2 S1 | S2 S1 | S3 S2 | S1 | S2 S1 | S2 S1 | S2 S1 | S1 | S3 S2 | S1 |
| Fertility (f) | S2 S1 | S2 S1 | S2 S1 | N1 S3 | S3 S2 | S3 | S2 S1 | S2 S1 | S2 S1 | S1 |
| Oxygen (o) | S2 S1 | S2 S1 | S2 S1 | S2 S1 | S2 S1 | S2 | S3 S2 | S3 S2 | S2 S1 | N2 S2 |
| Root development (r) | S2 S1 | S3 S2 | S3 S2 | S1 S2 | S2 S1 | N1 | S1 | S1 | N1 N1 | S1 |
| Flooding (d) | S2 S1 | S2 S1 | S2 S1 | S2 S1 | S2 S1 | S2 | S3 S2 | S2 S1 | S2 S2 | N2 S2 |
| Surface stones (u) | S1 | S2 | S3 | S1 | S2 S2 | N1 N1 | S1 | S1 | N1 N1 | S1 |
| Workability (s) | S2 S1 | S2 S1 | S3 S2 | S3 S2 | S3 S2 | S3 | S3 S2 | S3 S2 | S3 S2 | N2 S2 |
| Erosion (e) | S2 S1 | S3 S2 | N1 S3 | S1 | S3 S2 | S3 | S2 S1 | S3 S2 | N1 S1 | S1 |
| Overall rating | S2m-1 | S3r-1 | S3r-2 | N1r-3 | S3r-1 | N1rs-3 | S3o-2 | S3o-1 | N1rs-4 | N2o-4 |

Note: Mapping unit 11, 15 moderately suitable.
 Mapping units 12, 22, 33, 41, 42 are marginally suitable.
 The rest are either currently unsuitable or permanently unsuitable.

5.1 Management levels and their effect on the final suitability class:

Three management levels were discussed in paragraph 3.3. These form the framework under which the land utilisation types are defined. The differences between the three management levels are related to technology, labour, capital, farm sizes, infrastructure and income levels (table 3).

The traditional management level has the lowest inputs of the differentiating attributes. The commercial management level has the highest input and is the most modern. The intermediate management level has intermediate input and sophistication in relation to that of the traditional and commercial levels.

The effect of the management depends on how the farmers can manipulate the land qualities to their advantage, for example an area with about 50% rock-out crop is of very little interest to the commercial farmers because their farming system is highly mechanised so that tractors, ploughs and harvesters can hardly be used. On the other hand the traditional farmer can still use the land since he can plough in between the rock outcrops using a hand hoe. Since the final suitability in this study is function of the most limiting land quality, the effect of management on suitability will be dealt with by looking at how each management level affects the most limiting land quality in each mapping unit.

This section will take into account the possibilities of minor land improvement by a management level which may lead to a higher suitability rating.

Oxygen availability:

Traditional: As this has to do with poor drainage conditions, the traditional farmer can improve the suitability of the land by draining the land on which the crops will be grown. This is done by making ridges and planting on top of the ridges. This can improve the suitability of the land by one class.

Intermediate: The remedy for the improvement of the land can be achieved by planting on ridges but also by constructing simple drainage canals using hired labour. This can improve the land by at least one class.

Commercial: The construction of a good drainage system which the farmers can afford can raise the suitability of the land to the maximum.

Root development: Traditional and Intermediate: at these two levels of management impediment to root development is a big problem. The local farmers usually get around it by building ridges and planting on top of them this may not really improve the suitability class but may improve the yield to some extent.

Commercial: The commercial farmer may improve the suitability of the land by using deep tillage methods in case where the impediment layer is a clay layer but not when it is hard rock.

Flooding:

Traditional Intermediate and Commercial: At these three levels, flooding if controlled and channeled can be of great benefit. The farmer can improve the suitability of his land by more than a class including his moisture requirements.

Surface stones:

Traditional: Unless the percentage of surface stones is greater than 80% it does not pose a hinderance to cultivation for the traditional farmer as long as the soil is deep enough for crops to grow. Land with less than 30% surface rocks is well suited at traditional management level.

Intermediate and Commercial: At these two levels of management the occurrence of surface stones is a great hazard and hinderance to cultivation. The stones may damage implements and may break the legs of animals used for power traction. However, suitability class improvement are possible when stone picking machines are used especially at commercial level.

Workability:

Traditional: Since the traditional farmer does not use heavy instrument or animal power, workability as defined in this thesis does not pose a problem.

Intermediate and Commercial: When workability is the most limiting land quality the farmers at these two levels of management are greatly affected. Land can however be improved by keeping the moisture level in the soil at levels at which workability is greatly improved. This can be done by good drainage practices. The farmers can also avoid the workability limitation by working the soil only when its not too dry or too wet.

Erosion:

Traditional: Water erosion has not been found to greatly affect the traditional farmers in the area. This is mainly because they do not disturb the soil so much and their fields are too small to encourage running water to cause extensive damage. For erosion limitation that is not severe, the limitation should be waived at traditional management level.

Intermediate and Commercial: Erosion is a big problem for medium and large scale farmers such as those described in these management levels. The conservation and Extension department (conex 1963) made their land capability for agricultural

production in the medium and large scale farming area with emphasis on erosion control. The sizes of the farms and the tillage practices encourage soil erosion at these two management levels. Using soil erosion control measures, such as contouring, land suitability can be restored to its maximum.

Crop performance on two major mapping units (11, 41):

Experiments were carried out to observe performance of two maize varieties (Traditional variety i.e. Gaankata, and hybrid variety i.e. SR 52) at two management levels to augment the suitability ratings arrived at for each mapping unit in this land evaluation exercise.

The original intention was to make a statistical comparison between management levels and between the performance of the two varieties. Poor germination due to a very dry rain season did not allow this. Observations were however made on the performance of the crops that germinated (50%) in relation to the land qualities availability of moisture, availability of oxygen, and fertility. The observations results and discussions are done according to mapping 11 and 41, respectively.

Mapping unit 11:

Observation:

- All the seeds had a poor germination percentage
- All the crops on this mapping unit suffered moisture stress regardless of the management level.

- Both the hybrid and the local variety did not suffer from N deficiency when there was too much water as a result of heavy down pours.
- Water was observed to be restricted in movement at 80 cm.
- Yield was poor in the experimental plots (5 (90kg bags) per ha) and in the surrounding fields of local farmers (4 (90 kg bags per ha)).

From the observations made in the experimental plots, the most limiting land quality in mapping unit 11 is moisture availability although oxygen availability and restriction to root development become important at 82 cms where a heavy clay layer restricts water movement. The poor yields in the experimental plots and the surrounding local farmers fields are an indication that production heavily relies on rainfall in this mapping unit. Interviews with local farmers show that in times of good rainfall the average yield is 18 bags (90 kg bags per ha). The results of the experiment fully support the suitability rating arrived at in the land evaluation exercise in which moisture availability, root development and oxygen availability are the most limiting land qualities respectively.

Mapping unit 41:

Observation:

- The crops did not suffer from moisture stress
- All seed varieties had a poor germination percentage (50%)

- Both the hybrid and local variety suffered from N deficiency during flooding caused by heavy rains.
- Trafficability to the experimental plots was very difficult.
- The yields were poor in experiment plots (4 bags per ha in the traditional managed level and 6 bags per ha in the improved managed level).
- Surrounding farmers fields had 5 bags per ha.

According to the experiment, moisture availability is not a limiting land quality, however the flooding, oxygen availability and workability (trafficability) land qualities are the most limiting. In times of good rains flooding is a hazard as it restricts oxygen and Nitrogen availability in the soil. During periods of dry spells the soil does not suffer from lack of moisture. The results of the experiments agree with the suitability ratings arrived at in the land evaluation exercise.

Socio-economic survey of the Kapini area:

Introduction:

The survey was carried out with the aid of a questionnaire and a total of 200 people were interviewed.

Human resources:

Under this heading is discussed:

- Language and communication
- Tendency towards urbanisation (modernisation)
- Level of education
- Occupation (interest in agriculture)

Language and communication:

The population of Kapini is composed mainly of people from the Tonga language group whose dominant sub grouping in the area is Lenje. The Soli people live in the neighbouring chieftain-ships.

The people of Kapini can converse fluently in Tonga, Ila and 'town' Nyanja. 'Town' Nyanja is the Lingua Franca which is used in the city of Lusaka which lies some 15-25 km from the study area. 'Town' Nyanja is different from the true Nyanja that is spoken in the Eastern Province of Zambia in that it includes many words from English and other local languages such as Tonga, Lozi, and Bemba. The people of Kapini only use 'town' Nyanja for the purpose of communication with strangers and not in their homes. This shows that the people in the area of survey are ethnic - conscious. It is derogatory for one to abandon his own language in his own home. Children are rebuked against using 'town' Nyanja at home. 80% of those interviewed can speak and understand English, 20% can speak, understand and write English, while 30% cannot speak, understand or write English.

Tendency towards urbanisation (modernisation):

The most important indicators of urbanisation are language, dress, occupation, family size and contact with new industrial ideas.

The fact that most people can speak, write, and understand English is a good indication of a tendency towards urbanisation of the Kapini people. Some old people who can not write English but are able to speak and understand English have either been working in the city or on big colonial farms which were owned by Europeans. Most young people have learned the English language at School within the area of study at Schools in the city.

Dressing shows that the people of Kapini are moving away from the traditional dress to the modern dress used in the towns although the dresses (used by old men and women) are often extremely out-dated in the city. These clothes are cheap in town and are compatible with the pockets of the Kapini people.

Most people in Kapini are self employed. They are mostly subsistence farmers (60%), some are semi commercial farmers (30%), while some are commercial farmers (2%). About 8% of the people in Kapini are employed on large farms, at Kapini human development centre or in town. Many people are moving into wage employment in the city industries as the income is more reliable.

Being only some 15-25 km from Lusaka the people of Kapini are always in contact with city people and new industrial ideas. The Kapini human development project which is situated within the study area is intended to bring these new ideas to the people.

The extended family is only recognised by elderly people in the area. Most young people support only a nuclear family. The emergency of advanced modes of production are slowly killing the extended family system.

Level of education:

A good level of education is extremely important factor in production as it determines the way people are going to understand new technology and production economics... 30% of the people interviewed had no education while 70% have some form of education. Table 81 shows the levels of education of the people of Kapini interviewed.

Table 81: Educational level of Kapini residents:

| Educational level | Respondents | |
|--|-------------|------|
| | Number | % |
| No education | 60 | 30% |
| Lower primary (grades 1-4 ¹) | 52 | 26% |
| Upper Primary (grades 5-7 ²) | 68 | 34% |
| Lower Secondary (grades 8-10) | 16 | 8% |
| Upper Secondary (grades 11-12) | 4 | 2% |
| Technical or higher | 0 | 0% |
| Total | 200 | 100% |

1 = Standard 2

2 = Standard 6

The social infrastructure:

Under this heading are discussed the following items:

- Social - political organisation
- Public utilities and services.

Social - political organisation:

The social - political organisation in the Kapini area is controlled by both the traditional rulers and the United National Independence Party (UNIP). The area of study falls under chief Mungule and under several headmen, the most important of which is headman Kapini. Both the chief and the headman are members of UNIP and work under its guidelines with the help of the elected members of parliament. The people of Kapini are very political conscious and look up to UNIP to help them in solving the several economic and social problems that they have. Apart from UNIP and the traditional rulers social organisation is also being organised on self-help basis by the people of Kapini through the Kapini human development project.

Public utilities and services:

There is a very low provision of public services in the study area. The following are discussed under this heading:-

- Health
- education
- water
- transport

Health:

There is one clinic within the study area. The clinic is located at chief Mungule's local court, although most of the people are within the 12 km radius taken by the National Commission for Development planning as reasonable distance to health centre, the centre:-

- does not have a doctor
- it does not have facilities for keeping very ill patients
- it helps only with very small cases
- the staff consists of only a medical assistant and a helper

Hence the nearest health centre that is of help to the people is in Lusaka some 15-25 km or more away.

The human development project at Kapini having noticed this poor medical situation in the area, invited the trainee nurses and medical assistants to come out to Kapini to hold mobile clinic activities once every week. However, most people are not aware of this.

Education:

The education situation is much better than the health situation. There are 6 primary schools in the study area teaching up to the 7th grade. The school children have still to walk some 6 - 10 km to get to the nearest school. There is also one social welfare centre at Kapini but most people are not aware of it.

Water:

Water is drawn from bore holes or water wells. There is no piped water and people have to walk some 3 km distances to get to the nearest central well. Although the water in the wells is good ground water small animals, paper and sticks may fall in them as several of them are usually not covered. This may make the water a health hazard.

Transport and roads:

There is only one good road that passes through the study area from the main Kabwe - Lusaka road to chief Mungule's local courts. This road is not well looked after. During the rainy season it may become very poor and impassable. Accessibility can be greatly improved if the several small roads that criss-cross the study area are maintained.

A few buses are provided for people living in the study area. One bus to chief Mungule and one bus to Katuba. These busses are reported to have broken down a very long time ago and the author did not see any bus in the area during the six months of intensive work.

The local people mostly use private (pirate) transport (unauthorised carriers) to get around or they walk.

Table 82: Awareness of services provided in the study area:

| Services provided | People aware | |
|-------------------|--------------|------|
| | Number | % |
| Clinic | 200 | 100% |
| Mobile clinic | 80 | 40% |
| Road improvement | 20 | 10% |
| Public transport | 0 | 0% |
| Welfare centre | 80 | 40% |
| Spraying | 10 | 5% |
| Water treatment | 1 | 0.5% |

The above table shows that most of the people in the survey area are not aware that the services listed above are provided. Most people are, however, aware of the clinic services although they complain of distance and poor services. All the people are not aware that public transport in form of buses are provided for transport in the area these days. The table below gives an indication of the social services that the people in Kapini would like to see provided.

Table 83: Services that Kapini people desire:

| Service desired | People wishes | |
|----------------------------|---------------|------|
| | Number | % |
| School | 100 | 50% |
| Clinic | 200 | 100% |
| Buses | 200 | 100% |
| Better road (maintainance) | 200 | 100% |
| Treatment of water | 80 | 40% |
| Spraying | 120 | 60% |

The most popular services that the people demand (for) in the Kapini area are clinics, buses and better roads.

Capital and economic resources:

In this section is discussed the following ~~items~~:

- The description of the most important enterprises in the study area and their pattern.
- The enterprise calendar
- Labour availability and labour requirement for the important enterprises.
- Capital and land tenure.

Enterprise pattern:

- The most important crops in the area of study are Maize, groundnuts, fruits, tomato and cotton. Many other crops may be more important among some people but this study has limited the important crops to selected subsistence and commercial crops.
- Animal husbandry is an important enterprise in the area. All the farmers interviewed (20) had cattle, some had pigs and all had chicken.
- Maize is the only crop that is grown widely and on large areas.

Description of individual important enterprises:

SR 52 hybrid (maize) is quickly being adopted as the main variety although some farmers still use local varieties (i.e. Gaankata). Other varieties that have been used are:- Pioneer 95 an early (shorter) maturing variety. Its disadvantages is however that it may rot when the rains are prolonged. ZH1 has also been used but it is not as popular as SR 52.

Local varieties are used for 'Nshima' (hard porridge) and beer. The local variety named Gaankata owes its name to a local beer called Gaankata and it is used for brewing this beer.

Hybrid maize is sold to the National Agricultural Marketing Board (NAMBOARD) although it is quickly replacing local varieties as a source of 'Nshima' (hard porridge).

The maize stover is used as cattle or animal feed in the dry season. This is the most profitable enterprise.

Groundnuts are mainly used for home consumption while the surplus is sold locally.

Cotton is a cash crop which is grown by few farmers although it is quickly becoming popular among the local farmers. High labour requirements are used during harvesting.

Every farmer has fruits in his back yard. Non of these fruits are grown in what may be termed a field by normal standards. The fruits are used for local consumption or are sold.

Cattle are mainly used for draught power. Some farmers use cattle manure in their fields. Cattle are a social status symbol and are not sold anyhow unless; when they are ill, old or when their is need for money in the family. Farmers milk their cattle but do not sell the milk. Time of calving is between November and March.

Table 84: Enterprise calender:

| | |
|------------|---|
| October: | The enterprise calender for some farmers begins in October with land preparation. |
| November: | Most farmers begin land preparation with first rains and plant the seed. |
| December: | Main month for planting of maize, sunflower, cotton and sorghum and many other crops. |
| January: | End of planting of crops. Weeding of most crop begins. |
| February: | Ending of weeding. |
| March: | Intermediate farmers do winter ploughing. |
| April: | Beginning of harvesting e.g. the early maturing varieties. |
| May: | Harvesting continuous. |
| June: | Harvesting of maize, sunflower, cotton, sorghum and millet continues. |
| July: | Shelling of maize. |
| September: | Selling of produce. |

Labour:

Labour for work in the field is drawn from the household or family. The family size is 3 - 10 with usually 2 - 3 adults and the rest children.

Farm activities are carried out equally by both men and women although division of labour is a common feature. There is usually a labour deficit during weeding, planting and harvesting. During these periods casual labour is hired. Most of the, unskilled, labour is used in activities such as land preparation. In case of large fields, land preparation activities are done using oxen and ox drawn implements. Hiring of farm implements and oxen is not very common but some of the farmers interviewed hire these. Sometimes tractors are hired for ploughing. The Kapini human development project has special tractor hire services for land preparations. Some members of the family work permanently in Lusaka to earn some money for the family and only to work on the farm at peak labour periods or at week-ends. Some members of same families have migrated to Lusaka for good. This leaves people who are either too young or too old to carry out the heavy agricultural tasks.

Calculation of available labour:

- The average family size consists of 6 people with the following break down.
- The farmer = 20 mandays-month.

- The farmers' wife - 20 mandays-month
- 2 children over 16 years 20 x 2 mandays-month
- 2 children under 16 years 10 x 2 mandays-month
- The mandays are then summed to give 100 mandays per month available labour and 1200 mandays available labour per year (table 85).

Table 85: Available labour: (man/days).

| Month | 2 ha Maize | 1 ha Cotton | 1 ha Fruits | $\frac{1}{2}$ ha Tomato | Total | Available labour | Labour req. in excess of 100 |
|--------------|---------------|----------------|----------------|----------------------------|-------------|---------------------|---------------------------------------|
| October | 0 | 0 | 0 | 16 | 16 | 100 | - |
| November | 100 | 50 | 0 | 16 | 166 | 100 | 66 |
| December | 0 | 0 | 33 | 16 | 49 | 100 | - |
| January | 200 | 0 | 33 | 16 | 249 | 100 | 149 |
| February | 66 | 33 | 33 | 16 | 148 | 100 | 48 |
| March | 100 | 0 | 0 | 16 | 116 | 100 | 16 |
| April | 0 | 0 | 0 | 16 | 16 | 100 | - |
| May | 133 | 0 | 0 | 16 | 149 | 100 | 49 |
| June | 66 | 66 | - | 16 | 148 | 100 | 48 |
| July | 0 | 0 | 0 | 16 | 16 | 100 | - |
| August | 0 | 0 | 0 | 16 | 16 | 100 | - |
| September | 0 | 0 | 0 | 16 | 16 | 100 | - |
| Total | 731 | 149 | 99 | 192 | 1171 | 1200 | |

The average labour requirement for the average intermediate farmer in the area is 1171 mandays per year (Table 85). This is not in excess of the average available labour which is 1200 mandays per year. The farmers have however to hire casual labour during the year. In January during weeding and in May during harvesting the labour requirements of the farmers is in excess of the available labour for the maize enterprises. It is at peak level in November during land

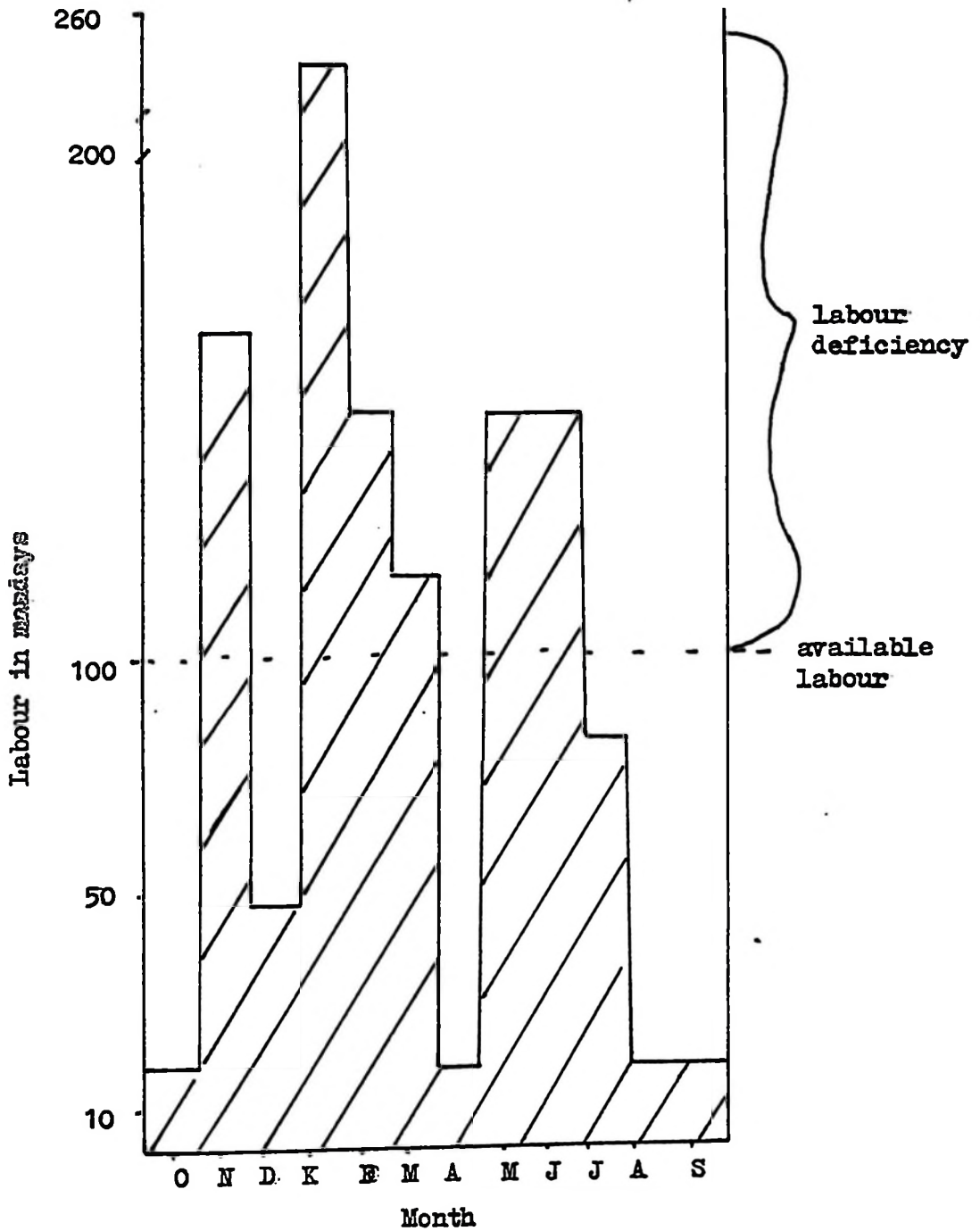
preparations for winter ploughing. In the cotton enterprise labour requirements hit peak level and June during harvesting, but are never in excess. The fruits and tomato enterprises require the least labour followed by cotton, tomato and citrus in that order. A visual impression of total labour requirements is given in the histogram (Fig. 6).

In conclusion it may be said that there is no real labour shortage in the area of study except for the peak periods when the farmer hires a few boys to harvest or weed the field. The reduction of labour requirement through the use of weeding and harvesting implements could be investigated.

Capital:

A common feature in subsistence farming in the Kapini area is a shortage of capital. This is shown in Table 87, where the gross margin for the maize enterprise is calculated.

Fig. 6: Histogram showing total labour, . available labour



N.B. According to the histogram there is labour deficiency in November, January, February, March, May, June, July.

Table 87: Calculation of gross margin for the maize enterprise:

| Revenue | Kwacha - ha ¹ |
|--|--------------------------|
| Maize 1800kg/ha @ 18.30 per 90 kg bag | K 366.00 |
| <u>Cost</u> | |
| Labour - 133 ² hired mandays per year | 133.00 |
| @: K20 per 20 mandays hired | |
| Fertiliser - 200 kg ha ammonia Nitrate | 60.00 |
| @: K14.95 per 50 kg bag | |
| - 200 kg D* compound @ | 60.00 |
| K 14.95 per 50 kg bag | |
| Seeds - 25 kg bag @ K 52 per 50 kg bag | 26.00 |
| Trans. of harvest - 3 loads @ K 3 per load | 9.00 |
| (7, 90 kg bags). | |
| Empty bags - (20 bags @ 50n each) | 10.00 |
| Total costs | 298.00 |
| Gross margin | 68.00 |

¹ Figures are rounded to the nearest Kwacha

² Calculated from the table showing labour requirements

* NPK ratio 10:20:10

The gross margin assumes that the farmer will sell all his produce. This is in fact not true as the intermediate farmer will often use some of his produce for home consumption. As maize may not be very profitable, it would be much better to grow more profitable crops or grow more maize.

The sources of income are very varied among the farming community of the Kapini area. Sales of farm produce such as crops and livestock are the major sources of funds. However others get income from sales of beer, charcoal and vegetables, while others have part time employment in Lusaka (table 88).

Table 88: Showing generalised sources of revenue of the people in Kapini (cash income sources, % people receiving from that source):

| Amount per month | Maize | G/ruits | Cotton | Fruits Veg. | Cattle | Char-coal | Beer |
|------------------|-------|---------|--------|-------------|--------|-----------|------|
| Less than K 10 | - | - | - | - | - | - | - |
| K 10-30 | - | 40% | - | - | - | - | - |
| K 30-49 | - | - | - | - | - | - | - |
| K 50-100 | 30% | - | - | 80% | - | 10% | 40% |
| K 100-500 | 10% | 10% | 5% | - | - | - | - |
| More than K 500 | 10% | - | - | 10% | 20% | - | - |

The tables show that most people derive their income from sales of vegetables and citrus especially tomatoes, oranges, bananas and mango which are sold by the tar road on the main Lusaka - Kabwe road. Groundnuts and Beer enterprises are all a very good source of income for the people. Most people earning above K 500 in the mentioned enterprises are commercial farmers. The people in Kapini have also indicated that it has been very difficult for them to get loans from credit organisations such as A.F.C. (Agricultural Finance Co.) or Commercial banks. Some of the farmers have indicated having received some small loans from AFC (the amounts of which were not specified) but that these loans were not given at the time when the farmers needed them e.g. during land preparation and during the buying of seed and fertiliser. Most of the loans were hence sometimes misdirected and hence misused.

In conclusion, it may be said that capital is more limiting than labour but that capital problems can easily be solved than labour problems. Capital problems can be overcome by growing crops with good profits. The growing of cash crops is in general not favourable to the small scale farmers because they do not have surplus labour and capital to run cash crop enterprises. However, for large scale farmers who have surplus labour, the growing of cash crops is very favourable. In land evaluation, the effect of such observations is that it lowers the suitability of cash crops at subsistence and intermediate farmer management level and increases the suitability of food crops. The opposite will be true for commercial farmer.

Technology:

The capital goods used in production in the area are often very simple. The subsistence farmers mainly uses the hoe, axe and sometimes oxen and ox-drawn implement. The intermediate farmer uses ox-drawn implements such as ploughs, carts and sledges. Low technology and low income levels among these two types of farmers dictates low capital investments and low capital returns.

Land:

Land is not a scarce resource in the area of study. It is expected that land may become a problems especially for small farmers as the city of Lusaka expands. The rural-urban fringe problem are already showing up.

The social economics of the area greatly affect the land evaluation results that have been out-lined in the chapter on (physical) land evaluation; for example the study area should be down graded in as far as the growing of cash crops is concerned for farmers with low labour, capital and technology input, while this is other wise for high labour, capital and technology input farmers. On the other hand, the people of Kapini are not resistant to new innovation. Acceptance of new innovation is extremely important in agriculture as this can improve production through the use of new technology. The social and political organisation in the area is in firm control:

and there is no much quarrelling among the people. UNIP and the chief see to it that the people are well represented and may air their complaints freely. Political tranquillity creates a good environment for production.

The parrallel approach (FAO 1976), would best illustrate the effect of social economics on land evaluation. The author, however, realises that these social economic short comings may become quickly out dated by price changes and hence greatly effect the results of a parrallel approach. For this reason, in this study, the evaluation is carried out at two different levels. By incorporating a social economic analyses, the study intends to show the economic viability of land use in the area without necessarily combining the two parts.

CONCLUSION

1. Soil mapping in Kapini has shown that at semi-detailed studies a free survey is highly suitable in an area in which geology, drainage, topography and other environment factors are well defined. However, for this kind of survey, highly reliable, that is high quality and up to date, aerial photographs are to be used.

2. Classification according to Soil Taxonomy (soil survey staff, 1975) and FAO-UNESCO legend (FAO-UNESCO, 1974) did not always directly correspond. This means that the systems are not easily translated into each other. For example, in mapping unit 33 the soils are classified as Paleustalfs (Soil Survey Staff, 1975) and as Luvisols (FAO-UNESCO, 1974). Paleustalfs and Luvisols are normally exclusive. Paleustalfs are more likely to correspond to Nitosols. It would seem that the problem, however, is that Ferric properties are not allowed in Nitosols (FAO-UNESCO, 1974). If Ferric properties could be allowed in Nitosols, a Ferric Nitosol could have been more appropriate for the soils of mapping unit 33. In mapping unit 41, Gleyic Luvisol (FAO-UNESCO, 1974) and oxic Haplustalf (Soil Survey Staff, 1975) look very unrelated to each other. The problem of correlation lies in the definition of diagnostic properties (in this case, the hydromorphic properties, in the two systems,) which are not well related.

3. In the genesis chapter it is strongly contested that climate is not the most important soil forming factor in Kapini. Topography and geology are the most important soil forming factor. Using field data, mineralogical data, micro-morphological data, chemical and other physical data the following pedogenic processes were found to be dominant in the soils of Kapini: ferrilization, desilication decomposition and synthesis.

4. Land evaluation was carried out according to FAO framework for land evaluation (1976). The system was found to be adaptable to local conditions and gives a better suitability class prediction than the local system. The Oxisols of mapping unit 32 are the poorest soils in terms of land utilisation requirements for the important and relevant land qualities outlined in the chapter on land evaluation. Mapping units 41, 42 and 11 are the most suitable to crop production. Social economically the area was found to be unsuitable to cash crop production at low management levels. The people of Kapini were found to accept technological innovation. The social and political situation was found to be conducive to agricultural development. In the studies on land evaluation the quantification of some land qualities was difficult. In the erosion land quality some important factors such as infiltration were left out because infiltration tests were not conducted to quantify this factor.

Suggestions for future work.

The fields of soil classification, pedogenesis and land evaluation have not been studied in detail in Zambia. As a result, proper agricultural and land use planning becomes difficult. The Ultimate aim should be to evolve local classification and land evaluation systems and to understand the processes of soil genesis of the Zambian soils. The following would help towards the achievement of such an aim.

1. The final evolution of a Zambian soil classification system can only be achieved with the exchange of ideas on soil classification with countries with similar soils. To this effect the setting up of Benchmark Sites Network for Agrotechnological Transfer (IBSNAT) should be of the highest priority. This will help characterise the Zambian soil to international standards. The use of soil taxonomy is recommended for international communication and national mapping since its classification criteria are well defined.
2. In soil genesis, studies should aim at understanding the several processes that are important in the development of Zambian soils. The importance of soil forming factors, such as geology topography and age should be investigated. The assumption that climate is the most important soil forming factor should be critically assessed.

3. The F.A.O. Frame-work for land evaluation (1976) should be tested in the field. Experimental sites for testing the land utilisation requirements for several land qualities should be set up in the major soil types. In this way there can be developed a local land evaluation system with a strong base.

CITED LITERATURE

- Allison, L.E. 1965. Organic carbon. In C.A. Black, D.D. Evans, J.L. White, L.E. Ensminger and F.E. Clark (eds), Methods of Soil Analysis, p. 1367-1378. American Society of Agronomy, Madison, Wisc.
- Ballantyne, A.O. 1957. A reconnaissance soil survey of Copperbelt of Northern Rhodesia, Rhodesia Agric. J. 57: (6): 558-571.
- Beek, K.H. 1975. Land utilization types in land evaluation. In land evaluation in Europe. Soil Bulletin 29, F.A.O. Rome, pp 87-106.
- Beinroth, F.H., H. Ikawa and G. Uehara. 1979. Classification of the soil series of Hawaii in four systems. A guide to correlating Tropical Soils, University of Hawaii, miscellaneous publication 166.
- Bibby, J.S. and Mackney. 1969. Land use capability classification. Technical Monography No.1, Soil Survey, Harpenden.
- Birkeland, P. 1974. Pedology, Weathering and Geomorphological Research. Oxford University Press, Oxford.
- Blake, G.R. 1965. Bulk density. In C.A. Black, D.D. Evans, J.L. White, L.E. Ensminger and F.R. Clark (eds), Methods of Soil analysis p. 374-390. American Society of Agronomy. Madison, Wisc.

- Bramner, H. 1973a. Crop suitability. Technical Guide No. 7, Soil Survey Unit, Mount Makulu, Chilanga.
- Bramner, H. 1973b. Soil profile descriptions, analytical data and an account of soil genesis and classification. Soil Survey Report No. 11, Soil Survey Unit, Mount Makulu.
- Bray, R.H. and I.T. Kurtz. 1945. Determination of total organic and available forms of phosphorus in soils. Soil Sci. 39: p. 39-44.
- Brinkman, R. 1970. Ferrollysis. A hydromorphic soil farming process. Geoderma 3, 199-206.
- Brown, G. 1961. The x-ray identification and crystal structure of clay minerals. Mineralogical Society (Clay minerals group) London.
- Buol, S.W., F.B. Hole, and R.J. Mc Cracken. 1973. Soil genesis and classification. Iowa State University Press, Iowa.
- Buol, S.W. 1983. Circular letter No. 10. International committee on classification of Oxisols (ICOMOX). North Carolina State University Raleigh.
- Bunyolo, A.M., A. Commissaris and R. Hennemann. 1982. Rating of land qualities, soil moisture and climatic conditions and their conversion into suitability in Zambia. Soil Survey Unit, Mount Makulu, Chilanga.

- Cheatle, R.J. 1975. Studies of the soils and land use in an area of the upper Likabula Valley, Malawi, unpublished M.Sc. thesis, University of Aberdeen, Aberdeen.
- Cheatle, R.J. 1980. A possible Nitosol at York farm, Makeni near Lusaka, Zambia. Soil Bulletin No. 4, Soil Survey Unit. Mount Makulu, Chilanga.
- Chishala, B. 1982. Aluminium saturation in some Zambian soils. Soil Survey Unit, Mount Makulu, Chilanga.
- Christian, C.S. and G.A. Stewart, 1968. Methodology of intergrated surveys. In: "Aerial Surveys and Intergrated studies". Proc. Toulouse Conf. 1964, UNESCO 233-280.
- Christian, C.S. and G.A. Stewart, 1953. General report on survey of Katherine - Darwin region, 1974 CSIRO Aust. Land Res. Ser. No. 1.
- Cline, M.G. 1949. Basic principles of soil classification. Soil Sci. 67: 81-91.
- Climatological dept. Zambia, 1970. Climatological summaries for Zambia , G.R.Z. Lusaka.
- Chinene, V.R. 1980. Detailed soil survey of (BONANZA) farm No. 2061. Lusaka Province. Soil Survey Unit, Mount Makulu, Chilanga.

- Costa de lemos, R. 1971. Progress in soil survey and its application in latin America. In. Systematic land and water resources appraisal. Latin America land water Bulletin 1 FAO, Santiago, Chile 102-112.
- Cook, N.G. 1973. Compositional variation in three typic haplustox containing mica. Soil Sci. 115: 159-169.
- Conex, 1963. Land classification and conservation in Northern Rhodesia, Department of agriculture government printers.
- Dalal-Clayton, D.B. 1980. Investigations into the nature and distribution of the Sandveld soils of the Central province of Zambia with observations on their land use potential. Soil Bulletin No. 6, Soil Survey Unit, Mount Makulu, Chilanga.
- Dalal-Clayton, D.B. and C. English, 1983. A proposed physiographic legend for Zambia (1st approximation), Soil Survey Unit, Mount Makulu, Chilanga.
- Day, P.R. 1965. Particle fraction and particle size analysis. In C.A. Black, D.D. Evans, J.L. White, L.E. Ensminger and F.E. Clark, (eds), Methods of Soil analysis, p. 545-567. American Society of Agronomy, Madison Wisc.

Dixey, F. 1945. The geomorphology of N. Rhodesia, Trans. Geol. Soc. S. Afro. Vol. 47, pp. 9-45.

F.A.O. 1974. Approaches to land classification. Soil Bulletin 22 F.A.O., Rome.

F.A.O. 1976. A framework for land evaluation. Soil Bulletin 32, F.A.O., Rome.

F.A.O. - UNESCO 1974. Soil map of the World, Vol. 1 Legend, Paris.

GRZ, 1965. The Republic of Zambia Soils (Map scale 1:2,500,000), Government Printers Lusaka.

Herbillon, A.J. 1981. Degree of weathering and surface properties of clays. In Greenland, D.J. (ed.). "Characterisation of soils in relation to their classification and management for crop production: examples from some areas of the humid tropics." Clarendon press Oxford.

Herbillon et al., 1966. Quoted in Herbillon A.J. 1981. Degree of weathering and surface properties of clays. In. Greenland D.J. (ed). "Characterisation of soils in relation to their classification and management for crop production: examples from some areas of the humid tropics." Clarendon press Oxford.

- Huang, P.M. and L.M. Kozak, 1970. Adsorption of hydroxyl-aluminium polymers by muscovite and biotite, nature and land 228: 1084-5.
- Jørgensen, P. 1983. Mineralogy of the soils of the Kaleya region, Mazabuka, unpublished differential thermal analysis (DTA) and X-ray diffraction, mineralogical data. Agriculture University of Norway (NLH), Dept. of Geology Aas.
- Jørgensen, P. and A. Njós, 1978. Studies of two upland soils from Mochipapa Regional Research Station Southern Province Soil Survey Bulletin No. 1 Soil Survey Unit, Mount Makulu, Chilanga.
- Jørgensen, A. and G. Heintzber, 1975. Methods in soil micromorphology. A technique for the preparation of large thin sections, Soil Survey Institute, Wageningen, The Netherlands.
- Henny, J. 1941. Factors of soil formation, McGraw hill, New York.
- Kalima, C. 1983. The Characterisation, Distribution and Extent of the major soils of the high rainfall areas of Zambia, paper presented at a seminar on soil productivity of the high rainfall area of Zambia. Lusaka, 8-10 Feb., 1983.

- Kellogg, C.E. 1949. Preliminary suggestions for the Classification and nomenclature of great soil groups in tropical and equatorial regions, Common. Bur. Sci. Tech. Common. 46: 76-85.
- Klingeziel, A.A. and P.D. Montgomery, 1961. Land capability Classifications. Agriculture handbook No. 210 US Dept. Agriculture; Soil Conservation Service, Washington D.C.
- Magai, R.N. 1981. Soils of the Ipafu development area, Copperbelt Province, Zambia, unpublished M.Sc. thesis. University of Aberdeen, Aberdeen.
- McLean, A.H. 1976. Moisture characteristics of some Zambian soils. Soil Survey Report No. 5 Mount Makulu, Chilanga.
- Middleton, H.E. 1930. Properties of soils that influence soil erosion, U.S. Dept. Agric. Tech. Bull. 1978.
- Mmikonga, A.A.M.S. 1982. Soil and land evaluation of section of the lower Kilombero valley unpublished M.Sc. thesis, University of Dar es Salaam, Morogoro.
- Milne, G. 1935. Some suggested units of classification and mapping particularly for East African Soils. Soil Res. 4: 183-198.

- Njós, A. and B.R. Singh, 1980. Field and laboratory exercises for a graduate course in soil physics. Institute of Soil Fertility and Management, Agricultural University of Norway, Aas, Norway.
- Ochtmann, L.H.J. and B. Debele, 1976. Reddish brown soils in Holetta region. Ethiopian Highlands. In FAO 1977. Second meeting of Eastern African Sub-Committee for soil correlation and land evaluation. Addis Ababa. FAO, Rome.
- Requier, J., D.L. Brameo and J.P. Cornet, 1970. A new system of soil appraisal in terms of actual and potential productivity (1st approximation)FAO, Rome.
- Simpson, J.G., A.R. Drysdall and H.H.J. Lambert, 1963. The Geology and Groundwater Resources in the Lusaka Area. Geol. Survey Report No. 16. Govt. Printers, Lusaka.
- Smith, G.D. 1965. Lectures on soil classification, pedologie spec. 4: 134 pp.
- Soil Survey Staff, 1951. Soil survey manual US Dept. Agric. Soil conservation service handbook 18, US Government Printing Office, Washington, D.C.
- Soil Survey Staff, 1960. Soil classification a comprehensive system, 7th approximation US Dept. Agr. Soil Conservation Service U.S. Government Printing Office Washington D.C.

- Soil Survey Staff 1967. Soil Survey Laboratory Methods; and procedures for collecting soil samples. U.S. Dept. Agric. Soil Conservation Service, Soil Survey Inv. Rep. 1. U.S. Govt. Printing Office, Washington, D.C.
- Soil Survey Staff 1975. Soil Taxonomy: a basic system of soil classification for making a interpreting soil surveys. U.S. Dept. Agric. Soil Conservation Service, Agric. handbook 436, US Govt. Printing Office, Washington, D.C.
- Soil Survey Unit 1968-83. Soil survey report numbers 1-125. Soil Survey Unit, Mount Makulu, Chilanga.
- Soil Institute of Iran 1970. Manual of land classification for irrigation. Publication No. 205 Iranian Ministry of Agriculture Teheran.
- Soil Science Society, 1971. Glossary of soil science terms. Soil Science Society, Washington.
- Sambroek, W.G. and W. Siderius 1976. Nitosols and their genesis. In FAO 1977. Second meeting of the Eastern African Sub-Committee for soil correlation and land evaluation. FAO, Rome.
- Storries, R.E. 1935. An index for rating the agricultural value of soils. California.

Strahler, A.N. 1975. Physical geography (4th ed) Wiley and Sons U.S.

Sys, C., A. Van Wambeke, A. Frankart, R. Gilson, P. Jongen, M. Jamagne, J.M. Berce and A. Pecrot 1961. La Cartographie des sols au Congo et au Congo et Ruanda-Urundi Ses Principes, Ses methodes, INEAC, Ser. Sci. Techn. No. 6 Bruxelles.

Sys, C. 1969. Les sols d'Afrique Centrale dans la Classification Americaine, 7 Eme approximation sols Afric. 14: 5-24

St. Serstevens A., P.G. Rouxhet, A.J. Herbillon 1978. Alteration of muscovite surface by distilled water and electrolyte solutions. Clay miner 13: 401-410.

Trapnell, C.G. 1943. The soils, vegetation and agricultural systems of N.E. Rhodesia. Government Printers, Lusaka.

Trapnell, C.G., J.D. Martin, and W. Allan 1948. Vegetation soil map of N. Rhodesia. Map scale 1:1,000,000 with memorandum. Govt. Printers, Lusaka.

Veenenbos, J.S. 1975. Land classification I. M.Sc. course on soil science and water management. Agricultural University Wageningen, The Netherlands, Unpublished lecture notes. Wageningen.

- Veldkamp, W.J. 1979. Land evaluation of valleys in a tropical rain area a case study Ph.D. thesis. Agriculture University of Wageningen The Netherlands.
- Veldkamp, W.J. 1980. Soil survey and land evaluation in the Mano river Union Area (Eastern Sierra Leone and Western Liberia). Land resources survey project. Monrouvia and Freetown.
- Veldkamp, W.J. 1982. Key to soil series of Zambia Survey Unit, Mount Makulu, Chilanga.
- Verheye, W. 1982a. Land evaluation classification and pedogenesis Personal Communication.
- Verheye, W. 1982b. "New concepts in land evaluation studies." Seminar delivered at the University of Dar es Salaam, Faculty of Agriculture, Forestry and Veterinary Science on 25/8/82 unpublished.
- Vink, P.A. 1975. Land use in advancing agriculture Springer - verlage, Berlin.
- Webster, R. 1960. Soil genesis and classification in Central Africa. Soil Fertility 25:
- Webster, R. 1965. A Catena of soils on the Northern Rhodesia Plateau J. Soil Sci. 16: 31-43.

Wishmeier, W.H. and D.D. Smith 1960. Universal soil-loss equation (USLE) to guide conservation farm planning. Trans. 7th Int. Cong. Soil Sc. Madison VI: 418-425.

Young, A. 1976. Tropical Soils and Soil Survey, Cambridge University Press, Cambridge.

Young, A. and P.F. Goldsmith 1977. Soil survey and land evaluation in developing countries; case study in Malawi, Geographical Journal 143: 407-431.

APPENDIX I

SOIL PROFILE DESCRIPTIONS AND ANALYTICAL DATA

1. INFORMATION ON THE SITE:

Profile number: LP/1/82

Mapping unit: 32

Soil name: Mpongwe (tentative)

Higher category classification:

FAO: Rhodic Ferralsol

Soil Survey Staff (USDA): Typic Haplustox

Date of examination: 21/7/82

Location: 35L PP 360095 Kapini area

Elevation: 1185 m

Land form: Plain

- (i) Physiographic positions: lower slope
- (ii) Land form: flat to very gentle undulation
- (iii) Microtopography: very few ant hills

Slope on which profile is sited: 0-1%

Land use: Cultivated: Maize and cotton in nearby fields.

Site of profile is not cultivated.

Climate: A pronounced seasonal rainfall climate with a distinct wet and dry season. Annual rainfall 8000m (Lusaka airport) ALT. 1280m.

II. GENERAL INFORMATION OF THE SOIL:

Parent material: Limestone

Drainage class: Well drained

Moisture conditions in profile: just moist below 141 cm.

Depth to ground water table: Unknown but greater than 3m.

Presence of surface stone, rock outcrops: None

Evidence of erosion: None

Presence of salt or alkali: None

III. BRIEF DESCRIPTION OF PROFILE:

Deep, well drained dark red clayey profile with subangular blocky structure throughout.

IV. PROFILE DESCRIPTION:

A 0-13 cm. Reddish brown (5YR 4/4) moist and light brown. (5YR 4/6) dry, sandy clay; moderate fine subangular blocky; sticky, plastic, friable moist, slightly hard dry; Many fine and medium pores; many fine common medium and few coarse roots; clear smooth boundary.

AB 13-36 cm. Dark red (2.5YR 3/6) moist and yellowish red (5YR 4/6) dry, clay; moderate and strong medium subangular blocky; sticky, plastic, friable moist, hard dry. Many fine and medium, common coarse pores; many fine, common medium and few coarse roots; Gradual smooth boundary.

BWs 36-80 cm. Dark red (2.5YR 3/6) moist, Red (2.5YR 4/6) dry, clay; moderate medium sub-angular blocky slightly sticky slightly plastic, friable moist, slightly hard dry; many fine and medium, few coarse pores; many fine, few medium and coarse roots; smooth gradual to diffuse boundary.

BWs₂ 80-280+ Dark red (2.5YR 5/6) moist and red (2.5YR 4/6) dry, clay; weak to moderate coarse subangular blocky structure; slightly sticky, slightly plastic, friable moist, slightly hard dry; many fine, common medium, few coarse pores, common fine and medium, few coarse roots diffuse smooth boundary.

| <u>SOIL MOISTURE CHARACTERISTICS:</u> | | | | |
|---------------------------------------|---------------------|-------------------|-----------------|-----------------------------|
| <u>Depth</u> (cm) | <u>Mapping unit</u> | <u>1/10 bar</u> % | <u>15 bar</u> % | <u>Available moisture</u> % |
| 0 - 13 | 32 | 19.93 | 10.18 | 8.75 |
| 13 - 36 | | 24.50 | 12.15 | 12.35 |
| 36 - 127 | | 21.87 | 13.61 | 8.76 |
| 127 - 200 | | 24.00 | 10.94 | 13.06 |

| <u>SOIL PHYSICAL CHARACTERISTICS:</u> | | | | | | |
|---------------------------------------|--|----------------------|----------------------|---------------------|------------------------|-------------------------|
| <u>Depth</u> (cm) | <u>Bulk Density</u> g/cm ³ | <u>Rolling limit</u> | <u>Plastic index</u> | <u>Sticky limit</u> | <u>Shrinking limit</u> | <u>Linear shrinkage</u> |
| 0-13 | 1.54 | 18.00 | 2.70 | 20.12 | 16.85 | 4.60 |
| 13-36 | 1.35 | 18.64 | 2.00 | 23.78 | 22.31 | 6.55 |
| 36-127 | 1.32 | 31.58 | 2.41 | 21.74 | 24.04 | 8.45 |
| 127-200 | 1.31 | 18.18 | 3.71 | 27.43 | 19.96 | 10.02 |

ANALYTICAL DATA:

PROFILE NO. 1.

RD 3/8/82

Grain size, mm

| Lab. No. | Depth (cm) | Clay | Silt | F. sand | M. sand | C. sand | Texture (USDA) |
|----------|------------|---------|----------------|---------------|---------------|---------------|----------------|
| | | 0.002 % | 0.002 - 0.05 % | 0.05 - 0.25 % | 0.25 - 0.50 % | 0.50 - 2.00 % | |
| 82- 2601 | 0-13 | 36 | 23 | 31 | 6 | 4 | CL |
| 02 | 13-36 | 54 | 22 | 17 | 4 | 3 | C |
| 03 | 36-80 | 57 | 20 | 16 | 3 | 4 | C |
| 04 | 80-127 | 64 | 18 | 14 | 2 | 2 | C |
| 05 | 127-202 | 62 | 25 | 11 | 1 | 1 | C |

Chemical data:

| Lab No. | Depth (cm) | Ex. Ca m.e.% | Ex. Mg m.e.. | Ex. K m.e.% | Ex. Na m.e.% | C.E.C. m.e.% | C.E.C. m.e 100g Clay |
|----------|------------|--------------|--------------|-------------|--------------|--------------|----------------------|
| 82- 2601 | 0-13 | 2.36 | 1.18 | 0.32 | 0.02 | 8.86 | 25 |
| 02 | 13-36 | 0.55 | 0.25 | 0.09 | T | 7.38 | 14 |
| 03 | 36-80 | 0.24 | 0.10 | 0.06 | 0.04 | 6.52 | 11 |
| 04 | 80-127 | 0.18 | 0.21 | 0.06 | T | 5.84 | 9 |
| 05 | 127-200+ | 0.20 | 0.26 | 0.05 | 0.03 | 5.84 | 9 |

| Lab No. | Depth (cm) | Org. C % | N Avail PPM | P PH (CaCl ₂) | PH (H ₂ O) | Base sat. % |
|----------|------------|----------|-------------|---------------------------|-----------------------|-------------|
| 82- 2601 | 0-13 | 1.49 | 8 | 5.0 | 5.8 | 44 |
| 02 | 13-36 | 0.85 | 2 | 4.1 | 4.9 | 12 |
| 03 | 36-80 | 0.82 | 1 | 4.1 | 4.9 | 7 |
| 04 | 80-127 | 0.20 | 2 | 4.2 | 5.2 | 8 |
| 05 | 127-200+ | | 1 | 4.5 | 5.4 | 9 |

NO = Not determined.

MICROMORPHOLOGY (THIN SECTIONS):

| <u>Horizon</u> | <u>Depth (cm)</u> |
|----------------|-------------------|
| B | 36 - 80 |

- skelet grains: fine sandy and silt (mostly quartz)
- plasma ordening: undulic (high iron content)
- special features: few ferric nodules with sharp edges
(transported) very few iron rich papules,
no clay cutans.

MINERALOGY:

| <u>Horizon</u> | <u>Kaolinite</u> | <u>Haematite</u> | <u>Goethite</u> | <u>Feldspars</u> |
|----------------|------------------|------------------|-----------------|------------------|
| B | +++ | + | + | - |

I. INFORMATION ON THE SITE:

Profile number: IP/2/82

Mapping unit: 33

Soil name: Mushemi (tentative)

Higher category classification:

F.A.O.: Ferric Luvisol

Soil Survey Staff (USDA): Oxic paleustalf

Date of examination: 21/7/82

Location: 35L PP 34115-3 (Moomba School) Kapini area

Elevation: 1140m

Land form: Plain

(i) Physiographic position: lower slope

(ii) Surrounding land; Flat to very gently undulating

(iii) Microtopography: None

Slope on which profile is sited: 1-3%

Land-use: Cultivation: maize and cotton -, profile site is cultivated with maize.

Climate: Seasonal climate with a distinct wet, and dry season.
Annual rainfall 800 m (Lusaka) Alt. 1154 m airport.

II. GENERAL INFORMATION THE SOIL:

Parent material: Limestone

Drainage class: Well

Moist conditions in profile: just moist at 71-149 cm

Depth to ground water table: 10 metres (seen in a water well).

Presence of surface stones, rock outcrops: Class 0 to class 1
(FAO 1977).

Evidence on erosion: None

III. BRIEF DESCRIPTION OF PROFILE:

The profile is dark brown. It occurs in shallow to moderately deep limestone area. Limestone rock out crops frequently. Soil texture is sandy clay in the top soil and clay loam in the sub-soil.

IV. PROFILE DESCRIPTION:

| | | |
|-----|----------|--|
| AP | 0-12cm | Dark brown (10YR 3/3) moist and yellowish brown (10YR 4/5) dry, sandy clay loam; weak fine subangular; sticky, slightly plastic, friable moist, slightly soft dry; many fine medium and coarse roots; clear smooth boundary. |
| Bts | 12-39 cm | Dark brown (7.5YR 4/4) moist and strong brown (7.5YR 5/6) dry, sandy clay to clay loam; moderately medium subangular blocky; sticky, plastic, friable moist, slightly hard dry; patchy moderately thick cutans on ped faces and old root channels. Many fine medium and coarse pores; many fine, few medium and coarse roots. Frequent small and hard iron and manganese concretions; gradual smooth boundary. |

Bts 39-71 cm Strong brown (7.5YR 4/6) moist and strong brown (7.5YR 5/6) dry, clay loam; moderate medium subangular blocky structure; sticky, plastic, friable moist, slightly hard dry; patchy thin cutans on ped faces; many fine, common medium and coarse pores; common fine roots; very frequent iron and manganese concretions; clear wavy boundary.

Bu 71-149 cm Manganese and iron concretions. These are hard, small and have a very frequent occurrence. They rest on limestone rock. Colour is strong brown. (7.5YR 4/6) moist, the boundary is abrupt Irregular.

SOIL MOISTURE CHARACTERISTICS:

| <u>Depth</u> (cm) | <u>Mapping unit</u> | <u>%</u> <u>1/10 bar</u> | <u>%</u> <u>15 bar</u> | <u>%</u> <u>Available</u> <u>moisture</u> |
|----------------------|---------------------|-----------------------------|---------------------------|---|
| 0 - 12 | 33 | 11.62 | 6.62 | 5.00 |
| 12 - 39 | | 16.05 | 8.55 | 7.50 |
| 39 - 71 | | 17.40 | 9.40 | 8.00 |
| 71 - 149 | | 9.40 | 6.10 | 3.00 |

SOIL PHYSICAL CHARACTERISTICS:

| <u>Depth</u> (cm) | <u>Bulk(g/cm³)</u> <u>density</u> | <u>Rolling</u> <u>limit</u> | <u>Plastic</u> <u>index</u> | <u>Shrinking</u> <u>limit</u> | <u>Linear</u> <u>shrinkage</u> |
|----------------------|---|--------------------------------|--------------------------------|----------------------------------|-----------------------------------|
| 0-12 | 1.49 | 13.80 | 4.33 | 14.60 | 2.60 |
| 12-39 | 1.52 | 14.20 | 7.76 | 14.89 | 2.61 |
| 39-71 | 1.56 | 16.33 | 12.00 | 18.50 | 2.40 |
| 71-149 | - | 18.39 | 14.00 | 18.70 | 2.40 |

ANALYTICAL DATA:

Profile No: 2-82

RD 3-8-82

Grain size mm:

| Lab. No. | Depth (cm) | Clay | Silt | F.sand | M.sand | C.sand | TEXTURE (USDA) |
|----------|------------|---------|----------------|---------------|---------------|---------------|----------------|
| | | 0.002 % | 0.002 - 0.05 % | 0.05 - 0.25 % | 0.25 - 0.50 % | 0.50 - 2.00 % | |
| 82- 2606 | 0 - 12 | 32 | 20 | 41 | 5 | 2 | SCL |
| 07 | 12-39 | 42 | 16 | 36 | 4 | 2 | C |
| 08 | 39-71 | 44 | 18 | 34 | 2 | 2 | C |
| 07 | 71-149 | 43 | 15 | 34 | 4 | 4 | C |

Chemical Data:

| Lab No. | Depth (cm) | Ex.Ca m.e.% | ExMg m.e.% | Ex.K M.e.% | Ex.Na m.e.% | C.L.C. m.e.% | C.L.C, m.e 100g clay |
|----------|------------|-------------|------------|------------|-------------|--------------|----------------------|
| 82- 2606 | 0-12 | 4.31 | 0.73 | 0.35 | T | 7.56 | 24 |
| 07 | 12-39 | 3.48 | 0.60 | 0.11 | T | 6.92 | 16 |
| 08 | 39-71 | 2.31 | 0.63 | 0.08 | T | 6.00 | 14 |
| 09 | 71-149 | 1.72 | 0.50 | 0.06 | 0.03 | 6.04 | 14 |

| Lab No. | Depth (cm) | Org.C % | N Avail P PPM | PH (CaCl ₂) | pH (h ₂ O) | Basic Sat. % | - |
|----------|------------|---------|---------------|-------------------------|-----------------------|--------------|---|
| 82- 2606 | 0-12 | 1.03 | 4 | 5.9 | 6.4 | 71 | |
| 07 | 12-39 | 0.78 | 2 | 5.8 | 6.3 | 61 | |
| 08 | 39-71 | 0.90 | 2 | 5.6 | 6.3 | 50 | |
| 09 | 71-149 | 0.19 | 2 | 5.8 | 6.3 | 58 | |

ND = Not determined.

MICROMORPHOLOGY (THIN SECTION):

Horizon Depth (cm)
B 39 - 71 cm

- skelet grains. fine and coarse sand (quartz)
- sepic plasma, consists of clay and some dispersed organic matter
- few clay cutans (ferric-argillans)
- ferric nodules and concretions present (plintite)

MINERALOGY:

| <u>Horizon</u> | <u>Depth</u> | <u>Clay fraction</u> | | | <u>Feldspar</u> | <u>Micas</u> |
|----------------|--------------|----------------------|------------------|-----------------|-----------------|--------------|
| | | <u>Kaolinite</u> | <u>haematite</u> | <u>Goethite</u> | | |
| B | 39-71(cm) | +++ | + | + | - | ++ |

| <u>Horizon</u> | <u>Fine sand</u> | | |
|----------------|------------------|--------------|---------------|
| | <u>Depth</u> | <u>Micas</u> | <u>Quartz</u> |
| B | 39-71 (cm) | + | ++ |

I. INFORMATION ON THE SITE:

Profile number: IP/3/82

Mapping unit: 41

Soil name: Ipafu (tentative)

Higher category classification (tentative)

F.A.O: Gleyic Luvisol

Soil Survey Staff (USDA): Oxic Haplustalf

Date of examination: 22/7/82

Location: 35L PP 335175 (Kapini) Kapini area

Elevation: 1126 m

Land form: Plain

(i) Physiographic position: lower slope

(ii) Surrounding land form: Flat

(iii) Microtopography: Very few anthills

Slope on which profile is sited: 0-1%

Land use: Cultivation: cotton, maize, sunflower.

profile site cultivated with sunflower.

Climate: Seasonal climate with distinct wet and dry season,

rainfall 100 mm (Lusaka international airport 1154 m)

II. GENERAL INFORMATION ON THE SOIL:

Parent material: Schist

Drainage class: moderately well

Moisture conditions in profile: just moist at 128-200 + cm

Depth to ground water table: 8 m (seen in water well)

Presence of surface stones, rock outcrops: None

Evidence of erosion: None on site but big gullies exist in mapping unit where soil has been disturbed.

III. BRIEF DESCRIPTION OF PROFILE:

Deep moderately well drained yellowish brown clayey profile with subangular blocky structure throughout.

IV. PROFILE DESCRIPTION:

AP_g 0-16. cm. Very dark greyish brown (2.5YR 3/2) moist and dark greyish brown (2.5YR 4/2) dry, sandy clay with few fine faint yellowish mottles; moderate fine to medium subangular; slightly sticky, slightly plastic, slightly firm moist, hard dry; few fine medium and coarse pores; few fine and medium common coarse roots; clear smooth boundary.

ABwg 16-44. cm. Dark brown (10YR 4/3) moist and yellowish brown (10YR 3/4) dry, clay with few fine faint yellow (10YR 8/8) mottles; moderate medium subangular; sticky, plastic slightly firm moist, hard dry; few fine and medium many fine and common medium roots; gradual smooth boundary.

Btsg, 22-78cm. Yellowish brown (10YR 5/6) moist and yellowish brown (10YR 5/6) dry, clay with common, medium distinct yellow (10YR 8/8) mottles; moderate medium to coarse sub angular blocky; sticky, plastic, slightly firm moist, hard dry; patchy moderately thick cutans on ped faces and old root channels, few fine and medium pores;; common fine and medium roots; very frequent iron and manganese concretions; clear smooth boundary.

Btsg₂ 78-128cm. Yellowish brown (10YR 5/6) moist and yellowish brown (10YR 5/6) dry, clay with many medium prominent yellow (10YR 8/8) mottles; moderate coarse sub-angular structure; sticky, plastic, slightly firm moist, slightly hard dry; patchy thin cutans on ped faces; many fine few medium and coarse pores; few fine roots; gradual smooth boundary.

SOIL MOISTURE CHARACTERISTICS:

| <u>Depth</u> <u>(cm)</u> | <u>Mapping unit</u> | <u>%</u> <u>1/10 bar</u> | <u>%</u> <u>15 bar</u> | <u>%</u> <u>Available</u> <u>moisture</u> |
|-----------------------------|---------------------|-----------------------------|---------------------------|---|
| 0-16 | 41 | 23.00 | 7.64 | 15.36 |
| 16-44 | | 25.00 | 8.66 | 17.34 |
| 44-78 | | 25.00 | 8.66 | 17.34 |
| 78-128 | | 25.12 | 8.61 | 17.51 |

Profile No: 3

ANALYTICAL DATA

RD 3-8-82

| Lab. No. | Depth (cm) | Grain size, mm | | | | | TEXTURE (USCS) |
|----------|------------|----------------|---------------------|----------------------|----------------------|----------------------|----------------|
| | | Clay 0.002 % | Silt 0.002 - 0.05 % | F.Sand 0.05 - 0.25 % | M.Sand 0.25 - 0.50 % | C.Sand 0.50 - 2.00 % | |
| 82-2610 | 0-16 | 45 | 27 | 25 | 2 | 1 | C |
| 11 | 16-44 | 67 | 21 | 13 | 1 | 1 | G |
| 12 | 44-78 | 68 | 19 | 9 | 2 | 2 | C |
| 13 | 78-128 | 66 | 18 | 12 | 2 | 2 | C |
| 14 | 128-200+ | 70 | 16 | 10 | 1 | 3 | C |

Chemical data.

| Lab. No. | Depth (cm) | Ex. Ca m.e.% | Ex. Mg m.e.% | Ex. K m.e.% | Ex. Na m.e.% | U.L.C. m.e.% | C.L.C. 100g clay | m.e.% Al ppm |
|----------|------------|--------------|--------------|-------------|--------------|--------------|------------------|--------------|
| 82-2610 | 0-16 | 7.20 | 1.82 | 0.51 | 0.04 | 12.20 | 27 | |
| 11 | 16-44 | 8.27 | 2.21 | 0.21 | 0.04 | 15.66 | 24 | |
| 12 | 44-78 | 7.79 | 2.21 | 0.21 | 0.05 | 14.14 | 21 | |
| 13 | 78-128 | 8.66 | 2.67 | 0.20 | 0.07 | 14.62 | 22 | |
| 14 | 128-200+ | 10.21 | 3.21 | 0.21 | 0.10 | 15.96 | 23 | |

| Lab. No. | Depth (cm) | Org. C % | Total N % | Av. N ppm | P ppm | pH (CaCl ₂) | pH (H ₂ O) | Base Sat. % | Free Fe ppm |
|----------|------------|----------|-----------|-----------|-------|-------------------------|-----------------------|-------------|-------------|
| 82-2 | 0 | 1.31 | | 2 | | 5.5 | 6.0 | 78 | |
| 11 | 16-44 | 0.82 | | 1 | | 5.5 | 6.0 | 69 | |
| 12 | 44-78 | 0.62 | | 1 | | 5.7 | 6.1 | 73 | |
| 13 | 78-128 | 0.18 | | 1 | | 6.3 | 6.5 | 79 | |
| 14 | 128-200+ | | | 1 | | 6.7 | 7.0 | 86 | |

NC = Not determined

SOIL PHYSICAL CHARACTERISTICS:

| <u>Depth (cm)</u> | <u>Bulk density (g/cm³)</u> | <u>Rolling limit</u> | <u>Plastic index</u> | <u>Sticky limit</u> | <u>Shrinking limit</u> | <u>Linear shrinkage</u> |
|-------------------|--|----------------------|----------------------|---------------------|------------------------|-------------------------|
| 0-16 | 1.60 | 5.51 | 4.12 | 12.61 | 14.00 | 2.60 |
| 16-44 | 1.57 | 12.85 | 9.57 | 12.20 | 15.60 | 3.25 |
| 44-78 | 1.45 | 16.32 | 14.63 | 20.50 | 18.00 | 3.00 |
| 78-128 | 1.45 | 16.36 | 12.64 | 20.62 | 18.10 | 2.80 |
| 128-200+ | 1.45 | 16.36 | 12.64 | 20.72 | 17.52 | 2.57 |

MICROMORPHOLOGY (THIN SECTIONS):

| <u>Horizon</u> | <u>Depth (cm)</u> |
|----------------|-------------------|
| B | 44 - 78 |

- skelet grains: fine sand and silt (dominantly quartz)
- plasma ordering: asepic-sepic (see special features)
- special features: locally skelspic (much less than 462 and 463)
 - very few clay cutans (much less than 462 and 463)
 - ferric nodules and concretions present (plinthite)
 - some ferric nodules (few mm to 1 cm) with diffuse boundary; in situ hydromorphism.

MINERALOGY:

| <u>Horizon</u> | <u>Depth (cm)</u> | <u>Clay fraction</u> | | | | | |
|----------------|-------------------|----------------------|------------------|-----------------|------------------|--------------|--------------------|
| | | <u>Kaolinite</u> | <u>Haematite</u> | <u>Goethite</u> | <u>Feldspars</u> | <u>Micas</u> | <u>Hall-oysite</u> |
| B | 44-78 | +++ | + | ++ | + | + | - |

Fine sand and silt

| <u>Horizon</u> | <u>Depth</u> | <u>Quartz</u> | <u>Micas</u> |
|----------------|--------------|---------------|--------------|
| B | 44-78 (cm) | ++ | + |

SOIL PHYSICAL CHARACTERISTICS:

| <u>Depth (cm)</u> | <u>Bulk (g/cm³) density</u> | <u>Rolling limit</u> | <u>Plastic index</u> | <u>Sticky limit</u> | <u>Shrinking limit</u> | <u>Linear shrinkage</u> |
|-------------------|--|----------------------|----------------------|---------------------|------------------------|-------------------------|
| 0-16 | 1.60 | 5.51 | 4.12 | 12.61 | 14.00 | 2.60 |
| 16-44 | 1.57 | 12.85 | 9.57 | 12.20 | 15.60 | 3.25 |
| 44-78 | 1.45 | 16.32 | 14.63 | 20.50 | 18.00 | 3.00 |
| 78-128 | 1.45 | 16.36 | 12.64 | 20.62 | 18.10 | 2.80 |
| 128-200+ | 1.45 | 16.36 | 12.64 | 20.72 | 17.52 | 2.57 |

MICROMORPHOLOGY (THIN SECTIONS):

Horizon Depth (cm)

B 44 - 78

- skelet grains: fine sand and silt (dominantly quartz)
- plasma ordering: asepic-sepic (see special features)
- special features: locally skelspic (much less than 462 and 463)
 - very few clay cutans (much less than 462 and 463)
 - ferric nodules and concretions present
(plinthite)
 - some ferric nodules (few mm to 1 cm) with diffuse boundary; in situ hydromorphism.

MINERALOGY:

Clay fraction

| <u>Horizon</u> | <u>Depth (cm)</u> | <u>Kaolinite</u> | <u>Haematite</u> | <u>Goethite</u> | <u>Feldspars</u> | <u>Micas</u> | <u>Hall-oysite</u> |
|----------------|-------------------|------------------|------------------|-----------------|------------------|--------------|--------------------|
| B | 44-78 | +++ | + | ++ | + | + | - |

Fine sand and silt

| <u>Horizon</u> | <u>Depth</u> | <u>Quartz</u> | <u>Micas</u> |
|----------------|--------------|---------------|--------------|
| B | 44-78 (cm) | ++ | + |

I. INFORMATION ON THE SITE:

Profile number: IP/4/82

Mapping unit: 42

Soil name: Ipafu I (tentative)

Higher category classification:

F.A.O; Ferric Luvisol

Soil Survey Staff (USDA); Oxic Haplustalf

Date of examination: 23/7/82

Location: 35L PP 329195 (Kapini) Kapini area

Elevation: 1013 m

Land form: Plain

(i) Physiographic position: lower slope/middle slope

(ii) Surrounding land form: few anthills

(iii) Microtopography: None

Slope on which profile is sited: 1 - 3%

Land use: None

Climate: Seasonal climate with distinct wet and dry season rainfall - 800 m (Lusaka airport 1280 m).

II. GENERAL INFORMATION ON THE SOIL:

Parent material: Schist

Drainage class: Well

Moisture conditions in profile: just moist at 113-180+

Depth to ground water table: 10m (see in water well)

Presence of surface stone, rock outcrops: None

Evidence of erosion: None on site but big gulleys have been seen in the mapping unit.

III. BRIEF DESCRIPTION OF PROFILE:

Deep well drained (?) clayey profile; top soil colour is very greyish brown (2.5YR 3/2) and sub soil colour of dark yellowish brown (10YR 3/4) moist.

IV. PROFILE DESCRIPTION:

- A 0-15 cm Very dark greyish brown (2.5YR 3/2) moist, dark greyish brown (2.5YR/4/2) dry, sandy clay; moderate medium sub-angular blocky; slightly sticky, slightly plastic, extremely firm moist, very hard dry; few fine, medium and coarse pores; few fine medium and coarse roots; clear smooth boundary.
- AB 15-65¹ cm Dark yellowish brown (10YR 3/4) moist, dark yellowish brown (10YR 4/4) dry, clay with few fine, faint mottles; moderate very coarse sub-angular blocky; sticky, plastic, extremely firm moist, very hard dry; many coarse few fine and medium pores; many fine, medium and coarse roots; gradual smooth boundary.
- Bbc 65-113 cm. Dark yellowish brown (10YR 4/6) moist, yellowish brown (10YR 5/8) dry, clay with few fine faint yellow (10YR 8/8) mottles; moderate medium to coarse sub-angular blocky; slightly plastic, slightly sticky; friable moist hard dry; thin patchy cutans; many fine and medium, few coarse pores; common fine, medium and coarse roots; very few iron and manganese concretions; diffuse smooth boundary.

Bt_s 113-200+ cm Yellowish brown (10YR 5/8) moist, brownish yellow
 (10YR 6/8) dry, clay with few fine faint yellow (10YR 8/8)
 mottles; moderate medium sub-angular blocky, stick,
 plastic, friable moist, hard dry; thin patchy cutans; many
 medium and fine few coarse pores; frequent hard iron
 concretions.

SOIL MOISTURE CHARACTERISTICS:

| <u>Depth</u> (cm) | <u>Mapping unit</u> | <u>%</u> <u>1/10 bar</u> | <u>%</u> <u>15 bar</u> | <u>%</u> <u>Available</u> <u>moisture</u> |
|----------------------|---------------------|-----------------------------|---------------------------|---|
| 0-15 | 42 | 23.00 | 7.60 | 15.40 |
| 15-65 | | 24.80 | 8.00 | 16.80 |
| 65-113 | | 25.12 | 8.61 | 17.51 |
| 113-200+ | | 25.12 | 8.61 | 17.51 |

SOIL PHYSICAL CHARACTERISTICS:

| <u>Depth</u> (cm) | <u>(g/cm³)</u> <u>Bulk</u> <u>density</u> | <u>Rolling</u> <u>limit</u> | <u>Plastic</u> <u>index</u> | <u>Stick</u> <u>limit</u> | <u>Shrinking</u> <u>limit</u> | <u>Linear</u> <u>shrinkage</u> |
|----------------------|--|--------------------------------|--------------------------------|------------------------------|----------------------------------|-----------------------------------|
| 0-16 | 1.60 | 5.39 | 4.11 | 12.50 | 14.00 | 2.60 |
| 16-44 | 1.50 | 12.00 | 9.45 | 13.71 | 15.00 | 2.77 |
| 44-78 | 1.40 | 16.30 | 14.51 | 20.45 | 18.00 | 3.00 |
| 78-128 | 1.43 | 16.33 | 12.77 | 20.59 | 18.51 | 2.64 |
| 128-200+ | 1.42 | 16.30 | 12.64 | 20.64 | 18.00 | 2.50 |

MICROMORPHOLOGY (THIN SECTIONS)

| <u>Horizon</u> | <u>Depth (cm)</u> |
|----------------|-------------------|
| B | 65 - 113 |

ANALYTICAL DATA:

Profile No. 4-82

RD 3-8-82

Grain size, mm

| Lab. No. | Depth (cm) | Clay | Silt | F. sand | h sand | C. sand | TEXTURE (USDA) |
|----------|------------|---------|----------------|---------------|---------------|---------------|----------------|
| | | 0.002 % | 0.002 - 0.05 % | 0.05 - 0.25 % | 0.25 - 0.50 % | 0.50 - 2.00 % | |
| 82- 2615 | 0-15 | 42 | 24 | 29 | 4 | 1 | C |
| | 16 15-65 | 53 | 22 | 22 | 2 | 1 | C |
| | 17 65-113 | 64 | 15 | 17 | 2 | 2 | C |
| | 18 113-180 | 60 | 18 | 19 | 1 | 2 | C |

Chemical data

| Lab. No. | Depth (cm) | ExCa m.e.% | Ex.Mg m.e.% | Ex.K m.e.% | Ex.Na m.e.% | CEC m.e.% | C.E.C. # 100g Clay |
|----------|------------|------------|-------------|------------|-------------|-----------|--------------------|
| 82- 2615 | 0-15 | 5.27 | 1.84 | 0.70 | 0.05 | 10-86 | 26 |
| | 16 15-65 | 3.61 | 1.19 | 0.21 | 0.03 | 10.36 | 20 |
| | 17 65-113 | 3.30 | 1.25 | 0.31 | 0.04 | 9.78 | 15 |
| | 18 113-180 | 2.93 | 1.36 | 0.33 | 0.04 | 8.88 | 15 |

| Lab No. | Depth (cm) | Org.C % | N Avail P ppm | pH (CaCl ₂) | pH (H ₂ O) | Base Sat. % |
|----------|------------|---------|---------------|-------------------------|-----------------------|-------------|
| 82- 2615 | 0-15 | 1.18 | 3 | 5.5 | 6.1 | 72 |
| | 16 15-65 | 0.67 | 2 | 4.8 | 5.5 | 49 |
| | 17 65-113 | 0.78 | 1 | 5.1 | 5.7 | 50 |
| | | | 1 | 5.4 | 5.9 | 52 |

ND = Not determined.

- skelet grains: fine sand and silt (dominantly quartz)
- plasma ordening: asepic-sepic (see special features)
- special features:
 - locally skelsepic (much less than 462 and 463).
 - very few clay cutans (much less than 462 + 463).
 - ferric nodules and concretions present (plinthite).
 - some ferric nodules (few mm to 1 cm) with diffuse boundary: in - situ hydromorphism.

MINERALOGY:

Clay fraction

| <u>Horizon</u> | <u>Depth (cm)</u> | <u>Kaolinite</u> | <u>Haematite</u> | <u>Goethite</u> | <u>Feldspars</u> | <u>Micas</u> |
|----------------|-------------------|------------------|------------------|-----------------|------------------|--------------|
| B | 65-113 | +++ | ++ | + | - | +- |

Fine sand and silt

| <u>Horizon</u> | <u>Depth (cm)</u> | <u>Quartz</u> | <u>Mica</u> |
|----------------|-------------------|---------------|-------------|
| B | 65 - 113 | ++ | + |

I. INFORMATION ON THE SITE:

Profile number: LP/5/82

Mapping unit: 11

Soil name: Kado (tentative)

Higher category classification:

F.A.O.: Ferric Luvisol

Soil Survey Staff (USDA): Oxic haplustalfs

Date of examination: 22/7/82

Location: Kapini area 35L PP 326227

Elevation: 1110m

Land form:

- (i) Physiographic position: middle slope (very gentle convex)
- (ii) Surrounding land form: gentle slope
- (iii) Microtopography: very few anthills

Slope on which profile is sited: gentle slope 0-3%

Land use: at the time of examination land was under scattered cleared patches of land in the woodland savannah. In vicinity were a few maize fields.

Climate: has a pronounced seasonal rainfall climate with a distinct wet and dry climate: Total annual rainfall is about 800 mm (Lusaka airport: 1280 mm).

II. GENERAL INFORMATION ON THE SOIL:

Parent material: Gneiss

Drainage class: well

Moisture conditions in profile: just moist below 82 cm.

Depth to ground water table: Unknown

Presence of surface stone, rock outcrops: None

Evidence of erosion: None

III. GENERAL DESCRIPTION OF PROFILE:

Deep well drained dark greyish brown sand loam soils. Top soil structure is very weak sub-angular blocky. Sub-soil structure is moderate sub-angular blocky.

IV. PROFILE DESCRIPTION:

- Au 0-14 cm Dark grey (10YR 4/1) moist and greyish brown (10YR 5/2) dry, sandy loam; weak fine sub-angular; slightly sticky, slightly plastic, friable moist, slightly hard dry; many fine, medium and coarse pores; few coarse, common medium and many fine roots; clear wavy boundary.
- ABg 14-54 cm Dark grayish brown (10YR 4/2) moist and light brownish grey (10YR 6/2) dry, loamy sand with few, fine, faint brownish yellow (10YR 6/8) mottles; moderate medium sub-angular blocky; slightly sticky, slightly plastic, friable moist, hard dry; many fine, medium and coarse roots. Clear smooth to wavy boundary.
- Btsg 54-82 cm Brown (10YR 5/3) moist, light brownish grey (10YR 6/3) dry, sandy loam, with few fine faint yellowish brown moderate coarse (10YR 5/8) mottles; medium coarse sub-angular; slightly sticky, slightly plastic,

friable moist, slightly hard dry; thick patchy cutans; many fine medium and coarse pores; Common fine, medium and coarse roots; very few iron and manganese concretions; clear wavy boundary.

Btsg₂ 83-141cm. Dark brown (10YR 4/3) moist, dark yellowish brown (10YR 4/4) dry, clay with common fine faint yellowish brown (10YR 5/8) mottles; moderate coarse to strong sub-angular; sticky, firm moist, hard dry; many fine medium and coarse pores; few fine and medium roots; few iron and manganese concretions; abrupt wavy boundary.

B/Csg 141-180+cm Yellowish brown (10YR 5/6) moist, clay with many coarse and prominent yellowish brown (10YR 5/8) and brownish yellow (10YR 6/8) mottles; moderate medium sub-angular; sticky, plastic, slightly firm moist, many fine common medium and coarse pores; few fine roots; very frequent iron and manganese concretions.

MOISTURE CHARACTERISTICS:

| <u>Depth</u> <u>(cm)</u> | <u>Mapping unit</u> | <u>%</u> <u>1/10 bar</u> | <u>%</u> <u>15 bar</u> | <u>%</u> <u>A.li.</u> |
|-----------------------------|---------------------|-----------------------------|---------------------------|--------------------------|
| 0-14 | 11 | 10.08 | 5.10 | 4.98 |
| 14-54 | | 11.60 | 7.11 | 4.49 |
| 54-82 | | 16.64 | 9.00 | 5.54 |
| 82-141 | | 24.00 | 8.00 | 16.00 |
| 141-180 | | 24.00 | 8.00 | 16.00 |

ANALYTICAL DATA

Profile No. 5-82

RD 3-8-82

Grain size, mm

| Lab No. | Depth (cm) | Clay | Silt | F. sand | M. sand | L. sand | TEXTURE (USDA) |
|----------|------------|---------|----------------|---------------|---------------|---------------|----------------|
| | | 0.002 % | 0.002 - 0.05 % | 0.05 - 0.25 % | 0.25 - 0.50 % | 0.50 - 2.00 % | |
| 82- 2619 | 0-14 | 24 | 14 | 38 | 17 | 7 | SCL |
| | 20 14-54 | 22 | 14 | 37 | 18 | 9 | SCL |
| | 21 54-82 | 24 | 10 | 39 | 19 | 8 | SCL |
| | 22 82-141 | 48 | 11 | 18 | 13 | 10 | C |
| | 23 141-180 | 47 | 11 | 18 | 12 | 12 | C |

CHEMICAL DATA

| Lab. No. | Depth (cm) | ExCa m.e.% | Ex.Mg m.e.% | Ex.K m.e.% | Ex.Na m.e.% | C.E.C. m.e.% | C.E.C. 100g cl |
|----------|------------|------------|-------------|------------|-------------|--------------|----------------|
| 82- 2619 | 0-14 | 5.38 | 0.83 | 0.46 | T | 6.38 | 27 |
| | 20 14-54 | 2.68 | 0.44 | 0.21 | T | 3.80 | 17 |
| | 21 54-82 | 1.78 | 0.45 | 0.15 | 0.07 | 2.74 | 11 |
| | 22 82-141 | 3.10 | 1.83 | 0.05 | T | 6.20 | 13 |
| | 23 141-180 | 1.68 | 1.86 | 0.06 | T | 5.40 | 11 |

| Lab. No. | Depth (cm) | Org.C % | N Avail ppm | Ph (CaCl ₂) | pH (H ₂ O) | Base Sat. % |
|----------|-------------|---------|-------------|-------------------------|-----------------------|-------------|
| 82- 2619 | 0-14 | 1.02 | 19 | 6.2 | 6.9 | 100 |
| | 20 04-54 | No soil | 3 | 6.2 | 7.0 | 88 |
| | 21 54-82 | 0.04 | 3 | 6.4 | 7.1 | 89 |
| | 22 82-141 | 0.13 | 3 | 6.5 | 7.1 | 80 |
| | 23 141-180+ | | 3 | 6.4 | 7.1 | 67 |

ND Not determined;

SOIL PHYSICAL CHARACTERISTICS:

| <u>Depth</u> (cm) | <u>Bulk(g/cm³)</u> <u>density</u> | <u>Rolling</u> <u>limit</u> | <u>Plastic</u> <u>index</u> | <u>Sticky</u> <u>limit</u> | <u>Shrinking</u> <u>limit</u> | <u>Linear</u> <u>shrinkage</u> |
|----------------------|---|--------------------------------|--------------------------------|-------------------------------|----------------------------------|-----------------------------------|
| 14-54 | 1.45 | 19.00 | 3.61 | 25.83 | 17.49 | 3.00 |

MICROMORPHOLOGY (THIN SECTIONS):

| <u>Horizon</u> | <u>Depth (cm)</u> |
|----------------|-------------------|
| AB | 14 - 54 |

- skelet grains: fine and coarse sand (dominantly quartz)
- plasma orientations: undulic (because of high org. matter content) and locally sepic (see below).
- special features: - very little skelsepic
- quite some clay cutans present with inside organic matter spots: organoferi-argillans
- big (few mm to 1 cm) meta-isotubules (i.e. small clods of B-horizon material with less organic matter with a high number of clay cutans without organic matter spots: ferri-argillans).

| <u>Lab. No.</u> | <u>Profile No.</u> | <u>Horizon</u> | <u>Depth</u> |
|-----------------|--------------------|----------------|--------------|
| m 82 459 | (IP - 5 - 82) | B | 54-82 cm |

- skelet grains: fine and coarse sand (quartz)
- plasma orientation; plasma contains fair amount of organic matter, is asepic to weakly undulic and locally sepic (see below)
- very many clay cutans !!! (organo-ferri-argillans and ferri-argillans)
- few meta-isotubules present (as well from A, B, or C-material)
- very few small ferric nodules (plinthite-gravel)

MINERALOGY:

Clay fraction

| <u>Horizon</u> | <u>Depth</u> (cm) | <u>Smectites</u> | <u>Micas</u> | <u>Kaoli- nite</u> | <u>Halloy- site</u> | <u>Haeme- tite</u> | <u>Geo- thite</u> | <u>Feld- spars</u> |
|----------------|----------------------|------------------|--------------|------------------------|-------------------------|------------------------|-----------------------|------------------------|
| B | 54-82 | ++ | + | +++ | + | + | + | + |

Fine and coarse sand

| <u>Horizon</u> | <u>Depth</u> (cm) | <u>Quartz</u> | <u>Micas</u> |
|----------------|----------------------|---------------|--------------|
| B | 54-82 | +++ | ++ |

I. INFORMATION ON THE SITE:

Profile number: LP/6/82

Mapping unit: 22

Soil name: Unknown

Higher category classification:

F.A.O: dystic regosol

Soil Survey Staff (USDA): Typic ustorthent

Date of examination: 24/7/82

Location: 35L PP 315141

Elevation: 1155m

Land form: plateau

(i) Physiographic position: upper slope

(ii) Surrounding land form: flat, 0-3%

(iii) Microtopography: None

Slope on which profile is sited: 2%

Land use: None

Climate: Tropical

II. GENERAL INFORMATION ON THE SOIL:

Parent material: Quartzites

Drainage class: well

Moist conditions in profile: just moist

Depth to ground water table: not known

Presence of surface stone, rock outcrops: few

Evidence of erosion: None

III. PROFILE DESCRIPTION:

- AP 0-16cm. Dark brown (10YR 3/3) moist and brown (10YR 4/3) dry, sandy loam; weak fine sub-angular; slightly sticky, slightly plastic, friable moist, slightly hard dry; many fine medium and coarse pores; many fine and medium, few coarse roots; very few fine gravels; clear smooth boundary.
- Ac 16-42 cm. Dark yellowish brown (10YR 3/6) moist and dark yellowish brown (10YR 4/6) dry, sandy loam to sandy clay loam; weak fine sub-angular blocky structure; slightly sticky, slightly plastic, friable moist, slightly hard dry; many fine medium and coarse impeded pores; many fine few medium and coarse roots; few fine and coarse gravels; gradual smooth boundary.
- Cs1 42-67 cm. Strong brown (7.5YR 4/6) moist and strong brown (7.5YR 5/8) dry, sandy clay loam; very weak fine sub-angular blocky; slightly sticky, slightly plastic, friable moist, slightly hard dry; many fine common medium and coarse roots; frequent iron and manganese concretions; very frequent fine gravel, coarse gravels and stones; abrupt smooth boundary.
- Cs2 67-150cm. Very frequent iron and manganese concretion; very frequent fine gravels coarse gravels, small stones and large stones.

ANALYTICAL DATA:

Profile No: LUP/6/82

11/8/82

Grain size, mm

| Lab No. | Depth (cm) | Clay | Silt | F.sand | M.sand | C.sand | TEXTURE (USDA) |
|---------|------------|---------|---------------|--------------|--------------|--------------|----------------|
| | | 0.002 % | 0.002 -0.05 % | 0.05 -0.25 % | 0.25 -0.50 % | 0.50 -2.00 % | |
| 849 49 | 0-16 | 31 | 15 | 25 | 23 | 6 | SCL |
| 50 | 16-42 | 39 | 21 | 21 | 17 | 9 | C |
| 51 | 42-67 | 44 | 16 | 20 | 11 | 9 | C |
| 52 | 67-150 | 45 | 15 | 19 | 10 | 11 | C |

Chemical data:

| Lab. No. | Depth (cm) | Ex.Ca m.e.% | Ex.Mg m.e.% | Ex.K m.e.% | Ex.Na m.e.% | C.E.C. M.e.% | C.E.C. m. 100g clay |
|----------|------------|-------------|-------------|------------|-------------|--------------|---------------------|
| 2849 | 0-16 | 1.64 | 0.77 | 0.12 | 0.02 | 5.66 | 18 |
| 50 | 16-42 | 0.82 | 0.28 | 0.05 | 0.01 | 2.24 | 19 |
| 51 | 42-67 | 0.73 | 0.50 | 0.04 | T | 2.24 | 5 |
| 52 | 67-150 | 0.55 | 0.52 | 0.03 | 0.01 | 4.64 | 10 |

| Lab No. | Depth (cm) | Org.C % | N Avail P ppm | pH (CaCl ₂) | sh (H ₂ O) | Base Sat. % |
|---------|------------|---------|---------------|-------------------------|-----------------------|-------------|
| 82/2849 | 0-16 | 0.92 | 12 | 4.8 | 5.6 | 46 |
| 50 | 16-42 | 0.70 | 4 | 4.6 | 5.5 | 16 |
| 51 | 42-67 | 0.35 | 4 | 4.6 | 5.6 | 57 |
| 52 | 67-150 | 0.32 | 3 | 4.6 | 5.4 | 24 |

ND = Not determined. T = Trace

ANALYTICAL DATA:

Profile No: LUP/6/82

11/8/82

Grain size, mm

| Lab No. | Depth (cm) | Clay | Silt | F.sand | M.sand | C.sand | TEXTURE (USDA) |
|---------|------------|---------|----------------|---------------|---------------|---------------|----------------|
| | | 0.002 % | 0.002 - 0.05 % | 0.05 - 0.25 % | 0.25 - 0.50 % | 0.50 - 2.00 % | |
| 849 49 | 0-16 | 31 | 15 | 25 | 23 | 6 | SCL |
| 50 | 16-42 | 39 | 21 | 21 | 17 | 9 | C |
| 51 | 42-67 | 44 | 16 | 20 | 11 | 9 | C |
| 52 | 67-150 | 45 | 15 | 19 | 10 | 11 | C |

Chemical data:

| Lab. No. | Depth (cm) | Ex. Ca m.e.% | Ex. Mg m.e.% | Ex. K m.e.% | Ex. Na m.e.% | C.E.C. M.e.% | C.E.C. m.e.u 100g clay |
|----------|------------|--------------|--------------|-------------|--------------|--------------|------------------------|
| 2849 | 0-16 | 1.64 | 0.77 | 0.12 | 0.02 | 5.66 | 18 |
| 50 | 16-42 | 0.82 | 0.28 | 0.05 | 0.01 | 2.24 | 19 |
| 51 | 42-67 | 0.73 | 0.50 | 0.04 | T | 2.24 | 5 |
| 52 | 67-150 | 0.55 | 0.52 | 0.03 | 0.01 | 4.64 | 10 |

| Lab No. | Depth (cm) | Org. C % | N. Avail P ppm | pH (CaCl ₂) | sh (H ₂ O) | Base Sat. % |
|---------|------------|----------|----------------|-------------------------|-----------------------|-------------|
| 82/2849 | 0-16 | 0.92 | 12 | 4.8 | 5.6 | 46 |
| 50 | 16-42 | 0.70 | 4 | 4.6 | 5.5 | 16 |
| 51 | 42-67 | 0.35 | 4 | 4.6 | 5.6 | 57 |
| 52 | 67-150 | 0.32 | 3 | 4.6 | 5.4 | 24 |

ND = Not determined.

T = Trace

SOIL MOISTURE CHARACTERISTICS:

| <u>Depth</u> (cm) | <u>Mapping unit</u> | <u>1/10 bar</u> | <u>% 15 bar</u> | <u>% Available moisture</u> |
|----------------------|---------------------|-----------------|---------------------|-------------------------------------|
| 0-16 | 22 | 13.67 | 7.44 | 6.23 |
| 16-42 | | 16.61 | 7.81 | 8.80 |
| 42-67 | | No soil | - | - |
| 67-150 | | No soil | - | - |

SOIL PHYSICAL CHARACTERISTICS:

| <u>Depth</u> (cm) | <u>Bulk (g/cm³) density</u> | <u>Rolling limit</u> | <u>Plastic index</u> | <u>Sticky limit</u> | <u>Shrinking limit</u> | <u>Linear shrinkage</u> |
|----------------------|--|--------------------------|--------------------------|-------------------------|----------------------------|-----------------------------|
| 0-16 | 1.38 | 13.85 | 4.33 | 13.30 | 14.68 | 2.9 |
| 16-42 | 1.64 | 5.26 | 14.74 | 12.50 | 14.88 | 2.25 |
| 42-67 | 1.69 | 16.33 | 9.76 | 20.69 | 18.52 | 2.80 |
| 67-150 | - | 20.83 | 12.70 | 20.77 | 18.73 | 1.40 |

MICROMORPHOLOGY (THIN SECTIONS):

| <u>Horizon</u> | <u>Depth (cm)</u> |
|----------------|-------------------|
| B | 16 - 42 |

- skelet grains: fine sand, coarse sand (+ silt), mainly quartz.
- plasma ordering: asepic-sepic (see special features)
- special features:
 - local skelsepic
 - no clay cutans
 - ferric concentration and ferric nodules present (plinthite ?).

MINERALOGY:

Clay fraction

| <u>Horizon</u> | <u>Depth</u> (<u>cm</u>) | <u>Kaolinite</u> | <u>Mica</u> | <u>Goethite</u> | <u>Haematite</u> |
|----------------|-------------------------------|------------------|-------------|-----------------|------------------|
| B | 16-42 | +++ | + | + | ++ |

Fine and coarse sand

| <u>Quartz</u> | <u>Mica</u> |
|---------------|-------------|
| +++ | + |

1. INFORMATION ON THE SITE:

Profile number: LP/7/82

Mapping unit: 32

Soil name: Mpongwe (tentative)

Higher category classification:

F.A.O: Rhodic Ferralsol

Soil Survey Staff (USDA): Typic Eustrustox

Date of examination: 24/6/82

Location: 35LPPP 316134

Elevation: 1155 m

Land form: Plain

(i) Physiographic position: plain

(ii) Surrounding land form: flat

(iii) Microtopography: None

Slope on which profile is sited: 1-2%

Land use: Maize cultivation

Climate: tropical

II. GENERAL INFORMATION ON THE SOIL:

Parent material: limestone

Drainage class: well

Moist conditions in profile: just, moist

Depth to ground water table: Not known

Presence of surface stone, rock outcrops: few

Evidence of erosion: None

III. BRIEF DESCRIPTION OF PROFILE:

The profile has sandy clay top soil and a clay loam sub-soil. The soil structure is weak sub-angular blocky throughout the profile.

IV. PROFILE DESCRIPTION:

AP 0-18 cm. Dark reddish brown (5YR 4/3) moist and yellowish brown (5YR 4/4) dry, sandy clay; moderate medium sub-angular blocky; sticky plastic, friable moist, hard dry; many fine medium and coarse pores; many fine and medium coarse roots; abrupt smooth boundary.

AB 18-48cm. Yellowish red (5YR 4/6) moist and yellowish red (5YR 5/6) dry, clay loam; very weak fine sub-angular blocky; sticky, plastic, friable moist, slightly hard dry; many fine and medium, common coarse pores; many fine medium roots; gradual to diffuse smooth boundary.

Bws 48-200cm. Red (2.5YR 4/6) moist and red (2.5YR 4/8) dry, dry clay; very weak sub-angular blocky; sticky; plastic, friable moist slightly hard dry; fine and medium few fine and medium common coarse pores; common fine and medium roots.

ANALYTICAL DATA

Profile No. LUP/7/82

RD 11/8/82

Grain size, mm

| Lab. No. | Depth (cm) | Clay | | Silt | | F.sand | | M.sand | | C.sand | | TEXTURE (USDA) |
|----------|------------|---------|---------|---------------|--------------|--------------|--------------|--------------|---------------|--------|---|----------------|
| | | 0.002 % | 0.002 % | 0.002 -0.05 % | 0.05 -0.25 % | 0.25 -0.50 % | 0.50 -2.00 % | 0.50 -2.00 % | 2.00 -20.00 % | | | |
| 82-28-53 | 0-18 | 43 | 20 | 28 | 7 | 2 | | | | | C | |
| 54 | 18-48 | 57 | 19 | 18 | 3 | 3 | | | | | C | |
| 55 | 48-82 | 56 | 18 | 21 | 3 | 2 | | | | | C | |
| 56 | 82-200 | 55 | 23 | 18 | 2 | 2 | | | | | C | |

Chemical Data:

| Lab. No. | Depth (cm) | Ex.Ca m.e.% | Ex.Mg m.e.% | Ex.K m.e.% | Ex.Na m.e.% | C.E.C. m.e.% | C.E.C. m.e. 100g clay |
|----------|------------|-------------|-------------|------------|-------------|--------------|-----------------------|
| 82/2853 | 0-18 | 4.32 | 2.04 | 0.43 | 0.01 | 9.60 | 22 |
| 54 | 18-48 | 3.23 | 2.66 | 0.17 | T | 11.24 | 20 |
| 55 | 48-82 | 2.51 | 3.44 | 0.09 | T | 9.46 | 17 |
| 56 | 82-200 | 2.05 | 3.48 | 0.08 | 8.88 | 16 | |

| Lab. No. | Depth (cm) | Org.C % | N Avail P ppm | pH CaCl ₂) | pH (H ₂ O) | Base Sat.% |
|----------|------------|---------|---------------|------------------------|-----------------------|------------|
| 82-2853 | 0-18 | 1.28 | 6 | 5.3 | 6.0 | 71 |
| 54 | 18-48 | 1.13 | 2 | 5.1 | 5.8 | 54 |
| 55 | 48-82 | 0.47 | 2 | 5.3 | 6.1 | 64 |
| 56 | 82-200 | 0.25 | 2 | 5.3 | 5.9 | 63 |

ND = Not determined:

SOIL MOISTURE CHARACTERISTICS:

| <u>Depth</u> (cm) | <u>Mapping unit</u> | <u>%</u> <u>1/10 bars</u> | <u>%</u> <u>15 bars</u> | <u>%</u> <u>Available moisture</u> |
|----------------------|---------------------|------------------------------|----------------------------|---------------------------------------|
| 0-13 | 32 | 19.93 | 10.18 | 8.75 |
| 13-36 | | 24.50 | 12.15 | 12.35 |
| 36-127 | | 21.87 | 13.61 | 8.76 |
| 127-200 | | 24.00 | 10.94 | 13.06 |

SOIL PHYSICAL CHARACTERISTICS:

| <u>Depth</u> (cm) | <u>Bulk density</u> (g/cm ³) | <u>Rolling limit</u> | <u>Plastic index</u> | <u>Sticky limit</u> | <u>Shrinking limit</u> | <u>Linear shrinkage</u> |
|----------------------|---|----------------------|----------------------|---------------------|------------------------|-------------------------|
| 0-13 | 1.54 | 10.00 | 2.70 | 20.12 | 16.85 | 4.60 |
| 13-36 | 1.35 | 18.64 | 2.00 | 23.78 | 22.31 | 6.55 |
| 36-127 | 1.32 | 31.58 | 2.41 | 21.74 | 24.04 | 8.45 |
| 127-200 | 1.31 | 18.18 | 3.71 | 27.43 | 19.96 | 10.02 |

MICROMORPHOLOGY (THIN SECTIONS):

| <u>Lab. No.</u> | <u>Profile No.</u> | <u>Horizon</u> | <u>Depth (cm)</u> |
|-----------------|--------------------|----------------|-------------------|
| M 82 461 | (IP-7-82) | B | 36-127 |

- skelet grains: fine sand and silty (mostly quartz and muscovite)
- plasma ordering: undulic (high iron content)
- special features: few ferric nodules with sharp edges (transported)
- very few iron rich papules
- no clay cutans.

MINERALOGY:

| <u>Horizon</u> | <u>Smectite</u> | <u>Illite</u> | <u>Halloysite</u> | <u>Kaillinite</u> | <u>Haematite</u> | <u>Goethine</u> | <u>Feldspars</u> |
|----------------|-----------------|---------------|-------------------|-------------------|------------------|-----------------|------------------|
| 36-127 cm | - | - | - | +++ | + | + | - |

I. INFORMATION ON THE SITE:

Profile number: LP/8/82

Mapping unit: 52

Soil name: Chilanga

Higher category classification:

F.A.O: Eutric Regosol

Soil Survey Staff (USDA): lithic ustorthent

Date of examination: 24/7/82

Location: 35L PP286107

Elevation: 1125 m

Land form: upper slope plateau.

(i) physiographic position: upper slope

(ii) surrounding land form: flat

(iii) microtopography:

Slope on which profile is sited: flat, 2%

Land use: None

Climate: Tropical

II. GENERAL INFORMATION ON THE SOIL:

Parent material: granite

Drainage class: well

Moist conditions in profile: just dry

Depth to ground water table: unknown

Presence of surface stone, rock outcrops: 50%

Evidence of erosion: None

Presence of salt or alkali: None

III. BRIEF DESCRIPTION OF PROFILE:

Dark brown loamy sand with a very weak sub-angular blocky structure.

IV. PROFILE DESCRIPTION:

A 0-8cm. Very dark brown (10YR 2/2) moist, and dark greyish brown (10YR 4/2) dry, loamy sand; very weak very fine sub-angular blocky; slightly sticky, slightly plastic, friable moist, slightly hard dry, many fine and medium, few coarse pores; many fine medium and coarse roots; frequent fine gravels; clear smooth boundary.

Bws 8-22cm. Dark brown (10YR 3/3) moist and brown (10YR 5/3) dry, loamy sand; very weak, very fine sub-angular blocky, slightly sticky slightly plastic, friable moist slightly hard dry; many fine and medium pores, very fine medium and coarse roots, frequent iron and manganese concretions; very frequent fine gravels; abrupt smooth boundary.

B/C 22-40cm. Many fine and medium, few coarse roots; very frequent iron and manganese concretions; very frequent fine and coarse gravels, small and large stones.

ANALYTICAL DATA

Profile No. LUP 8-82

RD 11-8-82

Grain size, mm

| Lab No. | Depth (cm) | Clay 0.002 % | Silt 0.002 -0.05 % | F. sand 0.05 -0.25 % | M. Sand 0.25 -0.50 % | C. sand 0.50 -2.00 % | TEXTURE (USDA) |
|---------|------------|--------------------|-----------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------|
| 82-2857 | 0-8 | 16 | 22 | 25 | 16 | 21 | SL |
| 58 | 8-22 | 14 | 14 | 35 | 12 | 23 | SL |
| 59 | 22-40 | 19 | 14 | 23 | 14 | 30 | SL |

Chemical data:

| Lab No. | Depth (cm) | Ex. Ca m.e.% | Ex. Mg m.e.% | Ex. K m.e.% | Ex. Na m.e.% | C.E.C. m.e.% | C.E.C. m.e.% 100g clay |
|---------|------------|-----------------|-----------------|----------------|-----------------|-----------------|---------------------------|
| 82-2857 | 0-8 | 2.09 | 0.77 | 0.21 | 0.02 | 4.68 | 29 |
| 58 | 8-22 | 1.16 | 0.58 | 0.24 | 0.01 | 3.30 | 24 |
| 59 | 22-40 | 0.57 | 0.79 | 0.27 | 0.02 | 3.24 | 17 |

| Lab No. | Depth (cm) | Org. C % | N Avail P ppm | pH (C.Cl ₂) | pH (H ₂ O) | Base Sat. |
|---------|------------|-------------|------------------|----------------------------|--------------------------|--------------|
| 82-2857 | 0-8 | 1.07 | 16 | 5.0 | 6.2 | 66 |
| 58 | 8-22 | 0.60 | 5 | 4.6 | 6.0 | 60 |
| 59 | 22-40 | 0.39 | 4 | 4.3 | 5.6 | 51 |

ND = Not determined

MOISTURE CHARACTERISTICS:

| <u>Depth</u> (cm) | <u>Mapping unit</u> | <u>%</u> <u>1/10 bar</u> | <u>%</u> <u>15 bar</u> | <u>Available</u> <u>moisture: %</u> |
|----------------------|---------------------|-----------------------------|---------------------------|--|
| 0-8 | 52 | 13.79 | 5.32 | 8.47 |
| 8-22 | | 10.47 | 7.50 | 3.97 |
| 22-40 | | 9.35 | 4.35 | 5.56 |

MINERALOGY:

| <u>Depth</u> (cm) | <u>fine earth</u> | |
|----------------------|-------------------|------------------|
| | <u>Kaolinite</u> | <u>Haematite</u> |
| 8-22 | +++ | + |

| <u>Depth</u> (cm) | <u>fine sand</u> | |
|----------------------|------------------|-------------|
| | <u>Quartz</u> | <u>Mica</u> |
| 8-22 | +++ | - |

I. INFORMATION ON THE SITE:

Profile number: LP/9/82

Mapping unit: 52

Soil name: Chilanga (tentative)

Higher category classification:

F.A.O.: Eutric Regosol

Soil Survey Staff (USDA): Lithic Ustorthent

Date of examination: 24/6/82

Location: 25L PP 278103

Elevation: 1125 m

Land form: Upper slope plateau:

(i) physiographic position: upper slope

(ii) surrounding land form: flat

(iii) microtopography: -

Slope on which profile is sited: flat, 2%

Land use: none

Climate: tropical

II. GENERAL INFORMATION ON THE SOIL:

Parent material: granite

Drainage class: well

Moist conditions in profile: just dry

Depth to ground water table: unknown

Presence of surface stone, rock outcrops: 50%

Evidence of erosion: none

Presence of salt or alkali: none

III. BRIEF DESCRIPTION OF PROFILE:

Dark brown loamy sand with a very weak sub-angular blocky structure.

IV: PROFILE DESCRIPTION:

0-10 cm. Black (10YR 2/1) moist and dark grey (10YR 4/1) dry, loamy sand to sandy loam; massive to very weak fine sub-angular blocky; slightly sticky, slightly plastic, friable moist, slightly hard dry; many fine and medium, common coarse pores; many fine medium and coarse roots; clear smooth boundary.

10-30 cm. Very dark greyish brown (10YR 3/2) moist and greyish brown (10YR 5/2) dry, sandy clay loam; massive to very weak fine sub-angular blocky; slightly sticky slightly plastic, friable moist slightly hard dry; many fine and medium common coarse pores; many fine medium and coarse roots; frequent iron concretion, gradual smooth boundary.

30-40 cm. Dark greyish brown (10YR 4/4) moist, and yellowish brown (10YR 5/4) dry, sandy clay loam; very weak fine sub-angular blocky; slightly plastic slightly sticky, friable moist slightly hard dry; many fine medium and coarse impeded interstitial pores; many fine medium and coarse roots; abrupt smooth boundary.

C/R 40 cm Quartz rocks.

ANALYTICAL DATA

Profile No. LUP/9/82

RD 11/8/82

Grain size, mm

| Lab No. | Depth (cm) | Clay | Silt | F. sand | M. sand | C. sand | TEXTURE (USDA) |
|---------|------------|---------|----------------|---------------|---------------|---------------|----------------|
| | | 0.002 % | 0.002 - 0.05 % | 0.05 - 0.25 % | 0.25 - 0.50 % | 0.50 - 2.00 % | |
| 82/2860 | 0-10 | 18 | 13 | 22 | 17 | 20 | SL |
| 67 | 10-30 | 12 | 20 | 38 | 14 | 16 | SL |
| 62 | 30-60 | 32 | 22 | 21 | 16 | 9 | SCL |

Chemical data:

| Lab No. | Depth (cm) | Ex. Ca m.e.% | Ex. Mg m.e. | Ex. K m.e.% | Ex. Na m.e.% | C.E.C m.e.% | C.E.C, m. 100g clay |
|---------|------------|--------------|-------------|-------------|--------------|-------------|---------------------|
| 82-2860 | 0-10 | 8.92 | 1.60 | 0.30 | 0.02 | 13.46 | 75 |
| 61 | 10-30 | 1.89 | 0.42 | 0.08 | T | 3.36 | 28 |
| 62 | 30-60 | 0.47 | 0.41 | 0.32 | 0.01 | 6.14 | 19 |

| Lab No. | Depth (cm) | Org. C | N. Avail P ppm | pH (CaCl ₂) | pH CH ₂ O | Base sat. % |
|---------|------------|--------|----------------|-------------------------|----------------------|-------------|
| 82-2860 | 0-10 | 3.31 | 30 | 5.2 | 6.4 | 81 |
| 61 | 10-30 | 0.36 | 8 | 4.8 | 6.3 | 71 |
| 62 | 30-60 | 0.42 | 83 | 3.7 | 4.9 | 20 |

ND = Not determined.

I. INFORMATION ON THE SITE:

Profile number: LP/10/82

Mapping unit: 11/12

Soil name: Kahare (tentative)

Higher category classification:

F.A.O.: Ferric Luvisol

Soil Survey Staff (USDA): Oxic Haplustalf

Date of examination: 24/7/82

Location: 35L PP 257224

Elevation: 1080 m

Land form: Plateau

(i) physiographic position: upper slope

(ii) surrounding land form: flat

(iii) microtopography: none

Slope of which profile is sited: 2%

Land use: none

Climate: tropical

II. GENERAL INFORMATION ON THE SOIL:

Parent material: gneiss

Drainage class: well

Moist conditions in profile: just dry

Depth to ground water table: unknown

Presence of surface stone, rock outcrops: none

Evidence of erosion: none

Bts 78-123 cm Yellowish brown (10YR 5/6) moist and light yellowish brown dry, sandy clay loam, with few medium to coarse distinct yellowish mottles; weak fine sub-angular; sticky, plastic, friable moist, slightly hard dry; common thick patchy cutans in old root channels and ped faces, many fine medium and coarse pores, many fine medium concretions abrupt smooth boundary.

Bu/C 123+ cm Laterites + Quartz stones.

SOIL MOISTURE CHARACTERISTICS:

| <u>Depth</u> | <u>Mapping unit</u> | <u>% 1/10 bar</u> | <u>% 15 bar</u> | <u>Available moisture</u> |
|--------------|---------------------|-----------------------|---------------------|-------------------------------|
| 0-12 | 11 | 9.09 | 4.72 | 4.37 |
| 12-42 | | 7.91 | 4.78 | 3.15 |
| 42-78 | | 19.93 | 4.54 | 5.39 |
| 78-123 | | 10.03 | 4.11 | 5.45 |

SOIL PHYSICAL CHARACTERISTICS:

| <u>Depth</u> | <u>Bulk (g/cm³) density</u> | <u>Rolling limit</u> | <u>Plastic index</u> | <u>Sticky limit</u> | <u>Shrinking limit</u> | <u>Linear shrinkage</u> |
|--------------|--|--------------------------|--------------------------|-------------------------|----------------------------|-----------------------------|
| 0-12 | 1.50 | 11.11 | 10.39 | 8.00 | 12.97 | 2.9 |
| 12-42 | 1.43 | 13.19 | 7.41 | 14.71 | 6.08 | 7.85 |
| 42-78 | 1.49 | 9.68 | 1.96 | 13.70 | 8.45 | 7.95 |
| 78-123 | 1.58 | 20.06 | 4.61 | 13.77 | 9.45 | 8.09 |

MICROMORPHOLOGY (THIN SECTION):

| <u>Lab. No.</u> | <u>Profile No.</u> | <u>Horizon</u> | <u>Depth (cm)</u> |
|-----------------|--------------------|----------------|-------------------|
| M 82 462 | (IP-10-82) | B | 42-78 |

- skelet grains: fine and coarse sand (mainly quartz)
- plasma ordering: sepic; plasma consists of clay + some dispersed organic matter
- Many nice clay cutans!! (some contain organic matter: black spots).
- Few big ferric nodules (transported ? plinthite ?)
- Few organic matter concentrations: organic fecal pellets.

MINERALOGY:

Clay fraction

| <u>Horizon</u> | <u>Depth (cm)</u> | <u>Kaolinite</u> | <u>Micas</u> | <u>Haematite</u> | <u>Goethite</u> | <u>Feldspars</u> |
|----------------|-------------------|------------------|--------------|------------------|-----------------|------------------|
| B | 42-78 | +++ | + | ++ | + | + |

Fine and coarse sand

| <u>Horizon</u> | <u>Depth (cm)</u> | <u>Quartz</u> | <u>Mica</u> |
|----------------|-------------------|---------------|-------------|
| B | 42-78 | +++ | + |

ANALYTICAL DATA

Profile No. LUP/10/82

RD 11/8/82

Grain size, mm

| Lab No. | Depth (cm) | Clay | Silt | F. sand | M. sand | C. sand | TEXTURE (USDA) |
|---------|------------|---------|----------------|---------------|---------------|---------------|----------------|
| | | 0.002 % | 0.002 - 0.05 % | 0.05 - 0.25 % | 0.25 - 0.50 % | 0.50 - 2.00 % | |
| 82-2863 | 0-12 | 12 | 14 | 47 | 19 | 8 | SL |
| 64 | 12-42 | 12 | 13 | 35 | 14 | 6 | SL |
| 65 | 42-78 | 23 | 14 | 43 | 14 | 6 | SCL |
| 66 | 78-123 | 27 | 15 | 39 | 11 | 8 | SLL |

Chemical data

| Lab No. | Depth (cm) | Ex. Ca m.e.% | Ex. Mg m.e.% | Ex. K m.e.% | Ex. Na m.e.% | C.E.C. m.e.% | C.E.C. m. 100g clay |
|---------|------------|--------------|--------------|-------------|--------------|--------------|---------------------|
| 82-2853 | 0-12 | 1.25 | 0.65 | 0.08 | T | 2.90 | 24 |
| 64 | 12-42 | 0.26 | 0.53 | 0.07 | T | 1.62 | 14 |
| 65 | 42-78 | 0.28 | 0.99 | 0.19 | T | 2.30 | 10 |
| 66 | 78-123 | 0.33 | 0.86 | 0.21 | T | 2.98 | 11 |

| Lab. No. | Depth (cm) | Org. C % | N. Avail P ppm | pH (CaCl ₂) | pH (H ₂ O) | Base Sat. % |
|----------|------------|----------|----------------|-------------------------|-----------------------|-------------|
| 82-2863 | 0-12 | 0.66 | 6 | 4.5 | 6.0 | 68 |
| 64 | 12-42 | 0.29 | 3 | 4.2 | 5.2 | 53 |
| 65 | 42-78 | 0.26 | 4 | 4.2 | 5.3 | 63 |
| 66 | 78-123 | 0.26 | 3 | 4.3 | 5.3 | 45 |

ND = Not determined

I. INFORMATION ON THE SITE:

Profile number: HP/11/62

Mapping unit: 11/12

Soil name: Mulobolo (tentative)

Higher category classification:

F.A.O. Ferric Luvisol

U.S.D.A. Oxic Haplustalf

Date of examination: 24/7/82

Location: 35L PP 215224

Elevation: 1035 m

Land form: Plateau

(i) physiographic position: upper slope

(ii) surrounding land form: flat

(iii) microtopography: none

Slope on which profile is sited: 1-~~3~~%

Land use: none

Climate: tropical

II. GENERAL INFORMATION ON THE SOIL:

Parent material: gneiss

Drainage class: well

Moist conditions in profile: just dry

Depth to ground water table: not known

Presence of surface stone, rock outcrops: none

Evidence of erosion: None

III. BRIEF DESCRIPTION OF PROFILE:

The soils have a loamy sand top soil with a massive like structure. The sub soil is sandy loam with a weak fine or medium sub-angular structure.

IV. PROFILE DESCRIPTION:

- A 0-15 cm Very dark greyish brown (10YR 3/2) moist and greyish brown (10YR 5/2) dry, loamy sand; massive to very weak, fine sub-angular; slightly sticky, slightly plastic, friable moist, slightly hard dry; many fine medium and coarse pores; many fine few medium and coarse roots; clear smooth boundary.
- AB 15-52 cm Dark brown (10YR 4/3) moist and yellowish brown (10YR 5/4) dry sandy loam; weak to moderate medium sub-angular; slightly sticky slightly plastic; friable moist, slightly hard dry; many fine medium and coarse pores; many fine few medium and coarse roots; gradual smooth boundary.
- Bt 42-79 cm Dark brown (10YR 4/3) moist and yellowish brown (10YR 5/4) dry, sandy clay loam with few fine and faint, yellowish brown mottles; weak medium sub-angular; slightly sticky slightly plastic friable moist slightly hard dry; common thin patchy cutans; few coarse many fine and medium pores; common fine roots; gradual smooth boundary.

Bt: 79-200 cm Yellowish brown (10YR 5/6) moist and brownish yellow (10YR 6/6) dry, sand clay with few fine and faint mottles; weak medium sub-angular blocky; slightly sticky slightly plastic, friable moist slightly hard dry, common thin patchy cutans; few coarse many fine and medium pores; few fine medium and coarse roots; diffuse smooth boundary.

MOISTURE CHARACTERISTICS:

| <u>Depth</u> | <u>Mapping unit</u> | <u>% 1/10 bar</u> | <u>% 15 bar</u> | <u>% available moisture</u> |
|--------------|---------------------|-----------------------|---------------------|-------------------------------------|
| 0-15 | 12 | 10.06 | 5.12 | 4.94 |
| 15-42 | | 11.64 | 7.17 | 4.47 |
| 42-79 | | 16.67 | 9.17 | 7.50 |
| 79-130 | | 16.07 | 7.49 | 8.56 |
| 130-200+ | | 17.44 | 9.26 | 8.18 |

SOIL PHYSICAL CHARACTERISTICS:

| <u>Depth</u> | <u>(g/cm³) Bulk density</u> | <u>Rolling limit</u> | <u>Plastic index</u> | <u>Sticky limit</u> | <u>Shrinking limit</u> | <u>Linear shrinkage</u> |
|--------------|--|--------------------------|--------------------------|-------------------------|----------------------------|-----------------------------|
| 0-15 | 1.60 | 17.33 | 4.10 | 16.84 | 14.65 | 2.9 |
| 15-42 | 1.34 | 15.00 | 1.67 | 19.36 | 14.88 | 2.8 |
| 42-79 | 1.45 | 19.40 | 2.79 | 25.85 | 17.52 | 3.2 |
| 79-130 | 1.28 | 22.03 | 2.97 | 22.37 | 17.75 | 2.80 |
| 130-200+ | 1.22 | 13.77 | 24.52 | 17.99 | 2.85 | |

Profile: LUP/11/82

Vegetation: land use:

ANALYTICAL DATA

Profile No. LUP/11/82.

Routine

RD 11/8/82

Grain size, mm

| Lab No. | Depth (cm) | Clay | Silt | F.sand | M.sand | C.sand | TEXTURE (USDA) |
|---------|------------|---------|---------------|--------------|--------------|--------------|----------------|
| | | 0.002 % | 0.002 -0.05 % | 0.05 -0.25 % | 0.25 -0.50 % | 0.50 -2.00 % | |
| 82-2867 | 0-15 | 22 | 12 | 51 | 12 | 3 | SCL |
| 68 | 15-42 | 25 | 11 | 49 | 11 | 4 | SCL |
| 69 | 42-79 | 30 | 12 | 36 | 18 | 4 | SCL |
| 70 | 79-130 | 32 | 10 | 43 | 11 | 4 | SCL |
| 71 | 130-2004 | 38 | 12 | 41 | 7 | 2 | SC |

Chemical data

| Lab No. | Depth (cm) | Ex.Ca m.e.% | Ex.Mg m.e.% | Ex.K m.e.% | Ex.Na m.e. | C.E.C. m.e.% | C.E.C. m.e. 100g clay |
|---------|------------|-------------|-------------|------------|------------|--------------|-----------------------|
| 82-2867 | 0-15 | 1.16 | 1.70 | 0.19 | T | 4.42 | 20 |
| 68 | 15-42 | 0.56 | 0.69 | 0.15 | T | 4.14 | 17 |
| 69 | 42-79 | 0.20 | 0.66 | 0.13 | 0.03 | 4.76 | 16 |
| 70 | 79-130 | 0.26 | 0.44 | 0.15 | 0.01 | 4.26 | 13 |
| 71 | 130-2004 | 0.23 | 0.72 | 0.15 | 0.02 | 4.46 | 12 |

| Lab No. | Depth (cm) | Org.C % | N Avail P ppm | pH (CaCl ₂) | pH (H ₂ O) | Base Sat. % | - |
|---------|------------|---------|---------------|-------------------------|-----------------------|-------------|---|
| 82-2867 | 0-15 | 0.90 | 17 | 4.4 | 5.3 | 69 | - |
| 68 | 15-42 | 0.39 | 6 | 4.5 | 5.0 | 34 | - |
| 69 | 42-79 | 0.21 | 4 | 3.8 | 4.1 | 21 | - |
| 70 | 79-123 | 0.44 | 5 | 3.7 | 4.8 | 20 | - |
| 71 | 123-2004 | | 3 | 4.2 | 5.4 | 25 | - |

MICROMORPHOLOGY (THIN SECTIONS):

| <u>Lab. No.</u> | <u>Profile No.</u> | <u>Horizon</u> | <u>Depth</u> |
|-----------------|--------------------|----------------|--------------|
| M 82 463 | (IP-11-82) | B | 42-79 |

- skelet grains: dominantly fine sand (mainly quartz)
- plasma ordering: sepic
- special features: locally skelsepic (less than 462)
many nice clay cutans !!
some ferric nodule-concretions (transported
plinthite)

MINERALOGY:

Clay fraction

| <u>Horizon</u> | <u>Depth (cm)</u> | <u>Kaolinite</u> | <u>Mica</u> | <u>Haematite</u> | <u>Goethite</u> | <u>Feldspars</u> |
|----------------|-------------------|------------------|-------------|------------------|-----------------|------------------|
| B | 42-79 | +++ | + | ++ | + | + |

fine sand fraction

| <u>Quartz</u> | <u>Micas</u> |
|---------------|--------------|
| +++ | + |

APPENDIX II

SOCIAL - ECONOMIC SURVEY QUESTIONNAIRE:

1. Name of interviewee and age

2. Name of Village

Language and communication:

3. What is your mother tongue

4. What other languages do you speak

5. Can you read English

6. Can you write English

7. What language do you use in your home

8. What language(s) do you use to speak to strangers.
social workers (i.e. UNIP) and economic planners

Tendency towards Urbanisation (modernisation)

9. Do you like to speak English and other language that are commonly
used in urban areas.

10. Do you like modern dressing

11. Do you like to move into a modern occupation i.e. Commercial
agriculture

- Industrial worker

12. Do you often get into contact with modern industrial ideas related to:

- agriculture
- building
- health
- community development etc.

13. How large is your family

14. How many people do you support financially

15. Would you like to support a few people (nuclear family) or a lot of people (extended family)

Level of education

16. How far have you gone in formal education (standard or grade)

17. Do you intend to get more formal education

Social infrastructure

18. Who controls the social organisation of your village

19. What role does the chief play

20. What role does the united National Independence Party play

Public utilities and services

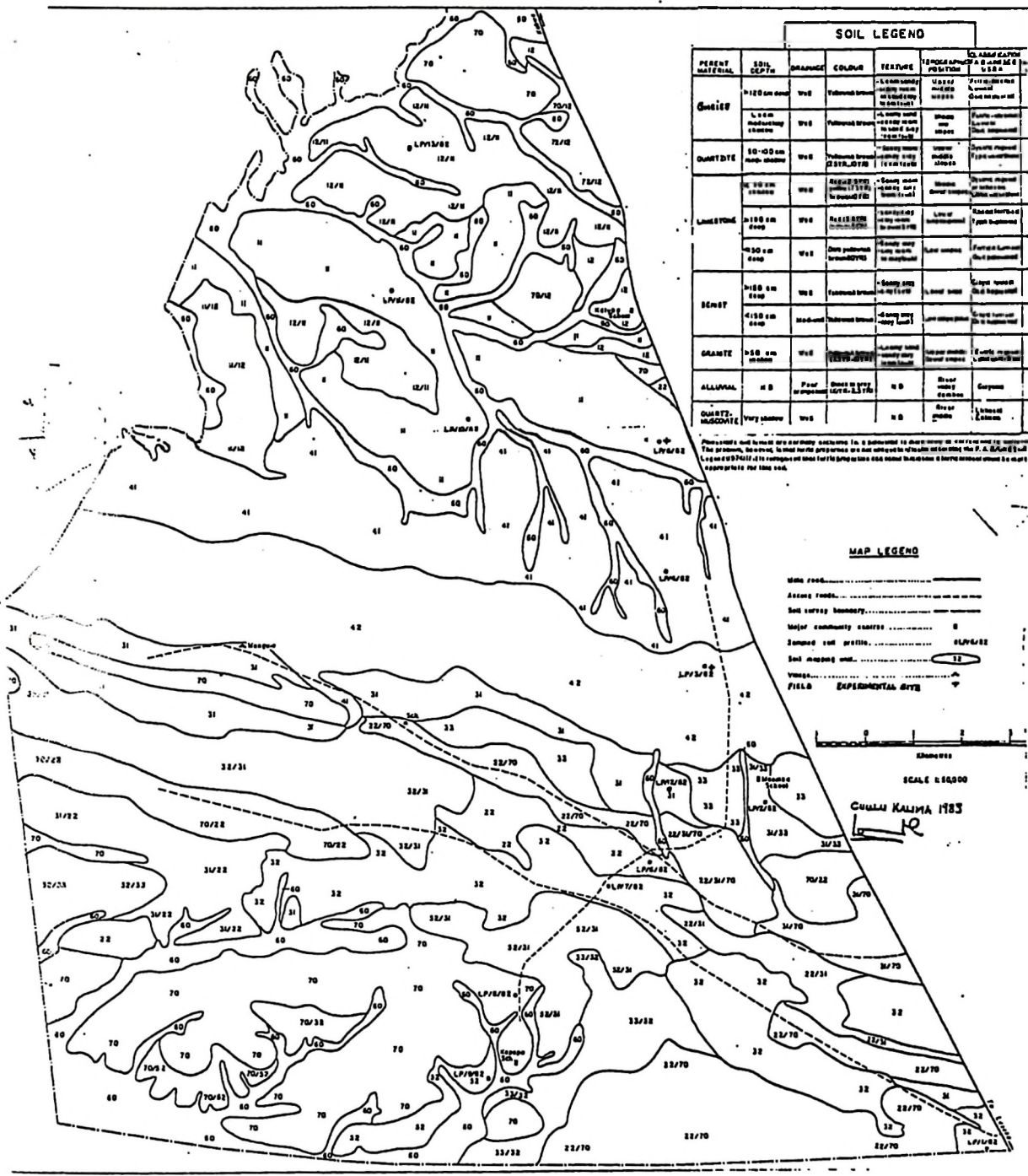
21. What do you think of the social services i.e. health, education, water, transport, roads.
22. Which of these services are you aware are provided in the village or in Kapini.
 - Clinic
 - Mobile clinic
 - Road improvement
 - Welfare centre
 - Spraying
 - Water treatment
23. Which services would you like to see provided in Kapini

Capital and economic resources

24. What are your most important enterprises
25. Where do you obtain your seeds for your agriculture industry
26. Do you ~~prefer~~ local or hybrid varieties
27. What are the uses of your farm or agricultural produce
28. What is your enterprise calendar like.

SEMI-DETAILED

SOIL MAP KAPINI AREA
ZAMBIA



SOIL LEGEND

| PARENT MATERIAL | SOIL DEPTH | DRAINAGE | COLOR | TEXTURE | TEMPERATURE | SOIL CLASSIFICATION |
|-------------------------|--------------|----------|--------------------|--------------------------------|-------------|---------------------|
| GNEISS | >120 cm deep | W/S | Yellowish brown | Light sandy loam to silty loam | Very hot | Very poor to poor |
| | 0-120 cm | W/S | Yellowish brown | Light sandy loam to silty loam | Very hot | Very poor to poor |
| QUARTZITE | 80-100 cm | W/S | Yellowish brown | Light sandy loam to silty loam | Very hot | Very poor to poor |
| | >100 cm | W/S | Yellowish brown | Light sandy loam to silty loam | Very hot | Very poor to poor |
| LAMPROPHYRE | >100 cm | W/S | Reddish brown | Light sandy loam to silty loam | Very hot | Very poor to poor |
| | >30 cm | W/S | Dark reddish brown | Light sandy loam to silty loam | Very hot | Very poor to poor |
| BASALT | >100 cm | W/S | Yellowish brown | Light sandy loam to silty loam | Very hot | Very poor to poor |
| | >150 cm | W/S | Yellowish brown | Light sandy loam to silty loam | Very hot | Very poor to poor |
| GRANITE | >50 cm | W/S | Yellowish brown | Light sandy loam to silty loam | Very hot | Very poor to poor |
| | >100 cm | W/S | Yellowish brown | Light sandy loam to silty loam | Very hot | Very poor to poor |
| ALLUVIAL | >100 cm | W/S | Yellowish brown | Light sandy loam to silty loam | Very hot | Very poor to poor |
| QUARTZITE MISCELLANEOUS | >100 cm | W/S | Yellowish brown | Light sandy loam to silty loam | Very hot | Very poor to poor |

MAP LEGEND

- Main road.....
- Access roads.....
- Soil survey boundary.....
- Major community centers.....
- Settlement and estate.....
- Soil mapping unit.....
- Village.....
- FIELD EXPERIMENTAL SITE.....



SCALE 1:50,000
CHUMBA KAPINI 1983

SOIL LEGEND

| PERENT MATERIAL | SOIL DEPTH | DRAINAGE | COLOUR | TEXTURE | TOPOGRAPHIC POSITION | CLASSIFICATION FA.O-UNESCO USDA | MAPPING UNIT |
|----------------------|-------------------------------|----------------------|--|--|------------------------------|---|--------------|
| GNESS QUARTZITE | > 120 cm deep | Well | Yellowish brown | -Loam sandy -sandy loam to sand clay loam (sub) | Upper middle slopes | Ferric-chromic Luvisol Oxic haplustalf | 11 |
| | Loam moderately shallow | Well | Yellowish brown | -Loamy sand -sandy loam to sand clay loam (sub) | Middle low slopes | Ferric-chromic Luvisol Oxic haplustalf | 12 |
| LIMESTONE | 50-100 cm mod- shallow | Well | Yellowish brown (7.5YR-10YR) | -Sandy loam -sandy clay loam (sub) | Upper middle slopes | Dystric regosol Typicustorthent | 22 |
| | < 50 cm shallow | Well | Red-(2.5YR) yellow (7.5YR) brown(10YR) | -Sandy loam -sandy clay loam (sub) | Middle lower slopes | Dystric regosol or lithosols Lithicustorthent | 31 |
| | > 150 cm deep | Well | Red (2.5YR) brown(5YR) | -Sandy clay -clay loam brown(5YR) | Lower slopes(plain) | Rhodicferralsol Typichaplustox | 32 |
| | < 150 cm deep | Well | Dark yellowish brown(10YR) | -Sandy clay -clay loam to clay(sub) | Low slopes | Ferric Luvisol Oxic paleustalf | 33 |
| SCHIST | > 150 cm deep | Well | Yellowish brown | -Sandy clay -clay (sub) | Lower slope | Gleyic luvisol Oxic haplustalf | 41 |
| | < 150 cm deep | Mod-well | Yellowish brown | -Sandy clay -clay (sub) | Low slope plain | Gleyic luvisol Oxic haplustalf | 42 |
| GRANITE | > 50 cm shallow | Well | Yellowish brown (7.5YR-10YR) | -Loamy sand -sandy clay loam (sub) | Upper-middle lower slopes | Eutric regosol Lithicustorthent | 52 |
| ALLUVIAL | N D | Poor or imperfect | Black to grey (10YR-2.5YR) | N D | River valley dambos | Gleysols | 60 |
| QUARTZ- MUSCOVITE | Very shallow | Well | | N D | River middle lower | Lithosol Entisols | 70 |

Paleustalfs and luvisols are normally exclusive i.e. a paleustalf is more likely to correspond to anitsoil. The problem, however, is that ferric properties are not allowed in nitosols according to the F. A. O./UNESCO Legend (1974) if it is recognised that ferric properties can occur in nitosols a ferric nitosol would be more appropriate for this soil.